# Fuzzy-Neuro Network in a CO-OFDM System: Various Membership Functions Comparison

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doi: https://doi.org/10.21467/proceedings.114.46

## Abstract

Fuzzy-Neuro Network based nonlinear equalizer (FNN-NLE) has been used for the extenuation of nonlinearities in optical communication systems. Until now, many membership functions with resilient backpropagation activation function was used for making FNN-NLE in a coherent optical orthogonal frequency division multiplexing (CO-OFDM) systems. Despite this, no research is reflecting the comparison of different membership functions (MFs). In this paper, various membership functions such as gaussian MF, gaussian combination MF, triangular MF, difference between two sigmoidal functions MF, pi shaped MF, generalized bell shaped MF, trapezoidal MF and product of two sigmoid functions MF has been compared. From this study, the maximum performance in terms of BER is achieved with gaussian membership function has been concluded.

**Keywords—** Fuzzy-Neuro Network based nonlinear equalizer (FNN-NLE), Membership functions, Bit Error Rate (BER).

## 1 Introduction

Today's communications systems i.e., 5G technique real motivation is to increase its speed and bandwidth in addition to security and quality of facilities. It has already been seen in previous studies that it is possible with the help of digital signal processing (DSP) techniques in addition to cost effectiveness. CO-OFDM based DSP technique was rapidly used for mitigating the dispersions present in long-haul high capacity coherent optical communication systems. The spectral efficiency of CO-OFDM system is very high [1]. For further improvement in dispersion tolerance of CO-OFDM systems various electrical techniques are used such as electronic dispersion compensation (EDC), pre-distortion compensation, and post- nonlinear compensation. Moreover, some optical techniques such as optical phase conjugation (OPC), dispersion compensating fiber (DCF), optical resonators, and fiber Bragg gratings (FBG) can be used for reducing various transmission problems of optical communication systems. However, both techniques have some demerits such as additional circuitry is required for electrical techniques and long fiber lengths for optical techniques.

For removing these demerits, Cyclic prefix (CP) was presented in a DSP based CO-OFDM system. And it has been noticed that by adding CP, the impact of chromatic dispersion (CD) along with polarization mode dispersion (PMD) was completely combated [1,3]. Since, in single CO-OFDM symbol, number of subcarriers are large which leads the increase in the time duration of a symbol. Further, it has improved the performance of CO-OFDM system but at the cost of addition CP increase. This increase in number of subcarriers symbols was reducing the spacing between the adjacent symbols of subcarriers. Moreover, various nonlinear effects or Kerr effects of optical fiber was affecting the subcarriers orthogonality. It has been noticed that with the change in subcarriers orthogonality the performance of optical systems was degraded. Moreover, it has been seen in previous studies that due to large value of peak-to-average power



Proceedings DOI: 10.21467/proceedings.114; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-947843-8-8

ratio (PAPR), the CO-OFDM system is very much sensitivite to various of fiber nonlinearities i.e., self-phase modulation (SPM) and cross-phase modulation (XPM)[4].

From the previous research it has been seen that linear equalizer are not sufficient to model fiber nonlinearities since the boundaries of these equalizers are linear [5]. Therefore, nonlinear equalizers (NLEs) were used for compensating the nonlinearities in CO-OFDM systems. Earlier Volterra Model based NLE [6,7] and Wiener-Hammerstein model-based NLE [8] was most commonly used. However, these techniques have many disadvantages such as more complexity and difficulty in implementation of inverse Volterra series transfer function (IVSTF) technique [9] and difficulty in estimating the filter coefficients of Weiner-Hammerstein NLE [8]. Therefore, artificial neural network based nonlinear equalizers (ANN-NLEs) were proposed in order to overcome the above-mentioned difficulties due to nonlinear decision boundaries [10]. It has seen in previous studies that fuzzy-neuro network based nonlinear equalizer (FNN-NLE) further improves the performance of CO-OFDM system [11]. Despite this, no research is reflecting the comparison of different membership functions on FNN-NLE.

In this paper, various other membership functions such as gaussian MF, gaussian combination MF, triangular MF, difference between two sigmoidal functions MF, pi shaped MF, generalized bell shaped MF, trapezoidal MF and product of two sigmoid functions MF. From this study, it has been seen that maximum performance is achieved with gaussian membership function in terms of BER.

This paper is divided into four sections. In First section the introduction of paper has been presented. Second section presents the simulation model and FNN-NLE. Various results and discussions have been presented in section third. Last section presents the conclusion of this work.

## 2 Simulation Model And FNN-NLE

### 2.1 Simulation Setup

Fig. 1 shows the basic block diagram of a CO-OFDM system used for simulation in this work. The incoming data is first modulated by 16-QAM modulation format followed by serial to parallel conversion. For frequency up-conversion of encoded complex subcarriers and multiplexing, the digital IFFT is used as an efficient and accurate technique. On the other hand, for demodulating and demultiplexing FFT technique is used. The IFFT can be calculated by using equation (1) [12];

$$x_{l,n}(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j2\pi k \frac{l}{N}} \qquad (1)$$

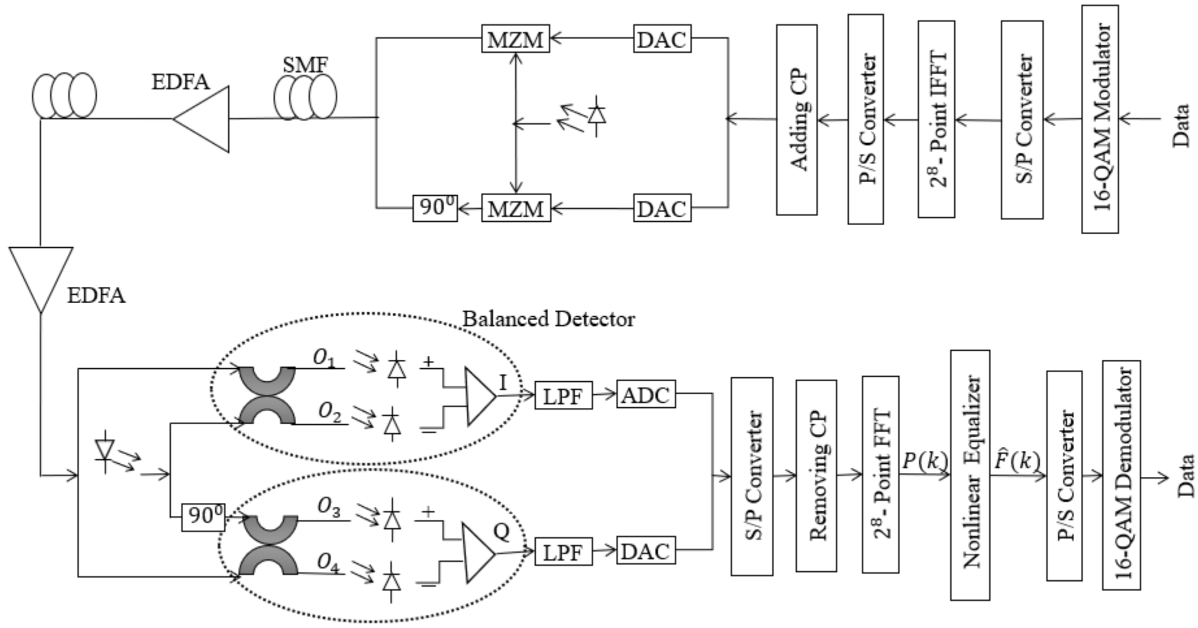
$$X(k) = A_{k,n} e^{2j\theta_{k,n}} \qquad (2)$$

where $X(k)$ is the encoded data of $k^{th}$ subcarrier and $N^{th}$ symbol. In equation (2) the $A_{k,n}$, $\theta_{k,n}$ represents the signal constellation points amplitude and phase respectively. At the receiver side, the FFT technique will be applied on received signal $y(t)$ to get frequency domain signal and presented in equation (3) [13]

$$Y_{k,n}(f) = \sum_{k=0}^{N-1} y_{l,n}(t) e^{-j2\pi k \frac{l}{N}},\ l = 0,1,2, \dots \dots . N-1 \quad (3)$$

In a CO-OFDM system inter-carrier interference (ICI) is generated due to interference between its adjacent subcarriers data symbols and any offset value of the transmitter and receiver subcarrier frequencies [14]. Various transceiver parameters used in this study for the analysis of nonlinear equalization for the compensation of nonlinearities are as follows: 1550nm wavelength, 64 number of CO-OFDM subcarriers, $2.6\text{x}10^{-20}$ $m^2/w$ nonlinear Kerr coefficient, 0.2dB/km Fiber Loss, 0.1ps/km$^{(1/2)}$ Polarization Mode Dispersion, 20 No. of Fiber spans, and 50Km each length , 5dB EDFA noise figure, 20dB EDFA gain, 16-

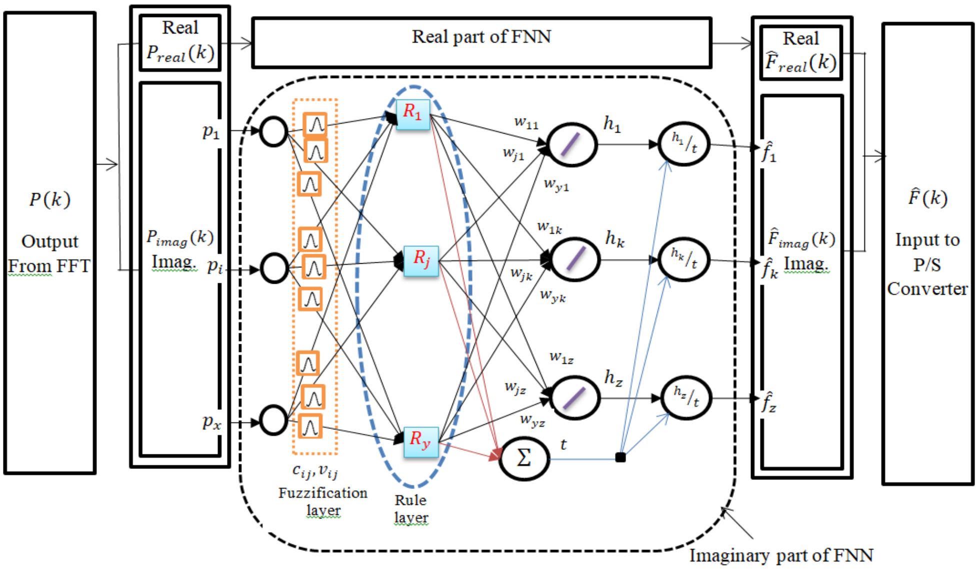
QAM modulation technique, 0.8A/W PIN photo-detector responsivity, 6.3 GSamples/s ADC sampling rate, 15dB Clipping Ratio, and 25% Cyclic Prefix Overhead.




Simulation Set-up for a CO-OFDM System

## 2.2 FNN-NLE Structure

Fuzzy neural networks (FNNs) have received much attention in the last several years for the control of indeterminate systems. FNN-NLE is preferred over ANN-NLE since in FNN-NLE technique learning parameters initial values can be chosen intuitively. In addition to this, FNN-NLE has some advantages over just fuzzy logic-based NLEs. The most important advantage is that the back-propagation algorithm or any other type of machine learning algorithm can be used for training the system. In this study, FNN-NLE with the singleton fuzzifier, the product inference engine, the center average defuzzifier, and the different membership functions has been used. Fig. 2 presents the network structure of FNN-NLE. In this structure, number of nodes in input layer is $m$, number of nodes in two hidden layers is $n$ and $o$, number of nodes in output layer is $o$. The value of $m$ is selected depending upon the inputs used in the network, $n$ is selected based on the number of rules used for fuzzifier, $o$ is selected based on the used M of M-QAM modulation format (Here, due to the usage of16-QAM modulation format the value of $o$is 16. In this structure, $x_i$ input vector ( $i$ is varied from 1 to $m$) with the help of different values of variances $v_{ij}$ and centers $c_{ij}$ is fuzzified. Here, $j$ is the number of fuzzy rule which is varying from 1 to $n$. After performing the multiplication of received outputs of rule layers i.e., $r_1 \dots \dots r_j \dots \dots r_n$ and their related weights i.e, $w_{jl}$. The value of $l$ is varied from 1 to $o$. The total sum of all the multiplication factors is defuzzified. In this work, the back-propagation algorithm with various membership functions such as gaussian MF (gaussmf), gaussian combination MF (gauss2mf), triangular MF (trimf), difference between two sigmoidal functions MF (dsigmf), pi shaped MF (pimf), generalized bell shaped MF (gbellmf), trapezoidal MF (trapmf) and product of two sigmoid functions MF (psigmf) has been used.

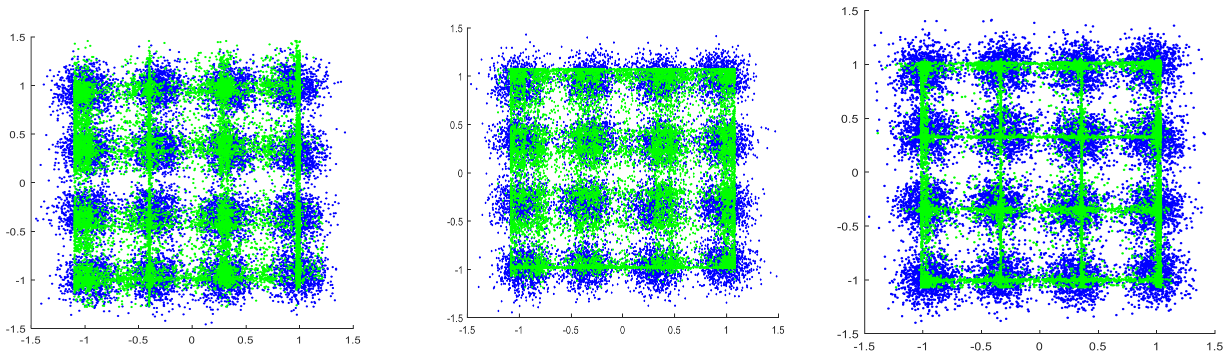


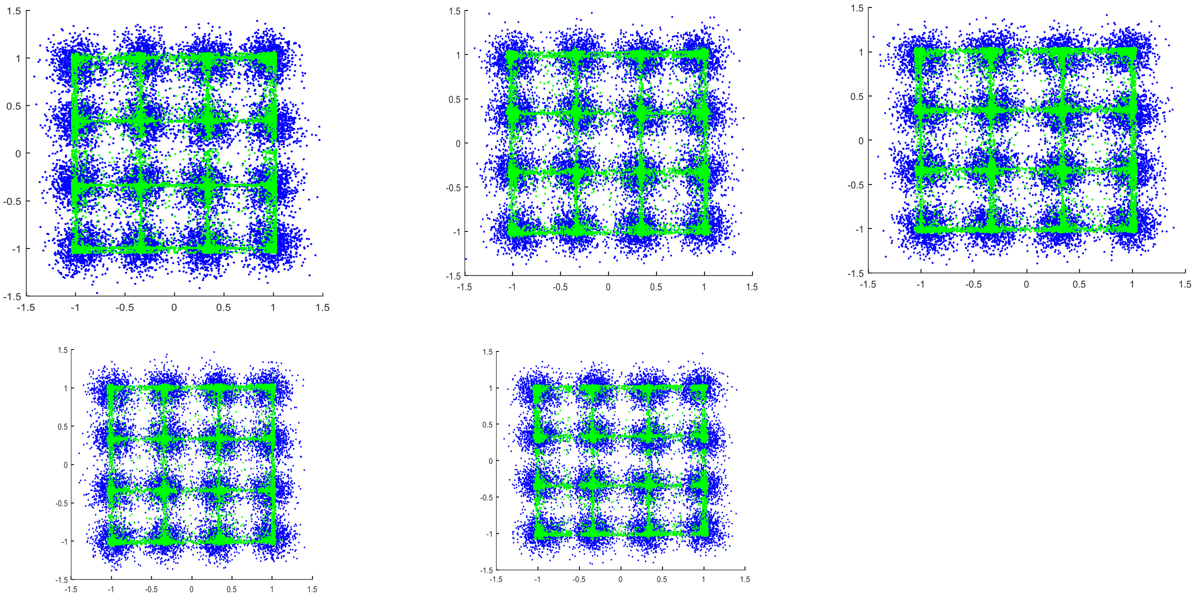

Fuzzy - Neuro Network based Nonlinear Equalizer Structure

## 3 Results and Discussions

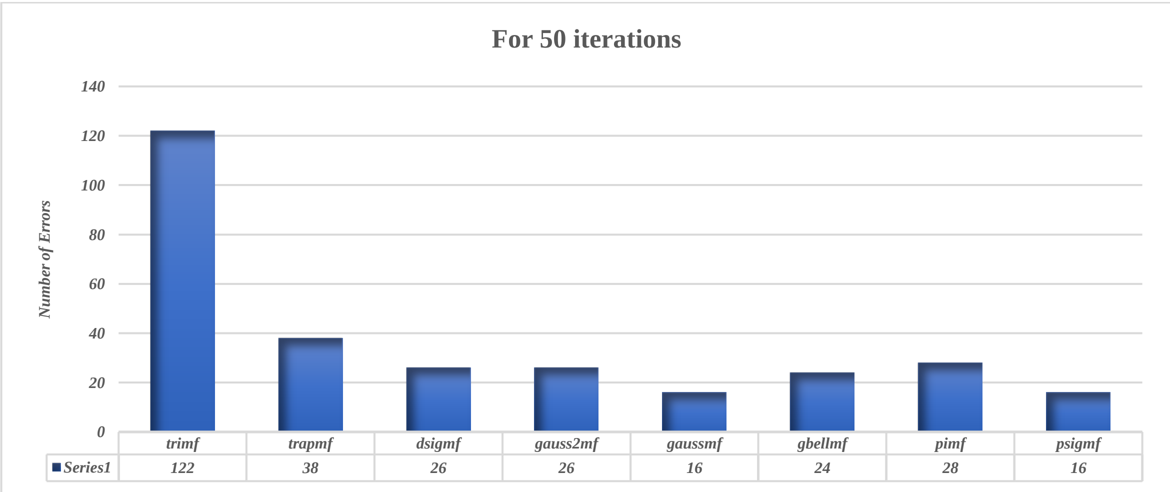
The results obtained with different membership functions has been summarized in Fig. 3 to Fig. 5. From the received 16-QAM constellation diagrams it has been noticed the performance with triangular (trimf) and difference between two sigmoidal functions (dsigmf) is not tolerable. Therefore, generally these two membership functions are not preferred. The performance with remaining membership functions is compared by using Fig. 4 and Fig. 5. Number of errors using different membership functions for FNN-NLE has been presented with 50, 100, 150, and 150 iterations in Fig. 4 (a), Fig. 4(b), Fig. 4(c) and Fig. 4(d) respectively. It has been seen from this Fig. 4 that maximum number of errors received is 122 in trimf, 42 in trimf, 34 in trimf, and 20 in trapmf with 50, 100, 150, and 150 iterations respectively. Moreover, it has been noticed from this Fig. 4 that minimum number of errors received is 16 in gaussmf and psigmf, 10 in gaussmf, 10 in gaussmf and psigmf, and 6 in gaussmf with 50, 100, 150, and 150 iterations respectively.

BER versus different membership functions for FNN-NLE has been presented with 50, 100, 150, and 150 iterations in Fig. 5 (a), Fig. 5(b), Fig. 5(c) and Fig. 5(d) respectively. It has been seen from this Fig. 5 that the highest value of BER received is $1.5 \times 10^{-3}$ in trimf, $5.25 \times 10^{-4}$ in trimf, $4.25 \times 10^{-4}$ in trimf, and $2.5 \times 10^{-4}$ in trapmf with 50, 100, 150, and 150 iterations respectively. Moreover, it has been noticed from this Fig. 5 that minimum number of errors received is $2 \times 10^{-4}$ in gaussmf and psigmf, $1.25 \times 10^{-4}$ in gaussmf, $1.25 \times 10^{-4}$ in gaussmf and psigmf, and $7.5 \times 10^{-5}$ in gaussmf with 50, 100, 150, and 150 iterations respectively.

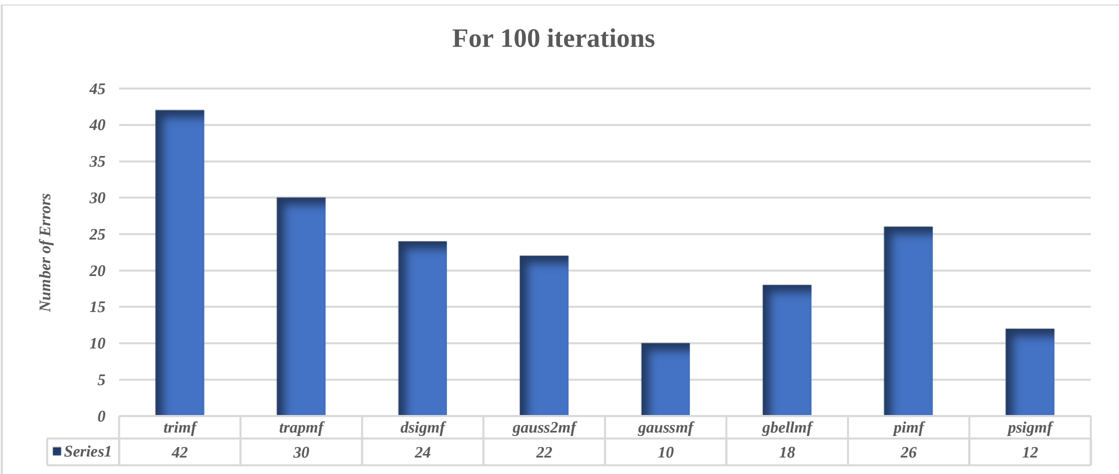




Received 16-QAM scatter plots with different membership functions (a) triangular (trimf) (b) trapezoidal (trapmf) (c) difference between two sigmoidal functions (dsigmf) (d) gaussian combination (gauss2mf) (e) gaussian (gaussmf) (f) generalized bell shaped (gbellmf) (g) pi shaped (pimf) (h) product of two sigmoid functions (psigmf)

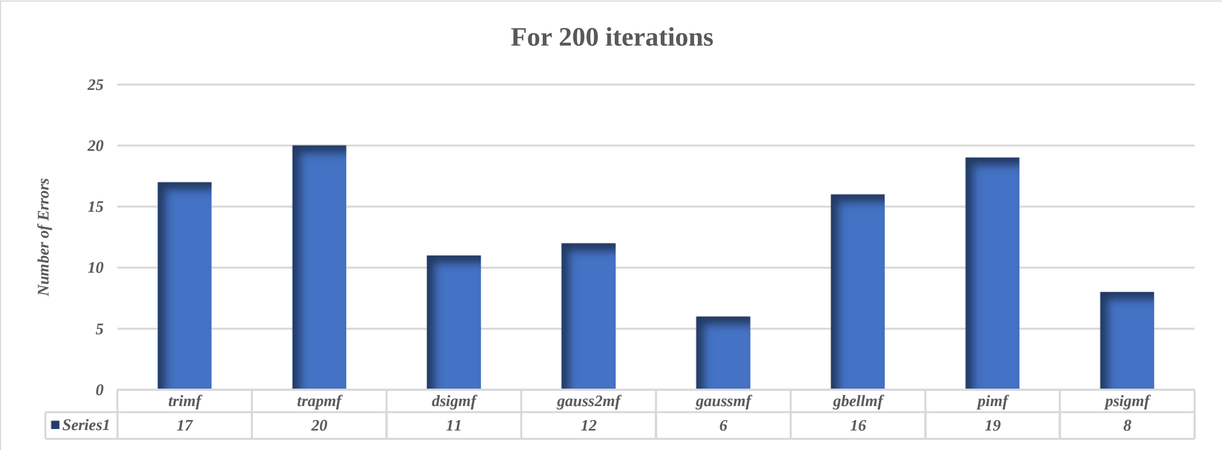



(a)



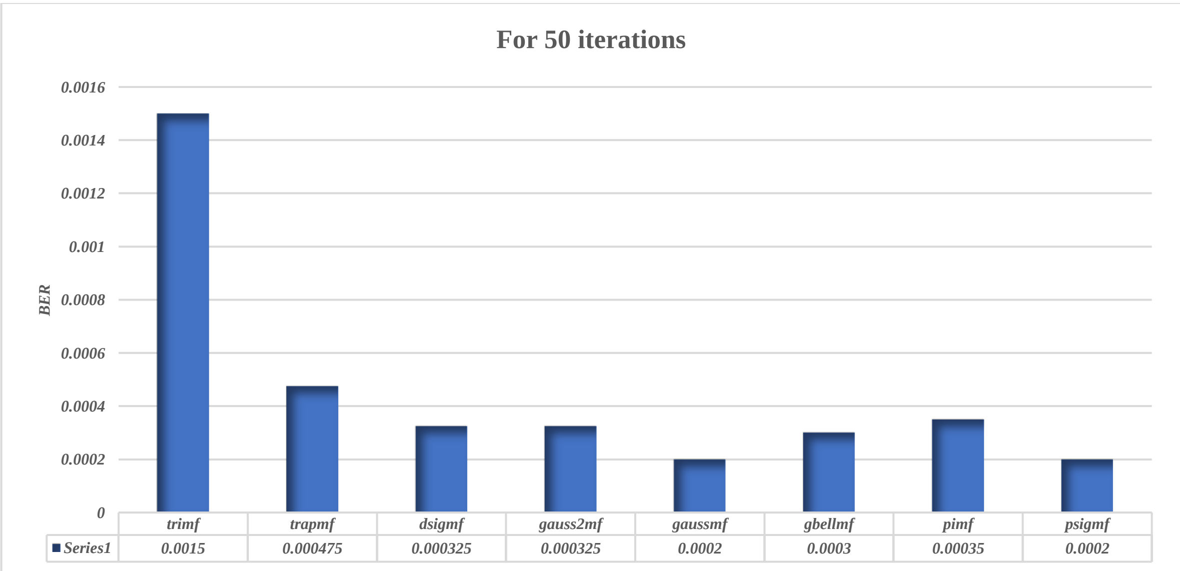

(b)


(c)




(d)

Numbers of errors with different membership functions for different number of iterations (a) 50 (b) 100 (c) 150 (d) 200




(a)



Proceedings DOI: 10.21467/proceedings.114
ISBN: 978-81-947843-8-8
Series: AIJR Proceedings
ISSN: 2582-3922


(b)


(c)


(d)

BER with different membership functions for different number of iterations (a) 50 (b) 100 (c) 150 (d) 200

## 4 Conclusion

It has been observed from the results that two membership functions i.e., gaussian membership function and product of two sigmoid functions has almost same performance with different number of iterations for FNN-NLE in CO-OFDM system. It has been concluded from the comparison that the best performance is received with gaussian membership function with every chosen number of iterations.

## References


[1] W. Shieh, H. Bao, and Y. Tang, "Coherent Optical OFDM: Theory and Design", *Opt. Express*, Vol.16, pp. 842-859, Jan. 2008.

[2] E. Ip, A. Pak Tao Lau, D. J. F. Barros, and J. M. Kahn, "Coherent Detection in Optical Fiber Systems", *Opt. Express*, Vol.16, pp.753-791, Jan.2008.

[3] W. Shieh and I. Djordjevic, *O*

[4] *FDM for Optical Communications*, Elsevier, Ch.7, 2010.

[5] G. P. Agrawal, *Nonlinear Fiber Optics*, Academic Press, 2007.

[6] P. Savazzi, L. Favalli, E. Costamagna and A. Mecocci, "A suboptimal approach to channel equalization based on the nearest neighbor rule," IEEE J. Sel. Areas Comm. Vol. 16, No. 9, pp. 1640-1648, Dec. 1998.

[7] L. Liu et. al., "Intra-channel nonlinearity compensation by inverse Volterra series transfer function," Journal of Lightwave Technology, vol. 30, no. 3, pp. 310–316, Feb. 1, 2012.

[8] E. Giacoumidis et. al., "Volterra-based reconfigurable nonlinear equalizer for coherent OFDM," IEEE Photonics Technology Letters, vol. 26, no. 14, pp. 1383–1386, Jul. 15, 2014.

[9] J. Pan and C. H. Cheng, "Wiener–Hammerstein Model Based Electrical Equalizer for Optical Communication Systems", Journal of Lightwave Technology, vol. 29, no. 16, August 15, 2011.

[10] J. Pan et .al., " Nonlinear electrical compensation for the coherent optical OFDM system, "Journal of Lightwave Technology, vol. 29, no. 2, pp. 215-221, Jan 2011.

[11] M. A. Jarajreh, et .al., "Artificial Neural Network Nonlinear Equalizer for Coherent Optical OFDM", IEEE Photonics Technology Letters, vol. 27, no. 4, pp. 387-390, Feb. 2015.

[12] G. Kaur and G. Kaur, "Non-linearities mitigation with fuzzy neural networks using a machine learning algorithm in a CO-OFDM system", IET Optoelctronics, 2019.

[13] L. Hanzo, S. X. Ng, T. Keller, and W. T. Webb, "Quadrature amplitude modulation: From basics to adaptive trellis-coded, turbo-equalised and space-time coded OFDM, CDMA and MGCDMA systems", Wiley: IEEE Press, 2004.

[14] E. Ip, A. P. T. Lau, D. J. F. Barros and J. M. Kahn, "Coherent detection in optical fiber systems", Optics Express, vol. 16, no. 2, pp. 753-791, 2008.

[15] J. L. Wei, "Intensity modulation of optical OFDM signals using low-cost semiconductor laser devices for next-generation PONs", Ph. D. Thesis. Prifysgol Bangor University, UK, 2010.