MULTI USER DETECTION USING FUZZY LOGIC EMPOWERED ADAPTIVE BACK PROPAGATION NEURAL NETWORK

S. Abbas, *M. Adnan Khan,* *A. Ata,* *G. Ahmad,* *A. Saeed,* *N. Anwar*

Abstract: In Wireless communication, Multiple Input and Multiple Output (MIMO) systems have always been quite popular. Multicarrier systems are established along with different techniques of space-time coding to accomplish the demands of these systems. One of the most popular techniques is Multi-Carrier Code Division Multiple Access (MC-CDMA) with Alamouti's Space-Time Block Codes (STBC). This article, proposed the Fuzzy Logic empowered Adaptive Back Propagation Neural Network (FLeABPNN) based Multi User Detection (MUD) system, which is used to determine the receiver weights of MC-CDMA with the scheme of two variations. The proposed FLeABPNN approach takes advantage of a neuro-fuzzy hybrid system which conglomerates the competences of both fuzzy logic and neural networks for multi-user detection. It is observed that due to the fuzzy logic-based learning rate, proposed FLeABPNN based receiver without relationship & with relationship achieved the 3.04×10^{-06} and 2.05×10^{-06} Bit Error Rate (BER) respectively. The proposed FLeABPNN based receiver gives fast convergence rate & low BER as compared to other suboptimal published techniques like GA & LMS. It also observed that the Computational Complexity of the proposed FLeABPNN based MC-CDMA receiver is less then LMS based receiver up to 18 users, but higher than GA based receiver.

Key words: *MC-CDMA, FLeABPNN, MIMO, BER, ANN, STBC, MMSE, GA, LMS*

1. Introduction

Multiple access techniques are very popular when it comes to real-time wireless communication systems. There are numerous varieties of multiple access techniques are Time Division Multiple Access (TDMA), Frequency Division Multiple

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Access (FDMA) & Code Division Multiple Access (CDMA), which were designed for achieving the high data rate with a maximum number of users. TDMA allows several users to share the same frequency channel by dividing the signal into different time slots. Frequency Division Multiple Access (FDMA) allows multiple users to send data through a single communication channel, by dividing the bandwidth of the channel into separate non-overlapping frequency sub-channels and allocating each sub-channel to a separate user. Similarly, Code Division Multiple Access (CDMA) also a multiple access technology where the users are separated by unique orthogonal codes, which means that all users can use the same frequency and transmit at the same time. [1–3].

The number of users of wireless communication systems is increasing day by day. To accommodate these users, Multi-Carrier Systems like Multi-Carrier CDMA (MC-CDMA) & Orthogonal Frequency Division Multiple Access (OFDMA) are used [4–6]. MC-CDMA is a multiple access scheme used in OFDM-based telecommunication systems, allowing the system to support multiple users at the same time over the same frequency band. Another addition to multicarrier systems is Multiple Input and Multiple Output (MIMO) that uses multiple antennas on both transmitter and receiver sides. This technology got good attention in Beyond 3rd Generation (B3G) wireless networks [7] due to the fact of maximum utilization of limited bandwidth [8], [9].

The performance of the MIMO based MC-CDMA system may suffer due to Multi-User Interference (MUI) and Near-Far Rate (NFR). To overcome these issues, different intelligent Multi-User Detection (MUD) algorithms have been proposed for MIMO based MC-CDMA systems [10]. Multi User Detection methods are classified as under:

- Blind methods

- Semi blind methods

- Training based methods

Training based methods are associated with different training symbols, which results in stable MIMO based multiuser estimation. Furthermore, the bandwidth efficiency of the system is also improved [8]. In recent years, there is an increase in the importance of training-based MIMO MUD. Four types of training-based multi-user estimators are Least Squared (LS), SLS estimator, linear MMSE channel estimator and Relaxed MMSE (RMMSE) method [11].

Blind methods; on the other hand, give high system throughput without any training streams. Various statistics based on blind multiuser detection methods have been developed. These methods can be characterized as second-order statistics & higher-order statistics-based techniques [8]. Decision directed estimation is also a kind of blind estimation method. Similarly, numerous other blind MUD algorithms have been designed for OFDM systems in [12].

Semi blind systems are suitable for practical applications. The computational complexity of semi-blind methods is low and few training symbols have been used as compared to training-based approaches. Few training symbols have been used by semi-blind techniques to provide primary MIMO channel & multi-user estimation [8].

Various multi-user data estimation techniques have been proposed for Space-Time Coded (STC) based MIMO systems by using a pilot signal [13]. Orthogonal Space-Time Block Codes (OSTBs) with Maximum Likelihood (ML) decoders have achieved maximum diversity with low complexity. The ML decoder should have appropriate multi-user information so that the received signals are decoded accurately [7].

Various algorithms like ML and Zero Forcing (ZF) have been designed for symbol estimation. As compared to the ML algorithm, the implementation of the ZF algorithm is simple and less complicated. ZF algorithm has been preferred for fast fading channels. However, the ML algorithm has given better results in such environments at the cost of high computational complexity. For each subcarrier, a candidate symbol vector is examined and then Euclidean distance between the received and the original symbol is calculated for all probable arrangements of transferred symbols. Moreover, there is an exponential increase in search space with an increase in the number of transmitter and receiver antennas. As a result, the computational complexity of the system is also increased [10]. The adaptive implementation of the MIMO system is better to approach in order to overcome the computation complexity problem [10, 36, 37].

Blind data estimation recognition has used iterative least square with projection. Moreover, heuristics approaches like those that Genetic Algorithm (GA), Pirahna Fish optimization (PFO), and Particle Swarm Optimization (PSO) are used along with ML-based multi-user data detection because these have the capability to decrease the search space and computational complexity of ML algorithms [14–19]. In MIMO based systems, the DE algorithm has also reduced the ML algorithm's search space and computational complexity of symbol detection 10, [16–19]. Apart from these, ML algorithms are designed to estimate multipath fading channel and transmitted data sequence jointly. The algorithm operates on the iterative approach and does not require any prior channel information [12, 20–24].

There are numerous strategies like Neural Network [25–27, 41], Genetic Algorithm (GA) [31–33] Differential Equation (DE), Cooperative Co-Evolutionary (CC) Algorithms [34], Particle Swarm Optimization (PSO) [40], Maximum Likelihood (ML) [5,6], Partial Opposite Mutant Particle Swarm Optimization (POMPSO), Total Opposite Mutant Particle Swarm Optimization (TOMPSO) [35–37], Island GA, Differential Equation (DE) and Island DE has been proposed which further enhance the performance of the 5-th generation communication network [20, 38, 39, 41, 42].

In this paper, we have proposed a new mechanism that helps to mitigate the Multi User Interference in MIMO based MC-CDM system named as Fuzzy Logic empowered Adaptive Back Propagation Neural Network (FLeABPNN). In proposed FLeABPNN, the learning rate of the backpropagation neural network is updated using fuzzy logic instead of using a constant learning rate. This improves the performance of the MIMO based MC-CDMA system as compared to the conventional LMS [28, 29] & GA based suboptimum receiver [16, 33] in terms of Convergence rate & Minimum Mean Square Error. Computational complexity is another challenging issue in modern communication [38–42]. The proposed FLeABPNN solution gives attractive results with low computational complexity.

The system model is described in Section [2]. The proposed FLeABPNN based MC-CDMA receiver model is described in Section [3]. Section [4] describes the

simulation results and discussion. Finally, the research work is concluded in Section [5] & Future work suggested in Section [6].

2. System Model

In this article, the MC-CDMA system used with Alamouti's STBC having two transmit and one receiver antenna. The number of both antennas can be increased as per the requirements. In the MC-CDMA receiver side signal received from the transmitter. After receiving the signal, a cyclic prefix is removed which adds at the transmitter end. Then taking the M-point Fast Fourier Transforms (FFT) after converting the data into serial to parallel. Finally, the received signal vector in the frequency domain is written as [16, 28, 29, 33]:

$$r(2i-1) = \sum_{u=1}^{U} \{\mathbf{fr}_{u,1}\mathbf{Sc}_{u,1}\, e_k(2i-1)\} + \mathbf{fr}_{u,2}\mathbf{Sc}_{u,2}\, e_k(i) + \dot{z}(2i-1), \quad (1)$$

$$r(2i) = \sum_{u=1}^{U} \{-\mathbf{fr}_{u,1}\mathbf{Sc}_{u,1}\, e_k^*(2i) + \mathbf{fr}_{u,2}\mathbf{Sc}_{u,2}\, e_k^*(2i-1)\} + \dot{z}(2i),$$

where $U, \dot{z}$, $\mathbf{fr}$ & $\mathbf{Sc}$ are representing the total number of users, complex Additive White Gaussian Noise (AWGN) with zero mean, frequency-domain channel response and spreading code respectively [33].

$$\begin{aligned}
\Upsilon(w_1, w_2) &= E[|\mathbf{W}^H r(i) - e_1(i)|^2] = \\
&= E[|\mathbf{w}_1^H r(i) - e_1(i-1)|^2] + E[|\mathbf{w}_2^H r(i) - e_1(i)|^2] = \\
&= \Upsilon_1(\mathbf{w_1}) + \Upsilon_2(\mathbf{w_2})
\end{aligned} \quad (2)$$

In the Mean Square Error (MSE) based receiver for MC-CDMA system with Alamouti's STBC achieved by using the following problem [16, 28, 29, 33].

$$[\mathbf{w}_{1,\text{opt}}, \mathbf{w}_{2,\text{opt}}] = \arg\left\{\min_{\mathbf{w}1} \Upsilon_1(\mathbf{w}_1) + \min_{\mathbf{w}2} \Upsilon_2(\mathbf{w}_2)\right\} \quad (3)$$

In [17–19] the relationship of weight vector is fulfilled as [16, 28, 29, 33]:

$$\mathbf{w}_{1,2} = \mathbf{w}_{2,3}^*, \mathbf{w}_{1,4} = -\mathbf{w}_{1,1}^* \quad (4)$$

The rate of convergence is increased by updating the weight of vectors. The improved MMSE based cost function can be written as [16, 28, 29, 33]:

$$\Upsilon = \Upsilon_{N1}(\mathbf{w}_d, \mathbf{w}_e) + \Upsilon_{N2}(\mathbf{w}_d, \mathbf{w}_e), \quad (5)$$

where

$$\Upsilon_{N1}(\mathbf{w}_d, \mathbf{w}_e) = E[|\mathbf{w}_d^H r(i-1) + \mathbf{w}_e^T r^*(2i) - e_1(i-1)|^2]$$

and

$$\Upsilon_{N2}(\mathbf{w}_d, \mathbf{w}_e) = E[|\mathbf{w}_e^H r(i-1) + \mathbf{w}_d^T r^*(2i) - e_1(i)|^2]$$

3. Proposed fuzzy logic empowered adaptive back propagation neural network (FLeABPNN) based MUD

Fig. 1 shows the proposed FLeABPNN based MC-CDMA receiver model in which the received signal is down-converted for the u-th user. The cyclic prefixes are removed in the first step after that signal is transferred from serial to parallel. After taking the FFT proposed FLeABPNN is used to optimize the weights of the receiver.
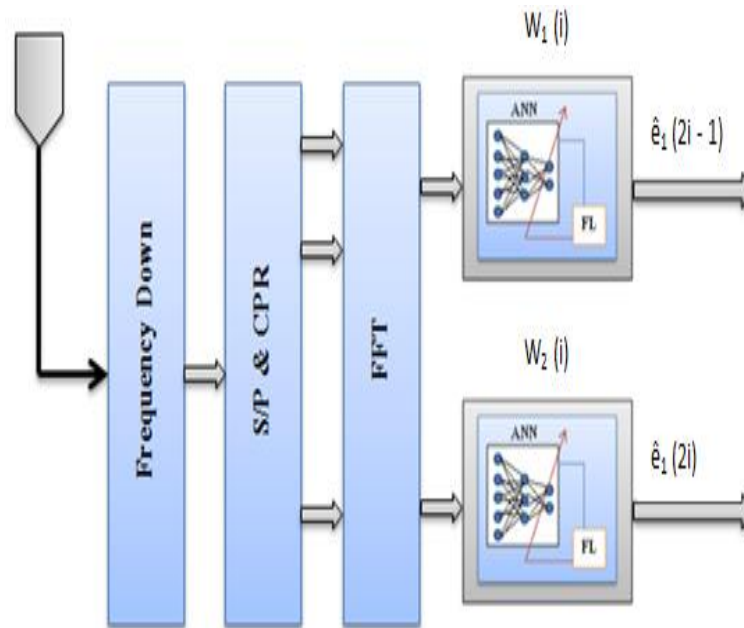

Fig. 1 *Proposed FLeABPNN based receiver system.*

Proposed FLeABPNN has used a total of three layers like input, hidden and an output layer. Different steps are involved in the algorithm of backpropagation which includes, Initialization of weight, Feedforward, Back Propagation of error and updating of weight and bias as shown in Tab. I. Every neuron present in the hidden layer has a Sigmoid activation function. Proposed FLeABPNN based MC-CDMA system can be written as

$$\psi_j = b_1 + \sum_{i=1}^{m} \left(\omega_{ij} \times \mathbf{r}_i \right), \tag{6}$$

$$\varphi_j = \frac{1}{1 + \mathbf{e}^{-\psi_j}}, \ \text{where } j = 1, 2, 3 \ldots n. \tag{7}$$

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Sr No.	Steps
1	Start
2	Initialization of both layer weights (ω_{ij} & υ_{jk}), Error (E)= 0 and the number of epochs £= 0
3	For each training pattern p – do the feedforward phase to – calculate ψ_j & φ_j using Eq. 6 & Eq. 7 – calculate ψ_k & φ_k using Eq. 8 & Eq. 9 – Compute output error signals and hidden layer error signals. – Then adjust weights ω_{ij} and υ_{jk} (backpropagation of errors) using Eq. 15 & Eq. 16.
4	£= £+ 1
5	Test stopping criteria: if no stopping criterion is satisfied, go to step 3.
6	Stop

Tab. I *Pseudocode of proposed FLeABPNN based MC-CDMA receiver.*

Input taken from the output layer is

$$\psi_k = b_2 + \sum_{j=1}^{n} (\upsilon_{jk} \times \varphi_j) \tag{8}$$

Output layer activation function is given below.

$$\varphi_k = \frac{1}{1+\mathrm{e}^{-\psi_k}} \quad \text{where } k = 1, 2, 3 \ldots r \tag{9}$$

$$E = \frac{1}{2} \sum_{k} (\tau_k - \varphi_k)^2 \tag{10}$$

Above equation represents back propagation error where, τ_k & out_k represent the desired output and estimated output.

Then rate of change in weight for the output, the layer is written as.

$$\Delta W \propto -\frac{\partial E}{\partial W}$$
$$\Delta \upsilon_{j,k} = -\epsilon \frac{\partial E}{\partial \upsilon_{j,k}} \tag{11}$$

After applying the Chain rule method Eq. 11 can be written as

$$\Delta \upsilon_{j,k} = -\epsilon \frac{\partial E}{\partial \varphi_k} \times \frac{\partial \varphi_k}{\partial \psi_k} \times \frac{\partial \psi_k}{\partial \upsilon_{j,k}} \tag{12}$$

After substituting the values in Eq. 12 the value of weight changed can be obtained as shown in Eq. 13.

$$\Delta v_{j,k} = \epsilon\,(\tau_k - \varphi_k) \times \varphi_k(1-\varphi_k) \times (\varphi_j)$$
$$\Delta v_{j,k} = \epsilon\xi_k\varphi_j, \tag{13}$$

where

$$\xi_k = (\tau_k - \varphi_k) \times \varphi_k\,(1-\varphi_k)\,.$$

Apply chain rule for the updating weights between input and hidden layers

$$\Delta\omega_{i,j} \propto -\left[\sum_k \frac{\partial \mathbf{E}}{\partial \varphi_k} \times \frac{\partial \varphi_k}{\partial \psi_k} \times \frac{\partial \psi_k}{\partial \varphi_j}\right] \times \frac{\partial \varphi_j}{\partial \psi_j} \times \frac{\partial \psi_j}{\partial \omega_{i,j}}$$

$$\Delta\omega_{i,j} = -\epsilon\left[\sum_k \frac{\partial \mathbf{E}}{\partial \varphi_k} \times \frac{\partial \varphi_k}{\partial \psi_k} \times \frac{\partial \psi_k}{\partial \varphi_j}\right] \times \frac{\partial \varphi_j}{\partial \psi_j} \times \frac{\partial \psi_j}{\partial \omega_{i,j}}$$

In the above equation, ϵ represents the constant,

$$\Delta\omega_{i,j} = \epsilon\left[\sum_k (\tau_k - \varphi_k) \times \varphi_k(1-\varphi_k) \times (\nu_{j,k})\right] \times \varphi_k(1-\varphi_k) \times \alpha_i$$

$$\Delta\omega_{i,j} = \epsilon\left[\sum_k (\tau_k - \varphi_k) \times \varphi_k(1-\varphi_k) \times (\nu_{j,k})\right] \times \varphi_j(1-\varphi_j) \times \alpha_i$$

$$\Delta\omega_{i,j} = \epsilon\left[\sum_k \xi_k\,(\nu_{j,k})\right] \times \varphi_j(1-\varphi_j) \times \alpha_i.$$

After simplification above equation can be written as

$$\Delta\omega_{i,j} = \epsilon\xi_j\alpha_i \tag{14}$$

where

$$\xi_j = \left[\sum_k \xi_k\,(\nu_{j,k})\right] \times \varphi_j(1-\varphi_j)$$

$$\nu_{j,k}^+ = \nu_{j,k} + \lambda_F \Delta v_{j,k} \tag{15}$$

The Eq. 15 is used for updating the weights between output & hidden layers.

$$\omega_{i,j}^+ = \omega_{i,j} + \lambda_F \Delta\omega_{i,j} \tag{16}$$

And the above equation is used for updating the weights between the input layer and the hidden layer.

In the above equations λ_F represents the learning rate of ABPNN. Convergence of ABPNN depends upon the careful selection of λ_F. In this article λ_F is updated using fuzzy logic as shown in given bellow

$$\lambda_F = FLC(e_s, \Delta e_s), \tag{17}$$

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Sr No.	Input Variables	Mathematical Representation of Membership Functions (MF)	Graphical Representation of MF
1	Error Square = ES $((\mu_{\mathrm{ES}}(e_s)))$ & Delta Error Square = DES $((\mu_{\mathrm{DES}}(\Delta e_s)))$	$\mu_{\mathrm{ES},VS}(e_s) = \begin{cases} \frac{0.25-e_s}{0.25}, & 0 \le e_s \le 0.25 \\ 0, & \text{else} \end{cases}$ $\mu_{\mathrm{ES},S}(e_s) = \begin{cases} \frac{e_s}{0.25}, & 0 \le e_s \le 0.25 \\ \frac{0.5-e_s}{0.25}, & 0.25 \le e_s \le 0.5 \end{cases}$ $\mu_{\mathrm{ES},M}(e_s) = \begin{cases} \frac{e_s-0.25}{0.25}, & 0.25 \le e_s \le 0.5 \\ \frac{0.75-e_s}{0.25}, & 0.5 \le e_s \le 0.75 \end{cases}$ $\mu_{\mathrm{ES},L}(e_s) = \begin{cases} \frac{e_s-0.5}{0.25}, & 0.5 \le e_s \le 0.75 \\ \frac{0.75-e_s}{0.25}, & 0.75 \le e_s \le 1 \end{cases}$ $\mu_{\mathrm{ES},VL}(e_s) = \begin{cases} \frac{e_s-1}{0.25}, & 0.75 \le e_s \le 1 \\ 0. & \text{else} \end{cases}$	
3	Output, Lamda $(\mu_{\mathrm{Output},L}(\lambda_F))$	$\mu_{L,VS}(\lambda_F) = \begin{cases} \frac{0.25-\lambda_F}{0.25}, & 0 \le \lambda_F \le 0.25 \\ 0, & \text{else} \end{cases}$ $\mu_{L,S}(\lambda_F) = \begin{cases} \frac{\lambda_F}{0.25}, & 0 \le \lambda_F \le 0.25 \\ \frac{0.5-\lambda_F}{0.5}, & 0.25 \le \lambda_F \le 0.5 \end{cases}$ $\mu_{L,M}(\lambda_F) = \begin{cases} \frac{\lambda_F-0.25}{0.25}, & 0.25 \le \lambda_F \le 0.5 \\ \frac{0.5-\lambda_F}{0.25}, & 0.5 \le \lambda_F \le 0.75 \end{cases}$ $\mu_{L,L}(\lambda_F) = \begin{cases} \frac{\lambda_F-0.5}{0.25}, & 0.5 \le \lambda_F \le 0.75 \\ \frac{0.75-\lambda_F}{0.25}, & 0.75 \le \lambda_F \le 1 \end{cases}$ $\mu_{L,VL}(\lambda_F) = \begin{cases} \frac{\lambda_F-1}{0.25}, & 0.75 \le \lambda_F \le 1 \\ 0, & \text{else} \end{cases}$	

Tab. II *I/O variables Membership Functions used in Proposed FLeABPNN based MC-CDMA receiver.*

where e_s and Δe_s are mean square error and normalized mean square error of the Proposed FLeABPNN system.

$$\Delta e_s = e_s(t) - e_s(t-1)$$

Mathematically and graphically Input / Output variable membership functions used in the Proposed FLeABPNN based system are shown in Tab. II.

There are four main parts in the fuzzy systems named as fuzzy prepositions, lookup table, inference engine and De- Fuzzifier.

The fuzzy preposition t-norm function is written as

$$t : e_s, \Delta e_s \rightarrow \lambda_F \tag{18}$$

the above equation can also be written in terms of fuzzy sets

$$t : [0,1] \times [0,1] \rightarrow [0,1] \tag{19}$$

$$\begin{aligned}
{[}(\mu_{\mathrm{ES}}(e_s),(\mu_{\mathrm{DES}}(\Delta e_s)] &= \min{[}(\mu_{ES}(e_s),(\mu_{\mathrm{DES}}(\Delta e_s)], \\
&= \mu_{\mathrm{ES,DES}}(e_s \Delta e_s)
\end{aligned} \tag{20}$$

The proposed FLeABPNN based MC-CDMA receiver lookup table consists of 10 I/O rules from 25 rules as shown in Tab. III.

Rules	Error Square (es)	Delta Error Square (Δes)	Lambda (λ)
1	VS (Very Small)	VS (Very Small)	VS (Very Small)
2	VS (Very Small)	S (Small)	VS (Very Small)
3	VS (Very Small)	M (Medium)	S (Small)
4	VS (Very Small)	L (Large)	M (Medium)
5	VS (Very Small)	VL (Very Large)	M (Medium)
6	S (Small)	VS (Very Small)	VS (Very Small)
7	S (Small)	S (Small)	S (Small)
8	S (Small)	M (Medium)	S (Small)
9	S (Small)	L (Large)	M (Medium)
10	S (Small)	VL (Very Large)	M (Medium)

Tab. III *Lookup table for proposed FLeABPNN based MC-CDMA receiver.*

In the fuzzy system membership function, IF-THEN rules are used as conditional statements. The important parts of fuzzy inference systems contain rules surface, rules viewer, etc. Proposed FLeABPNN based MC-CDMA receiver contains 25 rules denoted by Rv^η, where $1 \leq \eta \leq 25$.

- Rv^1 = IF error square is very Small AND delta error square is very Small THEN lambda is very Small

- Rv^2 = IF error square is very Small AND delta error square is Small THEN lambda is very Small

– Rv^{25} = IF error square is very large AND delta error square is very large THEN lambda is very large

Proposed FLeABPNN based MC-CDMA receiver inference engine Rv^η can be written as

$$Rv^\eta = \text{ES}^\eta \times \text{DES}^\eta \to \lambda_F^\eta \tag{21}$$

The above equation can be written as

$$\mu_{\text{ES}\cap\text{DES}}(e_s, \Delta e_s) = \mu_{\text{ES}}(e_s) \cap \mu_{\text{DES}}(\Delta e_s)] \tag{22}$$

The rules are interpreted as a single fuzzy relation defined by

$$R_{25} = \bigcup_{\eta=1}^{25} Rv^\eta \tag{23}$$

Assume two fuzzy sets named as $\aleph$ and $\emptyset$ also input and output of fuzzy inference engine individually. For R_{25} the output of Fuzzy Inference Engine is written as

$$
\begin{aligned}
&\mu_{\text{Very Slow}\cap\text{Slow}\cap\text{Medium}\cap\text{Large}\cap\text{Very Large}}(\emptyset) \\
&= \quad \sup_{\aleph\in(\text{ES},\text{DES})} t\left[\mu_\aleph(e_s, \Delta e_s), \mu_{R_{25}}(e_s, \Delta e_s, \lambda_F)\right]
\end{aligned} \tag{24}
$$

The Proposed FLeABPNN based MC-CDMA receiver Product Inference Engine (PIE) can be written as

$$
\begin{aligned}
&\mu_\xi \text{Lambda} = \\
&= \quad \max_{1\le\eta\le25}\left[\sup_{\aleph\in(\text{ES},\text{DES})}\left(\prod_{j=1}^{25}\left(\mu_{\text{ES},\text{DES}}(\text{ES},\text{DES}), \mu_{A_{1\aleph}A_{2\aleph}}(a_1, a_2)\right)\right)\right]
\end{aligned} \tag{25}
$$

Center of Gravity (CoG) DE fuzzifier is used in the Proposed FLeABPNN based MC-CDMA receiver. The CoG DE fuzzifier determines the CE as the center of the area as shown in Eq. 26 covered by the membership function of $\emptyset$, that is,

$$\text{CE} = \frac{\int \xi\mu_\xi(\xi)\,\mathrm{d}\xi}{\int \mu_\xi(\xi)\,\mathrm{d}\xi} \tag{26}$$

Fig. 2 shows the ruled surface of the Proposed FLeABPNN based MC-CDMA receiver. It is shown that if e_s and Δe_s are very small then λ_F is very small. Similarly, if e_s and Δe_s are very large then λ_F is very large.

Fig. 3 shown that if e_s is very small and Δe_s is small then change in learning rate λ_F of the proposed model is very small.

Fig. 4 shown that if e_s is very small and Δe_s is medium then learning rate λ_F of the proposed model is small. Similarly, Fig. 5 shows that if e_s is small and Δe_s is large then learning rate λ_F of the proposed model is medium.

Fig. 6 shows that the proposed model learning rate λ_F is large if e_s is medium and Δe_s is very high.

Similarly, Fig. 7 shows that if e_s is large and Δe_s is very large then proposed model learning rate λ_F is also very large.
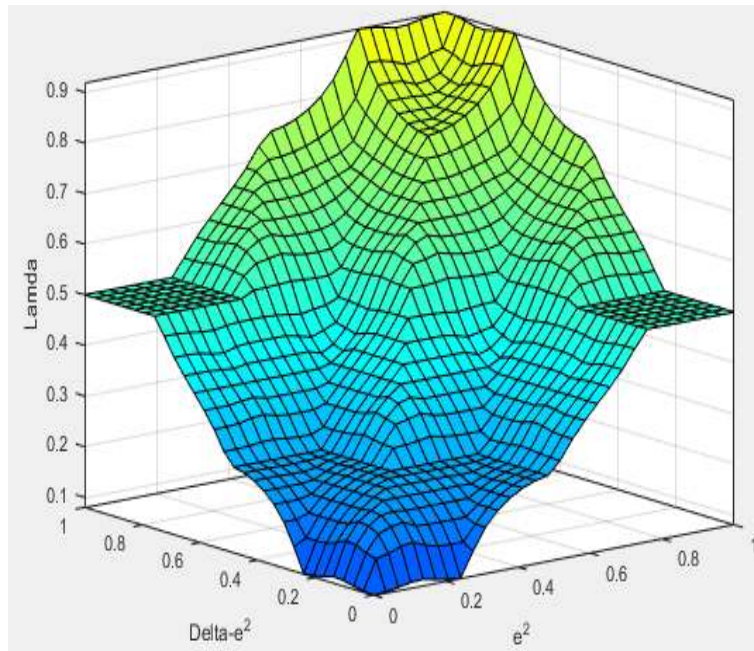
Fig. 2 *Proposed FLeABPNN based MC-CDMA receiver ruled surface.*
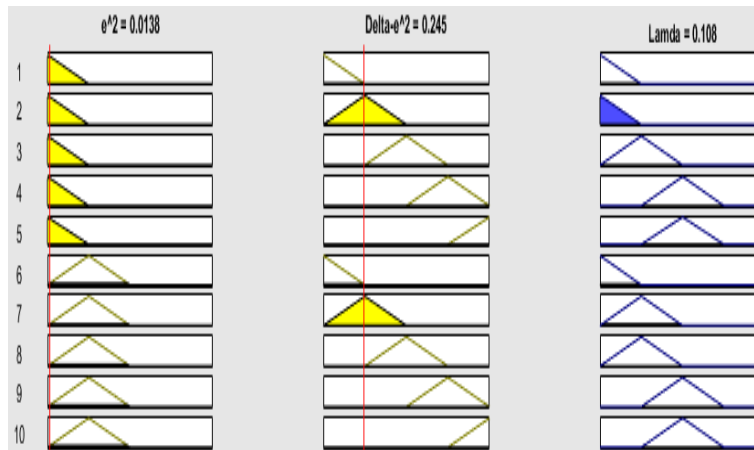

Fig. 3 *Proposed FLeABPNN based receiver Look up diagram for λ_F is very small.*

4. Results Analysis and Findings

MATLAB 2018 is used for simulation purposes. The MC-CDMA system is employed with A = 32 subcarriers, which is equal to the dimension of spreading code. The subcarrier spacing is 312 Hz and the time duration at the subcarriers is 0.32 ms. The spreading code real and imaginary parts are selected from $1/\sqrt{2}$ and
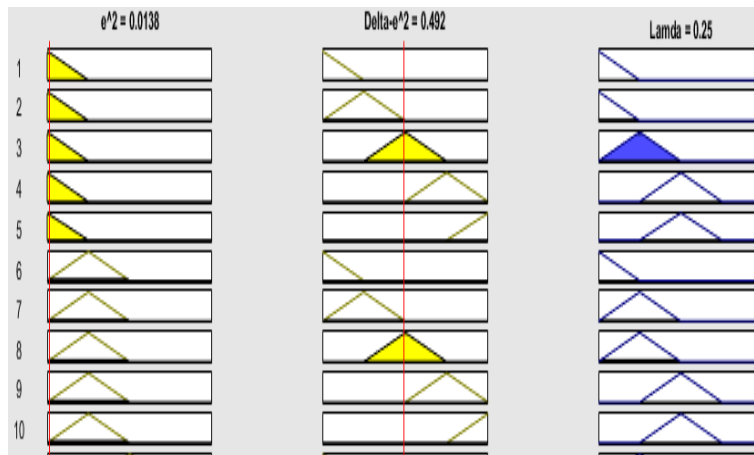
Fig. 4 *Proposed FLeABPNN based receiver Look up diagram for λ_F is small.*
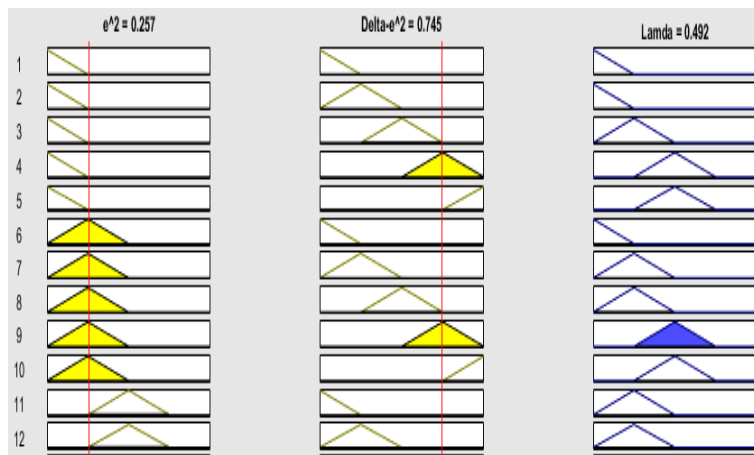
Fig. 5 *Proposed FLeABPNN based receiver Look up diagram for λ_F is medium.*

$-1/\sqrt{2}$ independently at random for each user. The Rayleigh flat fading channel is implemented using four paths. The fading gains are generated by using a complex Gaussian distribution, which are normalized such that the average energy of the channel is unity. The channel coefficients along spreading codes are fixed for whole observation.

The Figs. 8, 9, 10 and 11 signifies FLeABPNN based MC-CDMA receiver performance with respect to Minimum Mean Square Error (MMSE), convergence rate and complexity factor.

Fig. 8 shows the NoC vs MMSE with a fixed number of Hidden layers for both enhanced and a basic cost function with SNR is 25 dB. The 1-st, 2-nd, 3-rd & 4-th topmost curves show the performance in terms of MMSE of conventional (LMS) and accelerated GA based scheme without relationship as well as with relationship.
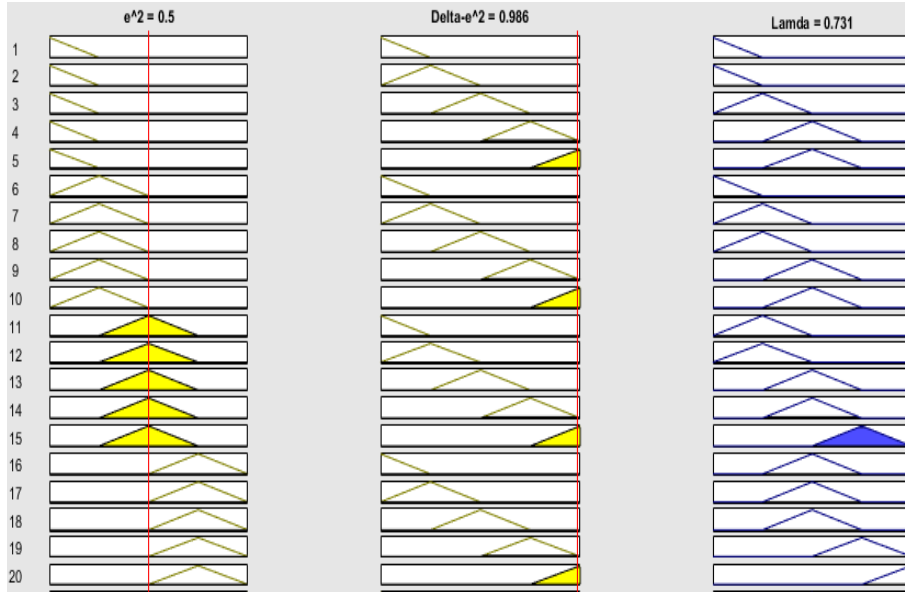
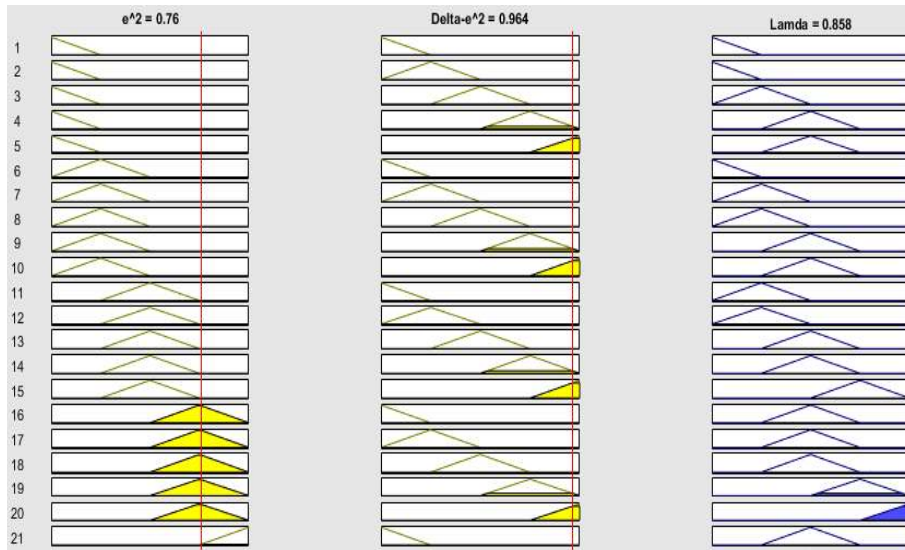**Fig. 6** *Proposed FLeABPNN based receiver Look up diagram for λ_F is large.*

Fig. 7 *Proposed FLeABPNN based receiver Look up diagram for λ_F is very large.*

It demonstrates that the LMS scheme without relationship & with relationship converges at 350-th, 250-th iteration to reach the same MMSE of 0.03 respectively. It very well may be seen that the accelerated GA based receiver without relationship & with relationship converges at 166-th, 90-th epoch respectively. The 2-nd last curve represents the proposed FLeABPNN based MC-CDMA receiver without a
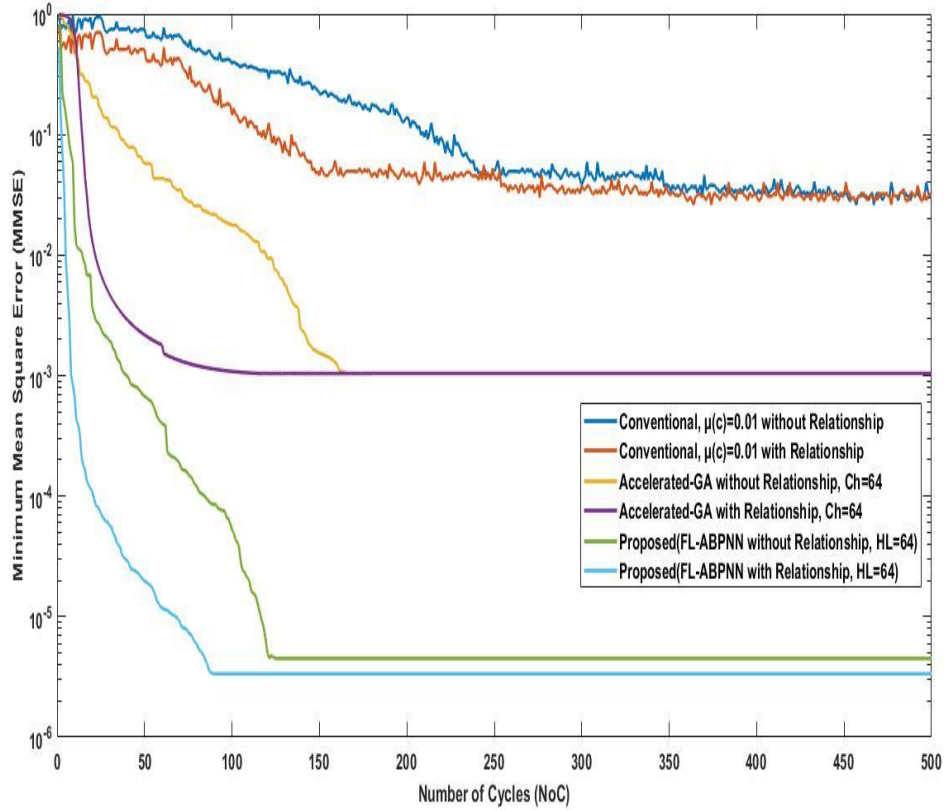
Fig. 8 *Minimum mean square error vs number of cycles (fixed hidden layers = 10).*

relationship. The bottom curve represents the proposed FLeABPNN based MC-CDMA receiver with the relationship. It very well may be seen the FLeABPNN receiver with relationship, converges at the 87-th cycle to achieve the MMSE of 3.4×10^{-06}. The FLeABPNN based MC-CDMA receiver without the relationship, converges at approximately 125-th cycle to achieve the MMSE of 4.5×10^{-06}. Hence, it very well may be said that FLeABPNN based MC-CDMA receiver with relationship converges faster, and lower MMSE than the FLeABPNN based MC-CDMA receiver without the relationship as well as conventional & accelerated GA schemes.

Fig. 9 demonstrates a number of users Vs factor of the complexity of conventional, accelerated GA and proposed FLeABPNN based MC-CDMA receiver schemes with both variations. The GA and conventional scheme complexity factor are calculated by $\frac{2^k}{\text{generations} \times \text{chromosomes}}$ and $k\,(B-1)\,(B+1)$ respectively [20]. And the complexity factor of FLeABPNN based MC-CDMA receiver scheme is calculated by

$$\frac{2^k}{\text{Input Layer Neurons} \times \text{Output Layer Neurons} \times \text{ Hidden Layer Neurons}}$$
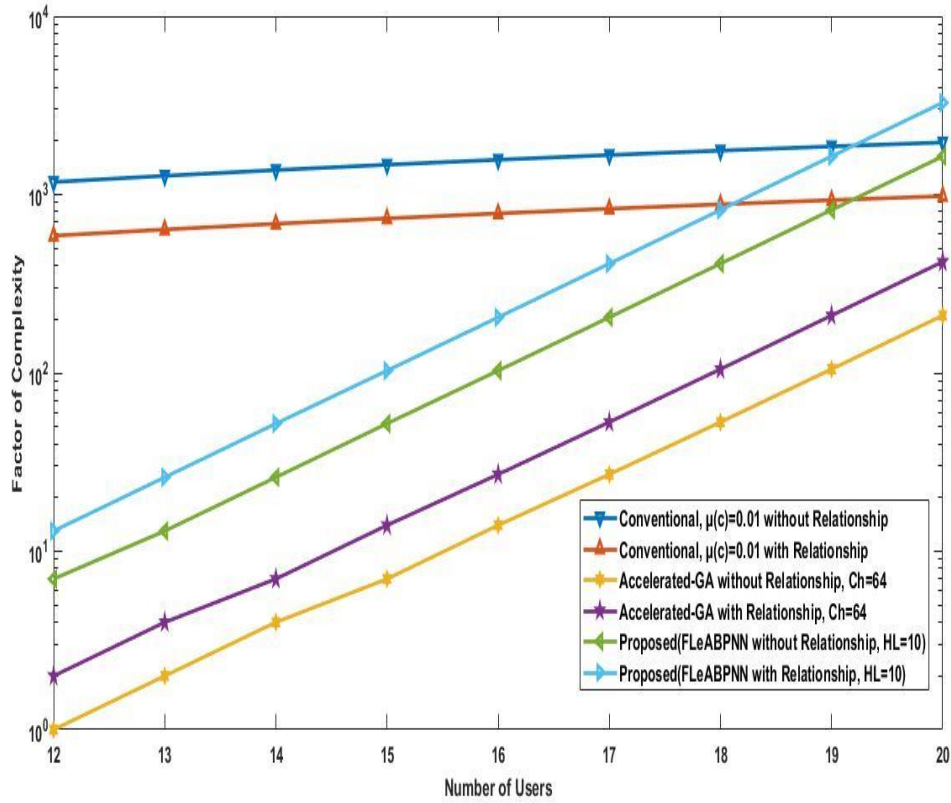
394

Fig. 9 *Complexity factor vs no of users with a fixed number of hidden layers.*

It very well may be seen in Fig. 9; the complexity factor has elevated up to 18 dB SNR. The LMS has the maximum complexity as compared to propose FLeABPNN based MC-CDMA receiver variations. The proposed FLeABPNN based MC-CDMA receiver with the maximum number of hidden layers (HL = 10) has the least complexity as compared to the conventional scheme. But Proposed FLeABPNN based MC-CDMA receiver complexity is higher as compared to accelerated GA based receiver. However, it seems from the behavior of the graphs that proposed FLeABPNN based MC-CDMA receiver with weight relationship has less complexity as compared to FLeABPNN based MC-CDMA receiver without weight relationship & conventional LMS based on MC-CDMA system.

Fig. 10 demonstrates the number of users vs the complexity factor for attaining the different bit error rate & a number of hidden layers. The conventional LMS is limited to $10^{-1.8}$ BER, accelerated GA is restricted to 10^{-3} BER, whereas the proposed FLeABPNN based MC-CDMA receiver is limited to 3 different BER's starting from 10^{-3} to $10^{-5.5}$. It is seen from the above figure that the proposed FLeABPNN based MC-CDMA receiver reaches low BER with fewer complications as compared to conventional LMS scheme up to 17 number of users, but, proposed FLeABPNN based MC-CDMA receiver attains low BER as compared to acceler-

ated GA at the cost of complexity. It also observed that the complexity factor is also increased with the increase in a number of hidden layers.
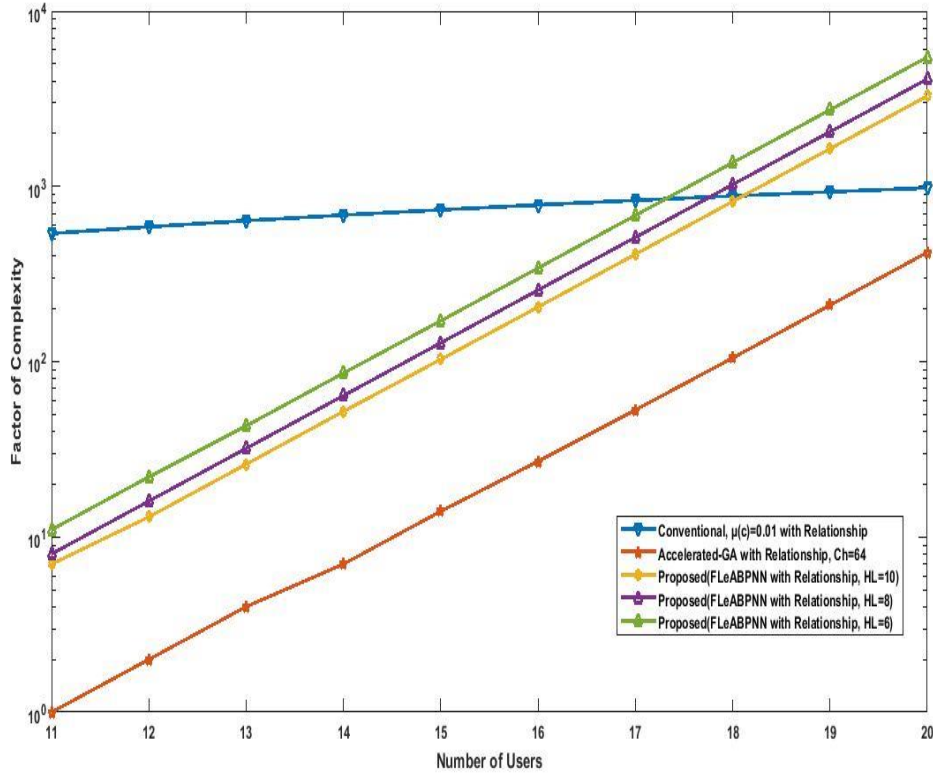

Fig. 10 *Factor of complexity vs number of user's with different number of hidden layers.*

Fig. 11 shows the number of user's vs Time Complexity (TC) for achieving the different bit error rates with the relationship. The arc illustrations from topmost to bottommost are:

- It is observed that the conventional scheme needs approximately 10^4 epochs to attain the 0.001 BER approximately.

- The accelerated GA with relationship limited at a 10^{-3} bit error rate with the number of chromosomes = 64. It might be seen that it needs $10^{5.9}$ epochs for 20 users with the end goal to accomplish BER = 10^{-3}.

- The 2-nd arc is for proposed FLeABPNN based MC-CDMA receiver with relationship restricted at 10^{-3} bit error rate and the number of hidden layers = 6. It very well may be seen that it required $10^{4.7}$ epochs for 20 users in order to attain the BER = 10^{-3}.

- The 3-rd arc is for proposed FLeABPNN based MC-CDMA receiver with relationship restricted at 10^{-3} bit error rate and the number of hidden layers

= 8 It very well may be seen that it required $10^{4.8}$ epochs for 20 users in order to reach the BER = $10^{-4.5}$.

- The 4-th arc is for proposed FLeABPNN based MC-CDMA receiver with relationship restricted at 10^{-3} bit error rate and a number of hidden layers = 10. It very well may be seen that it required $10^{4.9}$ epochs for 20 users in order to reach the BER = $10^{-5.5}$.
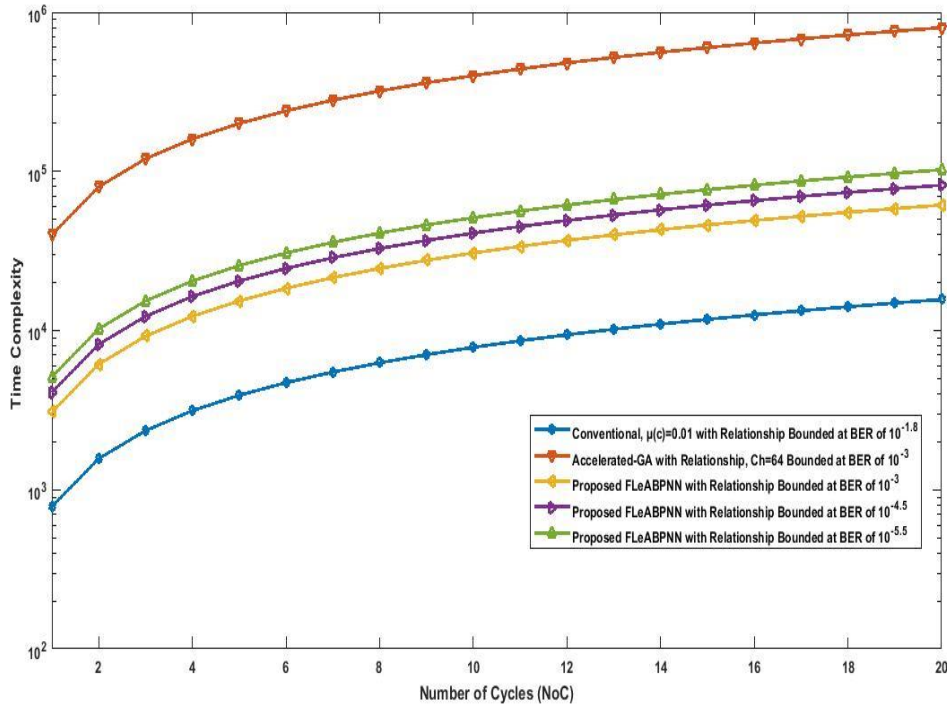

Fig. 11 *Number of user's vs time complexity for achieving the different BER with relationship.*

Hence, it very well may be said that the proposed FLeABPNN based MC-CDMA receiver with a relationship requires fewer cycles to accomplish any estimation of bit error rate for any number of users K as compared to accelerated GA receiver with the relationship.

Fig. 12 shows the Signal to Noise Ratio (SNR) vs Bit Error Rate (BER) with a fixed number of Hidden layers for both enhanced and a basic cost function with NoC, which is 250. The 1st, 2nd, 3rd & 4rth topmost curves show the performance in terms of BER of conventional (LMS) and accelerated GA based scheme without relationship as well as with relationship. It demonstrates that LMS scheme without relationship & with relationship gives 0.1202 & 0.1002 respectively at 20 dB SNR. It very well may be seen that the accelerated GA based receiver without relationship & with relationship gives 5.15×10^{-3} & 1.9×10^{-3}, respectively at 20 dB SNR.
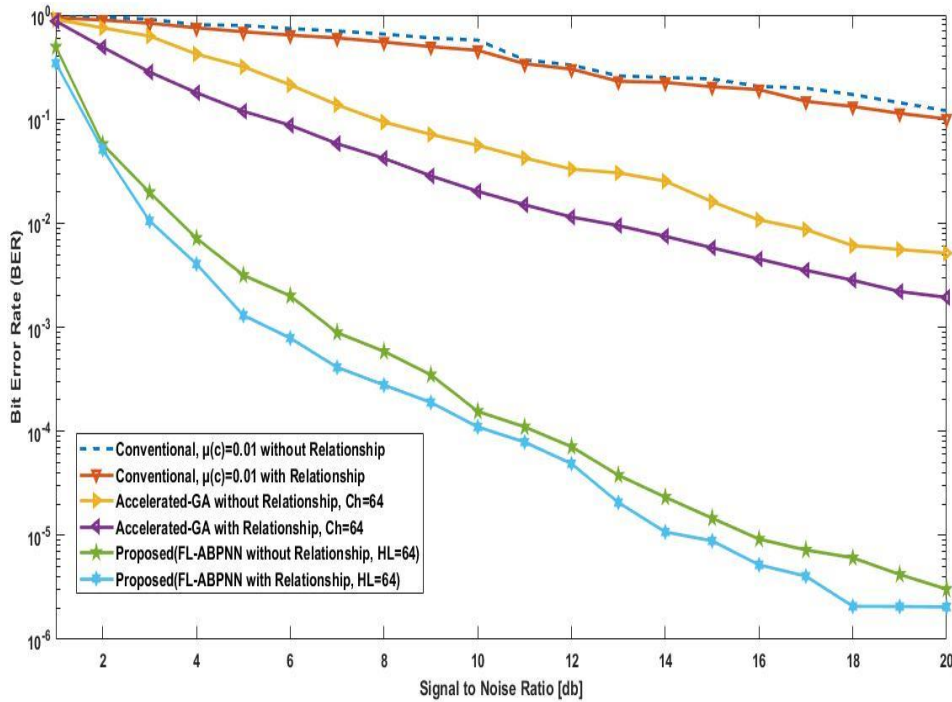
Fig. 12 *SNR vs BER (fixed hidden layers = 10).*

The 2nd last curve represents the proposed FLeABPNN based MC-CDMA receiver without a relationship. The bottom curve represents the proposed FLeABPNN based MC-CDMA receiver with the relationship. At SNR $= 20\,\text{dB}$ it very well may be seen the FLeABPNN receiver without relationship & with relationship achieve the BER of 3.04×10^{-06} & 2.05×10^{-06}, respectively. The FLeABPNN based MIMO-MC-CDMA receiver with a relationship gives more attractive BER as compared to others.

5. Conclusions

Modern contemporary technology world has given extensive rise to the number of users & multimedia applications. Futuristic technological models are leading to high data demand and fast convergence rate networks. This article attempted a hybrid solution of fuzzy and neural network for MUD. The proposed FLeABPNN based MIMO-MC-CDMA receiver gives the 2.05×10^{-06} BER & converges at the 87-th cycle to achieve the MMSE of 3.4×10^{-06} which are very attractive results as compared to previous published suboptimal based solutions like GA [33] & LMS [28, 29]. It is also observed that the proposed FLeABPNN based MC-CDMA receiver with weight relation converges faster with low BER & computational complexity as compared to without weight relationship-based solution.

6. Future Research Directions

The channel estimation is still not studied in this article; its mutual optimization along MUD is also another area of research. The mutation method of swarm algorithms can also be explored for further improvements. The model proposed in this article can be implemented in the field of medical diagnosis systems, channel equalization & channel estimation for accuracy and efficiency. Other vast areas of medicine and pharmacology can also be tested under this model.

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