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Robust Neural Network based Multiuser Detector in MC-CDMA for Multiple Access Interference Mitigation

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Abstract

The aim of this paper is to design a multiuser detector technique using artificial Neural Network under multiple access interference mitigation. To improve the performance of Multi Carrier Code Division Multiple Access (MC-CDMA) under multiple access interference, we have used a multilayered perceptron model of Neural Network that has three layers namely, input layer, hidden layer and output layer. The Neural Network is further trained by Levenberg-Marquardt algorithm. This algorithm uses the error function as key factor based on which the weights are adjusted to get the desired output. The Bit Error Rate (BER) performance of the system has been evaluated under Rayleigh and Stanford University Interim (SUI) channels for Binary Phase Shift Keying (BPSK) and Quadrature Amplitude Modulation (QAM) techniques. The proposed Neural Network based receiver is compared with Equal Gain Combining (EGC) and Maximal Ratio Combining (MRC) with varying number of users and Signal to Noise Ratio (SNR). Under SUI channel conditions and for a BER of 10^{-3}, the Neural Network based receiver shows an improvement of 1 dB and 8 dB than EGC and MRC receivers, respectively.

Keywords: Bit Error Rate, Equal Gain Combining, Maximal Ratio Combining, MC-CDMA, Neural Network

1. Introduction

Over the years multiple access techniques have gained popularity and are being used in wide range of real time applications. There are many multiple access techniques like Time Division Multiple Access (TDMA) in which many users can send data in different time slots in same frequency, Frequency Division Multiple Access (FDMA) in Figure 1, where users can send data at the same time in different frequencies and the other one is Code Division Multiple Access (CDMA) where users can send data at same time and in same frequency using different codes. Among all these techniques CDMA proves to be the best because of reasons like it can accommodate more users in a particular bandwidth compared to the other two, Security enhancement with spreading code technique etc[1–3].

Another most widely used technique is Orthogonal Frequency Multiplexing (OFDM). It is a type of digital multi carrier modulation scheme. First the signal to be transmitted is divided into many narrow band channels which are at different frequencies[4–6]. In Figure 2 OFDM uses large number of closely spaced sub carriers which are orthogonal to each other to transmit data parallelly instead of using a single sub carrier to transmit a high rate stream of data. Each sub carrier is modulated by regular modulation schemes such as Quadrature Amplitude Modulation (QAM), Phase Shift Keying (PSK) etc. at low symbol rate. The data rates of single carrier which transmits serially and multiple sub carriers which transmit parallelly will be similar. OFDM can be effectively used for minimizing the interference between channels which are close to each other in frequency. This technique can efficiently cope with problems like multipath fading and inter symbol interference.

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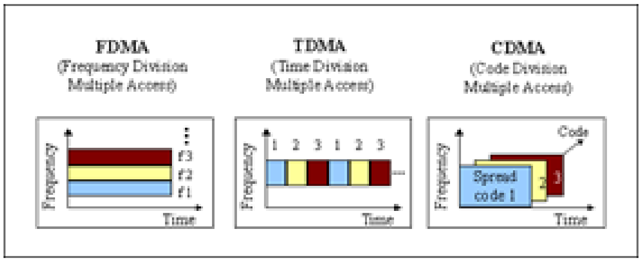

Figure 1. Multiple access techniques.

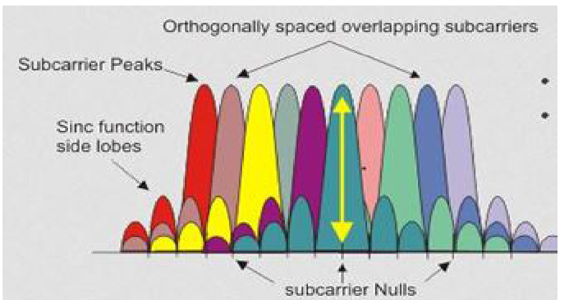

Figure 2. OFDM frequency spectra.

2. The MC-CDMA Principle

The Multicarrier Code Division Multiple Access (MC-CDMA) is the new emerging concept in the field of wireless communication which aims at improving performance in multipath links. It basically combines the methods used in CDMA and OFDM as shown in Figure 3. So it involves the advantages of CDMA (increased capacity, frequency diversity and security (spread spectrum technology)) and OFDM (robustness in multipath fading, resistance to inter symbol interference)[7–10]. Multiple parallel subcarriers carry each user's symbol so basically it is the spreading of each users symbol in the frequency domain. Then they are phase shifted according to code value. Code values are different, they vary per sub carrier and per user. Because each user has different code values the receiver can easily separate them. The parallel user symbols after IFFT are received in a serial way when converted by parallel to serial converter.

But this MC-CDMA system has two problems such as Multiple Access Interference (MAI) and Near Far Rate (NFR). There will be loss of orthogonality due to channel effect and also when number of active users increase, this is called MAI. When the interfering signal's power is large relatively than the desired user's signal, the NFR will occur. So, an appropriate Multiuser Detector (MUD) has to incorporate to mitigate these problems for MC–CDMA system. Among various MUDs, the non-linear NN based MUD is an efficient MUD for MC–CDMA system[11].

3. Artificial Neural Networks

Recently, Artificial Neural Networks (ANN) has become highly nonlinear classifiers by mimicking neural structure of the human brain. Similar to our brain the Artificial Neural Networks learn from example and perform its actions. The Neural Network model shown in Figure 4,

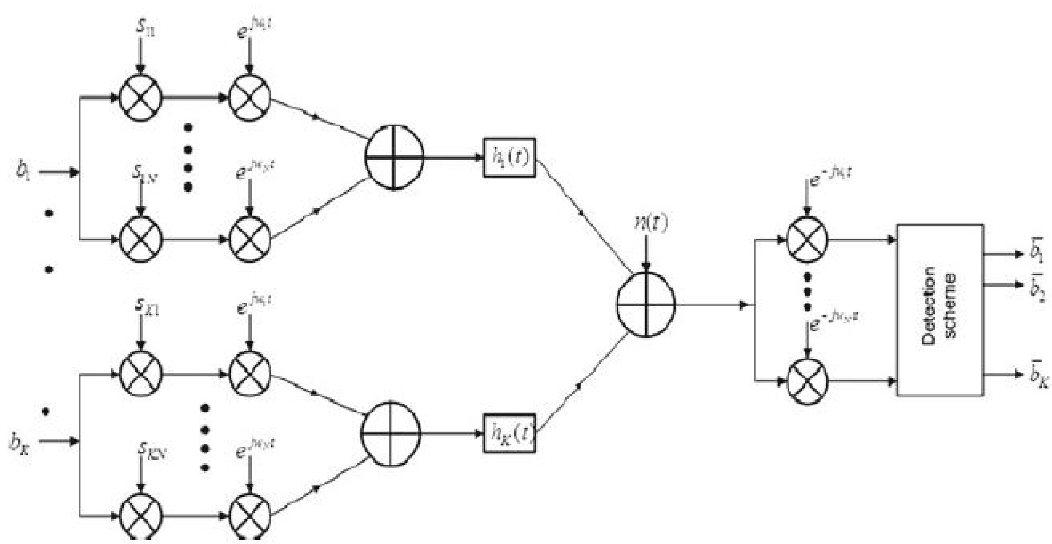

Figure 3. MC-CDMA system model.

basically consists of neurons which interconnected and thus pass information and exchange messages between each other. Particular numerical weights are assigned to each connection which can be varied based on experience depending on a particular application so as to get the desired output[12,13]. Learning ability is a key factor of neural networks. So with a Learning algorithm we can train a neural network, adjust its weight for a specific output. The type Neural Network we use here is multi layered perceptron which consists of input layer, hidden layer and output layer. Input layer of neurons just pass given input acting as buffers.

This paper is basically aimed at providing an efficient alternate for multiuser detection using Artificial Neural Networks based receiver. We have used a multilayered perceptron model of Neural Network which has three layers namely input layer, hidden layer, output layer. The Neural Network is further trained by Levenberg-Marquardt algorithm. This algorithm uses the error function as key factor based on which the weights are adjusted to get the desired output. The signal used is binary phase shifted keying modulated signal which then follows MC-CDMA technique.

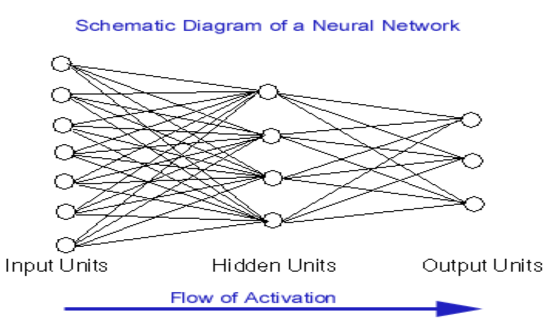

Figure 4. Neural Network model.

4. Design Approach

The uplink section in this paper mainly focuses MC-CDMA system. First the signal is Binary Phase Shift Keying (BPSK) modulated. Then it undergoes the MC-CDMA technique, where the each user signal is spread in the frequency domain. Each user symbol is allotted to a subcarrier and a code is allotted which decides the phase shift. The code which is multiplied to the bits is called spreading code. Further Inverse Fast Fourier Transform (IFFT) is done to this. Then Rayleigh channel is used as the medium to send this signal. At receiver side the Fast Fourier Transform (FFT) will be performed. The signal will then be passed on to detection scheme block which consists of the maximum ratio combining block and Neural Network block. The received signal at receiver after passing through the channel is given by:

$$r_n = \sum_{k=1}^{K}\sum_{n=1}^{N} A_k b_k S_{kn} h_{kn} e^{j\omega_n t} + n(t) \tag{1}$$

where, b_k is defined as the k^{th} user input bit, received amplitude of the k^{th} user is given by A_k, T_s is defined as the symbol interval, $w_n = 2\pi n/T_s$ is n^{th} component k^{th} user spreading code is denoted by S_{kn}. The spreading code length should be same as that of IFFT length. Rayleigh channel is characterized by flat fading for each frequency bin of every user and is denoted by complex coefficients h_{kn} as shown in Figures 7, 9 and 10. Further, $n(t)$ is the Additive White Gaussian Noise (AWGN) which has independent real and imaginary components with zero mean and σ^2 variance independently. As we have seen earlier that the received has to undergo FFT in order to nullify the effect of IFFT. So, the received signal for the n^{th} subcarrier index is given by:

$$r_n = \sum_{k=1}^{K} A_k b_k S_{kn} h_{kn} + n \tag{2}$$

Where, A is matrix consisting the amplitude levels of every user, b is the transmitted bit matrix consisting each user's message bits and n is called the AWGN noise matrix. In the conventional MRC receiver, the N parallel frequency domain channel outputs are de-spreaded by the de-spreading codes of every user and weight coefficients.

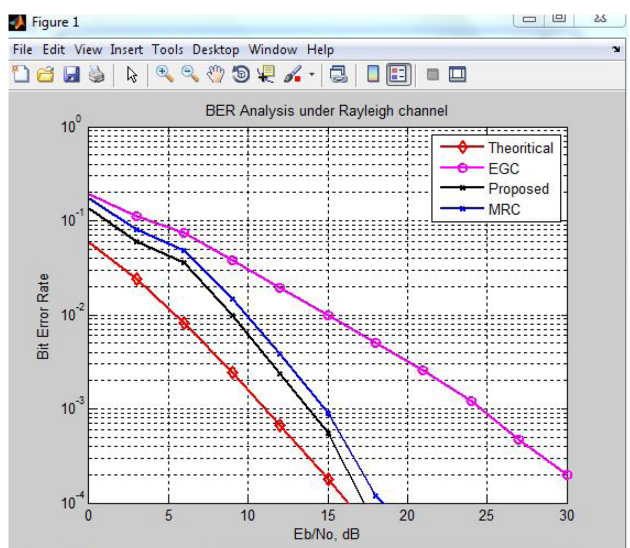

Figure 7. Using BPSK in Rayleigh channel.

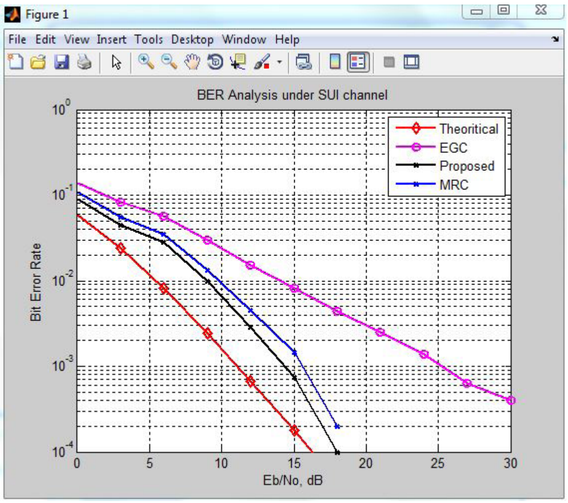

Figure 8. Using BPSK in SUI channel.

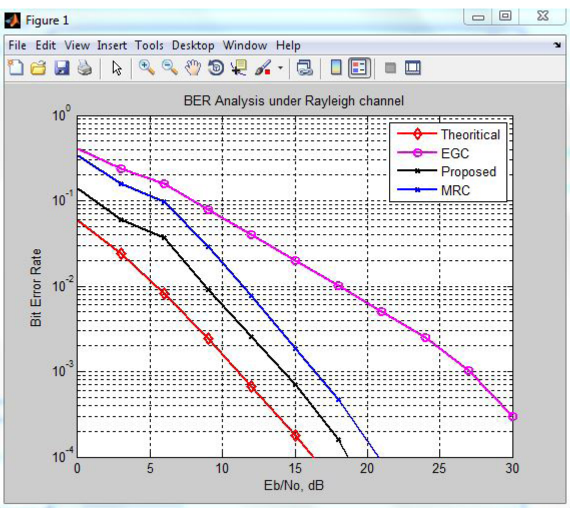

Figure 9. Using QAM in Rayleigh channel.

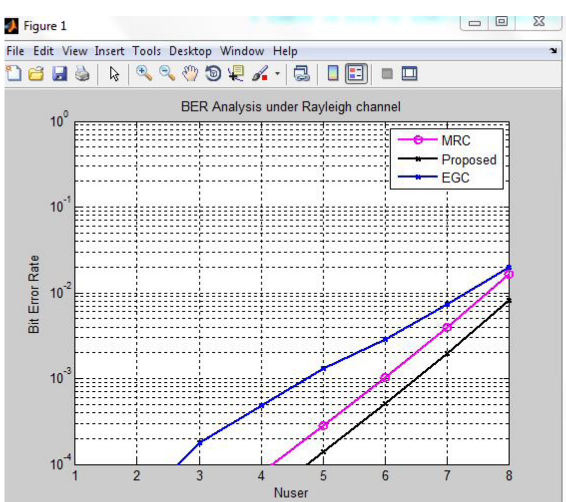

Figure 10. Using BPSK in Rayleigh channel as users increase.

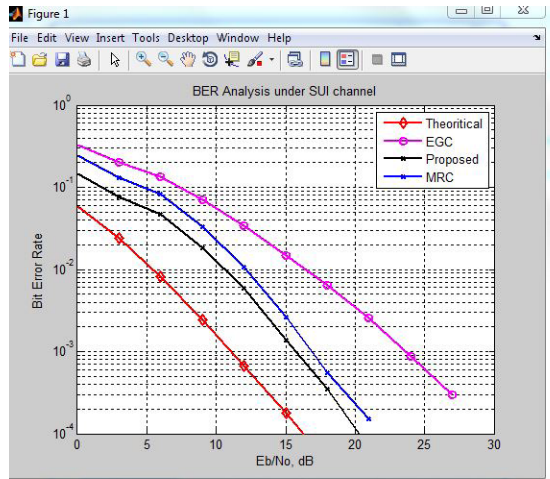

Figure 11. Using QAM in SUI channel.

5. The Levenberg Marquardt Algorithm

To adjust the weights of input layer to hidden layer and hidden layer to output layer the Levenberg–Marquardt algorithm[14–16] uses objective function that can be written as:

$$E(w) = \frac{1}{2}\sum_{k=1}^{C}\left(d_k - o_k\right)^2 \qquad (3)$$

k^{th} desired output is represented by d_k. k^{th} actual output is denoted by o_k, number of output points is denoted by c. The update formula for Levenberg–Marquardt algorithm is given as:

$$\Delta w = -\left(J^T J + \mu I\right)^{-1} J^T E \qquad (4)$$

Here J denoted the Jacobean matrix consisting derivative information of network errors with respect to network weights and biases. The rate of learning is denoted by μ, which determines the amount of weight that can be changed per each step. The network is trained at a faster rate when higher μ is equal to 1 and if the learning rate is small, the algorithm will take long time to optimize network weights.

The training steps are shown below:

- First initialize the weight and learning rate.
- Find the objective function which the sum squared of desired outputs and actual output.
- Using update formula solve for weights.
- The squared error is calculated using the updated

weight (w + Δw). If this error is less than the computed error in step 2, then learning rate is diminished by 0.1 times. Otherwise, increase the rate of learning by 10 times and proceed to step 3.

- If the error reached to a preset value, then stop the training algorithm.

6. MC-CDMA Receiver using ANN

Figures 5 and 6 depict the proposed MC–CDMA receiver using Neural Networks model. The signal after passing through Rayleigh channel is received by the detection scheme, which consists of the Fast Fourier Transform (FFT) block, Maximum Ratio Combining (MRC) block and Neural Networks (NN) block[17–20]. The spreading code of size N is assigned for each user. The $K \times N$ dimensional received signal S is fed to MRC receiver. The $K \times N$ dimensional channel matrix H is another input of the MRC receiver. The channel matrix H consists of frequency domain channel coefficient of k^{th} user and n^{th} sub-carrier as given below:

$$H = \begin{bmatrix} h_{11} & h_{21} & \cdots & h_{k1} \\ h_{12} & h_{22} & \cdots & h_{k2} \\ \vdots & \vdots & \ddots & \vdots \\ h_{1n} & h_{2n} & \cdots & h_{kn} \end{bmatrix} \quad (5)$$

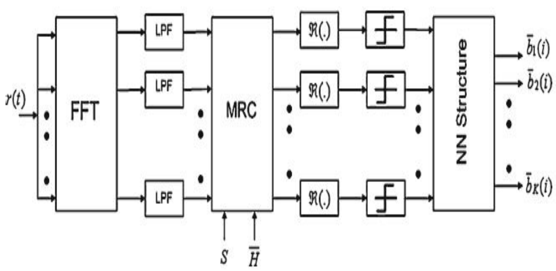

Figure 5. Neural Networks based MC-CDMA receiver.

As we see in the Figure 5 the outputs of Maximum Ratio Combining (MRC) block are taken as inputs for proposed Neural Networks (NN) receiver. The number of input, hidden and output nodes of the Neural Network model is chosen according to number of users in the MC–CDMA system. The network used here is a feed forward network. It is trained by Levenberg–Marquardt algorithm. The performance of the Neural Network based receiver is tested in different channel with different modulation schemes. It is compared against Equal Gain Combining (EGC) receiver and Maximum Ratio Combining receiver (MRC)[21–26].

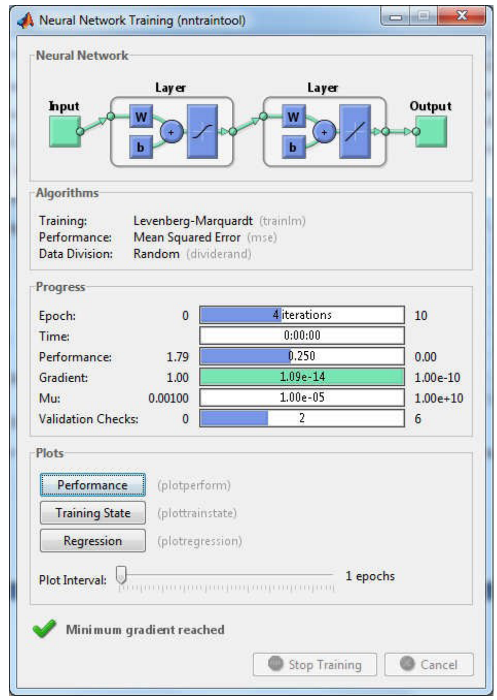

Figure 6. Neural Network training tool.

6. Simulation Analysis and Results

The simulations are performed with six different codes for comparisons of BER of receivers in different channels with different modulation schemes.

- First we simulate the BPSK signal and apply MC-CDMA technique and perform IFFT.
- We define the Neural Network and train it with Levenberg-Marquardt algorithm.
- We also define the other receivers EGC and MRC for the comparison multiuser detection.
- We label X axis as the E_b/N_0 and Y axis as BER.
- Using legend function we name the BER performance of each receiver.
- We also compare the BER performance as the number of users increase.

The following Table 1 shows the different modulation schemes used and different channels in which the BER performance is tested.

Table 1. BER simulations in different channels with different modulations

S.no	Type of modulation used	Channel used	BER performance when
1.	Binary Phase Shift Keying (BPSK)	Rayleigh	SNR is increased
2.	Binary Phase Shift Keying (BPSK)	Stanford University Interim (SUI)	SNR is increased
3.	Quadrature Amplitude Modulation (QAM)	Rayleigh	SNR is increased
4.	Binary Phase Shift Keying (BPSK)	Rayleigh	Number of users increase
5.	Quadrature Amplitude Modulation (QAM)	Stanford University Interim (SUI)	SNR is increased

- BER comparison of NN based, EGC, MRC receivers in Rayleigh Channel with BPSK modulation
  Here at a particular point Eb/N0 =15
  We see that BER values of:
  EGC receiver = 10^{-2}
  MRC receiver = $10^{-3.2}$
  NN based receiver = $10^{-3.5}$
- BER comparison of NN based, EGC, MRC receivers in SUI channel with BPSK modulation
  Here at a particular point Eb/N0 =15
  We see that BER values of:
  EGC receiver = $10^{-2.3}$
  MRC receiver = $10^{-2.9}$
  NN based receiver = $10^{-3.3}$
- BER comparison of NN based, EGC, MRC receivers in Rayleigh channel with QAM modulation
  Here at a particular point Eb/N0 =15
  We see that BER values of:
  EGC receiver = $10^{-1.9}$
  MRC receiver = $10^{-2.9}$
  NN based receiver = $10^{-3.4}$
- BER comparison of NN based, EGC, MRC receivers in Rayleigh with BPSK modulation as number of users increase
  Here at a particular point no. of users = 6
  We see that BER values of:
  EGC receiver = $10^{-2.8}$
  MRC receiver = 10^{-3}
  NN based receiver = $10^{-3.6}$
- BER comparison of NN based, EGC, MRC receivers in SUI channel with QAM modulation
  Here at a particular point Eb/N0 =15
  We see that BER values of:
  EGC receiver = $10^{-1.9}$
  MRC receiver = $10^{-2.8}$
  NN based receiver = $10^{-2.9}$

7. Conclusion

In this paper, we present an analysis on BER performance of three different receivers. The BER performances are tested when Signal to Noise Ratio (SNR) is increased and number of the users increased. The simulations were carried out in two different channels Rayleigh and Stanford University Interim (SUI) with different modulation techniques like Binary Phase Shift Keying (BPSK) and Quadrature Amplitude Modulation (QAM). The investigation was carried out using computer based Matlab simulations. The simulations focus on comparing BER performance between NN based receiver, Equal Gain Combining (EGC) receiver and Maximum Ratio Combining (MRC) receiver. The results of simulations show that the proposed Neural Network based receiver gives least BER values among all receivers and hence it proves that it can be efficiently used for multiuser detection.

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