MULTIUSER DETECTION USING NEURAL NETWORK FOR FD-MC-CDMA SYSTEM IN FREQUENCY SELECTIVE FADING CHANNELS

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ABSTRACT

Multiple combination of direct sequence CDMA is referred as the Multi-Carrier Code-Division Multiple Access (MC-CDMA). It is known that the MC-CDMA is a kind of signaling method which is used to perform optimal detection of carrier signals under the increased Doppler spread. Multi-user detection in a fading channel environment is a challenging problem in mobile communication MC-CDMA. To solve this problem in this work proposed a new multi-user detector using a Neural network. In order to improve the performance of the MC-CDMA system, Frequency Division is integrated to system known as FD-MC-CDMA system. The proposed FD-MC-CDMA system operates in frequency domain to detect multi-users in a frequency selective fading channel environment. Especially, FD-MC-CDMA divides users into subset of users and enable them to transmit their information through sub carriers instead of utilizing all carriers for information transmission. The proper selection of subset of carriers would ensure the full utilization of merits of frequency diversity which would lead to reduction of MAI experience faces by users. The performance of the proposed FD-MC-CDMA detector shows the ability of adaptive multi-user detection in fading channels such as Additive White Gaussian Noise (AWGN), Rayleigh and Rician fading channels. The simulations demonstrate that the proposed FD-MC-CDMA system structures not only perform similar to a Multiuser Detection (MUD) that detects one user at a time, but its computational complexity is significantly lower. The proposed system is measured in terms of Bit Error Rate (BER), Signal Noise Ratio (SNR) for the number of user’s simulations, although both have the same complexity.

Keywords: Mobile communication, Multi-user detector, Neural Networks, FD-MC-CDMA, Additive White Gaussian Noise (AWGN), Rayleigh and Rician frequency selective fading channels.
1. INTRODUCTION

Generally, every radio communication technologies utilize the Code-Division Multiple Access (CDMA) method for channel access [1]. CDMA is a kind of multiple access method which allows multiple transmitters to share excess information through single communication channel. Thus it is required to divide the bandwidth utilization to enable multiple users to share them. Here, interference effect can be reduced by introducing the spread spectrum technology and a special coding scheme among multiple users. Thus each transmission would be assigned with the code [1]. Various mobile phones utilize CDMA as the channel access procedure.

Many coding issues involved in CDMA systems, such as spreading sequence design, error control coding, adaptive modulation and coding, space time coding, signal processing and implementation, need to be solved. So here MC-CDMA is using instead of MC-CDMA, it improves the spreading sequence design.

In OFDM based telecommunication system, simultaneous support of multiple users at a same time can be enabled by introducing the multiple access method namely Multi-carrier code-division multiple access (MC-CDMA). MC-CDMA adapts the frequency domain based distribution procedure to spread the user symbol over multiple parallel sub carriers. However, this symbol value will be phase-shifted to either 0 degree or 180 degree based on code value received. These code values are different for every user. This code shift will be reversed in the receiver phase where every received sub carrier signal will be combined together based on weight values and signal strengths they carried with them. In the receiver side, separation of signal values of different users would be done based on different code values.

Multiuser detection is the process of decoding the information received from multiple users which are mutually interference to each other. This process will handle the information that are received from the regions such as wireless communications, high speed data transmission, DSL, satellite communication, digital television and magnetic recording [1]. The current research works focused on performing demodulation in less energy concerned inter chip and intra chip communication process. In multi user detection process, it considered both receiver side and sender side technologies for the prediction of combined interfering signals whereas in single user detection process only receivers are considered for the recovering just single user which is more robust than the multi user interference problem with increased noise level. In the recent technologies, it is difficult to avoid the mutual interference problems especially in wireless systems with utilization of orthogonal multiplexing systems such as TDMA, synchronous CDMA or OFDMA, multiuser interference originates from channel distortion and from out-of-cell interference [2].

The performance of CDMA would be affected greatly at the time of signal transmission over faded channel. Thus it is required to introduce the multi user detection (MUD) process and channel estimation technique which plays important role to resolve the interference issues and channel categorization problems. MC-CDMA ensures the good improved performance in terms of reduced error rate in frequency selective fading channels and also it can achieve the optimal handling of frequency diversity. However, presence of increased scalability of Multiple Access Interference (MAI) would reduce the MC-CDMA performance. This is resolved in this work by introducing the Frequency Division (FD) with MC-CDMA known as
FD-MC-CDMA. This method can utilize the frequency diversity merits effectively with reduced MAI values. FD-MC-CDMA enables users to transmit subset of carried information to support the subset of users instead of transmitting the all user information bits over all carriers. This can optimize the overall system capacity and throughput considerably well in the MC-CDMA.

Nemade et al [3] proposed biogeography base optimization (BBO) algorithm to perform multi user detection in the CDMA system. The main goal of BBO method is to reduce the error rate of user transmitted signals. This method assures the optimal solution detection by selecting proper values of immigration rate and emigration rate. Thus the user detection complexity can be reduced considerably with lesser interference issues in user transmitted signals. The proposed multi user detection system would be suitable for the user identification at run time by considering the detection complication and execution time. This methodology is implemented in the MATLAB simulation platform and the performance is measured based on evaluation parameters. Kaur and Mundra [4] discussed the comparison of several optimization methods for solving the optimal multiuser detection problem exactly or approximately. The purpose of using these algorithms is to provide complexity constraint alternatives to solving this nondeterministic polynomial-time (NP)-hard problem. An approximate solution is found firefly based optimization which is used to provide an exact solution. Simulations show that these approaches can have bit-error rate (BER) performance which is indistinguishable from the maximum likelihood performance. Multi-user detection technique is one of the key techniques used in CDMA system. This technique can reduce the multiple access interference and enhance the system performance and capacity. Monsees et al [5] proposed a combination of compressed sensing based detection known as Compressed Sensing based Multi User Detection (CS-MUD) with multicarrier access schemes. Name this novel combination Multicarrier CS-MUD (MCSM). Previous investigations on CS-MUD facilitate massive direct random access by exploiting the signal sparsity caused by sporadic sensor activity. The new combined scheme MCSM with its flexibility in accessing time-frequency resources additionally allows for either reducing the number of subcarriers or shortening the multicarrier symbol duration, i.e., gain a high spectral efficiency. Simulation results are given to show the performance of the proposed scheme. Huang et al [6] attempted to reduce the computational complexity by introducing the forcing mutation scheme integrated genetic algorithm (GA). The performance evaluation outcome proved that the proposed FME-MUD method provides better result than the existing GA-MUD for the heavy load systems. This performance is proved with six generation of GA.

Peixoto and Fernandes [7] introduced semi-blind receiver for a multiuser uplink DS-CDMA (Direct-Sequence Code-Division Multiple-Access) system in terms of relay aided cooperative communications. This work adapts the quadric linear Parallel Factor (PARAFAC) tensor decomposition for the receiver side signals to ensure the blind estimation of transmitter symbols, channel gains and spatial signatures for each user. These values are predicted by executing Alternating Least Squares (ALS) algorithm which is used to fit the tensor model. The performance evaluation has been carried out for the proposed received for different scenarios. Ravindrababu et.al [8] combined (PPIC and DPIC) these two techniques and propose a multistage multi-user (PD-PIC) detector for performance improvement and complexity reduction compared to conventional PIC detector. The performance is degraded as the number of user's increases in each technique. Shoreh et.al [9] analysed the execution performance of asynchronous optical multi-carrier code division multiple access (MC-CDMA) for both modulated and direct detection systems. This analysis is done for the next generation optimal access networks. The proposed method ensures the asynchronous resource sharing performance for frequency domain by employing the gold sequence. In long-achieve latent optical systems, fibre impedances corruption to the execution of standard optical
CDMA can be kept away from by recurrence area advanced remuneration techniques in the proposed MC-CDMA. In examination with symmetrical recurrence division different access, crest to-normal power proportion in the proposed MC-CDMA is diminished and offbeat asset sharing is accomplished. The execution of the proposed optical MC-CDMA framework is systematically assessed by driving shut shape conditions for flag to-impedance in addition to commotion proportion and bit error rate (BER) exhibitions.

Abdul-Aziz et al. [10] introduced the reduced-complexity interleaved multi-carrier CDMA (RC I-MC-CDMA) method to perform channel detection accurately. This method considers the variable spreading code length and interleaved sub-bands for the channel detection instead of continuous spreading coded with equal length. This is different than the conventional MC-CDMA method. The proposed method can support the varying complexity level of system design. The performance evaluation outcome proves that the proposed method can achieve lesser computational complexity where it is 95 lesser than conventional method for increased power of only 0.5 dBm. Sreesudha and Malleswari [11] implemented MC-CDMA system implemented with maximal-length, gold and ZCZ (Zero Correlation Zone) sequences. Multiple input-multiple output (MIMO) technology provides high transmission rate, reliability and diversity for communication systems. Also MC-CDMA system is implemented with 4 transmitting and 4 receiving antennas (4x4). BER (Bit Error Rate) performance is measured with three sequences in AWGN, Rayleigh fading channel. Itoh, and Ueda [12] proposed a multi-carrier CDMA modulation system for cellular mobile communication with two-way transmitter-receiver broadband far-field antenna array adaptation to the propagation path characteristics. Assume the frequency band is shared between the two directions and the same array antenna is used at each station for transmission and reception. Also assumed is error-free measurement of the transmittance from each of the transmitters to the array elements of the receivers. Botsinis et al. [13] designed low complexity soft-input soft-output quantum-assisted multi-user 12 detectors (QMUD), which may be conveniently incorporated into 13 state-of-the-art iterative receivers. Our design relies on extrinsic 14 information transfer charts. Our QMUDs are then employed 15 in multi-carrier interleave-division multiple-access (MC-IDMA) 16 systems, which are investigated in the context of different 17 channel code rate and spreading factor pairs, whilst fixing the total 18 bandwidth requirement. De [14] provided an analysis of the performance degradation of the single user detector algorithms in different multipath channels, and compares it to that of the fast joint detector algorithm in this paper. Also provides results at higher than chip rate sampling and illustrates the advantages of the new algorithm, as compared to the existing fast joint detectors and single user 4 detectors. Also considers some issues in the design of the fast joint detector algorithm, like the implementation of the inverse required in the method.

Kaddoum, [15] presented a Multi-user OFDM based Chaos Shift Keying (MU-OFDM-DCSK) modulation. In this system, the spreading operation is performed in time domain over the multi-carrier frequencies. Bao et.al [16] reviewed the error performance of multidimensional constellations in the multiple access and broadcast channels. More specifically, provided closed-form expressions for the pairwise error probability (PEP) of the joint maximum likelihood detection, for multiuser signalling in the presence of additive white Gaussian noise and Rayleigh fading.

2. SYSTEM MODEL

In this work, multiple access architecture by Frequency Division (FD) with MC-CDMA known as FD-MC-CDMA is introduced to achieve the frequency diversity benefits with reduced MAI level. This method attempts to transmit the sub set of carriers of sub set of users instead of transmitting all user information bits. Thus this method can ensure the optimal utilization of system capacity and throughput as like in MC-CDMA and achieves better
balance in probability of error rate performance by fixing the larger diversity gain values under increased network capacity. This performance improvement in increased diversity gain is obtained by equation (1) permitting the transmitters to perform simultaneous forwarding of data from N multiple carrier, and equation (2) utilizing receivers for the division of signals into multiple carrier components to achieve the effect frequency diversity. Be that as it may, MC-CDMA encounters execution debasement because of MA1 (multiple access interference) caused by the other dynamic clients having a similar N bearers. Ordinarily, the execution of the MC-CDMA framework is constrained by the measure of MAX. FDMA (Frequency Division Multiple Access) then again, totally keeps away from MA1 by assigning every client a one of a kind, symmetrical transmission recurrence. Be that as it may, in this transmission conspire, no recurrence assorted variety gains are accomplished at the receiver.

FDMA cannot provide better performance in fading channels. Thus in this work, new frequency based multiple access architecture is introduced namely FD-MC-CDMA whose processing flow is shown in figure 1. This method integrates the improved factors of FDMA and MC-CDMA to ensure the simultaneous utilization of frequency diversity with reduced MAL. The integration of FDMA and MC-CDMA is known as FD-MC-CDMA where the total N sub carriers will be separated into multiples groups. Each group contains L non-continuous sub carriers which can be separated under maximal utilization of bandwidth where the L is the available frequency diversity gain. Through this group of sub carriers, user information would be forward instead of utilizing all N sub carriers. The frequency diversity benefit in this method would provide same merits as conventional method MC-CDMA due to increased frequency separation between L sub carriers. And also, an only KII user who leads to reduced MA1 observed value from the group of L subcarriers are supported for each user. Thus the performance of the proposed multiple access architecture can be enhanced with increased diversity benefits and reduced MAI which is better than the conventional methods MC-CDMA and FDMA under similar network capacity. The proposed method not only improved than the conventional methods and also ensures the reduced computation load of receiver system. And also, proposed method ensures the flexibility in supporting the different users with different quality of service (QoS) requirements. This proposed method known to be improved version of our previous research work where the integration of FDMA and MC-CDMA is discussed [3]. However in our previous research work, receiver might degraded in its performance with the arrival of new multiple access scheme, thus the expected performance outcome cannot be achieved.

Figure 1 FD-MC-CDMA architecture
2.1. The Receiver with the Neural Network (NN) MAI Detector:

There are a lot of studies in the literature that use the NNs. In these studies, the outputs of the MFs are used for the training and the NN is trained to get the bits of the users. Also, we used the outputs of the MFs for the training, but we trained the NN to get MAI instead of the bits of the users. For this reason during the training, MAI is obtained from the outputs of the MFs, and then the NN is trained for this MAI. After training process, the NN is used as MAI detector. MAI which is detected by NNMAI receiver for the desired user is subtracted from the MFs output of this user and result is applied to the zero threshold circuit to get any bit of the desired user. The up-link transmission is considered and the number of the outputs of the NNs was chosen as the number of active users. MAI can be obtained from the training data during the training with Parallel Interference Canceller (PIC) approach. MAI can be calculated as (1)

\[
(MAI)_K = \sum_{i=j-K}^{k} A_i \rho_{jk} b_j(i)
\]  

However, used a different method to obtain MAI with lower computational complexity. The output of the MF for \( k \)th user for the training can be produced without noise as:

\[
y_k = A_k b_k + (MAI)_K
\]  

During the training, MAI can be obtained easily by subtracting known training user data from the

Produced output of the MF for this known training user data by using equation (2)

![Figure 2](image_url) Multiuser receiver with NN trained for signals of users in asynchronous channel

Two layer NNs are used in MAI detector and signal detector. Both NNs that are used at the detectors are exactly the same. Here, number of hidden and output neuron are selected based on number of users to be served and number of input layers are fixed as 3 times higher than the number of users. Levenberg-Marquardt algorithm is utilized here for the training purpose and tangent sigmoid activation function is utilized in the hidden layer. In output layer pure linear activation function was used. The receiver with the NN that is trained for signals of users is shown in Figure 3 and the receiver with the NN that is trained for MAI is shown in Figure 3 in the asynchronous channel.
2.2. Transmitter

The representation of k\textsuperscript{th} user’s transmission in conventional MC-CDMA system is given as

$$S^k(t) = b_k \text{Re}\left\{\sum_{i=1}^{N} \beta_i^k e^{j2\pi i\Delta f t} e^{j2\pi f_i t}\right\} g(t)$$ (3)

Where $b_k$ represents the information bit value of k\textsuperscript{th} user, $\Delta f$ is the frequency division value among neighbour carriers, f is known to be transmission frequency, $\beta_i$ value is either +1 or -1 which is decided in terms of Hadmard-Walsh codes and g(t) represents the rectangular waveform for the symbol duration T. Generally fading channels presents in wireless system known to have L fold frequency diversity with the order of 2, 3, or 4. In this work, the value of L is assumed to be 4 to make it ease. Here multiple access system is constructed with lesser MAI by allowing sub set of L=4 users that shares l=4 cameras through MC-CDMA. The representation of information transmitted by k\textsuperscript{th} user from the 4 users is given in (4)

$$s^k(t) = b^k \text{Re}\left\{\sum_{i=1}^{N} \beta_i^k e^{j2\pi i\Delta f t} e^{j2\pi f_i t}\right\} g(t)$$ (4)

Where $\beta_i^k$ = +1 or -1 at L=4 values of i and $\beta_i^k$= 0 elsewhere. Specifically, for L=4 fold diversity and N= 32 carriers: $\beta_i^k \in \{+1,-1\}$, $i = 1,9,17,25$ and $\beta_i^k$.L-1" =0, $i =1,9,17,25$ for one set of four users; $\beta_i^k \in \{+1,-1\}$, $i = 2,10,18,26$ and $\beta_i^k,-" = 0$, $i = 2,10,18,26$ for another four users; and so on...shown in Figure.1. Generally,

$$\beta_i^k = \begin{cases} \pm 1, & i = \frac{K}{N L} + 1, \frac{K}{N L} + \frac{N}{L} + 1, \frac{K}{N L} + 2 \frac{N}{L} + 1, \ldots \ldots \ldots \frac{K}{N L} + (L-1) \frac{N}{L} + 1 \\ 0, & \text{otherwise} \end{cases}$$ (5)

Here the total capacity of the system is maintained by utilizing the N/L sets of L=4 subcarriers. Here, it is ensured that the one user from the subset do not interfere with another user in another subset by multiplexing the frequency division values with different sets of L=4 users. It is assumed that the 4HW codes are utilized by each set of L=4 sub carriers as spreading code. The structure of user 1 transmitter is shown in figure 3.

2.3. Receiver

The signal received by FD-MC-CDMA method by the received after the completion transmission through frequency selective fading channel is represented as

$$r(t) = \sum_{k=1}^{K} b_k \text{Re}\left\{\sum_{i=1}^{N} \alpha_i \beta_i^k e^{j2\pi f_i t + 2\pi i\Delta f t + \phi_i}\right\} g(t) + \eta(t)$$ (6)
Multiuser Detection Using Neural Network For Fd-Mc-Cdma System In Frequency Selective Fading Channels

Where $\alpha_i$ represents the gain value, $\phi_i$ represents the phase offset value of $i^{th}$ subcarrier and $\eta(t)$ denotes the additive white Gaussian noise. Recall that for each user $k$, $\beta_i^k$, is non-zero in only $L=4$ of the $N$ subcarriers. The structure of user 1 receiver is shown in the figure 3. Here, after reception of signal at received end, decomposition would be carried out to find the $L$ information carrying subcarriers which is then will be de-spreaded by user 1’s spreading code. The decision variable produced by $i^{th}$ carrier is given as

$$r^{(1)} = \alpha_i b^{(1)} + \alpha_i \sum_{k \in U, i=1} b_k \beta_i^k \beta_i^{(1)} + \eta_i, i=1, 9, 17, 25$$  \hspace{1cm} (7)

Where $U$ represents the set of active users from the user 1’s carrier set. After decomposition, optimal combining method is invoked to integrate all $L=4$ subcarriers into the user 1’s set in order to achieve the better frequency diversity and reduced MAL value. This is accomplished by utilizing the maximum likelihood combining method (MLC): Consider ‘$F$’ is a maximum likelihood constraint based on which decision is taken as

$$F = p(r^{(1)} | b_1 = 1) >> p(r^{(1)} | b_1 = -1)$$  \hspace{1cm} (8)

Where $>>$ represents the condition scenario where output bit value is 1 if right term is greater than left terms else it is -1. Consider there is knowledge information can be obtained from the other users in the environment, thus the MAI of different cameras can be represented as independent which is given as

$$p(r_1 | b_1) = \sum_{\eta_i} \delta(r_i | b_1) = \sum_{\eta_i} (r_i^{(1)} - \alpha_i b_1)$$ \hspace{1cm} (9)

Where $\eta_i$ represents the random value with 0 mean and variance, $(K, - l) \alpha_i + No /2, K$, is the number of active users on user 1’s carrier set, and $No /2$ is the variance of the additive Gaussian noise. Applying the Gaussian approximation of MAI in equation (4) would resultant with the maximum likelihood decision rule as

$$D^1 = \frac{1}{L(1,9,17,25)^1} \frac{1}{(K-1)^2 + \frac{No}{2}} \hspace{1cm} (10)$$

The following decision of output data bit is taken after integrating the ML values with the hard decision devices

$$b_1 = \begin{cases} +1 \text{ if } D^1 > 0 \\ -1 \text{ elseewise} \end{cases} \hspace{1cm} (11)$$

3. SIMULATION RESULTS

Simulation results performed in AWGN, Rayleigh and Rician frequency selective fading channels for 31 bits spreading codes for 10 users. Simulations have been carried out in three different ways: Bit Error Rate (BER) is defined as the difference between the signal to noise ratio (SNR) value and the actual value. SNR value of first user is calculated as

$$SNR_1 = \frac{\text{Signal power}}{\text{noise power}} = \frac{A_1^2}{2\sigma^2}$$ \hspace{1cm} (12)

Where $\sigma^2$ is the variance of the noise with the zero mean value, $A_1$ is the amplitude of the first user?
As it is seen in Figure 4, length of the SNR affects the performance of the various methods under AWGN channel. The simulation results shown in terms of BER. As it is seen in Figure 4, increases the SNR in the training set improves the performance of the receiver. On the other hand, increases the number of bits in the training set increases the training time.

**Figure 4** BER versus SNR for different users in AWGN channel
Multiuser Detection Using Neural Network For Fd-Mc-Cdma System In Frequency Selective Fading Channels

As it is seen in simulation results in Figure 5, length of the SNR effects the performance of the various methods under Rayleigh channel. The simulation results are shown in terms of BER. In this, increases the SNR in the training set improves the performance of the receiver.

As it is seen in Figure 6, length of the SNR effects the performance of the various methods under Rician channel. The simulation results are shown and increases the SNR in the training set improves the performance of the receiver.

4. CONCLUSION AND FUTURE WORK
Multiple access architecture (FD-MC-CDMA) is proposed to perform simultaneous utilization of frequency diversity and achieve reduced Multiple Access Interference (MAI). The proposed method work in the frequency domain in order to predict the multiple users’ presence in the frequency selective fading channel environment. It is achieved by separating the entire transmission bandwidth into subset of carriers, and selecting the non-continuous subset carriers. Thus the optimal frequency diversity can be achieved with reduced MAL. The proposed receiver with the neural network MAI detector has got better Bit Error Rate (BER) performance than the neural network that detects user’s signal in AWGN and Rayleigh fading asynchronous channels for Signal Noise Ratio (SNR) simulations, and in AWGN asynchronous channels for the number of users simulations, although both have the same...
complexity. In future work it will be extended to Orthogonal Frequency Division Multiple Access (OFDM).

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Multiuser Detection Using Neural Network For Fd-Mc-Cdma System In Frequency Selective Fading Channels


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