Development of Adaptive Fuzzy Based Multi-user Detection Receiver for DS-CDMA

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Abstract. This paper investigates the problem of multiuser detector (MUD) for direct sequence code division multiple access (DS-CDMA) system. A radial basis function (RBF) receiver provides the optimum receiver performance. We propose a fuzzy implementation of the RBF receiver. This fuzzy receiver provides considerable computational complexity reduction with respect to RBF receivers. The fuzzy receiver provides exactly the same bit error rate performance (BER) as the RBF receiver. Extensive simulation studies validate our finding.

1 Introduction

The demand for increased capacity on mobile communication system such as GSM has led to newer technologies like code division multiple access (CDMA), wide band CDMA systems. It is believed that the capacity of CDMA technique is much higher then that of the established TDMA system [1]. CDMA allows frequency re-use in the neighboring cells and even distribution of the workload among the cells, and user transparent soft hand-off as the call is re-routed from one cell to another. With this CDMA technology has been used in voice, data and network communications.

CDMA systems suffer from interference from other users in the cell. It is also affected by channel multipath interference with fading in presence of additive white Gaussian noise (AWGN). Mitigation of these effects in receivers require high computational complexity. Instead of attempting to cancel the interference from other users in the system, the principle of multiuser detector [2] uses multiple access interference (MAI) as additional information to obtain a better estimate of the intended data. The multiuser detector (MUD) processes the signal at bit rate derived from the bank of matched filters. These processed signal are then processed by different types of receivers. Since the optimal decision boundary in DS-CDMA is non-linear [3], it can be optimally implemented by radial basis function (RBF) network [2, 4], at an expense of increased computational complexity. The complexity in terms of center calculation grows exponentially with the number of users. Considering DS-CDMA a non-linear classification problem, it has been shown that the non-linear receivers always outperform the conventional linear receivers. Existing non-linear receivers based on artificial neural network (ANN), multiple layer perceptron (MLP), polynomial series, recurrent networks can approximate the decision boundary well and possess superior performance, but at an expense of higher computational complexity and larger and complex training technique

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and therefore difficult for practical implementation.Thus considerable investigation is underway in this regard. Fuzzy systems have been extensively used for many non-linear applications including pattern classification. The close relationship between the fuzzy and the RBF [5] prompted us to use adaptive fuzzy systems as a candidate for DS-CDMA MUD receiver.

This paper is organized as follows, Following this section, DS-CDMA system model is outlined first. The next section provides a discussion on adaptive fuzzy filter and its implementation for MUD receiver for DS-CDMA. The performance of the proposed receiver with other standard receivers is discussed next. The last section provides the concluding remarks.

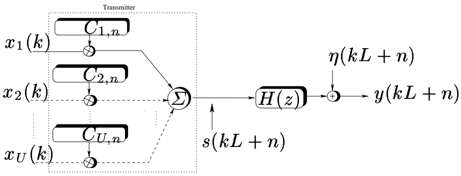


Fig. 1. DS-CDMA down link transmitter for U transmitting users.

2 DS-CDMA System Model

The system model considered in this paper is presented in Fig.1. It shows the down link scenario where the mobile unit receives signal $y(kL+n)$ from the base station. The information bits corresponding to one of U users are denoted as $x_i(k)$. $x_i(k)$ takes the value $+1/-1$ with equal probability and k denotes the time index of user transmitted symbols. The information bits transmitted by each user are convolved with each of their mutually orthogonal spreading sequences $C_{i,n}$. Gold code, convolution codes, Pseudo-noise (PN) codes [6] are some of the coding techniques used. With this the BW of $x_i(k)$ is enhanced. The processing gain (PG) of the system is defined as $PG = \frac{W}{B}$ where, W denotes the spreaded signal bandwidth (BW) and B is the unspreaded signal BW. The spreaded signal from each of the user are combined to form

$$s(kL+n) = \sum_{i=1}^{U} x_i(k) C_{i,n} \tag{1}$$

which is transmitted through the channel $H(z)$. The channel corrupts the signal with inter symbol interference (ISI) and effects of fading. AWGN also gets added to the signal. With this the received signal $y(kL+n)$ can be denoted as

$$y(kL+n) = H(z) \otimes s(kL+n) + \eta(kL+n) \tag{2}$$

where $\otimes$ denotes the convolution and $\eta(kL+n)$ is the AWGN component at chip rate. The job of the receiver is to estimate $x_i(k)$ of the desired user using the information content in $y(kL+n)$. The input is sampled at chip rate n and process the signal at sample rate k. This is called chip level based receiver (CLB). Due to high computational complexity of nonlinear CLB receivers multiuser detection is used [4]. The structure of a MUD receiver using RBF is shown in Fig.2. The output vector of the preprocessor $\tilde{\mathbf{x}}(k) = [\tilde{x}_1(k), \ldots, \tilde{x}_U(k)]^T$ is fed to a RBF network. The output of the RBF can be denoted as

$$t(k) = \sum_{j=1}^{2^U} w_j \exp\left(\frac{-\|\tilde{\mathbf{x}}(k) - \mathbf{c}_j\|^2}{2\sigma^2}\right) \tag{3}$$

where, the RBF has 2^U centres of dimension U, σ is the centre spread parameter and w_j denotes the weight associated with each centre. The RBF output $t(k)$ is passed through a hard limiter to provide $\hat{x}_i(k)$, the estimate of the transmitted symbol of the desired user $x_i(k)$. As the number of transmitting users increases, the computational complexity of the RBF receiver also increases in terms of number of centres.

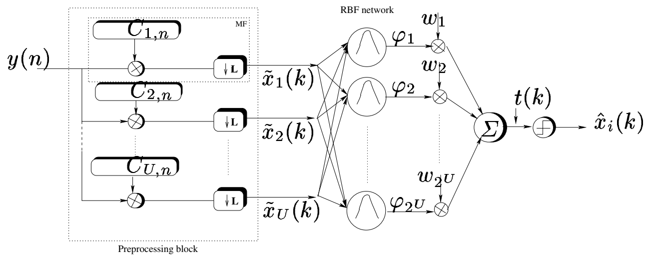


Fig. 2. RBF receiver with preprocessing stage.

3 Fuzzy Adaptive Filter for DS-CDMA

3.1 Adaptive Fuzzy Filters

Fuzzy logic system uses linguistic informations to process it's input. The fuzzifier converts the real world crisp input to a fuzzy output described by the membership function. The inference engine provides the relationship between the fuzzy input in terms of membership functions and the fuzzy output of the controller using a set of IF ... THEN ... rules derived from the rule base. The defuzzifier converts the inferences to provide the crisp output. Generally in a fuzzy system the rule base is generated in advance with expert knowledge of the system under consideration. In [7], online learning properties was introduced which provided scope for training the fuzzy system.

Wang et. al. presented fuzzy basis functions (FBF) and used them as a fuzzy filter [8] for channel equalization. Later on the fuzzy implementation of MAP equalizer was investigated [5]. It was shown that the fuzzy equalizer can provide the MAP decision function like RBF. These equalizers address some of the problems associated with the previously reported fuzzy equalizers. In this paper we implement a modification of these fuzzy filters for MUD in DS-CDMA scenario.

3.2 Fuzzy Filter for DS-CDMA Multi-user Detection Receiver

The RBF receiver decision function in (3) discussed in the previous section can also be represented as

$$t(k) = \sum_{j=1}^{2^U} w_j \left\{ \prod_{i=1}^{U} \exp\left(\frac{-\|\tilde{x}_{j,i}(k) - c_{j,i}\|^2}{2\sigma^2}\right)\right\} \tag{4}$$

where $1 \leq i \leq U$ constitute the i^{th} components of the RBF centre and the RBF input. The inner product of $\exp(.)$ of vector has been replaced by product of $\exp(.)$ of scalar terms of the vector. The function presented in (4) can be represented by a fuzzy system shown in Fig.3. The output of the preprocessing block, feeds the fuzzy filer. The fuzzy filter consists of fuzzifier with Gaussian membership function. The centres of the membership function are located at -1 and $+1$. There are 2^U rules in the rule base. The product inference block provides 2^U outputs generated with product rule. The defuzzifier provides a weighted sum of it's input from inference block with it's set of weights. The receiver so designed is presented in Fig.3. This receiver can be considered as an alternative implementation of RBF receiver [5]. This fuzzy receiver proposed here can be trained with gradiant search algorithm like LMS.

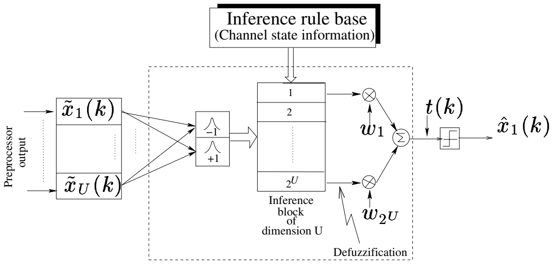


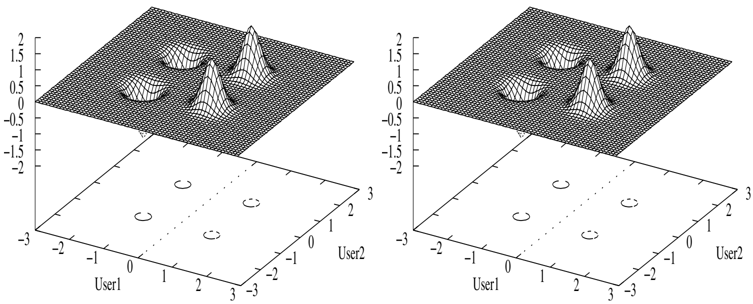
Fig. 3. Fuzzy implementation of RBF receiver.

An example is considered to describe the details of the fuzzy receiver discussed here. If the number of users in the scenario discussed here is $U = 2$, there will be $2U = 4$ fuzzified inputs to the inference engine from a total of 2 input scalars constituting the input vector. The number of rule base is $2^U = 4$ and the output defuzzifier combines these 4 inference outputs with suitable weights. If the number of active user increases to 6 the number of fuzzy inputs will be $2U = 12$ and number of inference rule will be $2^U = 64$.

Table 1. Computational complexity for MUD receivers using RBF and Fuzzy.

U	*Tech-que*	*Centres/ Rule*	*Multiplication.*	*Addition/ Subtraction/ Comparison*	$exp(.)$
2	RBF	4	12	8	4
	Fuzzy1	4	12	8	4
7	RBF	128	1024	896	128
	Fuzzy1	128	910	142	14

This receiver proposed provides considerable computational complexity reduction compared to RBF receiver. The computational complexity comparison between RBF and fuzzy receiver when 2 and 7 users are active is presented in Table.1. From the table it can be seen that, the fuzzy based MUD receiver provides the RBF implementation of MUD receiver with considerable computational complexity reduction in terms of multiplication, addition and $\exp(.)$ calculations.



(a) RBF Receiver (b) Fuzzy Receiver

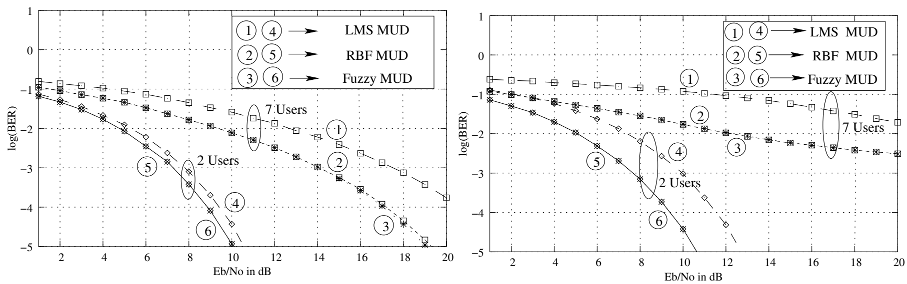
Fig. 4. Surface plot and decision boundary of RBF and Fuzzy MUD receivers at $E_b/N_o = 10dB$.

4 Simulation Results

Extensive simulation studies were conducted to validate the proposed fuzzy MUD receiver for DS-CDMA application. The results obtained were compared with MUD receivers using RBF network and simple linear receiver using LMS training. During the training period the receiver parameters were optimized/trained with 1000 random samples and parameters so obtained were averaged over 50 experiments. The parameters of the receiver were fixed after the training phase. The RBF and fuzzy receiver decision surface along with their decision boundaries for a two user case is plotted in Fig.4. From here it can be seen that the fuzzy MUD receiver provides a decision boundary exactly same as the RBF receiver.

In the next phase of simulation studies, bit error rate (BER) was considered as the performance index. Monte Carlo simulations were conducted to estimate the BER performance of fuzzy MUD receiver and was compared with RBF and linear MUD receivers. A total of 10^7 bits were transmitted by each user and a minimum 100 errors were recored. The tests were conducted for different levels of E_b/N_o and varying number of users active in the cell.

The BER performance of the three types of receivers with 2 users and 7 users active in the system is shown in Fig.5. Fig.5(a) shows the performance for channel $H(z) = 0.5 + z^{-1}$ and Fig.5(b) shows the performance for the channel $0.3482 + 0.8704z^{-1} +$



(a) $H(z) = 0.5 + 1z^{-1}$ (b) $H(z) = 0.34 + 0.87z^{-1} + 0.34z^{-2}$

Fig. 5. BER performance for varying E_b/N_o.

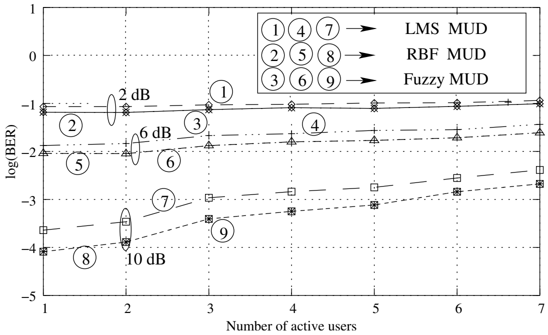


Fig. 6. BER performance for varying no of users at different values of E_b/N_o.

$0.3482z^{-2}$. From the BER performance it can be seen that the fuzzy receiver provides a performance which is exactly same as RBF receiver. Following this, performance of the fuzzy receiver was tested for varying levels of users active in the system for a fixed value of E_b/N_o in the channel. The channel used for the test is characterized by $0.407 - 0.815z^{-1} - 0.407z^{-2}$. The BER performance for E_b/N_o of 2dB, 6dB and 10dB is shown in Fig.6. The simulation studies show that the proposed fuzzy receiver performs exactly same as optimal RBF MUD receiver.

5 Conclusion

In this paper the RBF based MUD receiver has been implemented with fuzzy system. This fuzzy receiver proposed uses Gaussian membership function, product inference and center of gravity defuzzifier. This receiver provides computational complexity reduction over the optimal RBF receiver. Simulation studies show that the performance of the receiver proposed is exactly similar to RBF receiver.

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