Comparison of GA-RBF Assisted MUD with the Conventional MLSE MUD for Synchronous DS-CDMA System

Developed by

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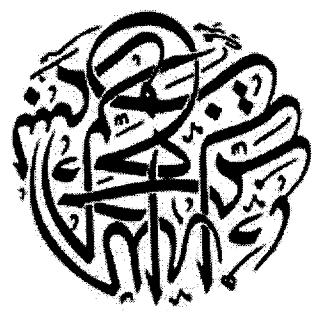

Certificate of Approval

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Dedicated to my father "Dr. Hussain Khattak"

Abstract

In this Thesis, comparison of Genetic Algorithm - Radial Basis Function Assisted Multi-user Detection scheme (GA-RBF MUD) with the conventional Maximum Likelihood Sequence Estimator Multi-user Detection (MLSE MUD) for a Synchronous DS-CDMA system have been investigated. Multi-user Interference (MUI), Inter symbol Interference (ISI) and Inter Chip Interference (ICI) are present when using multi-user detection schemes, which makes the detection very inefficient. These are the major problem to be handled in the CDMA communication system. For detecting the received signal of all the users, with out any interference, Radial Basis function Aided Multi-user Detection (RBF-MUD) scheme is used. It is impossible to implement it in real time environment because the numbers of users are very high. So its complexity becomes very excessive. It is only possible to use it in real time when the number of users is low. In this contribution RBF-MUD is used with a low complexity. For reducing the number of RBF-MUD centers, Genetic Algorithm is used. In this scheme Walsh codes have been examined and they have comparatively demonstrated for the results of different number of users. The proposed scheme can perform sufficiently well with very low computational complexity to the optimum Maximum Likelihood Sequence Estimator scheme with increasing number of users. From the computer simulations it has shown that GA-RBF reduces the complexity but it performance is slightly degraded.

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Moreover I am grateful to my friends for their endless support and encouragement which made this dissertation a fruitful experience. Here I would like to convey my sincere acknowledgment to my family for their everlasting efforts and prayers.

(Shujaat Hussain).

Contents

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Glossary

2G	2nd Generation
3G	3rd Generation
AMPS	Advance Mobile Phone System
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CDMA	Code Division Multiple Access
CIR	Channel Impulse Response
CSI	Channel State Information
DS	Direct Sequence
FDMA	Frequency Division Multiple Access
FFH	Fast Frequency Hopping
GA	Genetic Algorithm
GSM	Global System of Mobile
ICI	Inter Chip Interference
ISI	Inter Symbol Interference
ITU	International Telecommunication Union
MF	Match Filter
MMSE	Minimum Mean Square Error
MUD	Multi User Detection
MRC	Maximum Ratio Combining
MT	Multi Tone

PIC	Parallel Interference Canceller
RBF	Radial Basis Function
SDMA	Space Division Multiple Access
SFH	Slow Frequency Hopping
SIC	Successive Inferference Cancellor
SNR	Signal to Noise Ratio
SSS	Spread Spectrum Signal
SUD	Single User Detection
TH	Time Hopping
TDMA	Time Division Multiple Access
TD-SCDMA	Time Duplex-Smart antenna aided CDMA
UMTS	Universal Mobile Telecommunication System
UTRA	UMTS Terrestrial Radio Access
ZF	Zero Forcing

CHAPTER 1

Introduction

1.1 Introduction to thesis

Direct Sequence multiple access (DS), also called the Direct Sequence Code Division Multiple Access (DS-CDMA) [1], is the third generation (3G) systems access technology. With the transmission of high bit rates, like 2 mbps various severe problems may arise. Inter Symbol Interference (ISI), Inter Chip Interference (ICI) and Multi-user Interference (MUI) are the major problem appeared in the CDMA communication system. Therefore in order to get rid of these severe problems various Multi-user schemes are implemented [2].

Junitti et al [3], was the pioneer who proposed the Genetic Algorithm Multi-user Detection (GA-MUD) for a Synchronous DS-CDMA system which communicates over an Additive white Gaussian Noise (AWGN) channel. Yen et al [4] [5], compared the performance of GA-MUD with the Verdu's optimum MUD [2]. He demonstrated that the performance of the GA based MUD approaches the single-user performance bound is computationally less complex then that of conventional MUD.

In this Thesis I consider a specific Multi-user Detection scheme called the Radial Basis Function assisted Multi-user Detection [6]. Chen et al [7] [8], proposed the Radial Basis Function Multi-user Detection (RBF-MUD) which approaches the performance of the optimum Bayesian maximum a posteriori (MAP) Multi-user Detection [6].This particular Multi-user Detection Scheme is better then that of the conventional Multi-user Detection scheme. Edinburgh team [9] [10] [11], was the first one who implemented the RBF based

MUD and better improvement is made in [12]. It is not widely used in practical implementation because of its high complex nature.

In this Thesis I proposed the employment of Genetic Algorithm aided and Radial Basis Function assisted Multi-user Detection (GA-RBF MUD) for reduction of the complexity, and compared its performance with the optimum Maximum Likelihood Sequence Estimator Multi-user detection (MLSE-MUD). To improve the performance I used the Genetic Algorithm (GA) for selecting the RBF centers. Here the RBF centers, which have the high contribution in the performance, are selected while the remaining RBF centers which have the low contribution in the performance are neglected. Therefore the reduction of RBF centers reduces from 2^K to P. As P is the population size in GA.

1.2 Contribution

The major contribution I made in this Thesis are given below:

i. Genetic Algorithm aided and Radial Basis Function assisted Multi-user Detection (GA-RBF MUD) scheme is used and compared with the optimum Maximum Likelihood Sequence Estimator Multi-user Detection (MLSE-MUD) with the cost of lower computational complexity.

ii. The employment of this scheme is for synchronous DS-CDMA system for downlink scenario, which communicates over non-dispersive AWGN channel.

iii. As spreading codes, Walsh codes are used for K=10, 15 and 20 users and they are comparatively demonstrated.

1.3 Organization

This Thesis is outlined as:

1. **Chapter 2:** This chapter is about commonly used wireless access technology. Also various Multi-user detection schemes are discussed with their advantages and disadvantages.

2. **Chapter 3:** In this chapter I discussed the Genetic Algorithm and its structure that how it works.
3. **Chapter 4:** This chapter is devoted for GA-RBF based MUD for Synchronous DS-CDMA system. Here Walsh codes are used as a spreading code and simulation results are comparatively demonstrated for K=10, 20 and 30 users.
4. **Chapter 5:** In this chapter, the conclusion and future work are discussed regarding the scheme.

CHAPTER 2

CDMA and Multi-user Detection

2.1 Introduction to Wireless Access Technology

A finite amount of radio spectrum shared simultaneously by many users is called multiple access techniques. There are three major access techniques used to share the available bandwidth in a wireless communication system. These are Frequency Division Multiple Access (FDMA) [13], Time Division Multiple Access (TDMA) [13], Code Division Multiple Access (CDMA) [14] [15], and Space Division Multiple Access (SDMA) [16] [17].

2.1.1 Frequency Division Multiple Access (FDMA)

In Frequency Division Multiple Access (FDMA), individual channels are assigned to individual users, as can be seen from Figure 2.1.

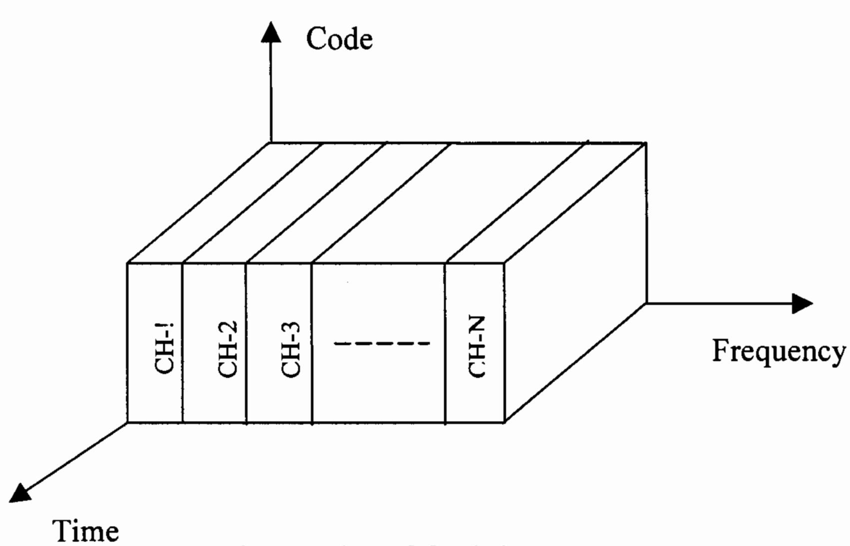

Figure 2.1: FDMA Scheme

Here a unique frequency band is assigned to each user. Advanced Mobile Phone System (AMPS), which is the first generation US analogue system, is based on FDMA

2.1.2 Time Division Multiple Access (TDMA)

The division of radio spectrum into the time slots is called the Time Division Multiple Access (TDMA) system. A dedicated time slot is assigned to each user to communicate either it transmit or receive, as shown in Figure 2.2. A Global System for Mobile Communication GSM [18], which uses the both TDMA and Frequency Division Duplexing i.e. TDMA/FDD. FDD is a system where pair of frequencies are assigned to the users as a channel i.e. one is uplink channel and the other is down link channel.

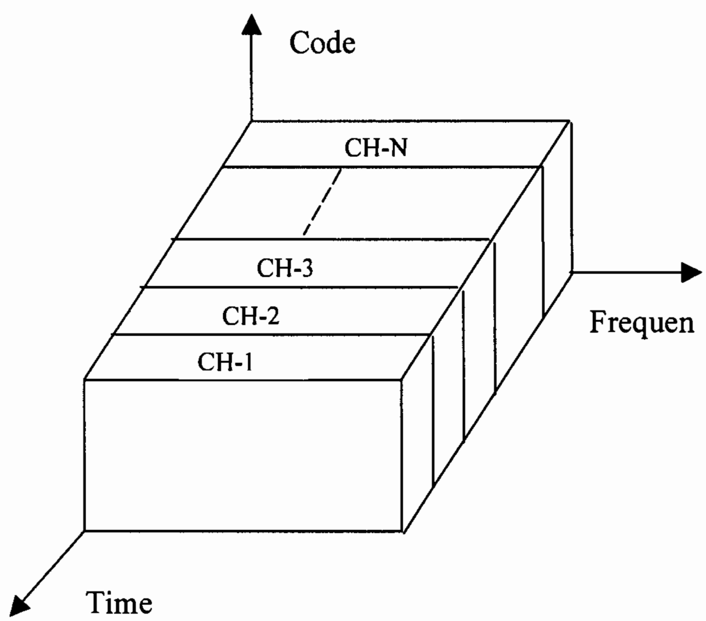

Figure 2.2: TDMA Scheme

2.1.3 Code Division Multiple Access (CDMA)

Code Division Multiple Access (CDMA) is more sophisticated from FDMA and TDMA. Here all the users share the same carrier frequency when they transmit. Here each user is assigned a unique code sequence or signature sequence called pseudo-random code words and all of these code words are orthogonal to each other. As can seen from figure 2.3. In the receiver end time correlation operation is applied and it will detect only the specific desired code word. While due to decorrelation operation all the other code words are considered as noise. CDMA is some time called the Spread Spectrum Multiple Access (SSMA). Spread Spectrum signals means that for the transmission of digital information, their bandwidth W is

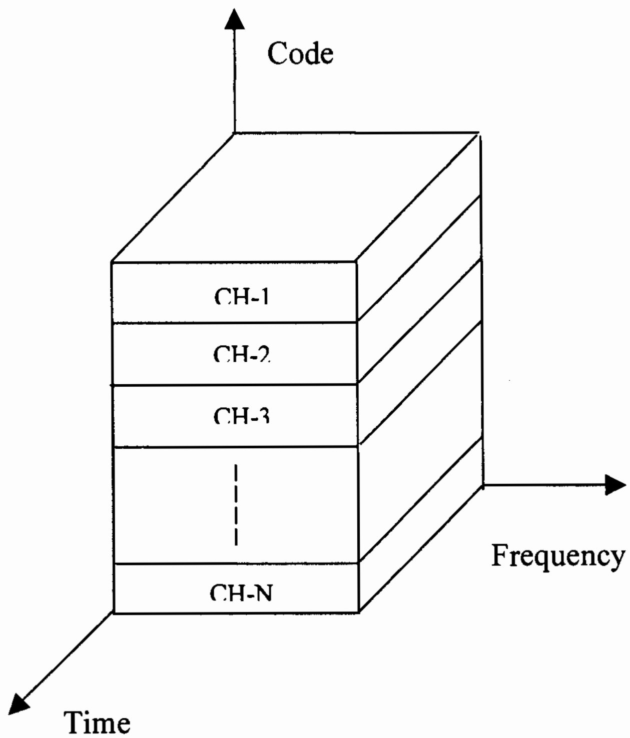

Figure 2.3: CDMA Scheme.

higher then the information rate R. Direct Sequence CDMA (DS-CDMA) [15], Frequency Hopping CDMA (FH-CDMA) [16], and Time Hopping CDMA (TH-CDMA) [19], are the three common technique of the spread spectrum communication system. Besides these techniques some hybrid techniques are also available by combining these techniques. These are Multi-carrier CDMA (MC-CDMA) [20], Direct Sequence CDMA/Frequency Hopping CDMA (DS/FH), Time Hopping CDMA/Frequency Hopping CDMA (TH/FH) and Direct Sequence CDMA/Frequency Hopping CDMA/Time Hopping CDMA (DS/FH/TH). Besides this MC-CDMA [16], is further subdivided into MC-DS-CDMA [15], and Multi tone CDMA (MT-CDMA) [13].

In DS-CDMA, information bits are directly modulated, which uses a pseudo-random noise sequence and in a result a bandwidth DS-spread signal appeared. In Frequency Hopping CDMA (FH-CDMA), the available channel bandwidth is sub divided into number of frequency slots. The available frequency slots are occupied by the transmitted signal and these are handled by the frequency hopping techniques. FH-CDMA are sub divided into two parts these are Slow Frequency Hopping (SFH) and Fast Frequency Hopping (FFH). Slow Frequency Hopping (SFH) is performed at symbol rate while in Fast Frequency Hopping (FFH) there are multiple hops per symbol. Besides DS-CDMA and FH-CDMA, there is another Hopping technique which is called Time Hopping CDMA (TH-CDMA) [19]. The time interval which is larger then the information rate reciprocal, is subdivide into a large number of time slots is called TH-CDMA. The information symbol which are coded are transmitted as a block of one or more code words in a time slot which are pseudo-randomly selected.

There are various CDMA techniques which are deployed in the context of Second Generation (2G) [21], and the Third Generation (3G) [15], systems. In 1995, the United State has deployed the popular 2 G CDMA standard called as Interim Standard 95 IS-95 [15] [21], technique also known as CDMA-ONE. In 1998, the Wide band CDMA (W-CDMA) [15] [22], is deployed. It is also called Universal mobile Telecommunication Service (UMTS) [15] [23], and also CDMA 2000 [15] [24], is deployed. These both are 3G based technologies. The Chinese technology named as Time-Duplex Smart Antenna aided CDMA (TD-SCDMA) [25], was also improved by ITU.

2.1.4 Space Division Multiple Access (SDMA)

The latest Wireless Access technology is the Space Division Multiple Access (SDMA) [15] [16]. Controlling the radiated signal in space for each user is done by Space Division Multiple Access (SDMA). Spot beam antenna are used in SDMA system. For reducing the

Multiple Access Interference (MAI) in SDMA, TD-SCDMA [25] standard is used. In SDMA sectorized antenna and adaptive antenna are used.

2.2 Importance of Multi-user Detection (MUD)

With the use of RAKE receiver [1], the multipath components have been resolved in DS-CDMA system. By getting the diversity gain, the delayed, attenuated and phase rotated signal component are combined by the RAKE fingers. If the number of Rake fingers increases, the diversity increases. For minimizing the "near-far" effect, strict power control is required for RAKE based CDMA system. This means that the users which are near to the transmitter are getting high received power from those who are away from the transmitter. Therefore degradation in performance will occur on those users which are far away from the transmitter.

In CDMA, all the users are orthogonally coded to each other and in ideal case it is desirable that the fading is the cause of destroying the orthognallity of codes. But in real time implementation it is not possible to maintain the orthognallity of all the users. Especially in the case of up-link scenario, where all the mobile subscriber transmit asynchronously from various distances. Therefore because of multi-path effect, it is difficult to maintain the ideal chip synchronization of all the users, so the spreading code orthognallity is destroyed. Because of these reasons MAI appeared in the CDMA system. Single User detection (SUD) and Multi-user Detection (MUD) are the two techniques which are used for detecting the sent signal in the environment of multi-user. In SUD only the desired user information is detected while the remaining user information is considered as noise, while is MUD the information of other users are detected as a useful information. So for my proposed work I used Multi-User Detection (MUD).

2.3 Structure of Basic Multi-User detector

Suppose K users synchronously transmitting in time and the spreading wave form of all the users are known by the multi-user receiver which demodulate and detect the signals of all the users is called Multi-User Detection. For example, on a non dispersive AWGN channel three synchronous users communicate. After passing through the match filter, the output of each user is

$$\begin{aligned} z_1 &= B_1x_1 + \rho_{21}B_2x_2 + \rho_{31}B_3x_3 + n_1 \\ z_2 &= \rho_{12}B_1x_1 + B_2x_2 + \rho_{32}B_3x_3 + n_2 \\ z_3 &= \rho_{13}B_1x_1 + \rho_{23}B_2x_2 + B_3x_3 + n_3 \end{aligned} \tag{2.1}$$

Here the received signals amplitude are denoted by B_i where $i = 1,2,3$. The transmitted bits by three users are denoted by x_1 where $i = 1,2,3$. Cross correlation co-efficient between the user spreading codes are ρ_{ij} where $i = 1,2,3$ and $j = 1,2,3$. n_i denotes the noise of three users where $i = 1,2,3$. We can write the above equation 2.1 in matrix form as well like;

$$\begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix} = \begin{bmatrix} 1 & \rho_{21} & \rho_{31} \\ \rho_{12} & 1 & \rho_{32} \\ \rho_{13} & \rho_{23} & 1 \end{bmatrix} \begin{bmatrix} B_1 & 0 & 0 \\ 0 & B_2 & 0 \\ 0 & 0 & B_3 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix} \tag{2.2}$$

or we can write it as:

$$\mathbf{z} = \mathbf{RBx} + \mathbf{n} \tag{2.3}$$

Here $\mathbf{R}$ is the cross correlation matrix of $K \times K$ dimensional which contain the cross correlation co-efficient of every pair spreading codes. The amplitude of the received signal is denoted by matrix $\mathbf{B}$ which is a diagonal matrix. The vector $\mathbf{x}$ is the bits that are transmitted. The vector $\mathbf{n}$ is the corresponding noise and vector $\mathbf{z}$ is the output of the matched-filter of all the K users.

2.4 Various Multi-User Detection Schemes

Here I will discuss various Multi-User Detection Schemes which are:

1: Maximum Likelihood Sequence Estimator (MLSE) Detector.

2: Decorrelating Detector.

3: Minimum Mean Square Error (MMSE) Detector.

4: Successive Interference Cancellation (SIC) Detector.

5: Parallel Interference Cancellation (PIC) Detector.

6: Multistage Interference Cancellation (MIC) Detector.

2.4.1 Maximum Likelihood Sequence Estimator (MLSE) Detector

Figure 2.4 shows the MLSE Multi-user Detection (MLSE-MUD). Here $r(t)$ is the received signal which is multiplied by the signature sequence of $g_i(t)$, where $i = 1,\dots,L$ for de-spreading and it is passed through the correlators. The vector $\mathbf{r}_l$ where $\mathbf{r}_l = [r_1,\dots,r_L]^T$ is the output of the correlators. MLSE Multi-user Detection (MLSE-MUD) is then employed which gives a desired output. The outputs of the correlators are:

$$\mathbf{r}_l = [r_1,\dots,r_K]^T \tag{2.4}$$

$$= \mathbf{R}_s \mathbf{b}_K + \mathbf{n} \tag{2.5}$$

Where

$$\mathbf{b}_K = \left[\sqrt{\varepsilon_1} b_1,\dots,\sqrt{\varepsilon_K} b_K\right]^T \tag{2.6}$$

Matrix $\mathbf{R}_s$ is the correlation matrix with elements ρ_{jk} where ρ_{jk}, can be written as:

$$\rho_{jk} = \int_0^T g_j(t) g_K(t)\, dt \tag{2.7}$$

In the MLSE -MUD, the correlation metrics will maximize the cost function:

$$C(r_l, b_l) = 2\mathbf{b}_l^T \mathbf{r}_l - \mathbf{b}_l^T \mathbf{R}_s \mathbf{b}_l \tag{2.8}$$

In the information sequence of K users, the possible choices of the bits are 2^K. For each sequence the optimum detector computes the correlation metric and that sequence is selected which contain the larger correlation metrics. The complexity of this optimum detector is very high as it increases exponentially with increasing number of users K. In real time implementation MLSE is not the ideal MUD because its complexity increases with increasing number of users. Therefore various sub-optimum MUD have been introduced which are less complex in nature [15] [2].

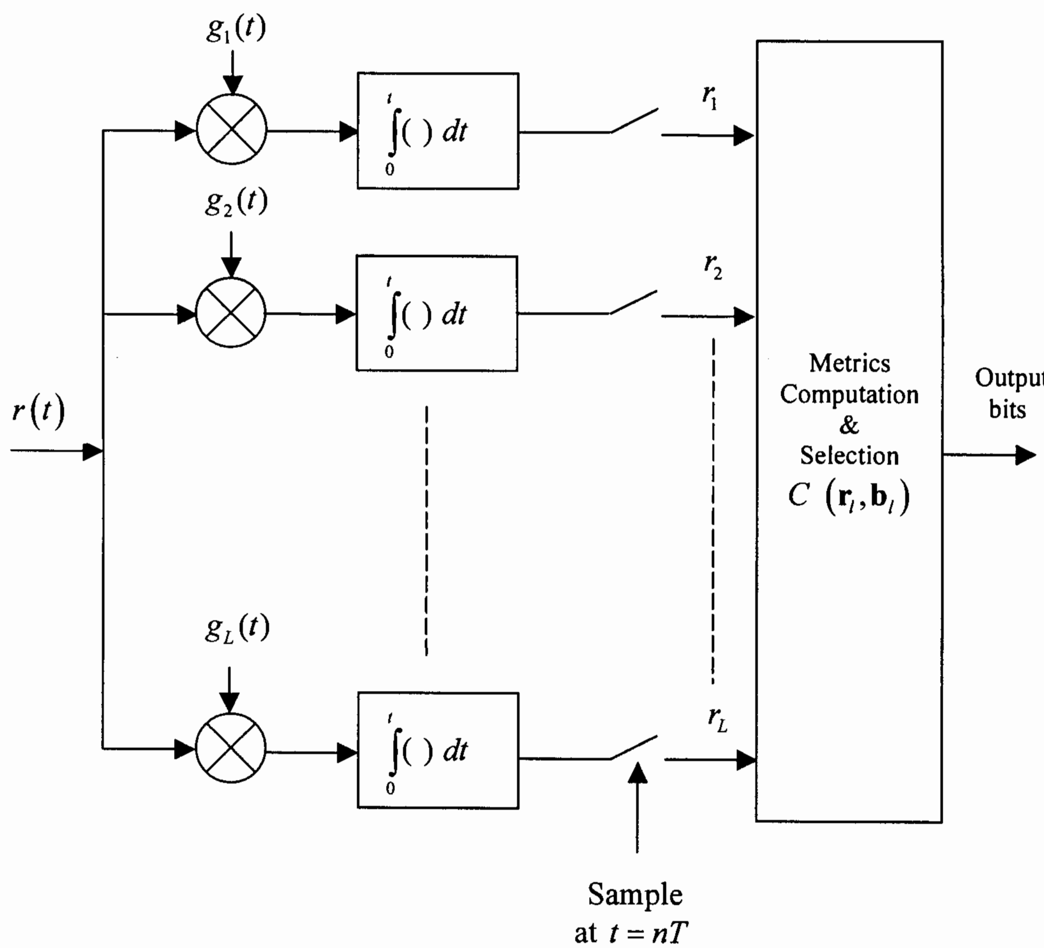

Figure 2.4: MLSE Multi-user Detection (MLSE-MUD)

2.4.2 Decorrelating Detector

Conventional Detector is more complex, as we increase the number of users its complexity increases linearly. So in order to reduce this complexity we use sub optimum detector. As can be seen from Figure 2.5. If we correlate the received signal $r(t)$ with the corresponding signature wave form $g_K(t)$, so from this Multi-User Interference (MAI) is decorrelated. In case of symbol –synchronous transmission the vector $\mathbf{r}_L$ is the received signal vector, which is the output of L matched filter i.e.

$$\mathbf{r}_L = \mathbf{R}_s \mathbf{b}_L + \mathbf{n}_L \tag{2.9}$$

The value of $\mathbf{b}_L$ that minimizes the likelihood function is given by:

$$\Omega(\mathbf{b}_L) = (\mathbf{r}_L - \mathbf{R}_s \mathbf{b}_L)' \mathbf{R}_s^{-1} (\mathbf{r}_L - \mathbf{R}_s \mathbf{b}_L) \tag{2.10}$$

After minimizing we get the result

$$\mathbf{b}_L^{\circ} = \mathbf{R}_s^{-1} \mathbf{r}_L \tag{2.11}$$

Now by taking the signature of elements of $\mathbf{b}_L^{\circ}$ the signals which are detected are obtained as:

$$\hat{\mathbf{b}}_L = sng(\mathbf{b}_L^{\circ}) \tag{2.12}$$

Here the computational complexity is linear in L because by applying linear transformation on the correlator's output vector, we obtained the estimated $\mathbf{b}_L^{\circ}$. Therefore the detector based on equation (2.6) is called decorrelating detector. The advantages of Decorrelating Detector are:

- It has better performance improvement over the conventional single user detector.
- Here the received signal amplitude in not necessary to be estimated.
- As compared to the MLSE detector it is less complex.
- It also controls near far problems.

It has several dis-advantages:

- Here amplification is required.
- At the output of decorrelating detector, the power of the noise associated with the term $\mathbf{R}_n^{-1}$ is always greater then the original noise term $\mathbf{n}$.
- When the number of users L is high, the complexity of inverting the cross correlation matrix $\mathbf{R}$ is high.

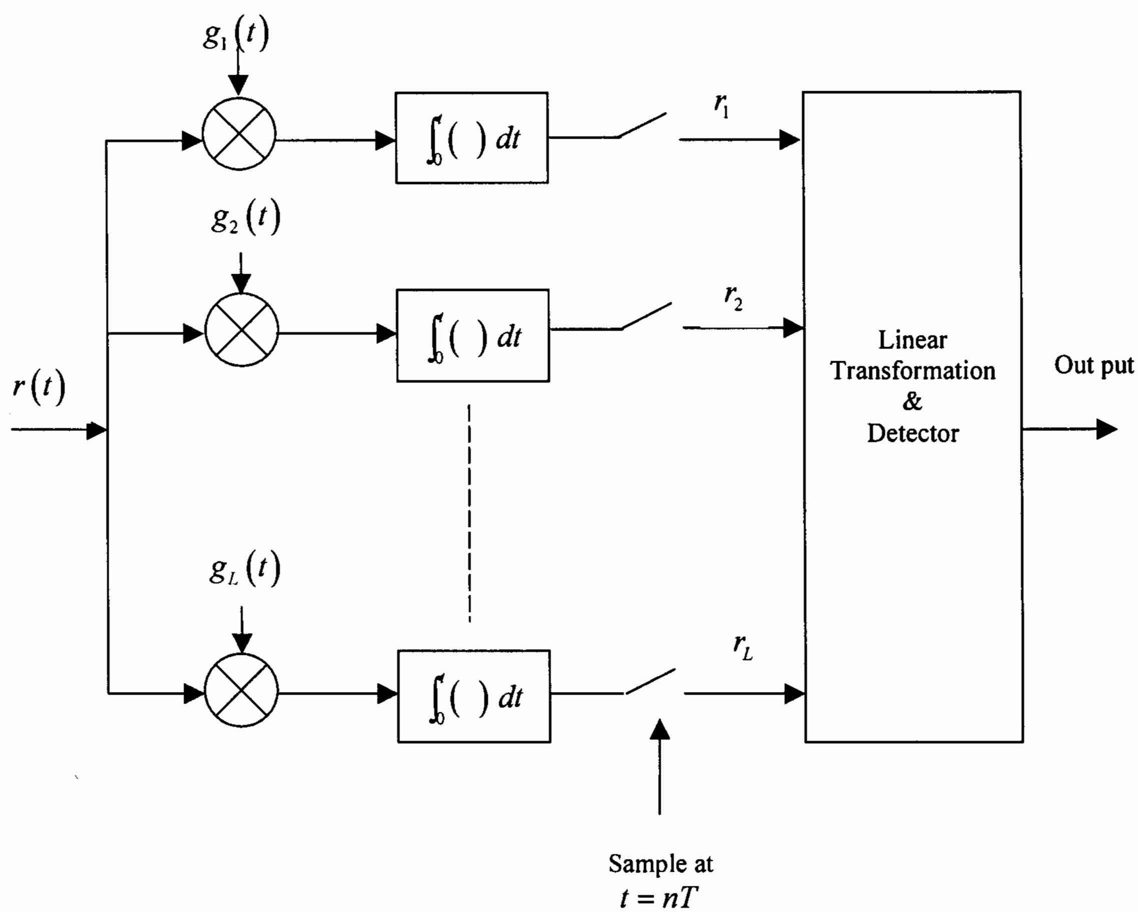

Figure 2.5: Structure of Decorrelation Detector

2.4.3 Minimum Mean Square Error (MMSE) Detector

A linear Decoleratting detector has many problems, one of which is amplification of noise. To get rid of this problem we can deployed Minimum Mean Square Error Multi-User

Detection (MMSE-MUD). With the implementation of MMSE-MUD, we can mitigate the effect of MAI as well as the effect of background noise of the L users. The major disadvantages of MMSE-MUD are that:

- Here the received signal amplitude of all the L users needs to be estimated.
- Matrix inversion is also involved in MMSE-MUD but it is more complex then the Decorrelating Multi-User Detector.

2.4.4 Successive Interference Cancellation (SIC) Detector

SIC is another Multi-User Detection Scheme. The phenomenon of this technique is by removing the interference signal wave forms from the received signal one at a time. Here all the L users have been arranged according to their received signal power. Thus the user having the strongest received signal is demodulated first. After the demodulation and detection of the signal, the estimated signal of this user is subtracted from the received signal. The remaining signal is then processed for another user in order to get its estimated data. After transmitted the estimated data of this user, the corresponding modulated signal is reconstructed and subtracted from the remaining composite signal from which the highest power user's signals are already cancelled.

This process is repeated up to the lowest power user. By this approach the cross correlations among the users do not appear. In case of synchronous transmission, instead of using this approach to demodulate the user signals according to the power at the output of cross correlators or matched filter's, the correlation metrics is applied. In SIC to cancel the interference the received signal power is estimated. Multi-user interference arises when estimated errors, which result in performance degradation. The user's interference whose signal's are weaker then the user's signal's being detected is treated as interference. While demodulating the user information, the computational complexity linearly increases with increasing number of user's. Also when demodulating the weakest user, the delay arises which increases linearly with increasing number of user's.

2.4.5 Parallel Interference Cancellation (PIC) Detector

The parallel Interference Cancellation (PIC) Detector estimates and eliminates the MAI of all the interfering user's from the signal of desired user in parallel.

2.3.6 Multi-stage Interference Cancellation (MIC) Detector

Multi-stage Interference Cancellation (MIC) is a scheme which uses multiple iteration's while detecting the user bits and cancelling the interference.

CHAPTER 3

Genetic Algorithm and Radial Basis Function

3.1 Introduction of Genetic Algorithm

In 1975, Holland was the first one who introduced the technique "Genetic Algorithm" which is based on the theory of evolution. It was further improved by Goldberg, De Jong and many others. Optimization plays a major role in various scientific computing. This technique can solve a multi-objective and non-differential problem that is why this is considered as a powerful optimization technique. This technique is based on Darwinian Theory of biological evolution i.e. "The Survival of the Fittest". To solve the optimization problem in a very large multi-dimensional search space Genetic Algorithm plays a major role. Genetic Algorithm have become an important optimization tool for the field such as signal processing, control, Robotics, system identification, artificial intelligence and electromagnetic engineering. The major operations in Genetic Algorithm are selection, crossover, mutation and elitism. Genetic Algorithm is probabilistic in nature. That is designed to escape local minima. When other optimization techniques are failed to give satisfactory result Genetic Algorithm is employed. This is robust in noisy environment as well as in multi-objective environment. The main problem in the employment of Genetic Algorithm is that this is time consuming to reach optimal solution as this is based on population. The problem of pre-mature convergence also arises and it may also miss global optima due to its stochastic nature.

The various steps including in Genetic Algorithm (GA) are described given below:

3.2 Encoding

In GA, encoding plays a major role for optimization. The conventional encoding scheme is Binary encoding. There are some other encoding schemes which are not used extensively these are Gray codes, Real numbers and combination of Binary [17], and Real numbers [18]. Those parameters in GA, which have to be optimized, are encoded into a length of finite string. There are N characters of these encoded strings and each character is called Gene. From the combination of the genes longer string is generated known as chromosomes of length L. From these chromosomes population of two dimensional array is generated which is of N rows and L columns. The binary encoding scheme is shown in the Figure 3.1, where chromosomes consist of genes which are string of 1's and 0's.

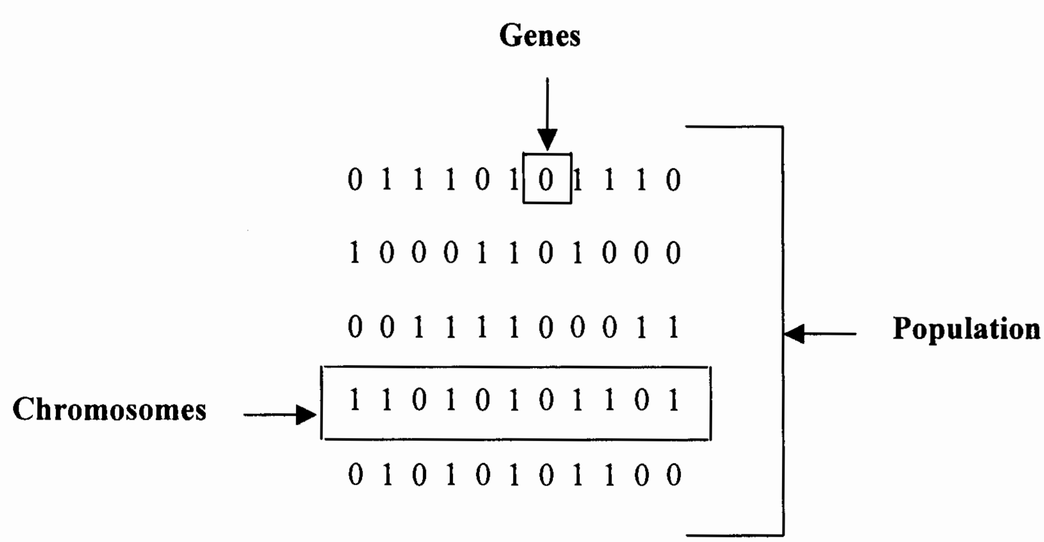

Figure 3.1: Binary encoding scheme.

3.3 Population Initialization

In order to get sophisticated results initial condition plays important role in Genetic Algorithm (GA).Therefore to start GA with initial condition gives better results and it performance improves. Normally in GA randomly initial population is used because it is global optimization technique. Therefore GA is independent from initial condition.

3.4 Defining Fitness function

Fitness function plays an important role in the process of GA. For the selection of fit chromosomes fitness function is used. It is also the responsibility of the fitness function to differentiate between the fit and the unfit chromosomes. Fitness function depends upon the objective function. Due to the accuracy of the objective function the survival of the fit chromosomes occurs.

3.5 Population Size

Defining population size in GA is a problem specific. Care must be taken to select the population size. GA performance depends upon the diversity gain. There fore in order to get more diversity a sufficient population size is needed [26]. With the increase in chromosome length, the population size increases. Increasing or decreasing the chromosomes of the population size depends upon the problem. Some time small population is not good for optimized result in GA and also care must be taken to select the sufficient population to get optimized result.

3.6 Selection Process

In Genetic Algorithm (GA), selection operation plays a pivotal role [27]. In this process those chromosomes are selected which are more fit.

Therefore in order to generate the next population these fit chromosomes are used. There are various selection schemes depending upon the problem. These are:

- Roulette wheel Selection.
- Tournament Selection.
- Rank based Selection.
- Random number tournament.

3.7 Crossover Operator

Crossover plays an important role in GA. In order to get two off-springs, the chromosomes of two parents are partially exchange. This process is called crossover [26]. Here the bits of two parent chromosomes are exchange at the specific location. There are two main type of crossover which depends upon the problem.

- Genotype crossover (conventional)
- Phenotype crossover(Arithmetic)

Further more the conventional crossover contains sub crossover processes which are problem specific. These are:

- Single point crossover method.
- Two point crossover method.
- Multi-point crossover method.
- Uniform crossover.

3.8 Mutation Operator

Protection of GA from converging to non optimal solution is done through Mutation process. This process produces diversity in GA. The process of Mutation operator starts only after the generation of all the off-springs. This process is also probabilistic in nature. In this process GA contain new search space because crossover operation is not eligible to access all the space parameter of given population. There are two main types of Mutation process

3.8.1 Genotype Mutation

Genotype mutation consist of two type of mutation operator, these are random mutation and bit wise complement mutation. For non-binary representation random mutation scheme is applied and bit wise complement is applied on string of bits. Here bits are randomly selected in chromosomes and they are inverted with a probability of 0.001.

3.8.2 Phenotype Mutation

Phenotype mutation consists of static mutation and dynamic mutation. In static mutation new values are assigned to randomly selected parameters.

3.9 Elitism

In the optimization of GA, the fitness of individual plays very important role. The optimization of GA suffers due to loss of high fitness individual during crossover operation. Therefore to maintain the high fitness individual, the process of elitism is used. The process of elitism may be employed by two possible ways i.e.

- The separate pool of high fitness individuals is generated and they are selected from the mating pool of the given individuals. From this separate pool new generations are generated.
- Without employing selection or crossover operation, the population of fit individuals is added to the next population.

3.10 Population Replacement Schemes

Employment of various Genetic operators on a parent population gives rise to the off-spring population. So the next generation is ready for the process. Various methods are available for selecting the next generation which are:

3.10.1 Generational Replacement

As from the name it is clear that the generational replacement is the process of the replacement of the given generation to the newly generated generation. Here the population of parent is completely replaced by the off-springs which are newly generated. The population of newly generated off-springs completely replaces the parent population therefore the size of both of the generation should ideally be equal, except when the process of elitism is involved.

3.10.2 Overlapping Replacement

To be the part of the next generation, competition between the off-spring population and the parent population arises due to the overlapping replacement technique. In this technique the size of the off-spring population is not restricted. It may be equal or smaller then the parent population depending upon the certain parameters of the problem.

3.11 Termination of the GA

The termination of Genetic Algorithm (GA) may occur due to different techniques.

3.11.1 Time Dependent

This technique is based upon the computational time. In this technique improved generations are generated but due to some time limitation its termination occurs before pre-defined threshold.

3.11.2 Precision Dependent

In this technique fit populations are generated until it reached to the desired threshold.

After that it is terminated.

3.12 Flow chart of GA

The basic flow chart of the Genetic Algorithm (GA) is given below that how it works:

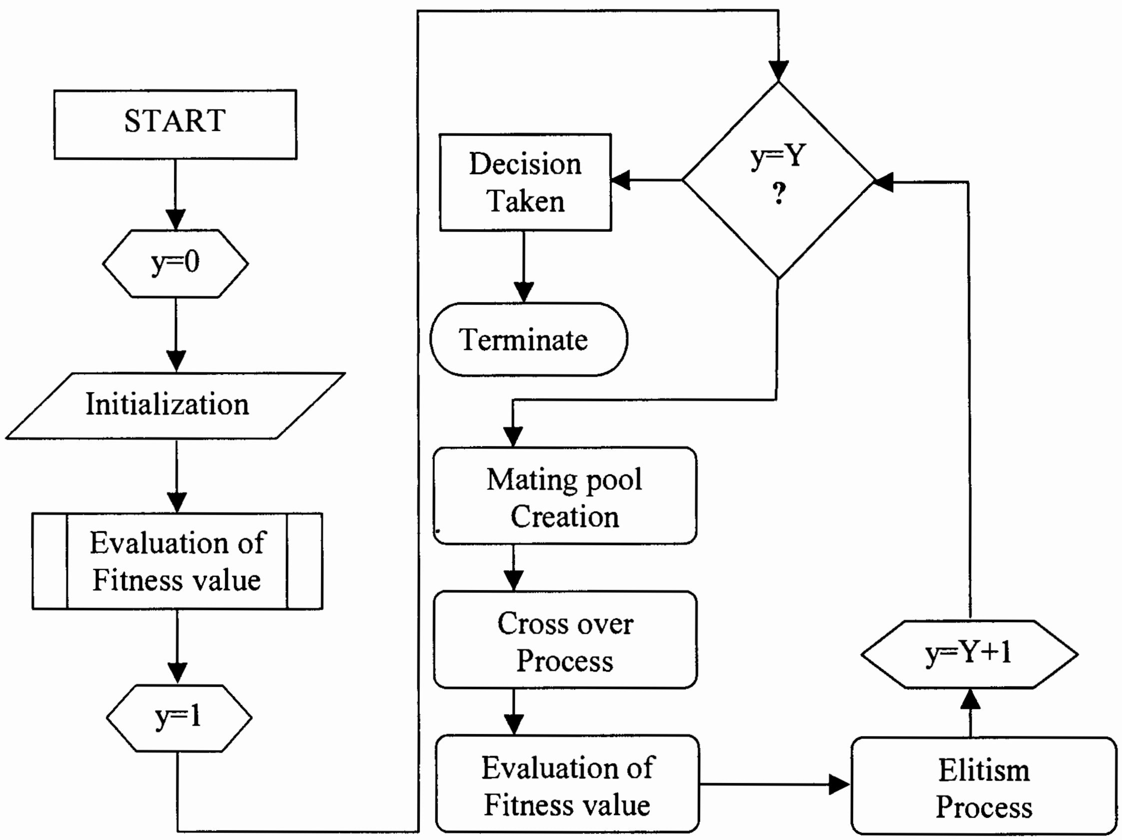

Figure 3.2: Flow chart of the GA

STEP 1: At the start of the process there is no generation.

STEP 2: In the process of initialization the received vector is mutated such that an initial generation occur.

STEP 3: In the process of fitness value evaluation, the fitness of chromosomes is evaluated. After their evaluation it is becomes appropriate.

STEP 4: The first generation occurs. If this is the desired generation, the decision will be taken and the process will be terminated. If not then it will continue.

STEP 5: Among the first generation, creation of mating pool arises.

STEP 6: In order to get off-springs, crossover process is applied.

STEP 7: Again the process of fitness value evaluation occurs among the newly generated off-springs and it checks the comprehensive fitness.

STEP 8: The process of elitism is used. Here the unfit individuals are deleted.

STEP 9: The new generation is generated. This process is repeated until it reaches to some desired value.

3.13 Radial Basis Function (RBF) network

The process of Radial Basis Function (RBF) network was first introduced in 1880's and it was inspired by basic Neural Network Design. Radial Basis Function (RBF) are used in various scientific field globally such as channel equalization, voice recognition, identification of system, control system, modeling of electronic equipment parameters, restoration of image, modeling of 3-D objects etc. The architecture of RBF network [28], are characterized into three main portion which are, input portion, hidden portion and the output portion as can be seen from the Figure 3.3.

- **Input portion**

In the Input portion $\mathbf{q}$ number of input vector are employed where $\mathbf{q}=[q_1,q_2,q_3,...q_M]^T$ and these RBF network inputs are non-linear in nature.

- **Hidden portion**

The Hidden portion contain non-linear activation function which is represented by ζ_k where $k=1,...,K$. Here RBF occurs due the activation function.

- **Output portion**

The Output portion of the RBF network gives rise to the linear output. In this portion the result of the hidden units are implemented.

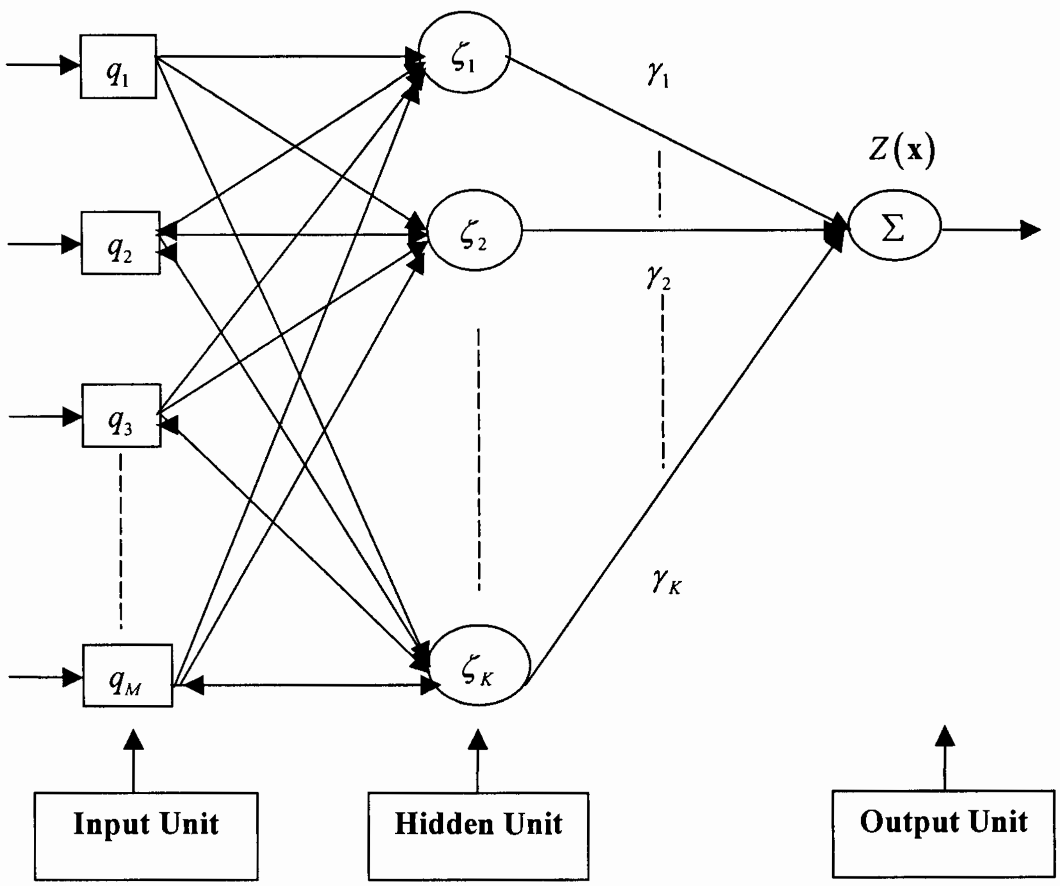

Figure 3.3: Architecture of a RBF network

These three units play an important role to implement the RBF network. Radial Basis Function (RBF) occurs when the Euclidean norm of the input vector $\mathbf{q}$ and the center point $\mathbf{c}$, which is the RBF centers are employed i.e. Euclidean norm $\|\mathbf{q}-\mathbf{c}\|$.There Radial Basis function can be written as :

$$\zeta_k(\mathbf{q}) = \zeta(\|\mathbf{q}-\mathbf{c}_k\|), \qquad k = 0,...M \tag{3.1}$$

Radial Basis function (RBF) can be represented as Gaussian function which can be written as:

$$\zeta_k(\mathbf{q}) = \exp\left[-\frac{\|\mathbf{q}-\mathbf{c}_k\|^2}{2\sigma_k^2}\right], \qquad k = 0,\dots M. \tag{3.2}$$

We can write Radial Basis Function (RBF) network mathematically as:

$$Z(\mathbf{q}) = \sum_{k=0}^{M} \gamma_k \zeta_k(\mathbf{q}). \tag{3.3}$$

Where γ_k is the Radial Basis Function (RBF) network weight. To finding the RBF network weights, it is known as network training.

CHAPTER 4

GA-RBF Assisted Multiuser Detection for DS-CDMA

4.1 Basic Model of Synchronous DS-CDMA system

Discrete time Synchronous DS-CDMA system model is shown in the Figure 4.1. An input data bit which is $h^{(i)}$ where $i = 1,...,K$ are multiplied with the corresponding spreading sequence of $g^{(i)}$, where $i = 1,...,K$, give rise to the spreaded signal which is represented by $q^{(i)}$, where $i = 1,...,K$. These spreaded signals are summed up to a composite signal of vector $\mathbf{q}$ with their correspo0nding noise $\mathbf{n}$.

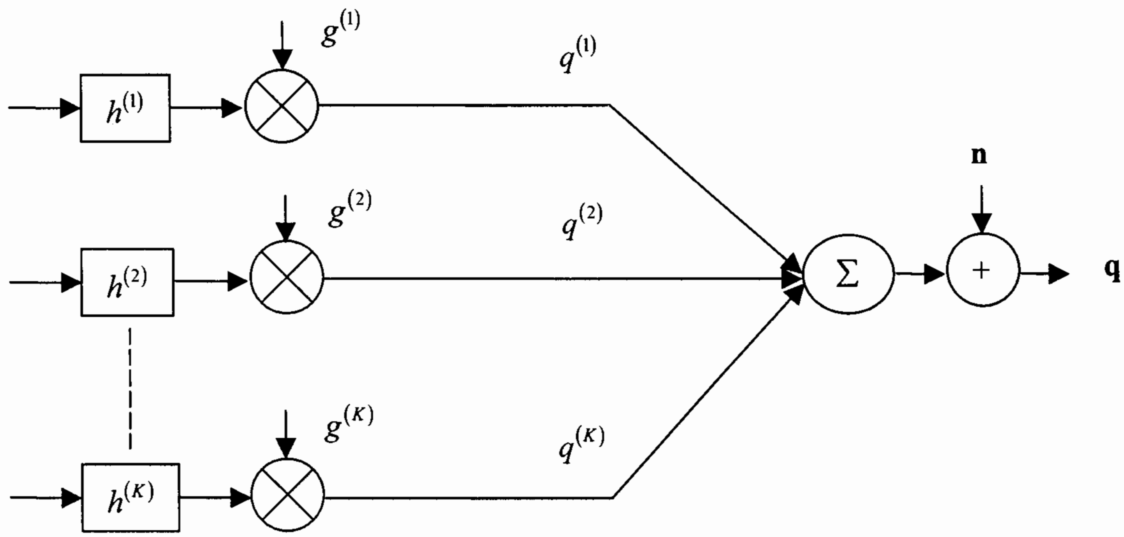

Figure 4.1: The Basic DS-CDMA system model

The Figure 4.1 can be represented mathematically as:

$$\mathbf{q} = \sum_{i=1}^{K} q^{(i)} + \mathbf{n} \tag{4.1}$$

$$= \sum_{i=1}^{K} h^{(i)} g^{(i)} + \mathbf{n} \tag{4.2}$$

4.2 Optimum Multi-user Detection for Synchronous Transmission

Figure 4.2 shows the optimum Multi-user Detection (MUD) for synchronous system supporting K users.

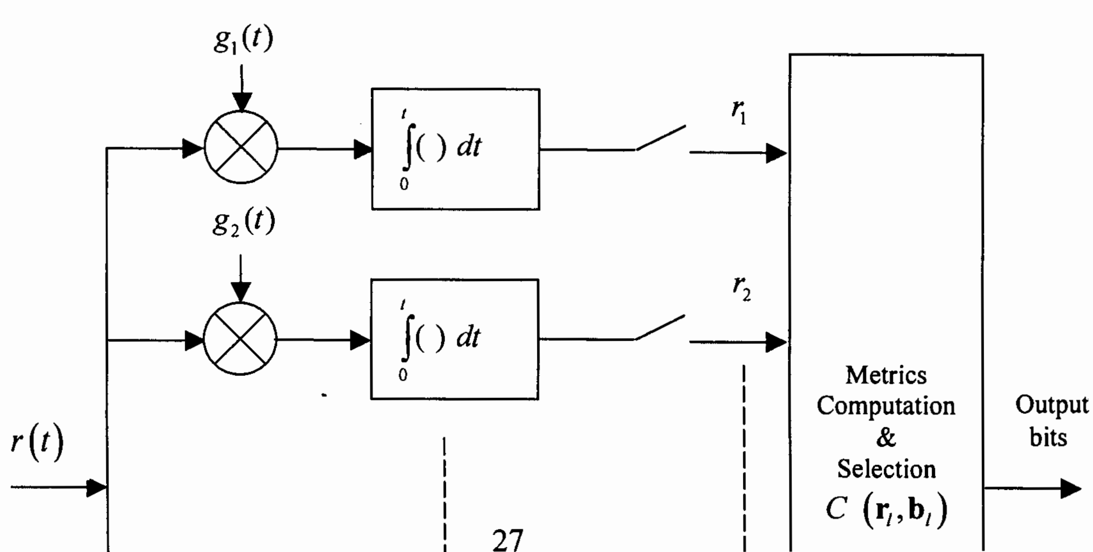

Figure 4.2: Structure of Optimum MUD

Here $r(t)$ is the received signal which is multiplied by the signature sequence of $g_i(t)$, where $i = 1,...,L$ for de-spreading and it is passed through the correlators. The vector $\mathbf{r}_l$ where $\mathbf{r}_l = [r_1,...,r_L]^T$ is the output of the correlators. Multi-user detection is then employed which gives a desired output. As from the Verdus optimum Multi-user detection (MUD) [2], the outputs of the correlators are:

$$\mathbf{r}_l = [r_1,...,r_K]^T \tag{4.3}$$

$$= \mathbf{R}_s \mathbf{b}_K + \mathbf{n} \tag{4.4}$$

Where $$\mathbf{b}_K = \left[\sqrt{\varepsilon_1} b_1,...,\sqrt{\varepsilon_K} b_K\right]^T \tag{4.5}$$

Matrix $\mathbf{R}_s$ is the correlation matrix with elements ρ_{jk} where ρ_{jk}, can be written as:

$$\rho_{jk} = \int_0^T g_j(t) g_K(t)\, dt \tag{4.6}$$

According to Verdus [2], optimum Multi-user Detection (MUD), the correlation metrics will maximize the cost function:

$$C\left(r_l, b_l\right) = 2\mathbf{b}_l^T \mathbf{r}_l - \mathbf{b}_l^T \mathbf{R}_s \mathbf{b}_l \tag{4.7}$$

In the information sequence of K users, the possible choices of the bits are 2^K. For each sequence the optimum detector computes the correlation metric and that sequence is selected which contain the larger correlation metrics. The complexity of this optimum detector is very high as it increases exponentially with increasing number of users K .There fore in order to reduce the complexity, In this thesis I merged the Radial Basis Function (RBF) MUD with the Genetic Algorithm (GA) MUD to get the GA-RBF MUD and compared it with the optimum MUD. These will be considered in the next section.

4.3 Multi-user Detection based on RBF

Figure 4.3 shows the Multi-user Detection based on Radial Basis Function (RBF) for a synchronous DS-CDMA system. Here it is composed of multiple outputs and each output give rise to an impendent RBF network.

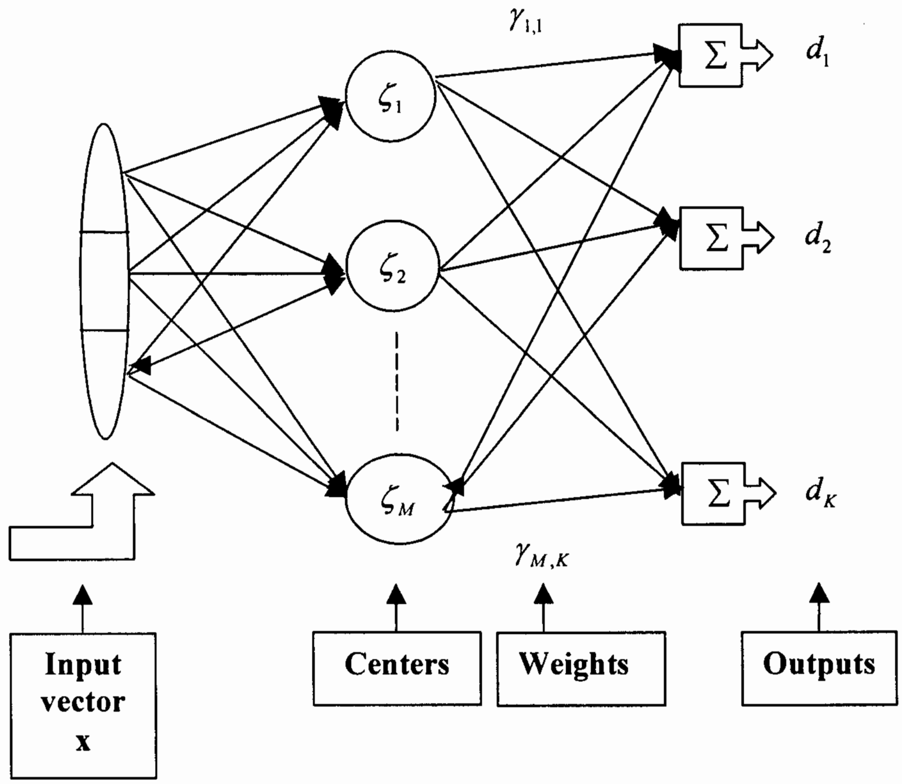

Figure 4.3: MUD based on RBF

Which can be represented as follows :

$$d_k = \sum_{i=0}^{M} \gamma_{i,k} \zeta_{i'}(\mathbf{x}) \qquad k = 1,\dots,K \tag{4.8}$$

Where $\gamma_{i,k}$ represents the weights of RBF based MUD and $\zeta_{i'}(\mathbf{x})$ denotes the Radial Basis Function where the $\zeta_{i'}(\mathbf{x})$ is given by:

$$\zeta_i(\mathbf{x}) = \exp\left[-\frac{\|\mathbf{x}-\mathbf{c}_i\|^2}{2\sigma_i^2}\right] \tag{4.9}$$

Where vector $\mathbf{x}$ is the input vector and vector $\mathbf{c}_i$ is the RBF center. $2\sigma_i^2$ is the spread of the Gaussian function.

4.4 Merging of GA and RBF Multi-user Detection

In this section I have introduced, GA-RBF assisted Multi-user Detection for synchronous DS-CDMA system. Figure 4.4 shows the structure of GA-RBF assisted MUD.

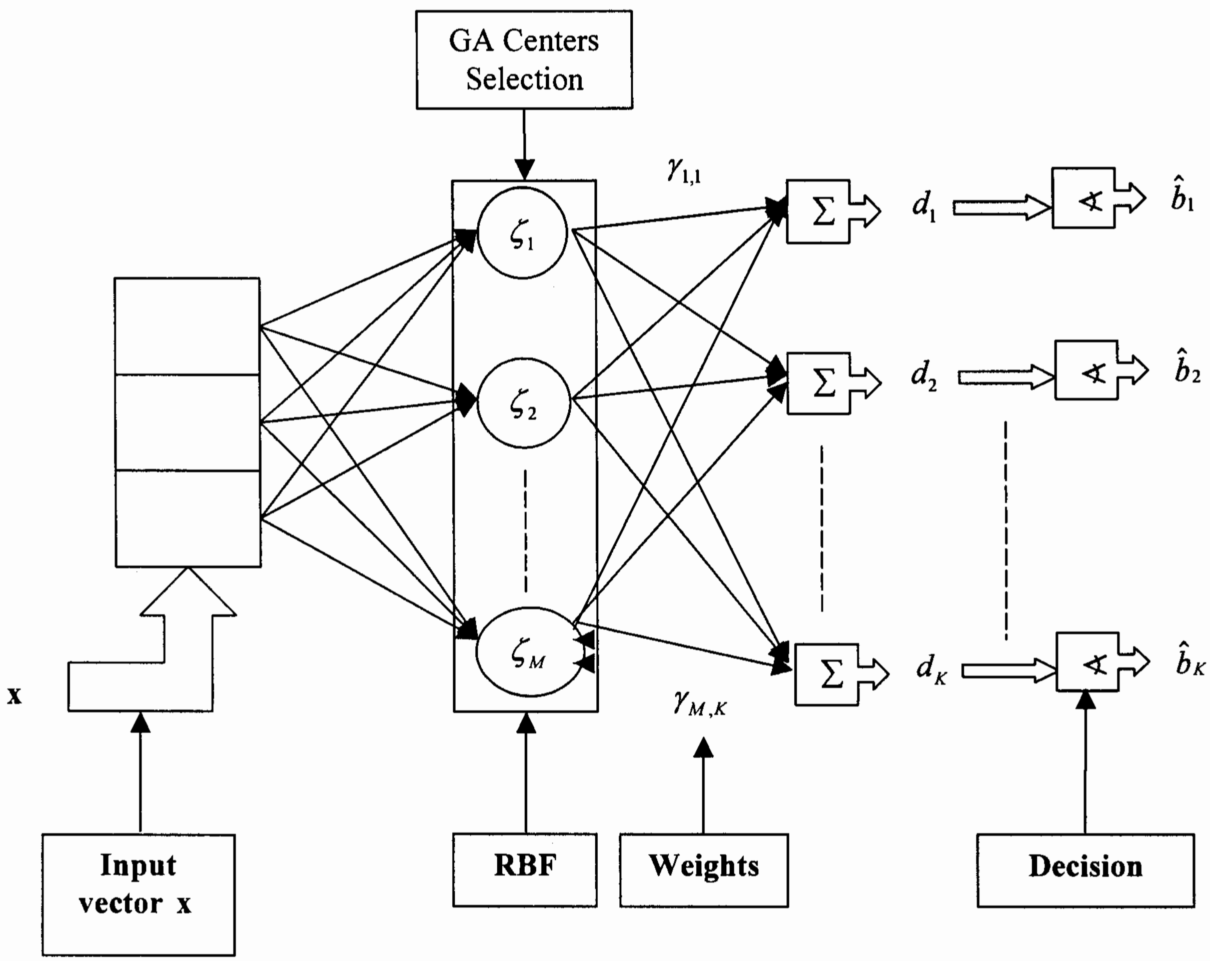

Figure 4.4: Architecture of GA-RBF assisted MUD

Here vector **x** is multi-user composite received signal vector at the output of the AWGN channel. ζ_i are the RBF centers which are weighted by RBF weights denoted as $\gamma_{i,k}$ where $i=1,\dots,M$ and $k=1,\dots,K$. These weighted RBF centers are summed up to give rise the output vector denoted as d_k where:

$$d_k = \sum_{i=0}^{M} \gamma_{i,k} \zeta_i(\mathbf{x}) \tag{4.10}$$

And

$$\zeta_i(\mathbf{x}) = \exp\left[-\frac{\|\mathbf{x} - \mathbf{c}_i\|^2}{2\sigma_i^2} \right] \tag{4.11}$$

The vector $\mathbf{d}$ which is output of the GA-RBF assisted MUD can be written as:

$$\mathbf{d} = \boldsymbol{\gamma}.\zeta \tag{4.12}$$

Where

$$\zeta = (\zeta_1(x), \ldots, \zeta_M(x))^T \tag{4.13}$$

And $\boldsymbol{\gamma}$ is

$$\boldsymbol{\gamma} = \begin{pmatrix} \gamma_{1,1} & \gamma_{2,1} & \cdots & \gamma_{M,1} \\ \gamma_{1,2} & \gamma_{2,2} & \cdots & \gamma_{M,2} \\ \vdots & \vdots & & \vdots \\ \gamma_{1,K} & \gamma_{2,K} & \cdots & \gamma_{M,K} \end{pmatrix} \tag{4.14}$$

There are 2^K possible M channel outputs as can be seen from Figure 4.4. Its complexity increases with increasing number of users K. Therefore for the reduction of the complexity GA is merged in RBF to give rise the GA-RBF assisted MUD. Here the RBF centers are selected due to the process of GA. The RBF centers, which have the high contribution in the performance, are selected while the remaining RBF centers which have the low contribution in the performance are neglected. Therefore the reduction of RBF centers reduces from 2^K to P. As P is the population size in GA.

4.5 Simulations Parameters

The Simulation parameters used in this experiment are:

- BPSK modulation.
- Walsh codes are used as spreading codes.

- Total Spreading Gain N i.e. Walsh=8.
- Selection method for GA is fitness proportionate.
- Mutation method for GA is standard binary mutation.
- Crossover method used in GA is crossover single point, multipoint and Heuristic.
- Mutation probability for GA is 0.1.
- Crossover probability for GA is 1.
- Process of Elitism is used.
- There is no incest prevention.

4.6 Simulation Results

In this experiment GA-RBF is investigated for different number of users in contrast to different complexities of GA in terms of ($P \times Y$). Here P is for population size and Y is the total number of generations. From graphs we can readily deduce following results.

For small number of users i.e. K=10, GA-RBF converges quickly as we increase the complexity and SNR. It is apparent from the Figure 4.5 that by doubling the complexity that is from $(P \times Y) = (20 \times 10) = 200$ to $(P \times Y) = (40 \times 10) = 400$ we get an order difference in BER performance. Also we can see that for the complexity of 500 the BER is approximately 2×10^{-4}, if the SNR is 14 dB. This is a reasonable BER. And we get approximately the same performance as MLSE just by little more increasing the complexity.

With increasing the number of users from $K = 10$ to $K = 20$, we have to increase the complexity further in order to get better results, as we can see from Figure 4.6. So for the complexity of 60×20 = (1200) we get a BER of approximately 2×10^{-4}, if the SNR is 14dB. So same results can be achieved for even doubling the users with increase in the complexity.

Further, for K=30 users, we go for a complexity of 50×30 (1500), as we can see from Figure 4.7. Here we get the BER of 10^{-3}, if the SNR is 14dB. This is reasonable BER. But still this complexity is very small compared to the optimum complexity offered by MLSE. There we have complexity of 2^{30} which is more than 5000 times greater than GA-RBF complexity.

By employing different crossover methodologies, we get different improvements in result, which is shown in Figure. 4.8. In this experiment all the results are calculated for crossover Heuristic.

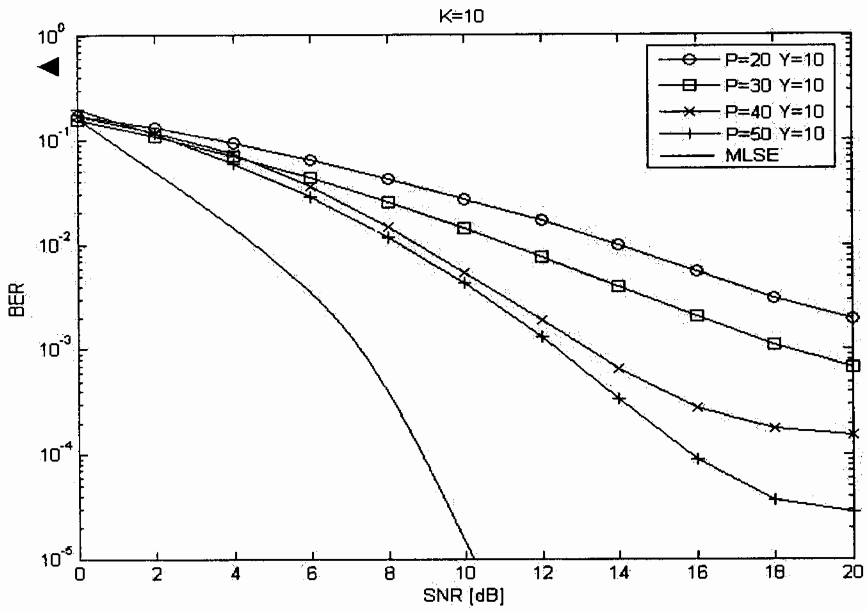

Figure 4.5: BER performance of the GA-RBF assisted MUD for Synchronous DS-CDMA system, using 8-chip Walsh code. The number of users supported are K=10. The number of generations are Y=10 and the population size is P=20, 30, 40 and 50

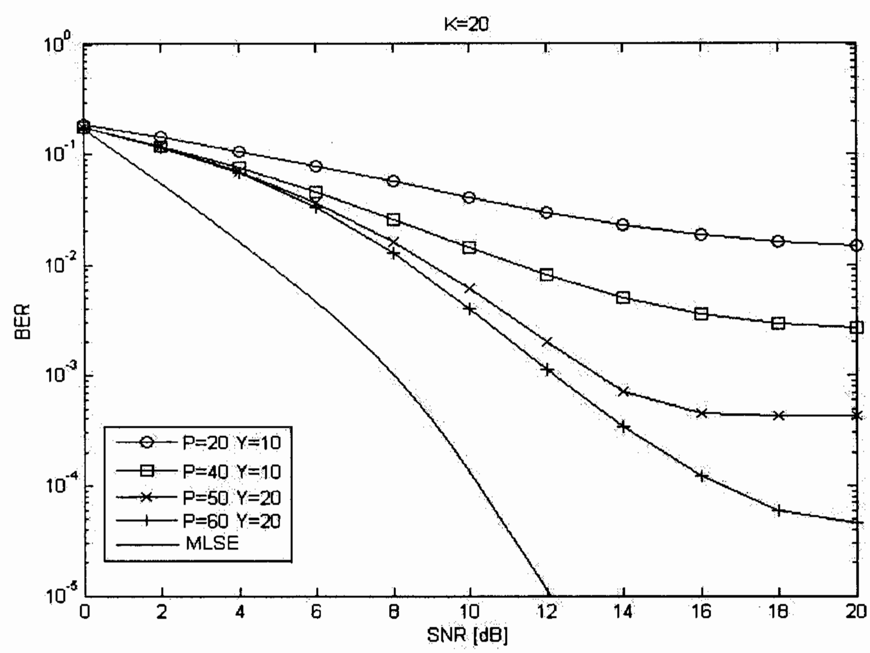

Figure 4.6: BER performance of the GA-RBF assisted MUD for Synchronous DS-CDMA system using 8-chip Walsh code. The number of users supported are K=20. The number of generations are Y=10, 20 and the population size is P= 20, 40, 50 and 60.

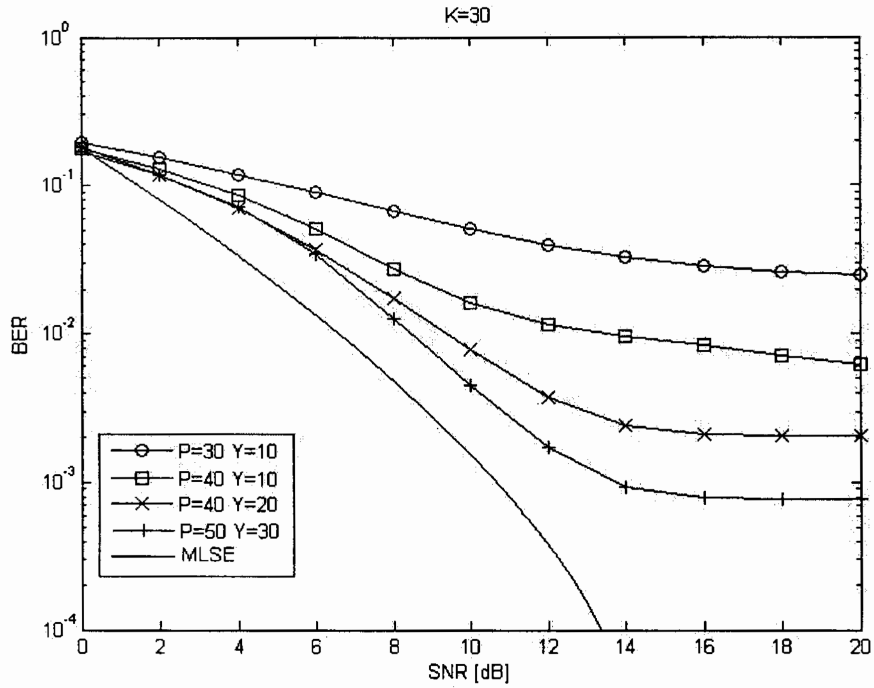

Figure 4.7: BER performance of the GA-RBF assisted MUD for Synchronous DS-CDMA system using 8-chip Walsh code. The number of users supported are K=30. The number of generations are Y=10, 20, 30 and the population size is P= 30, 40 and 50.

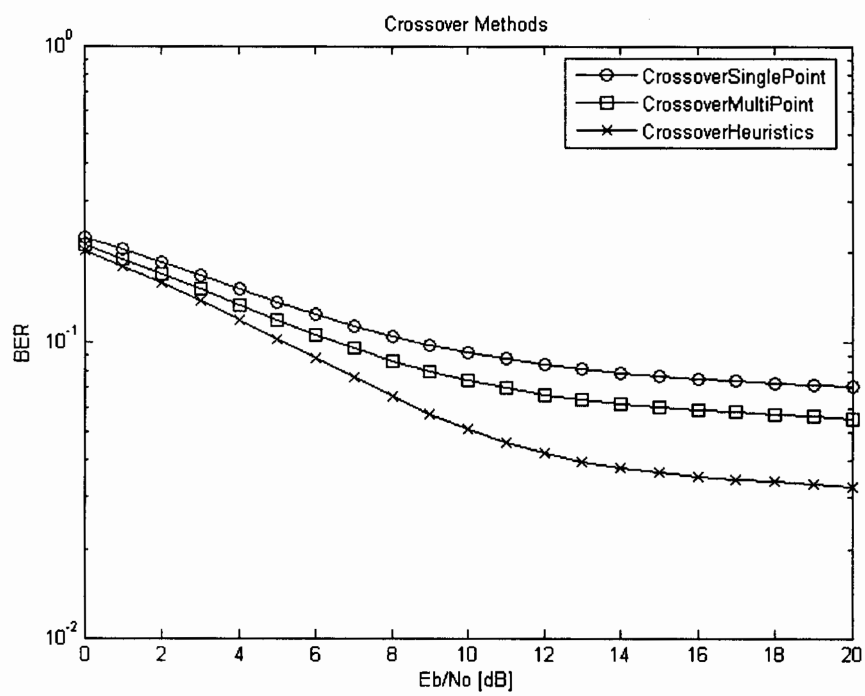

Figure 4.8 Effect of three crossover methodologies of GA over BER performance

CHAPTER 5

Conclusions and Future Work

5.1 Conclusions

Investigated scheme works better for synchronous scenarios in CDMA system in conjunction with Walsh spreading codes as shown in previous chapter results.

If the number of users are K=10, then the complexity of optimum Maximum Likelihood Sequence Estimitator (MLSE) is 2^K= 2^{10}(1024). In contrast the complexity of GA-RBF assisted MUD for K=10 users are $P \times Y$=50X10=500. This means the complexity of proposed scheme is two times less than the optimum MLSE. If the number of users increases from $K=10$ to K=20, the complexity of MLSE is 2^K= 2^{20}(1048576) and the proposed scheme complexity is $P \times Y$=40X50=(2000), so proposed scheme complexity is 525 times less than the optimum MLSE. If the numbers of users are $K = 30$, the complexity of MLSE is 2^K= 2^{30}(1073741824) and the proposed scheme complexity is $P \times Y = 50 \times 30(1500)$, so proposed scheme complexity is 715827 times less than the optimum MLSE.

Also this scheme works better with increasing number of users.

5.2 Future Work

Further this scheme can be extended for asynchronous scenarios (uplink). Also different variations of GA techniques results in further refining the results; so can be investigated.

Here I did all experiments using Walsh codes, which are orthogonal in nature and less vulnerable to errors and MAI. But in practice it is hard to find orthogonal codes for high number of users, so one can go for non-orthogonal codes like Kasami, Gold sequences and results can be investigated.

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