Multiuser Detection for Asynchronous MC-CDMA System Using Genetic Algorithm

By

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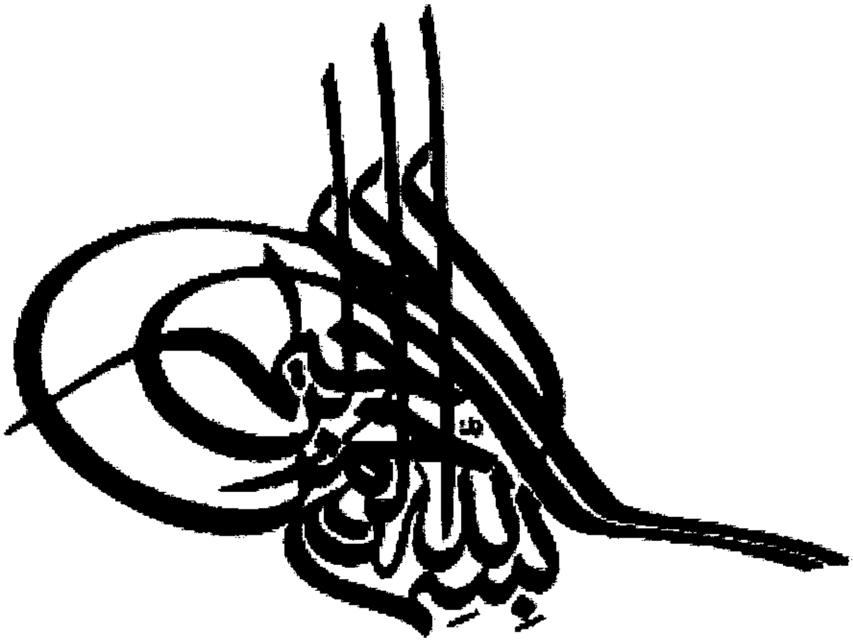
بسم الله الرحمن الرحيم

Dedicated to my parents and teachers

Abstract

In purposed scheme "Genetic Algorithm assisted Multi user Detection for Asynchronous MC-CDMA system", *receiver optimization techniques* are being investigated. In multi-user detection, multiple access interference (MAI) is introduced which makes the detection very inefficient. The proposed system is less vulnerable to this hazard in CDMA communication. In this proposed scheme Orthogonal Frequency Division Multiplexing (OFDM) has been used for attaining frequency diversity gain. Same signal is sent over different carrier frequencies and these carrier frequencies being properly separated in frequency space do not interfere with each other and hence capacity is added up. In purposed scheme the receiver has been optimized by using different variations of genetic algorithm & complexity has been reduced. In this scheme we also examined the role of Walsh spreading sequences and demonstrated the results for different number of users. The proposed scheme can perform sufficiently well with very low computational complexity compared to the optimum maximum likelihood scheme with increasing number of users.

Acknowledgements

First of all I am grateful to Almighty Allah, The Kind and Merciful, Who enabled me to complete this work. Then, I would like thank to my supervisor Dr. A. N. Malik, for his continuous encouragement and enthusiasm. His enthusiasm in searching for new ideas in digital communications has always inspired and motivated me to reach new horizons of research. I never saw a person, who always treated me as his own child and paid special attention to me, my studies and my research at all stages. The thing that I have been learning from him is not just a range of solutions to the communication problems, but his insight, his way of conducting research and his art of guidance inspired me in the completion of my research work.

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Contents

CHAPTER 1

Introduction

1.1 Introduction to thesis

Orthogonal Frequency Division Multiplexing (OFDM) has recently gained a lot of attention and is a potential candidate for 4G systems. OFDM is very efficient in spectrum usage and is very effective in a frequency selective channel. By taking advantage of recent improvements in Digital Signal Processing (DSP) and RF technologies, OFDM can provide higher data rates and is a very good choice for service providers to compete with wire-line carriers. A variation of OFDM which allows multiple accesses is Multi-Carrier CDMA (MC-CDMA) which is essentially an OFDM technique where the individual data symbols are spread using a spreading code in the frequency domain.

The technique Multi-carrier Code Division Multiple Access (MC-CDMA) is a combination of Direct Sequence CDMA (DS-CDMA) and Orthogonal Frequency Division Multiplexing (OFDM). In MC-CDMA systems we employ spreading sequences in the frequency domain instead of applying spreading sequences in the time domain for spreading each bit. So at the cost of a reduced spreading gain we are capable of achieving frequency diversity gain.

The most important properties of a direct sequence (DS) spread spectrum technique are: multiple access capabilities, multipath interference rejection, narrowband interference rejection, and secure and privacy capabilities.

If we detect only single user in multi-user communication environment then this sort of detection is known as Single User Detection (SUD). In this detection only the signal of user of interest is considered as useful information while the rest users' data is considered as a noise. Similarly, the case of considering the other users' data as useful information is known as Multiuser Detection (MUD).

In the literature lot of Multi-user Detection schemes have been proposed. The Maximum Likelihood (ML) MUD scheme is basic Interference Cancellation (IC) scheme for MC-CDMA has been proposed in literature. In this specific MUD, all the possible combinations of the transmitted signal has been constructed by the receiver and employs the estimated channel transfer function for generating all possible received signals, in order to find the one, which has the smallest Euclidean distance from the received signal. The results of ML detection are optimum, so it is named as optimum detection, but its main disadvantage is that the complexity increases exponentially if we increase the number of users. However, it requires the calculation of 2^K number of possible received signal combinations in conjunction with Binary Phase Shift Keying (BPSK) modulation.

The motivation behind this research effort is to study the use of genetic algorithm. The proposed Genetic Algorithm Assisted Multiuser Detection scheme has been applied on Asynchronous Multicarrier CDMA system. By using this receiver optimization technique the complexity is reduced up to a mark able figure with the excessive number of users.

1.2 Contribution

Some of the major contributions of the thesis are listed below.

i. Genetic Algorithm (GA) [52, 53] is investigated for Asynchronous MC-CDMA system communication over Rayleigh Fading channel.

ii. The sub optimum scheme, Genetic Algorithm (GA), is capable of achieving approximately the same results as ML based MUD at a significant lower computational complexity.

iii. The different variations of sub optimum scheme are investigated for achieving batter results.

iv. Comparative *demonstration* using Walsh codes (N=16) and M=4 Multicarriers for K=10, 15 & 20 users. As N is number of chip pre bit or length of each signature & M is number of subcarriers.

v. Investigated the complexity reduction factor as compared to optimum detection, versus increasing number of users.

1.3 Organization

The outline of the dissertation is as follows:

Chapter 2 In this chapter there is the discussion about the different Multiple Access Technologies like Scheduling MA, Frequency Division Multiple Access, Time Division Multiple Access, Random Access MA, Code Division Multiple Access (CDMA) & Space Division Multiple Access (SDMA).

Chapter 3 In this chapter there is the discussion about the Multiuser detection schemes. In it I've elaborate the Joint detection, Interference cancellation schemes & combined schemes

Chapter 4 this chapter is also devoted to the Genetic Algorithm, its brief portfolio.

Chapter 5 In this chapter a GA-assisted MUD is invoked for Asynchronous MC-CDMA system (base station). Simulation results are demonstrated for K=10,15 and 20 number of simultaneous users, using Walsh Codes over M=4 orthogonal carriers. Also complexity reduction factor is simulated versus increasing number of users.

Chapter 6 In this chapter, the thesis is concluded and future extendable dimension regarding this scheme are mentioned and references are listed in the end.

CHAPTER 2

Multiple Access Technology
And Spread Spectrum systems

Whenever there is a limited communication channel resource that is accessed by more than one independent user then the need for Multiple Access (MA) techniques arises. MA techniques are used to share the common transmission channel among all users in the system. This technology should be robust to channel impairments and changing conditions and the receiver has a capability to separate the desired signal from the signals they are interfering. As shown in Figure 2.1, the MA techniques can be classified into four main groups as follows [1, 2].

2.1 Scheduling MA

Simultaneous access avoids from multiple users by scheduling all transmissions. In this the channel capacity is divided among the users in a static fashion & scheduling protocol can either be implemented as a fixed assignment as well. Unlike the fixed assignment, the demand assignment does not waste channel capacity on idle users and additional overhead and delay are introduced to sort out active users. Examples of demand assignment MA protocols are roll-call polling and token-passing [1].

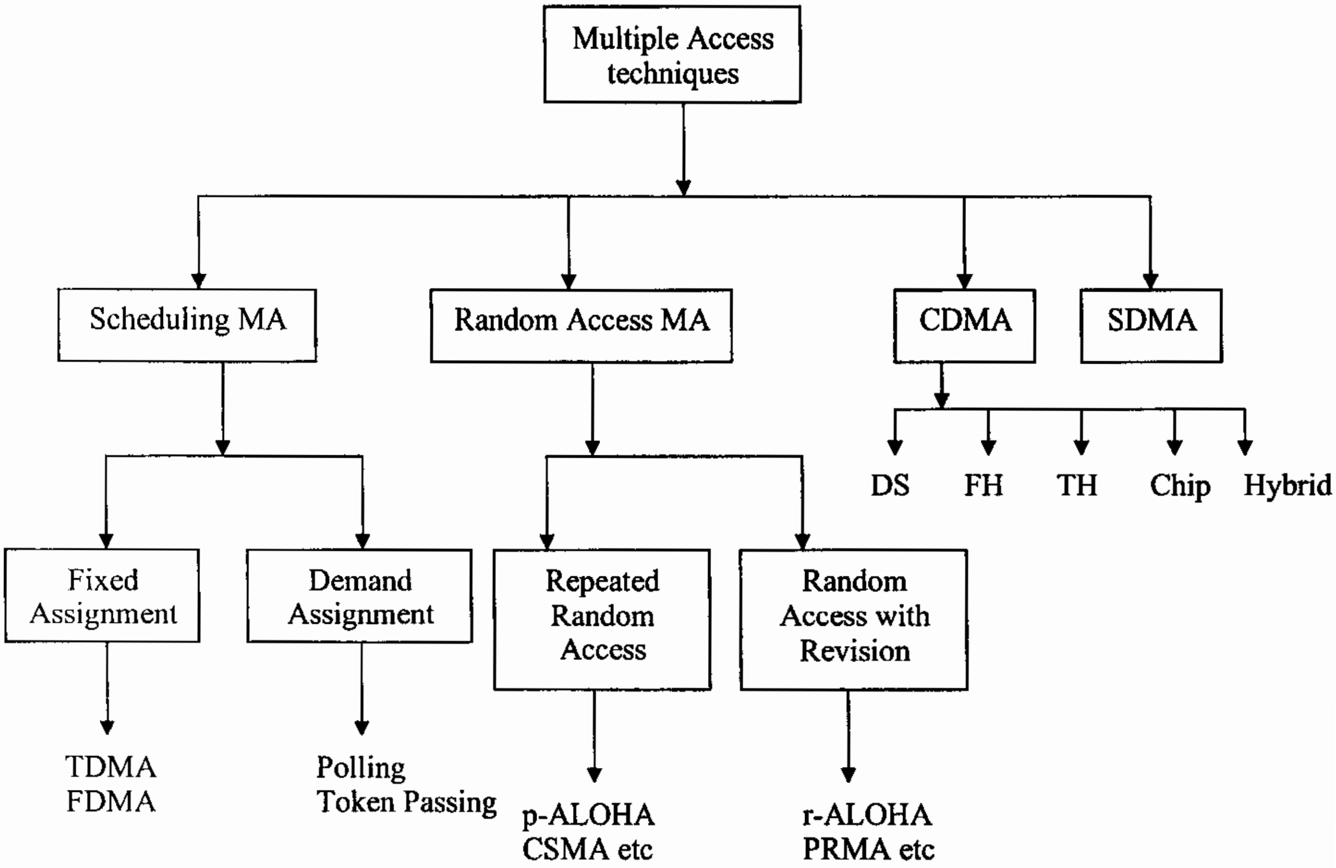


Figure 2.1: Radio Classification of the Multiple Access technology.

The radio communication systems use fixed assignment multiple access to divide a single high-capacity multiple access channel into smaller orthogonal channels. This is done by channel partition in terms of disjoint frequency bands known as Frequency Division Multiple Access (FDMA), these disjoint time slots are known as Time Division Multiple Access (TDMA). Hence, their capacities are the number of channel partitions. To avoid co-channel interference, guard times and bands are inserted between adjacent transmissions in TDMA and FDMA respectively. To avoid co-channel interference In cellular radio systems, the concept of frequency reuse is used to place a minimum distance between cells using the same frequencies. In a good designed frequency reuse plan is a compromise between high spectral efficiency (i.e., high reuse factor) & high reception quality (i.e., low reuse factor). TDMA and FDMA both provide a simple MA solution in slowly varying traffic network. The FDMA is simpler than TDMA, bacause no synchronization between users is required.

The discussion of fix assignment scheduling multiple access techniques are as under.

2.1.1 Frequency Division Multiple Access

In the Frequency Division Multiple Access (FDMA) the frequency bands are conceded as channels. In a particular application the frequency range allocated, is divided into a number of non-overlapping frequency bands in witch one band is assign to one user. For avoiding cross-channel interference, guard bands are allocated between each pair of frequency bands in which there should be no component of either signal from the adjacent bands. FDMA was the dominant multiple access technique used in analog telephone voice transmission in previous decades [3].

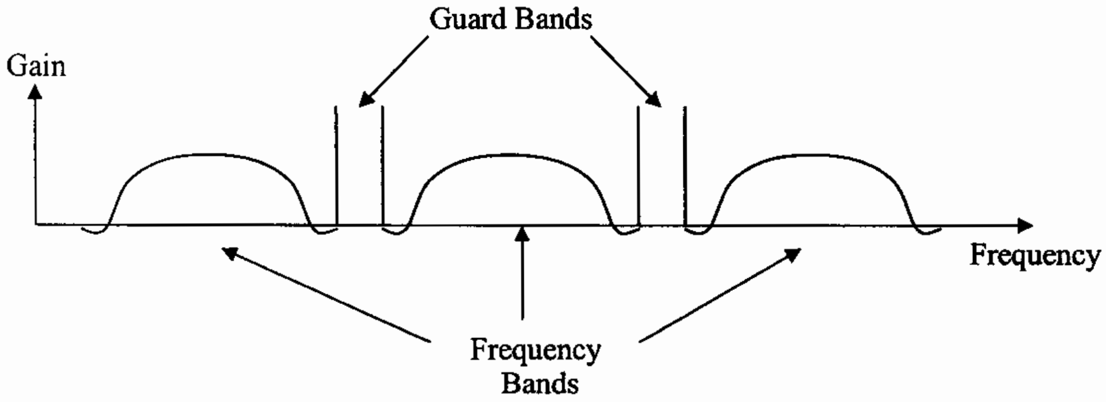


Figure 2.2: Illustration of the concept of FDMA.

In FDMA system, channels comprise different frequency bands; one frequency band is allocated to each user for transmission in the uplink. The Advanced Mobile Phone System (AMPS) belongs to this class & was the first standardized cellular system and; it uses the 800 MHz to 900 MHz band and allocates 30 kHz for each channel [4,5]. Analog frequency modulation (FM) is used by AMPS. An AMPS-based system is simpler than the other cellular systems and can be based on analog modulation for its continuous transmission properties. AMPS system has several drawbacks. An AMPS handset may need to change transmission frequency during the handoff. Furthermore, static channel sharing of AMPS leaves the idle channels unused & allocation of multiple channels per user become difficult. The limitation system capacity is a serious disadvantage of the AMPS system [6]. To address the capacity limitations of AMPS Narrowband analog mobile phone service (NAMPS) was proposed as an interim solution. In NAMPS, each 30 kHz channel is divided into three 10 kHz channels & each channel carried a single voice conversation. The capacity is increased but the channels in NAMPS remain statically shared and the idle channels remain unused.

2.1.2 Time Division Multiple Access

In Time Division Multiple Access (TDMA) time slots are the orthogonal channels. A time frame of appropriate length is divided into a number of time slots. Each user is allocated one slot in each frame in the given transmission environment. For avoiding cross-channel interference, guard bands are allocated between transmission slots in which no user can transmit [7]. Bits are allocated within each time slot for control flags & training sequences.

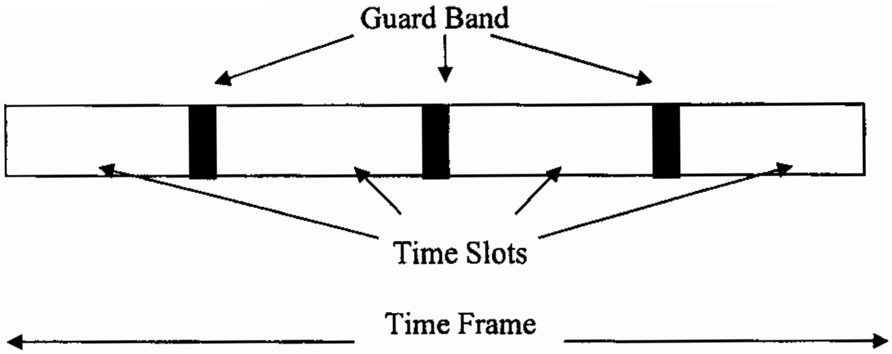


Figure 2.3: Illustration of the concept of TDMA.

It provides multiple accesses by sharing the same transmission resource at different times by different users. It is easier to implement handoff in a TDMA system as compared to an FDMA system due to its non-continuous nature of transmissions. So the inter-symbol interference (ISI) occurs due to wideband channels. Required compensation for ISI is achieved by means of an equalizer [3].

In FDMA, the difficulty of allocating multiple frequency bands to the single user creates a limitation in bandwidth. It is easier to combine time slots as compare to combine frequency bands, TDMA systems are more batter as compare to FDMA systems in achieving high bandwidth links. The recent evolution of the Global System for Mobile (GSM) [8] for enhanced data rates for global evolution (EDGE) [11] & general packet radio service (GPRS) [9,10] capabilities makes use of this particular feature. If, due to these reasons, time division multiple accesses are superior to FDMA, it also has some disadvantages. TDMA systems are less robust to multipath effects and have more stringent synchronization requirements. Once again, if dynamic access is not introduced then channel sharing is static in nature while unused time slots are wasted.

To achieving the benefits of TDMA without putting the AMPS out of service, digital AMPS (DAMPS) was proposed as a TDMA "overlay" on the AMPS network [12]. It is one of the first digital cellular standards and it uses the same channel bandwidth as AMPS but on each available frequency band, time multiplexes multiple channels. The possible combinations of FDMA and TDMA are like NAMPS with TDMA overlays [13]. GSM [8, 18] standard uses a hybrid TDMA and FDMA system, which is quite popular in Europe. To increase the system capacity, these systems use different techniques, but all FDMA and TDMA systems and their hybrids rely on static sharing of the channel in different ways.

2.2 Random Access MA

When several users transmit simultaneously it resolves the contention (or collision). ALOHA is the first random access system. It was proposed for packet radio network in 1969 [15]. The ALOHA protocols assumes that with every transmission there is the possibility of contention. If the channel is not free, contention is detected and the user can defer its own transmission. Random access can be further divided into repeated random access and random access with reservation [1]. Some examples of random access multiple Access systems include p(ure)-ALOHA), r(eservation)-ALOHA, Carrier Sense Multiple Access (CSMA) and Packet Reservation Multiple Access (PRMA).For bursty channels The random access MA is most suitable whereby the probability of simultaneous transmissions of more than one user occurring is very low.

2.3 Code Division Multiple Access (CDMA)

It is between scheduling and random multiple accesses. It allows the transmission of number of users simultaneously without contention, but if more users are added interference level increases. Due to its anti-jamming property and low probability of detection, it was developed for use in military applications. Its basic concept is expansion of the bandwidth of information-bearing signal by using of the spread spectrum modulation.

Orthogonal channels are formed as a consequence of signal modulation in Code Division Multiple Access (CDMA) [9, 16]. All users transmit at the same time and within the same frequency range but each of their signals are spread by the signature sequence. Signals of all users are statistically uncorrelated. By correlation all users' signals are recovered at the receiver end. Graphical depictions of CDMA techniques are shown as under.

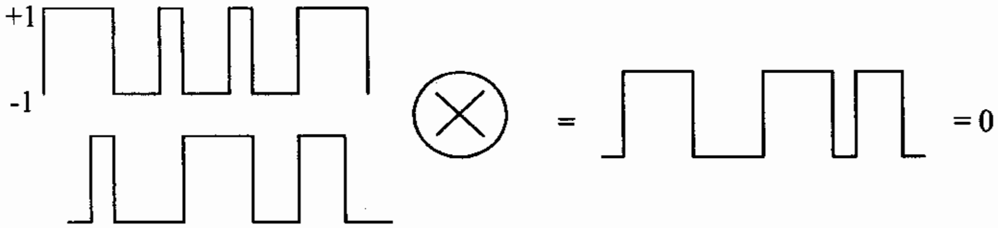


Figure 2.4: Illustration of the concept of CDMA.

Each user is assigned a unique code such that its transmitted signal is spread into a wideband signal in CDMA system. At the Matched Filter receiver, assuming quasi-orthogonal codes, only the desired signal is "de-spread" and other signals appear as noise and remain wideband. Thus, CDMA can also refer to as spread spectrum MA. CDMA signals can be divided into a number of groups as follows based on the modulation methods.

2.3.1 Direct Sequence (DS)

In this case the signal heaving information is multiplied by the spreading sequence. The usual form of modulation scheme is some form of Phase Shift Keying. The main difference of DS-CDMA from all other CDMAs is the interference in the DS case is reduced by averaging it over a wide time interval, while in others the interference is reduced by avoiding it for most of the time.

2.3.2 Frequency Hopping (FH)

A FH-CDMA system occupies only fraction of spread bandwidth (i.e., hop bin) at one time and on the other hand a DS-CDMA system uses the entire spread bandwidth. Non-coherent demodulations are normally used because of the difficulty of maintaining phase references as the frequency hops. FH-CDMA has less stringent synchronization requirement and is less sensitive to channel gain and phase fluctuations as compare to DS-CDMA.

2.3.3 Time Hopping (TH)

The transmission of information-bearing signal is in discontinuous manner, short bursts at time intervals determined by the spreading sequence. The implementation of TH is simpler than that of FD-CDMA but the required synchronization time in TH-CDMA is longer comparatively. The TH-CDMA is similar to a TDMA protocol if all users' transmissions are synchronized.

2.3.4 Chirp Modulation

This modulation is almost used in military radars. The radar transmits a low power signals and their frequencies varying continuously over a wide range.

2.3.5 Hybrid Modulation

In order to mitigate some of the disadvantages, this modulation combines various CDMA signaling methods. Multi-Carrier (MC)-CDMA is a hybrid CDMA which has received much attention recently. It is a combination of CDMA and orthogonal frequency division multiplex signaling. In MC-CDMA, using a given code in the frequency domain, the information-bearing signal is spread, and is potentially robust to frequency selective fading channels [1].

2.4 Space Division Multiple Access (SDMA)

This multiple access technique controls the radiation pattern of each user in space [17, 18]. The use of sectorized/adaptive antennas is a common application of SDMA. Antenna direction can be fixed or adjusted dynamically, in order to steer in the direction corresponding to the desired signal. The interfering signals that lie outside the antenna's main beams can be attenuated through antenna gain. Space Division Multiple Access is basically beamforming applied to multiple users simultaneously. Each user is allocated by one beam pattern. The main beams are quite narrow and referred as pencil beams. The space surrounding the antenna array receiver is partition by the pencil beams. This scenario is equivalent, in terms of capacity per user [19], to each user being the only transmitter in a cell without interference and with an omnidirectional antenna. There are only finite number of independent beams may be formed which is the same as the number of antennas [20].

CHAPTER 3

Multiuser detection schemes

Multiuser detection (MUD) is a promising approach of overcoming the limitations of the conventional DS-CDMA detector and to provide an efficient use of the available frequency spectrum. Significant increase in capacity is the major benefit of using MUD in a cellular system. A main limitation of MUD is the receiver complexity. A major concern is the constraints in cost, size and weight of the receiver. Therefore, there is a need to provide mobile multiuser receivers that have reasonable computational complexity and acceptable performance to ensure practical implementation.

In Figure 3.1, an overview of MUD is presented. MUD can be divided mainly into three categories: interference cancellation (IC), joint detection (JD) schemes and structures with combined schemes. The first category is a bank of conventional detectors followed by filters that performs non-linear or linear transformations. Joint detection structures are generally computationally more expensive due to complex matrix calculations and inversions as compared to the conventional detector. The interference cancellation schemes are characterized by the regeneration and subtraction of interference based on the data estimates. Finally, a third category of MUD is considered as the group of multiuser detectors that combine detection techniques from the two groups of MUD as mentioned above.

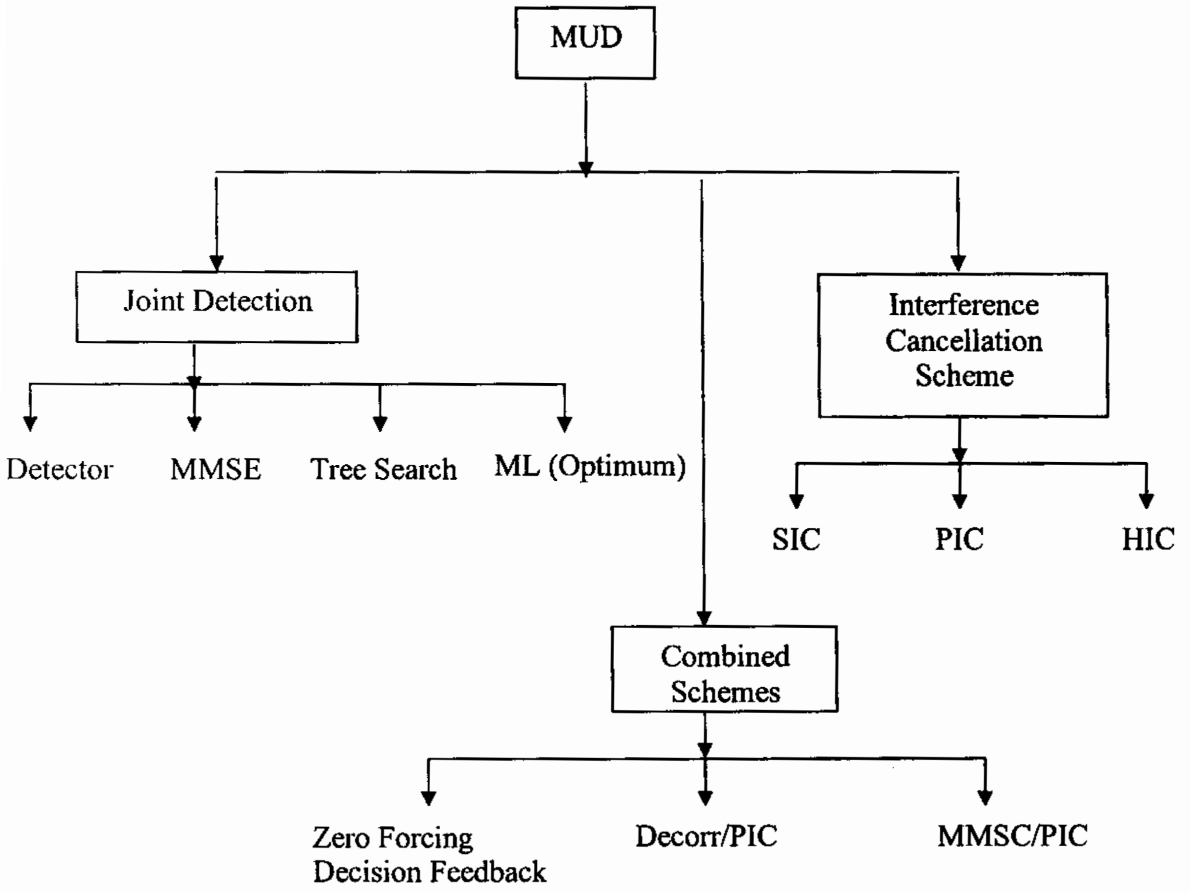


Figure 3.1: General classification of multiuser detection structures.

To simplify the discussion on the multiuser detector structures, we will assume a conventional synchronous DS-CDMA system model over an AWGN channel (no multipath). The received signal can be expressed in a matrix notation as follow

$$\mathrm{r}(t) = \mathrm{CAb}(t) + \mathrm{n}(t) \tag{3.1}$$

Where the N^*U matrix of codes C is given as

$$\mathrm{C} = \begin{bmatrix} c_{1,1} & c_{2,1} & \Lambda & c_{U,1} \\ c_{1,2} & c_{2,2} & \Lambda & c_{U,1} \\ \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} \\ c_{1,N} & c_{2,N} & \Lambda & c_{U,N} \end{bmatrix}$$

A is the user's amplitude matrix of dimensions $U*U$ and denoted by

$$\mathrm{A} = \begin{bmatrix} \sqrt{P_1} & 0 & \Lambda & 0 \\ 0 & \sqrt{P_2} & \Lambda & 0 \\ \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} \\ 0 & 0 & \Lambda & \sqrt{P_U} \end{bmatrix}$$

The users' data and noise components are mentioned respectively in vector form are

$$\mathrm{b}(t) = [b_1(t) \quad b_2(t) \quad \Lambda \quad b_U(t)]^T \ \& \ \mathrm{n}(t) = [n_1(t) \quad n_2(t) \quad \Lambda \quad n_N(t)]^T .$$

The noise vector elements of are considered independent and identically distributed (i.i.d) Gaussian noise samples with zero mean and two-sided power spectral density equals to $\sigma^2 = N_o/2$. In this section we will present some of the multiuser detector.

3.1 Joint detection

In this section the most important JD techniques proposed in the literature is to be discussed. The most widely recognized joint multiuser receiver s is the optimal multiuser detector or the maximum likelihood (ML) detector introduced by Verd'u in 1986 [27]. However, but its computational complexity which grows exponentially with the number of users, $O(2^U)$. There is a big difference in performance and complexity between the conventional detector and the ML detector, over the last 15 years. Therefore most of the search has been in finding sub-optimal multiuser detectors that show good performance and complexity. Instead of the high complexity of the ML, its performance serves as a benchmark for the comparison with other sub-optimal multiuser detector structures. The sub-optimal structures are divided into two classes, namely linear and non-linear detection methods. A brief description of these detectors is given in the sections given below.

3.1.1 Optimum multiuser detector

The optimum multiuser detectors are divided into two categories, jointly optimum and individually optimum multiuser detector. In jointly optimum multiuser detector receiver selects the most likely transmitted vector of symbols $\mathrm{b}(t)$ given that $\mathrm{r}(t)$ was received. In other words, the minimum probability of sequence error decision is obtained by selecting the vector $\mathrm{b}(t)$ that maximises the joint *a* posteriori probability (APP) $p(b(t) \mid r(t))$.The objective of the individually optimum multiuser detector is to find the most likely transmitted symbol $b_u(t); u \in \{1,2,.....U\}$, i.e to maximize the APP $p(b_u(t) \mid r(t))$. The two decision criteria either for jointly or individually detection is the MAP and the ML criteria. So the individually optimum multiuser detector achieves the minimum probability of error for each user. Now we are focusing our attention to the analysis on only this type detector structure. Mathematically, the MAP decision criterion is given as

$$\begin{aligned} \hat{b}_u(t) &= \arg_{b\in\{-1,1\}}^{\max} p(b_u(t) = b \mid r(t)) \\ &= \arg_{b\in\{-1,1\}}^{\max} \sum_{\Omega_b} p(b(t) \mid r(t)) \end{aligned} \tag{3.2}$$

Where Ω_b is the set of vectors $\mathrm{b}(t)$ with $b_u(t) = b$.

By Using Bayes' theorem the APP in (3.2) can be expressed as

$$\hat{b}_u(t) = \arg_{b\in\{-1,1\}}^{\max} \sum_{\Omega_b} \frac{p(r(t) \mid b(t))pr(b(t))}{pr(r(t))} \tag{3.3}$$

Where $p(r(t) \mid b(t))$ is the conditional probability of the observed signal, $r(t)$, given $b_u(t)$ and $pr(b(t))$ is the *a priori* probability of b(t) being transmitted. So $pr(r(t))$ is not dependent on $b_u(t)$, it can be neglected from equation (3.3) resulting

$$\hat{b}_u(t) = \arg_{b\in\{-1,1\}}^{\max} \sum_{\Omega_b} p(r(t) \mid b(t))pr(b(t)). \tag{3.4}$$

The probability function $p(r(t) \mid b(t))$ can be computed as

$$p(r(t) \mid b(t)) = \frac{1}{(2\pi\sigma^2)^{N/2}} \exp\left(-\frac{\|r(t) - x(t)\|^2}{2\sigma^2} \right) \tag{3.5}$$

Where

$$\|r(t) - x(t)\|^2 = \sum_{n=1}^{N} \left(r_{t,n} - x_{t,n}\right)^2 \tag{3.6}$$

Where at time t the received vector is $r(t) = [r_{t,1}, r_{t,2}, \Lambda\ , r_{t,N}]^T$ and $x(t) = [x_{t,1}, x_{t,2}, \Lambda\ , x_{t,N}]^T$ is the channel input when b(t) is transmitted.

Therefore in the case of the ML criterion, the *a priori* probability of b(t) $i.e\, pr(b_u(t))$ for all $u \in \{1,2,\Lambda\ ,U\}$ is not taken into account as it is assumed that all symbols occur with equal probability. Therefore, (3.4) is simplified to

$$\hat{b}_u(t) = \arg_{b\in\{-1,1\}}^{\max} \sum_{\Omega_b} p(r(t) \mid b(t)) \tag{3.7}$$

Where Ω_b is defined as before. It is clear, however, that if the *a priori* probabilities are equal, so the results of both the MAP and the ML criteria will be the same. In other words, the optimum multiuser detector searches through all possible combinations in $\mathrm{b}(t)$ and selects only the closest to the received signal $\mathrm{r}(t)$ based on the Euclidean distance.

Euclidean distance can be calculated either at the chip level (3.6) or at the bit level. The decision rule of the ML multiuser detector with equal *a priori* information and using (3.6) can be then written as

$$\hat{b}_u(t) = \begin{cases} 1 & if \sum_{\Omega_1} \exp\left(- \frac{\left\| r(t - x(t)) \right\|^2}{2\sigma^2} \right) > \sum_{\Omega_{-1}} \exp\left(- \frac{\left\| r(t - x(t)) \right\|^2}{2\sigma^2} \right) \\ -1 & otherwise \end{cases} \tag{3.8}$$

For a synchronous DS-CDMA system in AWGN channel, the resulting complexity of the ML multiuser detector is $O(2^U)$.

RBF detector. In [28] it was shown that if all of the system parameters are known (number of users and their spreading codes) then individually optimum multiuser detector for a synchronous DS-CDMA system can be implemented with a radial basis function (RBF) network. The RBF detectors output is a linear combination of 2^U with U as the number of users. Mathematically, the RBF detector output can be expressed as

$$f(r(t)) = \sum_{l=1}^{2^U} w_l \phi_l \left(\left\| r(t) - a_l(t) \right\| \right)$$

Where $\phi_l ; l \in \{1,2,\Lambda\ ,2^U\}$ is a scalar and radially symmetric non-linear function (normally a Gaussian kernel function [29]) with $a_l(t)$ and w_l as the *l*th centre and *l*th weight that optimize some performance criterion. The norm of a vector $\|\cdot\|$ is the Euclidean distance between the vectors $r(t)$ and $a_l(t)$. For all possible combinations of the data vector $b(t)$ the noise free received vectors represented as the vector of centers $\{a_l(t)\}; l \in \{1,2,\Lambda\ ,2^U\}$. For the RBF detector the decision rule is then given as

$$\hat{b}_u(t) = \operatorname{sgn}\left[\sum_{l=1}^{2^U} w_l \exp\left(-\frac{\|r(t)-a_l(t)\|^2}{2\sigma^2}\right)\right] \tag{3.9}$$

As w_l is substituted by the value of $b_u(t)$ (+1 or -1) associated with the *l*th centre $a_l(t)$.

This detector can also be applied when the received signal are preprocessed by the conventional detector, *i.e* detection at the bit rate. The noise components are neither correlated with the signal nor other noise components without pre-processing the received signal. Therefore Euclidean distance is the optimum measure for the chip rate RBF detector. However, due to pre-processing the noise components becomes correlated [3, 29] and Euclidean distance measure non-optimum. So, the bit rate RBF detector will reflect the correlated nature of the noise components by using the Mahalanobis distance [30] rather than using Euclidean distance.

$$\hat{b}_u(t) = \operatorname{sgn}\left[\sum_{l=1}^{2^U} w_l \exp\left(-\frac{(r(t)-a_l(t))^T \mathrm{V}^{-1}(r(t)-a_l(t))}{2}\right)\right] \tag{3.10}$$

Where

$$V = E[(r(t)-a_l(t))(r(t)-a_l(t))^T]$$

Similarly the ML detector, the complexity of the RBF detector is $O(2^U)$ for an AWGN channel.

3.1.2 Linear multiuser detectors

A number of reduced complexity detectors based on linear techniques have been proposed due to the complexity of the optimum detector. By applying a linear transformation to the output vector of the conventional DS-CDMA detector, this group of detectors mitigates interferences. In this section we study the two most common linear detectors, the minimum mean squared error (MMSE) detectors and decorrelator. First, the decorrelator detector [31–33] is a transformation which applies the inverse of the correlation matrix leaving the received signal without interference. The drawback of this detector is noise enhancement. The other detector is the MMSE detector [45–34] which takes into account the background noise and utilizes the knowledge of the received signal powers.

The output vector of the conventional detector (bank of U matched filters), equation (3.1) is multiplied by C^T

$$Y(t) = \mathrm{RAb}(t) + z(t) \tag{3.11}$$

Where Z(t) is the vector with the correlated noise created by the bank of matched filters and R is the correlation matrix.

Decorrelator detector. By considering that the correlation matrix R is positive definite (*i.e* invertible) and inspection of (3.11), it is clear that by multiplying both sides of (3.11) with the inverse of R the users signals in the system can be decoupled. Thus, the soft decision estimate of the decorrelator detector is

$$\begin{gathered} R^{-1}y(t) = Ab(t) + R^{-1}z(t) \\ \hat{b}(t) = Ab(t) + z^{dec}(t) \end{gathered} \tag{3.12}$$

Now $z^{dec}(t)$ is a noise vector with zero mean and covariance matrix $V^{dec} = \sigma^2 R^{-1}$, and $\hat{b}(t) = [\hat{b}_1(t), \hat{b}_2(t), \Lambda\ \hat{b}_U(t),]^T$ .From (3.12), we can see that the user u(uth component of $\hat{b}(t)$) does not contain interference from other users, therefore, the MAI is completely canceled by the decorrelator detector. Performance gain is provided by this detector over the conventional detector. One more significant feature is that it does not need to estimate the amplitudes of received users. Moreover the level power of the users are independent from each other. The decorrelator detector performs the optimum near-far resistance performance metric. Furthermore the complexity is linear with the number of users $O(U)$.

More over there are two significant disadvantages of this detector. Firstly, it causes noise enhancement which can be observed from the term $R^{-1}z(t)$ in (3.12). It has been shown in [35] that at the output of the conventional detector, the noise power associated with the noise term $R^{-1}z(t)$ is always greater or equal to the noise term. So, it can occur that if the MAI is weak, the conventional detector will outperform the decorrelator. It is simply due to the MAI terms is smaller than the noise enhanced term in (3.12). The second and drawback is the need to invert the matrix *R*. For synchronous systems the problem is somewhat simplified to invert a *U*U* matrix, where detection can be performed at a bit basis. However, the dimensions of this matrix increase with the message length for asynchronous systems. The computation required is substantially increased. This situation cans worst in multipath channels where the paths are treated as an indusial users. Many suboptimal approaches to implementing the decorrelator detector have already been presented in literature [36–37].

Minimum mean squared error (MMSE) detector. Just like the decorrelator detector, the MMSE detector applies a linear transformation to the output of the conventional detector (3.11). However, as distinct from the decorrelator, the MMSE detector takes into account utilizes knowledge of the received signal power and background noise. The MMSE detector makes a balance between the residual interference and the noise enhancement. This transformation is selected to minimize the mean-square error between its output and the data, *i.e*

$$\min_{T \in R^{U \times U}} E[\|b(t) - Ty(t)\|^2]$$

Where T is the $U*U$ transformation matrix. Thus, the soft decision estimate vector of the MMSE detector is given as [38]

$$\hat{b}(t) = (R + \sigma^2 A^{-2})^{-1} y(t) \tag{3.13}$$

The MMSE detector minimises the squared error in presence of noise, and becomes the decorrelator detector without noise. Its performance is very similar to the decorrelator, when the SNR is relatively high $(\sigma^2 \to 0)$ but MMSE is better at low SNR's. Alternatively, if the MAI is small as compared with the noise, the MMSE detector approaches the conventional detector. For combating ISI for a single-user channel, the analogy to the MMSE detector is the MMSE linear equalizer [3].

Important drawbacks of this detector are that it requires an estimate of the received amplitudes and that its performance depends on the power of the interfering users. In terms of complexity, the MMSE detector faces, like the decorrelator detector, the problem of implementing matrix inversion. So most of the sub-optimal approaches are implementing by decorrelator detector are applicable to the MMSE detector.

Moreover, the DS-CDMA receiver structure can be confined to being a finite impulse response (FIR) filter. Therefore, MMSE detector can also be implemented with a single-user FIR filter without the need of pre-processing the received signal with the conventional detector. By supposing the received signal as given in (3.1), the Wiener filter theory [39, 40] states that the optimal weights for a FIR w_u is given by

$$w_u = \phi_{rr}^{-1}\phi_{rb}^{u} \tag{3.14}$$

Where the *N*N* matrix ϕ_{rr} is the autocorrelation matrix of the input signal *r*(*t*) suppose that the data is independent from different users, *i.e* $E[b_k(t)b_u(t)] = 0$ with $k \neq u$ and $k,u \in \{1,2,\Lambda,U\}$ then it can be shown [41] that

$$\begin{aligned} \phi_{rr} &= E[r(t)r^T(t)] \\ &= CPC^T + \sigma^2 I \end{aligned} \tag{3.15}$$

Where $P = A^2$ is a *U*U* diagonal matrix with A as defined in (3.1) and *C* is the *N*U* matrix with the codes, and I is the identity matrix with dimensions *N*N*. The *N*1* vector ϕ_{rb} represents the desired response, *i.e* $\phi_{rb}^{u} = P_u c_u(t)$ for the *u*th user. The soft estimate of the

For *u*th user wiener detector output is then given as

$$\begin{aligned} \hat{b}_u(t) &= w_u^T r(t) \\ &= p_u c_u(t)^T (CPC^T + \sigma^2 I)^{-1} r(t) \end{aligned} \tag{3.16}$$

3.1.3 Non-linear multiuser receivers

These detection techniques are generally overcome the problem of complexity, however, it generates poor performance in the receiver at the presence of high levels of MAI and/or ISI. This degradation is due to that, in such scenarios the desired signals are no longer linearly separable [42]. Therefore, non-linear detection have to be considered. Recently, tree search technique, have been studied extensively. In general, tree search based sub-optimal detectors provide with the next best performance to the optimum detector but with a significant reduction in complexity. A number of such detectors have been proposed for improving performance. These include the following detector structures mentioned below:

Pre-selection maximum likelihood (PSML) multiuser detector. It is reduced complexity ML detector it uses two distinct stages in approximating the ML solution [43]. Figure 3.3 shows the structure of PSML detector.

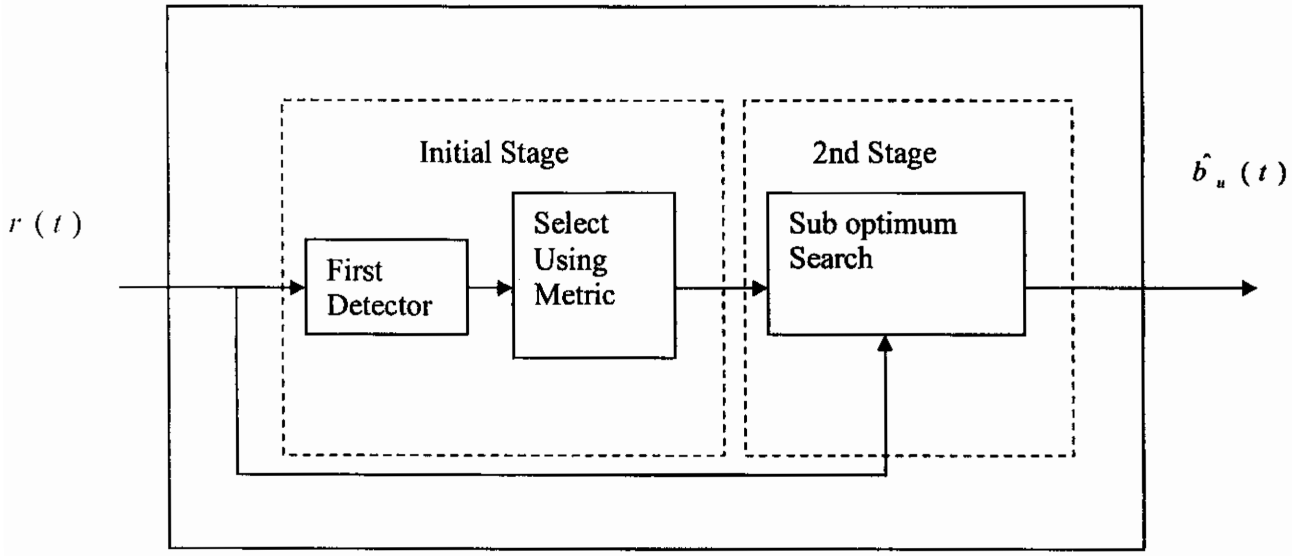


Figure 3.2: PSML multiuser detector structure.

the PSML detector uses an initial stage to assess the received signal in order to confine the search to a smaller number of possible combinations. The basic functioning of the first stage is to make the soft estimates of the interfering users which are used to provide with a measure of how likely they can be correctly detected. The initial detector provides with the soft estimates of the users' symbols & implemented by a linear detection technique, *i.e* MMSE, conventional detector or decorrelator detectors. On the bases on these estimates, a metric of how likely each symbol can be detected correctly is obtained by using the magnitude of the likelihood ratio |*LLR*|. After first stage, a hard decision is made on those users' symbols with the highest metrics. On the other way around, the symbols with lower |*LLR*| values are kept as soft estimates for the second stage of the detector. Second stage of the detector is the optimum multiuser detector with reduced complexity as the number of possible combinations has been reduced by the hard decision made by the first stage. It was shown in [43] that the PSML detector approximated the ML with less complexity at the expense of small degradation performance.

M-Algorithm and T-Algorithm detectors. The M or T algorithms [44] are breadth-first trellis search algorithms. It differ only in the criterion used to discard paths. M-algorithm instead maintains the M paths of minimum metrics & then a search through all M remaining paths is applied to get the soft outputs of the M-algorithm detector. In T-algorithm, the criterion to discard paths is different. It initially finds the overall best path of minimum metric and then rejects all paths whose metrics exceed this minimum metric by more than a threshold T. So the number of paths kept by the T-algorithm is variable.

Greedy detector. The most recent multiuser detector is the greedy detector (GD) which was proposed in [45]. This algorithm utilises the coefficients of the user's symbols as weights in the maximum likelihood metric to indicate the order in which symbols can be estimated.

On the bases of these coefficients, this detector forms a modified trellis tree with complexity is lower than that needed for the optimum multiuser detector. Performance gain is achieved by the GD with a complexity only of the order of $U^2 \log U$ as compared to the 2^U of the optimum multiuser detector.

3.2 Interference cancellation schemes

Second way of performing MUD is using an interference cancellation. This Type of detectors can be classified mainly into three categories: parallel interference cancellation (PIC), successive interference cancellation (SIC) and hybrid interference cancellation (HIC).

The principle of these schemes is to estimate MAI generated by each user at the receiver the in order to subtract it.

PIC detector. With known powers and codes of all interfering users, the PIC detector [33, 46] makes an estimate of MAI for each user and subtracts them in a parallel scheme. The first bit estimates, $\hat{b}_u(t)$ for $u \in \{1,2,\Lambda\ ,U\}$ are provided by the output of a bank of conventional detectors. These estimates are then again spreaded and added to regenerate the MAI estimates for each of the user.

SIC detector. The SIC detector [32, 33] takes the serial approach for canceling interference. Initially SIC detector consists of sorting the users' signals out in the descending order according to theirs powers, which are estimated by the output of the conventional detector. The first stage of SIC is to regenerate the transmitted signal of the strongest user. Then this regenerated signal provides an estimate of the MAI caused by the strongest user, $b_1(t)$, then it is subtracted from the total received signal $r(t)$ yielding a partially cleaned version of the received signal $r_1(t)$.If the estimate of user is accurate, then the remaining users see less MAI in the next stages. So, this new version of the received signal can used to detect the next strongest user in the system. This process is continued til all users are detected.

Hybrid detector. When the group of subtractive interference cancellation schemes combine certain positive features of the SIC and PIC detector into a hybrid scheme. Advantage of these schemes is that at the expense of some performance degradation, they offer hardware reduction & delay over the conventional SIC and PIC. Some examples of this type of structures are the schemes proposed in [32, 33, 36–37, 47].

3.3 Combined schemes

In Last group of multiuser detectors are those schemes that combine a linear transformation with subtractive cancellation schemes. Zeroforcing decision-feedback (ZF-DF) detector, decorrelator/PIC, MMSE/PIC, etc, [32, 33, 37, 46–48] are the examples of this detection schemes.

In ISI channels [3], ZF-DF detector is an analogous to the decision-feedback equalisers. It is a linear transformation is performed at an initial stage followed by a form of SIC detection. SIC operates by making decision and subtracting the interference in a descending order of the signal strength. This thing is clarify that, the success of any cancellation scheme relies on the initial data estimates.

CHAPTER 4

The Genetic Algorithm

4.1 Introduction

Main idea in this Theory of Charles R. Darwin is the survival of the fittest, it is also known as natural selection. According to the theory, in a population of living things, better chance to stay alive which is fitter generally. So, they, and their offspring who inherit their genetic content partially or completely from their parents, have a more probability to go into next generations, and thus have a more chance to transfer their genetic material to individuals which will appear in successor generations. Genetic Algorithms, which is also known as Evolutionary Algorithms, is a well known and widely accepted local search algorithm, which tries to simulate this theory.

4.2 Concepts Of Genetic Algorithm

Genetic algorithm provides number of potential solutions in parallel. GA initially creates a *population*. The population is a set of *individuals*, from which each has its own genetic content: *chromosome*. In GA, this genetic content, which is represented as a string over a finite alphabet, belongs to a potential solution instance to the problem, and it is accordingly coded to a problem-specific coding scheme. In the initial population creation process, the genetic contents of individuals "chromosomes" are generally produced in a random fashion in order to assure diversity in the initial population. After that, in process of *evolution*, individuals and their offspring are transferred to new generations & then taking into consideration the quality of their chromosomes, which is called *fitness*. Fitness is the function which takes an individual as an argument, evaluates its eligibility as a solution to that problem by examining its genetic content (chromosome), and assigns a fitness value to the individual as a result. The stronger fitness value gives to an individual a better chance to be selected for survival or reproduction.

The individual that exists in the current generation may be selected directly, or it may be matched with another individual and the resulting offspring may be transferred to the next generation. The parameter that determines what percentage of the new generation will be composed of the individuals directly transferred from the previous generation and what percentage will be composed of newly produced offspring is *Reproduction probability*.

At some point GA should stop the simulation of the evolution process. GA may be terminated after exceeding a predetermined time threshold, after producing a predetermined number of generations or reaching a desired fitness threshold. GA is generally terminated when it *converges*. Convergence occurs when most of the individuals in a population have very similar genetic properties. In some situations, this may happen very rapidly so that it becomes impossible to reach to the desired solution. This problem, which is called *premature convergence*, is just like to the problem of stuck on a local maximum that is encountered in local search methods. In order to overcome the problem of premature convergence, *mutation* can be employed

While the transfer of genetic contents from parents to offspring, something may go wrong, and random changes may occur in chromosome. Such changes may also occur when an individual is exposed to extreme conditions such as radiation. As a result, the fitness value of the individual can be degrading. However, this helps to keep diversity in population and such changes provide very good results in the next generations.

By introducing a *mutation probability* parameter, in GA the concept of mutation is employed. Before inserting an individual to the next generation, random changes on its chromosome is performed according to this probability.

CHAPTER 5

GA Assisted Multiuser Detection for MC-CDMA

5.1 Introduction

Multi-carrier Code Division Multiple Access (MC-CDMA) is transmission technique, which is the combination of Orthogonal Frequency Division Multiplexing (OFDM) and Direct Sequence CDMA (DS-CDMA). In this system we employ spreading sequences in the frequency domain for spreading each bit instead of applying spreading sequences in the time domain for spreading each bit. Hence we are capable of achieving frequency diversity gain at the cost of a reduced spreading gain.

Where multiple users are communicating simultaneously, then there are two types of detections, one is single user detection and other is multiuser detection. In Single User Detection (SUD) the single user is the user of interest & rest users data is treated as noise. Similarly in case of Multiuser Detection (MUD), the rest users data is also consider as useful information.

5.2 System Model

System considered here consisting of K number of simultaneous user communicating over Rayleigh fading channel with known channel parameters. Each bit of each user is being spread independently using different spreading codes, and then independently modulated over orthogonal frequencies in order to get frequency diversity gain by mean of maximum ratio combining. Further, codes for each carrier is independent, so for M number of multicarriers and a spreading code having N number of chip length the total spreading gain is MN. The multiusers are detected from MC-CDMA Signal by using genetic algorithm at receiver end.

The detailed system model is given as under.

5.2.1 Signal Modal

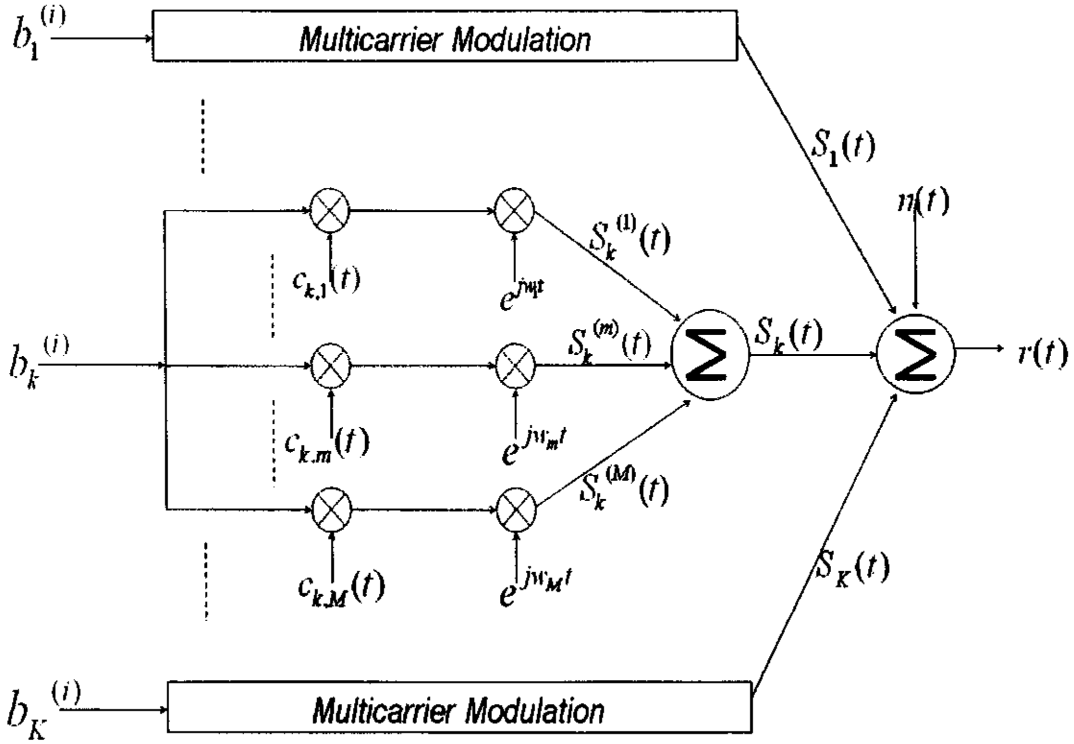


Figure 5.1 The transmitter of MC-CDMA system

We consider an asynchronous MC-CDMA system illustrated in Figure 5.1. In this system there are K number of users where k 1,2,3,4,….,K. The user data is modulated as Binary phase shift keying (BPSK). So each user bit has the value either -1 or 1. As $b_k^{(i)} \in \{1,-1\}$ is the *k*th user bit at *i*th instant & A_k is the amplitude of *k*th user bit. Observe in the figure that the bit $b_k^{(i)}$ is spread to M parallel subcarriers heaving frequencies ω_m where m = 1, . . ., M, then each conveying one of the M number of N-chip spreading signature sequences $c_{k,m}(t)$, where m = 1, . . ., M. Each spreading signature sequence spans (0, T_b) and we have $T_b / T_c = N$, where Tb and Tc are the bit duration and chip duration, respectively. It means that, there are N numbers of chips pre bit or length of each spreading signature sequence is N. Each of M spreading signatures is mapped to a different subcarrier. In other words, a single-carrier system occupying the same bandwidth as the multicarrier system considered would use a spreading signature having NM chips/ bit, and both of these systems have a processing gain of NM. Hence, the transmitted symbol of kth user associated with the mth subcarrier at ith instant can be expressed as:

$$S_k^{(m)}(t) = A_k b_k^{(i)} c_{k,m}(t - iT_b)e^{j\omega_m t} \tag{5.1}$$

where A_k is the amplitude of kth user bit, $b_k^{(i)}$ belongs to (1, -1), k = 1,…., K denotes the ith transmitted bit of kth user, while the kth user's signature waveform is $c_{k,m}(t)$, k = 1,…., K & m = 1, . . ., M on the mth subcarrier, which has a length of N chips.

Composite signal for kth user at ith instant is given as.

$$S_k(t) = \sum_{m=1}^{M} S_k^{(m)}(t) = \sum_{m=1}^{M} A_k b_k^{(i)} c_{k,m}(t - iT_b)e^{j\omega_m t} \tag{5.2}$$

Where $S_k(t)$ is statically independent.

5.2.2 Channel

Each user's signal $S_k(t)$ propagates through an independent, slowly fading, non-dispersive single-path Rayleigh Fading channel and the fading envelope is statistically independent for all the users. Hence, the single –tap narrowband Channel Impulse Response (CIR) of the *k*th user on the *m* subcarrier can be expressed as: $\alpha_{k,m}e^{j\phi_{k,m}}$, where the channel gain(amplitude) $\alpha_{k,m}$ is a Rayleigh distributed random variable, while the phase $\phi_{k,m}$ is uniformly distributed between $[0,2\pi]$.The channel noise is all white Gaussian (AWGN).As τ_k is transmission delay associated with *k*th user. About the transmission delays we have the following three assumptions.

1. $0 \le \tau_1 \le \tau_2 \le \tau_3 ..... \le \tau_k .... \le \tau_K < T_b$
2. $\tau_k = lT_c \ where \left(0 \le l < N\right)$
3. Delays are known at receiver end.

5.2.3 Receiver

Having described the transmitter and the channel, The received signal for *k*th user at instant 'i' is given as:

$$\begin{aligned} r_k^{(i)}(t) &= S_k(t) \otimes h(t) \\ r_k^{(i)}(t) &= S_k(t) \otimes \{\alpha_{km}\delta(t-\tau_k)e^{-j\phi_{km}} + n(t)\} \\ r_k^{(i)}(t) &= \alpha_{k,m}S_k(t-\tau_k)e^{-j\phi_{km}} + noise\ terms \end{aligned} \tag{5.3}$$

As we know that from Equation (5.2):

$$S_k(t) = \sum_{m=1}^{M} A_k b_k^{(i)} c_{k,m}(t - iT_b)e^{j\omega_m t}$$

So the *k*th user's signal at instant 'i' is given as:

$$r_k^{(i)}(t) = \sum_{m=1}^{M} A_k b_k^{(i)} \alpha_{k,m} c_{k,m}(t - iT_b - \tau_k)e^{j\omega_m(t-\tau_k)}e^{-j\phi_{km}} + noise \tag{5.4}$$

The received signal at instant *i* is.

$$r^{(i)}(t)=\sum_{k=1}^{K}\sum_{m=1}^{M}A_k b_k{}^{(i)}\alpha_{k,m}c_{k,m}(t-iT_b-\tau_k)e^{j\omega_m(t-\tau_k)}e^{-j\phi_{k,m}}+nois \qquad (5.5)$$

The total received signal is

$$r(t)=\sum_{i=-\infty}^{\infty}\sum_{k=1}^{K}\sum_{m=1}^{M}A_k b_k{}^{(i)}\alpha_{k,m}c_{k,m}(t-iT_b-\tau_k)e^{j\omega_m(t-\tau_k)}e^{-j\phi_{k,m}}+nois \qquad (5.6)$$

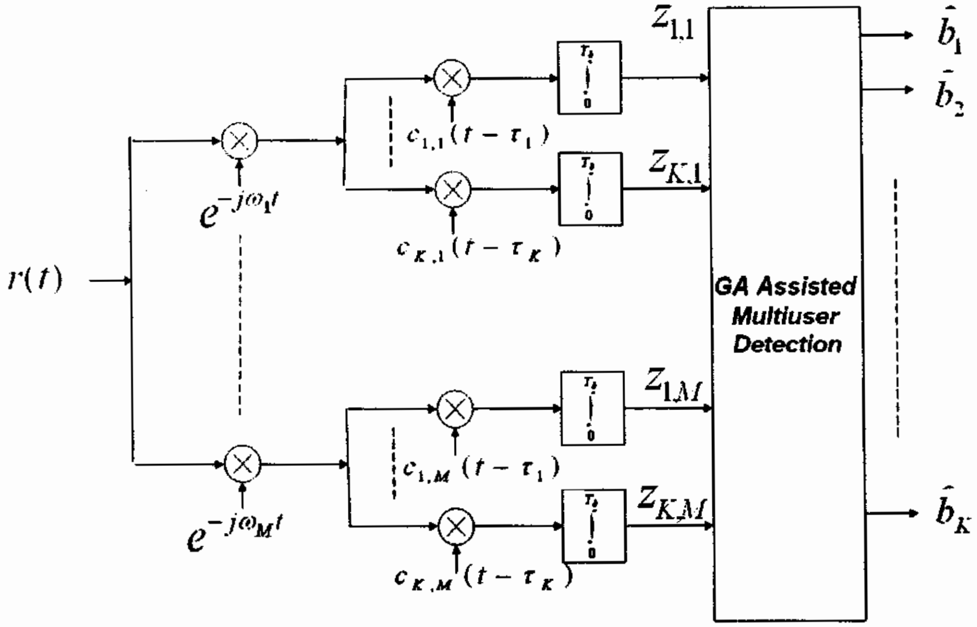


Figure 5.2: Schematic of the GA assisted MUD aided MC-CDMA receiver

The received signal associated with m-th carrier is.

$$r_m(t)=\sum_{i=-\infty}^{\infty}\sum_{k=1}^{K}A_k b_k{}^{(i)}\alpha_{k,m}c_{k,m}(t-iT_b-\tau_k)e^{j(\omega_m t-\phi_{k,m})}+n(t) \qquad (5.7)$$

Here *K* is the number of users supported and *n(t)* is the Gaussian noise process with a variance of $N_0/2$.

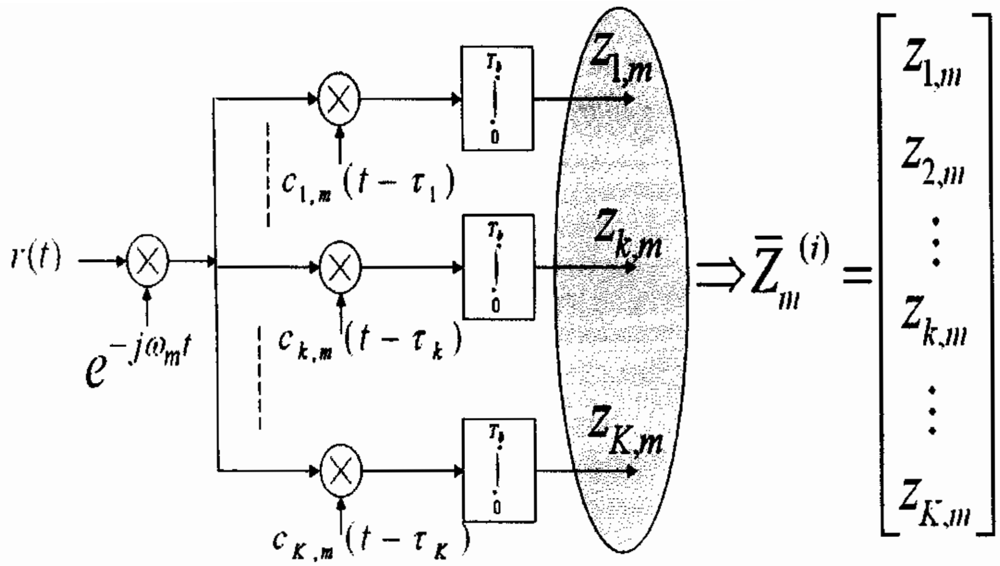


Figure 5.3: Schematic for the mth subcarrier out put from matched filter

For m-th subcarrier the out put of matched filter is given as:

$$\bar{z}_m^{(i)} = [z_{1,m}, z_{2,m}, z_{3,m}, \ldots\ldots\ldots, z_{k,m}, \ldots\ldots\ldots z_{K,m}] \tag{5.8}$$

As

$$z_{k,m} = \int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} r_m(t) e^{-j\omega_m t} c_{k,m}(t - iT_b - \tau_k) dt \tag{5.9}$$

By using Equation 5.7 in Equation 5.9 we will get

$$z_{k,m} = \int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} [\sum_{i=-\infty}^{\infty}\sum_{j=1}^{K} A_j b_j^{(i)} \alpha_{j,m} c_{j,m}(t - iT_b - \tau_j) e^{j(\omega_m t - \phi_{j,m})} + n(t)] e^{-j\omega_m t} c_{k,m}(t - iT_b - \tau_k) dt$$

As it is asynchronous case so the above term for *i*, *i*+1 & *i*-1

$$z_{k,m} = \int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} \begin{bmatrix} \sum_{j=1}^{K} A_j b_j^{(i)} \alpha_{j,m} c_{j,m}(t - iT_b - \tau_j) e^{j(\omega_m t - \phi_{j,m})} + \\ \sum_{j=1}^{K} A_j b_j^{(i+1)} \alpha_{j,m} c_{j,m}(t - (i+1)T_b - \tau_j) e^{j(\omega_m t - \phi_{j,m})} + \\ \sum_{j=1}^{K} A_j b_j^{(i-1)} \alpha_{j,m} c_{j,m}(t - (i-1)T_b - \tau_j) e^{j(\omega_m t - \phi_{j,m})} + \\ n(t) \end{bmatrix} e^{-j\omega_m t} c_{k,m}(t - iT_b - \tau_k) dt$$

By simplifying the above term we will get three main terms and noise term.

$$\begin{aligned} z_{k,m} &= \int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} \sum_{j=1}^{K} A_j b_j^{(i)} \alpha_{j,m} c_{j,m}(t - iT_b - \tau_j) e^{-j\phi_{j,m}} c_{k,m}(t - iT_b - \tau_k) dt \\ &+ \int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} \sum_{j=1}^{K} A_j b_j^{(i+1)} \alpha_{j,m} c_{j,m}(t - iT_b - T_b - \tau_j) e^{-j\phi_{j,m}} c_{k,m}(t - iT_b - \tau_k) dt \\ &+ \int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} \sum_{j=1}^{K} A_j b_j^{(i-1)} \alpha_{j,m} c_{j,m}(t - iT_b + T_b - \tau_j) e^{-j\phi_{j,m}} c_{k,m}(t - iT_b - \tau_k) dt \\ &+ Noise\,Term \end{aligned}$$

Now we will simplify all three terms one by one.

Simplification of 1st term is given as under

$$\begin{aligned} &\int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} \sum_{j=1}^{K} A_j b_j^{(i)} \alpha_{j,m} c_{j,m}(t - iT_b - \tau_j) e^{-j\phi_{j,m}} c_{k,m}(t - iT_b - \tau_k) dt \\ &= \sum_{j=1}^{K} A_j b_j^{(i)} \alpha_{j,m} e^{-j\phi_{j,m}} \int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} c_{j,m}(t - iT_b - \tau_j) c_{k,m}(t - iT_b - \tau_k) dt \\ &= \sum_{j=1}^{K} A_j b_j^{(i)} \alpha_{j,m} e^{-j\phi_{j,m}} \rho_{j,k} \end{aligned}$$

Where

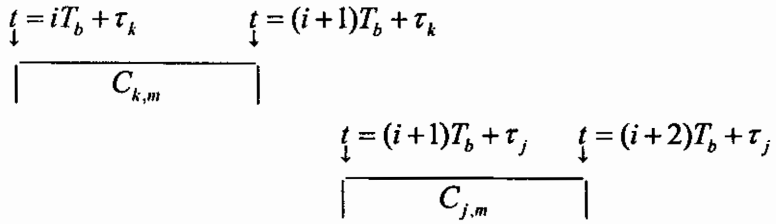
$$\rho_{j,k} = \int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} c_{j,m}(t - iT_b - \tau_j) c_{k,m}(t - iT_b - \tau_k) dt$$

Simplification of 2nd term is given as under

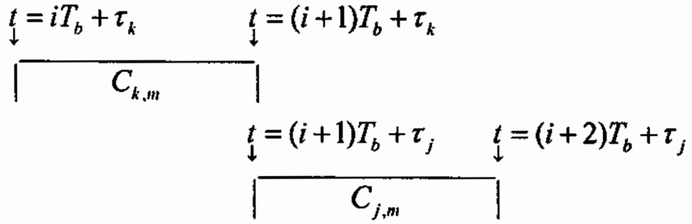
$$\int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} \sum_{j=1}^{K} A_j b_j^{(i+1)} \alpha_{j,m} c_{j,m}(t-iT_b-T_b-\tau_j) e^{-j\phi_{j,m}} c_{k,m}(t-iT_b-\tau_k)dt$$

$$= \sum_{j=1}^{K} A_j b_j^{(i+1)} \alpha_{j,m} e^{-j\phi_{j,m}} \int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} c_{j,m}(t-iT_b-T_b-\tau_j) c_{k,m}(t-iT_b-\tau_k)dt$$

If $k < j$

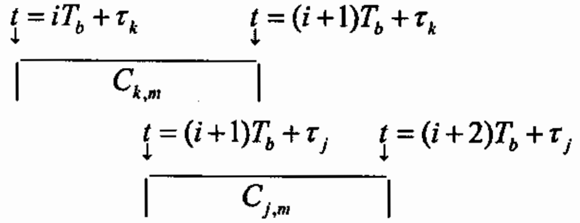


If $k = j$



$$\Rightarrow \int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} c_{j,m}(t-iT_b-T_b-\tau_j) c_{k,m}(t-iT_b-\tau_k)dt = 0 \qquad \text{for } k \le j$$

If $k > j$



$$\Rightarrow \int_{iT_b+T_k}^{(i+1)T_b+\tau_k} c_{j,m}(t-iT_b-T_b-\tau_j) c_{k,m}(t-iT_b-\tau_k)dt$$

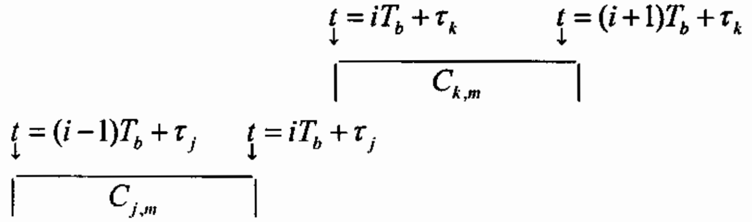
$$= \int_{0}^{\tau_k-\tau_j} c_{j,m}(t') c_{k,m}(t'+T_b+\tau_j-\tau_k)dt' = \rho'_{j,k} \quad \text{for } k > j$$

Simplification of 3rd term is given as under

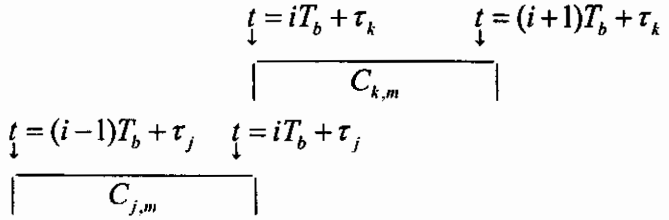
$$\int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} \sum_{j=1}^{K} A_j b_j^{(i-1)} \alpha_{j,m} c_{j,m}(t-iT_b+T_b-\tau_j) e^{-j\phi_{j,m}} c_{k,m}(t-iT_b-\tau_k)dt$$

$$= \sum_{j=1}^{K} A_j b_j^{(i-1)} \alpha_{j,m} e^{-j\phi_{j,m}} \int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} c_{j,m}(t-iT_b+T_b-\tau_j) c_{k,m}(t-iT_b-\tau_k)dt$$

If $k > j$

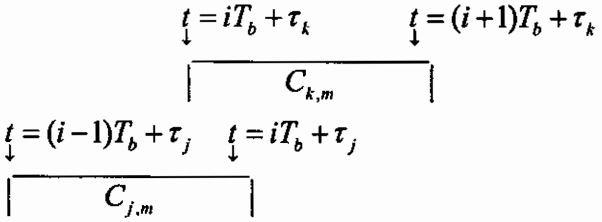


If $k = j$



$$\Rightarrow \int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} c_{j,m}(t-iT_b+T_b-\tau_j) c_{k,m}(t-iT_b-\tau_k)dt = 0 \qquad for\ k \ge j$$

If $k < j$



$$\Rightarrow \int_{iT_b+\tau_k}^{(i+1)T_b+\tau_k} c_{j,m}(t-iT_b+T_b-\tau_j) c_{k,m}(t-iT_b-\tau_k)dt$$

$$= \int_{0}^{\tau_j-\tau_k} c_{j,m}(t'+T_b+\tau_k-\tau_j) c_{k,m}(t')dt' \qquad for\ k < j$$

So after simplification Equation 5.9 becomes.

$$
\begin{aligned}
z_{k,m} &= \sum_{j=1}^{K} A_j b_j^{(i)} \alpha_{j,m} e^{-j\phi_{j,m}} \rho_{j,k} && (5.10)\\
&+ \sum_{j=1}^{K} A_j b_j^{(i+1)} \alpha_{j,m} e^{-j\phi_{j,m}} \int_0^{\tau_k-\tau_j} c_{j,m}(t') c_{k,m}(t'+T_b+\tau_j-\tau_k) dt' && \textit{for } k > j\\
&+ \sum_{j=1}^{K} A_j b_j^{(i-1)} \alpha_{j,m} e^{-j\phi_{j,m}} \int_0^{\tau_j-\tau_k} c_{j,m}(t'+T_b+\tau_k-\tau_j) c_{k,m}(t') dt' && \textit{for } k < j\\
&+ \textit{Noise Terms}.
\end{aligned}
$$

Using vector notation, the out put of matched filter at *i*th instant is given as.

$$
\bar{Z}_m^{(i)} = R_m[1] W_m A \bar{b}^{(i-1)} + R_m[0] W_m A \bar{b}^{(i)} + R_m^T[1] W_m A \bar{b}^{(i+1)} + n_i \tag{5.11}
$$

Where

$$
A = \begin{bmatrix} A_1 & 0 & \cdots & 0 \\ 0 & A_2 & 0 & \vdots \\ \vdots & 0 & \ddots & 0 \\ 0 & \cdots & 0 & A_K \end{bmatrix}, \quad W_m = \begin{bmatrix} \alpha_{1,m} e^{-j\phi_{1,m}} & 0 & \cdots & 0 \\ 0 & \alpha_{2,m} e^{-j\phi_{2,m}} & 0 & \vdots \\ \vdots & 0 & \ddots & 0 \\ 0 & \cdots & 0 & \alpha_{K,m} e^{-j\phi_{K,m}} \end{bmatrix}
$$

$$
R_m[0] = \begin{bmatrix} 1 & \rho_{12} & \cdots & \rho_{1k} \\ \rho_{21} & 1 & \rho_{23} & \rho_{2K} \\ \vdots & \rho_{31} & \ddots & \vdots \\ \rho_{K1} & \rho_{K2} & \cdots & 1 \end{bmatrix}, \quad R_m[1] = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ \rho'_{21} & 1 & 0 & 0 \\ \vdots & \rho'_{31} & \ddots & \vdots \\ \rho'_{K1} & \rho'_{K2} & \cdots & 1 \end{bmatrix}
$$

$$
\& \quad b^{(i)} = \begin{bmatrix} b_1^i \\ b_2^i \\ \vdots \\ b_K^i \end{bmatrix}, \quad b^{(i+1)} = \begin{bmatrix} b_1^{i+1} \\ b_2^{i+1} \\ \vdots \\ b_K^{i+1} \end{bmatrix}, \quad b^{(i-1)} = \begin{bmatrix} b_1^{i-1} \\ b_2^{i-1} \\ \vdots \\ b_K^{i-1} \end{bmatrix}
$$

5.3 Detection

According to equation 5.11, the noise sampling vector $\mathbf{n_m}$ can also be expressed as:

$$
\bar{n}_m = \bar{Z}_m^{(i)} - R_m[1] W_m A \bar{b}^{(i-1)} - R_m[0] W_m A \bar{b}^{(i)} - R_m^T[1] W_m A \bar{b}^{(i+1)} \tag{5.12}
$$

Hence, the object function of the optimum ML detector on the *m*th subcarrier can be expressed as:

$$
J^{(m)}(\mathrm{b}^{(i)}) = \arg\{ \min_{\mathrm{b}(i-1),\mathrm{b}(i),\mathrm{b}(i+1)} E[\bar{\mathrm{n}}_m, \bar{\mathrm{n}}_m^{\;T}] \} \tag{5.13}
$$

Hence, according to Equation 5.13, the GA's objective metric for the *m*th subcarrier, which has to maximize, can expressed as:

$$J^{(m)}(\mathrm{b}^{(i)}) = \exp\{-\left\| \bar{Z}_m{}^{(i)} - R_m[1]W_m A\bar{b}^{(i-1)} - R_m[0]W_m A\bar{b}^{(i)} - R_m^T[1]W_m A\bar{b}^{(i+1)} \right\|^2\} \tag{5.14}$$

Where $\|\cdot\|$ denotes the Eucledian norm of a complex quantity expressed for the arbitrary variable $v = a + jb$ as $\|v\| = \sqrt{a^2 + b^2}$.

Therefore, when combining the signals of the M subcarriers, the modified objective function becomes:

$$\begin{aligned} J(\mathrm{b}^{(i)}) &= \sum_{m=1}^{M} J^{(m)}(\mathrm{b}^{(i)}) \\ &= \exp\{-\sum_{m=1}^{M} \left\| \bar{Z}_m{}^{(i)} - R_m[1]W_m A\bar{b}^{(i-1)} - R_m[0]W_m A\bar{b}^{(i)} - R_m^T[1]W_m A\bar{b}^{(i+1)} \right\|^2\} \end{aligned} \tag{5.15}$$

Therefore for achieving the optimum performance, we have to maximize the metric of Equation 5.15. More explicitly, the optimum decision concerning the vector $\mathbf{b}^{(i)}$ will maximize the correlation matrix in above equation provided that $\mathbf{b}^{(i-1)}$ & $\mathbf{b}^{(i+1)}$ perfectly known to receiver. However, in practice the receiver is oblivious of $\mathbf{b}^{(i+1)}$ during the detection of $\mathbf{b}^{(i)}$, unless these are estimate based on pilot bite or training bits. Further more $\mathbf{b}^{(i-1)}$ is never perfectly known by the receiver as a consequence of channel errors. Hence we have to invoke the appropriate strategies for finding the responsible choices of ($\mathbf{b}^{(i-1)}$, $\mathbf{b}^{(i)}$, $\mathbf{b}^{(i+1)}$) for maximization of equation 5.15.

For initializing GA, we simply start from received K-bit vector from Maximum Ratio Combining (MRC) output. Which will devise our $\mathbf{b}^{(i+1)}$ vector. Now the previous K-bit vector $\mathbf{b}^{(i)}$ can be taken simply by a random bits pattern. Further the first population is subject to mutation in the $\mathbf{b}^{(i+1)}$ vector. Which can as a whole produce 2^K number of K-bit vectors (mutated versions of received vector) but we shall take according to affordable complexity, that will be designated as first generation of GA. Once the machinery has been started we are no more away from the results.

Now the first generation is ready for the fitness evaluation, after that we shall sort them out with respect to their fitness value. Now for further generations we will arrange crossovers among the mating pool of first generation. As a result of these crossovers we obtained offsprings, now arranging all with respect to their fitness value and second generation is obtained. The poor chromosomes will diminish from the pool. The process will continue until some criteria are met. After that the highest fitness chromosome will be designated as *the most probable sent* or detected vector.

The detail flow chart for GA assisted detection is given as under.

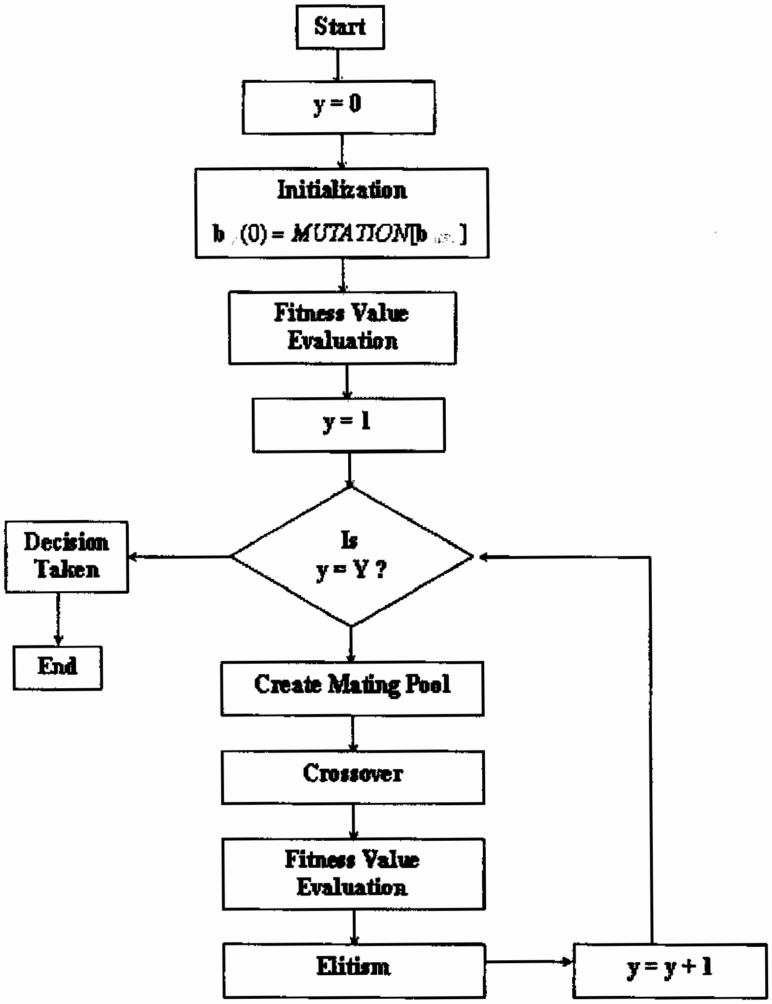


Figure 5.4: A flowchart depicting the structure of a genetic algorithm assisted MUD in the context of the asynchronous MC-CDMA base station receive.

5.4 Simulation Results

The basic parameters of GA used in our simulations are listed below in the table.

Parameters	**Value**
Modulation Scheme	BPSK
Spreading Code	WALSH codes
Number of subcarriers *M*	4
Length of subcarrier spreading signature *N*	WALSH = 16
Total spreading gain *N M*	64
GA's selection method	Fitness-proportionate
GA's mutation method	Standard binary mutation
GA's crossover method	Crossover single and multipoint
GA's mutation probability	0.1
GA's crossover probability	1
Elitism	Yes
Incest Prevention	No

Table 5.1: The basic simulation parameters used by the GA assisted MUD aided MC-CDMA system

Here various results are shown in figures below, namely the figure 5.5 reveals the fact that with increase in SNR and affordable complexity we can achieve desired level of BER. In figure 5.6 this fact is further verified where we the complexity is extended up to 800 while the complexity of optimum is 1024, and results are even considerable, since 10^{-5} is a good BER. Also we can achieve single user bound with increase in SNR and complexity affordable.

Now by extending number of users to 15 we can see that we need even more complexity to achieve the same results. Here we can see that for 1600 complexity we can get a significant BER. In figure 5.6 we have examined the BER under GA with K=20 number of supporting users. We increased complexity up to 2100 which is still far less than the actually optimum complexity and we obtained a significant reduction in BER but with high SNR.

In short, we can achieve the single user bound by

- Increasing the affordable complexity which is product of population size P and number of generations Y
- Increasing SNR

But the benefit we are achieving by elegance of GA, we still need very small fraction of complexity compare to ML detector. It is about 525 times less than that of optimum complexity. This is shown in the figure 5.9 that with increasing number of supporting users, complexity is reduced and complexity reduction factor $\frac{2^K}{P.Y}$ is increased. Further better results can be obtained by different variations of GA.

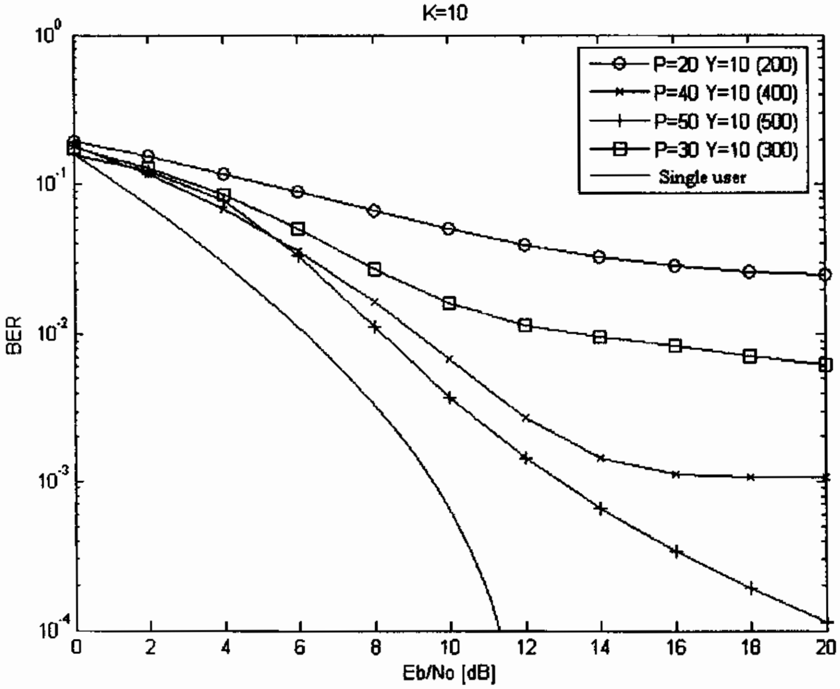


Fig 5.5: BER performance is demonstrated using Walsh Codes with various complexities, 200-500 with number of users K=10.

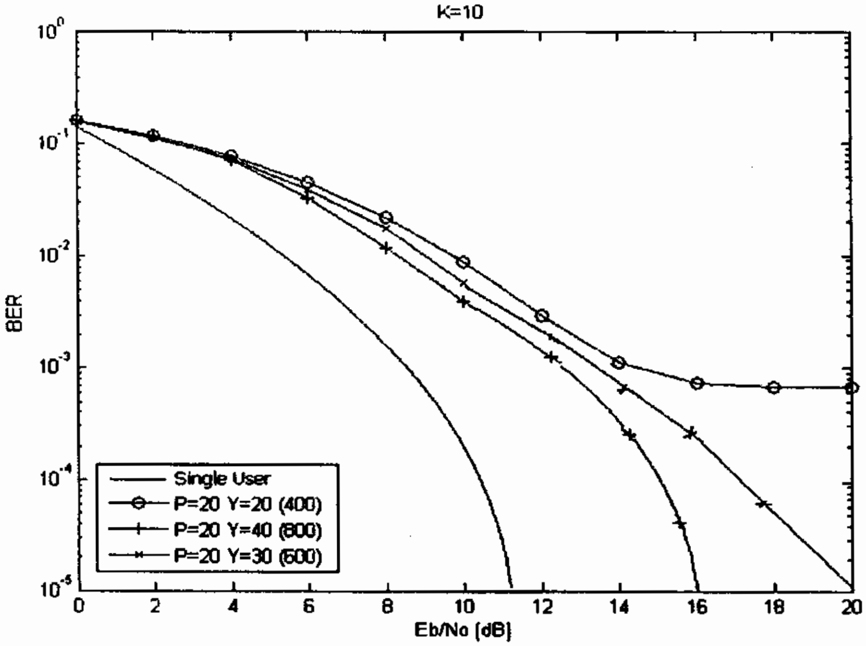


Fig5.6:BER performance is demonstrated using Walsh Codes with increasing complexity up to 800, with number of users K=10.

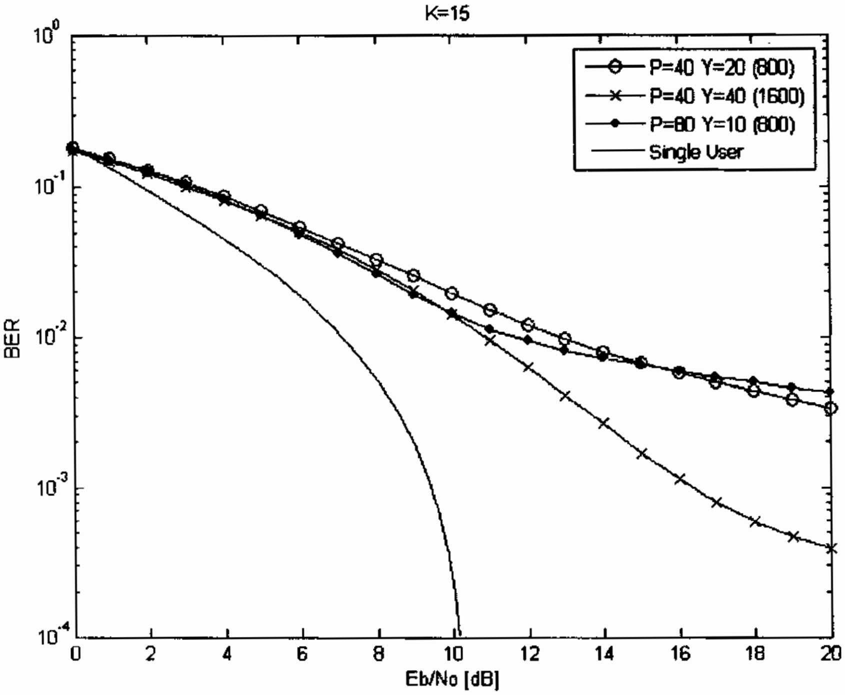


Fig 5.7: BER performance is demonstrated using Walsh Codes with various complexities, 800 and 1600 with number of users K=15.

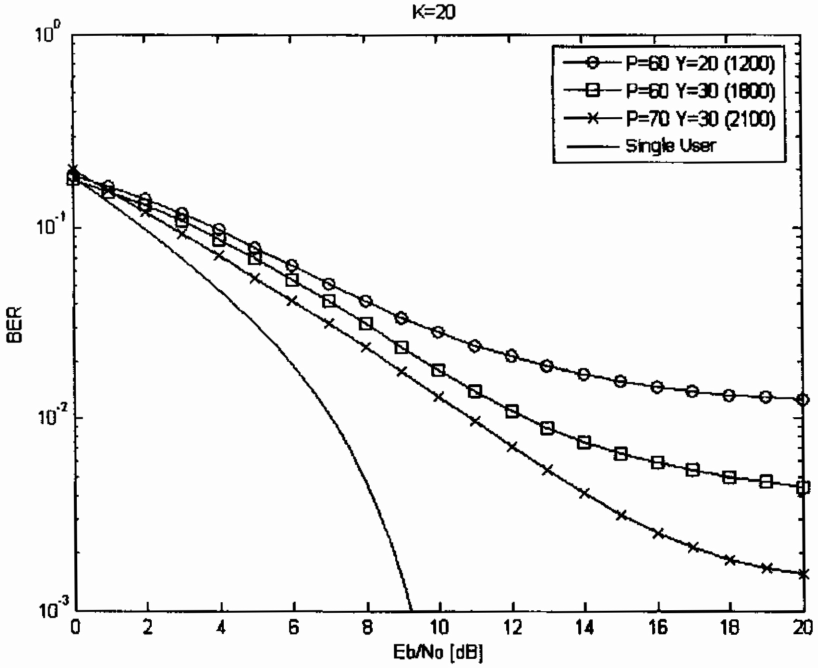


Fig 5.8:BER performance is demonstrated using Walsh Codes with various complexities, 1200-2100 with number of users K=20.

Complexity Factor

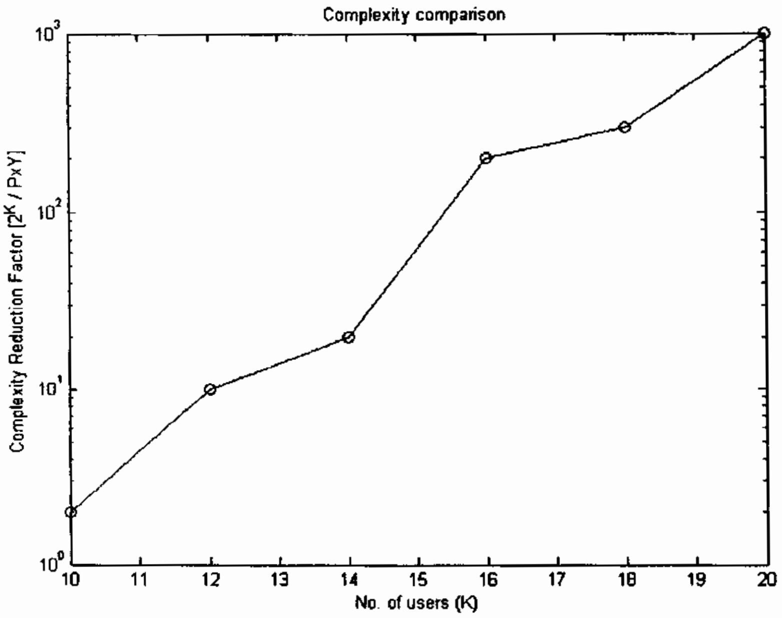


Fig 5.9: Complexity reduction factor using GA is demonstrated with increasing number of users K

Conclusions

Summary

In conclusion, the GA assisted MUD is capable of significantly reducing the detection complexity in comparison with optimum MUD, especially when the number of users supported is higher than K=15. Population size plays a key role in decreasing the BER instead of number of generations. Further this reduction in complexity is as large as it is about·525 times less than that of optimum one for K=20 and this factor goes even high for high number of users. Since in practical situations number of supported users is significantly high then this scheme plays elegant role.

This discussion further can be extended to sufficiently large number of users, change in crossover and mutation techniques as given in chapter 4; may vary the results in a positive direction and with further low complexity. This was done using Walsh codes the orthogonal in nature; scheme can be verified for non orthogonal codes like Kasami and Gold sequences. This all was done in an un-coded fashion, further this work can be carried out with channel coding schemes like turbo codes, space time block codes with different transceivers. Different diversity schemes can also be employed.

References

[1] R.Prasad, Ed., CDMA for Wireless Personal Communications, Artech House, Inc., Boston, 1996.

[2] N.Abramson, \Multiple Access in Wireless Digital Networks," Proc. Of IEEE, vol. 82, no. 9, pp. 1360{1370, Sept. 1994.

[3] J.G. Proakis, *Digital Communications*, McGraw-Hill,New York,3rd edition, 1995,ISBN:0070517266.

[4] R.Nelson and D. Westin,"The Evolution of the North American Cellular Network, "*Telecommunications (International Edition)*,v ol. 26,no. 9,pp. 24–28, September 1992.

[5] F.H. Blecher,"Adv anced Mobile Phone Service," *IEEE Transactions on Vehicular Technology*,v ol. VT-29,no. 2,pp. 238–244,Ma y 1980.

[6] J. E. Padgett,C. G. G¨unther,and T. Hattori, "Overview of Wireless Personal Communications," *IEEE Communications Magazine*,pp. 28–41,Jan uary 1995.

[7] K.Raith and J. Uddenfeldt. Capacity of Digital Cellular TDMA Systems. *IEEE Transactions on Vehicular Technology*, 40(2):323–332, May 1991.

[8] ETSI, "GSM Specifications, Series 01-12," Standard Document, ETSI Standard.

[9] K.S. Gilhousen, I. M. Jacobs, R. Padovani, A. J. Viterbi, L. A. Weaver, Jr., and C. E. Wheatley III. On the Capacity of a Cellular CDMA System. *IEEE Transactions on Vehicular Technology*, 40(2):303–311, May 1991.

[10] J.Cai and D. J. Goodman, "General Packet Radio Service in GSM," *IEEE Communications Magazine*, vol. 35, no. 10,pp. 122–131,October 1997.

[11] R.V. Nobelen, N. Seshadri, J. Whitehead and S. Timiri, "An adaptive radio link protocol with enhanced data rates for GSM evolution," *IEEE Personal Communications*, pp. 54–64,F ebruary 1999.

[12] TIA/EIA IS-54, "Cellular System Dual-Mode Mobile Station-Base Station Compatibility Standard," Standard Document, April 1992, Telecommunication Industry Association Standard.

[13] B.Jabbari,"Cost-effectiv e Networking via Digital Satellite Communications," *Proceedings of the IEEE*,v ol. 72,no. 11,pp. 1556 1563,No vember 1984.

[18] M.Rahnema,"Ov erview of the GSM System and Protocol Architecture," *IEEE Communications Magazine*,v ol. 31,no. 4,pp. 92–100,April 1993.

[15] N.Abramson, \Development of the ALOHANET," IEEE Trans. Inform. Theory, vol. 31, pp. 119{123, Mar. 1985.

[16] W.C.-Y. Lee. Overview of Cellular CDMA. *IEEE Transactions on Vehicular Technology*, 40(2):291–302, May 1991.

[17] J.C.Liberti, Ed., Spatial Processing for High Tier Wireless Systems, Bellcore Pub. IM-558, Sept. 1996.

[18] S.Moshavi, \Multi-User Detection for DS-CDMA Communications," IEEE Commun. Magazine, vol. 34, no. 10, pp. 124{136, Oct. 1996.

[19] P.B. Rapajic. Information Capacity of the Space Division Multiple Access Mobile Communication System. *Wireless Personal Communications*, 11:131–159, Nov 1999.

[20] R.A. Monzingo and T. W. Miller. *Introduction to Adaptive Arrays*. John Wiley & Sons, 1980.

[21] J. H. Winters, J. Salz, and R. D. Gitlin. The Impact of Antenna Diversity on the Capacity of Wireless Communication Systems. *IEEE Transactions on Communications*, 42:1740–1751, Feb/Mar/Apr 1994.

[22] Y.Li, M. J. Feuerstein, and D. O. Reudnik. Performance Evaluation of a Cellular Base Station Multibeam Antenna. *IEEE Transactions on Vehicular Technology*, 46(1):1 9, Feb 1997.

[23] J. Viterbi. CDMA: Principles of Spread Spectrum Communication. Addison-Wesley Wireless Communications, 1995.

[24] R.L. Pickholtz, D.L. Schilling, and L.B. Milstein. "Theory of Spread-Spectrum Communications—A Tutorial". IEEE Transactions on Communications, 30(5):855–884, May 1982.

[25] R.L. Pickholtz, L.B. Milstein, and D.L. Schilling. "Spread Spectrum for Mobile Communications". IEEE Transactions on Vehicular Technology, 40(2):313–321, May 1991.

[26] R.C. Dixon. Spread Spectrum Systems. Wiley, New York, second edition, 1984.

[27] S. Verdu. "Minimum Probability of Error for Asynchronous Gaussian Multiple-Access Channels". *IEEE Transactions on Information Theory*, IT-32:85–96, January 1986.

[28] U. Mitra and H.V. Poor. "Neural Network Techniques for Multiuser Demodulation". In *IEEE International Conference on Neural Networks*, pages 1538–1543, 1993.

[29] B.Mulgrew. "Applying Radial Basis Functions". *IEEE Signal Processing Magazine*, 13(2):50–52, March 1996.

[30] R.O.Duda and P.E. Hart. *Pattern Classification and Scene Analysis*. J. Wiley and Sons, New York, USA, 1st edition, 1973.

[31] K.S.Schneider. "Optimum Detection of Code Division Multiplexed Signals". *IEEE Transaction Aerospace Elect. Systems*, AES-15:181–185, January 1979.

[32] R.Kohno, M. Hatori, and H. Imai. "Cancellation Techniques of Co-Channel Interference in Asynchronous Spread Spectrum Multiple Access Systems". *Elect. and Commun. In Japan*, 66-A(5):20–29, 1983.

[33] S.Moshavi. "Multi-User Detection for DS-CDMA Communications". *IEEE Communications Magazine*, pages 124–136, October 1996.

[34] Z.Xie, R.T. Short, and C.K. Rushforth. "A Family of Suboptimum Detectors for Coherent Multi-User Communications". *IEEE Transactions on Selected Areas in Communications*, 8(4):683–690, May 1990.

[35] R.Lupas-Golaszewski and S. Verdu. "Asymptotic Efficiency of Linear Multi-User Detectors". In *Proc. 25th Conf. on Decision and Control, Athens, Greece*, pages 2094–2100, December, 1986.

[36] S.Verdu. "Multi-User Detection". In *Advances in Statistical Signal Processing, vol. 2, JAI Press*, pages 369–409, 1993.

[37] S.Moshavi. "Survey of Multi-User Detection for DS-CDMA Systems". In *Bellcore pub., IM-555*, August 1996.

[38] S. Verdu. *Multiuser Detection*. Cambridge Univeristy Press, 1998.

[39] S. Haykin. *Adaptive Filter Theory*. Prentice-Hall, 1991.

[40] D.G.M. Cruickshank. "Optimal and Adaptive FIR Filter Receivers for DS-CDMA". In *Personal Indoor and Mobile Radio Communications (PIMRC)*, pages 1339–1343, August 1994.

[41] D.G.M. Cruickshank. "Optimal and Adaptive FIR Filter Receivers for DS-CDMA". *In Proceedings PIMRC*, pages 1339–1343, 1994.

[42] R.Tanner, D.G.M. Cruickshank, C.Z.W. Hassell Sweatmann, and B. Mulgrew. "Receivers for Nonlinearly Separable Scenarios in DS-CDMA". *IEE Electronics Letters*, 33(25):2103–2105, December 1997.

[43] E.A. Al-Susa and D.G.M. Cruickshank. "Pre-selection Based Reduced Complexity MLMUD for DS-CDMA Systems". In *IEEE Vehicular Technology Conference, VTC 2001 Spring*, pages 491–495, May 2001.

[44] L.Wei, L.K. Rasmussen, and R. Wyrwas. "Near Optimum Tree Search Schemes for Bit Synchronous Multiuser CDMA Systems over Gaussian and Two Path Rayleigh-Fading Channels". *IEEE Transactions on Communications*, 45:691–700, June 1997.

[45] A.AlRustamani. "Greedy Multiuser Detection Over Single-Path Fading Channel". In *Proceedings of the 5th IEEE International Symposium on Spread Spectrum Techniques and Applications (ISSSTA), NY, USA, vol1.*, pages 708–712, September 2000.

[46] M.K.Varanasi and B. Aazhang. "Multistage Detection in Asynchronous Code-Division Multiple-Access Communications". *IEEE Transactions on Communications*, 38(4):509– 519, April 1990.

[47] P.Patel and J. Holtzman. "Performance Comparison of a DS/CDMA System Using a Successive Interference Cancellation (IC) Scheme and a Parallel IC Scheme under Fading". In *IEEE International Conference on Communications, New Orleans*, pages 510–514, May 1994.

[48] A.Duel-Hallen. "A Family of Multi-User Decision-Feedback Multi-User Detectors for Asynchronous Code-Division Multiple-Access Channels". *IEEE Transactions on Communications*, 43(2/3/4):421–434, February/March/April 1995.

[49] R.M. Buehrer, N.S. Correal, and B.D. Woerner. "A Comparison of Multiuser Receivers for Cellular CDMA". In *in Proceedings of IEEE Global Communications Conference, GLOBECOM'96 (London, UK)*, pages 1571–1577, November 1996.

[50] J. Bolgh and L. Hanzo, *Third-Generation Systems and Intelligent Networking,* John and Wiley and IEEE Press, 2002.

[51] R. Steele and L. Hanzo, *Mobile Radio Communications*. IEEE Press-John Wiley, 2 ed., 1999.

[52] D. E. Goldberg, *Genetic Algorithms in Search, Optimization, and Machine Learning*. ISBN 0201157675, MA USA: Addison-Wesley, August 2001.

[53] M. Mitchell, *An Introduction to Genetic Algorithm.* Cambridge, Massachusetts: MIT Press, 1996.