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Performance Estimation of DS-CDMA Receivers Using Genetic Algorithm

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Abstract

Direct sequence-code division multiple access (DS-CDMA) technique is used in cellular systems where users in the cell are separated from each other with their unique spreading codes. These systems suffer from multiple access interference (MAI) due to other users transmitting in the cell, channel inter symbol interference (ISI) due to multipath nature of channels in presence of additive white Gaussian noise (AWGN).

This paper presents an investigation on use of new type of DSCDMA receiver called Genetic Algorithm based DS-CDMA receiver. Genetic Algorithm is robust optimization technique and does not fall into local minima, hence this gives better weight optimization of any system.

Extensive simulation studies demonstrate the performance of the different linear and nonlinear DS-CDMA receivers like RAKE receiver, matched filter (MF) receiver, minimum mean square error (MMSE) receiver using gold sequences and the performance has been compared with GA based receiver. It is seen that GA based DS-CDMA receiver performs much better than other type of receivers.

Keywords: *DS-CDMA, genetic algorithm-based multi-user detector.*

1. Introduction

Spread spectrum techniques have been wildly used in wired and wireless communications. The spreading of the signal spectrum gives us many advantages such as robustness against interference and noise, low probability of intercept, realization of Code Division Multiple Access (CDMA) and so on. In order to spread the bandwidth of the transmitting signals, pseudo-noise (PN) sequences have been used extensively in spread-spectrum communication systems [1]. Obviously, the maximal length shift register sequences (M-sequences) and Gold sequences are the most popular spreading sequences in spread spectrum systems. Many other codes like Walsh code and Chaotic code were reported for the better performance of the CDMA system.

At the receiver end we extract the spreading code in order to retrieve the data from the received noisy signal. This code extraction is done by means of the adaptive channel equalization. Many types of channel equalization techniques like Least Mean Square (LMS), Recursive Least Square (RLS), Decision Feedback Equalizer (DFE) and so on were reported for the code extraction of the CDMA system. All the equalization methods mentioned above are gradient based algorithms. So they suffer from the so called problem in channel equalization local minima. Hence they stick around the local minima and never fall into the global minima. Again the above mentioned equalization techniques are not able to handle the nonlinearity associated with a channel.To overcome the local minima problem many evolutionary computing methods such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Bacteria Foraging Optimization (BFO) were proposed. As being these techniques are non gradient based algorithm they completely search the search space and fall into the global minima never to the local minima. In this paper we will use GA based channel equalization to improve the performance of the CDMA system.The section begins with an exposition of the principal motivation behind the work undertaken in this paper. Following this, section III provides a brief literature survey on GA. Section IV outlines the contributions made in this paper. At the end, section V presents the paper layout.

2. DS-CDMA System and Overview

In this section the principle of spread spectrum and its application in multiple accesses is discussed. Multiple access schemes are used to allow many mobile users to share simultaneously a finite amount of radio channels in a fixed radio spectrum. The sharing of the spectrum is required to achieve high capacity by simultaneously allocating the available bandwidth to multiple users.

2.1 Spread Spectrum Communication Techniques

As a simple, expansion of the bandwidth is not sufficient to be termed as the spread spectrum, but the bandwidth expansion must be accomplished with the separate signature, known as spreading sequence. Both transmitter and the receiver know this spreading sequence. It is also independent of the data bits [10]. All the sequences are randomly distributed, and there is no correlation between any two sequences.

2.2 DS-CDMA Transmitter Principles

The simplest transmitter for downlink of a DS-CDMA is shown in Figure 1. The transmitted signal s(kL + n), at time t = nT_{bit} is constructed by coherently summing the spreading sequence of each user $C_{i,n}$ by those users bit $x_i(k)$ over all active users , to give

$$s(kL+n) = \sum^{U}_{i=1} C_{i,n}\, x_i (k) \qquad (1)$$

In the uplink case the process is same except that the users are no longer synchronized, and which is modeled by inserting user-specific time delay on the resulting spread

2.3 DS-CDMA Receiver Principles

The work of the receiver is to recover the data x(n) by converting the spectrum of the received signal vector $\underline{y}(n)$. This is done by multiplying the received signal with the required spreading sequence, which is generated locally by the receiver. The received signal, consisting of M_r chips is passed to the block of delay elements, where Z^{-1} represents a delay of one chip, until the complete M_r chip signal has been read. These values are then passed to multiplier block in parallel, which forms the scalar product of $\underline{y}(n)$ and the tap weight vector $\omega\_ \epsilon C^{Mr}$ where M_r is the number of tap weights, in this Figure 2 it is 8. This finite impulse response block produces a soft output $\tilde{x}(n)$,which is then passed through the decision block to give a hard estimate, $\tilde{x}(n)$, of the original data bit x(n).

This is the structure of simplest receiver, commonly known as MF receiver with L tap weights w_n: $1 \leq n \leq L$ matched to the original spreading sequence of the desired user. In practice, synchronization of the chip level signal is a highly non-trivial process. The performance of this receiver has been shown to degrade considerably as the number of simultaneously transmitting users increases. Hence improving the capacity of SS systems is achieved either by reducing the total interference by enhancing the single user detection methods or by making use of multiple access interference (MAI) through improved interference cancellation or multiuser detection technique (MUD).

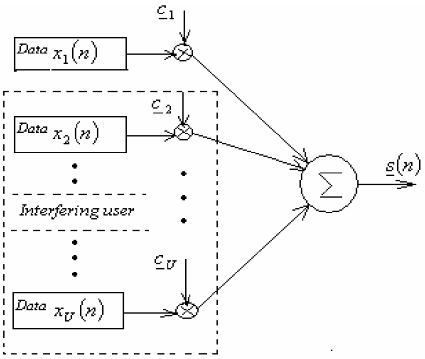

Figure 1. Simplified synchronous DS-CDMA downlink transmitters for U active users.

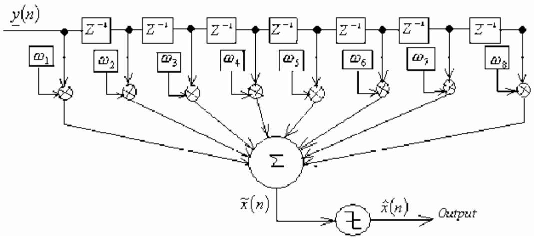

Figure 2. DS-CDMA correlator receiver with 8 tap weights.

2.4 Pseudo Noise (PN) DS/SS System

Spread spectrum signals for digital communications were originally invented for military communication, but nowadays are used to provide reliable communication in a variety of commercial applications including mobile and wireless communications, which provide resistance to hostile jamming, hide the signal by transmitting it at low power, or make it possible for multiple users to communicate through the same channel. In conventional DS/SS, in order to spread the bandwidth of the transmitting signals, the binary pseudo-noise (PN) sequences have been used extensively in spread spectrum communication (SS) systems. It is a deterministic, periodic signal that is known to both transmitter and receiver, whose appearance has the statistical properties of sampled white noise. It appears, to an unauthorized listener, to be a similar to those of white noise. Therefore, it is not easily intercepted by adversary.

2.5 Pseudo Noise (PN) DS/SS System

A pseudo random (PN) sequence is a code sequence of 1's and 0's whose autocorrelation has properties similar to those of white noise. Some of the popular PN sequences are Maximal length shift register sequences (m-sequences), gold sequences etc.

E.1 M-Sequence

Maximal length shift register sequences are by definition, thelongest codes that can be generated by a given shift register or a delay element of a given length. In binary shift register sequence generators, the maximum length sequence is 2^n-1 chips, where n is the number of stages in the shift register.

E.2 Gold sequences

For CDMA applications, m-sequences are not optimal. For CDMA, we need to construct a family of spreading sequences, one for each which, in which the codes have well-defined cross-correlation properties. In general, m-sequences do not satisfy the criterion. One popular set of sequences that does are the Gold sequences. Gold sequences are attractive because only simple circuitry is needed to generate a large number of unique codes.

3. Introduction to Genetic Algorithm

A pseudo random (PN) sequence is a code sequence of 1's and 0's whose autocorrelation has properties similar to those of white noise. Some of the popular PN sequences are Maximal length shift register sequences (m-sequences), gold sequences etc.

3.1 Components of Binary Genetic Algorithm

The GA begins, like any other optimization algorithm, by defining the optimization variables, the cost function, and the cost. It ends like other optimization algorithms too, by testing for convergence. In between, however, this algorithm is quite different. A path through the components of the GA is shown as a flowchart in Figure 3.Each block in this "big picture" overview is discussed in detail in this section.

3.2 Selecting the Variable sand the Cost Function

A cost function generates an output from a set of input variables (a chromo- some). The cost function may be a mathematical function, an experiment, or a game. The object is to modify the output in some desirable fashion by finding the appropriate values for the input variables. We do this without thinking when filling a bathtub with water. The cost is the difference between the desired and actual temperatures of the water. The input variables are how much the hot and cold spigots are turned. In this case the cost function is the experimental result from sticking your hand in the water. So we see that determining an appropriate cost function and deciding which variables to use are intimately related. The term fitness is extensively used to designate the output of the objective function in the GA literature. Fitness implies a maximization problem. Although fitness has a closer association with biology than the term cost, we have adopted the term cost, since most of the optimization literature deals with minimization, hence cost. They are equivalent. The GA begins by defining a chromosome or an array of variable values to be optimized. If the chromosome has Nvar variables (an Nvar-dimensional optimization problem) given by $P_1,P_2,P_3,\ldots,P_{Nvar}$ then the chromosome is written as an N_{var} element row vector.

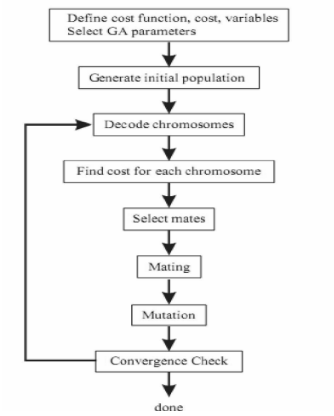

Figure 3. Flowchart of a binary GA.

$$\text{Chromosome} = [P_1,P_2,P_3,\ \ldots,\ P_{Nvar}] \quad (2)$$

For instance, searching for the maximum elevation on a topographical map requires a cost function with input variables of longitude (x) and latitude (y)

$$\text{Chromosome} = [x,y] \quad (3)$$

Where Nvar=2. Each chromosome has a cost found by evaluating the cost function, f , at $P_1,P_2,P_3,\ \ldots,\ P_{Nvar}$

$$\text{Cost} = f\,(\text{chromosome}) = f\,(P_1,P_2,P_3,\ \ldots,\ P_{Nvar}) \quad (4)$$

Putative solutions to the target problem are evaluated using "Cost functions", otherwise known as "Objective functions". Based upon the result of such functions, evolutionary pressures may be applied to a set of solutions. The objective function will obviously be problem specific, but there are certain features which should be avoided for the effective application of a GA. Such unfavorable objective functions are discussed below, but often the problems may be alleviated by choosing a different encoding scheme, by normalizing the input parameters, or by rebasing the function. An advantage of GAs over many search or optimization algorithms is that derivatives of this function are not required. This fact ensures that GAs may be readily applied on fitness landscapes (or potential surfaces) which contain discontinuities or singularities without any special treatments [7].

Often the cost function is quite complicated, as in maximizing the gas mileage of a car. The user must decide which variables of the problem are most important. Too many variables bog down the GA. Important variables for optimizing the gas mileage might include size of the car, size of the engine, and weight of the materials.

Other variables, such as paint color and type of headlights, have little or no impact on the car gas mileage and should not be included. Sometimes the correct number and choice of variables comes from experience or trial optimization runs. Other times we have an analytical cost function [8].

3.3 The Population

The GA starts with a group of chromosomes known as the population. The population has N_{pop} chromosomes and is an N_{pop}-
* N_{pop} matrix filled with random ones and zeros generated using

$$Pop=round\ (rand\ ((N_{pop}\ ,N_{bits}))) \quad (5)$$

Where the function (N_{pop} ,N_{bits}) generates a (N_{pop} , N_{bits}) matrix of uniform random numbers between zero and one. The function round rounds the numbers to the closest integer which in this case is either 0 or 1.Each row in the pop matrix is a chromosome. The chromosomes correspond to discrete values of longitude and latitude. Next the variables are passed to the cost function for evaluation.

3.4 Selection

Now it's time to play matchmaker. Two chromosomes are selected from the mating pool of N_{keep} chromosomes to produce two new offspring. Pairing takes place in the mating population until Npop-Nkeep offspring are born to replace the discarded chromosomes. Pairing chromosomes in a GA can be as interesting and varied as pairing in an animal species.

GA selection operators perform the equivalent role to natural selection. The overall effect is to bias the gene set in following generations to those genes which belong to the most fit individuals in the current generation.

There are numerous selection schemes described in the literature; Roulette wheel selection, tournament selection, random selection, stochastic sampling. These, in essence, mimic the processes involved in natural selection.

3.5 Mutations

The exact purpose of the mutation operations depends upon who you talk to. Mutations enable the GA to maintain diversity whilst also introducing some random search behavior. As for crossover, many types of mutation operator may be conceived depending upon the details of the problem and the chromosomal representation of solutions to that problem.

Random mutations alter a certain percentage of the bits in the list of chromosomes. Mutation is the second way a GA explores a cost surface. It can introduce traits not in the original population and keeps the GA from con- verging too fast before sampling the entire cost surface. A single point mutation changes a 1 to a 0, and vice versa. Mutation points are randomly selected from the Npop * Nbits total number of bits in the population matrix. Increasing the number of mutations increases the algorithm’s freedom to search outside the current region of variable space. It also tends to distract the algorithm from converging on a popular solution. Mutations do not occur on the final iteration.

3.6 The Next Generation

After the mutations take place, the costs associated with the off spring and mutated chromosomes are calculated.

3.7 Convergence

The number of generations that evolve depends on whether an acceptable solution is reached or a set number of iterations is exceeded. After a while all the chromosomes and associated costs would become the same if It were not for mutations. At this point the algorithm should be stopped [9].

4. Performance of Linear Receivers for DS/SS System

A direct sequence code division multiple access (DS-CDMA) communications system receiver has three main obstacles to overcome. The first one is multiple access interference (MAI) from other users, which is a direct result of using DS-CDMA. In a cellular system, MAI will be non-stationary due to slow power variations caused by fading and it may undergo step changes when a new user starts or stops transmission (the birth or death of a signal).The transmission channel is responsible for the other two obstacles inter symbol interference caused by multipath and additive noise. To overcome these, many receiver structures have been proposed for the reception of DS-CDMA in a cellular environment.

4.1 Multi user Receiver

Multiuser receivers [21] are a class of receivers that use knowledge of all the PN sequences to exploit the structure of the MAI. Instead of being separately estimated, as in a single user detection, the users are jointly detected for their mutual benefit. A CDMA receiver can either process the received signal at the chip rate or symbol rate (user bit rate).Figure 4 shows chip rate receivers, which consists of a bank of matched filters (MFs) or RAKEs. A bank of MF sis for the non-dispersive AWGN channel, whereas RAKEs[22] are considered for multipath channels. Current mobiles have a simple RAKE because of its simplicity, whereas base stations can have a bank of MFs (or RAKEs) as depicted in figures 4 and 5. However, structure Figure 4 suffers from MAI and therefore has limited performance. Performance improvement can be gained, when carrier to interference ratio (CIR) information from the interferers is taken into account to combat MAI, as structure in Figure5 suggests. This structure is known as the multi user detector (MUD) and is usually suggested for the asynchronous uplink receiver. It could also be used in a modified version as a single user detector in mobiles and might be implemented in the next generation of mobile systems.

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A receiver structure which processes the received signal at the chip rate is known as a chip level based (CLB) receiver. Receivers, shown in Figure 5, which process at the symbol rate and consist of a front end bank of filters, will be called preprocessing based (PPB) receivers.

Because all optimum receivers are too complex for practical applications, the search for simple rand near optimum receivers became vital and goes on. Most proposals are based on the multi user concept, which is preprocessing based (PPB) for several reasons. First, they relate to Verdu's UD receiver, since they consider it optimum.

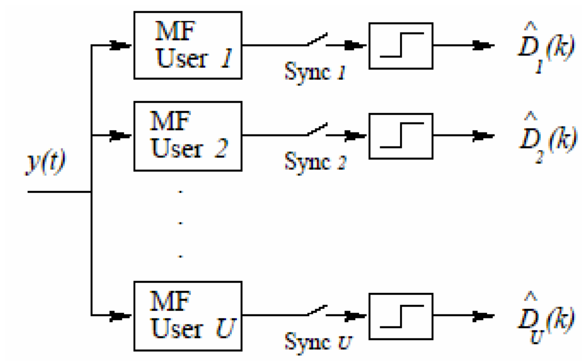

Figure 4. Conventional bank of single user receivers with MFs or RAKEs

4.2 Matched Filter

The conceptually simplest receiver, the matched filter (MF) receiver, is simply the correlate or receiver with M tap weights, ω_j: $1 \le j \le M$ matched to the complex conjugate time-reverse of the original spreading sequence of the required user which, without loss of generality, we may take to be user 1. The simplest CDMA receiver is the MF receiver, where w is replaced by C_d, the Spreading sequence vector of the desired user. In a multipath fading channel, w corresponds to the convolution between C_d and H_{ch}, implemented as a RAKE.

In practice, the acquisition and synchronization of the chip-level signal is a highly non-trivial task. A very simple and well known detector for SS signals is the matched filter detector, as shown in figure 6. The matched filter detector basically consists of a tapped-delay-line (TDL) filter of which the number of taps equals the spreading sequence length N. The output vector (K) of the tapped delay line

$$\underline{y}(k) = [y(k), y(k-1), \dots, y(k-N+1)]^T \quad (6)$$

is multiplied with a vector of constant weight

$$\underline{w} = [w_0, w_1, \dots, w_{N-1}]^T \quad (7)$$

The resulting scalar product is applied to a decision function e.g. a sign function. For the matched filter case, the weights w_k are matched to the user specific sequence code.

$$w_l = pn_u(N-1-l), 0 \le l < N \quad (8)$$

So that the matched filter output can be summarized as follows:

$$\tilde{D}(k) = \underline{w}^T . \underline{y}(k) = \sum_{l=0}^{N-1} w_l . y(k-l) \quad (9)$$

Provided that the receiver is perfectly synchronized to the transmitter, the TDL extracts a set of chips that represents a particular sequence and the multiplication with the weights is equivalent to dispreading operation. A following decision device such as sign function leads to the final estimate $\tilde{D}(k)$ of the transmitted data bit D(k), hence

$$\hat{D}(k) = sgn\left(\tilde{D}(k)\right) \quad (10)$$

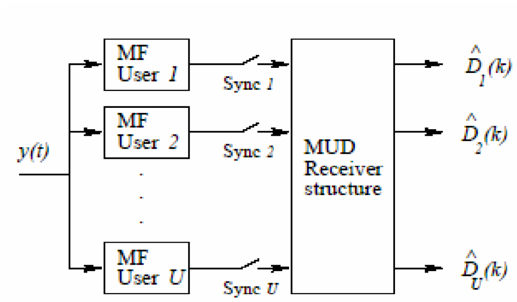

Figure 5. Verdu's proposed multiuser detector scheme with MFs for the AWGN channel

4.3 MMSE receiver

The motivation for the use of adaptive algorithms lies in the desire to change the individual taps of the receiver filter to respond to changes in the communication channel. The traditional implementation of adaptive receivers is that a sequence of a priori known training data is incorporated into the data stream at prearranged times. It is important to acknowledge that this effectively reduces the overall data rate of the system, which is the main drawback of this approach.

The goal of any adaptive algorithm is to use this training data to force the receiver tap weights to minimize some cost or penalty function, f_{Pen} (.), of the difference metric between the original data bit and its estimated value.

The only requirement for this penalty function is that it be a monotonic increasing function of the absolute value of its argument, with a global minimum at zero. Here, the number of training bits is given by N_{train} and the sequence of training data by $\{x(n): 1 \le n \le N_{train}\}$.

MMSE receiver is an adaptive filter [23] as shown in Figure 7, in which the number of receiver tap weights Nr is set to length of the spreading code M.

The MMSE criteria provide equalizer tap coefficients w(k) to minimize the mean square error at the equalizer output before the decision device. This condition can be represented as

$$j=\varepsilon|e(k)|^2 \quad (11)$$

$$e(k)=s(k-d)-y(k) \quad (12)$$

Where (k) is the error associated with filter output y(k). However, the MMSE criteria optimize the equalizer weights for minimizing the MMSE under noise and ISI. Minimization of MMSE criteria provides equalizers that satisfy the Wiener criterion. The evaluation the equalizer weights with these criteria requires computation of matrix in version and the knowledge of the channel, which in most cases is not available. With this penalty function, the resulting target tap weights have been shown to be given by the Wiener filter, so that these algorithms may be viewed as an iterative approximation to the Wiener filter.

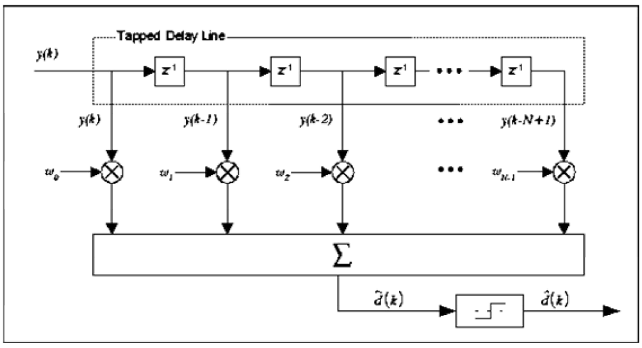

Figure 6. Matched filter.

However, adaptive algorithms like LMS and RLS can be used to recursively update the equalizer weights during the training period.

Two adaptive methods which employ this least square error penalty function are the least mean square (LMS) and the more complex recursive least squares (RLS) algorithms.

LMS algorithm is depicted schematically in Figure 8.

In LMS algorithm, correlation with an FIR filter is performed to obtain a (soft) estimate, xˆ , of the training data bit x(n) , as in the correlate or receiver. The error e(n) in this estimate is then used to update the tap weights of the FIR receiver filter. In the LMS algorithm, this is performed by simple weighting of the error by step size u.

5. Simulation Results

In order to validate the proposed GA for DS-CDMA applications, extensive simulation studies were conducted. All the simulation studies were conducted on a 2.90GHz Laptop with 4GB of RAM with Microsoft windows seven operating system.

All the simulations are done in Matlab. During the training period the receiver parameters were optimized/ trained with1000 random samples and the parameters so obtained were averaged over 50 experiments. The parameters of the receiver were fixed after the training phase.

Bit error rate (BER) was considered as the performance index. In this section, the BER performance of the different linear receivers like matched filter and MMSE receiver using gold spreading sequences is done and the performance is compared with GA assisted DSCDMA down link receiver using gold sequences. In all the experiments randomly generated +1/-1samplesweretransmittedforeachuser. In all the simulations, gold sequences of 31chips are considered. These samples were spread using gold sequences of length 31 corresponding to each of the users. For comparison with gold sequences, the maximum permissible user's in the system is restricted to 31.

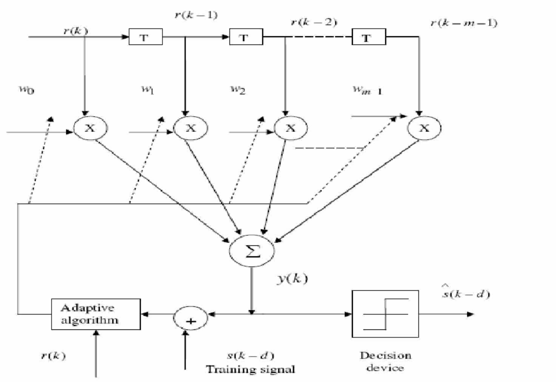

Figure 7. MMSE receiver

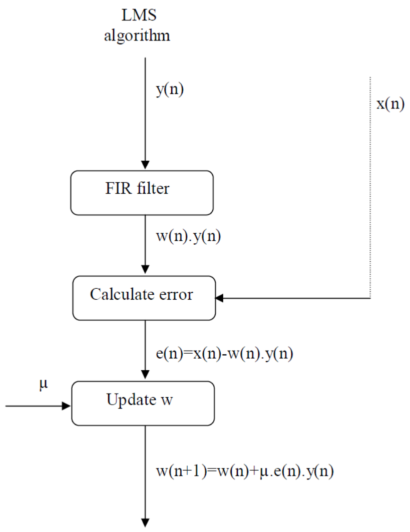

Figure 8. LMS algorithm.

After spreading, the sequences were added and transmitted through the non-dispersive channel. The channel corrupted the transmitted signal with AWGN. The channel output was fed to the various linear receiver structures like Matched filter and MMSE receiver. A total of 10^5 bits were transmitted by each user and a minimum of 1000 errors were recorded. The tests were conducted for different levels of SNR. Additionally tests were also conducted by varying number of active users in the system for fixed value of SNR.

5.1 Performance comparison of different receivers for channel without ISI.

In Figure 9 performance of different receivers were investigated for varying SNR conditions. Performance gold sequences for 4 users are plotted in Figure 9. It is seen that when the number of users is 4, there is a 1dB performance difference at a BER of 10^{-5} between GA assisted CDMA receiver and the matched filter receiver, and 5dB performance difference between GA assisted CDMA receiver and MMSE receiver**.**

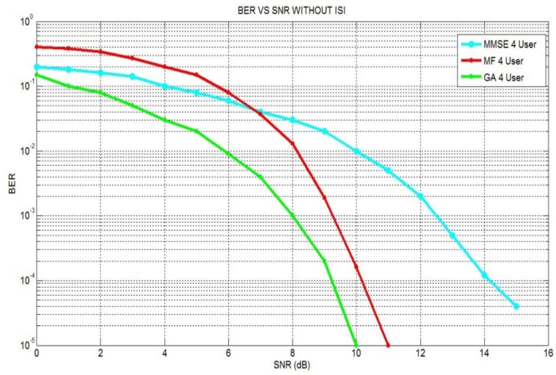

Figure 9. BER performance of different receivers for varying SNR for 4 users being active in the system.

5.2 Performance comparison of different receivers for channel with ISI

In this section, we consider a stationary multipath channel $h=1+0.5Z^{-1}+0.2Z^{-2}$ .In AWGN the number of chips of transmitted is number of chips of the spreading sequence i.e., 31 in this case. In case of multipath channel, inter symbol interference (ISI) is induced from the previous and next symbol into account. So the number of chips will increase. Here, the multipath channel consists of 3 taps. Hence all receiver structures exploit N+ (L-1) = 31+ (3-1) = 33 chips instead of 31. Matched filter is used in AWGN channel whereas Rake receiver is used in Multipath channel.

In Figure 10 performance of different receivers were investigated for varying SNR conditions and the multipath channel $H_{ch}=1+0.5Z^{-1}+0.2Z^{-2}$. In Figure 10 performance of different receivers were investigated for varying SNR conditions. Performance gold sequences for 4 users are plotted in Figure 10.

It is seen that when the number of users is 4, there is a 1dB performance difference at a BER of 10^{-5} between GA assisted CDMA receiver and the matched filter receiver and also for RAKE receiver, and 2 dB performance difference between GA assisted CDMA receiver and MMSE receiver.

6. Conclusion

In this section various linear receivers like Matched filter, MMSE receiver and RAKE receiver is explained. BER performance of different linear receivers using gold sequences is evaluated. It is seen that GA based DS-CDMA receiver performs much better than other type of receivers.

6.1 Scope of Further Research

Simulations can be extended to some more nonlinear receivers like neural network receivers.

Faster convergence of GA based CDMA receiver can also be investigated. Simulations can be extended to larger spreading codes like 63,127 chip etc.

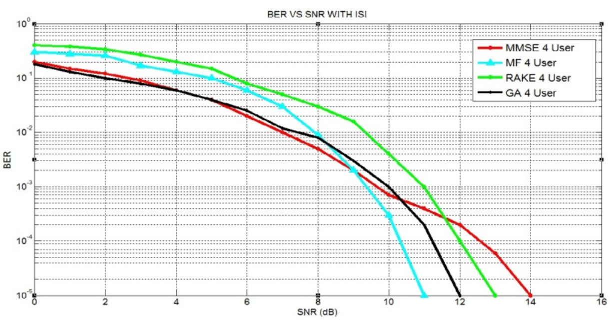

Figure 10. BER performance of different receivers for varying SNR for 4 users being active in the system in multipath channelHch=1+0.5Z^(-1)+0.2Z^(-2).

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