Multiuser Detection in CDMA Fast Fading Multipath Channel using Heuristic Genetic Algorithms

Muhammad Naeem, Syed Ismail Shah, and Habibullah Jamal

***Abstract*—**In this paper, a simple heuristic genetic algorithm is used for Multistage Multiuser detection in fast fading environments. Multipath channels, multiple access interference (MAI) and near far effect cause the performance of the conventional detector to degrade. Heuristic Genetic algorithms, a rapidly growing area of artificial intelligence, uses evolutionary programming for initial search, which not only helps to converge the solution towards near optimal performance efficiently but also at a very low complexity as compared with optimal detector. This holds true for Additive White Gaussian Noise (AWGN) and multipath fading channels. Experimental results are presented to show the superior performance of the proposed techque over the existing methods.

***Keywords*—**Genetic Algorithm (GA), Multiple Access Interference (MAI), Multistage Detectors (MSD), Successive Interference Cancellation.

I. Introduction

WIRELESS communication continues to experience rapid growth, showing a large increase in number of users [1]. Cost of network operation, power consumption, number of users and low error rate are the main issue of emerging wireless technologies. A type of wireless technology, which has become very popular over the last few years, is the direct sequence Code Division Multiple Access (DS-CDMA). CDMA is an attractive multiuser scheme that allows users to transmit at the same carrier frequency and at the same time but different codes in an uncoordinated manner. However, this creates multiple access interference (MAI), which, if not controlled, can seriously deteriorate the quality of reception.

Multi-user detection refers to techniques, which detect the transmitted information of several users jointly. Compensation for MAI is critical for satisfactory performance of DS-CDMA systems. The performance of optimum multi-user detection [2-4] is significantly superior over Conventional Detector (CD) also known as Matched Filter, but at the cost of very high computational complexity.

The Computational complexity increases exponentionally with the number of users. Research efforts are now concentrated on the development of fast converging low complexity sub-optimal multi-user detection receivers [2-4]. The multistage detector is one of the sub optimal multi-user detectors, which relies on improving each stage's estimate by subtracting the estimate of MAI obtained by previous stage. Multistage detector is non-linear and requires the exact knowledge of the user powers.

Combinatorial optimization based multi-user detectors have been proposed in [5-11]. In [7] a pure genetic algorithm (GA) based detector is used in Additive White Gaussian Noise (AWGN) in synchronous channel. In recent years many other combinatorial algorithm based detectors like Memetic [6], Evolutionary Programming [8] and Tabu search [12] have been developed for synchronous DS-CDMA. In this paper, we consider heuristic genetic algorithm for multistage multi-user detection in asynchronous multipath channels.

The paper is organized as follows. In the next section we present the system model for fast fading multipath Multi-user detection (MUD) environment. Section 3 describes the multistage detectors used in the context of genetic algorithms. Section 4 presents the genetic parameter description. In Section 5 GA based detection procedure is explained and simulation results are provided. The paper is concluded in Section 6.

II. System Model

We assume BPSK modulation and use direct sequence spread spectrum signaling, where each active mobile unit possesses a unique signature sequence (short repetitive spreading code) to modulate the data bits. The base station receives a summation of the signals of all the active users after they travel through different paths in the channel. The multipath is caused due to reflections of the transmitted signal that arrive at the receiver along with the possibility of the line-of-sight component being received also. These channel paths induce different delays, attenuations and phase-shifts to the signals and the mobility of the users causes fading in the channel. Moreover, the signals from different users interfere with each other in addition to the additive white Gaussian noise (AWGN) present in the channel.

Multiuser channel estimation refers to the joint estimation of the unknown channel parameters for all users to mitigate these undesirable effects and accurately detect the received bits of different users. Whereas MUD refers to the detection of the received bits for all users jointly by canceling the interference between the different users. The performance of

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multiuser detection depends greatly on the accuracy of the channel estimates. The model for the received signal at the output of the multipath channel that we use is based on the one presented in [15] and is described in the next section.

A. Single-User Channel Representation

As shown in Fig. 1, the complex baseband signal x(t) at the output of the channel is related to the transmitted complex baseband signal s(t) by

$$x(t) = \int h(t,\tau) s(t-\tau) d\tau \tag{1}$$

Where $h(t,\tau)$ is the time-varying impulse response of the channel [5], [15]. The channel produces time and frequency shifts in the signal. An equivalent representation is in terms of the channel spreading function $H(\theta,\tau)$

$$x(t) = \int_0^{T_m} \int_{-B_d}^{B_d} H(\theta,\tau) s(t,\tau) e^{j2\pi\theta t} d\theta d\tau \tag{2}$$

$$H(\theta,\tau) \equiv \int h(t,\tau) e^{-j2\pi\theta t} dt \tag{3}$$

In (2), T_m is the multipath spread of the channel and denotes the maximum delay produced by the channel. Similarly, B_d is the Doppler spread and denotes the maximum (one-sided) Doppler shift introduced by the channel. Fast-fading channels encountered in practice exhibit Doppler spreads on the order of 100–200 Hz due to relative motions of the users .for a spread spectrum signal s(t) of duration T and chip interval T_c, the channel admits the canonical decomposition [15]:

$$x(t) \approx \frac{T_c}{T} \sum_{l=0}^{L} \sum_{m=-M}^{M} H_k^{ml} s_k(t - lT_c) e^{j\frac{2\pi mt}{T}} \tag{4}$$

where $L = \lceil T_m / T_c \rceil, M = \lceil TB_d \rceil$ and $H^{ml} \equiv \hat{H}(m/T, lT_c)$, L denotes the number of multipath components and M the number of Doppler compenents.

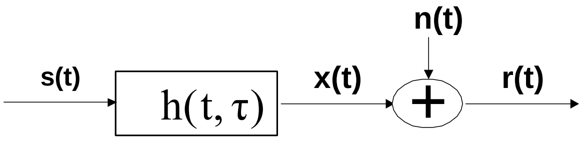

Fig.1 Wireless channel: a linear time-varying system

B. Multiuser Signal Model

To model a multi-user scenario we assume a K-user direct sequence CDMA system with BPSK (Binary Phase Shift Keying) modulation with each transmitted signal selected from a binary alphabet and limited to [0,T], where T is the symbol period. Each user transmits a zero mean stationary bit sequence with i.i.d. Components and different users are independent of each other. The signal at the input of the receiver is given by

$$r(t) = x(t) + n(t) \tag{5}$$

$$r(t) = \sum_{i=-I}^{I} \sum_{k=1}^{K} b_k(i) x^i{}_k(t) + n(t) \tag{6}$$

Where $b_k(i) \in \{-1,1\}$ is the i^{th} bit of the Kth user, $x_k^i(t)$ is the unmodulated received baseband signal for the i^{th} bit of the k^{th} user and n(t) is the complex baseband additive white Gaussian noise (AWGN) . In terms of the representation (4), the signal can be expressed as

$$x_k^i(t) \approx \frac{T_c}{T} \sum_{l=0}^{L} \sum_{m=-M}^{M} H_k^{ml}(i) s_k(t - iT - lT_c) e^{j\frac{2\pi mt}{T}} \tag{7}$$

where $s_k(t)$ is the spreading waveform of the k^{th} user and $H_k^{ml}(i)$ are the channel coefficients corresponding to the i^{th} bit of the K^{th} user. Note that we have absorbed the signal powers and the carrier phases for the different users in the channel coefficients $H_k^{ml}(i)$

In vector notation these signals can be expressed as

$$s_k^{ml}(t) \equiv s_k(t - lTc) e^{j\frac{2\pi mt}{T}} \tag{8}$$

$$s_k^m(t) \equiv \left[s_k^{m0}(t), s_k^{m1}(t), \cdots, s_k^{mL}(t) \right]^T \tag{9}$$

Where m= -M,-M+1,…….,0,….,M-1,M

Similarly $H_k^{ml}(i)$ and $b_k(i)$ can be represented as

$$H(i) \equiv \begin{bmatrix} h1(i) & 0 & \cdots & 0 \\ 0 & h2(i) & 0 & \cdots \\ \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & hk(i) \end{bmatrix} \tag{10}$$

$$b(i) \equiv \left[b_1(i), b_2(i), \cdots, b_k(i) \right]^T \tag{11}$$

in term of above notations the received signal can be expressed as

$$r(t) \approx \sum_{i=-I}^{I} s^T(t - iT) H(i) b(i) + n(t) \tag{12}$$

Thus the received signal is a linear combination of time-shifted signals $s_k^{ml}(t)$.

At the output of correlator for p^{th} bit we get

$$z(p) = \int r(t) s^*(t - pT) dt \approx RH(p) b(p) + w \tag{13}$$

Where

$$R \equiv \int r(t) s^*(t - pT) dt = \begin{bmatrix} R_{11} & R_{12} & \cdots & R_{1k} \\ R_{21} & R_{22} & \cdots & R_{2k} \\ \vdots & \vdots & \vdots & \vdots \\ R_{k1} & R_{k2} & \cdots & R_{kk} \end{bmatrix} \tag{14}$$

And

$$w = \int s^*(t - pT) n(t) dt \tag{15}$$

is a zero-mean complex Gaussian noise vector.

Thus $z = RHb + w$ (16)

C. Multiuser Detector for Fast Fading Channels

The optimal minimum probability of error receiver in fast multipath fading channel uses maximal-ratio-combining (MRC) and defined as

$$\hat{b}_k = sign\{Re[\, h_k^H z_k \,]\}$$
$$\hat{b}_k = sign\left\{ Re\left[\sum_{l=0}^{L} \sum_{m=-M}^{M} H_k^{*ml} z_k^{ml} \right] \right\}, k = 1,2,\cdots,K \qquad (17)$$

Which combines the different multipath Doppler shifted signal components. MRC requires the knowledge of the channel coefficients $H_k^{ml}(i)$, which can be estimated through a pilot signal. For optimum multi-user detector, minimum probability of error reception is achieved by maximum likelihood (ML) receiver.

$$\hat{b}_{opt} = \arg\max\; p(z \mid b)$$
$$= \arg\max -(z - RHb)^H R^{-1}(z - RHb)$$
$$= \arg\max[\sum_{k=1}^{K} 2\,\mathrm{Re}[h_k^H z_k] b_k - \sum_{k=1}^{K}\sum_{m=1}^{K} b_k [H_k^H R H_m] b_m] \qquad (18)$$

Where H_k is the K[th] column of H. The effect of fast fading is incorporated via multipath-Doppler channel coefficient matrix H. The relation given by (18) is the required optimum solution used in next sections using Genetic algorithm as the first stage of multistage multiuser detector. In the next section we describe the GA based multiuser detection for fast fading channels.

III. GA based Multiuser Detection for Fast Fading Channels

Genetic algorithms are a part of evolutionary computing, which is a rapidly growing area of artificial intelligence. Genetic algorithms are powerful optimization tools that have been successfully applied to various hard problems in science and engineering [13]. One application of the GA is to solve the optimal CDMA multiuser detection problem, which is one of the hardest signal processing problems in multiple access wireless communication. First we will briefly describe Genetic algorithms then we present multistage multiuser detector based on these algorithms.

A. Search Space

The space of all feasible solutions is called search space. Each point in the search space represents one feasible solution. Each feasible solution can be "marked" by its value or fitness for the problem. We look for a solution, which is one point (or more) among feasible solutions or the search space. This search for a solution is then equivalent to finding an extreme (minima or maxima) in the search space. The search space can be wholly known at the time of solving the problem, but usually we know only a few points from it and we generate other points as the process of finding solution continues.

B. NP-hard Problems

NP stands for nondeterministic polynomial. In NP problems are those that cannot be solved in polynomial time. However, it is possible to "guess" the solution (by some nondeterministic algorithm) and then check it, in polynomial time. If we have a technique that can guess, we would be able to find a solution in some reasonable time.

Usually the NP problems are restricted to NP-complete problems. In this case the answer is considered to be either yes or no. However, when the task to be solved has complicated outputs we consider what is known as NP-hard problems. This class is not as limited as class of NP-complete problems.
One of the characteristics of the NP-problems is that some simple algorithm to find a solution looks obvious at a first sight like just trying all the possible solutions. However, this algorithm is very slow (usually O (2^n)) and for a bit larger problems it is not usable at all.

IV. Parameters of GA

The simplest form of genetic algorithm involves three types of operators: selection, crossover, and mutation.

A. Selection

This operator selects chromosomes in the population for reproduction. The fitter the chromosome, the more times it is likely to be selected to reproduce. Selection is based on fitness function.

B. Crossover

This operator randomly chooses a locus and exchanges the subsequences before and after that locus between two

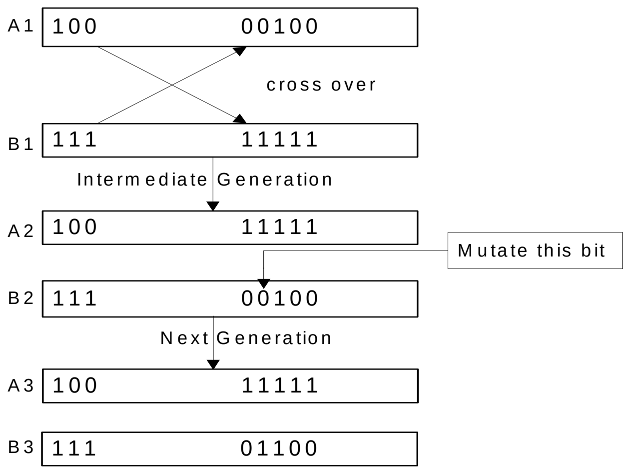

Fig. 2 Crossover and mutation example

chromosomes to create two offspring. For example, the strings 10000100 and 11111111 could be crossed over after the third locus in each to produce the two offspring 100-11111 and 111-00100. The crossover operator roughly mimics biological recombination between two single-chromosome organisms. Fig 2 explains cross over and mutation.

C. Mutation

This operator randomly flips some of the bits in a chromosome. For example, the string 00000100 might be mutated in its second position to yield 01000100. Mutation

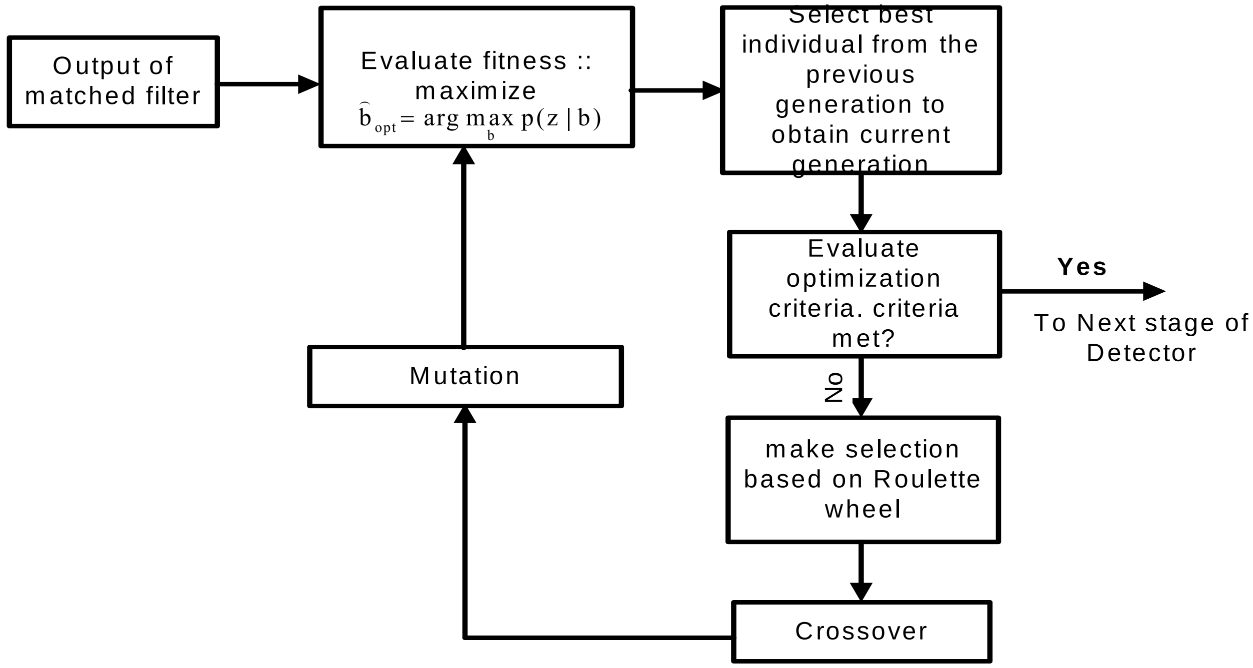

Fig. 3 GA algorithm for multistage multiuser detection

can occur at each bit position in a string with some probability, usually very small (e.g., 0.001).

There are two basic parameters of GA - crossover probability and mutation probability.

Crossover probability represents the frequency of the crossover. If there is no crossover, the offspring is exact copy of parents. If there is a crossover, offspring is made from parts of parents' chromosome. If crossover probability is 100%, then all the offspring is made by crossover. If it is 0%, whole new generation is made from exact copies of chromosomes from old population (but this does not mean that the new generation is the same!).

Mutation probability describes how often parts of a chromosome is mutated. If there is no mutation, offspring is taken after crossover (or copy) without any change. If mutation is performed, part of chromosome is changed. If mutation probability is 100%, whole chromosome is changed, if it is 0%, nothing is changed. Mutation prevent falling GA into local extreme, but it should not occur very often, because then GA will in fact change to random search.

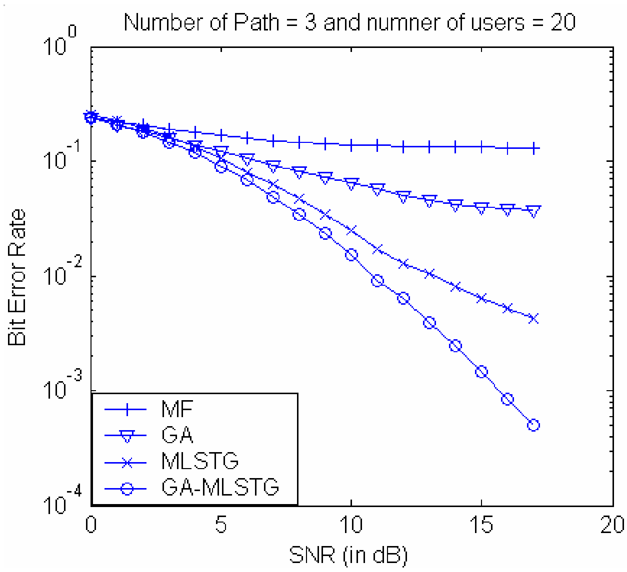

Fig. 4 Performance comparison of Matched Filter (MF), Genetic Algorithm (GA), Multistage (MLSTG) Genetic and Genetic multistage (GA-MLSTG) multiuser detectors

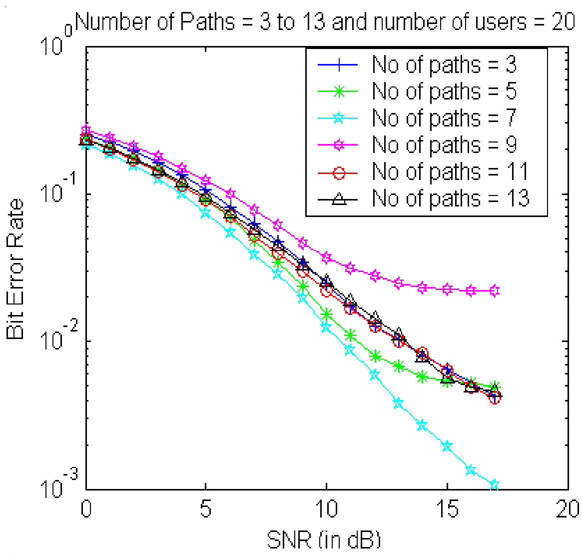

Fig. 5 Performance comparison of Genetic Multistage detector with different paths

V. GA Based Detection Procedure

In multiuser detection GA act as heuristic search method used for an efficient searching and fast converging tool for the optimum multiuser detection. As GA requires initial population, for multistage multiuser detection multipath correlator (7) output is taken as initial population for first stage. In this detector, the outcome of the GA algorithm is used as initial estimate of multistage detector. In multistage detectors initial estimate is the key factor in performance boost. So, we expect the multistage detector to perform better if initial estimate is good.

Given a clearly defined problem to be solved and a bit string representation for candidate solutions, a simple GA works as follows:

1. *Start with a randomly generated population of n l-bit. Where n is number of user and l is bit sequence.*
2. *Calculate the fitness function f(x) of each chromosme x in the population. The main purpose of fitness function is to get best chromosome (sequence of bits in our case) for optimum detection as in (18). The objective of fitness function is to maximize (18). The basic algorithm to get optimum solution is shown in fig 3. In order to reach to an acceptable solution using GA, best individuals in a population must be manipulated in such a way so that they reach to better states as described by fitness function. For better fitness values the search must not be allowed to get trapped into one area in the search space and increase in crossover rate will also narrow the search*
3. *Repeat the following steps until n users have been created: Select a pair of parent chromosomes (bits) from the current population, the probability of selection being an increasing function of fitness. Selection is done "with replacement," meaning that the same chromosome can be selected more than once to become a parent. With probability pc (the "crossover probability" or "crossover rate"), cross over the pair at a randomly chosen point (chosen with uniform probability) to form two offspring. If no crossover takes place, form two offspring that are exact copies of their respective parents.*
4. *Mutate the two offspring at each locus with probability pm (the mutation probability or mutation rate), and place the resulting chromosomes in the new population. If n is odd, one new population member can be discarded at random.*
5. *Replace the current population with the new population.*
6. *Go to step 2*

Each iteration of this process is called a generation. A GA is typically iterated for anywhere from 50 to 500 or more generations. The entire set of generations is called a run. At the end of a run there are often one or more highly fit chromosomes in the population. Since randomness plays a large role in each run, two runs with different random-number seeds will generally produce different detailed behaviors. GA researchers often report statistics (such as the best fitness found in a run and the generation at which the individual with that best fitness was discovered) averaged over many different runs of the GA on the same problem.

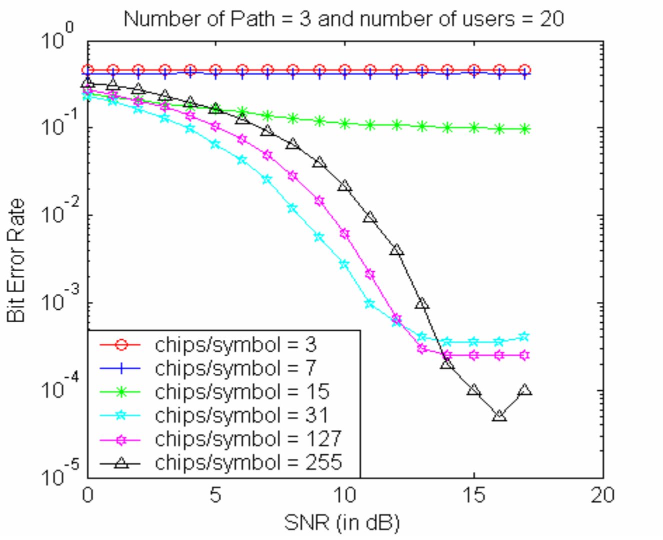

Fig. 6 Performance comparison of Genetic Multistage detector with 3 paths and different number of chips/symbols

A. Simulation Results

In this section simulation results are presented based on evaluating the BER performance of the GA-based multistage multiuser detector. Fig. 4 shows the BER performance against the average signal-to-noise ratio (SNR). Result is based on 3 paths and 20 users. For the sake of comparison, the BER performance of a Matched Filter (MF) or Conventional Detector (CD) and Multistage Multiuser detector (MLSTG) also shown. Simulation results have shown that the performance genetic multistage multiuser detector (GA-MLSTG) in multipath fast fading Channel is much better than the ordinary multistage detector. In Fig 5 performance of genetic with different number of paths is compared keeping number of user = 20. In Fig 6 BER performance is compared by varying number of chips per symbol, while keeping number of paths = 3 and number of users = 20. We can see that as the number of chips per symbol increases we get better results.

VI. Conclusion

In this paper we proposed a novel signal processing technique based on Genetic algorithm, which shows better results as compare to other MUD techniques. Multistage detector based on these genetic search algorithms is simulated with different conditions; no of paths, no of users and numbers of chips per symbols. These results exhibit superior performance of proposed algorithm over previous MUD techniques.

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