Performance Evaluation of Genetic Algorithm Assisted synchronous Direct Sequence CDMA Systems

Prasanta Kumar Pradhan
Dept. of Electronics & Comm. Engg.
National Institute of Technology
Rourkela, India-769008
Email: pradhanp@nitrkl.ac.in

Sarat Kumar Patra (SMIEEE)
Dept. of Electronics & Comm. Engg.
National Institute of Technology
Rourkela, India-769008
Email: skpatra@nitrkl.ac.in

***Abstract*—In this paper, we applied genetic algorithm (GA) scheme as a suboptimal detection of a bit-synchronous code division multiple access (CDMA) systems over a Gaussian channel.The GA scheme attempts to search for the user's transmitted bit sequence that optimizes the correlation matrix employed.Simulation results showed that the Bit Error Rate (BER) performance of our proposed multiuser detector is better than those of conventional receivers like Minimum Mean Square Error(MMSE),Matched Filter(MF) and Rake Receivers.**

***Index Terms*—GA, DS-CDMA, Evolutionary computing, Rake receiver, MMSE**

I. INTRODUCTION

Code division multiple access [1], [2] is an attractive multiuser scheme that allows many users to transmit the signal at the same carrier and time slot in an uncoordinated manner. However, as the transmitted signal travels in a medium or a channel, the signal is corrupted by the noise present in the channel.Again as the signal travels in air medium, multipath propagation effects due to reflection and refraction.This multipath components of the signal creates inter symbol interference (ISI), which - if not controlled - can seriously deteriorate the quality of reception at the receiving end [3]. Many methods (linear and nonlinear) have been proposed for reducing the amount of ISI present in the received signal. Among the linear technique as Minimum Mean Square Error (MMSE), Matched Filter (MF) and Rake Receiver are simulated.

Conceptually, the simplest receiver, the MF receiver, is simply the correlator receiver with M tap weights. In a single user system, the matched filter is the optimum receiver for signals corrupted by Additive White Gaussian Noise (AWGN). In a multiuser environment, however, the performance degrades with increase in number of users. The matched filter is multiple-access limited-and strong interferers with high power compared to the desired user cause severe problem. This is called the near-far problem. The optimal linear receiver for multi-user detection is MMSE receiver which uses adaptive algorithm. 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. In traditional implementation of adaptive receivers and transmission conditions, a sequence of a priori known training data is incorporated into the data stream at prearranged times. As the name suggests, the MMSE detector minimizes the mean square error between the transmitted bit and the decision variable which is an output of linear transformation. The detector circumvents the noise enhnacement problem faced by the decorrelating detector. The linear transformation thus comprises of terms involving the received power levels and the thermal noise power. This detector offers improvement in BER performance, but a the received power levels have to be estimated. Erroneous estimations can lead to degradation of performance. As MMSE employs Least Mean Square (LMS) or Recursive Least Square (RLS) algorithm [4] so there is a chance of falling in local minima because LMS and RLS are gradient based algorithms. Generally communication channels are associated with some nonlinearity. But LMS and RLS are not robust to nonlinearity. Additionaly the channel can be affected by ISI. In order to mitigate the multipath fading, a diversity receiver is used in the Direct Sequence CDMA (DS-CDMA) systems which achieves gain by combining multipath signal components with different delays, and is known as RAKE receiver. The conventional present day RAKE receivers have multiple fingers, with each finger processing an assigned multipath. Each finger consists of despreading block, correlator, code generator and compensator. A RAKE receiver allows each arriving multipath signal to be individually demodulated and then combined to produce a stronger and more accurate signal. RAKE takes advantage of multipath diversity where the diversity order is equal to the number of combined multipath components. Obviously, RAKE receiver needs good channel estimation. RAKE receiver is (in maximum-likelihood sense or equivalently, in terms of minimizing BER) the optimal receiver in single-user case. However, in multi-user systems the performance of RAKE receiver is quite poor compared to some alternatives (due to multiple access interference).

GA is a non-gradient based evolutionary computation method and the algorithm searches for possible solution in the search space. It always settles near optimal global minima. GAs [5], [6], [7] have been employed for solving many complex optimization problems in Numerous fields like travelling sells man, bio-informatics, antenna optimization and many more. Again multiuser DS-CDMA system being a nondeterministic polynomial (NP) problem [8], GA can suitable for such an application. This was the motivation for using GA in this problem.

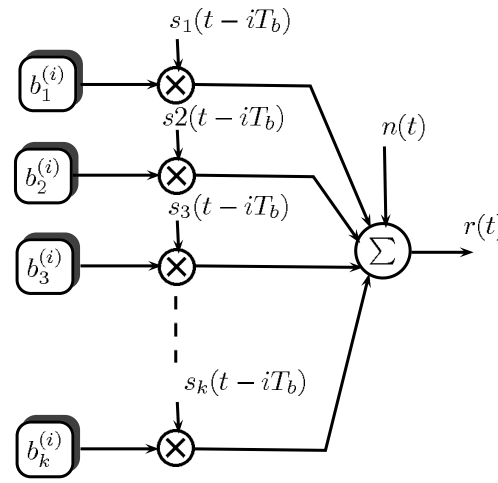

Fig. 1. Simplified synchronous DS-CDMA downlink Transmitter for K active users

II. SYSTEM DESCRIPTION

For analysis we consider the most basic multiple-access signal model where a baseband contains K-user time invariant synchronous AWGN system, employing periodic (short) spreading sequence and operating with a Binary Phase Shift Keying (BPSK) modulation. The simplified DS-CDMA downlink transmitter is shown in Figure 1. The contineous time wave form received by a given user can be modelled as [9]

$$r(t) = \sum_{k=1}^{K} A_k \sum_{i=0}^{M-1} b_k[i] s_k(t-iT) + n(t) \qquad (1)$$

Where M is the number of data symbols per user in data frame of interest; T is the symbol interval; $A_k, \{b_k[i]\}_{i=0}^{M-1},\ and\ s_k(t)$ denote, the received complex amplitude, the transmitted symbol stream, and normalized signaling waveform of the kth user respectively. $n(t)$ is the baseband complex Gaussian ambient noise with independent real and imaginary components and each with double sided power spectral density $\sigma^2 = N_0/2$, N_0 the power per unit bandwidth of $n(t)$. It is assumed that for each user k, $\{b_k[i]\}_{i=0}^{M-1}$ is a collection of independent equiprobable ± 1 random variables, and the symbol stream of different users are independent. For the Direct sequence Spread Spectrum (DSSS) format, each user's signaling waveform is of the form

$$s_k(t) = \frac{1}{\sqrt{N}} \sum_{j=0}^{N-1} c_{j,k} \psi(t - jT_c), \qquad 0 \le t \le T, \qquad (2)$$

Where N is the processing gain, $\{c_{j,k}\}_{j=0}^{N-1}$ is a signature sequence of $\pm 1's$ assigned to the kth user, and $\psi(.)$ is a chip waveform of duration $T_c = T/N$ and unit energy i.e $\int_0^{T_c} \psi^2(t)dt = 1$.

At the receiver, the received signal $r(t)$ is filtered by a chip-matched filter and then sampled at chip rate. Thus the resulting discrete-time signal corresponding to the ith symbol is given by

$$r\{i\} = \sum_{k=1}^{K} A_k b_k[i] s_k + n(i) \qquad (3)$$

$$= SAb[i] + n(i), \qquad (4)$$

With $r[i] \triangleq \begin{bmatrix} r_0[i] \\ r_1[i] \\ \vdots \\ r_{N-1}[i] \end{bmatrix}$, $s_k \triangleq \frac{1}{\sqrt{N}} \begin{bmatrix} c_{0,k} \\ c_{1,k} \\ \vdots \\ c_{N-1} \end{bmatrix}$, $n[i] \triangleq \begin{bmatrix} n_0[i] \\ n_1[i] \\ \vdots \\ n_{N-1}[i] \end{bmatrix}$ $S \triangleq [s_1\, s_2 \cdots s_K]$, $A \triangleq diag(A_1\, A_2 \cdots A_K)$ and $b[i] \triangleq \begin{bmatrix} b_1[i]\ b_2[i]\ \cdots\ b_K[i] \end{bmatrix}^T$.

Assuming that we are interested in demodulating the data bits of a particular user, say user 1, $\{b_1[i]\}_{i=0}^{M-1}$, based on the received waveforms $\{r[i]\}_{i=0}^{M-1}$. A linear receiver for this purpose can be described by a weight vector $w_1 \in \mathbb{C}^{\mathbb{N}}$ such that the desired user's data bits are demodulated according to

$$z_1[i] = w_1^H r[i] \qquad (5)$$

$$\hat{b}_1[i] = sign\{R(A_1^* z_1[i])\} \qquad (6)$$

Where $z_1[i]$ is the demodulated data and $b_1[i]$ is the expected demodulated bit. '$*$' stands for conjugate and 'H' stands for Harmitian transpose. From the (5), it is clear that once the weight vector is estimated there is no problem for estimating the bit sequence. The weight vector can be trained by different adaptive algorithms like LMS, RLS, Rake receiver and etc. Here we have applied GA for estimation of the weight vector.

III. GA BASED DS-CDMA RECEIVER

In GA based synchronous CDMA system, initial solutions of the problem concerned are first encoded into a population of K- bit individuals, constituted by all possible K-bit combinations of the users. These K-bit individuals are then subjected to genetic operations such as selection, crossover and mutation in order to generate better solutions. While GAs are not perfect, i.e., they do not always find the optimal K-element vector in the 2^Ksized optimization space, they are efficient in attaining near optimal solutions significantly faster than conventional point-by-point exhaustive search techniques, specially in the large solution spaces associated with supporting many users [3]. A GA-based multiuser detector was first proposed by Juntti et al. [8], where the analysis was based on a synchronous CDMA system communicating over an additive white Gaussian noise (AWGN) channel. In this paper we have applied GA to DS-CDMA with AWGN and multipath channel resulting in ISI.

The model of GA assisted DS-CDMA receiver is shown in Figure 2. In our simulation model we have used Gold Code as spreading code and the processing gain $N = 31$ (i.e number of chips in the Gold Code is 31). After spreading

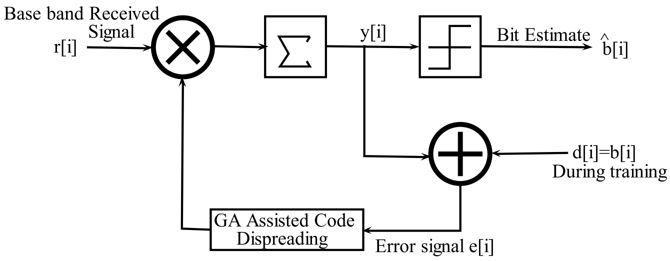

Fig. 2. GA Assisted DS-CDMA Receiver

the data for all user, frames from all user are added and the resulting data is transmitted. At the receiver end the received signal is first multiplied by a spreading code. After spreading the received signal the frame bits are summed up and passed through a hard limiter to get the desired data bit. During training period, the summed up data after spreading the received signal is compared with the desired transmitted bit. This comparison will give one a error signal which will be equal to $e[i] = b_1^i - y[i]$. Where $e[i]$ is the error signal, $y[i]$ is the summed up data after spreading at ith iteration and b_1^i is the desired transmitted bit of user 1 at ith iteration (Here we are detecting the user 1's bit sequence at the receiver end). The error signal $e[i]$ will be used for updating the spreading sequence. GAs [5], [6], [7] can be invoked in robust global search and optimization procedures that are well suited for solving complex optimization problems. In this paper, we employed GAs in order to detect the transmitted usersŠ bit vector b^i. The structure of the proposed GA-based multiuser detector can be best understood with the aid of the flowchart shown in Figure 3, which will be often referred to during our further discourse.

GA algorithms commence their search for the optimum solution at the $j = 0$th generation with an initial population of individuals. The number of individuals in the population is given by the population size P, which is fixed throughout the entire GA. Each individual is associated with a figure of merit, more commonly known in GAs as the fitness value, which has to be evaluated. The fitness value, denoted as $b_p(j)$ for $p = 1 \cdots P$, which is computed. Based on the evaluated fitness, a new population of individuals is created for the$j+1th$ generation through a series of processes, which are referred to in GA parlance as *selection, crossover and mutation* [5]. These processes are designed to improve the average, and possibly the maximum fitness, of the new population as compared to the old population.

A. Selection

As suggested by the terminology, the selection process selects two so-called parents from a mating pool consisting of T individuals, where $2 \leq T < P$, in order to produce two so-called offspring for the next generation population. In this simulation we take population size 16 and selection rate 0.5. Individuals having T the highest fitness values in the population are placed in the mating pool. This simulation uses rank weight selection. The individuals in the mating pool are selected as parents according to a probabilistic function based on their corresponding figure of merit p_n which is given by

$$p_n = \frac{N_{keep} - n + 1}{\sum_{n=1}^{N_{keep}} n}$$

where N_{keep} is number of individuals survives for next generation and n is rank of an individual.

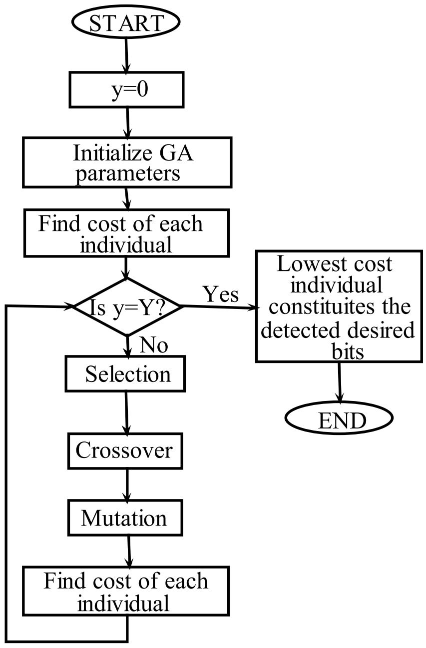

Fig. 3. Flow Chart of GA

B. Crossover

The antipodal bits corresponding to the desired bits of the parent vectors are then exchanged using the uniform crossover process in order to produce two offspring. The process of uniform crossover invokes a crossover mask, which is a sequence consisting of randomly generated 1s and 0s.

C. Mutation

The mutation process [5], [6] refers to the alteration of the value of an antipodal bit corresponding to the desired bits in the offspring from 1 to or vice versa, with a probability p_m. Here, we set $p_m = 1/2K$, such that on average only one bit in each individual is mutated.

IV. Simulation Results

We have simulated the DS-CDMA system using GA. To validate the result we have compared the performance of GA based receiver with MMSE and RAKE receiver. In all cases BER was considered as the performance criteria. All simulation are based on Monte Carlo simulation. Simulation parameters are as follows:
Length of the Gold code is 31 bits.

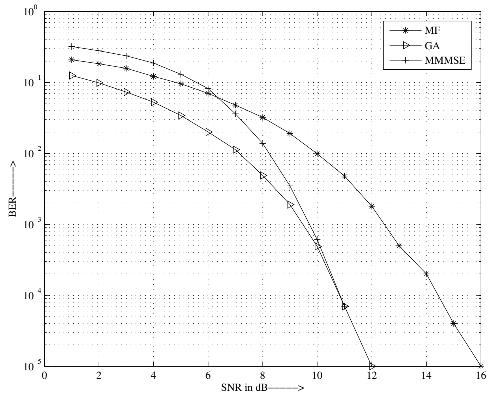

Fig. 4. Performance Comparison of DS-CDMA system with 7 user without any channel

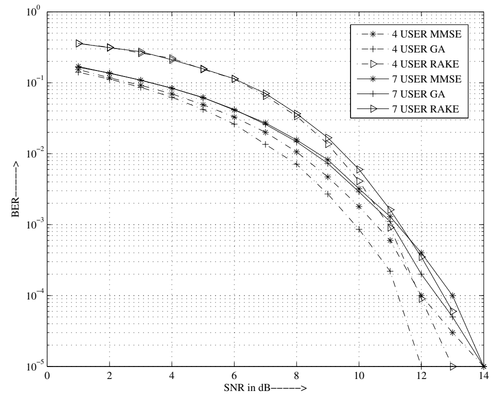

Fig. 5. Performance Comparison of DS-CDMA system for 4 user and 7 user with channel $1 + .5z^{-1} + .2z^{-2}$

Number of training samples for MF, MMSE and RAKE receiver is 2000 where as for GA it is 200.
Number of bits for BER calculation is 10^6.
Learning rate 0.0015.

The results are presented in Figure 4 through Figure 6. Figure 4 presents the performance of different receivers for AWGN channel with 7 users. It can clearly seen that GA provides the best performance. At low Signal to Noise Ratio (SNR), GA outperforms MMSE and MF receiver. However, at high SNR, GA and MMSE perform similarly.

Next we considered channel with ISI and AWGN. The channel considered was $1 + 0.5z^{-1} + 0.2z^{-2}$. The BER performance of different receivers is plotted in Figure 5 for 4 users and 7 users using 31 bit Gold code. From the results it is seen that GA performs better than MMSE and RAKE receiver. The performance difference is higher under low SNR and also where number of users is more.

To evaluate the performance of GA we studied the receiver performance at 8 dB SNR and the number of users were varied from 4 to 30. The result is plotted in Figure 6. It is evident from the result that GA receiver outperforms MMSE and RAKE receiver. For a BER of 10^{-3} GA can accommodate 3 users more than MMSE and RAKE receiver.

V. Conclusion

It is seen that the MMSE and RAKE Receivers have computational complexity that is proportional to the number of users. In GA the complexity also depends on number of users. It is more than MMSE and RAKE receiver. It is also seen that GA provides slow convergence during training compared MMSE receiver. But it requires less number of training sample.

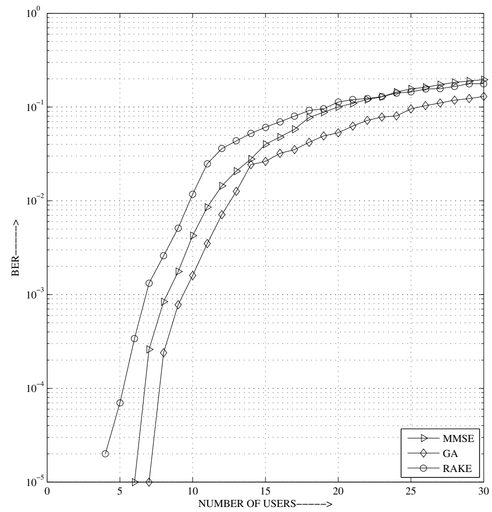

Fig. 6. Number of users and BER plot at SNR=8 dB with channel $1 + .5z^{-1} + .2z^{-2}$

References

[1] S. Verdu, "Minimum probability of error for asynchronous gaussian multiple access channels," *IEEE Trans. Inform. Theory*, vol. 32, pp. 85–96, Jan 1986.

[2] R. Prasad, *CDMA for Wireless Personal Communications*. Artech House, Inc, 1996.

[3] K. Yen and L. Hanzo, "Genetic-algorithm-assisted multiuser detection in asynchronous cdma communication," *IEEE Transactions on Vehicular Technology*, vol. 53, no. 5, September 2004.

[4] S. U. Qureshi, "Adaptive equalization," *Proceedings of The IEEE*, vol. 73, no. 9, September 1985.

[5] R. L. Haupt and S. E. Haupt, *Practical Genetic Algorithm*. A John Wiley & Sons, Inc., Publication, 2004.

[6] D. Goldberg and M. Reading, *Genetic algorithm in Search Optimization and Mechine learning*. Addison-Wesley, 1989.

[7] *An Introduction to Genetic Algorithm*. MIT Press, 1996.

[8] M. Juntti, "Genetic algorithms for multiuser detection in synchronous cdma," in *IEEE Internatinal Symposium, Information Theory,*, 1997, pp. 492–492.

[9] X. Wang and H. V. Poor, *Wireless Communication System*. Pearson Education, India, 2004.