Multiuser detection in CDMA — A comparison of minimum mean square error and simulating annealing heuristic algorithm

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Abstract: In the conventional single user detector in Direct Sequence-Code Division Multiple Access (DS-CDMA) systems, multiple access interference and near-far effect cause limitation of capacity. On the other hand, the optimal multiuser detector (OMUD) suffers from computational complexity that grows exponentially with the number of active users. During the last two decades, there has been a lot of interest in development of suboptimal multiuser detectors, which are low in complexity but deliver reasonable performance. In this paper, we present a novel multiuser detector based on the heuristic algorithm known as simulating annealing algorithm (SA). We evaluate performances of the proposed algorithm and compare it to the performances of Minimum Mean Square Error (MMSE) multiuser detectors. We show that the new algorithm outperforms the other one.

Key words: Direct Sequence-Code Division Multiple Access (DS-CDMA), Multiuser Detection (MUD), Simulating Annealing (SA), Minimum Mean Square Error (MMSE), Bit-Error Rate (BER).

Introduction

In Direct-Sequence Code Division Multiple Access (DS-CDMA) systems, Multiple Access Interference (MAI) is regarded as the main source limiting the system capacity. Multiuser Detection (MUD) is a well-known technique dealing with MAI (Hsieh & Wub, 2011). Different from the architecture of conventional single-user receivers, MUD conducts detections for all users simultaneously and can achieve much better performance. In (Verdu, 1986) a maximum-likelihood multiuser receiver was first proposed. Although significant performance enhancement can be obtained, the required computational complexity is very high, growing exponentially with the user number. This adversely affects its real world applications. As a consequence, many suboptimum alternatives were then proposed (Moshavi, 1996; Duel-Hallen et al., 1995; Verdu, 1998).

Recently, there has been considerable interest in linear multi-user detection based on MMSE criterion (Moshavi, 1996). It is shown that MMSE detector, relative to other detection schemes has the advantage that explicit knowledge of interference parameters is not required, since filter parameters can be adapted to achieve the MMSE solution. Although it does not achieve minimum Bit-Error Rate (BER), MMSE detector has been proved to achieve the optimal near-far resistance.

Recently, methods based on heuristic algorithms are being applied to improve the performance of suboptimal multiuser detectors. They view the MUD problem from a combinatorial optimization form and try to approximate the optimal solution iteratively. Genetic algorithms were the first heuristic algorithms applied to the MUD problem(Ergun & Hacioglu, 2000; Yen & Hanzo, 2000; Yen & Hanzo, 2001; Yen & Hanzo, 2004; Wu et al., 2003). In (Tan & Rasmussen, 2002) a tabu search algorithm is proposed. In (Morra et al., 2009) a particle swarm algorithm is tested and in (Ciriaco et al., 2006) evolutionary algorithm is proposed. In this work a MUD detector based on Simulating Annealing (SA) is proposed.

The rest of the article is organized as follows: Section II gives a system model description. Section III describes the proposed simulating annealing multiuser detection algorithm. Section IV gives the simulation results and section V draws the conclusion.

System model

In this paper, we consider the vector channel mode of a simple K users symbol synchronous CDMA system with a common single path additive white Gaussian noise (AWGN) channel, in order to clearly demonstrate the characteristics of each of the detection strategies. For synchronous system with a common single-path AWGN channel, it is sufficient to consider the signal received in one signal interval. Hence, the continuous time received waveform may be expressed as

(1)

Where is the signature waveform of the user, is the information bit transmitted by user k, and is the WGN process with two-sided power spectral density.

Each signature waveform is zero outside the bit interval, and the information bits of the users are assumed to be independent and equiprobable.

The sampled output of the matched filter (MF) of the kth user is

(2)

Letting the vector of MF output samples be defined as, the data vector, then the vector of the matched filter outputs can be expressed as

(3)

Where the amplitudes of the K users are collected into a diagonal matrix

And R is the correlation matrix with elements

(4)

The Gaussian noise vector z has zero mean and autocorrelation matrix

(5)

Note that y constitutes a set of sufficient statics for estimating the transmitted data vector d.

The optimum ML detector selects the most likely (maximum likelihood) hypothesis given the matched filter output

(6)

Since we are considering an AWGN channel, the negative log-likelihood function based on the is proportional to. The binary constrained ML problem is then described as

(7)

The solution to (7) requires a search over all the possible combinations of the components of the vector d. it is thus clear that the computational complexity increases exponentially with the number of users (Tan & Rasmussen, 2004).

Simulating annealing multiuser detection

Figure1 shows a flowchart of the Simulating Annealing Multi-user detection.

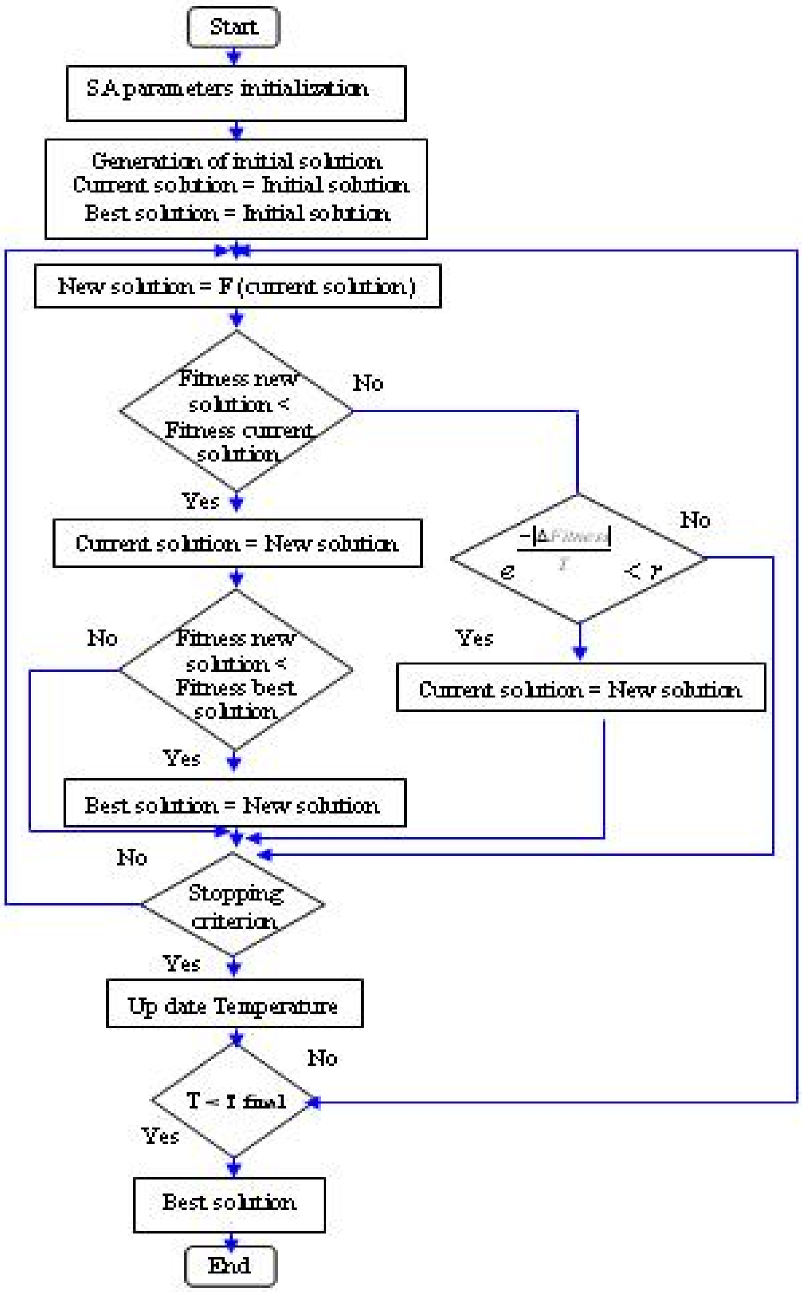

Figure 1: Flow chart of the SA-MUD

The basic algorithm is shown bellow

1. 1.Definition of the input data: initial temperature $T_{initial}$, final temperature T_{final}, temperature reduction factor , number of iterations at fixed temperature *itr*. As well as, the DS-CDMA MUD parameters: such as the number of users k and the length of spreading sequence N.

1. 2.Initialization of the best solution of the SA algorithm by the initial solution. The output of the matched filter (MF) is included as the first initial trial vector of the generation of the population.

1. 3. Generation of a neighboring solution (new solution) from the current solution. The generation is performed by which is a random transformation function of the solution, in our case; it is based on a single mutation between elements selected randomly of the current solutions vector. If the fitness value of the new solution is less than the fitness value of the current solution, the current solution becomes the new solution. If not this current solution will become the new solution according to the Boltzmann probability.

1. 4. The fitness of this new solution is also compared with the fitness of the best solution, if the fitness of this new solution is less than the fitness of best solution, best solution will be the new solution.

1. 5. This process is repeated for a number of iterations fixed in advance.

1. 6. After the updated temperature, we test the algorithm stopping criterion.

1. 7. End

Simulations, results and analysis

In this section the performance of the above described systems will be analyzed by simulations. After the specification of the system parameters the simulation results of the synchronous DS-CDMA system with simulated annealing (SA) multi user detection over an AWGN channel with Gold spreading code N=31 will be presented. All the users are transmitting with the same power. Figure 2 shows BER versus Es/No of the MMSE and SA-MUD.

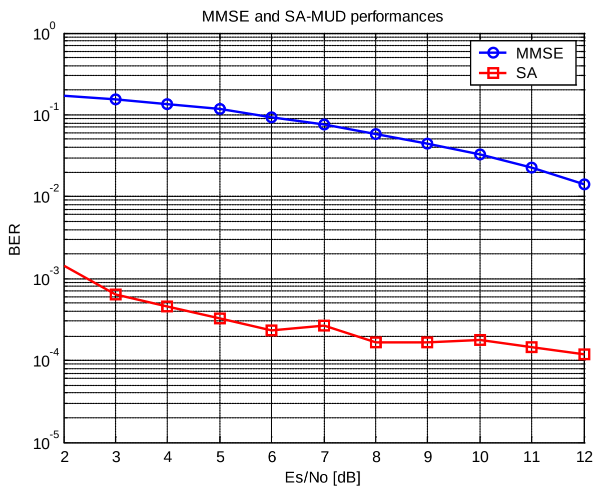

Figure 2: The BER vs. Es/No of SA-MUD (N=31, K= 20, *itr*=300)

In Figure 2 it can be seen that the proposed SA-MUD performs best, since it shows the least BER in comparison of the MMSE detector (in this simulation the number of users is K=20 and the number of iteration *itr*=300). This algorithm proved its efficiency and power since its BER=10^{-4} on the other hand the BER of the MMSE is about BER=10^{-2}.

Figure 3 shows the SA and MMSE algorithms performances evolution according to the total iteration numbers (*itr*). The SA algorithm gives the best performances for a high iteration numbers.

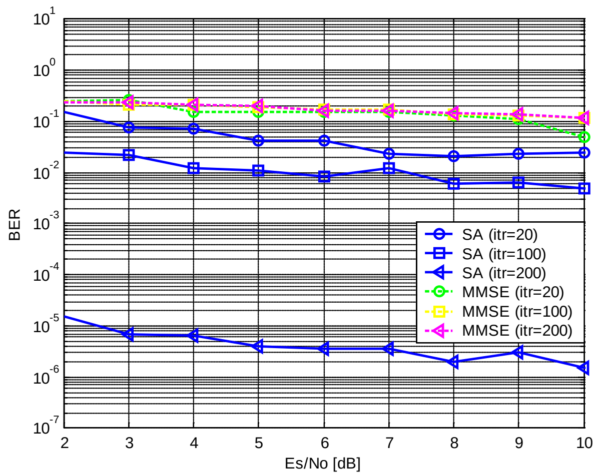

Figure 3: The BER vs. Es/No of SA-MUD (N=31, K= 10)

For the same iteration number (*itr*=100) and with different number of users (K=4 & 14), the SA detector performance is better if the number of users is smaller as seen in Figure 4.

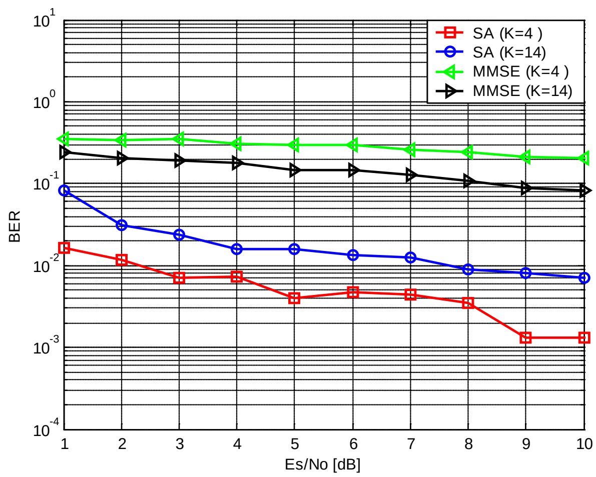

Figure 4: The BER vs. Es/No (N=31, *itr*= 100)

A common form in order to compare algorithms complexity can be done through the O notation, which means the order of magnitude of the algorithm complexity. But comparing algorithms only with O can be insufficient, mainly when they are similar or have the same order of magnitude [Ciriaco et al., 2006]. This work presents the algorithms complexity using only the mean computational time required for a specific optimization as illustrated in Figure 5, rather than the O notation and the number of computed instructions

The CPU time is obtained in the MATLAB environment on a 1,66 GHz; Pentium Intel(R) Core (TM)2 CPU T5500; personal computer with 1,00 Go of RAM.

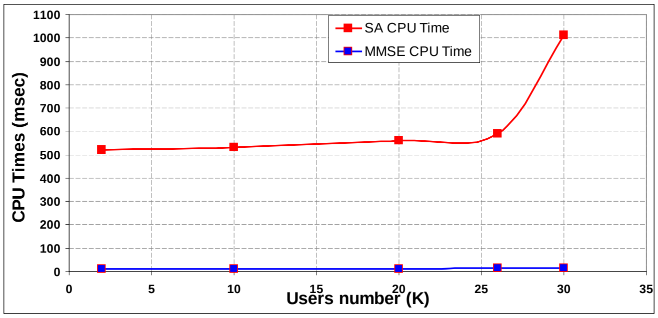

Figure 5: CPU Times comparison of various user numbers (N=31, itr=200)

The execution time is not affected by increasing the number of users and it does not progress exponentially as shown in Figure 5.

Conclusions

A novel simulating annealing algorithm with an extremely low complexity has been proposed for DS-CDMA multiuser detection. From the investigations conducted, it is observed that the BER performance of the proposed receiver is much better in comparison with conventional MMSE receiver. Thus, it is shown that the SA detection algorithm is a very promising multi-users detection especially for the future mobile radio systems. In future work, we plan to widen our investigations to the new meta-heuristic algorithms.

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