PSO-Algorithm-Assisted Multiuser Detection for Multiuser and Inter-symbol Interference Suppression in CDMA Communications

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Abstract
Applying particle swarm optimization (PSO) algorithm has become a widespread heuristic technique in many fields of engineering. In this paper, we apply PSO algorithm in additive white Gaussian noise (AWGN) and multipath fading channels. In the proposed method, PSO algorithm was applied to solve joint multiuser and inter-symbol interference (ISI) suppression problems in the code-division multiple-access (CDMA) systems over multipath Rayleigh fading channel and consequently, to reduce the computational complexity. At the first stage, to initialize the POS algorithm, conventional detector (CD) was employed. Then, time-varying acceleration coefficients (TVAC) were used in the PSO algorithm. The simulation results indicated that the performance of PSO-based multiuser detection (MUD) with TVAC is promising and it is outperforming the CD.

Keywords: Code Division Multiple Access, Particle Swarm Optimization Algorithm, Multiple Access Interference, Inter-Symbol Interference, Multiuser Detection.

1. Introduction

In direct sequence code-division multiple-access (CDMA) systems, different users transmit signals in the same time and frequency band. Users employ unique spreading codes to be distinguished. Some advantages of utilizing CDMA are: increased capacity, frequency reuse, soft handoff, no need to frequency management or assignment, no guard time, and multipath combating [1]. Direct sequence CDMA (DS-CDMA) is a popular CDMA technique in the wireless communications. The DS-CDMA transmitter multiplies each user’s signal by a spreading code. One of the most important problems that limit the capacity of the DS-CDMA systems is the multiple access interference (MAI) that directly relies on the cross-correlations between the spreading codes of all active users. The other problem nominated near-far occurs when the power level of certain users is significantly higher than the others. The near-far problem is an important factor that influences the user capacity and performance of CDMA systems. To obviate this problem, the multiuser detection (MUD) has been introduced as an important method in CDMA systems [2]. In multipath channels, the received signal at the receiver is the combination of delayed versions of the original signal leading to another problem called inter-symbol interference (ISI). The optimum multiuser detector minimizes the probability of error and evaluates a log-likelihood function over the set of all possible users' information sequences. Thus, employing the optimum multiuser detection (OMD) to suppression of MAI (and ISI) in the CDMA systems [3] is an NP-hard problem that increases the computational complexity exponentially with the number of all active users. High computational complexity of OMD leads to considerable efforts in the development of suboptimum detectors with low complexity.

The conventional detector (CD) is one of the suboptimum detectors that are used in CDMA systems. It is to pass the received signal through a bank of filters matched to the users’ spreading codes and detects the signal of a user treating the other users’ signals as noise. In multipath Rayleigh fading channel, the conventional single user detector is the Rake receiver that combines the outputs of the matched filters that uses the maximum ratio combining (MRC) technique [4].

To solve the NP-hard multiuser detection problems, various optimization algorithms that reduce the complexity of the optimum detector are employed. Particle swarm optimization (PSO) algorithm is one of the optimization algorithms that are applied as an optimization tool in various fields of engineering. Kennedy and Eberhart [5] in 1995 proposed PSO algorithm that is based on the observations of social behavioral models of bird flocking, fish schooling and swarming. It requires the process of initialization to produce the population of random particles. A particle is allocated to a random velocity. Particles fly through the

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solution space and a fitness criterion evaluates each of them. Particles accelerate toward those particles that have better fitness values in the swarm. PSO algorithm contains a very simple concept and can be implemented by a few lines of computer code that require only primitive mathematical operators. It is computationally inexpensive in terms of memory and speed as well [6]. At first, PSO was developed for optimization of a continuous variable. Then a discrete binary version of the PSO algorithm was proposed in [7].

In [8], [9] PSO algorithm have been employed to solve the MUD problems in DS-CDMA systems in order to reduce the computational complexity. In [10] binary PSO (BPSO) version was applied to solve the MUD problems. In [11] the de-correlating detector (DD) or linear minimum mean square error (LMMSE) detector was used to initialize the PSO-based MUD. Then, by optimizing an objective function that incorporates the linear system of the DD or LMMSE detector, the PSO algorithm was applied to detect the received data bit in the receiver. However, in these papers ISI problem was not considered. Applying the theory of MUD and evolutionary computation, [12] proposed a hybrid genetic engine, which is suitable for detection of CDMA signals in presence of MAI and ISI. [13] proposed the multiuser detection that uses simulated annealing-genetic algorithm. In [14] a multiuser detector based on tabu simulated annealing genetic algorithm was proposed. In [15] and [16] multiuser detection using quantum clone genetic algorithm and immune clone selection Algorithm were proposed, respectively. Neural network-based CDMA interference cancellation techniques were proposed in [17]. Multiuser detection using hyper differential evolution (H-DE) algorithm was proposed in [18]. In [19] a multiuser detection technique for the DS-CDMA system over a single-path Nakagami-m fading channel is proposed.

In this paper, we considered a DS-CDMA system over additive white Gaussian noise (AWGN) and multipath fading channels. We proposed to apply PSO algorithm to the multiuser detection over multipath Rayleigh fading channel. The conventional detector (CD) is used as the first stage to initialize the PSO algorithm and time-varying acceleration coefficients (TVAC) were used in PSO algorithm. The rest of this paper is structured as follows. In section 2, we introduce our CDMA system model over AWGN and multipath Rayleigh-fading channels, as well as the overview of the CD, DD and optimum multiuser detector. In section 3, the PSO algorithm in AWGN channel and proposed PSO algorithm and its application to CDMA system over multipath channel are given. In section 4, the computation complexity analysis is presented. The simulation results are presented in section 5, and finally conclusions are drawn in section 6.

2. The Model of DS-CDMA systems

We consider binary phase shift keying (BPSK) transmission through a common AWGN and multipath Rayleigh fading channels shared by *K* simultaneous users employing a DS-CDMA system. Each user is assigned a normalized spreading code $s_k(t)$ of duration *T*, where *T* is the symbol duration. A normalized spreading code can be expressed as:

$$\mathrm{s_k(t)} = \sum_{\mathrm{n=0}}^{\mathrm{N-1}} \mathrm{a_n^k(t)p(t - nT_c)} \tag{1}$$

$$\int_0^{\mathrm{T}} \mathrm{s_k^2(t)\, dt} = 1 \tag{2}$$

Where $[\, a_n^k(t) \in \{+1\,, -1\}\,, 0 \le n \le N-1]$ is the spreading sequence, $p(t)$ is the spreading chip whose duration is $T_c = T/N$. Spreading codes are assumed to be zero outside the interval [0,T]. We describe the model of a CDMA communication system in AWGN and multipath Rayleigh fading channels.

2.1 AWGN channel

We consider a baseband DS-CDMA system over a common AWGN channel, which adds a white random process $n(t)$ to the delayed transmitted signal, with *K* active users. The baseband received signal *r(t)* can be written as

$$\mathrm{r(t)} = \sum_{\mathrm{k=1}}^{\mathrm{K}} \sqrt{\mathrm{E_k}}\mathrm{b_k(t)s_k(t)} + \mathrm{n(t)} \tag{3}$$

Where *n(t)* is white Gaussian noise with power spectral density (PSD) σ^2.

The problem is to observe *r(t)* and to detect the transmitted bits such that the error probability is minimum. The first step is to reduce *r(t)* to a set of vector forming a sufficient statistics for *b*. A sufficient statistic of *r(t)* is the sampled output of the matched filter (MF) of all the users. Each filter matched to spreading code of a different user. The MF output is then given by

$$y_k = \int_0^T r(t)s_k(t)dt \quad , k = 1, \dots, K \tag{4}$$

Conventional Detector (CD)

CD is to pass the received signal through a bank of filters matched to the users' spreading codes and then to decide on the information bits based on the output

$$\hat{b} = sgn\,[y] = sgn\,[RAb + z] \tag{5}$$

Where *b,z,y* denote, the data, noise vector and output of *K* matched filter, respectively. b, z, y, A and R defined as

$$b = [b_1, b_2, \dots, b_K]^T \tag{6}$$

$$\begin{cases} z = [z_1, z_2, \dots, z_K]^T \\ z_k = \int_0^T n(t)\, s_k(t)dt \quad , k = 1, \dots, K \end{cases} \tag{7}$$

$$y = [y_1, y_2, \dots, y_K]^T \tag{8}$$

$$A = diag\,[\sqrt{E_1}, \sqrt{E_2}, \dots, \sqrt{E_K}]^T \tag{9}$$

$$R = \begin{bmatrix} 1 & R_{1,2} & \cdots & R_{1,K} \\ R_{2,1} & 1 & \cdots & R_{2,K} \\ \vdots & \vdots & \ddots & \vdots \\ R_{K,1} & R_{K,2} & \cdots & 1 \end{bmatrix} \quad (10)$$

Where R is a normalized cross-correlation matrix. The elements of the $K \times K$ matrix R are given by

$$R_{ij} = \int_0^T s_i(t) s_j(t) dt \quad (11)$$

Where R_{ij} is the cross-correlation coefficient between the ith user's spreading code $s_i(t)$ and jth user's spreading code $s_j(t)$.

De-correlating detector

The CD does not use any information about the other users in CDMA system and therefore can't combat MAI. The DD applies the inverse of the correlation matrix R to the output of the matched filter as shown in Fig. 1.

$$\hat{b} = sgn(R^{-1}y) = sgn(Ab + R^{-1}n) \quad (12)$$

It is optimum for near-far resistance but it is not optimum in the sense of minimum bit error rate (BER) [**Error! Bookmark not defined.**].

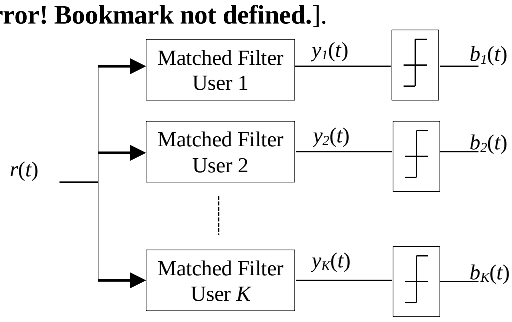

Fig. 1 Decorrelating detector for AWGN channel.

Optimum Multiuser Detection (OMD)

The optimum multiuser detector selects the data sequence b that maximizes the likelihood function that results in the following detection [**Error! Bookmark not defined.**]:

$$b^* = arg\left\{ \max_{b \in \{-1,1\}^K} [2\, y^T Ab - b^T ARAb] \right\} \quad (13)$$

The OMD rule searches over the 2^K possible combinations of the components b.

2.2 Multipath Fading Channel

We consider BPSK transmission over multipath Rayleigh-fading channels shared by K users employing DS-CDMA, as illustrated in Fig. 2.

The transmitted frame consisting of $2P$+1 number of bits for each user is assumed to be propagating over L independent Rayleigh-fading paths to the base station's receiver.

The impulse response of channel for kth user is

$$h_k(t) = \sum_{l=1}^{L} c_{k,l} e^{-j\phi_{k,l}} \delta(t - t_{k,l}) \quad (14)$$

Where $c_{k,l}$, $t_{k,l}$ and $\phi_{k,l}$ are the lth path gain, propagation delay and phase for kth user, respectively.

In the Rayleigh-fading channels, the channel gain is a zero-mean complex Gaussian random variable, where the amplitude $c_{k,l}$ is Rayleigh distributed and the phase $\phi_{k,l}$ is uniformly distributed between $[0,2\pi)$. Both $c_{k,l}$ and $\phi_{k,l}$ are independent for different k and l. The received signal can be written as

$$r(t) = \sum_{i=-P}^{P} \sum_{k=1}^{K} \sqrt{\frac{E_b}{T_b}}\, b_k(i) s_k(t - iT) * h_k(t) + n(t) \quad (15)$$

Where the symbol * denotes convolution, $E_k(i)$ and $b_k(i)$ are the power, the ith transmitted information bit of the kth user, respectively; $b_k(i) \in \{+1, -1\}$ is independent equal probability random variable.

$s_k(t)$ is the normalized spreading code of kth user and consists of bipolar rectangular pulses of period with $N\, T_c$, where T_c is the chip period, N is the length of code, such that $N = T/T_c$, and T is the data bit period. AWGN, resulting from receiver thermal noise ($n(t)$), is also considered in this system with PSD σ^2.

The output of the filter matched to the lth path of k at time iT is obtained as

$$y_{k,l}(i) = \int_{-\infty}^{\infty} r(t) s_k(t - iT - t_{k,l}) dt \quad (16)$$

Via matrix notation, the outputs of matched filter can be rewritten as

$$Y = RAWB + n \quad (17)$$

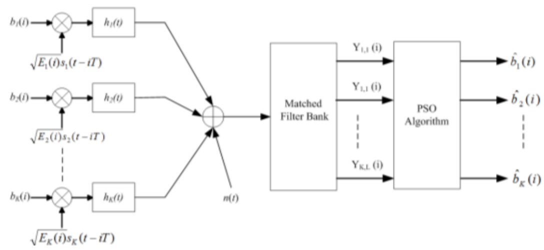

Fig. 2 System model for asynchronous PSO-based multiuser CDMA

Where

$$\begin{cases} Y = (Y(-P), \dots, Y(i), \dots, Y(P)) \\ Y(i) = (Y_1(i), \dots, Y_K(i)) \\ Y_k(i) = (Y_{k,1}(i), \dots, Y_{k,L}(i)) \end{cases} \quad (18)$$

$$\begin{cases} b = [b(-P), \dots, b(P)]^T \\ b(i) = [b_1(i)\, 1, \dots, b_K(i)\, 1] \end{cases} \quad (19)$$

Here $1 = (1, \dots, 1)^L$ is an L dimensional vector with all elements equal to 1. A is the matrix of received signal coefficients for all K users defined as

$$\begin{cases} A = diag(\alpha(-P), \dots, \alpha(P)) \\ \alpha(i) = (\alpha_{1,1}(i), \dots, \alpha_{1,L}(i), \dots, \alpha_{K,1}(i), \dots, \alpha_{K,L}(i)) \end{cases} \quad (20)$$

$$\begin{cases} W = diag(W(-P), \dots, W(P)) \\ W(i) = diag(\sqrt{\frac{E_b}{T_b}}\, I_{LK}) \end{cases} \quad (21)$$

Here I_{LK} is an LK-by-LK identity matrix.

Where $\alpha_{k,l} = c_{k,l} e^{-j\phi_{k,l}}$ and R is the correlation matrix,

$$R^{(i)} = \begin{pmatrix} R_{1,1}^{(i)} & \cdots & R_{1,K}^{(i)} \\ \vdots & \ddots & \vdots \\ R_{K,1}^{(i)} & \cdots & R_{K,K}^{(i)} \end{pmatrix} \quad (22)$$

Where

$$R_{k,\acute{k}}^{(i)} = \begin{pmatrix} R_{k,\acute{k}}(1,1,i) & \dots & R_{k,\acute{k}}(1,L,i) \\ \vdots & \ddots & \vdots \\ R_{k,\acute{k}}(L,1,i) & \dots & R_{k,\acute{k}}(L,L,i) \end{pmatrix} \quad (23)$$

R represents the cross-correlation functions between the spreading codes of users. $R_{k,\acute{k}}(l,\acute{l},i)$ is $k\acute{k}$th element is obtained as

$$R_{k,\acute{k}}(l,\acute{l},i) = \int_{-\infty}^{\infty} s_k(t - t_{k,l})\, s_{\acute{k}}(t - t_{\acute{k},\acute{l}} + iT) \quad (24)$$

$R_{k,\acute{k}}(l,\acute{l},i)$ represents the correlation between the *k*th user's *l*th multipath component and the $\acute{k}$th user's $\acute{l}$th multipath component.

n is Gaussian noise vector $[n_{k,l}]$ where

$$n_{k,l}(i) = \int_{-\infty}^{\infty} n(t) s_k(t - iT - t_{k,l}) dt \quad (25)$$

The conventional detector is the Rake receiver for each user, which combines the outputs of matched filters using the maximum ratio combining (MRC) method.

$$Y_k = Re\left\{\sum_{l=1}^{L} \alpha_{k,l}^{*}\ Y_{k,l}\right\} \quad (26)$$

The optimum multiuser detector selects the data sequence that maximizes the log-likelihood function as follows [20]

$$\Lambda(\mathcal{B},\alpha) = \sum_{i=-P}^{P} \frac{1}{N_0} \Big(2\Re\{\beta^H B^{(i)}\, Y^{(i)}\} - \sum_{i'=-P}^{P} \beta^T B^{(i)} R^{(i-i')}\, B^{(i')} \alpha^{*}\Big) \quad (27)$$

Where

$$\beta_{k,l} = \alpha_{k,l} \sqrt{\frac{E_b}{T_b}} \quad (28)$$

$$\beta = (\beta_{1,1}, \beta_{1,2}, \dots, \beta_{1,L}, \beta_{2,1}, \dots, \beta_{K,L})$$

And $(.)^H$ and $(.)^*$ denote the conjugate transpose and conjugate, respectively.

3. PSO Algorithm

A low-complexity multiuser detector for CDMA systems over AWGN and multipath Rayleigh fading channel by applying the PSO technique is presented in this section. Each solution is represented by a particle in the search space. The particles "fly" or "swarm" through the search space to find the maximum fitness returned by the objective function.

3.1 Parameters of the PSO Algorithm

The parameters of PSO algorithm for the CDMA systems with *K* users, and AWGN and *L* multipath channels are briefly stated and defined in the following list.

- **Population size *NP*:** It is the total number of particles in the PSO algorithm.
- **Particle x_d^{itr}:** It is a candidate solution represented by a *K* dimensional vector for AWGN channel and *K*(2*P*+1) dimensional vector for multipath channel. The *d*th particle position at the *itr*th iteration for AWGN channel is defined as

$$\mathrm{x_d^{itr}} = [\mathrm{x_{d,1}^{itr}}, \dots, \mathrm{x_{d,K}^{itr}}] \quad (29)$$

Where $x_{d,k}^{itr}$ is the position of the data bit of *k*th user of the *d*th particle.

The *d*th particle position at the *itr*th iteration for multipath channel is defined as

$$\mathrm{x_d^{itr}} = [\mathrm{x_{d,1,-P}^{itr}}, \dots, \mathrm{x_{d,k,i}^{itr}}, \dots, \mathrm{x_{d,K,P}^{itr}}] \quad (30)$$

Where $x_{d,k,i}^{itr}$ is the position of the *i*th data bit of *k*th user of the *d*th particle.

- **Particle velocity:** since each particle moves it has a velocity v_d^{itr} , where is a *K* and *K*(2*P*+1) dimensional vector for AWGN and multipath channels, respectively. Velocity of particles limited by the $[V^{min}, V^{max}]$.
- **Particle best:** each particle remembers its best position visited so far denoted as $pbest_d^{itr}$.
- **Global best:** each particle knows the best position visited so far among the entire swarm denoted as $gbest^{itr}$.
- **Acceleration coefficients:** c_1 and c_2 represent the weighting of the stochastic acceleration terms that pull each particle toward *pbest* and *gbest* positions. In the original PSO algorithm, the acceleration coefficients are kept constant for all iterations. It was reported in [21] that using time varying acceleration coefficients (TVAC) can enhance the performance of PSO algorithm.

$$c_1 = (c_{1f} - c_{1i}) \frac{itr}{itrmax} + c_{1i} \quad (31)$$

$$c_2 = (c_{2f} - c_{2i}) \frac{itr}{itrmax} + c_{2i} \quad (32)$$

Where c_{1i}, c_{1f}, c_{2i} , and c_{2f} are constants.

- **Objective function:** during each iteration of the algorithm, each solution is evaluated by an objective function to determine its fitness.

We use the log-likelihood function as fitness function. Problem in this paper is to find the particle position to maximize the following cost function Eq.(13) and Eq.(27) for AWGN and multipath channels, respectively.

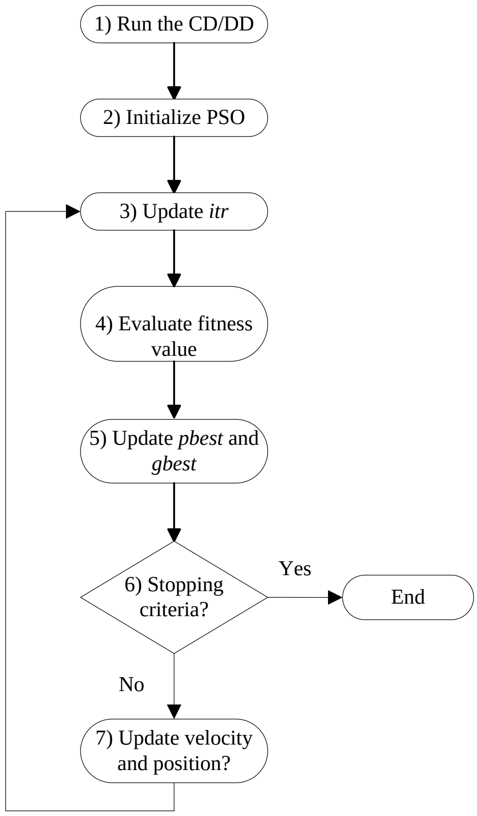

Fig. 3 Flowchart of PSO algorithm.

3.2 PSO Algorithm

The PSO algorithm flowchart is shown in Fig. 3. The PSO algorithm has the following steps:

1) Run the CD/DD.
2) Initialize the population: a bad initial guess for the PSO algorithm can result in poor performance. In *itr=1*, we set $x_{d=1}^{itr=1}$ to the Rake receiver output using MRC method and conventional/de-correlating detector for multipath fading and AWGN channels, respectively, while the rest of the initial particles $\{x_d^{itr}\}_{d=2:NP}^{itr=1}$ are randomly generated in the search space.
   Evaluate fitness of each particle and update $pbest_d^{itr}$ and $gbest^{itr}$.
3) Update velocity and position: the velocity and position of the dth particle in *(itr+1)*th iteration is updated using below equations:

$$v_d^{itr+1} = v_d^{itr} + c_1 * rand(\ ) * \left(pbest_d^{itr} - x_d^{itr}\right) + c_2 * rand(\ ) * \left(gbest^{itr} - x_d^{itr}\right) \quad (33)$$

$$x_d^{itr+1} = x_d^{itr} + v_d^{itr+1} \quad (34)$$

In the binary version of PSO algorithm, the particle position is not a real value, but it is either the binary 0 or 1. According to the rule below, we update each component of particle position.

$$\begin{aligned} &if\ rand < S\left(v_d^{itr+1}\right)\ then\ x_d^{itr+1} = 1\,, \\ &if\ rand > S\left(v_d^{itr+1}\right)\ then x_d^{itr+1} = -1 \end{aligned} \quad (35)$$

Where $rand(\ )$ and $S(\ )$ are a uniform random number between 0 and 1 and sigmoid function $S(x) = \frac{1}{1+exp(-x)}$, respectively [**Error! Bookmark not defined.**].

4) Stopping criteria: Loop to Step 3) until iterations the maximum number of iteration *itrmax* is reached.

4. Computation Complexity Analysis

It is well known that the computational complexity of the optimum detector in synchronous systems is exponential with the number of active users and in asynchronous systems is exponential with the number of active users and the length of the frame. In synchronous system with *K* active users and the computation Eq.(13) needs Q_G operations containing multiplication and addition operations. The computational complexity of the OMD is $Q_{OMD}=2^K.Q_G$ operations. In asynchronous system, suppose that there are *K* active users and each user transmits 2*P*+1 bits and the computation Eq.(27) needs Q_G operations containing multiplication and addition operations. The computational complexity of the OMD is $Q_{OMD}=2^{K(2P+1)}.Q_G$ operations.

With the number of particles *NP* and the maximum number of iterations *itrmax*, the computational complexity of our PSO-based MUD is $Q_{PSO\text{-}basedMUD}=itrmax.NP.Q_G$ operations. Computational complexities of *NP* and *itrmax* have a linear relationship with the dimensionality of the problem of the number of active users *K* and the length of the frame 2*P*+1.

The relationship between the computational amounts of two algorithms is

$$Q_{PSO-basd\ MUD} \ll Q_{OMD} \quad (36)$$

5. Simulation Results

In this section, simulations are presented to evaluate the BER performance results.

5.1 AWGN Channel

We present simulation results to compare the BER performance of the CD, DD and PSO-based MUD. It is assumed that CDMA system supports users' transmission over an AWGN channel with *K=6* and *7* bits gold sequence has been used as the spreading codes.

In Fig. 4, we compare the BER performance of different population size *NP* for $c_1=c_2=2$, and $V_{max}=V_{min}=4$.

As can be observed, the BER of PSO-based MUD is improved with *NP*.

In Fig. 5, The CD and DD output is used as $x_{d=1}^{itr=1}$ (PSO-C and PSO-D in Fig. 5) for initializing of PSO algorithm, respectively. Also, we compare the BER performance of DD, CD and PSO-based MUD that all of the particles randomly initialized (PSO in Fig. 5).

It is shown that CD and DD have a poor performance. The C-PSO and D-PSO MUD achieve a better performance.

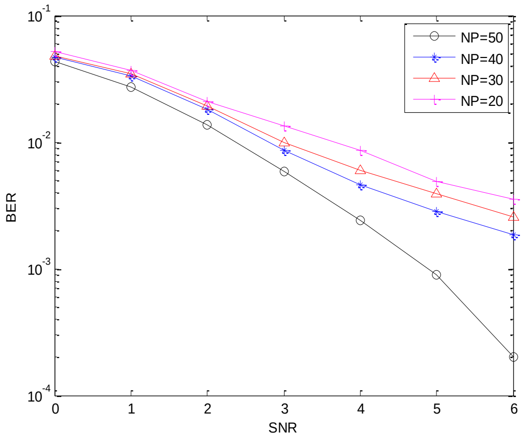

Fig. 4 BER for different population size.

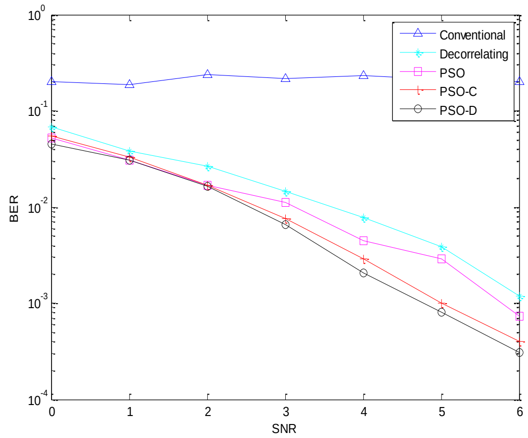

Fig. 5 BER of CD, DD and detection using PSO algorithms.

5.2 Multipath Fading Channel

We consider two users CDMA system to evaluate the BER performance. Assume that the channel has two paths and 7 bits gold sequence has been used as the spreading codes.

1) In the simulation system, *K=2*, *L=2*, $V_{max} = 2, V_{min} = -2, NP = 15, itrmax = 25$.

Under the different SNR, the performance of Rake detector and PSO-based MUD has been shown in the Fig. 6.

As can be observed, the BER of PSO-based MUD is lower than BER of Rake detector.

In [22] c_1 and c_2 are selected as follows:

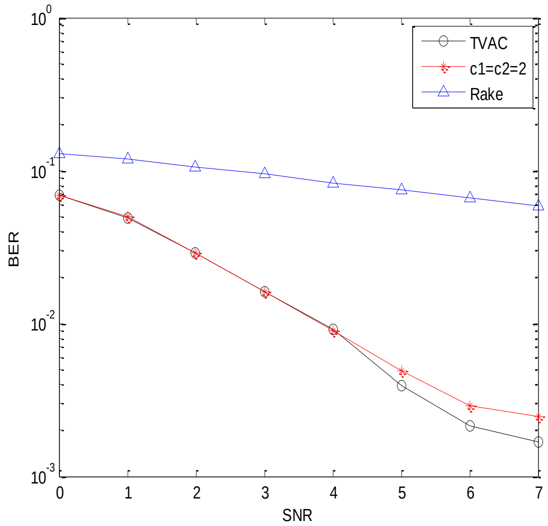

Fig. 6 BER of CD and detection using PSO algorithms.

$$c_1 = (0.5 - 2.5)\frac{itr}{itrmax} + 2.5 \qquad (37)$$

$$c_2 = (2.5 - 0.5)\frac{itr}{itrmax} + 0.5 \qquad (38)$$

Under the different SNR, the performance of PSO-based MUD for $c_1 = c_2 = 2$ and PSO-based MUD for Eq.(37), Eq.(38) has been shown in the Fig. 6.

As can observed, the BER of PSO-based MUD for Eq.(37), Eq.(38) is lower than BER of PSO-based MUD for $c_1 = c_2 = 2$.

2) In Fig. 7, we compare the average BER performance against the number of active users *K*, given SNR = 8 dB for the asynchronous CDMA system. It can be observed that PSO-based detector has a better BER performance than the Rake detector at the same *K*.
3) Fig. 8, plots the BER performance of PSO-based and Rake detector against the *Ei/E1* (*i*=2) from 0 to 9 dB, given the number of active user *K*=2 for the asynchronous CDMA system.

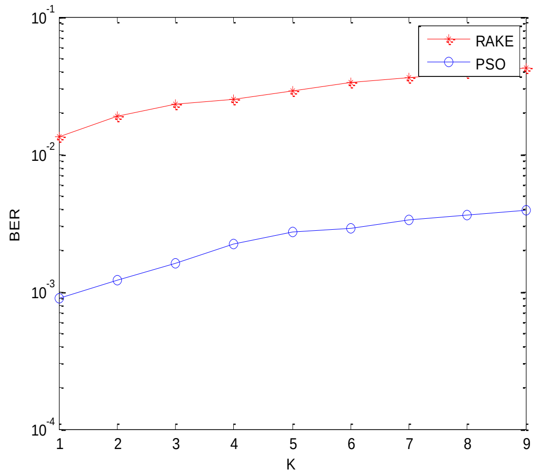

Fig. 7 BER against the number of active users *K*, given SNR = 8 dB for the asynchronous CDMA system.

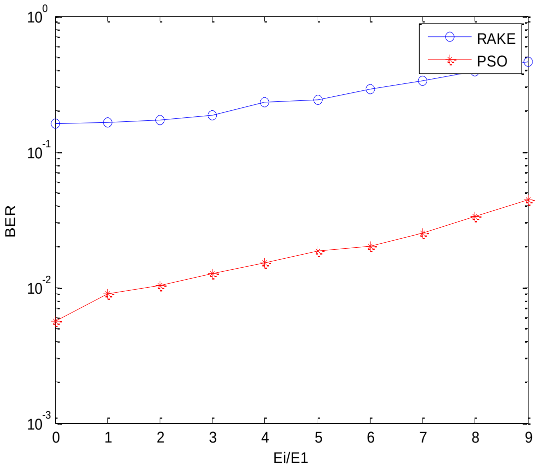

Fig. 8 BER performance against the *Ei/E1* (*i*=2).

6. Conclusions

In this paper, we exploited PSO algorithm in MUD over AWGN and multipath channels. PSO algorithm offered a much lower computational complexity than the OMD algorithm. In the proposed method for joint multiuser and inter-symbol interference suppression in multipath channel, output of the CD was applied as the first stage to initialize the position of a particle. The simulation results showed that the PSO-based MUD has better capability against bit error than CD and using the TVAC can enhance the performance of PSO algorithm.

References

[1] Lee, W. C. Y, “Overview of cellular CDMA”. IEEE Trans.Vehi. Tech. Vol . 40, No. 2, 1991, pp. 291–302.

[2] S.Verdu, Multiuser Detection. Cambridge, MA: Cambridge Univ. Press, 1998.

[3] S.Verdu, “Minimum probability of error for asynchronous Gaussian multiple-access channels,” IEEE Trans. Inform. Theory, Vol. IT-32, pp. 58-96, Jan. 1986.

[4] J. G. Proakis, Digital Communications. New York: McGraw-Hill, 1989.

[5] J. Kennedy and R. C. Eberhart, “Particle swarm optimization,” in Proc. IEEE Int. Conf. Neural Networks, Vol. IV, Perth, pp. 1942–1948, Australia, Nov./Dec. 1995.

[6] R. Eberhart and J. Kennedy, “A new optimizer using particles swarm theory,” inProc. ISMMHS, 1995, pp. 39–43.

[7] J. Kennedy and R. Eberhart, “A discrete binary version of the particle swarm algorithm,” inProc. IEEE CSMC, 1997, pp. 4104–4108.

[8] C. Liue, Y. Xiao, “Multiuser detection using the particle swarm optimization algorithm,” proceedings of ISCIT2005, pp. 350-353.

[9] H. L. Hung, Y. F. Huang and J. H. Wen, “A particle swarm optimization based multiuser detector for DS-CDMA communication systems,” 2006 IEEE International Conference on systems, Man, and Cybernetics, pp. 1956-1961, Taipei, Taiwan, October 8-11, 2006.

[10] Z. Su Lu and S. Yan,” Multiuser Detector Based on Particle Swarm Algorithm,” IEEE 6th CAS Symp. on Emerging Technologies: Mobile and Wireless Camm. pp. 783-786, Shanghai, China, May 3 I-June 2,2004.

[11] K. K. Soo, Y. M. Siu, W. S. Chan, L. Yang and R.S. Chen “Particle-swarm-optimization-based multiuser detector for cdma communications,” IEEE Trans. Vehicular technology, Vol. 56, No. 5, september 2007.

[12] S. Abedi and R. Tafazolli, “Genetically modified multiuser detection for code division multiple access systems,” IEEE Journal On Selected Areas IN Communications, Vol. 20, No. 2, pp. 463-473, FEBRUARY 2002.

[13] Y. Zhou, H. Wang, Y. Wei and J. Wang, "Simulated Annealing-Genetic Algorithm and Its Application in CDMA Multi-user Detection," 3rd International Conference on Intelligent Networks and Intelligent Systems (ICINIS), pp. 638-640, 2010.

[14] Z. Li and D. Ming, "Multi-user detection based on tabu simulated annealing genetic algorithm," International Conference on Instrumentation, Measurement, Computer, Communication and Control (IMCCC), pp. 948-951, 2012.

[15] L. Zhang, L. Zhang and H. Peng, "Quantum clone genetic algorithm based Multi-user detection," The 2nd International Conference on Next Generation Information Technology (ICNIT), pp. 115-119, 2011.

[16] Y. Wang, Z. Feng and L. Jia," A Novel Multiuser Detector Based on Immune Clone Selection Algorithm," Conference on Circuits, Communications and System (PACCS), pp. 238-241, 2010.

[17] B. Geevarghese, J. Thomas, G. Ninan, and A. Francis," CDMA Interference Cancellation Techniques Using Neural Networks in Rayleigh channels," 2013 International Conference on Information Communication and Embedded Systems (ICICES), pp.856-860, Feb. 2013.

[18] Z. Albataineh, F. Salem, " New Blind Multiuser Detection in DS-CDMA Using H-DE and ICA Algorithms," International Conference on 2013 4th Intelligent Systems Modelling & Simulation (ISMS), pp. 569-574, Jan. 2013.

[19] V. K. Pamula, S. R. Vempati, H. Khan, and A. K. Tipparti, " Multiuser Detection for DS-CDMA Systems over Nakagami-m Fading Channels using Particle Swarm Optimization," 2013 IEEE 9th International Colloquium on Signal Processing and its Applications, pp. 275-279, March 2013.

[20] U. Fawer and B. Aazhang, “A multiuser receiver for code division multiple access communications over multipath channels,” IEEE TRANSACTIONS ON COMMUNICATIONS, vol. 43, NO. 2/3/4, pp. 1556-1565, FEBRUARY/MARCH/APRIL 1995.

[21] A. Ratnaweera, S. K. Halgamuge and H. C. Watson, “Self-organizing hierarchical particle swarm optimizer with time-varying acceleration coefficients,” IEEE Trans on Evolutionary Computation, Vol. 8, No. 3, pp. 240-255. June 2004.

[22] W. Yao, S. Chen, S.Tan and L.Hanzo, ”Minimum bit error rate multiuser transmission designs using particle swarm optimisation,” IEEE. Trans on Wireless Communications, Vol. 8, No. 10, pp. 5012-5017. October 2009.

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