A Parallel Form Constant Module Algorithm for Blind Multi-user Detection in a Multicarrier CDMA Receiver

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Abstract: - A blind adaptive multi-user detector for multi-carrier code-division multiple accesses (MC-CDMA) based on constant modulus algorithm (CMA) with an orthogonalized structures is proposed. The proposed system improves the performance of previously proposed blind MC-CDMA receiver by using a subband decomposition approach, in which the adaptation is carried out, independently, each band using the CMA to minimize a common error. Simulations shows that proposed approach reduce the computation cost while keeping a fairly good detection performance.

Key-Words: - Blind detection, Multi-carrier CDMA, CMA, Subband decomposition, Multiuser detection.

1 Introduction

As the radio frequency spectrum is a scarce resource, future wireless radio networks need to make efficient use of it by providing high capacity in terms of the number of users allowed in the system. As a consequence, modulation and multiple access techniques designed specifically for wireless channels play an important role in achieving this goal. For mobile communication systems, diversity reception is essential to reduce the effects of fading radio channels. Direct-sequence code division multiple access (DS-CDMA) is a multiplexing technique where several independent users share a common channel by modulating preassigned signature waveforms. The receiver then observes the sum of the transmitted signals over an additive white Gaussian noise (AWGN) channel.

The major limitation on the performance and channel capacity of DS-CDMA system is the multiple-access interference (MAI) due to simultaneous transmissions. The conventional matched filter (MF) detector cannot suppress MAI efectively, and it suffers from the near-far problem. Since CDMA is not fundamentally MAI limited, multiuser detection (MUD) techniques can substantially improve the performance of a CDMA system. While the optimal multiuser detector, which is essentially a maximum-likelihood (ML) sequence detector, has prohibitive complexity many other multiuser detectors with relatively low complexity such as decision feedback detector, successive or parallel interference canceller, and linear multiuser detectors have been developed. The linear decorrelator removes all cross-correlations between active users and thereby eliminates MAI at the price of enhancing noise [2].

On other hand, multicarrier CDMA radio systems have been proposed to enhance diversity reception as compared to single-carrier DS-CDMA systems [1]. An MC--CDMA system operating within the same total bandwidth as the single carrier system can produce better performance, even though the order of diversity of the channel is the same in both cases. This is because the diversity gain actually obtained at the receiver can be greater for multi-carrier signaling.

Recently, blind adaptive multi-user detection has received special attention and several blind adaptive detectors have been proposed [1]–[3]. The main motivation for employing a blind detector is to avoid the requirements of a training sequence, which is commonly required in most of the adaptive multi-user detectors proposed previously. Blind detection avoids the requirements for prior knowledge of system parameters, and under appropriate initial conditions its performance is not considerably degraded when compared to detectors requiring a training sequence. In this sense, the constant modulus algorithm (CMA) has been widely applied to cancel intersymbol interference (ISI) for digital transmission through band-limited channels. So, based on the combined channel and equalizer parameter space, a finite-length tap filter with CMA tap updates will be able to converge nearly to global minimum.

In this paper, we suggest an alternative approach for blind multiuser detection based on CMA.

Enforcing that the main tap be greater than zero, all ambiguities are avoided. A structure based on the asynchronous MC-DS-CDMA model proposed in [4] for fading multipath dispersive subcarrier channels is investigated. Similar than in the original structure, an array receiver is employed at the base station so that processing is performed jointly in the spatial, temporal and multi-carrier domains, producing a significant performance enhancement. However, to improve the performance of [4], we introduce a decision-feedback blind adaptive multi-user detector (DFMBD) and a constant modulus algorithm, where a CMA is used to estimate the composite channel vector of a particular user at the end of the receiver. To reduce the DFMBD computational complexity this paper proposes an alternative approach for blind adaptive multi-user detection based on subband decomposition in which instead of a long tap filter, a subband decomposition approach is used to transform the system input into a finite number of mutually orthogonal filters bank, which are independently updated using the CMA to minimize a common error. This approach provides an important because the adaptation process is performed over filters with shorter lengths, which leads to reduce the complexity overall system.

The rest of the paper is organized as follows. In Section 2 the system model is provided. Section 3 describes the basic concepts of blind multiuser detection and describes a method to implement it. In Section 4 provides the subband decomposition method and the use of this theory to develop a fast blind multiuser detector. In Section 5 provides simulation results to show the performance of the proposed blind equalization scheme and finally, Section 6 provides the conclusion of this research.

2 System Model

In this section we describe an asynchronous MC-CDMA spatio temporal array communication system subject to a frequency selective channel, which is based on the work of Sadler and Manikas [4].

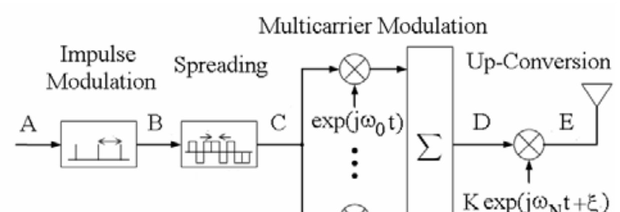

Fig. 1. Multicarrier CDMA system model

2.1. Transmitter

Consider the block diagram of a particular mobile transmitter shown in Fig. 1. At point A, the *i*th user produces a sequence of complex channel symbols according to the M-ary modulation scheme to be employed, where M is the number of points in the signal constellation. The channel symbols are denoted by $\{b_i[n]\in C, \forall \in Z\}$ and have a rate of $r_{cs}=r_b=\log_2(M)$ symbols per second. In this paper quaternary phase shift keying (QPSK) is considered, where each symbol being imparted has unit energy. The channel symbol sequence is then transformed into an impulse train at point B given by

$$b_i(t)=\sum_{n=-\infty}^{\infty} b_i[n]\delta(t-nT_{cs}) \quad nT_{cs}\le t<(n+1)T_{cs} \tag{1}$$

where $T_{cs}=1/r_{cs}$ is the channel symbol period and $\delta(t)$ is the delta function. Convolving this signal with one period of a

$$m_i(t)=\sum_{n=-\infty}^{\infty} b_i[n]c_{PN,i}(t-nT_{cs}). \tag{2}$$

pseudo-noise (PN) signal spreads the signal over a wider bandwidth, producing a baseband DS-CDMA signal at point C, where a single period of the PN-signal for the *i*th user is modelled by

$$c_{PN,i}(t)=\sum_{m=0}^{N_c-1}\alpha_i[m]p_c(t-mT_c) \quad mT_{cs}\le t<(m+1)T_{cs} \tag{3}$$

where $\alpha_i[m]$ is the *i*th user's PN-sequence of length N_c and $p_c(t)$ is a rectangular, chip pulse waveform of duration T_c. Note that a short code system is being used, so the number of chips per symbol is equal to the length of the PN-sequence.

The DS-CDMA signal now modulates N_{cs} subcarriers, which are summed to produce the signal at point D, which is then up converted to the carrier frequency to produce the transmitted radio frequency signal at point E,

$$y_i(t)=\sum_{k=0}^{N_{sc}-1}\sqrt{P_i}\exp\left(j(2\pi F_c t+\varsigma_i)\right)\exp\left(j2\pi F_k t\right)m_i(t) \tag{4}$$

in which P_i is the transmitted power, F_c is the carrier frequency and ς_i is a random phase offset relative to the base station receiver.

2.2 Channel Model

The radio channel is assumed to be fading and multipath dispersive so that the array complex baseband channel impulse response for the kth subcarrier, j th path of the i th user are given by

$$\mathbf{c}_{ijk}(t) = \beta_{ijk}\mathbf{S}_{ijk}\delta(t-\tau_{ij}) \quad (5)$$

where β_{ijk} is the complex path coefficient which encompasses random phase shifts and fading effects. τ_{ij} is the path delay and will be the same for all subcarriers, for a particular path. The vector $\mathbf{S}_{ijk}$ is the array manifold vector at a frequency of $F_c + F_k$ for a specific path. In general the parameters β_{ijk}, τ_{ij} and $\mathbf{S}_{ijk}$ can be assumed to be independent of time for symbols transmitted during the channel coherence time. For this case, the channel is assumed to be quasi-stationary.

2.3 Array Receiver Front Model

At the base station the superimposed radio signals for all users, paths and subcarriers are received through an antenna array. We consider M mobile stations with K_i paths for the i th user. After the carriers are removed, the $N \times 1$ complex received signal vector at point F of figure 2 is given by

$$\underline{x}(t) = \sum_{i=1}^{M}\sum_{j=0}^{K_i}\sum_{k=0}^{N_{sc}-1}\beta_{ijk}\underline{S}_{ijk}\exp(j2\pi F_k(t-\tau_{ij}))m_i(t-\tau_{ij}) + \underline{n}(t) \quad (6)$$

Once this signal is discretized through a bank of samplers operating at a rate of $1/T_s$ where $T_s = T_c/qN_{sc}$ and $q \in N$ is the oversampling factor, the samples are passed through N tapped delay lines of length $2L$. A long vector $\mathbf{x}(n)$ is formed at point G by concatenating the contents of the tapped delay lines for all antennas and reading the entries every symbol period,

$$\mathbf{x}(n) = [x_1(n)\; x_2(n) \ldots x_N(n)]^T \quad (7)$$

This multicarrier space-time received signal vector contains the signals associated with the n th instant symbol, furthermore, contributions from the previous and next data symbols are present due to the lack of synchronization. This vector consider the contributions from all subcarriers and its derivation is explained in [4]

3 Blind Multiuser Detector

According to the receiver structure considered above, a blind adaptive multiuser detector can consist of a bank of equalizers followed by quantizers as shown in Fig. 2. The output of the equalizer for the i th user can be expressed as

$$d_i(n) = \sum_{l=1}^{i} w_{il}x_l(n) = \mathbf{w}_i^T(n)\mathbf{x}_i(n) \quad i = 1,2,\ldots K \quad (8)$$

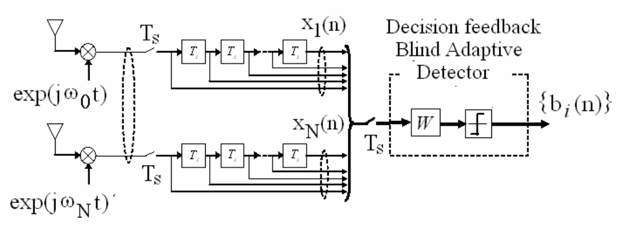

Fig. 2 Blind decision feedback detector

where $\mathbf{w}_i(n)$ and $\mathbf{x}_i(n)$ represent the tap coefficient vector and the input signal vector of the equalizer at the n th instant, respectively. Since the information bits have been assumed to take on antipodal binary values ± 1, the Godard cost function [6] has the form as follows:

$$J(d_i(n)) = \frac{1}{4}E\left[\left(d_i^2(n)-1\right)^2\right] \quad i = 1,2,\ldots K \quad (9)$$

The objective of the blind equalizer is to minimize the cost function (9) by adjusting the tap coefficients adaptively. Assuming $\mathbf{w}_i(n)$ at the n th instant are known, the recursive formula for the next decision can be written as

$$\mathbf{w}_i(n+1) = \mathbf{w}_i(n) - \mu\frac{\partial J(d_i(n))}{\partial \mathbf{w}_i(n)} \quad i = 1,2,\ldots K \quad (10)$$

where μ is the step-size parameter. By differentiating $J(d_i(n))$ and dropping the expectation operation, we can get the recursive formula as follows:

$$\mathbf{w}_i(n+1) = \mathbf{w}_i(n) - \mu\mathbf{x}_i(n)d_i(n)\left(d_i^2(n)-1\right) i = 1,2,\ldots K\,. \quad (11)$$

From (11), only the signal $x_i(n)$ contains the desired information bit $b_i(n)$ of user i, the minimization of the cost function (10) naturally results in an optimal solution for i th user only if the main tap coefficient w_{ii} is not equal to zero. After convergence of the blind equalizer, the decision for i th user at the n th instant can be made by taking the sign of $d_i(n)$

$$\hat{b}_i(n) = \operatorname{sgn}(d_i(n)) \quad (12)$$

Decision feedback introduces a nonlinear process, which has the potential of improving performance beyond the constraints imposed by linear detectors. Such detectors are, however, prone to error propagation in case of erroneous decisions. It is therefore important to detect users according to received amplitude. We can extent a blind CMA detector to include decision feedback. The development of the algorithm progresses as follows.

Based on the noise-whitened statistics, equalization for user 1 is not necessary because $x_i(n)$ is not perturbed by MAI from the other users. The decision for user 1 is made directly as

$$\hat{b}_i(n) = \mathrm{sgn}(r_i(n)) = \mathrm{sgn}(x_i(n)) \quad (13)$$

For user 2, since the decision for user 1 has been made, the equalization for the user can be realized by feeding back the decision $\hat{b}_1$ as

$$r_2(n) = w_{2,2}x_2(n) + w_{2,1}\hat{b}_1(n) \ . \quad (14)$$

The decision for user 2 can be obtained as

$$\hat{b}_2(n) = \mathrm{sgn}(r_i(n)) = \mathrm{sgn}(r_2(n)). \quad (15)$$

Similarly, for the i th user, the equalizer output of can be expressed as

$$d_i(n) = w_{i,i}x_i(n) + w_{i,i-1}\hat{b}_{i-1}(n) + w_{i,i-1}\hat{b}_{i-1}(n) + \cdots + w_{i,1}\hat{b}_1(n) \quad (16)$$

$$= \mathbf{W}_i^T(n)\hat{\mathbf{X}}_i(n), \quad i = 2,3,\ldots,M \quad (17)$$

where

$$\hat{\mathbf{X}}_i(n) = \left[x_i(n)\,\hat{b}_{i-1}(n)\,\hat{b}_{i-i}(n)\ldots\hat{b}_1(n)\right] \quad (18)$$

is the input vector of the equalizer at the n th instant. Therefore, the decision for the i th user can be made by

$$\hat{b}_i(n) = \mathrm{sgn}(r_i(n)) \quad i = 1, 2, \ldots, M \quad (19)$$

Substituting (16) into (10)–(12), we get the decision feedback blind equalization algorithm. The recursive formula of the tap coefficients for the blind equalizer can be rewritten as

$$\mathbf{W}_i(n+1) = \mathbf{W}_i(n) - \mu\hat{\mathbf{X}}_i(n)d_i(n)\left(d_i^2(n) - 1\right). \quad (20)$$

Combining (16)–(19), we obtain the decision-feedback blind adaptive multiuser detector (DFBD). It can be expected that the performance of the DFBD is superior to that of the blind adaptive multiuser detector described in Section III, because the noise of the feedback signals can be cancelled completely provided that the decisions for the former users are correct. Similar to the blind adaptive multiuser detector, the DFBD is also free of the phase and permutation ambiguities.

4 Parallel Realization Form

Consider the transfer function of the adaptive filter, *H(z)* whose transfer function is given by:

$$H(z) = \sum_{i=0}^{N-1} h_i z^{-i} \quad (21)$$

where h_i is the *ith* coefficient of the transversal filter. Using a subband decomposition approach, $W(z)$ can be represented in terms of a bank of M subfilters operating in parallel as follows:

$$H(z) = \left[1, Z^{-1}, \ldots, Z^{-(M-1)}\right] C^T \begin{bmatrix} G_0(Z^L) \\ G_2(Z^L) \\ \vdots \\ G_{M-1}(Z^L) \end{bmatrix} \quad (22)$$

where C represents an orthogonal transform of $MxM, G_r(Z^L)$ denotes a subfilter with transfer function given by [10]

$$W_r(Z^L) = \sum_{l=0}^{K-1} w_{r,l} Z^{-lL} \quad (23)$$

L is a factor of interleave between coefficients and K is the number of coefficients in each subfilter. Next using discrete cosine transform as orthogonal transform C in (22), the equations (21)-(23) lead to the parallel structure of adaptive blind decision-feedback detector is shown in Fig 3, whose transfer function is given by

$$H(z) = \sum_{r=0}^{M-1} C_r(z) W_r(z), \quad (24)$$

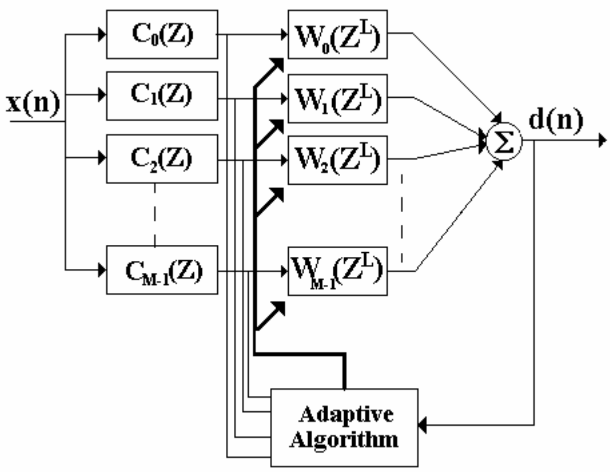

Fig. 3 Fast parallel form equalizer for the ith user.

where $C_r(z)$ is the discrete cosine transform. To save computational effort, $C_r(z)$ can be calculated recursive as follows

$$C(n,r) = 2\cos\left(\frac{\pi r}{N}\right) C(n-1,r) - C(n-2,r) - \cos\left(\frac{\pi r}{N}\right) \left(x(n-N-1) - x(n-1)(-1)^r - x(n-N) + x(n)(-1)^r\right) \qquad (20)$$

Coefficients $w_{i,j}$ are jointed updated for every user. The special function of this model is improving convergence rates of gradient-based blind adaptive algorithms.

5. Simulation results

In this section, the performance of the blind adaptive multiuser detector is estimated by simulations for asynchronous CDMA systems. The performance of the proposed structure is compared with de conventional equalizer based on training in Fig. 4. Figure 5 shows the performance of the blind DFE with respect to users number in de system and Fig. 6 shows the parameter trajectories of the blind equalizer for the 3th user.

To compare the performance of subband decomposition based and a full band blind adaptive decision-feedback multiuser detector in a DS-CDMA system, the Gold codes was used for the PN-sequences and QPSK modulation, where the full band structure will provide an upper limit for the detector performance. The expectation operation in the cost function (21) is very difficult to do in practice; so, we will use the time average cost function defined as

$$\bar{J} = \frac{1}{4N}\sum_{i=1}^{N}\left[x^2(i)-1\right]^2 \qquad (21)$$

The evaluation results are shown in Figs. 7-9.

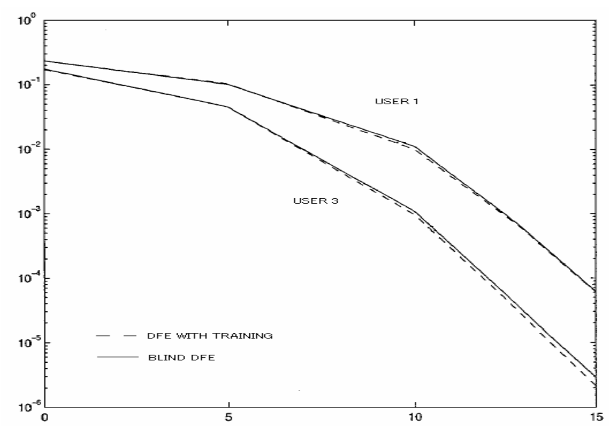

Fig. 4 Performance of conventional and proposed blind equalizer structures.

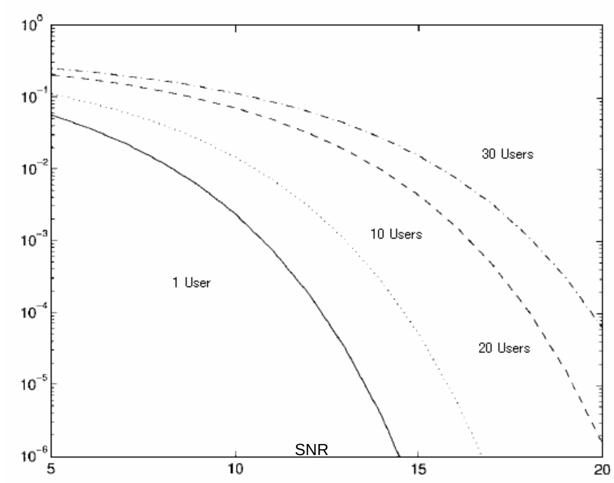

Fig. 5 Performance of the Blind equalizer proposed with respect to users number.

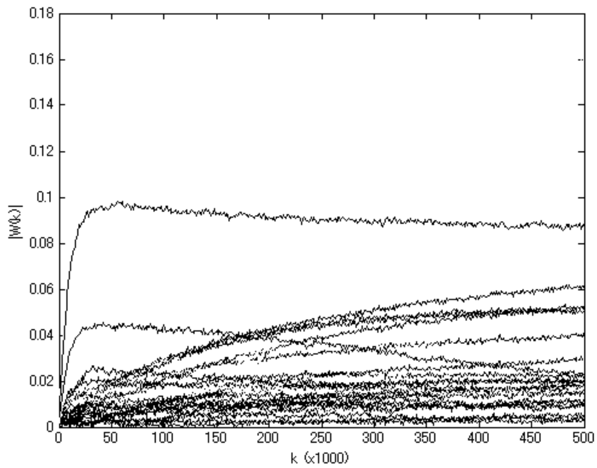

Fig 6 Parameters trajectories of the blind equalizer for the 3th user.

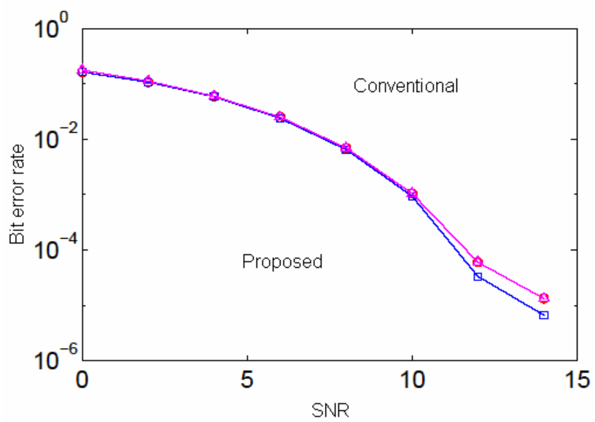

Fig 7 Bit error rate for conventional blind adaptive detector and proposed model with 15 users.

Simulation results shown that the performance of proposed method is similar to conventional algorithm with respect to BER, however, the algorithm with subband decomposition get better convergence rates offering the same estimation error compared with the conventional detector.

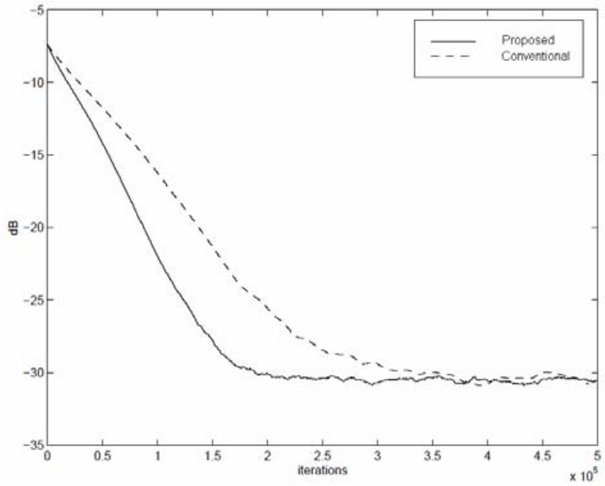

Fig 8 MSE Performace.

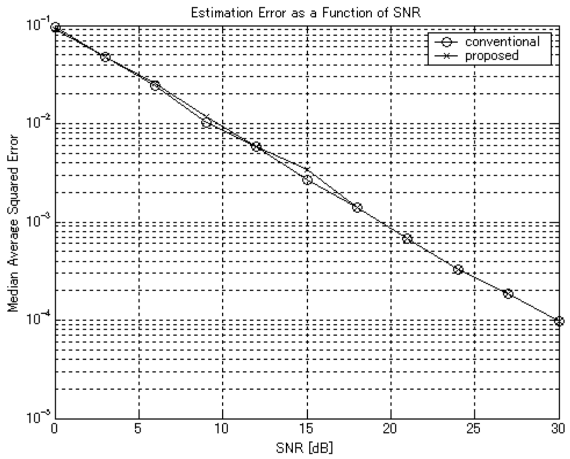

Fig 9 Estimation error for 15 users.

5. Conclusions

In this paper we have presented the application of constant modulus algorithm to blind multiuser detection. We used as a reference a blind multicarrier CDMA receiver proposed before in the literature. To improve bit error rate, we used a decision feedback equalizer at the end of the receiver, which does not require knowing about parameters of the system. Simulation results show that the proposed structure has a similar performance compared with conventional equalizer. However, the complexity of the proposed algorithm increase rapidly as the users number increase. This algorithm does not exploit all rich structure of multicarrier CDMA systems, so, future work can be realized to improve the proposed method considering others characteristics of the system.

An alternative approach to blind multiuser detection in CDMA communication systems with reduced complexity was introduced. The proposed method uses a decision-direct structure to combine subband decomposition and blind adaptation of the equalizer. Simulation results show that proposed algorithm achieves a near performance compared with conventional method but it reduces the complexity in adaptation process, which increase convergence rates of the algorithm.

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