Computers and Electrical Engineering 36 (2010) 160–168

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Blind multiuser detection for MC-CDMA with antenna array

Xiaofei Zhang, Gaopeng Feng, Xin Gao, Dazhuan Xu

Department of Electronic Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

ARTICLE INFO

Article history:
Received 4 June 2008
Received in revised form 3 August 2009
Accepted 24 August 2009
Available online 18 September 2009

Keywords:
MC-CDMA
Antenna array
Multiuser detection
Trilinear model

ABSTRACT

We investigate the characteristics of the received signal as trilinear model for multi-carrier code division multiple access (MC-CDMA) system with antenna array, and propose a blind multiuser detection method for MC-CDMA system in this paper. The trilinear-based multiuser detection algorithm (Trilinear-MUDE) that we presented exploits the versatile diversity in MC-CDMA system while require neither channel information nor statistical characteristics. The algorithmic performance indicates that the proposed algorithm is very close to the nonblind MMSE method, and better than minimum output energy (MOE) receiver and matched filter. Numerical results also reveal its compatibility in condition of small sampling sizes.

1. Introduction

Motivated by the communication technology of multi-carrier code division multiple access (MC-CDMA) where both orthogonal frequency-division multiplexing (OFDM) and code division multiple access (CDMA) has been collaborated, extensive attentions have been paid up for MC-CDMA as merits in the context of 4G communication systems. It is well-known that MC-CDMA systems can have inherent advantages such as high spectral efficiency, robustness to frequency selective channels, narrow band interference rejection and multiple access capability [1], therefore, special use of antenna array at the receiver are normally exploited throughout the spatial domain to provide an extra way of cochannel interference cancellation. Also, analysis for the use of adaptive antenna array in MC-CDMA base station has been confirmed for its enhancement of system capacity [2]. Many multiuser detection methods [3–20] for MC-CDMA system have been put forward in the past decade, for instance, the optimal multiuser detection takes advantage of maximum likelihood sequence for detection and can have an exponential complexity in the number of users [3]. Meanwhile, a lot more attention has been devoted to the development of suboptimal receivers, which have good multiuser detection properties with more moderate complexity to ensure their practical implementation. Some decorrelating detectors for MC-CDMA systems have been developed in [4] and [5]. Linear minimum mean-squared error (LMMSE) multiuser detectors [6] have been proposed as effective techniques to mitigate multi-access interference (MAI) in MC-CDMA systems. The multiuser detection algorithms in [4–6] require the perfect channel information or channel estimation, while imperfect channel information deteriorates performance [7]. In addition, Fantacci et al. [8] utilizes the pilot for channel estimation and then multiuser detection. Seen from the blind methods for multiuser detection which does not require channel information, training sequence or pilot, characteristics of constant modulus [9] and Kurtosis maximization [10] have been treated for blind multiuser detection in MC-CDMA system. The constant modulus method is dependant on statistics characteristic of the source signal. For shaped sources with near-Gaussian kurtoses, the cost surface of constant modulus has been raised and flattened, and hence no longer compatible for stochastic gradient descent [11]. Minimum output energy (MOE) [12] and minimum variance [13] are also presented for blind multiuser detection in MC-CDMA system. To step further, subspace-based method [14,15] and neural networks [16] are constructed for

E-mail address: fei_zxf@163.com (X. Zhang)

0045-7906/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compeleceng.2009.08.002

blind MC-CDMA multiuser detection, which often require larger snapshots to perform well. However, the weakness of most existing blind methods lies on their insufficient availability for all diversity forms.

Trilinear decomposition or PARAllel FACtor (PARAFAC) analysis has been first introduced as a data analysis tool in psychometrics, most of the research in the area is conducted in the context of chemometrics, chromatographic and flow injection analysis. In this paper, we construct the received signal of MC-CDMA system with antenna array as trilinear model, and derive a trilinear decomposition-based blind multiuser detection algorithm (Trilinear-MUDE) which requires no statistics characteristic of the source signal. When fully utilizing the spread, spatial and temporal diversity in the MC-CDMA system, the proposed algorithm does not require channel fading information or direction of arrival (DOA) knowledge. Comparing to blind MOE receiver or matched filter, our algorithm can have better performance and support small sample sizes. We also investigate the algorithmic performance for multiuser detection under variable user numbers.

We construct the remainder of this paper as follows: Section 2 develops the data model. Section 3 deals with both identifiability issues and algorithmic presentations. Section 4 shows out the simulation results, and Section 5 summarizes our conclusions.

Notations: $(\cdot)^*$, $(\cdot)^T$, $(\cdot)^H$, $(\cdot)^\dagger$, $(\cdot)^{-1}$ and $\|\,\|_F$ denote the complex conjugation, transpose, conjugate–transpose, inverse, pseudo-inverse operations and Forbenius norm, respectively. $diag\{\mathbf{v}\}$ stands for diagonal matrix whose diagonal is the vector $\mathbf{v}$; $\min(\cdot)$ is get minimum elements of an array; $\mathbf{I}_P$ denotes a $P \times P$ identity matrix; $\mathbf{1}_{N\times 1}$ is an $N \times 1$ vector of ones.

2. The data model

We assume that there are K users in the MC-CDMA system, where the receiver has been equipped with an I-element uniform-linear-array (ULA) antenna array. The transmitter structure of the kth user can be shown in Fig. 1.

The symbol sequence of the kth user is $\mathbf{b}_k = [b_k(1), b_k(2), \ldots, b_k(L)]^T$, where $b_k(l) \in \{\pm 1\}$, L stands for the symbol length, and the data symbol $\mathbf{b}_k$ is binary phase shift-keying (BPSK) modulated and transmitted in parallel over N subcarriers, each multiplied by a different element of the distinct spreading sequence $\mathbf{c}_k$. The output signal of spread spectrum is given by $\mathbf{u}_k = \mathbf{c}_k\mathbf{b}_k^T$, where $\mathbf{c}_k = [\,c_k(1) \quad c_k(2) \quad \cdots \quad c_k(N)\,]^T$ represents the spread code of the kth user, in which $c_k(n) \in \{\pm 1\}$. Noted that the signal $\mathbf{u}_k$ has been processed under multi-carrier modulation. Hence, the multi-carrier modulation can be denoted as IFFT. We denote the output signal of multi-carrier modulation as $\mathbf{d}_k = \mathbf{F}^H\mathbf{u}_k = \mathbf{F}^H\mathbf{c}_k\mathbf{b}_k^T$, where $\mathbf{F}$ is the discrete Fourier transform matrix with $N \times N$, and $\mathbf{F}^H$ stands for inverse discrete Fourier transform. We assume that each of the K users only has a single path to its antenna array receiver. We also assume that the signals of K users synchronously arrive at their receivers. The received signal of the ith antenna can be given in this form

$$\mathbf{X}_i = \sum_{k=1}^{K} \mathbf{d}_k h_{i,k} = \sum_{k=1}^{K} \mathbf{F}^H\mathbf{c}_k\mathbf{b}_k^T h_{i,k} = \mathbf{F}^H\mathbf{C}\, diag\{h_{i,1}, h_{i,2}, \ldots, h_{i,K}\}\mathbf{B}^T, \quad i = 1, 2, \ldots, I \tag{1}$$

where $h_{i,k}$ is the channel response between the kth user and the ith antenna of array antennas, and $\mathbf{C} = [\,\mathbf{c}_1 \quad \mathbf{c}_2 \quad \cdots \quad \mathbf{c}_K\,] \in \mathbb{R}^{N\times K}$, $\mathbf{B} = [\,\mathbf{b}_1 \quad \mathbf{b}_2 \quad \cdots \quad \mathbf{b}_K\,] \in \mathbb{R}^{L\times K}$ represent the spreading matrix and the source matrix, respectively. Now we Define channel matrix,

$$\mathbf{H} = \begin{bmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,K} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,K} \\ \vdots & \vdots & \ddots & \vdots \\ h_{I,1} & h_{I,2} & \cdots & h_{I,K} \end{bmatrix} \in \mathbb{C}^{I\times K}, \quad h_{i,k} = h_{j,k}e^{-j2\pi d(i-j)\sin\theta_k/\lambda} \tag{2}$$

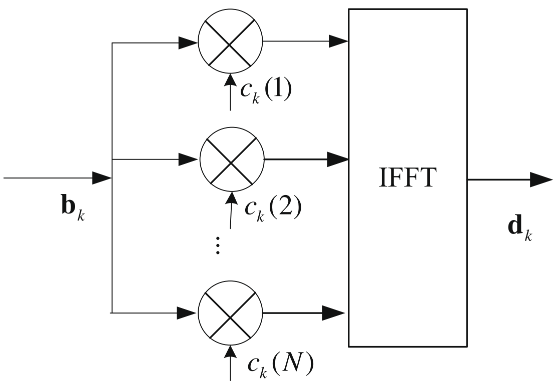

Fig. 1. The transmitter structure of the kth user.