Blind MIMO Channel Estimation of CDMA System

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Abstract

In this paper, a blind receiving system for Multiple Input Multiple Output (MIMO) channel estimation of Code Division Multiple Access (CDMA) system based on Independent Component Analysis (ICA) is proposed. The proposed receiving system exploits the statistical independence of the received signals in order to blind wireless channel estimation processes. The MIMO channel matrix is estimated by gradient kurtosis-based objective function of the received signals. In contrast to other approaches, the proposed method does not require any modification in the transmission side or using the training signals. Simulation results demonstrate the benefits of the proposed method comparing with other conventional methods.

***Keywords*:** Blind Channel Estimation, Code Division Multiple Access, Independent Component Analysis, MIMO Wireless Systems.

الخلاصة

في هذا البحث يتم تقديم نظام استقبال أعمى لإشارات نظام تعدد الوصولية بتقسيم الشفرة متعددة المداخل متعددة المخارج بالاعتماد على طريقة التحليل المستقل للعناصر. يستغل نظام الاستقبال المقترح البناء الإحصائي لمصادر الإشارات المستلمة لغرض تخمين وإلغاء تأثير قناة الانتشار اللاسلكية على الإشارة المستلمة. يتم تخمين تأثير قناة الانتشار باستخدام طريقة انحدار المعادلة الموضوعية للإشارات المستلمة. يتميز الأسلوب المقترح بأنه لا يتطلب أي تعديل لجهاز الإرسال أو إرسال إشارات التدريب. وتوضح نتائج المحاكاة فوائد الطريقة المقترحة مقارنة مع أساليب تقليدية أخرى.
الكلمات المفتاحية : استقبال اعمى ، تحليل المكونات المستقلة، الأنظمة اللاسلكية MIMO.

I. Introduction

Multiple Input Multiple Output (MIMO) wireless systems are shown to provide significantly higher data rate than Single Input Single Output (SISO) systems, these MIMO systems are widely used at wireless electronic applications [Goldsmith A., 2005]. Enhanced spectral efficiency, and increased capacity feature among the typically benefits of MIMO systems [Vicente Z. and Nandi A. K., 2004]. By employing multiple transmit and receive antennae, the Co-Channel Interference (CCI) (which caused by multiple inputs) and Inter Symbols Interferences (ISI) (due to multipath propagation), can be eliminated through the channel estimation and equalization processes at receiver [Vicente Z. and Nandi A. K., 2004]. The methods of the channel estimation can be classified into training signals and Blind Source Separation (BSS) based methods.

Code Division Multiple Access (CDMA) is the main kinds of technologies for the implementation of 2G and 3G cellular telephony systems [Tanner R. and Woodard J., 2004]. The CDMA systems are using the concept of spreading codes to transform the user's signals into spread-spectrum coded signals. The spreading codes are used for providing the access to multiple users simultaneously, and identifying the signals destination of each individual user from other users. In wireless multiuser communication systems, the received signal is further degraded by the other incoming signals, originating from other users which they transmitting over the same frequency band. This may occur, from Multi-User Interference (MUI), caused by differences of the received signal's power or loss the orthogonality of the spreading codes. These types of interference need to be cancelled, for achieving a reliable detection of the received signals. Using the MIMO systems allows for using spatial processing, such as beamforming, in canceling interference. The CDMA's properties of resistance to the narrowband interference [Verdu S., 2002], and the high capacity of MIMO system, make the combination of these two technologies a promising new method for wireless transmission systems.

For estimation the Channel State Information (CSI) in reception side in order to complete the symbol's detection process, the training signals based methods make use of training sequences. Linear receiving method such as the Zero Forcing (ZF) or the Minimum Mean Squared Error (MMSE) detectors are good examples of the training based methods. The ZF detector aims at the joint minimization of ISI and CCI in the absence of noise, the ZF detector can lead to severe noise amplification in noisy scenarios. The MMSE detector [Vicente Z. and Nandi A. K, 2004] avoids this drawback.

Most of the works related to the training signals based methods brings considerably extra bandwidth. An adaptive MIMO frequency domain equalization training based method is proposed in [Vijaya L. M and Linga K R., 2012] with training signals up to 5% of the total transmitted signal frames. Blind Source Separation based methods is able to obtain the CSI without using the training sequences, based on both Second Order Statistics (SOS) and Higher Order Statistics (HOS) of the received signals. The blind equalizer coefficient (which used to mitigate the effects of wireless channel) can be directly obtained from the statistics of the received signals without using the training sequences which costs extra bandwidth and spectral. The precoding of the transmitted signals is proposed in [Järmyr S., *et al*, 2010] and the blind channel estimation is obtained by exploring the signal covariance matrix based on SOS at receiver. The SOS based method is sensitive to the Gaussian noise, but the higher order statistic based one is able to reduce the effects of Gaussian noise [Hyvarinen A., *et al*, 2001]. ICA based on the assumption of mutual statistical independence between the sources of data, is employed for estimation the original signals directly from the statistics of received signals, by maximizing the non-Gaussianity of received signals, without knowing the CSI, as long as the transmitted signals are linearly independent [Hyvarinen A., et al, 2001].

A blind channel estimation of MIMO system with a multi-dimensional autoregressive (AR) model based on BSS is proposed in [Routtenberg T. and Tabrikian J., 2010] using the Finite-Alphabet (FA) structure of the transmitted signals as a prior information for estimation the MIMO channel and the original transmitted signals. A blind signal estimation based on BSS is applied for MIMO system in [Zhao X. and Davies M., 2010], the Forward-Error Correcting (FEC) coding is apply to the transmitted signals to improve the BSS signals estimation quality i.e., by achieving low complexity and improved convergence of the blind algorithm. A semi-blind channel estimation approach for MIMO systems is proposed in [Xu C., 2011], where the proposed method is a combination of methods based on both ICA and the pilot carriers. The ICA based interferences suppression including the CCI and ISI for MIMO systems are proposed in [Ranganathanl R., et al, 2011] by exploding the statically independence of the received signals.

ICA has attracted special attentions in the wireless communication fields for blind interference suppression of the CDMA systems [Raju, K., 2006], and Blind Multi User Detection (BMUD) system. The BMUD is the process of simultaneously estimation multiple symbol sequences associated with multiple users in the downlink of a multiuser CDMA communication system using only the received data [Yu M., 2011].

Despite these rich literatures, none of the previous approaches is able to blindly estimation the MIMO channel matrix and the multiuser CDMA signals completely in blind fashion without modification in transmission side (using the training sequence or precoding).

In this paper, the proposed blind receiving system is used for estimating the MIMO channel matrix. The estimated channel matrix then used for estimation the multiuser CDMA original symbols that transmitted over the MIMO fading channel. The MIMO channel matrix is estimated blindly based on minimizing a kurtosis-based objective function. The proposed method does not require using the training sequence or any modification in transmission side. The paper is organized as follows: The multiuser CDMA system model that transmitted over the MIMO channel are provided in section II. The proposed multiuser CDMA blind receiving system based ICA and the ICA assumptions are presented in section III. The simulation results are presented in section IV. Finally, the main conclusions of this study are presented in section V.

II. System Model

The proposed multiuser CDMA system model with N_t transmit and N_r receive antennae is illustrated in Fig. (1). The user's data information blocks of signal are first mapped into a digital modulation and separated using the spreading chips codes for signal's spreading process. The signals are transmitted over flat fading wireless channel via N_t transmit antennae. The channel's impulse responses remain constant during the duration of the user's data block that consist of N_s symbols and vary independently from one block to another. The received block of CDMA signals $x_r(k,i)$ through r^{th} receiving antennae can be described as the following:

$$x_r(k,i) = [x_1(k,i), x_2(k,i), \ldots, x_{Nr}(k,i)] \quad (1)$$

where k is the time instant of the symbol i (i = 1, 2, . . . ,N_s), r is the receiving antennae's index (r =1,2. …, N_r). The m^{th} received block, denoted by $x_m(k,i)$ over the wireless fading channel can be written as:

$$\begin{aligned} x_{m,r}(k,i) &= H_{r,q}(k)\ s_{m,q}(k,i) + n(k,i) \\ &= \begin{bmatrix} H_{1,1}(k) & \cdots & H_{1,N_t}(k) \\ \vdots & \ddots & \vdots \\ H_{N_r,1}(k) & \cdots & H_{N_r,N_t}(k) \end{bmatrix} \begin{bmatrix} s_{m,1}(k,i) \\ \vdots \\ s_{m,N_t}(k,i) \end{bmatrix} + n(k,i) \end{aligned} \quad (2)$$

where the $s_m(k,i)$ matrix with size of (N_t×N_s) and the $x_m(k,i)$ matrix with size of (N_r×N_s) are the complex valued baseband signals, while the $H(k)$ matrix with size of (N_r×N_t) is the MIMO flat fading channel impulse response matrix, q is the index of transmission antennae (q =1, 2, …,N_t). The elements of $H(k)$ matrix are independent identically distributed (i.i.d), with Rayleigh distribution of amplitude and uniformly distribution of phase. The $n(k,i)$ with size of (N_r×N_s) is the Additive White Gaussian Noise (AWGN), with a zero mean and unit variance.

The m^{th} spreading user's data block $s_m(k,i)$ result form the spreading process of the original user's data information $b_u(k,i)$ using spreading chip code of the u^{th} user which denoted by $C_u(k,i)$ as the following

$$s_m(k,i) = \sum_{u=1}^{U} b_u(k,i)\, C_u(k,i) \tag{3}$$

where u =1,2, . . .,U, U is the number of users.

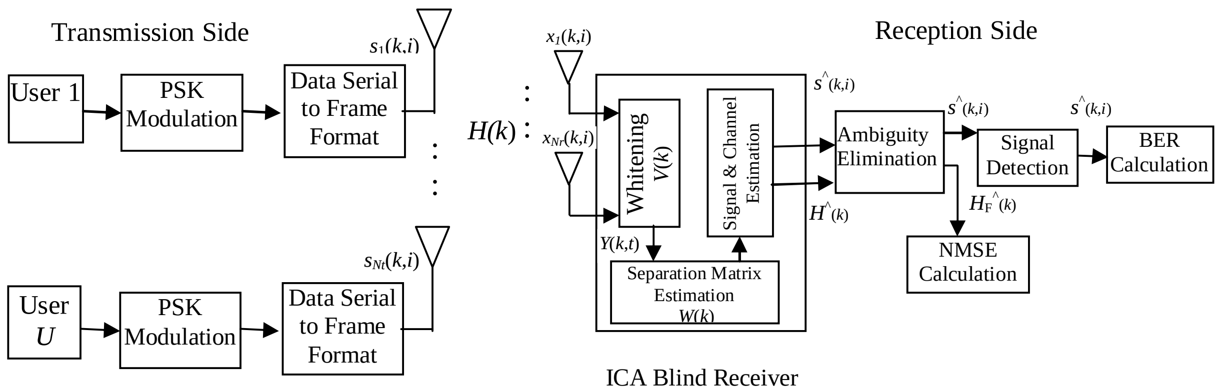

Fig. 1. The Proposed Multiuser CDMA System with Blind Receiving System based on ICA

III. The Proposed Multiuser CDMA Blind Receiving System based ICA

ICA is aimed to extracting the original sources of signals from the received linear mixture of signals based on statistics of the received signals only. In order to use the ICA to estimate the original transmitted signals without the knowledge of CSI, the following assumption has to be met [Hyvarinen A., *et al*, 2001]

1) The transmitted signals must be statistically independence with a zero mean.
2) The transmitted signals have a nongaussian distributions.
3) The number of reception antennae has to be equal or more than the number of transmission antennae.
4) The average transmission power on each antenna is normalized to unity that implies that:

$$E[s_m(k,i)s_m^H(k,i)] = I_{Nt} \tag{4}$$

where the superscripts $(\cdot)^H$ denote Hermitian process, I_{Nt} is the $N_t \times N_t$ identity matrix and $E[\cdot]$ is the expectation operator. It is shown from system model of equation (2) that the received signals x_m are a linear mixture of the transmitted blocks s_m. The ICA is employed in the reception side for blind channel estimation then the estimated channel matrix is used for blind multiuser signal estimation.

The first step of the proposed blind channel method based on ICA is the whitening process of the received signals as the following: the Principal Component Analysis (PCA) is a common method frequently used to whiten the received signals through estimation the whitening matrix $V(k)$. The whitening matrix $V(k)$ is obtained based on the Eigen Value Decomposition (EVD) analysis of the autocorrelation matrix R_{xx} of the received signals $x_m(k,i)$ as the following [Hyvarinen A., *et al*, 2001]

$$\begin{aligned} R_{xx}(k) &= E[x_m(k,i)x_m^H(k,i)] \\ &= U(k)\Lambda(k)U^H(k) \end{aligned} \tag{5}$$

where $U(k)$ is the $N_r \times N_t$ matrix of eigenvectors of R_{xx} and $\Lambda(k)$ is the $N_t \times N_t$ diagonal matrix of eigenvalues of R_{xx}. The autocorrelation matrix R_{xx} of the received signals can be also analysis as

$$\begin{aligned} R_{xx}(k) &= E[x(k,i)x^H(k,i)] \\ &= H(k)E[s_m(k,i)s_m^H(k,i)]H^H(k) \\ &= H(k)H^H(k) \end{aligned} \tag{6}$$

The whitening matrix is given by [Hyvarinen A., *et al*, 2001]

$$V(k) = \Lambda^{-1/2}(k)U^H(k) \tag{7}$$

From equation (5) and (6) the estimated channel matrix $\hat{H}(k)$ can be expressed as

$$\hat{H}(k) = U(k)\Lambda^{-1/2}(k)W^H(k) \tag{8}$$

where $W(k)$ is the $N_t \times N_t$ full rank separation matrix. The whitened data blocks $Y_m(k)$ is given by

$$Y_m(k,i) = V(k)\, x_m(k,i) \tag{9}$$

The second step of the proposed method is the determination of the $\hat{H}(k)$ matrix by estimating the separation matrix $W(k)$, which is unknown at the blind receiving side. Estimation the separation matrix $W(k)$ is performed by maximizing the statistical independence of the received signals. The maximizing of the statistical independence is based on maximizing the nongaussianity of the received signals. The Kurtosis $K[s]$ is one measurement of the nongaussianity of a random variable s, which is defined for a complex data as the following [Hyvarinen A., *et al*, 2001]]

$$K[s] = E[|s|^4] - 2(E[|s|^2])^2 - E[ss]E[s^*s^*] \tag{10}$$

where $(.)^*$ corresponds to the complex conjugate. The separation matrix $W(k)$ can be estimated by optimization (maximizing or minimizing) the objective function $J(W)$, which is based on kurtosis of the estimated blocks $\hat{s}_m(k,i)$. Since the kurtosis of the most digital modulation types (ASK, PSK and QAM) is negative, therefore, the proposed optimization approach is performed by minimizing the objective function $J(W)$ which depends on the separation matrix $W(k)$ under the unitary constraint $W(k)W^H(k) = I_{N_t}$. The estimation of $W(k)$ by minimizing the objective function $J(W)$ can be expressed as the following

$$W(k) = \left\{ \min_{W(k)} \quad J(W) = \sum_{k=1}^{n} K[\hat{s}(k,i)] \right. \tag{11}$$

The minimization of the proposed objective function *J(W)* is performed by computation the gradient of the objective function. The gradient of the proposed objective function Γw is defined as

$$\Gamma w = \frac{\partial J(W)}{\partial W} = K(w^H \hat{s}_m(k,i))[E\{\hat{s}_m(k,i)(w^H \hat{s}_m(k,i))^3\} - 3w\|w\|^2] \tag{12}$$

where (w) is one row of the $W(k)$ matrix. Since the optimization of the objective function Γw is under the unitary constraint $W(k)W^H(k) = I_{N_t}$, the gradient-based of the objective function must be complemented by projecting $W(k)$ on the unit sphere after every step, by dividing $W(k)$ by its norm.

To further simplifying the proposed method, the latter term in brackets of equation (12) can be omitted, since it does not changing the direction of the (w) norm in the gradient-based objective function but changing its value only. Where, the direction of (w) is interesting, and any change in the norm is insignificant because the norm is normalized to unity anyway. Thus, the gradient of the proposed objective function is obtaining as the following:

$$\Gamma w = \frac{\partial J(W)}{\partial W} = K(w^H \hat{s}_m(k,i))[E\{\hat{s}_m(k,i)(w^H \hat{s}_m(k,i))^3\}] \tag{13}$$

The proposed method is described in the following steps for a fixed step size (μ) :

1. Compute R_{xx} and perform the eigenvalue decomposition according to the equation (5).
2. Compute the whitened blocks Y_m according to the equation (9).
3. Initialize the separation matrix *W(k)* randomly.
4. Calculate the initial estimation block of signal $\tilde{s}_m(k,i) = W(k) \times Y_m(k,i)$.
5. Set the objective function $J_{old} \leftarrow J(W)$.
6. Compute the gradient of the objective function Γw according to the equation (13).
7. Updating $W(k)$ in the direction of the negative gradient, $W(k) \leftarrow W(k) - \mu\Gamma w$.
8. Normalizing $W(k)$ based on unitary constraint, $W(k) \leftarrow W(k)/\|W(k)\|$.
9. If the objective function is not converged $J_{old} - J(W) < \varepsilon$ (where ε is a small threshold value), then go back to step 5.
10. Compute $\hat{H}(k)$ according to the equation (8), then estimated the block of users data as the following: $\hat{s}_m(k,i) = \hat{H}^{-1}(k)\tilde{s}_m(k,i)$.
11. Estimate the original user's data information after multiuser detection (demodulation and despreading) of the estimated signals.

The estimated channel matrix $\hat{H}(k)$ is estimated up to the permutation and phase rotation ambiguities, because of the ambiguities problems of the ICA. The ICA estimated block $\hat{s}_m(k,i)$ is not the same as the transmitted block $s_m(k,i)$, there exists ambiguity matrix $G(k)$ comparing with the original transmitted signals as [XI C., 2009]

$$\hat{s}_m(k,i) = G(k)s_m(k,i) \tag{14}$$

The ambiguity matrix $G(k)$ is composed by two indeterminacies as the following [XI C., 2009]

$$G(k) = P(k)D(k) \tag{15}$$

where $P(k)$ is the $N_t \times N_t$ permutation ambiguity matrix, and $D(k)$ is the $N_t \times N_t$ phase rotation ambiguity matrix. Considering the set of all calculated ambiguities matrices $L(k)$ as the following

$$L(\mathrm{k}) = P(k)D(k) \tag{16}$$

After the channel matrix estimation, the ambiguity of channel matrix is removed by post-multiplying $\hat{H}(k)$ by $L_F(k)$ where [XI C., 2009]

$$L_F(k) = \arg \min_{L(k)\in G(k)} \left\| H(k) - \hat{H}(k)L(k) \right\|^2 \tag{17}$$

The final estimated channel matrix $\hat{H}_F(k)$ is defined as the following [XI C., 2009]

$$\hat{H}_F(k) = L_F(k)\hat{H}(k) \tag{18}$$

The Normalized Mean Square Error (NMSE), which is defined as the normalized difference between the original channel matrix $H(k)$ and the final estimated channel matrix $\hat{H}_F(k)$ can be defined as the following [XI C., 2009]:

$$NMSE = \frac{\left\| H(k) - \hat{H}_F(k) \right\|^2}{\left\| H(k) \right\|^2} \tag{19}$$

IV. Simulation Results

The performances of the proposed blind receiving system are evaluated through a computer simulation under environment of MATLAB. Performances of the proposed blind receiving system were quantified through: (1) The average Bit Error Rate (BER) that obtained after the multiuser signals detection process. (2) The NMSE which described by equation (19).

For each SNR, ten thousand independent simulations were performed to approximate the BER and NMSE. The channel is modulated as a Rayleigh distribution for amplitude and uniform distribution for phase with zero mean and unit variance. Walsh spreading code sequences with (32) Spreading Factor (SF) is adopting for spreading process and multiuser systems with (10) users. The transmission signals are a PSK modulation of (1000) symbols for each user. The threshold value ε is (10^{-5}). Considering the MIMO system with N_t of (2) transmit antennae. For the blind algorithms, there is no guarantee that the algorithm will find the global minimum, so, the performances of the proposed methods are evaluated using the multistart initialization. Where, the proposed algorithm runs several times with new random starting points and selects the estimated separation matrix *W*(*k*) which minimizes the objective function Γw. The ZF and MMSE detectors with perfect CSI are used as benchmarks.

Fig. (2) and (3) present the performances comparison of the proposed ICA blind receiving system with (2), (4) receiving antennae and MMSE, ZF detectors as (SNR versus BER). Where at (5 dB) SNR, the proposed system had a (1×10^{-4}) BER, comparing to (1.5×10^{-5}) and (3×10^{-3}) BERs of the MMSE, ZF detectors as shown in Fig. (2). For the systems with (4) receiving antennae, the proposed system had a (8×10^{-6}) BER, comparing to (1×10^{-6}) and (1×10^{-3}) BERs related to MMSE, ZF detectors for (5 dB) SNR as shown in Fig. (3). The BER of the proposed system is compared to the one obtained with the MMSE detector and better than ZF detector with perfect CSI.

Fig. (4) and (5) display the performances comparison of the proposed ICA blind receiving system of (2), (4) receiving antennae and MMSE, ZF detectors as (SNR versus NMSE). For the systems of (2) receiving antennae, the proposed system had a (5×10^{-6}) NMSE, comparing to (2×10^{-6}) and (6×10^{-5}) NMSEs obtained by MMSE, ZF detectors for (7 dB) SNR as shown in Fig. (4). For the systems with (4) receiving antennae, the proposed system had a (2×10^{-6}) NMSE, comparing to (1×10^{-6}) and (1×10^{-5}) NMSEs obtained by MMSE, ZF detectors at (7 dB) SNR as illustrated in Fig. (5). The proposed ICA blind receiving system has a good NMSE performance close to the MMSE detector and outperforms ZF detector, because the noise and fading environments have a severe impacts on the ZF detector's performance even with CSI while the proposed ICA receiving system have an improvement performances, showing the ability to resolve ambiguities effectively, and the ability of the ICA to reduce the noise, fading effects.

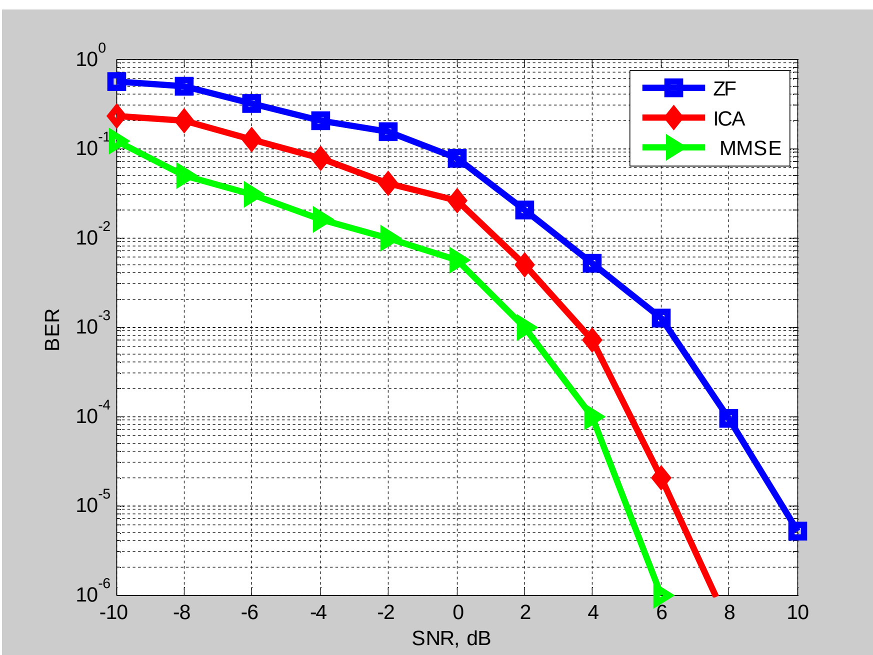

Fig. 2. SNR vs. BER performance comparison for (N_t=2, N_r=2).

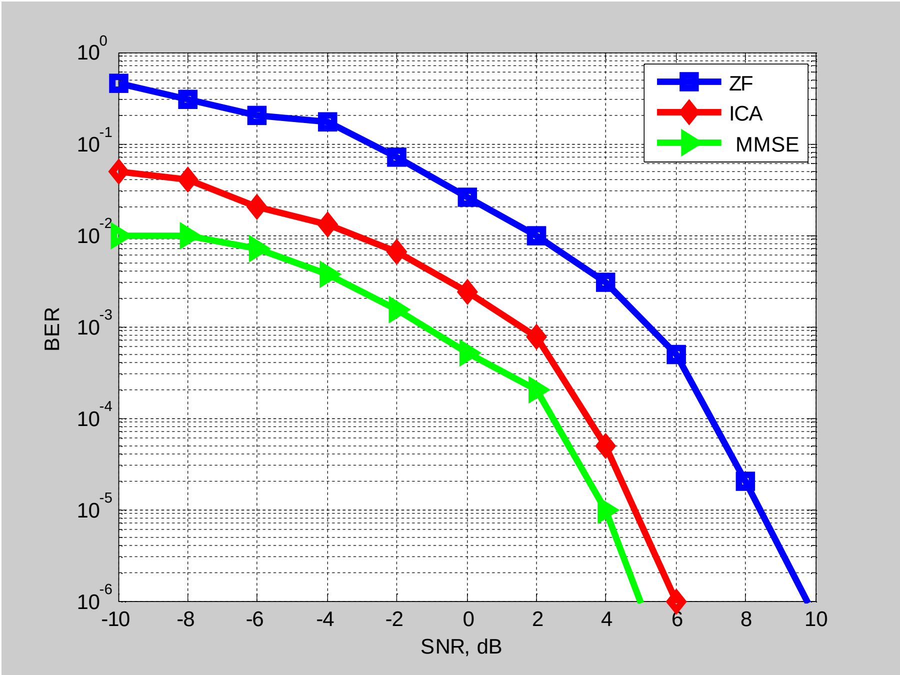

Fig. 3. SNR vs. BER performance comparison for (N_t=2, N_r=4).

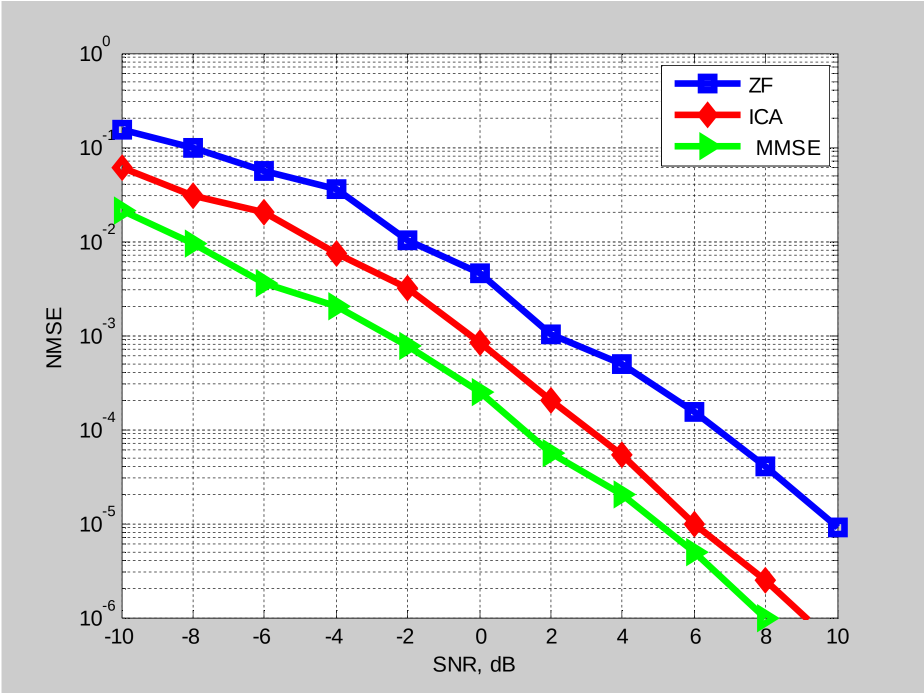

Fig. 4. SNR vs. NMSE performance comparison (N_t=2, N_r=2).

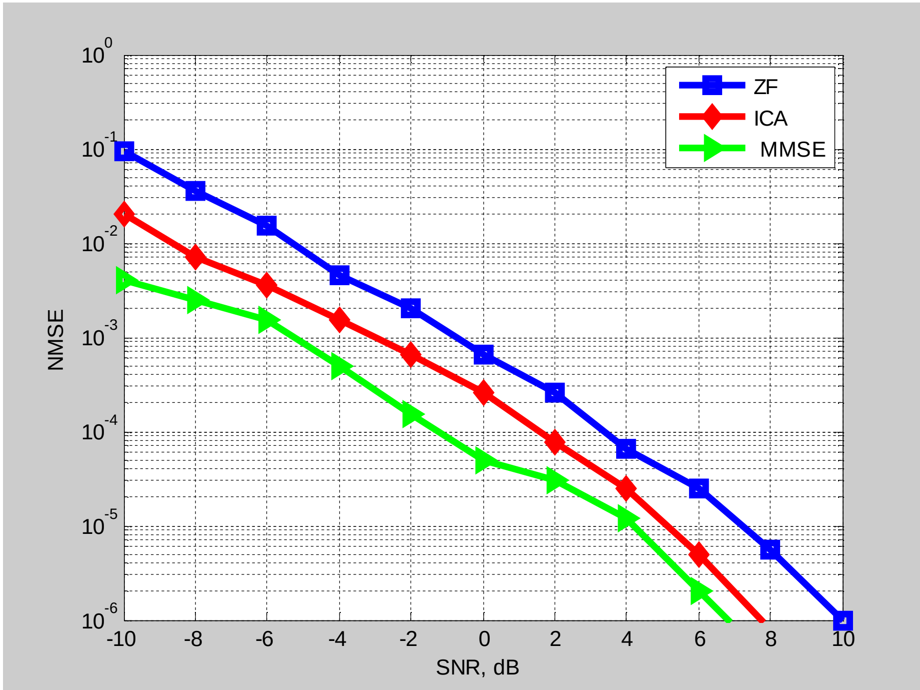

Fig. 5. SNR vs. NMSE performance comparison (N_t=2, N_r=4).

V. Conclusions

This paper proposed a blind ICA receiving system for multiuser CDMA wireless communication systems. The proposed receiver performed the channel estimation and multiuser signals detection blindly. The proposed method is based on the minimization of a kurtosis-based objective function. The proposed ICA blind receiving system has good performances close to the MMSE based equalization with perfect CSI, and better than that of ZF detector showing the ability, to mitigate the wireless channel effects.

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