# BLIND DETECTION IN IDMA SYSTEMS

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Abstract: Interleaved Division Multiple Access (IDMA) is a new access scheme that has been proposed in the literature to increase the capacity of wireless channels. The performance of such systems depends on the accuracy of the channel state information (CSI) at the receiver. In this paper, a Noisy-Independent Component Analysis (N-ICA) based IDMA receiver for multiple access communication channels is proposed and compared to classical receivers. The N-ICA component is applied as a post processor. The estimation of CSI will often have some measurement errors, which degrade the accuracy of symbol detection. Using blind methods, this overhead can be eliminated. Simulation results demonstrate that N-ICA post processor provides an improvement in performance in terms of bit error rate (BER) in loaded systems and it offers an efficient alternative to systems with block channel estimation. When the system is not loaded, the proposed post processor presents the same performance as conventional IDMA receiver with less iterations leading to a complexity reduction.

## 1 INTRODUCTION

Recently proposed Interleave-Division Multiple-Access (IDMA) communication system is one of the most promising technologies for high data rate wireless networks. IDMA can be regarded as a special case of Code Division Multiple Access (CDMA). In CDMA systems, users are separated using signatures or spreading codes; while in IDMA systems, distinct interleavers are employed to separate users. This principle has been studied previously and its potential advantages have been demonstrated (Ping, 2006). Moreover, since conventional IDMA detector is sensitive to channel estimation errors, a good channel tracking algorithm is mandatory. This might drastically increase the overall complexity at the receiver. In order to overcome those drawbacks, in this paper, we propose a new blind receiver for IDMA systems. In our approach, a Noisy Independent Component Analysis (N-ICA) scheme is introduced as a post processor. So, we propose to detect and separate the transmitted symbols without channel tracking and by including the noise in the global model; leading to the N-ICA model. We will show that our model is very suitable for symbol detection and separation in the IDMA context. In terms of complexity, as a post processor, the proposed solution starts the processing just after conventional IDMA processing.The remainder of this paper is organized as follows. The next section is devoted to the IDMA system model. In section 3, we detail the proposed N-ICA model for IDMA. In section 4, an estimation algorithm is presented for N-ICA in an IDMA context. Using some evaluation criteria, computer simulation results are presented in section 5 to provide a comparative study. Conclusions are drawn in section 6.

## 2 SYSTEM MODEL

As shown in figure 1, we consider an IDMA system with $K$ users. A single path channel and BPSK modulation are considered here. The $nth$ bit $d_k(n)$ in the sequence $d_k$ of $kth$ user is spread, generating a sequence vector denoted $\mathbf{c}_k$=$[c_k(1), c_k(2), ..., c_k(J)]^T$ where $J$ is the frame length $C$ is the spreading factor and the superscript $T$ is the transpose operator. Then $c_k$ is permutated by an interleaver $\pi_k$. At the output of the



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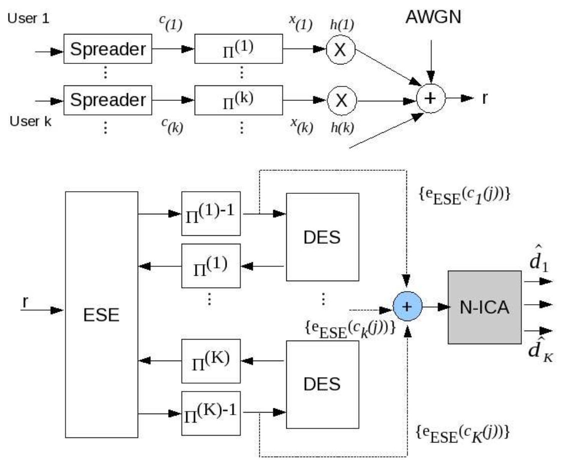


Figure 1: System model.

interleaver, the vector $\mathbf{x}_k$=$[x_k(1), x_k(2), ..., x_k(J)]^T$ is obtained. The elements in $c_k$ and $x_k$ are considered as chips. The chip rate is $C$ times higher than the bit rate. Users are distinguished mainly by their respective interleavers $\pi_k$. Each user can has its own signature sequence or all users can share the same spreading code (Ping,2004). The received signal can be modeled as:

$$r(t) = \sum_{m=1}^{M} \sum_{k=1}^{K} h_k d_k(m) s_k(t - mT - \tau_k) + n(t) \quad (1)$$

where $h_k$ is the path gain, $d_k(m)$ is the $kth$ user's $mth$ data bit, $s_k(.)$ is $kth$ user's binary interleaved chip sequence (this is a specific feature for IDMA) used in the interval $[0,T]$;$T$ is the bit duration, $s_k(t) \in \{-1,1\}$. The delay of the path is denoted by $\tau_k$ and $n(j)$ zero-mean Additive White Gaussian Noise (AWGN) with variance $\sigma^2 = No/2$.

# 3 ICA AND N-ICA PRINCIPLE

The application of ICA consists of estimating the unknown input signals from the output signals without prior knowledge of the channel state information (Hyvarinen,1999). Let's suppose that the sources are statistically independent. This is a fundamental assumption for using ICA that is generally verified in communication systems (Huovinen, 2007). The extraction of the sources can be done by ICA by exploiting the essential features of the sources and system. In the simplest form of ICA, we observe $n$ scalar variables $r_1, r_2, ..., r_n$ which are linear combinations of $l$ unknown independent sources or components ICs denoted by $b_1, b_2, ..., b_l$. If we express the observed random variables with the vector, $\mathbf{r}$=$(r_1, r_2, ..., r_n)^T$. and the ICs variables $b_j$ with the vector $\mathbf{b}$=$(b_1, b_2, ..., b_l)^T$ then the relationship is given by (Huovinen, 2007):

$$\mathbf{r} = \mathbf{G}\mathbf{b} \quad (2)$$

In the noisy ICA model, the noise is assumed to be additive and the observed data can be expressed as:

$$\mathbf{r}_m = \mathbf{G}\mathbf{b}_m + \mathbf{n} \quad (3)$$

where $\mathbf{r}_m$ is the $mth$ observed data vector, $\mathbf{G}$ is an unknown full rank mixing matrix, $\mathbf{b}_m$ is an unknown non gaussian source vector and $\mathbf{n}$ is an additive Gaussian noise process. The goal is to estimate the noise free ICs $\mathbf{b}_m$ using only the observations $\mathbf{r}_m$ and the assumption of the independence of the sources. This means that a set of vectors $\mathbf{w}_1, \mathbf{w}_2$.. should be estimated such that $\mathbf{W} = [\mathbf{w}_1, \mathbf{w}_2, ...]$ is the separating matrix; therefore, the output source estimations $\mathbf{w}_1^T \mathbf{r}_m$, $\mathbf{w}_2^T \mathbf{r}_m$... i.e.:

$$\mathbf{y}_m = \mathbf{W}^T \mathbf{r}_m \quad (4)$$

are independent and each of them can be used to represent one of the sources.

## 3.1 Mathematical Representation of IDMA by N-ICA Model

In this subsection, we develop the theoretical framework and show the similarity between Noisy ICA model and IDMA system model.

We focus our attention on synchronous IDMA systems for simplicity and brevity. However, the method can be extended to an asynchronous system by extending the observation interval. Equation (1) can be simplified to model the received signal of a synchronous IDMA system by:

$$r_m(t) = \sum_{k=1}^{K} h_k d_{k,m} s_k(t) + n(t) \quad (5)$$

After chip rate sampling i.e. $C$ equal spaced samples per symbol are taken, the sampled data is processed within a window of specific size (Mahafenno, 2007). For synchronous model, data propagated through a single path channel fall into the same window of size $T$ for desired and interfering symbols.

The samples are then collected into a $C$x1 vectors $\mathbf{r}_m$.

$$\mathbf{r}_m = \sum_{k=1}^{K} h_k d_{k,m} \mathbf{s}_k + \mathbf{n}_m \quad (6)$$

Here $\mathbf{s}_k$ is the $C$ x1 vector representation of $kth$ user's interleaved signature sequence and $\mathbf{n}_m$ denotes the noise vector.

The last equation can be rewritten in a matrix form:

$\mathbf{b}_m = [d_{1,m}, d_{2,m}, ..., d_{K,m}]$

$$\mathbf{s}_1 = \left[s_{1,1}, s_{2,1}, ..., s_{C,1}\right]^T \; C\text{x1 vector}$$

$$\mathbf{r}_m = \left[\mathbf{s}_1, \mathbf{s}_2, ..., \mathbf{s}_K\right] \begin{bmatrix} h_1 & 0 & .. & 0 \\ 0 & h_2 & .. & 0 \\ : & : & .. & : \\ 0 & 0 & .. & h_K \end{bmatrix} \begin{bmatrix} b_{1,m} \\ b_{2,m} \\ : \\ b_{K,m} \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ : \\ n_K \end{bmatrix}$$

$$\mathbf{r}_m = [\mathbf{s}_1 h_1, \mathbf{s}_2 h_2, ..., \mathbf{s}_K h_K]\mathbf{b}_m + \mathbf{n}_m \qquad (7)$$

Equation (7) can be represented in a more compact form:

$$\mathbf{r}_m = \mathbf{G}\mathbf{b}_m + \mathbf{n}_m \qquad (8)$$

where the $C$x$K$ matrix $\mathbf{G}$ is assumed full rank. We can see the similarity between the IDMA model of equation (8) and the N-ICA model of equation (3). The goal of the Noisy-ICA based IDMA detection is to recover the symbol vector $\mathbf{b}_m$ for each user $k$ without knowing the parametric form of $\mathbf{G}$ which depends on the channel coefficients. The objective is to estimate the filter weight $\mathbf{w}$ such that the variable at the output of the filter is one of the ICs(source signal):

$$y_m = \mathbf{w}^T \mathbf{r}_m \qquad (9)$$

If BPSK modulation is used, the symbol of desired user $k$ can be obtained by using this decision formula:

$$\hat{b}_{k,m} = sgn(\mathbf{w}^T \mathbf{r}_m) \qquad (10)$$

## 4 N-ICA ESTIMATION ALGORITHM

The proposed system is a hybrid structure composed of two parts where a classical IDMA receiver is combined with a N-ICA block as shown in figure 1. Block IDMA, described in the previous section, works for a number of iterations $(it)$ after which the block N-ICA takes over. The proposed N-ICA will act as a post processor attached to an IDMA receiver in the presence of noise. The aim of our N-ICA block is to avoid continuous tracking of channel state information. In this section, we will derive estimation algorithms for the proposed N-ICA post processor in IDMA context.

### 4.1 Principal Component Analysis based Processing

The Principal Component Analysis (PCA) based part of the model consists of whitening the input signals. This step of processing is achieved by using the PCA in (Davies, 2004) to extract the Principal Components (PCs). It is based on the diagonalization concept of the input signals covariance matrix. This can be done for the noiseless case as follows

$$\mathbf{Y} = \Lambda^{-1/2}\mathbf{U}^T \mathbf{G}\mathbf{B} \qquad (11)$$

where the matrix $\mathbf{U}$ corresponds to the Eigen vector of the data covariance matrix $\mathbf{C}$ and the diagonal matrix $\Lambda$ that contains the related Eigen values: $\Lambda^{-1/2} = diag[\lambda_1^{-1/2}, \lambda_2^{-1/2}, ..., \lambda_n^{-1/2}]$. This PCA processing can be extended to noisy data using bias removal technique (Ekici,2004). In the regular ICA process, the covariance matrix of the noise free data $\mathbf{r}_m^{(nf)}$ can be given by:

$$\mathbf{C} = E\{\mathbf{r}_m^{(nf)}(\mathbf{r}_m^{(nf)})^T\} = \mathbf{G}\mathbf{G}^T \qquad (12)$$

On the other hand, the covariance matrix of the observed noisy data can be written as:

$$\Gamma = E\{\mathbf{r}_m(\mathbf{r}_m^T)\} = \mathbf{G}\mathbf{G}^T + \sigma^2 I = \mathbf{C} + \mathbf{C}_n \qquad (13)$$

where $\sigma^2$ is the noise power and $\mathbf{C}_n$is the diagonal noise covariance matrix. In the noise bias removal technique, the Eigen values and vectors of matrix $\Gamma - \mathbf{C}_n$ is used for whitening instead of matrix $\Gamma$ which is called quasi-whitening (Hyvarinen,1999). In fact, quasi whitening can be performed on the noisy data as follows:

$$\mathbf{z} = (\Lambda - \sigma^2 I)^{-1/2}\mathbf{U}^T \mathbf{r}_m \qquad (14)$$

The covariance matrix of quasi white data is then given by :

$$E\{\mathbf{z}\mathbf{z}^T\} = I + \sigma^2(\Lambda - \sigma^2 I)^{-1} \qquad (15)$$

From (15), we notice that the covariance matrix is different from the identity matrix. Therefore, we have to take into account the non-whiteness of the data. This is achieved by using the fast ICA algorithm that is presented in the next subsection.

### 4.2 Fast ICA Algorithm

The purpose of this work is to establish a new scheme in which the system can take into account such random deformations in the detection step. To improve the performance, the presence of the noise should be reduced to the minimum using the extracted PCs without additional prior knowledge of their statistical properties. This is the purpose of the ICA based part of the model. Therefore, the ICA model should include a noise term as well in its linear transform matrix. We have used two algorithms for detecting and separating the received signals: IDMA algorithm (Schoeneich,2005), and the fastICA in IDMA in (Hamza, 2009). The second ICA approach that we present here is our contribution to take into account the noise in the ICA model. This means that the bias due to noise should be removed, or at least reduced. The N-ICA algorithm performs as follows:

Let $k$ be the desired user, $\mathbf{r}_m, m = 1, .., M$ the received block data and $\hat{b}$ denotes the estimate of $b$.

1. First perform PCA for dimension reduction
2. Quasi- whitened the noisy data using (15)
3. Start ICA
   Let t=1 and update
   $$\mathbf{w}(t) = \Gamma^{-1}E\{\mathbf{z}_m(\mathbf{w}(t-1)^T\mathbf{z}_m)^3\} - 3E\{(\mathbf{w}(t-1)^T\mathbf{z}_m)^2\}\mathbf{w}(t-1)$$
   where $\Gamma = I + \sigma^2(\Lambda - \sigma^2 I)^{-1}$
   Normalize $\mathbf{w}(t) : \mathbf{w}(t) \leftarrow w(t)/\sqrt{\mathbf{w}(t)^T\Gamma\mathbf{w}(t)}$
   If $|\mathbf{w}(t)^T\mathbf{w}(t_1)| < (1-10^{-4})$, let t= t+1 and go to step 3.
4. Output the estimated desired user's bit: $\hat{b}_{k,m} = sgn(z_m)$

The blind nature of our proposed scheme presents the advantage of not altering the capacity of the channel. Moreover, the N-ICA block starts once the number of iterations of the classical IDMA receiver finishes. Hence, it does not generate additional complexity.

## 5 NUMERICAL RESULTS

To evaluate the detection and separation ability of the proposed N-ICA model, performances are presented in terms of raw Bit Error Rate (BER) before decoding for different Signal to Noise Ratios (SNR). We consider a time varying single path channel (extension to multipath case can be obtained via state augmentation), BPSK modulation and Gold spreading codes of length $C$. Among the parameters that influence the performances are the effect of load rate and the number of iterations for IDMA block. The obtained results are presented in figures 2 to 4.

In Figure 2, performances of our proposed receiver are presented for different values of $\tau$ (rate of load) and a sprading factor of 63. We notice that our proposed scheme handles very well the Multi Access Interferences (MAI) since convergence is warranted even at very loaded systems ($\tau \geq 100\%$).

Figure 3 shows the added value of our proposed post-processor N-ICA when compared to the conventional IDMA receiver for loading rate 100% and a spreading factor of 31. We notice that both convergence speed and better BER performances are achieved. Therefore, the proposed N-ICA approach can be employed in high loading rates in order to improve the performance of the system in terms of quality of service. Moreover, in case of low loading rate ($\leq 50\%$), the proposed post processor allows a reduction in the number of iterations needed by the IDMA block leading to complexity reduction of the overall receiver.

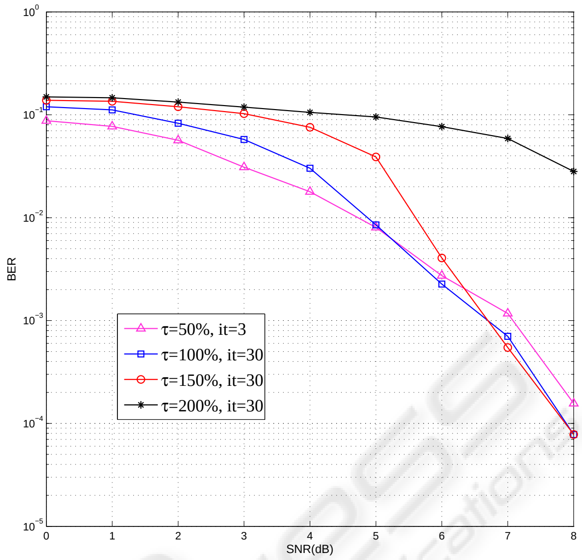


Figure 2: IDMA-N-ICA performance comparison for different rate load and $C$=63.

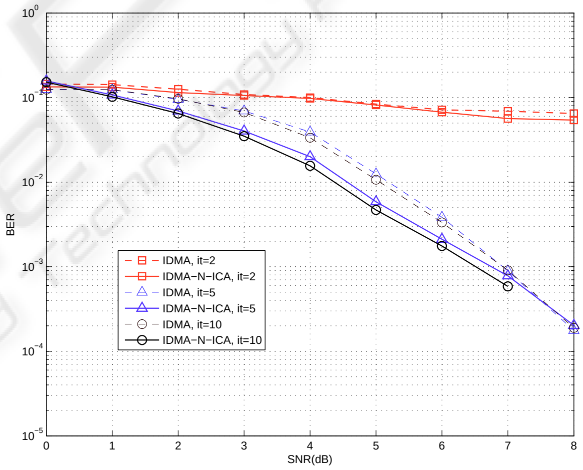


Figure 3: Performance comparison between IDMA and IDMA-N-ICA receivers when $\tau$=100% and $C$=31.

In the last simulation scenario, we evaluate the added value of the noisy ICA post processor over the ICA post processor. Figure 4 provides a comparison between IDMA, IDMA-ICA and IDMA-N-ICA receivers with a spreading factor of 31 and a load rate of 100%. When SNR is low, N-ICA outperforms the ICA post processor. However, when SNR is high, both receivers present the same performance. These observations are expected since N-ICA takes into account the presence of noise. It is worth noting also that both IDMA-ICA and IDMA-N-ICA receivers outperforms the conventional IDMA receiver.

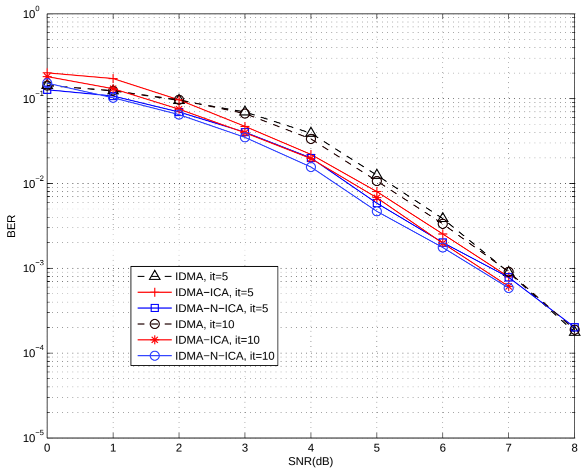


Figure 4: Performance comparison between IDMA, IDMA-ICA and IDMA-N-ICA receivers.

## 6 CONCLUSIONS

In this paper, N-ICA post processor is proposed in IDMA context. N-ICA algorithm constitutes an efficient tool for symbol recovery and it offers an efficient alternative to the IDMA systems with block channel estimation. The major contribution of this work is the application of blind detection technique in the IDMA context. The proposed algorithm has better performance compared to the IDMA receiver in loaded systems because it allows dimension reduction (PCA) which helps to reduce the amount of noise in the system. For unloaded systems, the proposed post processor allows a complexity reduction by reducing the number of iterations needed by the IDMA block. In future work, to better analyze the complexity of the proposed scheme, FPGA implementation of IDMA and proposed post processor will be realized.

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