MITIGATION OF CONTINUOUS-WAVE JAMMING IN DS-CDMA SYSTEMS USING BLIND SOURCE SEPARATION TECHNIQUES

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ABSTRACT

In this paper we consider blind interference suppression in direct sequence spread spectrum communication system with co-existing continuous wave (CW) jammer. Especially, blind source separation techniques are utilized. However, unlike in recent works only a single antenna element is employed. Numerical examples are given to illustrate achieved performance gains.

1. INTRODUCTION

The final objective in the reception of any communication system is to estimate the symbols that carry information, but there exists many prerequiste tasks, too. In direct sequence (DS) spread spectrum communications chip timing estimation tends to be one of the most challenging tasks. It also the most important task since it ultimately makes reliable demodulation possible.

Interference mitigation is one of the most important tasks in the sense of improving overall system performance and capacity. This is to remove the interference dependent demodulation of traditional single user detection based RAKE [1] receiver which relies only on the processing gain. Interference mitigation or multiuser detection (MUD) has been under active research since Verdú's invention [2] and has resulted with multitude of suboptimal solutions with less computational load [3]. These also include blind techniques which are especially suitable e.g. in downlink (i.e. base to mobile) communications where many of the essential system parameters are unknown. Blind interference mitigation is useful especially in short code DS systems. This is because the statistics of multiple access interference may remain roughly the same much longer, which in turn enables one to learn the structure of interference, and consequently, to mitigate it.

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Another way to enhance receiver performance is to use multiple antenna sensors [4], e.g. an antenna array, by which the spatial diversity can be utilized. This enables the use of directional antennas, which can point its beam in a specific direction to reduce the interference level for a desired user. In addition to timing estimation, the direction-of-arrival estimation thus becomes a prequiste task.

In this paper we consider blind interference suppression in the presence of continuous wave (CW) jamming. Especially, blind source separation (BSS) based techniques are employed. This was recently treated in [5] when an antenna array reception was utilized. Thus, the contribution of jammer was first extracted from the information bearing signal after which standard detection was performed for the appropriately chosen source. In this paper only one sensor is employed and the jammer is treated as an additional user in the system. Recently proposed advanced BSS-based receivers [6, 7] are employed and achieved performance gains are evaluated.

2. SYSTEM MODEL

A standard spread spectrum system with direct sequence spreading is assumed. In addition we assume a continuous wave (CW) jammer with a single tone to cause an intentional interference for the system.

Suppose $r(t)$ is the baseband spread spectrum signal. When transmitting the signal a carrier frequency of f_c is used, so that the transmitted DSB-modulated signal is equal to $r(t)e^{j2\pi f_c t}$. Jammed signal in a reception is then (assuming ideal channel for a while for notational simplicity)

$$y(t) = r(t)e^{j2\pi f_c t} + j(t), \tag{1}$$

where

$$j(t) = \sqrt{J}e^{j(2\pi f_j t+\phi)} \tag{2}$$

is the CW jammer. Here J is jammer's power, f_j is the frequency of jammer's CW, and ϕ is the phase of CW. The phase is assumed uniformly distributed over $[0, 2\pi)$. In the reception the signal is down-converted to the baseband, which yields

$$\begin{aligned} \hat{r}(t) &= y(t)e^{-j2\pi f_c t} && (3) \\ &= r(t) + \sqrt{J}e^{j(2\pi(f_j - f_c)t + \phi)}. && (4) \end{aligned}$$

If we assume that jammer is locked to the carrier frequency, i.e. $f_j = f_c$, then one gets

$$\hat{r}(t) = r(t) + \sqrt{J}e^{j\phi}, \quad (5)$$

which means that CW jamming actually introduces a random bias in the received signal. In other case, i.e. when $f_j \neq f_c$, a slowly varying bias $\sqrt{J}e^{j(2\pi(f_j - f_c)t + \phi)}$ is present in the received signal.

The channel model is assumed to be a block fading DS-CDMA downlink model. Thus the data describing the mth symbol have the form

$$\begin{aligned} r_m(t) &= \sum_{k=1}^{K} b_{km} \sum_{l=1}^{L} a_l s_k(t - mT - d_l) \\ &+ n(t) + \sqrt{J}e^{j\phi}, \end{aligned}$$

in which the mth symbol is sent for K users, and received via L paths. The complex coefficient of the path l is denoted by a_l, which is assumed to remain the same during the data block of, say, M symbols. mth data symbol of kth user is denoted by b_{km}. $s_k(\cdot)$ is kth user's binary chip sequence, supported by $[0, T)$, where T is the symbol duration. For notational simplicity, the path delays are assumed to be discretized, and hence $d_l \in \{0, \ldots, (C-1)/2\}$. The delays are assumed to remain constant during the block of M data symbols. n is gaussian noise.

By chip-matched filtering, and using processing window size of two symbols, we get the sampled data

$$\begin{aligned} \mathbf{r}_m &= \sum_{k=1}^{K} \Bigg[b_{k,m-1} \sum_{l=1}^{L} a_l \underline{\mathbf{g}}_{kl} + b_{km} \sum_{l=1}^{L} a_l \mathbf{g}_{kl} \\ &+ b_{k,m+1} \sum_{l=1}^{L} a_l \overline{\mathbf{g}}_{kl} \Bigg] + \mathbf{n}_m + \sqrt{J}e^{j\phi}\mathbf{1}. && (6) \end{aligned}$$

Here $\mathbf{1}$ denotes a vector of entries 1 only, and the code vectors of length $2C$ are defined as

$$\begin{aligned} \underline{\mathbf{g}}_{kl} &= \underline{\mathbf{g}}_k(d_l) \stackrel{\text{def}}{=} [s_k[C - d_l + 1] \ldots s_k[C] \; \mathbf{0}^T_{2C-d_l}]^T \\ \mathbf{g}_{kl} &= \mathbf{g}_k(d_l) \stackrel{\text{def}}{=} [\mathbf{0}^T_{d_l} \; s_k[1] \ldots s_k[C] \; \mathbf{0}^T_{C-d_l}]^T && (7) \\ \overline{\mathbf{g}}_{kl} &= \overline{\mathbf{g}}_k(d_l) \stackrel{\text{def}}{=} [\mathbf{0}^T_{C+d_l} \; s_k[1] \ldots s_k[C - d_l]]^T \end{aligned}$$

With a simple manipulation, we can get a compact representation for the data,

$$\mathbf{r}_m \stackrel{\text{def}}{=} [\mathbf{G} \; \mathbf{1}]\mathbf{b}_m + \mathbf{n}_m, \quad (8)$$

where the $2C \times 3K$ dimensional code matrix $\mathbf{G}$ contains the code vectors and path strengths while the $3K+1$-vector $\mathbf{b}_m$ contains the symbols and bias due to the jammer,

$$\begin{aligned} \mathbf{b}_m &= [b_{1,m-1}, b_{1m}, b_{1,m+1}, \cdots && (9) \\ &\quad , b_{K,m-1}, b_{Km}, b_{K,m+1}, \sqrt{J}e^{j\phi}]^T. && (10) \end{aligned}$$

From the data model (8) it is seen that that DS signal with CW jamming still obeys the linear mixing model.

3. JAMMER MITIGATION BY ICA

Whitening of the data is a common preprocessing task in ICA. This linear mapping can be accomplished e.g. by the means of eigenvalue decomposition as follows:

$$\mathbf{y}_m = \mathbf{W}\mathbf{r}_m. \quad (11)$$

Here $\mathbf{W} \stackrel{\text{def}}{=} \mathbf{\Lambda}_s^{-\frac{1}{2}}\mathbf{U}_s^H$, where $\mathbf{\Lambda}_s$ and $\mathbf{U}_s$ correspond to the $3K+1$ principal eigenvalues and -vectors of the data autocorrelation matrix $E\{\mathbf{r}_m\mathbf{r}_m^H\}$, respectively. For the noiseless data, whitening will give

$$\mathbf{y}_m = \mathbf{A}\mathbf{b}_m, \quad (12)$$

where $\mathbf{A}$ represents the resulting mixing matrix, $\mathbf{A} = \mathbf{W}[\mathbf{G} \; \mathbf{1}]$. In ICA the task now is to find the inverse mapping $\mathbf{A}^+$, such that separated signals $\mathbf{A}^+\mathbf{y}_m$ are least dependent.

It is easy to see that $\mathbf{A}$ is an orthonormal matrix under the assumption of uncorrelated symbols ($\mathbf{b}_m$) in the data ($\mathbf{r}_m$). Therefore, by estimating a column $\mathbf{A}_k$ of $\mathbf{A}$, one can estimate a source signal b_{km} as $\hat{b}_{km} = \mathbf{A}_k^H\mathbf{y}_m$. But since ICA assumes only the independence of the sources (and of course the linear mixture model), there is no guarantee that the *desired* source is estimated. To overcome this problem of user identification, in [6, 7] ICA was considered as an additional post-processing tool for conventional receivers. Roughly speaking, the job of a conventional receiver was to estimate the symbols of the desired user, say b_{km}, $m = 1, ..., M$. Then, since the symbols of different users can be assumed uncorrelated, we can estimate the the kth column of the mixing matrix $\mathbf{A}$ as

$$\hat{\mathbf{A}}_k = E\{\mathbf{y}_m\hat{b}_{km}\} \quad (13)$$

In this paper the symbols are estimated by either traditional RAKE [1] receiver or subspace MMSE receiver [8] to be attached a post-processing and jammer mitigating ICA block.

4. NUMERICAL EXPERIMENTS

We tested the algorithms using simulated DS-CDMA downlink data with block fading channel. Short Gold codes of the length $C = 31$ were used. The length of the block was

$M = 400$ BPSK symbols, during which the channel was fixed. The number of users was either $K = 5$ or $K = 10$ and the number of paths was $L = 2$. Path gains obeyed zero mean normal distribution, and the path delays were randomly chosen from $\{0, 1, \ldots, (C-1)/2\}$. The delays and the path gains were assumed to be known. Both Signal-to-Jammer Ratio (SJR) and Signal-to-Noise Ratio (SNR) were either fixed or varied with respect to the desired user from -20 dB to 20 dB. 1000 independent runs were performed. RAKE and subspace MMSE receivers were used as reference methods.

Figs. 1 and 2 shows the achieved bit-error-rate as a function of SNR in a system of $K = 5$ users when SJR is fixed to -20 dB and 0 dB, respectively.

Figs. 3 and 4 shows the achieved bit-error-rate as a function of SJR when $K = 5$ and $K = 10$ users occupies CW jammed system, respectively. In both figures it is seen that RAKE is inadequate in the presence of strong CW and consequently, RAKE can't give a reliable initialization for RAKE-ICA. On the other hand, when the SJR level is moderate, ICA can give a clear improvement. An improvement also for subspace MMSE receiver is gained, unaffected by the jammer power.

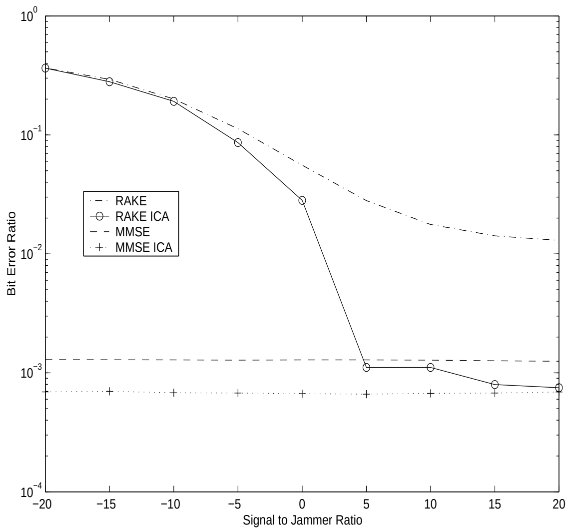

Fig. 1. Bit-error-rate as a function of SNR. The system includes $K = 5$ users of equal strength in a block fading channel with two paths of equal strength. Signal-to-jammer ratio is -20 dB and BPSK modulation is used.

5. CONCLUSIONS

In this paper we considered multisensor multiuser reception in a DS-CDMA system with a block fading channel.

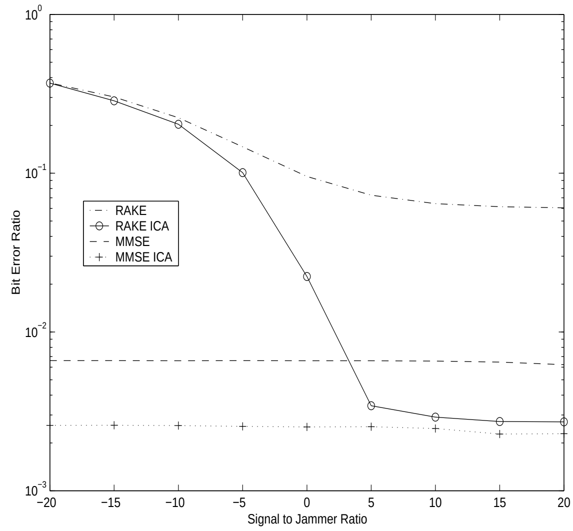

Fig. 2. Bit-error-rate as a function of SNR. The system includes $K = 5$ users of equal strength in a block fading channel with two paths of equal strength. Signal-to-jammer ratio is 0 dB and BPSK modulation is used.

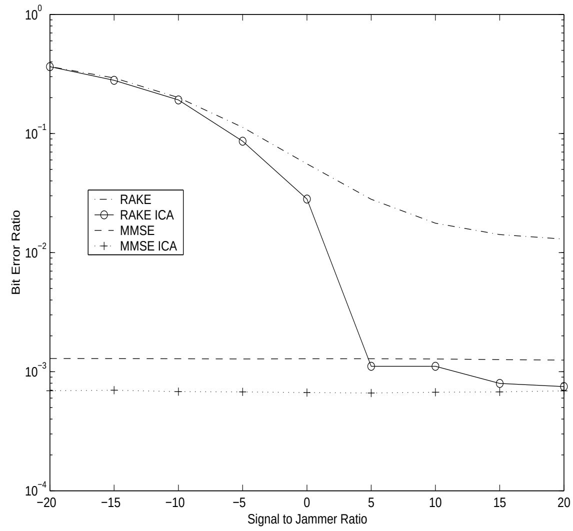

Fig. 3. Bit-error-rate as a function of SJR. The system includes $K = 5$ users of equal strength in a block fading channel with two paths of equal strength. Signal-to-noise ratio is 10 dB and BPSK modulation is used.

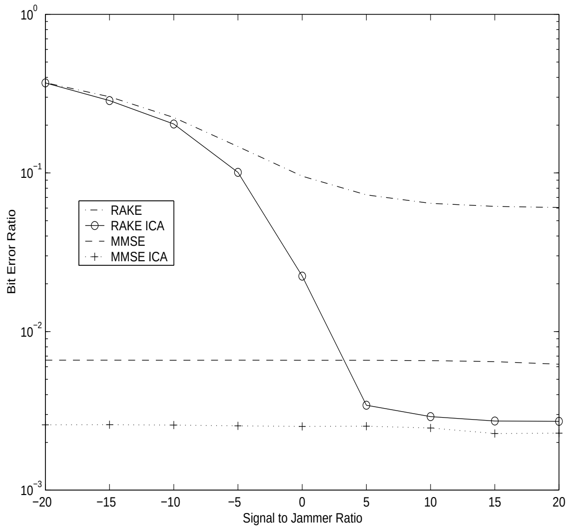

Fig. 4. Bit-error-rate as a function of SJR. The system includes $K = 10$ users of equal strength in a block fading channel with two paths of equal strength. Signal-to-noise ratio is 10 dB and BPSK modulation is used.

Especially, the use of a statistical technique called independent component analysis (ICA) as a post-processing tool for conventional array receivers was studied. Numerical experiment indicated that ICA can enhance the performance especially with moderate/high SNR values. The enhancement in BER was of order 10^{-1} to 10^{-2}, both in single and two sensor reception. By considering two antenna elements, the enhancement also occured with much a wider MAI region. The results indicated, however, the need of switching device to turn ICA procesing on only when it is expected to improve performance. This is of future research.

6. REFERENCES

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