SEMI-BLIND INTERFERENCE SUPPRESSION ON COHERENT MULTIPATH ENVIRONMENTS

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ABSTRACT

Blind source separation (BSS) can be used to separate an interfering source from a set of desired signals. By exploiting the statistical independence between the source signals and the interference, we present an alternative to the blind beamformer for suppressing the interference. [1, 2] presented the concept of combining Independent Component Analysis (ICA) with a conventional detection for suppressing jammers in a single-path environment. This paper address a broader view of interference suppression in coherent multipath environment. Computer simulations demonstrate the performance and applicability of our structure.

1. INTRODUCTION

This paper address the issue of interference suppression in the presence of coherent multipaths for a DS-CDMA array system. Coherent signals arise in the presence of multipath propagation or smart jammers [3]. Simple jamming can be compensated by the use of very long spreading codes at the cost of bandwidth expansion.

Beamforming is another method for canceling the interfering source. This can be done by steering a spatial null for the interfering sources while maintaining a gain in the direction of search for targets. This requires that the look direction is well separated. Most beamforming methods employ second-order-statistics-based criteria for estimating the optimum beamforming weight vector. This requires the knowledge of the *array response* in the desired signal direction to be known. Moreover, they fail to perform optimally when there are signals coherent with the desired signal [4] and they tend to cancel the desired signal in the output [5]. Many methods make an explicit assumption about the array configuration and hence are not directly applicable to blind beamforming.

Coherent multipaths do not make a difference for blind beamforming. Coherent multipath signals is identical to that of independent signals with no multipath because each coherent multipath from a given source causes only a re-parameterization of the steering vector for that source [3]. Since these signals can be considered as independent, we present an alternative blind source separation method based on the principles of *independence* to suppress the gaussian noise, interfering sources, so that one is left with only the desired signal.

We assume a DS-CDMA system, with multiple sources and interferences. Our assumptions are:

(A1) The desired sources are statistically independent among themselves. They are independent of all other interfering sources.

(A2) All sources may be subject to multipath propagation.

(A3) The channel is a flat-fading multipath propagation channel.

(A4) There is at most one Gaussian signal.

We now present a ICA-based *Post-Switching* system called ICA-RAKE. The method is semi-blind, because the although the separation is blind, identification of sources requires the use of some a prior information.

2. SYSTEM MODEL

We assume a standard spread spectrum system [6] with direct sequence spreading. The interfering source is a jammer signal. After down conversion, the signal received at the nth antenna is

$$\begin{aligned} r_n(t) &= \sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{l=1}^{L} a_{ml}\, b_{km} s_k(t-d_l) e^{j(n-1)\theta_l} \\ &+ \quad q(t)e^{j(n-1)\theta_q} + n(t). \end{aligned} \tag{1}$$

$s_k(t)$ and $q(t)$ represent the baseband spread spectrum signal of user k and the jammer signal, respectively. The path gain, a_{ml} corresponds to the m'th symbol on path l. b_{km} are the kth user symbol. $s_k(\cdot)$ is kth user's binary chip sequence, supported by $[0, T)$, where T is the symbol interval, and $n(t)$ is Gaussian noise [6]. θ_l and θ_q, are the directions of arrival corresponding to paths of the information and jammer signal, respectively.

The interfering source is a jammer signal that is either a CW signal or a bit pulsed signal of the form

$$q(t) = \delta_p(t)\sqrt{Q}e^{j(2\pi f_\triangle t+\phi)} \quad (2)$$

where $\delta_p(t) = 1$ with a probability p. $p = 1$ implies continuous wave jamming case, while in the bit-pulsed jamming case, the probability of a symbol being jammed is $p \in (0, 1)$. The power, frequency offset to the carrier frequency, and phase of the jammer signal are denoted respectively by Q, $f_\triangle$, and ϕ. The phase is assumed to be uniformly distributed over the interval $[0, 2\pi)$.

In the vector notation, the received data can be represented as

$$\mathbf{r}(t) = [r_1(t) \cdots r_{N_a}(t)]^T \stackrel{\text{def}}{=} \Theta[h_l(t) \;\; q(t)]^T + \mathbf{n}(t) \quad (3)$$

where Θ is a $N_a \times L$ dimensional matrix,

$$\Theta = \begin{bmatrix} 1 & \dots & 1 & 1 \\ e^{j\theta_1} & \dots & e^{j\theta_L} & e^{j\theta_q} \\ \vdots & \vdots & \vdots & \vdots \\ e^{j(N_a-1)\theta_1} & \dots & e^{j(N_a-1)\theta_L} & e^{j(N_a-1)\theta_q} \end{bmatrix}, \quad (4)$$

$\mathbf{n}(t)$ is the additive white Gaussian noise (AWGN) vector, N_a is the number of elements in the antenna array and $h_l(t)$ corresponds to the information bearing signal received along path l.

3. INDEPENDENT COMPONENT ANALYSIS

Blind Source Separation is possible under certain assumption. By assumption (A1) sources $h(t)$ and the jammer $q(t)$ are independent. A BSS technique based on independence of sources is the Independent Component Analysis (ICA) [7].

The mixing model as in (3) satisfies the independence requirements (A1). The independent sources $h(t)$ and the jammer $q(t)$ are mixed by the array steering matrix Θ. ICA separates these components by estimating an unmixing matrix $\hat{\Theta}$. Then the estimates of these signals can be obtained as components of the two-dimensional vector $\hat{\Theta}\mathbf{r}(t)$. Due to its blind nature, the order and scaling is arbitrary.

Here, we use the FastICA algorithm for complex mixtures [7, 8]. FastICA is based on kurtosis, and has a cubic convergence [7]. FastICA requires the data to be prewhitened spatially. This is because the separating matrix is constrained to be orthogonal after this stage. Whitening involves transforming the data of $\mathbf{r}(t)$, so that their components become uncorrelated and have unit variance. Whitening is often carried out by PCA, and the covariance matrices estimates are better when the block sizes are reasonably large.

Separation of the sources from their whitened mixtures $\mathbf{y}(t)$ is obtained by updating the ith column $\hat{\theta}_i$ of the orthogonal separating matrix $\hat{\Theta}$ according to [7]

$$\hat{\theta}_i^+ = \mathrm{E}\{\mathbf{y}(t)[\hat{\theta}_i^H \mathbf{y}(t)]^* |\hat{\theta}_i^H \mathbf{y}(t)|^2\} - \gamma\hat{\theta}_i \quad (5)$$

where $\hat{\theta}_i^+$ is the updated value of $\hat{\theta}_i$, and * denotes complex conjugation. The constant γ is 2 for complex-valued signals, and 3 for real ones. In practice, the expectation E in (5) is replaced by computing the respective average over the available set of whitened data vectors $\mathbf{y}(t)$. The update rule (5) uses the standard cubic nonlinearity which maximizes the kurtosis, but other versions of the complex FastICA do exist, and are more suitable for data with impulsive noise[7]. Finally, the columns of $\hat{\theta}_i^+$ are orthonormalized via the Gram-Schmidt orthogonalization procedure.

4. SELECTION AND POST-SWITCHING: ICA-RAKE RECEIVER

The separation matrix $\mathbf{W}$ is a scaled permuted version of the mixing matrix $\mathbf{A}$. This indeterminacy results in separation of the sources, but identifiability requires the use of preamble sequences [2, 1]. Additionally, these preamble sequences can be used to determine the extent of jamming. The correlation estimated pilot sequences $\tilde{s}_d^{I,p}(t), \tilde{s}_d^{R,p}(t)$ (obtained from the ICA and RAKE branches) and the true pilot sequence $s_d^p(t)$ can be used to determine the switching strategy.

$$\max_{I,R} \left(\mathrm{E}\{\tilde{s}_d^{I,p}(t)s_d^p(t)\}, \mathrm{E}\{\tilde{s}_d^{R,p}(t)s_d^p(t)\} \right) \quad (6)$$

Final decision can be made using the branch that provides the highest correlation. Additionally, these pilot sequences can be used in the initialization phase to determine the right block size if jammer mitigation is required to increase the accuracy of PCA. A schematic of the proposed method is shown in Fig. 1.

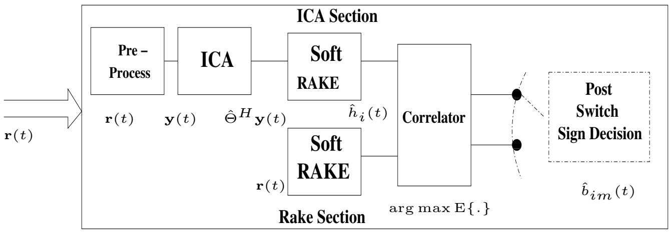

Fig. 1. Semi-Blind Interference Cancellation. $\mathbf{r}(t)$ is the received data. Pre-processing involves centering and whitening the data. The separation matrix $\hat{\Theta}$ is estimated by ICA and selection and soft decision, the correlator switches the Sign Detector to the desired branch.

5. SIMULATION RESULTS

The simulation setup was a DS-CDMA downlink channel with up to $L = 5$ coherent multipaths. The system has $K = 8$ users, spread with short Gold codes of length $C = 31$. Interference was a bit pulsed jammer signal with a jamming probability $p = 0.5$. The first set of experiments determined the capability of ICA-RAKE to mitigate the jammer in the presence of a coherent multipath. Here the data block was $M = 5000$ QPSK symbols and the results are based on 2000 independent runs. During each run, a user was selected at random and the Signal-to-Jammer ratio (SJR) was varied, while the Signal-to-Noise Ratio (SNR) was constant at $SNR = 20dB$. The number of multipaths were assumed to be $L = 2$ here. The Bit-Error-Rate (BER) results are shown in Fig.2. Figure 2 shows the gain induced by pre-processing the signal with ICA. Even when the jammer power is quite low, ICA offers about 2.5dB gain compared to RAKE (eg. 10-15dB SJR region of Fig.2). In the case of multipath, the jammer induced interference component is separated by ICA. Since final post processing is done by a conventional RAKE receiver, there is a certain loss in performance. The effect of an additional multipath can be seen only after -15dB, before which the presence of a strong jammer helps in offsetting the inter path interferences.

The second set of experiments were aimed at determining the effect of block length M in canceling the interferences. Since RAKE follows symbol by symbol decoding, the block length should not affect the results. ICA involves whitening and dimension reduction, usually performed by PCA. Hence, data length goes a long way in determining the interference canceling capability of ICA. The results in Fig. 3 shows the Block-Error-Rate (BLER) under -30dB SJR with a SNR of 20dB. While the increases in block size does not affect conventional detection, blind detection is greatly aided by a slight increase in block size. In a channel with $L = 1$ path, a target block error rate of 10^{-2} can be achieved with a block size of around $M = 500$ symbols. Similarly, with a block size of $M = 1000$ symbols target block error rates of 0.01 can be achieved in a channel with $L = 2$ coherent multipaths. By measuring the slopes Fig. 4 of these curves, we can determine the ideal block size for a particular coherent channel. Block size determination can be used in the initialization phase for the semi-blind receiver.

Fig. 5 shows the distribution of correct bits in a $L = 1$ and a $L = 5$ coherent path channel. The jammer power was -30dB with SNR=20dB. The block size was $M = 5000$ QPSK symbols or $10,000$ bits. The top figures are for ICA-RAKE while the bottom figures are for a conventional RAKE receiver. With a single path pre-processing with ICA almost gets rid of the jammer. Most of the blocks have atleast 95% correct bits. Without pre-processing the RAKE receiver most blocks have atmost 10% correct bits, which the maximum number of correct bits at around 65%. This demonstrates the ICA-RAKE's jammer mitigation ability. When the number of coherent paths is increased to $L = 5$, most blocks have atleast 70% correct bits in the case of ICA-RAKE while conventional detection is not capable of handling a strong jammer along with interpath interference.

6. CONCLUSIONS

This paper examined the effect of coherent multipaths in the case of a semi-blind interference suppression technique. Under strong interferences, this technique was able to suppress the interfering source in the presence of a multipath channel. Further more, the effect of block size on the quality of the results were examined. From the experiments it is evident that the interfering source is suppressed without any suppression of the desired signal. Further more, the method is able to provide reasonable BLER even in the presence of 5 coherent paths.

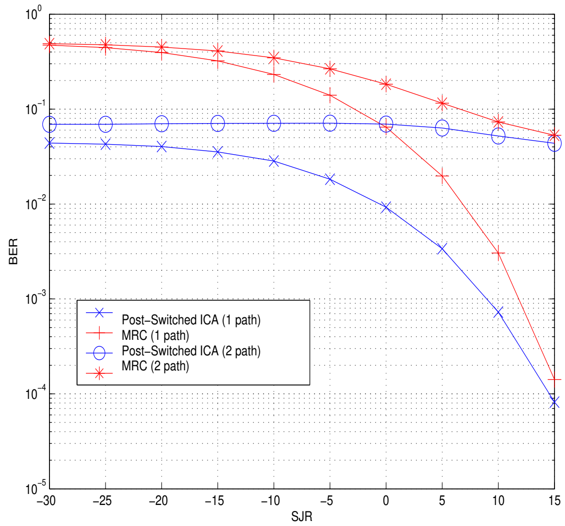

Fig. 2. Bit-error-rate as a function of SJR at an average SNR = 20 dB. This system had $K = 8$ users of equal strength in $L = 1, 2$ path system. The interference was a bit pulsed jammer with a jamming probability $p = 0.5$ The antenna was a $2, 3$ element array, respectively.

7. REFERENCES

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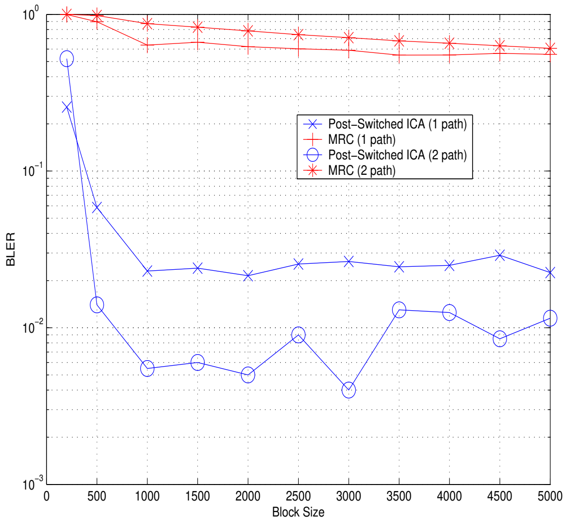

Fig. 3. Block-error-rate as a function of block size at an SJR = -30dB and SNR = 20 dB. This system had $K = 8$ users of equal strength. The results are for both single path and 2 coherent path channels. The interference was a bit pulsed jammer with a jamming probability $p = 0.5$

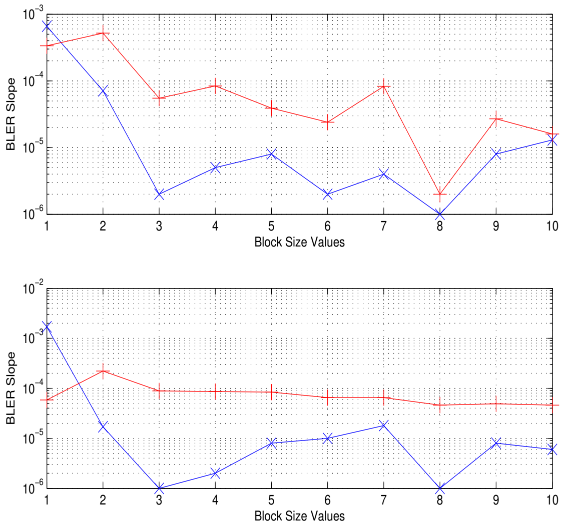

Fig. 4. Block size determination for a $L = 1, 2$ coherent path channel. Upper figure shows the slope for a $L = 1$ path channel. Bottom figure is for a $L = 2$ coherent path channel. It is evident from them that best slope for this channel is at value 3 of this figure. This corresponds to a block size of $M = 1000$. This block size is sufficient for a reasonable BLER.

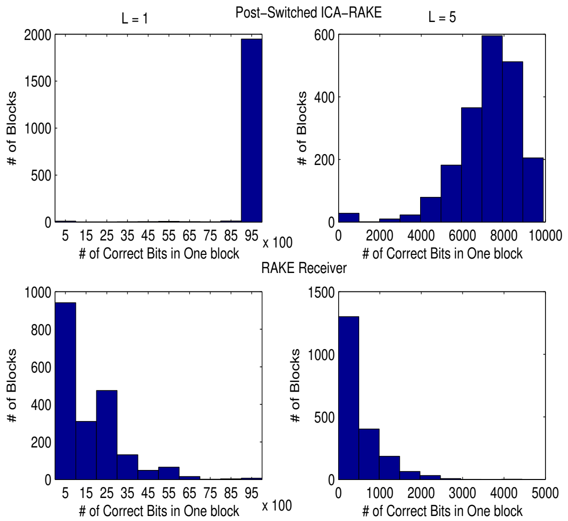

Fig. 5. Distribution of correct bits per block for both the methods for $L = 1$ (left) path and $L = 5$ (right) paths.Simulation setup is similar to the above ones. ICA-RAKE has more than 95% correct bits in most blocks for $L = 1$ while most blocks have atleast 70% correct symbols under $L = 5$ coherent paths.

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