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Blind Space-time Rake Structure based on Second Order Statistics for DS-CDMA

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Abstract—This paper presents a new algorithm that ensures low complexity implementation of a blind ST Rake receiver for DS-CDMA. The algorithm is applicable for both periodic and non-periodic spreading sequences provided that the system utilizes two layers of code separation: a spreading code layer and a scrambling code layer. The new method consists of two kinds of recursions: PAST recursions for a desired signal vector up-date and RLS-like recursions for a correlation matrix of interference and noise up-date. The proposed method maintains performance of a blind batch mode eigenanalysis method, while ensuring convergence and tracking properties of a RLS optimal combiner.

I. INTRODUCTION

 Space-time rake receivers utilise space dimension to suppress co-channel interference while coherently combining the desired signal multipaths. In blind implementation the statistics of the desired user, likewise interference to be suppressed, are acquired without the use of training sequences. This contribution considers space-time rake architectures that are based on second order statistics only. This is also an extension to our previous concept of orthogonal re-spread [1], which insures low-complexity implementation.

Blind space-time techniques based on the second-order statistics (SOS) of the received data are sufficient for channel equalisation due to the multichannel properties. The SOS based techniques are more attractive compared to e.g. higher-order statistics based methods due to the fact that the SOS can be estimated fairly accurately using little data sample support only, which is a typical scenario in mobile communications. Towards this end and in the context of DS-CDMA a number of techniques have been recently

proposed. References [3,4] utilise a method where in addition to the information obtained after de-spreading, pre-correlation (prior to de-spreader) information is also used. Owing to the fact that pre- and post-correlation matrices differ by a rank one matrix, a solution is found as the largest eigenvector of a matrix pencil formed by signal and interference matrices. Reference [5] provides alternative method for obtaining additional information to this problem. Here thanks to auto-correlation properties of the spreading codes, additional information is taken from the time-bins where desired signal is not present. In our previous contribution [1] we proposed another technique that provides additional information by means of double parallel de-spreading. The orthogonal re-spread (OR) technique provides performance benefits compared to the aforementioned techniques. However the OR is constrained by link structure of the CDMA system, which has to be a WCDMA-like system.

All the above techniques lead to computationally expensive eigenanalysis techniques. However computationally feasible subspace tracking algorithms exist for standard eigenvalue problems, the generalised eigenvalue subspace tracking remains an issue. In attempt to address it [6] provides RLS-type solution, however it is based on [5] and it does not benefit from PAST [2] inclusion. To this end we propose a RLS-like adaptive implementation of the OR method in this contribution. The proposed method provides performance comparable to the eigenanalysis-based approaches, however at the reduced computational cost.

This paper is organised as follows: The next section presents a signal model and reviews the method of Orthogonal Re-spread. The following section develops a new algorithm. Numerical examples and conclusions wrap up this paper.

II. SIGNAL MODEL

The method presented herein exploits the structure of the up-link WCDMA shown in figure 1.
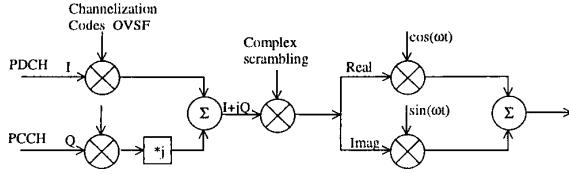
Figure 1: Structure of the uplink W-CDMA [8].

The physical channels PDCH (data) and PCCH (control) are mapped to I and Q branches respectively. Both branches are then spread by two different orthogonal variable spreading factor (OVSF) channelisation codes and scrambled by the complex code. Each part of the complex scrambling code is either long Gold code (40960 chips) or short Kasami code (256 chips). The scrambling codes are used to maintain semi-orthogonality for all possible lags between users in the asynchronous system.

This semi-orthogonality is also a source of multiple access interference (MAI). After de-scrambling both data and control channel remain mutually orthogonal, which is guaranteed by OVSF codes and the fact that they are transmitted in the same physical radio channel.

The Orthogonal Re-spread method uses one of the remaining OVSF code that is orthogonal to all traffic and control channels. De-spreading with such a code ensures that all control and data channels of the desired user are removed.

The whole reception process described above can be summarised with the following signal model:

$$x(t) = \sum_{i=1}^{M} \sum_{l=1}^{L} \sqrt{p_{i,l}}\, z_{i,l}(t - \tau_{i,l}) s(t - \tau_{i,l}) a_{i,l} + n(t) \tag{1}$$

Where: x represents received signal vector by the N element antenna array, a is the (N x 1) antenna response vector, z – scrambling code, L – number of multipath components, M – number of users, p – power, and s is given by:

$$s(t - \tau_{i,l}) = c_{i,l}^{(d)}(t - \tau_{i,l}) b_{i,l}^{(d)}(t - \tau_{i,l}) + j \cdot c_{i,l}^{(c)}(t - \tau_{i,l}) b_{i,l}^{(c)}(t - \tau_{i,l}) \tag{2}$$

Where: $c^{(d)}$ is OVSF code assigned to the PDCH (data channel), $b^{(d)}$ is the PDCH sequence, $c^{(c)}$ is OVSF code assigned to the PCCH (control channel), $b^{(c)}$ is the PDCH sequence.

The received de-spread PCCH signal is given by:

$$y_D(t) = -j \cdot \int_{\tau}^{T+\tau} z_{i,l}(t - \tau_{i,l}) c_{i,l}^{(c)}(t - \tau_{i,l}) x(t) dt \tag{3}$$

Applying re-spread code $c^{(r)}$ which is orthogonal to both PDCH and PCCH channels:

$$c^{(d)}(c^{(r)})^T = c^{(c)}(c^{(r)})^T = 0 \tag{4}$$

The re-spread signal is given by:

$$y_R(t) = -j \cdot \int_{\tau}^{T+\tau} z_{i,l}(t - \tau_{i,l}) c_{i,l}^{(r)}(t - \tau_{i,l}) x(t) dt \tag{5}$$

Now de-spread and re-spread sample correlation matrices can be defined as:

$$\hat{R}_{XX} = \frac{1}{N_S} \sum_{i=1}^{N_S} y_D(t) y_D^H(t) \tag{6}$$

$$\hat{R}_{IN} = \frac{1}{N_S} \sum_{i=1}^{N_S} y_R(t) y_R^H(t) \tag{7}$$

III. ALGORITHM DESCRIPTION

The beamformer weights can be chosen to directly maximise the signal-to-interference ratio:

$$w_{MSIR} = \arg\max_w \left\{ \frac{w^H R_{SS} w}{w^H R_{IN} w} \right\} \tag{8}$$

Where: w is the beamformer weight vector. The solution to (8) is given by (9) which is a joint eigenvalue problem (R_{SS}, R_{IN}) [7]. The matrix R_{SS} can be estimated as $R_{SS} = R_{XX} - R_{IN}$.

$$R_{SS} w = \frac{w^H R_{SS} w}{w^H R_{IN} w} R_{IN} w \tag{9}$$

Associated with the maximal eigenvalue $\lambda_{max} = SIR_{max} = \lambda = \frac{w^H R_{SS} w}{w^H R_{IN} w}$ is the eigenvector w_{MSIR}, which represents the optimum beamformer weights. If the spreading factor (SF) is large, then the effect of interchip interference (ICI) can be neglected [5]. In that case the signal correlation matrix is rank one - $rank\{R_{SS}\} = 1$ due to the presence of coherent multipaths. Eq. (9) then can be further reduced to:

$$w_{MSIR} = \alpha R_{IN}^{-1} r \tag{10}$$

where: r is the crosscorrelation vector between received and desired signal and α a constant. The vector r is also called a spatial signature of the desired signal.

A search for the beamformer weights based on (9) involves eigenanalysis and as a result it is computationally very demanding. Next we develop an algorithm that recursively updates the solution given by (10). The proposed algorithm

possesses the ability to track the non-stationary environment and is computationaly much more attractive than the batch mode of (9). The algorithm consists of two parts that are performed in parallel. The first part updates the spatial signature of the desired signal based on a PAST recursion. The second part updates the correlation matrix of interference and noise only $\mathbf{R}_{IN}$ (the Orthogonal Respread matrix).

A. Desired Signal Acquisition Step - PAST recursion

The aim of this part of the algorithm is to acquire the spatial signal vectors for a set of the rake beamformers. As aforementioned, it can be assumed that the signal subspace (in the space only domain and for a CDMA system) is accurately described by a rank one approximation. This amounts to tracking only one dominant eigenvector of the observed de-spread signal. There are a number of subspace decomposition methods described in the literature. However, in our application it is required to apply a method that does work in a on-line fashion and preferably does not explicitly construct the covariance matrix. The recently developed PAST algorithm [2]- *Projection Approximation Subspace Tracking* seems to be an ideal candidate.

The cost function for the PAST algorithm is defined as:

$$J\left(\mathbf{W}\left(t\right)\right) = \sum_{i=1}^{t} \beta^{t-i} \left\| \mathbf{y}\left(i\right) - \mathbf{W}\left(t\right)\mathbf{u}\left(i\right) \right\|^2 \qquad (11)$$

Where: $\mathbf{W}(t)$ − spans the desired signal subspace, $\mathbf{u}(t)$ is the approximation of the projection of $\mathbf{y}(t)$ - the observed signal vector onto columns of $\mathbf{W}(t)$. The parameter β - the forgetting factor is inserted to ensure that the data from the previous observations are down weighted to ensure tracking properties in a non-stationary environment.

As mentioned above in our application we are interested in a rank one approximation of the signal sub-space. For this case the cost function in (11) can be modified to a recursion given by:

$$\mathbf{r}\left(t\right) = \mathbf{r}\left(t-1\right) + \frac{1}{d\left(t\right)}\left(\mathbf{y}\left(t\right) - \mathbf{r}\left(t-1\right)u\left(t\right)\right)u^*\left(t\right) \qquad (12)$$

Where: $\mathbf{r}$ − is the rank one approximation to the desired signal in the space domain. The above signal approximation is just a perturbed desired signal vector.

B. The Inverse of Interference plus Noise Covariance Matrix update - The "RLS-like" recursion

The second part of the algorithm that is performed in parallel consists of an update of an inverse of the covariance matrix of the interference and noise − the OR matrix. This is a standard recursion based on so-called matrix inversion lemma or Woodbury identity:

$$\mathbf{R}^{-1}\left(t\right) = \mathbf{R}^{-1}\left(t-1\right) - \frac{\mathbf{R}^{-1}\left(t-1\right)\mathbf{q}\left(t\right)\mathbf{q}^H\left(t\right)\mathbf{R}^{-1}\left(t-1\right)}{1+\mathbf{q}^H\left(t\right)\mathbf{R}^{-1}\left(t-1\right)\mathbf{q}\left(t\right)} \qquad (13)$$

Casting our problem onto the above identity, denoting $\mathbf{P}(t) = \mathbf{R}_{IN}^{-1}(t)$, $\mathbf{q}(t) = \mathbf{y}_R(t)$ and also introducing a forgetting factor β_2:

$$\mathbf{P}(t) = \beta_2^{-1}\mathbf{P}(t-1) - \beta_2^{-1}\mathbf{k}(t)\mathbf{y}_R(t)\mathbf{P}(t) \qquad (14)$$

Where $\mathbf{k}(t)$ is referred to as the Kalman gain vector and it is defined as:

$$\mathbf{k}(t) = \frac{\beta_2^{-1}\mathbf{P}(t-1)\mathbf{q}(t)}{1+\beta_2^{-1}\mathbf{q}(t)^H\mathbf{P}(t-1)\mathbf{q}(t)} \qquad (13)$$

Finally the desired beamformer weight vector is given by:

$$\mathbf{w}(t) = \mathbf{P}(t)\mathbf{r}(t)$$

Table 1: *Summary of the proposed algorithm.*

1. **Initialize**: $\mathbf{r}(0) = \mathbf{1}_{(Mx1)}$; d, β_1, $\beta_2 \le 1$; $\mathbf{P}(0) = \delta\mathbf{I}$
2. **For each time instant t calculate:** $$u(t) = \mathbf{r}^H(t-1)\mathbf{y}_D(t)$$ $$d(t) = \beta_1 d(t-1) + u^H(t)u(t)$$ $$\mathbf{r}(t) = \mathbf{r}(t-1) + \frac{1}{d(t)}\left(\mathbf{y}_D(t) - \mathbf{r}(t-1)u(t)\right)u^*(t)$$ $$\mathbf{k}(t) = \frac{\beta_2^{-1}\mathbf{P}(t-1)\mathbf{y}_R(t)}{1+\beta_2^{-1}\mathbf{y}_R(t)^H\mathbf{P}(t-1)\mathbf{y}_R(t)}$$ $$\mathbf{P}(t) = \beta_2^{-1}\mathbf{P}(t-1) - \beta_2^{-1}\mathbf{k}(t)\mathbf{y}_R(t)\mathbf{P}(t)$$ $$\mathbf{w}(t) = \mathbf{P}(t)\mathbf{r}(t)$$ $$u(t) = \mathbf{w}^H(t)\mathbf{x}(t)$$

IV. SIMULATIONS RESULTS

In this section we examine the behaviour and performance of the proposed algorithm. As the performance metric the output SINR for the three considered algorithms is compared. The base station of the W-CDMA system is

equipped with an eight element adaptive array with up to three beamformer rake branches per user. Figure 2 depicts SINR versus load in the central cell given by a number of simultaneously served medium data rate users – MDR. Each of the users transmit signals with a spreading factor SF = 64, which is equivalent to 60 kb/s. Co-channel interference from other cells is modeled as a spatially and temporally white Gaussian noise. As it can be seen from the figure the performance of the proposed algorithm (Adaptive blind PAST-RLS) closely matches the performance of the eigen based blind batch methed. Both the blind methods however under perform as compared to the optimal combining with RLS updating. However in the considered example the optimal combiner uses a training sequence that occupies the whole control channel. In W-CDMA standard training takes 60% of the control channel. Hence it is expected that for this case the performance gap would be much narrower. Figure 3 depicts convergence characteristics for 300 runs in a stationary environment for the proposed algorithm together with trained RLS. A gap between the two figures remains fixed for the reason mentioned above, however most notably the convergence speed remains the same.
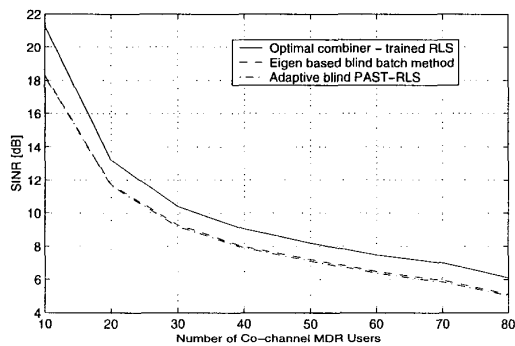

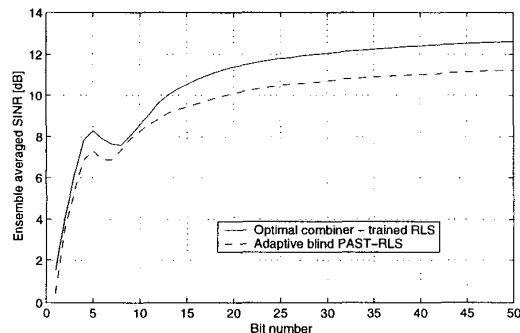*Figure 2: Mean output SINR versus the number of Medium Data Rate users (SF = 64).*

Figure 3: Convergence properties of the proposed method.

V. CONCLUSIONS

In this contribution we have proposed a new algorithm for iterative and reclusive weights update of a space-time rake receiver without the use of training sequence. The method combines the PAST recursions for the desired signal vector update together with RLS-like recursions for the correlation matrix of interference and noise only. This concatenation maintains the desirable speed of convergence of RLS type of algorithms while preserving the performance of eigenanalysis based batch blind methods.

The method can be further enhanced by invoking square-root type of RLS recursions for greater resilience against inherent instability problems of the standard Kalman RLS algorithm.

ACKNOWLEDGEMENTS

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