Subspace Receiver Techniques for DS-CDMA Systems in Space Diffused Vector Channels

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Abstract: This work is motivated by the fact that basestation receiver performance degrades significantly in spatially diffused multipath channels. Herein, this problem is addressed for array DS-CDMA systems in spatially diffused vector channels. Firstly, multipath spatial diffusion is cast as a signal model perturbation problem and then two subspace based receiver techniques are proposed that effectively remove this perturbation. Both approaches give superior performance compared to similar receivers that ignore the spatial spread. Computer simulation results are presented to corroborate the claim.

Key Words: DS-CDMA, Diffused Vector Channels, Model Perturbation, STAR manifold

1 Introduction

Antenna array DS-CDMA systems are designed to utilize the spatio-temporal diversity provided by the multipath vector channel in the uplink. In urban cell sites, where the antenna array of the base station is fixed high above tall buildings, each multipath signal arrives as a colletion of inseparable paths [1]. This phenomena is called spatial diffusion of the multipaths and is shown in Fig. 1. The diffuse characteristic of the vector channel precludes efficient directions, times of arrival estimation and data detection. Various techniques have been proposed for direction of arrival (DOA) only estimation [2-4] in diffused channel but not for joint DOA and time of arrival (TOA) estimation. Thus, in [5] we proposed a joint DOA, time of arrival (TOA) and spread angle estimator of multipaths in space diffused vector DS-CDMA channels.

It is usual to treat the vector channel as due to point-like signal sources, eventhough each of the multipaths is spread in space. Herein we show how signal model perturbations are introduced and performance degrades due to spatially diffused Co-channel multipath interference. Thus, established performance bounds [6] become unrealistic in practical channels, where spatial diffusion does exists. Therefore, it is imperative that new performance bounds are established by taking into account perturbations caused by spatial diffusion of the wireless vector channel. In this paper, two subspace techniques that utilize the vector channel parameters such as DOA, TOA and spatial spread are presented to cancel the deleterious effects of multipath spatial diffusion.

The rest of the paper is organised as follows. In Section 2, the DS-CDMA system model is established and the model perturbation due to spatial diffusion in the vector channel is identified. In Section 3, two subspace receiver techniques to cancel the diffused source perturbation are presented. Simulation results are presented in Section 4 and the paper concluded in Section 5.

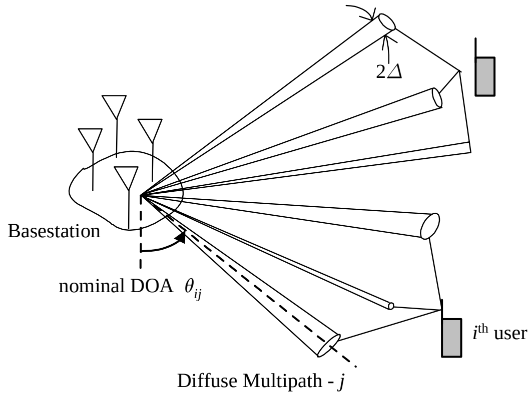

Fig. 1: Spatially diffused multipath channel

2 System Model

The uplink of an antenna array DS-CDMA system is considered. The signal received at the N element array ouput through a space-diffused vector channel can be written as

$$\underline{x}(t) = \sum_{i=1}^{M}\sum_{j=1}^{K_i}\sum_{k=1}^{L_{ij}} \beta_{ijk}\,\underline{S}(\theta_{ijk}) m_i(t-\tau_{ijk}) + \underline{\text{n}}(t) \quad (1)$$

where $\underline{S}_{ijk} = \exp\left(-\frac{j2\pi}{\lambda}\left[\underline{r}_x, \underline{r}_y, \underline{r}_z\right]\underline{u}_{ijk}\right)$ is the array manifold vector and $\left[\underline{r}_x, \underline{r}_y, \underline{r}_z\right]$ the 3-dimensional Cartesian coordinates of the array elements.

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$\underline{u}_{ijk} = \left[\cos\theta_{ijk}\cos\phi_{ijk} \;\; \sin\theta_{ijk}\cos\phi_{ijk} \;\; \sin\phi_{ijk}\right]^T$ is the unit vector in the direction $(\theta_{ijk}, \phi_{ijk})$ where θ is the azimuth and ϕ the elevation angle which, without loss of generality is set to 0° in this paper. $\underline{\mathrm{n}}(t)$ is the AWGN noise and β_{ijk}'s are the path coefficients which encompass the effects of shadowing, reflection and random phase offset between the different users. The i^{th} user's signal arrives through K_i spatially diffused multipaths, each made up of L_{ij} inseparable point-like paths. It is usual to treat $L_{ij} = 1$, which corresponds to the point-like signal source case. But as found through studies [1], each multipath is in fact a collection of closely spaced paths that cannot be separated by the receiver. This is due to constraints on the antenna array resolution [7] and estimation algorithm limitations. The baseband signal $m_i(t)$ of the i^{th} user can be expressed as

$$m_i(t) = \sum_{n=-\infty}^{\infty} b_i[n]\, c_{PN,i}(t - nT_{cs}) \qquad (2)$$

where $nT_{cs} \leq t < (n+1)T_{cs}$ $b_i[n]$ is the n^{th} symbol of duration T_{cs} and c_{PN} is one period of the spreading waveform

$$c_{PN,i}(t) = \sum_{m=0}^{\mathcal{N}_c - 1} \alpha_i[m]\, p(t - mT_c) \qquad (3)$$

$\{\alpha_i[m] \in \pm 1,\ m = 0,\ 1, \cdots (\mathcal{N}_c - 1)\}$ is the i^{th} user's pseudo-noise (PN) sequence of length $\mathcal{N}_c$ and $p(t)$ is the rectangular chip pulse shaping waveform of duration T_c.

Since each multipath undergoes localized scattering, TOA of any k^{th} path within the j^{th} diffused multipath of i^{th} user $\tau_{ijk} \approx \tau_{ij}$ (coherent scattering) and the spatial diffusion θ_{ijk} can be written as

$$\theta_{ijk} = \theta_{ij} + \tilde{\theta}_{ijk} \qquad (4)$$

where, θ_{ij} is the nominal direction of each of the multipaths and $\tilde{\theta}_{ijk}$ is the perturbation around the aforementioned nominal direction. The maximum angular diffusion in the j^{th} path is taken to be $2\Delta_{ij}$. By using a first order Taylor series expansion about the nominal DOAs of the array manifold vectors, (1) can be rewritten as

$$\begin{aligned}\underline{x}(t) &= \sum_{i}^{M}\sum_{j}^{K_i}\sum_{k}^{L_{ij}} \beta_{ijk}\underline{S}(\theta_{ij} + \tilde{\theta}_{ijk})\, m_i(t - \tau_{ij}) + \underline{\mathrm{n}}(t) \qquad (5)\\ &= \sum_{i}^{M}\sum_{j}^{K_i}\sum_{k}^{L_{ij}} \beta_{ijk}\left(\underline{S}(\theta_{ij}) + \tilde{\theta}_{ijk}\underline{\dot{S}}(\theta_{ij})\right) m_i(t - \tau_{ij}) \\ &\qquad + \underline{\mathrm{n}}(t) \\ &= \sum_{i}^{M}\sum_{j}^{K_i}\left(\rho_{ij}\underline{S}(\theta_{ij}) + \psi_{ij}\underline{\dot{S}}(\theta_{ij})\right) m_i(t - \tau_{ij}) + \underline{\mathrm{n}}(t)\end{aligned}$$

where $\underline{\dot{S}}_{ij}$ is the first derivative of $\underline{S}_{ij}$ with respect to θ, $\rho_{ij} = \sum_{k}^{L_{ij}} \beta_{ijk}$ and $\psi_{ij} = \sum_{k}^{L_{ij}} \beta_{ijk}\tilde{\theta}_{ijk}$ is the weighted spatial perturbation of the j^{th} multipath.

Equation (5) is now recast in a form that reveals the perturbation of the conventional signal model (point-like signal sources), due to the spatial diffusion of the multipaths

$$\underline{x}(t) = \sum_{i}^{M} \mathbb{S}_i \mathbb{P}_i \underline{m}_i(t) + \sum_{i}^{M} \dot{\mathbb{S}}_i \mathbb{Q}_i \underline{m}_i(t) + \underline{\mathrm{n}}(t) \qquad (6)$$

where, $\mathbb{S}_i = [\underline{S}_{i1}, \underline{S}_{i2}, \cdots \underline{S}_{iK_i}] \in \mathcal{C}^{N \times K_i}$, $\mathbb{P}_i = \text{diag}\{\rho_{i1}, \rho_{i2}, \cdots \rho_{iK_i}\}$, $\dot{\mathbb{S}}_i = [\underline{\dot{S}}_{i1}, \underline{\dot{S}}_{i2}, \cdots \underline{\dot{S}}_{iK_i}]$, $\mathbb{Q}_i = \text{diag}\{\psi_{i1}, \psi_{i2}, \cdots \psi_{iK_i}\}$, $\text{diag}\{\,\cdot\,\}$ is a square matrix with elements on main diagonal and $\underline{m}_i(t) = [m_i(t - \tau_{i1}), m_i(t - \tau_{i2}), \cdots m_i(t - \tau_{iK_i})]^T$. The second term in (6) is the model perturbation due to spatial diffusion but ignored in practice.

Next, the output of each antenna in the array is sampled at chip rate and passed through a tapped delay line (TDL) of length $2\mathcal{N}_c$ to be able to accommodate delays of the multipaths up to a symbol period. Each tap in the TDL introduces a delay equivalent to the chip period. The output of all the taps are then concatanated once every symbol period T_{cs}, to form the $\mathcal{L} = 2\mathcal{N}_c N$ dimensional discretised output vector $\underline{x}[n]$. If the sampled output of the k^{th} antenna TDL is $\underline{x}_k[n] \in \mathcal{C}^{2\mathcal{N}_c}$, the output $\underline{x}[n]$ of the TDL arrangement during the n^{th} symbol period can be written as

$$\underline{x}[n] = \left[\underline{x}_1[n]^T, \underline{x}_2[n]^T, \cdots \underline{x}_N[n]^T\right]^T \in \mathcal{C}^{\mathcal{L}} \qquad (7)$$

This signal $\underline{x}[n]$ due to a lack of synchronization between users and the base station and a TDL of length spanning two symbol periods being used, during any symbol period 'n' will have contributions from the $(n-1)^{\text{th}}$ and $(n+1)^{\text{th}}$ symbols as well. In order to include this lack of synchronism in the discretised signal model, the array manifold vector $\underline{S}_{ij}$ is extended to the Spatio Temporal ARray (STAR) manifold vector $\underline{\mathfrak{h}}_{ij}$ defined as

$$\underline{\mathfrak{h}}_{ij} \triangleq \underline{S}_{ij} \otimes \mathbb{J}^{l_{ij}} \underline{\mathfrak{c}}_i \qquad (8)$$

where $l_{ij} = \lceil \tau_{ij}/T_c \rceil$ is the discretised path delay, $\otimes$ the kronecker product and $\underline{\mathfrak{c}}_i$ is derived using the i^{th} user's PN code as follows

$$\underline{\mathfrak{c}}_i \triangleq \left[\alpha_i[0], \alpha_i[1], \cdots \alpha_i[\mathcal{N}_c - 1], \underline{0}_{\mathcal{N}_c}^T\right]^T \qquad (9)$$

The matrix $\mathbb{J}$ (or $\mathbb{J}^T$) is the down (or up) shift operator of a column vector, defined as

$$\mathbb{J} = \begin{bmatrix} \underline{0}_{2\mathcal{N}_c - 1}^T & 0 \\ \mathbb{I}_{2\mathcal{N}_c - 1} & \underline{0}_{2\mathcal{N}_c - 1}^T \end{bmatrix} \qquad (10)$$

and $\mathbb{J}^{l_{ij}}\underline{\mathfrak{c}}_i$ denotes downshifting $\underline{\mathfrak{c}}_i$ by l_{ij} positions to signify a delayed (τ_{ij}) multipath component of the signal.

Making use of the STAR manifold vectors, $\underline{x}[n]$ can now be written as

$$\underline{x}[n] = \sum_{i=1}^{M}\sum_{j=1}^{K_i}\left(\rho_{ij}\mathbb{H}_{ij}\underline{b}_i[n] + \psi_{ij}\dot{\mathbb{H}}_{ij}\underline{b}_i[n]\right) + \underline{\mathrm{n}}[n] \quad (11)$$

where, $\mathbb{H}_{ij} = [\underline{\mathfrak{h}}_{ij}^{prv}, \underline{\mathfrak{h}}_{ij}, \underline{\mathfrak{h}}_{ij}^{nxt}]$; $\dot{\mathbb{H}}_{ij} = [\dot{\underline{\mathfrak{h}}}_{ij}^{prv}, \dot{\underline{\mathfrak{h}}}_{ij}, \dot{\underline{\mathfrak{h}}}_{ij}^{nxt}]$; $\underline{b}_i[n] = [b_i[n-1], b_i[n], b_i[n+1]]^T$; $\dot{\underline{\mathfrak{h}}}_{ij} = \dot{\underline{S}}_{ij} \otimes \mathbb{J}^{l_{ij}}\mathfrak{c}_i$ while $\underline{\mathfrak{h}}^{prv}(\dot{\underline{\mathfrak{h}}}_{ij}^{prv})$, $\underline{\mathfrak{h}}_{ij}^{nxt}(\dot{\underline{\mathfrak{h}}}_{ij}^{nxt})$ - the ISI inducing components, are obtained by multiplying $\underline{\mathfrak{h}}_{ij}(\dot{\underline{\mathfrak{h}}}_{ij})$ by (12) and (13) respectively:

$$\mathbb{J}^{prv} = \mathbb{I}_N \otimes \left(\mathbb{J}^T\right)^{\mathcal{N}_c} \quad (12)$$

$$\mathbb{J}^{nxt} = \mathbb{I}_N \otimes \mathbb{J}^{\mathcal{N}_c} \quad (13)$$

Equation (11) is now rewritten in a form that reveals the perturbation in the discretised signal model

$$\underline{x}[\mathrm{n}] = \sum_{i}^{M} \mathbb{H}_i\mathbb{P}_{d,i}\underline{b}_i[n] + \sum_{i}^{M} \dot{\mathbb{H}}_i\mathbb{Q}_{d,i}\underline{b}_i[\mathrm{n}] + \underline{\mathrm{n}}[\mathrm{n}] \quad (14)$$

where, $\mathbb{H}_i = [\mathbb{H}_{i1}, \mathbb{H}_{i2}, \cdots \mathbb{H}_{iK_i}] \in \mathcal{C}^{\mathcal{L}\times 3K_i}$, $\dot{\mathbb{H}}_i = [\dot{\mathbb{H}}_{i1}, \dot{\mathbb{H}}_{i2}, \cdots \dot{\mathbb{H}}_{iK_i}] \in \mathcal{C}^{\mathcal{L}\times 3K_i}$, $\mathbb{P}_{d,i} = \mathbb{P}_i \otimes \mathbb{I}_3$ and $\mathbb{Q}_{d,i} = \mathbb{Q}_i \otimes \mathbb{I}_3$.

3 Subspace Techniques for Perturbation Cancellation

The vector channel parameters such as DOAs, TOAs and angular spread (2Δ) of the multipaths are assumed estimated, for example using the method described in [5]. From the diffused channel framework established in (11) it is clear that the signal subspace of the received data is not entirely defined by the STAR manifold vectors corresponding to the nominal {DOA, TOA} alone. The linear combination of the STAR manifold vectors $\underline{\mathfrak{h}}_{ij}$ (due to nominal DOAs, TOAs) together with the linear combination of $\dot{\underline{\mathfrak{h}}}_{ij}$ (perturbation terms) $\forall j = 1 \ldots K_i$ define the signal subspace more completely. To harness this observation in cancelling the perturbation due to spatial diffusion, we introduce two subspace based techniques below.

3.1 Spatial Spread angle based:

Since the received signal is spanned by STAR manifold vectors $\underline{\mathfrak{h}}_{ij}(\theta, l)$ parametrised by θ and l that belong to $(\widehat{\theta}_{ij} - \Delta_{ij}) \le \theta \le (\widehat{\theta}_{ij} + \Delta_{ij})$ and $l = \lceil \widehat{\tau}_{ij}/T_c \rceil$ respectively, $\forall j = 1 \ldots K_i$; to derive a set of basis vectors $\mathbb{G}_i$ that spans the i^{th} user's signal subspace, the following spatio-temporal covariance matrix $\mathbb{R}_i$ is defined:

$$\begin{aligned}\mathbb{R}_i &= \sum_{j=1}^{K_i}\int_{\widehat{\theta}_{ij}-\widehat{\Delta}_{ij}}^{\widehat{\theta}_{ij}+\widehat{\Delta}_{ij}} \underline{\mathfrak{h}}_{ij}(\theta, l)\underline{\mathfrak{h}}_{ij}(\theta, l)^H d\theta \quad (15)\\ &= \sum_{j=1}^{K_i}\int_{\widehat{\theta}_{ij}-\widehat{\Delta}_{ij}}^{\widehat{\theta}_{ij}+\widehat{\Delta}_{ij}} \underline{S}(\theta)\underline{S}(\theta)^H \otimes \underline{\mathfrak{c}}_i(\widehat{\tau}_{ij})\underline{\mathfrak{c}}_i(\widehat{\tau}_{ij})^H d\theta\end{aligned}$$

where $\widehat{\theta}_{ij}$, $\widehat{\tau}_{ij}$ and $\widehat{\Delta}_{ij}$ denote estimated quantities. In practice, (15) can be evaluated numerically. Since $\mathbb{R}_i$ is obtained by integrating $\underline{\mathfrak{h}}_{ij}(\theta, l)\underline{\mathfrak{h}}_{ij}(\theta, l)^H$ over all possible values of spatial spread of the multipaths, the basis vectors $\mathbb{G}_i$ derived from $\mathbb{R}_i$ will span the diffused signal subspace more closely. $\mathbb{G}_i \in \mathcal{C}^{\mathcal{L}\times D_i}$ is chosen to be the set of D_i eigenvectors corresponding to the most significant eigenvalues of $\mathbb{R}_i$. The dimension D_i depends on the DOAs, TOAs and spatial spread of the multipaths. In practice D_i can be found by applying a preselected threshold on the eigenvalues of $\mathbb{R}_i$ to delineate the diffused signal subspace. i.e. eigenvectors belonging to eigenvalues that are above the threshold are taken to represent the diffused signal subspace. Threshold set at 40 dB below maximum eigenvalue seems to be suitable for most spread scenarios.

Next, the set of basis vectors $\mathbb{G}_i$ are optimally combined to form the effective 'diffused' STAR vector channel $\underline{h}_i$ between the i^{th} user and array receiver as follows

$$\underline{h}_i \approx \mathbb{G}_i\underline{g}_i \quad (16)$$

where $\underline{g}_i$ is the combining vector to be estimated. To estimate $\underline{g}_i$ the orthogonality of each user's vector channel with $\mathbb{E}_{\mathrm{n}} \in \mathcal{C}^{\mathcal{L}\times(\mathcal{L}-D)}$ - the noise subspace of $\underline{x}[n]$ is utilized, where D is the maximum of all possible values of D_i. This translates to the minimization of the projection of $\underline{h}_i$ into $\mathbb{E}_{\mathrm{n}}$:

$$\begin{aligned}\Xi_1 &= \min_{\underline{g}} \ \underline{h}_i^H\mathbb{E}_{\mathrm{n}}\mathbb{E}_{\mathrm{n}}^H\underline{h}_i \quad (17)\\ &= \min_{\underline{g}} \ \underline{g}_i^H\mathbb{G}_i^H\mathbb{E}_{\mathrm{n}}\mathbb{E}_{\mathrm{n}}^H\mathbb{G}_i\underline{g}_i\end{aligned}$$

But it is clear that $\underline{g}_i$ is different than $\underline{0}$ and $|\underline{g}_i|$ can be set to be 1 without loss of generality. Hence the $\widehat{\underline{g}}_i$ that minimizes (17) is the eigenvector corresponding to the minimum eigenvalue of $\mathbb{G}_i^H\mathbb{E}_{\mathrm{n}}\mathbb{E}_{\mathrm{n}}^H\mathbb{G}$. The component of $\underline{h}_i$ that causes ISI is obtained by substituting the estimate $\widehat{\underline{h}}_i$ into (12) and (13).

3.2 'Spread' STAR manifold based:

It should be noted that the effective 'diffused' STAR vector can also be defined as a linear combination of the STAR manifold vectors corresponding to nominal {DOAs, TOAs} and a linear combination of the associated perturbation terms. i.e.,

$$\begin{aligned}\underline{h}_i &= \sum_{j=1}^{K_i} \underline{\mathfrak{h}}_{ij} + \psi_{ij}\underline{\dot{\mathfrak{h}}}_{ij} \\ &= \sum_{j=1}^{K_i} \underline{S}_{ij} \otimes \mathbb{J}^{l_{ij}}\mathfrak{c}_i + \psi_{ij}\underline{\dot{S}}_{ij} \otimes \mathbb{J}^{l_{ij}}\mathfrak{c}_i \\ &= \sum_{j=1}^{K_i} \left(\mathbb{M}_{ij} \otimes \mathbb{J}^{l_{ij}}\mathfrak{c}_i\right)\underline{p}_{ij}\end{aligned} \tag{18}$$

From (18) it is clear that the effective vector channel can be written in terms of a set of basis vectors. The basis vectors are the STAR manifold vectors corresponding to the nominal {DOAs, TOAs} and the first derivatives of the STAR manifold vectors with respect to θ. The set of basis vectors $\mathbb{G}_i \in \mathcal{C}^{\mathcal{L}\times 2K_i}$ now, using the 'spread' STAR manifold method become:

$$\mathbb{G}_i = \left[\mathbb{M}_{i1} \otimes \mathbb{J}^{l_{i1}}\mathfrak{c}_i, \mathbb{M}_{i2} \otimes \mathbb{J}^{l_{i2}}\mathfrak{c}_i, \ldots \mathbb{M}_{iK_i} \otimes \mathbb{J}^{l_{iK_i}}\mathfrak{c}_i\right] \tag{19}$$

It is seen from (19) that the number of basis vectors have doubled to $2K_i$ in the case of spatial diffusion, while for the point-like signal source case only K_i basis vectors will suffice to represent the effective vector channel. To estimate $\underline{h}_i$ the following combining vector $\underline{p}_i$ needs to be estimated:

$$\underline{p}_i = \left[\underline{p}_{i1}^T, \underline{p}_{i2}^T, \ldots \underline{p}_{iK_i}^T\right]^T \in \mathcal{C}^{2K_i\times 1} \tag{20}$$

To estimate the combining vector $\underline{p}_i$ the orthogonality of $\underline{h}_i$ with the noise subspace $\mathbb{E}_{\text{n},x} \in \mathcal{C}^{\mathcal{L}\times(\mathcal{L}-3M)}$ is utilized. Since only an estimate of the noise subspace is available, the projection of $\underline{h}_i$ into the noise subspace is minimized by varying the combining vector $\underline{p}_i$. This translates to the following cost function Ξ_5:

$$\Xi_2 = \arg\min_{\underline{p}} \underline{p}_i^H \mathbb{G}_i^H \mathbb{E}_{\text{n},x}\mathbb{E}_{\text{n},x}^H \mathbb{G}_i \underline{p}_i \tag{21}$$

But it is clear that $\underline{p}_i$ is different than $\underline{0}$ and $\left|\underline{p}_i\right|$ can be set to 1 without loss of generality. Hence the $\widehat{\underline{p}}_i$ that minimizes (21) is the eigenvector corresponding to the minimum eigenvalue of $\mathbb{G}_i^H \mathbb{E}_{\text{n},x}\mathbb{E}_{\text{n},x}^H \mathbb{G}_i$.

Every second element of $\widehat{\underline{p}}_i$ is proportional to ψ_{ij}/ρ_{ij}, the weighted spread factor of the j^{th} diffused multipath. A small value indicates that the degree of spread in the multipath is proportionately small. Since $\left|\widehat{\underline{p}}_i\right| = 1$, the relative ratios of every second value will always provide an indicator to the degree of spread of the multipaths. Hence a suitable threshold can be chosen such that when the spread indicator is above or below this threshold a decision could be made on the type of vector channel regeneration method to be employed. This feature is very useful to automatically choose the channel regeneration method based on the multipath spatial spread. The 'spread' STAR manifold based method is suitable for small angular spreads, while the spatial angle based method is suitable over a wide range of spatial spread but with a slightly higher computational requirement. Therefore depending on the spatial spread the receiver type can be switched if the spatial diffusion changes significantly.

The estimates of the effective vector channel can now be utilized in devicing receiver weights. A zero-forcing type receiver weight vector $\underline{w}_1$ that utilizes the effective vector channel estimates is presented below, taking user-1 to be the desired user:

$$\underline{w}_1 = \kappa_1 \mathbb{P}_{\mathbb{H}_{int}}^{\perp} \widehat{\underline{h}}_1 \tag{22}$$

where κ_1 is a normalization factor and the total interference matrix $\mathbb{H}_{int}$ is given by

$$\mathbb{H}_{int} = \left[\mathbb{J}^{prv}\mathbb{H}, \mathbb{H}_{-1}, \mathbb{J}^{nxt}\mathbb{H}\right] \tag{23}$$

where $\mathbb{H} = \left[\widehat{\underline{h}}_1, \widehat{\underline{h}}_2, \widehat{\underline{h}}_3, \ldots, \widehat{\underline{h}}_M\right]$ and $\mathbb{H}_{-1} = \left[\widehat{\underline{h}}_2, \widehat{\underline{h}}_3, \ldots, \widehat{\underline{h}}_M\right]$ does not include the desired user's effective channel vector. The complement projection operator $\mathbb{P}_{\mathbb{H}_{int}}^{\perp} = \mathbb{I}_{\mathcal{L}} - \mathbb{H}_{int}\left(\mathbb{H}_{int}^H \mathbb{H}_{int}\right)^{-1}\mathbb{H}_{int}^H$, where $\mathbb{I}$ is the identity matrix.

4 Simulation Studies

A uniform linear array of five elements, spaced half wavelength apart was simulated. Gold codes of length 31 were used for user PN-sequences with QPSK modulation. The simulation channel model is as follows. Each multipath of the users were made up of several paths, clustered around nominal directions with Uniform distribution and maximum spatial spread 2Δ. This simulates a worst-case scenario of spatial spread. Path delays were set uniformly in the region of 0 to T_{cs} and path coefficients generated with random phases.

Initially, the performance of both the receivers against varying degrees of spatial diffusion of the multipaths is considered. Four users, each with three spatially diffused multipaths were considered at an input SNR of 20 dB. The desired user was assumed to be the first user, without loss of generality. The interfering user's powers were 10 dB higher than the desired user, to simulate a near-far scenario. The SNIR_{out} plots of the desired user, computed using the weight vector given in (22), is shown in Fig.2. It is clear that the performance of the 'spread' STAR manifold based receiver (dashed-line) is satisfactory up to about 6° spatial diffusion. However beyond 6° spread, the performance of the spread angle based receiver (solid-line) is still better, showing very little degradation over the entire spread range considered. In a similar receiver, when the STAR manifold vectors that are parametrised only by the nominal DOAs, TOAs is used (dashed-dot line), the output performance is seen to degrade rapidly with spatial diffusion.

Next, the near-far resistance of the subspace receivers is analyzed at a spatial diffusion of 6° of the multipaths. The plots in Fig. 3 reveals that the receiver loses it's near-far capability when the perturbation due to spatial diffusion is completely ignored (dashed-dot line). The 'spread' STAR manifold based method (dashed-line) remains resistant only up to a near-far ratio of 10 dB, while the spread angle based method (solid-line) is near-far resistant.

5 Conclusions

The wireless vector channel is characterized by spatial diffusion of the multipaths in addition to DOAs and TOAs. Hence, receivers designed for point-like signal sources become ineffective. Thus, two subspace receiver techniques have been proposed for, antenna array DS-CDMA systems in spatially diffused vector channels. In channels with small spreads, the 'spread' STAR manifold based method is cost effective, while for larger spreads and high near-far ratios the spatial spread based method should be used. Both the proposed techniques have indicators to switch the processing method to accommodate high or low spread of the multipaths. Moreover, the proposed diffused channel estimation methodology can be combined with any receiver type to improve performance in spatially diffused channels.

References

[1] K.I. Pedersen, P.E. Mogensen and B.H. Fleury, "A stochastic model of the temporal and azimuthal dispersion seen at the base station in outdoor propagation environments", *IEEE Trans. Veh. Technol.*, vol. 49, No. 2, pp. 437-447, Mar. 2000.

[2] S. Valaee, B. Champagne and P. Kabal, "Parametric localization of distributed sources", *IEEE Trans. Signal Processing*, vol. 43, No. 9, pp. 2144-2153, Sep. 1995.

[3] D. Astely, B. Ottersten, A.L. Swindlehurst, "A generalized array manifold model for local scattering in wireless communications", in *Proc. ICASSP 97'*, Vol.5, pp. 4021-4024, 1997.

[4] R. Raich, J. Goldberg, H. Messer, "Bearing estimation for a distributed sorce: modeling, inherent accuracy limitations and algorithms", *IEEE Trans. Signal Processing*, Vol.48, No.2, Feb. 2000.

[5] T.S. Naveendra and A. Manikas, "Spatio-temporal array DS-CDMA systems: localized scattering channel estimation", in *Proc. IEEE GLOBECOM* 02', vol. 1, pp. 399-403, Nov. 2002.

[6] X. Wang, H.V. Poor, "Blind equalization and multiuser detection in dispersive CDMA channels", *IEEE Trans. Commun.*, Vol. 46, No.1, Jan. 1998.

[7] A. Manikas, H.R. Karimi and I. Dacos, "A study of the detection and resolution capabilities of a one-dimensional array of sensors by using differential geometry," in *Proc. Inst. Elect. Eng.*, Vol. 141, pp. 83-92, April 1994.

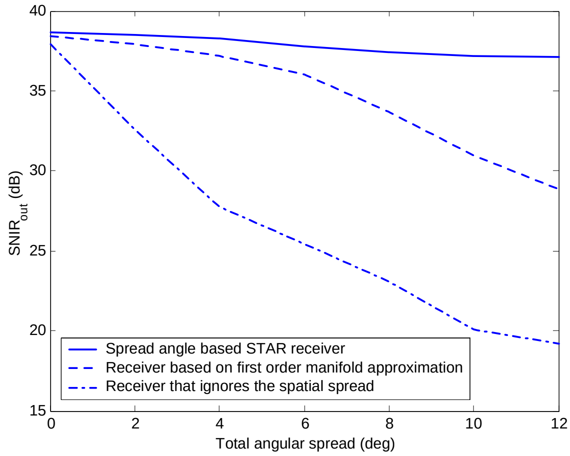

Fig. 2: $SNIR_{out}$ Vs total spatial spread

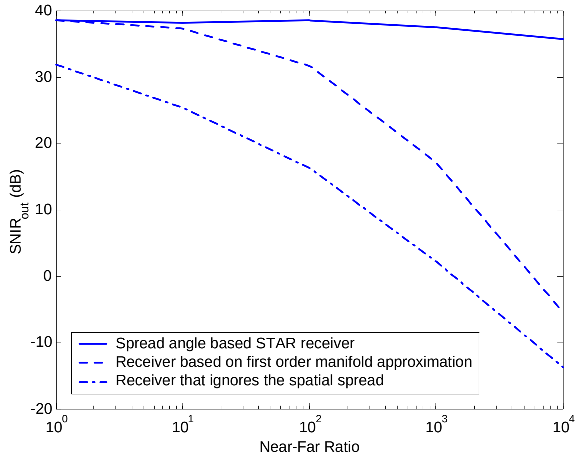

Fig. 3: $SNIR_{out}$ Vs near-far ratio