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A SUBSPACE APPROACH FOR BLIND ESTIMATION OF TIME-VARYING CHANNELS UNDER STBC TRANSMISSIONS

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ABSTRACT

In this paper we consider the problem of blind estimation of time-varying multiple-input multiple-output (MIMO) channels under space-time block coded (STBC) transmissions. Firstly, the time-varying channel is deterministically represented by means of a basis expansion model (BEM), which reduces the number of parameters to be estimated. Secondly, the STBC structure is exploited to blindly recover the channel parameters by means of a subspace technique, which reduces to the solution of a generalized eigenvalue problem (GEV). Unlike previous approaches, the proposed method provides very accurate results even for non-orthogonal STBCs and high Doppler frequencies, which is illustrated by means of some numerical examples.

1. INTRODUCTION

In the last ten years, several families of STBCs have been proposed to exploit the spatial diversity in MIMO systems [1, 2]. A common assumption for most of the STBCs is that perfect channel state information is available at the receiver, which has motivated an increasing interest in blind channel estimation algorithms [3–5]. The main advantage of blind techniques resides in their ability to avoid the penalty in bandwidth efficiency or signal to noise ratio (SNR) associated, respectively, to training based approaches or differential techniques [6–8].

Although the literature on blind and semiblind channel estimation under STBC transmissions is abundant [3–5], only a few works have considered the problem of time-varying channels. On the one hand, in [9–11] the authors have applied several semiblind techniques, originally designed for static channels, to the tracking of slow-varying MIMO channels. On the other hand, in the particular case of orthogonal STBCs (OSTBCs), several adaptive versions of the blind technique in [3] have been recently proposed [12–14]. However, these techniques are limited to very slow-varying channels and most of them rely on the periodic transmission of pilot symbols.

In this paper we propose a technique for the blind estimation of time-varying MIMO channels under STBC transmissions. Specifically, the time-varying channel is deterministically modeled through a basis expansion model (BEM) [15] (see also [16]), which allows us to reduce the number of parameters to be estimated. The BEM parameters are estimated by means of a subspace method, which is inspired by the unconstrained blind maximum likelihood decoder and reduces to the extraction of the eigenvector associated to the largest eigenvalue of a GEV. Thus, the proposed technique is able to fully exploit both the parametric representation of the channel and the structure induced by the STBC. Furthermore, since it is solely based on the second order statistics (SOS) of the observations, it is independent of the particular signal constellation and therefore it can be directly applied when the sources have been precoded in order to exploit the temporal diversity [16]. Finally, the performance of the proposed method is illustrated by means of some simulation examples.

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2. DATA MODEL

Throughout this paper we will use bold-faced upper case letters to denote matrices, e.g., $\mathbf{X}$, with elements $x_{i,j}$; bold-faced lower case letters for column vector, e.g., $\mathbf{x}$, and light-faced lower case letters for scalar quantities. Superscript $\hat{(\cdot)}$ will denote estimated matrices, vectors or scalars, the identity matrix of dimension p will be denoted as $\mathbf{I}_p$, and $\mathbf{0}$ will denote the zero matrix of the required dimensions. The superscripts $(\cdot)^T$ and $(\cdot)^H$ denote transpose and Hermitian. The real and imaginary parts of a matrix $\mathbf{A}$ are denoted as $\Re(\mathbf{A})$ and $\Im(\mathbf{A})$. The trace and Frobenius norm will be denoted as $\text{Tr}(\mathbf{A})$ and $\|\mathbf{A}\|$, respectively. Finally, the column-wise vectorized version of matrix $\mathbf{A}$ will be denoted as $\text{vec}(\mathbf{A})$, and $\otimes$ will denote the Kronecker product.

2.1 Review of Space-Time Block Coding Systems

Let us consider a flat-fading multiple-input multiple-output (MIMO) system with n_T transmit and n_R receive antennas. Assuming that the sources are encoded with a linear space-time block code (STBC) transmitting M information symbols during L uses of the channel (transmission rate $R = M/L$), the n-th block of data can be expressed as

$$\mathbf{S}(\mathbf{s}[n]) = \sum_{k=1}^{M'} \mathbf{C}_k s_k[n],$$

where[1] $M' = 2M$, $\mathbf{s}[n] = [s_1[n], \ldots, s_{M'}[n]]^T$ contains the real and imaginary parts of the M information symbols, and $\mathbf{C}_k \in \mathbb{C}^{L\times n_T}$, $k = 1, \ldots, M'$, are the code matrices.

A common assumption for all the STBC systems is that the MIMO channel remains constant during the L channel uses. Thus, considering N consecutive STBC data blocks, the complex signal at the n_R receive antennas can be written,

[1] We consider the general case of complex STBCs. In the particular case of real codes we have $M' = M$.

for $n = 0,\dots,N-1$, as

$$\mathbf{Y}[n] = \mathbf{S}(\mathbf{s}[n])\mathbf{H}[n] = \sum_{k=1}^{M'} \mathbf{W}_k(\mathbf{H}[n])s_k[n] + \mathbf{N}[n], \quad (1)$$

where $\mathbf{H}[n] \in \mathbb{C}^{n_T \times n_R}$ represents the time-varying MIMO channel, $\mathbf{N}[n] \in \mathbb{C}^{L \times n_R}$ is the white complex noise with zero mean and variance σ^2, and

$$\mathbf{W}_k(\mathbf{H}[n]) = \mathbf{C}_k\mathbf{H}[n], \qquad k = 1,\dots,M'.$$

Defining now $\mathbf{y}[n] = \mathrm{vec}(\mathbf{Y}[n])$, eq. (1) yields

$$\mathbf{y}[n] = \mathbf{W}(\mathbf{h}[n])\mathbf{s}[n] + \mathbf{n}[n], \qquad n = 0,\dots,N-1,$$

where $\mathbf{h}[n] = \mathrm{vec}(\mathbf{H}[n])$, $\mathbf{n}[n] = \mathrm{vec}(\mathbf{N}[n])$, and $\mathbf{W}(\mathbf{h}[n])$ can be seen as the n-th complex equivalent channel, whose k-th column is given by

$$\mathrm{vec}(\mathbf{W}_k(\mathbf{H}[n])) = \mathbf{D}_k\mathbf{h}[n], \qquad k = 1,\dots,M',$$

with $\mathbf{D}_k = \mathbf{I}_{n_R} \otimes \mathbf{C}_k$. However, in order to exploit the impropriety[2] of the sources $\mathbf{s}[n] \in \mathbb{R}^{M' \times 1}$ we will use the following real data model

$$\tilde{\mathbf{y}}[n] = \tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])\mathbf{s}[n] + \tilde{\mathbf{n}}[n], \qquad n = 0,\dots,N-1,$$

where $\tilde{\mathbf{h}}[n] = \left[\Re(\mathbf{h}^T[n]), \Im(\mathbf{h}^T[n])\right]^T$, $\tilde{\mathbf{y}}[n]$ and $\tilde{\mathbf{n}}[n]$ are defined analogously to $\tilde{\mathbf{h}}[n]$, the n-th real equivalent channel $\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n]) = \left[\Re\left(\mathbf{W}^T(\mathbf{h}[n])\right)\, \Im\left(\mathbf{W}^T(\mathbf{h}[n])\right)\right]^T$ is given by

$$\underbrace{\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])}_{2Ln_R \times M'} = \left[\tilde{\mathbf{D}}_1\tilde{\mathbf{h}}[n] \quad \tilde{\mathbf{D}}_2\tilde{\mathbf{h}}[n] \quad \cdots \quad \tilde{\mathbf{D}}_{M'}\tilde{\mathbf{h}}[n]\right], \quad (2)$$

and the extended code matrices are

$$\tilde{\mathbf{D}}_k = \underbrace{\begin{bmatrix} \Re(\mathbf{D}_k) & -\Im(\mathbf{D}_k) \\ \Im(\mathbf{D}_k) & \Re(\mathbf{D}_k) \end{bmatrix}}_{2Ln_R \times 2n_Tn_R}, \qquad k = 1,\dots,M'.$$

Finally, we must note that the properties of a particular STBC are determined by the equivalent channel matrices $\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])$. For instance, in the case of OSTBCs, these matrices satisfy

$$\tilde{\mathbf{W}}^T(\tilde{\mathbf{h}}[n])\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n]) = \|\mathbf{H}[n]\|^2\mathbf{I}_{M'}, \qquad \forall \mathbf{H}[n], \quad (3)$$

which, under a Gaussian distribution for the noise, reduces the maximum-likelihood (ML) receiver to [1]

$$\hat{\mathbf{s}}^{\mathrm{ML}}[n] = \frac{\tilde{\mathbf{W}}^T(\tilde{\mathbf{h}}[n])\tilde{\mathbf{y}}[n]}{\|\mathbf{H}[n]\|^2}.$$

2.2 Channel Model

As previously pointed out, the MIMO channel is assumed to be static during the transmission of a STBC block, which implies that the channel variations are relatively slow. In other words, we can assume that the n-th MIMO channel $\mathbf{H}[n]$ is correlated with the previous and past channels $\mathbf{H}[m]$, for $m = 0,\dots,N$. Under this assumption, the MIMO channel will be well approximated by the basis expansion models (BEM) introduced in [15, 16]. Specifically, we consider that there exists an orthogonal low-rank basis $\mathbf{F} \in \mathbb{C}^{N \times L_c}$ such that the N consecutive MIMO channels $\mathbf{H}[n]$ can be deterministically modeled as

$$\underbrace{\begin{bmatrix} \mathbf{H}[0] \\ \vdots \\ \mathbf{H}[N-1] \end{bmatrix}}_{\mathbf{H}} = \underbrace{(\mathbf{F} \otimes \mathbf{I}_{n_T})}_{\mathscr{F}} \underbrace{\begin{bmatrix} \mathbf{\Theta}_1 \\ \vdots \\ \mathbf{\Theta}_{L_c} \end{bmatrix}}_{\mathbf{\Theta}}, \quad (4)$$

where $L_c \leq N$ is the number of parameters controlling the complexity of the model and $\mathbf{\Theta} \in \mathbb{C}^{L_cn_T \times n_R}$ is the parameter matrix defining the MIMO channel. Thus, the BEM exploits the correlation among the N MIMO channels $\mathbf{H}[n]$, $n = 0,\dots,N-1$, which suggests that blind techniques based on this model will provide better results than differential approaches, which only consider $\mathbf{H}[n] \simeq \mathbf{H}[n-1]$.

As a particular basis, the columns of $\mathbf{F}$ can be selected as the Fourier vectors of length N at normalized frequencies

$$\omega_k = \frac{\pi(2k+1-L_c)}{N}, \qquad k = 0,\dots,L_c-1,$$

which models time-varying channels with maximum normalized Doppler shift [15, 16]

$$f_D = \frac{f_c}{f_s}\frac{v_{\max}}{v_{\mathrm{light}}} = \frac{L_c-1}{2NL},$$

where f_c and f_s denote the carrier and symbol frequencies, $v_{\max}$ is the maximum relative velocity between the transmitter and the receiver, and v_{light} is the speed of light.

3. PROPOSED BLIND CHANNEL ESTIMATION TECHNIQUE

Recently, several efforts have been made in order to blindly recover the source, or the time-varying channel, under STBC transmissions. However, the proposed approaches reduce to adaptive versions [12–14], or even to a direct application [9–11], of (semi)-blind techniques specifically designed for static MIMO channels.

In this section we propose a new technique which completely exploits both the structure of the transmitted signals (induced by the STBC) and the parametric representation of the time-varying MIMO channel. The proposed approach reduces to the extraction of the main eigenvector of a GEV, and since it is solely based on the SOS of the observations, it is independent of the specific signal constellation. Therefore, it can be directly applied even when the sources $\mathbf{s}[n]$ have been linearly precoded to exploit the temporal diversity [16].

3.1 Preliminaries

Let us consider a Gaussian distribution for the noise and a set of N data blocks at the receiver side. The unconstrained maximum likelihood (UML) estimator of the channel parameters and the information symbols can be formulated as

$$\left\{\hat{\mathbf{\Theta}}^{\mathrm{UML}}, \hat{\mathbf{s}}^{\mathrm{UML}}[n]\right\} = \underset{\mathbf{\Theta},\mathbf{s}[n]}{\operatorname{argmin}} \sum_{n=0}^{N-1} \left\|\tilde{\mathbf{y}}[n] - \tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])\mathbf{s}[n]\right\|^2.$$

[2]Note that the source vectors $\mathbf{s}[n]$ are real and the equivalent channels $\mathbf{W}(\mathbf{h}[n])$ are complex.

Thus, under the mild assumption[3] of full-column rank equivalent channels $\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])$, and after solving for $\mathbf{s}[n]$, the above criterion can be rewritten as

$$\hat{\mathbf{\Theta}}^{\text{UML}} = \underset{\mathbf{\Theta}}{\operatorname{argmax}} \sum_{n=0}^{N-1} \tilde{\mathbf{y}}^T[n]\tilde{\mathbf{U}}(\tilde{\mathbf{h}}[n])\tilde{\mathbf{U}}^T(\tilde{\mathbf{h}}[n])\tilde{\mathbf{y}}[n], \qquad (5)$$

where $\tilde{\mathbf{U}}(\tilde{\mathbf{h}}[n]) \in \mathbb{R}^{2Ln_R \times M'}$ is an orthogonal basis for the subspace spanned by $\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])$. Furthermore, taking into account that $\tilde{\mathbf{U}}(\tilde{\mathbf{h}}[n])\tilde{\mathbf{U}}^T(\tilde{\mathbf{h}}[n])$ is the projection matrix onto the cited subspace, the UML decoder can be viewed as a subspace method which amounts to maximizing the energy of the projection of the observations $\tilde{\mathbf{y}}[n]$ (or *empirical signal subspace*) onto the *parameter-dependent signal subspace* defined by the equivalent channels $\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])$. Finally, the right-hand side term in (5) can be bounded by

$$\sum_{n=0}^{N-1} \tilde{\mathbf{y}}^T[n]\tilde{\mathbf{U}}(\tilde{\mathbf{h}}[n])\tilde{\mathbf{U}}^T(\tilde{\mathbf{h}}[n])\tilde{\mathbf{y}}[n] \leq \sum_{n=0}^{N-1} \|\tilde{\mathbf{y}}[n]\|^2,$$

and it is clear that, in the absence of noise, the equality is attained by the actual MIMO channels.

3.2 Proposed Criterion

In a general situation the dependency of $\tilde{\mathbf{U}}(\tilde{\mathbf{h}}[n])$ with $\tilde{\mathbf{h}}[n]$ is not trivial, and the solutions of the UML decoder can not be obtained in closed-form. Here, we propose an alternative subspace method based on the following criterion

$$\hat{\mathbf{\Theta}} = \underset{\mathbf{\Theta}}{\operatorname{argmax}} \sum_{n=0}^{N-1} \operatorname{Tr}\left(\tilde{\mathbf{W}}^T(\tilde{\mathbf{h}}[n])\tilde{\mathbf{y}}[n]\tilde{\mathbf{y}}^T[n]\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])\right),$$
$$\text{s.t.} \qquad \sum_{n=0}^{N-1} \left\|\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])\right\|^2 \|\tilde{\mathbf{y}}[n]\|^2 = M', \qquad (6)$$

i.e., we propose to maximize the projection of the *parameter-dependent signal subspace* onto the *empirical signal subspace*.

Here, we must note that the energy constraint in (6) does not only avoid trivial solutions, but also ensures that, in the case of OSTBCs (see eq. (3))

$$\sum_{n=0}^{N-1} \operatorname{Tr}\left(\tilde{\mathbf{W}}^T(\tilde{\mathbf{h}}[n])\tilde{\mathbf{y}}[n]\tilde{\mathbf{y}}^T[n]\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])\right) \leq$$
$$\leq \sum_{n=0}^{N-1} \frac{\left\|\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])\right\|^2}{M'} \|\tilde{\mathbf{y}}[n]\|^2 = 1,$$

where the equality is attained, in the absence of noise, by the actual MIMO channels, i.e., the theoretical solutions of the proposed criterion are those of the UML decoder.

Unfortunately, in the case of general STBCs the above criterion is not necessarily maximized by the true MIMO channels. This can be seen as a consequence of the non-orthogonality of the equivalent channels $\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])$, which provokes spurious channel estimates trying to concentrate most of the energy of $\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])$ along the direction defined by the observed vector $\tilde{\mathbf{y}}[n]$. However, taking into account that the maximization is simultaneously made for the N channels $\mathbf{H}[n]$, and that in a practical situation the number of parameters is $L_c << N$, we see that in general there are not enough degrees of freedom to select the spurious MIMO channels. Therefore, as it will be shown in the simulations section, in practice the proposed criteria provides very accurate channel estimates even for non-orthogonal codes.

[3] This condition is satisfied by the most common STBCs.

3.3 Practical Implementation

Unlike $\tilde{\mathbf{U}}(\tilde{\mathbf{h}}[n])$, the dependency of $\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])$ with respect to $\tilde{\mathbf{h}}[n]$ is explicitly given by (2), which allows us to rewrite (6) as

$$\hat{\mathbf{\Theta}} = \underset{\mathbf{\Theta}}{\operatorname{argmax}} \sum_{n=0}^{N-1} \tilde{\mathbf{h}}^T[n]\mathbf{\Xi}[n]\tilde{\mathbf{h}}[n],$$
$$\text{s.t.} \qquad \sum_{n=0}^{N-1} \tilde{\mathbf{h}}^T[n]\mathbf{\Psi}[n]\tilde{\mathbf{h}}[n] = M',$$

where

$$\mathbf{\Xi}[n] = \sum_{k=1}^{M'} \tilde{\mathbf{D}}_k^T \tilde{\mathbf{y}}[n]\tilde{\mathbf{y}}^T[n]\tilde{\mathbf{D}}_k, \qquad \mathbf{\Psi}[n] = \|\tilde{\mathbf{y}}[n]\|^2 \sum_{k=1}^{M'} \tilde{\mathbf{D}}_k^T \tilde{\mathbf{D}}_k.$$

Now, taking into account the channel model in (4), and defining the vectors $\theta_k = \operatorname{vec}(\mathbf{\Theta}_k)$, $\tilde{\theta}_k = \left[\Re(\theta_k^T), \Im(\theta_k^T)\right]^T$ and $\tilde{\theta} = \left[\tilde{\theta}_1^T, \ldots, \tilde{\theta}_{L_c}^T\right]$, the final channel estimation criterion is

$$\hat{\tilde{\theta}} = \underset{\tilde{\theta}}{\operatorname{argmax}}\, \tilde{\theta}^T \mathbf{\Xi} \tilde{\theta}, \qquad \text{s.t.} \qquad \tilde{\theta}^T \mathbf{\Psi} \tilde{\theta} = M',$$

where

$$\mathbf{\Xi} = \sum_{n=0}^{N-1} \mathbf{\Omega}^T[n]\mathbf{\Xi}[n]\mathbf{\Omega}[n], \qquad \mathbf{\Psi} = \sum_{n=0}^{N-1} \mathbf{\Omega}^T[n]\mathbf{\Psi}[n]\mathbf{\Omega}[n],$$

and the matrices $\mathbf{\Omega}[n]$ are obtained from the n-th row ($\mathbf{f}^T[n]$) of the orthogonal basis $\mathbf{F}$ as

$$\mathbf{\Omega}[n] = \Re(\mathbf{f}^T[n]) \otimes \mathbf{I}_{2n_T n_R} + \Im(\mathbf{f}^T[n]) \otimes \begin{bmatrix} \mathbf{0} & -\mathbf{I}_{n_T n_R} \\ \mathbf{I}_{n_T n_R} & \mathbf{0} \end{bmatrix}.$$

Thus, the estimate of the channel parameters $\hat{\tilde{\theta}}$ is obtained, up to a real scalar, as the eigenvector associated to the largest eigenvalue β of the following generalized eigenvalue problem (GEV)

$$\mathbf{\Xi}\hat{\tilde{\theta}} = \beta \mathbf{\Psi} \hat{\tilde{\theta}}.$$

4. SIMULATION RESULTS

In this section the performance of the proposed technique is illustrated by means of some Monte-Carlo simulations. In all the experiments we have used $n_T = 4$ transmit antennas and STBCs with length $L = 4$, the source signals belong to a QPSK constellation, the channel parameters $\mathbf{\Theta}$ have been generated as i.i.d. Gaussian random variables, and we compare the performance of a MMSE detector with perfect channel knowledge and with the channel estimates provided by the proposed technique. The parameter controlling the complexity of the BEM has been selected as $L_c = 5$, which trans-

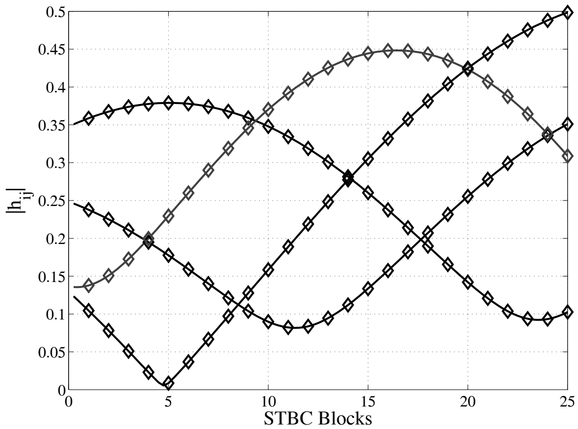

Figure 1: Evolution of a time-varying channel during 100 symbol periods. $L_c = 5$, $N = 128$, $L = 4$, $f_D \simeq 3.9 \cdot 10^{-3}$.

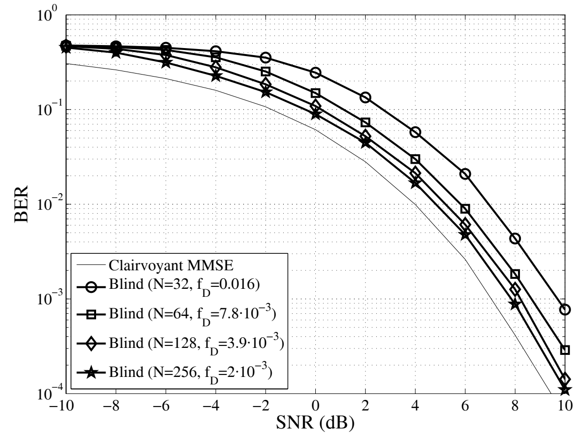

Figure 3: Bit error rate after MMSE decoding. OSTBC, $n_T = 4$, $n_R = 2$, $M = 3$, $L = 4$ and $L_c = 5$.

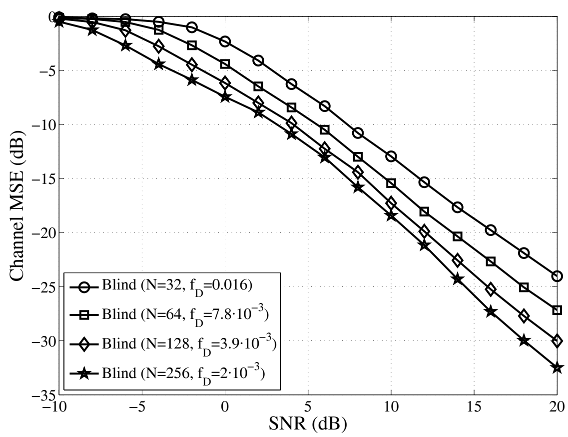

Figure 2: MSE in the channel estimate of the proposed technique. OSTBC, $n_T = 4$, $n_R = 2$, $M = 3$, $L = 4$ and $L_c = 5$.

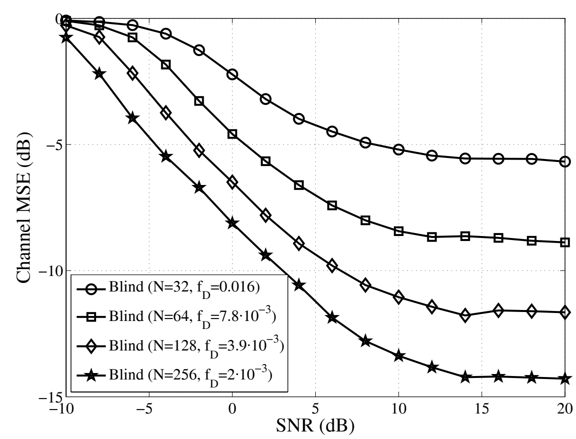

Figure 4: MSE in the channel estimate of the proposed technique. QSTBC, $n_T = n_R = M = L = 4$ and $L_c = 5$.

lates into normalized Doppler frequencies of

$$f_D = \frac{1}{2N},$$

and we have used different data block sizes ($N = 32, 64, 128, 256$). As an example, Fig. 1 shows the evolution of the absolute value of four channel coefficients during the transmission of 25 STBC blocks (100 symbol periods) with $N = 128$ ($f_D \simeq 3.9 \cdot 10^{-3}$). As can be seen, although the MIMO channel can be considered static during the transmission of a STBC block, the proposed blind channel estimation technique is able to work with fast-varying channels.

4.1 Results for Orthogonal Codes (OSTBCs)

In the first set of experiments we consider a system with $n_R = 2$ receive antennas using the OSTBC presented in Eq. (7.4.10) of [1], whose parameters are $M = 3$ and $L = 4$ ($R = 3/4$). Fig. 2 shows the mean square error (MSE) of the channel estimates as a function of the signal to noise ratio (SNR). As can be seen, the proposed technique is able to blindly recover the channel and, as it was expected, the accuracy of the estimates increases with the temporal coherency of the channel, which increases with N. On the other hand, Fig. 3 shows the bit error rate (BER) after MMSE decoding, where we can see that for moderate Doppler frequencies, the performance of the proposed technique is close to that of the receiver with perfect channel knowledge.

4.2 Results for Non-Orthogonal Codes

The previous experiments have been repeated for a system with the quasi-orthogonal STBC (QSTBC) proposed in [2] ($n_T = M = L = 4$) and $n_R = 4$ receive antennas. The MSE in the channel estimate is shown in Fig. 4, where we can see that the non-orthogonality of the equivalent channels $\tilde{\mathbf{W}}(\tilde{\mathbf{h}}[n])$ provokes a noise-floor in the channel estimates. However, the noise floor decreases with the temporal coherence of the channel and, as can be seen in Fig. 5, for practical SNRs and Doppler frequencies, the system performance is dominated by the noise and not by the errors in the channel estimate.

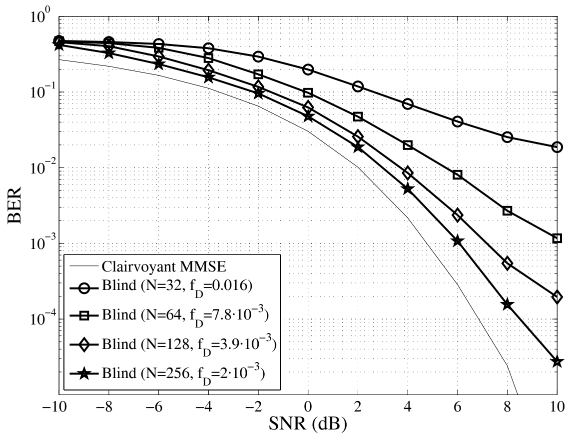

Figure 5: Bit error rate after MMSE decoding. QSTBC, $n_T = n_R = M = L = 4$ and $L_c = 5$.

5. CONCLUSIONS

In this paper a new subspace method for blind estimation of time-varying channels under STBC transmissions has been proposed. Specifically, the time-varying MIMO channel has been deterministically represented by means of a basis expansion model, which permits the reduction of the number of parameters to be estimated. The proposed technique is solely based on the SOS of the received signals, and therefore it is independent of the specific signal constellation. Furthermore, its computational complexity reduces to the extraction of the main eigenvector of a generalized eigenvalue problem and, unlike previous approaches, it is able to recover the channel in a completely blind manner even for non-orthogonal STBCs. Finally, the performance of the proposed technique has been illustrated by means of some numerical examples.

REFERENCES

[1] E. G. Larsson and P. Stoica, *Space-Time Block Coding for Wireless Communications*, Cambridge University Press, New York, USA, 2003.

[2] H. Jafarkhani, *Space-Time Coding: Theory and Practice*, Cambridge University Press, 2005.

[3] S. Shahbazpanahi, A. B. Gershman, and J. H. Manton, "Closed-form blind MIMO channel estimation for orthogonal space-time block codes," *IEEE Transactions on Signal Processing*, vol. 53, no. 12, pp. 4506–4517, Dec. 2005.

[4] W. K. Ma, B. N. Vo, T. N. Davidson, and P. C. Ching, "Blind ML detection of orthogonal space-time block codes: Efficient high-performance implementations," *IEEE Transactions on Signal Processing*, vol. 54, no. 2, pp. 738–751, Feb. 2006.

[5] N. Ammar and Z. Ding, "Blind channel identifiability for generic linear space-time block codes," *IEEE Transactions on Signal Processing*, vol. 55, no. 1, pp. 202–217, Jan. 2007.

[6] V. Tarokh and H. Jafarkhani, "A differential detection scheme for transmit diversity," *IEEE Journal on Selected Areas in Communications*, vol. 18, no. 7, pp. 1169–1174, July 2000.

[7] G. Ganesan and P. Stoica, "Differential modulation using space-time block codes," *IEEE Signal Processing Letters*, vol. 9, no. 2, pp. 57–60, Feb. 2002.

[8] Y. Zhu and H. Jafarkhani, "Differential modulation based on quasi-orthogonal codes," *IEEE Transactions on Wireless Communications*, vol. 4, no. 6, pp. 3005–3017, Nov. 2005.

[9] S. Zhou, B. Muquet, and G. Giannakis, "Subspace-based (semi-) blind channel estimation for block precoded space-time OFDM," *IEEE Transactions on Signal Processing*, vol. 50, no. 5, pp. 1215–1228, May 2002.

[10] Zhiguo Ding, D.B Ward, and Woon Hau Chin, "A general scheme for equalization of Space-Time Block-Coded systems with unknown CSI," *IEEE Transactions on Signal Processing*, vol. 54, no. 7, pp. 2737–2746, July 2006.

[11] Jwo-Yuh Wu and Ta-Sung Lee, "Nonredundant precoding-assisted blind channel estimation for single-carrier space-time block-coded transmission with frequency-domain equalization," *IEEE Transactions on Signal Processing*, vol. 55, no. 3, pp. 1062–1080, Mar. 2007.

[12] J. Vía, I. Santamaría, J. Pérez, and D. Ramírez, "Blind decoding of MISO-OSTBC systems based on principal component analysis," in *IEEE International Conference on Acoustic, Speech, and Signal Processing (ICASSP 2006)*, Toulouse, France, May 2006.

[13] J. Vía, I. Santamaría, and J. Pérez, "Blind identification of MIMO-OSTBC channels combining second and higher order statistics," in *European Signal Processing Conference (EUSIPCO 2006)*, Florence, Italy, Sept. 2006.

[14] B. Balakumar, S. Shahbazpanahi, and T. Kirubarajan, "Joint MIMO channel tracking and symbol decoding using kalman filtering," *IEEE Transactions on Signal Processing*, vol. 55, no. 12, pp. 5873–5879, Dec. 2007.

[15] G.B. Giannakis and C. Tepedelenlioglu, "Basis expansion models and diversity techniques for blind identification and equalization of time-varying channels," *Proceedings of the IEEE*, vol. 86, no. 10, pp. 1969–1986, Oct. 1998.

[16] G. B. Giannakis, Z. Liu, X. Ma, and S. Zhou, *Space Time Coding for Broadband Wireless Communications*, Wiley-Interscience, 2006.