A Kalman Filter-Based Channel Estimator for Generalized Group-Coherent Codes

Murilo Bellezoni Loiola, Renato Machado, and Dimas Irion Alves

***Resumo*— Neste artigo, propõe-se um algoritmo semicego para estimação de canais MIMO adaptado para o uso de códigos grupo-coerente. O desempenho da proposta é avaliado para canais de comunicação planos e variantes no tempo. O estimador proposto utiliza um filtro de Kalman para rastrear o canal em sistemas que empregam códigos grupo-coerente no transmissor. Baseado nos coeficientes estimados, o receptor faz uma avaliação de SNR instantânea para cada um dos 2_f^b códigos disponíveis no transmissor e então envia b_f bits de informação ao transmissor para que o mesmo realize a transmissão do próximo bloco de dados com o código grupo-coerente mais adequado. Avaliações são feitas para transmissões sujeitas a diferentes condições de mobilidade e para diferentes níveis de quantização do canal de realimentação. Resultados de simulação revelam que o estimador proposto proporciona um desempenho muito próximo ao caso em que a estimação do canal é considerada perfeita e também que o sistema baseado no filtro de Kalman proposto apresenta o mesmo desempenho para diferentes níveis de quantização do canal de realimentação.**

***Palavras-Chave*— Códigos grupo-coerente; estimação de canal MIMO; filtro de Kalman.**

***Abstract*— In this paper we propose a semiblind algorithm for estimation of MIMO channel adapted for the use of group-coherent codes. The performance of the proposed algorithm is evaluated for Rayleigh, flat, and time-varying MIMO channels. The proposed estimator considers a Kalman filter to track the channel in MIMO systems that employ group-coherent codes at the transmitter. Based on the estimated coefficients, the receiver evaluates the instantaneous SNR for each one of 2_f^b codes available in the transmitter, and then sends b_f information bits to the transmitter for the choice of the more appropriate code to send the next block of data. Also, simulations are performed for transmissions under different mobility and quantized feedback channel conditions. Simulation results reveal that the proposed estimator provides a performance very close to the one that considers a perfect channel knowledge and also that the performance of the proposed kalman filter-based receiver is approximately the same for different quantized feedback conditions.**

***Keywords*— Group-coherent codes; Kalman Filter; MIMO channel estimation.**

I. INTRODUCTION

Space-time codes are an effective and practical way to exploit spatial diversity in multiple-input, multiple-output (MIMO) systems, allowing the system to benefit from transmit diversity without any power increment and with no channel knowledge at the transmitter. Among the existing space-time coding schemes, orthogonal space-time block codes (OSTBCs) [1] are of particular interest because they achieve full diversity at low receiver complexity. More specifically, the maximum likelihood (ML) receiver for OSTBCs consists of a linear receiver followed by a symbol-by-symbol decoder [1].

When a feedback channel from the receiver to the transmitter exists so that the channel state information (CSI) is known at the transmitter, MIMO communication systems can obtain significant performance improvements [2]. In this case, OSTBCs are not appropriate, since they can not improve their performances from the extra feedback information. For this reason, Machado and Uchôa-Filho [3] have proposed a hybrid transmit antenna/code selection scheme that chooses from a list of space-time block codes the best code to be used with a subset of transmit antennas. This selection uses the feedback information and the code selection is based on the instantaneous error probability minimization criterion. This idea has been refined later in [4].

Also, the so called group-coherent codes (GCCs) have been proposed by Akhtar and Gesbert [5] for pN_T transmit antennas and $p-1$ feedback bits, where N_T is the number of antennas of the OSTBC considered for the GCC design. The transmit diversity order achieved is pN_T. In [6], the GCCs have been extended to yield a better error performance, considering the "trivial" code (one information symbol transmitted over one transmit period via a single transmit antenna), with $(p-1)\log_2(r)$ feedback bits, where r is some positive power of 2. Herein, this scheme is named generalized group-coherent code (GGCC).

In all space-time coded schemes presented so far, the decoders must have perfect channel knowledge to correctly decode the received signals. Unfortunately, this channel information is not normally available to the receivers; therefore channel estimation techniques are essential for the system to work properly. Also, when the channel is time-varying due to the mobility of the transmitter and/or receiver, to changes in the environment, or to carrier frequency mismatch between transmitter and receiver, the channel estimation becomes more challenging because, in these cases, the estimation algorithm must be able to track the channel variations. One of the most widely known approaches to channel tracking is Kalman filtering [7].

The use of Kalman filters to estimate channels in orthogonal space-time block coded systems is developed in [8]–[11]. However, to the best of authors knowledge, there is no work devoted to the study of the performance degradation of GGCCs with imperfect channel information. For this reason, we propose in this paper a channel estimator based on Kalman

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filter for systems employing GGCCs. We also analyze the impact of such imperfect CSI to the performance of GGCCs.

The remainder of this paper is organized as follows. Section II presents the system model. Section III details the proposed channel estimator. In Section IV, simulation results are shown. Finally, Section V outlines the main conclusion and final remarks of this paper.

II. System model

A. Channel model

We consider a MISO system with N_T transmit antennas sending data blocks of length l to one receive antenna. The channel is assumed to be flat and constant during the transmission of each data block and can change between consecutive blocks. According to the widely used wide-sense stationary uncorrelated scattering (WSSUS) model [12], the channel coefficients are modeled as dependent, zero-mean, complex Gaussian random variables with time autocorrelation function

$$\mathrm{E}\left[h_{k,i}h_{t,i}^{*}\right] \approx \mathcal{J}_0(2\pi f_D T_s\,|k-t|), \tag{1}$$

where $h_{k,i}$, $i=1,\ldots,N_T$ is the i^{th} element of vector $\mathbf{h}_k$, $\mathcal{J}_0$ is the zero-order Bessel function of the first kind, $f_D T_s$ is the normalized Doppler rate and T_s is the symbol duration.

Although exact modeling of channel dynamics by finite length autoregressive (AR) processes is impossible because the time autocorrelation function (1) is nonrational and its spectrum is bandlimited, we can approximate the time evolution of channel coefficients by low-order AR processes [9], [13]. Therefore, following [9], [13], we herein approximate the MISO channel variations by a first order AR process. Thus, the time evolution of the channel is given by

$$\mathbf{h}_k = \beta\mathbf{h}_{k-1} + \mathbf{w}_k, \tag{2}$$

where $\beta = \mathcal{J}_0(2\pi f_D T_s)$, $\mathbf{w}_k$ is a vector of length N_T containing independent samples of circularly symmetric, zero-mean, Gaussian excitation noise with covariance matrix $\mathbf{Q} = \sigma_w^2\mathbf{I}_{N_T}$, and $\sigma_w^2 = (1-\beta^2)P_k$, with $P_k = \mathrm{E}\left[|h_{k,m}|^2\right]$, $m=1,\ldots,N_T$.

B. Orthogonal Space-Time Block Codes

In space-time block coding, the matrix $\mathbf{C}_k$ represents a mapping that transforms a block of n complex symbols, $\mathbf{x}_k = [x_{k,1}\ x_{k,2}\ \cdots\ x_{k,n}]^{\mathsf{T}}$, to an $l \times N_T$ complex matrix [1]. The space-time codeword $\mathbf{C}_k$ is then used to transmit these n symbols in l time slots, achieving a rate of n/l.

The matrix $\mathbf{C}_k$ is said to be an Orthogonal Space-Time Block Code (OSTBC) if [1]: 1) all elements of $\mathbf{C}_k$ are linear functions of symbols of $\mathbf{x}_k$ and their complex conjugates and 2) for an arbitrary $\mathbf{x}_k$, the matrix $\mathbf{C}_k$ satisfies $\mathbf{C}_k^{\mathsf{H}}\mathbf{C}_k = \|\mathbf{x}_k\|^2\mathbf{I}_{N_T}$, where $\mathbf{I}_{N_T}$ is the identity matrix of order N_T, $\|\cdot\|$ represents the Euclidean norm and $(\cdot)^{\mathsf{H}}$ denotes the conjugate transpose of a matrix.

C. Generalized Group-Coherent Codes

OSTBCs are particularly attractive for practical implementations because of their low complexity maximum-likelihood decoder and the fact that they achieve full spatial diversity without any channel knowledge at the transmitter [1]. However, if any channel state information (CSI) is available at the transmitter via a limited feedback channel, OSTBCs are not the best choice because they can not use the extra information provided by feedback to improve performance. In this case, GGCCs can provide an improved performance.

As shown in [14], a GGCC designed for pN_T transmit antennas, where $N_T \geq 1$ and p is an integer greater than two, consists of a family of OSTBCs represented by the 2^{p-1} matrices $\mathbf{G}_k$

$$\mathbf{G}_k = \frac{1}{\sqrt{p}}\left[\,\mathbf{C}_k \quad \beta_{1,k}\mathbf{C}_k \quad \beta_{2,k}\mathbf{C}_k \quad \cdots \quad \beta_{p-1,k}\mathbf{C}_k\,\right], \tag{3}$$

where $\mathbf{C}_k$ is an OSTBC, $\beta_i = e^{j\theta_i}$, $\theta_i \in [0, 2\pi)$ and k is a the time index representing the transmitted block. Without loss of generality, we can assume $\theta_0 = 0$. The choice of θ_i depends on the information fed back by the receiver, and is made to minimize the instantaneous error probability based on the CSI [14].

If we stack the signals received by the single receive antenna during time instants $1,\ldots,l$, we can write these signals as

$$\mathbf{r}_k = \mathbf{G}_k\mathbf{h}_k + \mathbf{n}_k, \tag{4}$$

where $\mathbf{n}_k$ is a vector containing zero-mean, additive white Gaussian noise (AWGN) samples with variance σ_n^2.

III. Proposed Channel Estimator

In order to formulate the problem of channel estimation as one of state estimation, we need two equations named process and measurement equations, respectively [7]. The process equation describes the dynamic behavior of the state variables to be estimated, while the measurement equation presents the relationship between the state variables and the observed system output. As we focus on channel tracking, we can use (2) as the process equation and $\mathbf{h}_k$ as the state vector. The system output, in our case, is the channel output $\mathbf{r}_k$ in (4). Therefore, our state-space model is given by

$$\begin{cases} \mathbf{h}_k = \beta\mathbf{h}_{k-1} + \mathbf{w}_k & \text{Process equation} \\ \mathbf{r}_k = \mathbf{G}_k\mathbf{h}_k + \mathbf{n}_k & \text{Measurement equation} \end{cases} \tag{5}$$

Hence, from (5) the conventional Kalman filter is given by

$$\hat{\mathbf{h}}_{k|k-1} = \beta\hat{\mathbf{h}}_{k-1|k-1} \tag{6a}$$
$$\mathbf{P}_{k|k-1} = \beta^2\mathbf{P}_{k-1|k-1} + \mathbf{Q} \tag{6b}$$
$$\mathbf{K}_k = \mathbf{P}_{k|k-1}\mathbf{G}_k^{\mathsf{H}}\left(\mathbf{G}_k\mathbf{P}_{k|k-1}\mathbf{G}_k^{\mathsf{H}} + \mathbf{R}\right)^{-1} \tag{6c}$$
$$\hat{\mathbf{h}}_{k|k} = \hat{\mathbf{h}}_{k|k-1} + \mathbf{K}_k\left(\mathbf{r}_k - \mathbf{G}_k\hat{\mathbf{h}}_{k|k-1}\right) \tag{6d}$$
$$\mathbf{P}_{k|k} = \left(\mathbf{I}_{N_T} - \mathbf{K}_k\mathbf{G}_k\right)\mathbf{P}_{k|k-1}, \tag{6e}$$

where $\hat{\mathbf{h}}_{i|j}$ represents the channel estimate at time instant i obtained from the signals received until time j, $\mathbf{P}_{i|j}$ is the estimation error covariance matrix at instant i, computed from the signals received until instant j, $\mathbf{Q} = \sigma_w^2\mathbf{I}_{N_T}$ is the covariance matrix of $\mathbf{w}_k$, $\mathbf{R} = \sigma_n^2 \mathbf{I}_{N_T}$ is the covariance matrix of $\mathbf{n}_k$ and $\mathbf{K}_k$ is known as Kalman gain matrix.

To exploit the structure of any GGCC in the channel estimator, let's consider a GGCC $\mathbf{G}_k$ designed for pN_T transmit antennas

$$\mathbf{G}_k = \frac{1}{\sqrt{p}} \begin{bmatrix} \mathbf{C}_k & \beta_{1,k}\mathbf{C}_k & \beta_{2,k}\mathbf{C}_k & \cdots & \beta_{p-1,k}\mathbf{C}_k \end{bmatrix}. \quad (7)$$

By defining the weighting vector $\mathbf{b}_k$ as

$$\mathbf{b}_k = \frac{1}{\sqrt{p}} \begin{bmatrix} 1 & \beta_{1,k} & \beta_{2,k} & \cdots & \beta_{p-1,k} \end{bmatrix}, \quad (8)$$

it is possible to write (7) as

$$\mathbf{G}_k = \mathbf{b}_k \otimes \mathbf{C}_k, \quad (9)$$

where $\otimes$ represents the Kronecker product [15].

In order to simplify the notation, we define $\mathbf{G}_k = \mathbf{G}_k$. Therefore, we obtain

$$\begin{aligned} \mathbf{M}_k &= \mathbf{G}_k^{\mathsf{H}}\mathbf{G}_k = (\mathbf{b}_k \otimes \mathbf{C}_k)^{\mathsf{H}} (\mathbf{b}_k \otimes \mathbf{C}_k) \\ &= \left(\mathbf{b}_k^{\mathsf{H}} \otimes \mathbf{C}_k^{\mathsf{H}}\right)(\mathbf{b}_k \otimes \mathbf{C}_k) = \mathbf{b}_k^{\mathsf{H}}\mathbf{b}_k \otimes \mathbf{C}_k^{\mathsf{H}}\mathbf{C}_k, \end{aligned} \quad (10)$$

where were used the properties of Kronecker products [15].

Remembering that $\mathbf{C}_k^{\mathsf{H}}\mathbf{C}_k = \|\mathbf{x}\|^2\mathbf{I}_{N_T}$ for an OSTBC and assuming an M-PSK modulation, the matrix $\mathbf{M}_k$ can be computed as

$$\begin{aligned} \mathbf{M}_k &= \mathbf{G}_k^{\mathsf{H}}\mathbf{G}_k = \mathbf{b}_k^{\mathsf{H}}\mathbf{b}_k \otimes \alpha\mathbf{I}_{N_T} \Rightarrow \mathbf{M}_k = \mathbf{G}_k^{\mathsf{H}}\mathbf{G}_k \\ &= \alpha\mathbf{b}_k^{\mathsf{H}}\mathbf{b}_k \otimes \mathbf{I}_{N_T}, \end{aligned} \quad (11)$$

with $\alpha = \|\mathbf{x}\|^2$ a constant representing the energy of uncoded data block.

We start now to develop a Kalman channel estimator that takes into account the structure of GGCCs, which is described by (9) and (11). Using the fact that $\mathbf{R} = \sigma_n^2\mathbf{I}_{N_T}$, it is possible to apply the matrix inversion lemma to the Kalman gain matrix (6c) to obtain

$$\begin{aligned} \mathbf{K}_k &= \mathbf{P}_{k|k-1}\mathbf{G}_k^{\mathsf{H}}\left(\mathbf{G}_k\mathbf{P}_{k|k-1}\mathbf{G}_k^{\mathsf{H}} + \mathbf{R}\right)^{-1} \\ &= \mathbf{P}_{k|k-1}\mathbf{G}_k^{\mathsf{H}}\left[\frac{1}{\sigma_n^2}\mathbf{I}_{N_T} - \frac{1}{\sigma_n^4}\mathbf{G}_k\left(\frac{1}{\sigma_n^2}\mathbf{G}_k^{\mathsf{H}}\mathbf{G}_k + \mathbf{P}_{k|k-1}^{-1}\right)^{-1}\mathbf{G}_k^{\mathsf{H}}\right] \\ &= \frac{1}{\sigma_n^2}\mathbf{P}_{k|k-1}\left[\mathbf{G}_k^{\mathsf{H}} - \frac{1}{\sigma_n^2}\mathbf{G}_k^{\mathsf{H}}\mathbf{G}_k\left(\frac{1}{\sigma_n^2}\mathbf{M}_k + \mathbf{P}_{k|k-1}^{-1}\right)^{-1}\mathbf{G}_k^{\mathsf{H}}\right] \\ &= \frac{1}{\sigma_n^2}\mathbf{P}_{k|k-1}\left[\mathbf{I}_{N_T} - \frac{1}{\sigma_n^2}\mathbf{M}_k\left(\frac{1}{\sigma_n^2}\mathbf{M}_k + \mathbf{P}_{k|k-1}^{-1}\right)^{-1}\right]\mathbf{G}_k^{\mathsf{H}}. \end{aligned} \quad (12)$$

Employing the matrix inversion lemma once more, it is possible to write the inverse matrix in (12) as

$$\left(\frac{1}{\sigma_n^2}\mathbf{M}_k + \mathbf{P}_{k|k-1}^{-1}\right)^{-1} = \mathbf{P}_{k|k-1} - \frac{1}{\sigma_n^2}\mathbf{P}_{k|k-1}\left(\frac{1}{\sigma_n^2}\mathbf{M}_k\mathbf{P}_{k|k-1} + \mathbf{I}_{N_T}\right)^{-1}\mathbf{M}_k\mathbf{P}_{k|k-1}. \quad (13)$$

By using (13), (12) can be written as

$$\mathbf{K}_k = \mathbf{A}_k\mathbf{G}_k^{\mathsf{H}}, \quad (14)$$

where $\mathbf{A}_k$ is given by

$$\mathbf{A}_k = \frac{1}{\sigma_n^2}\mathbf{P}_{k|k-1}\left\{\mathbf{I}_{N_T} - \frac{1}{\sigma_n^2}\mathbf{M}_k\mathbf{P}_{k|k-1}\left[\mathbf{I}_{N_T} - \frac{1}{\sigma_n^2}\left(\frac{1}{\sigma_n^2}\mathbf{M}_k\mathbf{P}_{k|k-1} + \mathbf{I}_{N_T}\right)^{-1}\mathbf{M}_k\mathbf{P}_{k|k-1}\right]\right\}. \quad (15)$$

Replacing (14) into (6d) results in

$$\begin{aligned} \hat{\mathbf{h}}_{k|k} &= \hat{\mathbf{h}}_{k|k-1} + \mathbf{K}_k\left(\mathbf{r}_k - \mathbf{G}_k\hat{\mathbf{h}}_{k|k-1}\right) \\ &= \hat{\mathbf{h}}_{k|k-1} + \mathbf{A}_k\mathbf{G}_k^{\mathsf{H}}\mathbf{r}_k - \mathbf{A}_k\mathbf{G}_k^{\mathsf{H}}\mathbf{G}_k\hat{\mathbf{h}}_{k|k-1} \\ &= \hat{\mathbf{h}}_{k|k-1} + \mathbf{A}_k\mathbf{G}_k^{\mathsf{H}}\mathbf{r}_k - \mathbf{A}_k\mathbf{M}_k\hat{\mathbf{h}}_{k|k-1} \\ &= \left(\mathbf{I}_{N_T} - \mathbf{A}_k\mathbf{M}_k\right)\hat{\mathbf{h}}_{k|k-1} + \mathbf{A}_k\mathbf{G}_k^{\mathsf{H}}\mathbf{r}_k, \end{aligned} \quad (16)$$

and using (6a)

$$\hat{\mathbf{h}}_{k|k} = \beta\left(\mathbf{I}_{N_T} - \mathbf{A}_k\mathbf{M}_k\right)\hat{\mathbf{h}}_{k-1|k-1} + \mathbf{A}_k\mathbf{G}_k^{\mathsf{H}}\mathbf{r}_k. \quad (17)$$

Finally, replacing (14) into (6e) results in

$$\begin{aligned} \mathbf{P}_{k|k} &= \left(\mathbf{I}_{N_T} - \mathbf{K}_k\mathbf{G}_k\right)\mathbf{P}_{k|k-1} = \left(\mathbf{I}_{N_T} - \mathbf{A}_k\mathbf{G}_k^{\mathsf{H}}\mathbf{G}_k\right)\mathbf{P}_{k|k-1} \\ &= \left(\mathbf{I}_{N_T} - \mathbf{A}_k\mathbf{M}_k\right)\mathbf{P}_{k|k-1}. \end{aligned} \quad (18)$$

By defining

$$\mathbf{B}_k = \mathbf{I}_{N_T} - \mathbf{A}_k\mathbf{M}_k, \quad (19)$$

and gathering (6b), (14), (17), and (18), we obtain the Kalman channel estimator for GGCC systems

$$\mathbf{P}_{k|k-1} = \beta^2\mathbf{P}_{k-1|k-1} + \mathbf{Q} \quad (20a)$$

$$\mathbf{A}_k = \tfrac{1}{\sigma_n^2}\mathbf{P}_{k|k-1}\left\{\mathbf{I}_{N_T} - \tfrac{1}{\sigma_n^2}\mathbf{M}_k\mathbf{P}_{k|k-1}\left[\mathbf{I}_{N_T} - \tfrac{1}{\sigma_n^2}\left(\tfrac{1}{\sigma_n^2}\mathbf{M}_k\mathbf{P}_{k|k-1} + \mathbf{I}_{N_T}\right)^{-1}\mathbf{M}_k\mathbf{P}_{k|k-1}\right]\right\} \quad (20b)$$

$$\mathbf{B}_k = \mathbf{I}_{N_T} - \mathbf{A}_k\mathbf{M}_k \quad (20c)$$

$$\hat{\mathbf{h}}_{k|k} = \beta\mathbf{B}_k\hat{\mathbf{h}}_{k-1|k-1} + \mathbf{A}_k\mathbf{G}_k^{\mathsf{H}}\mathbf{r}_k \quad (20d)$$

$$\mathbf{P}_{k|k} = \mathbf{B}_k\mathbf{P}_{k|k-1} \quad (20e)$$

It is worth noting that the conventional Kalman filter equations in (6c)–(6e) depend on the transmitted symbols contained in matrix $\mathbf{G}_k$. However, in the Kalman filter exploiting the structure of GGCCs, only the channel estimate update equation (20d) has an explicit dependance on the transmitted and received signals. All other equations depend only on parameters of the system, such as the prediction error covariance matrix $\mathbf{P}_{k|k-1}$, the variance σ_n^2 of the measurement noise and the code used. Hence, it is possible to compute (20a)–(20c) and (20e) off-line, i.e., even before the beginning of the data transmission, which could help in the reduction of the computational burden during the execution of the algorithm.

IV. Simulation Results

In this section we present some simulation results to illustrate the performance of the proposed channel estimation algorithm. The results are obtained through computer simulation and are expressed in terms of bit error rate (BER) *versus* SNR (γ_0). In all simulations we use BPSK modulation and consider a wireless communication scheme with two transmit antennas at the transmitter and one receive antenna at the

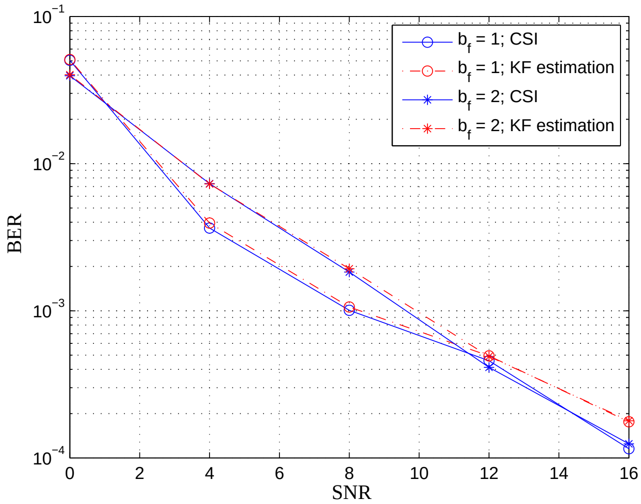

Fig. 1. BER performance for $f_D T = 0$ – no time varying.

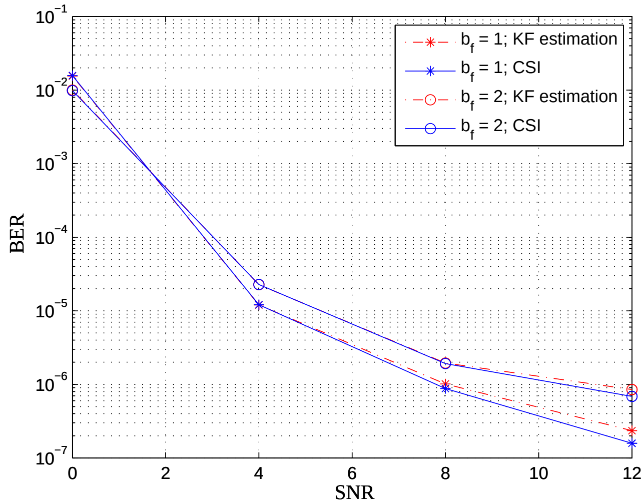

Fig. 2. BER performance for $f_D T = 0.0015$.

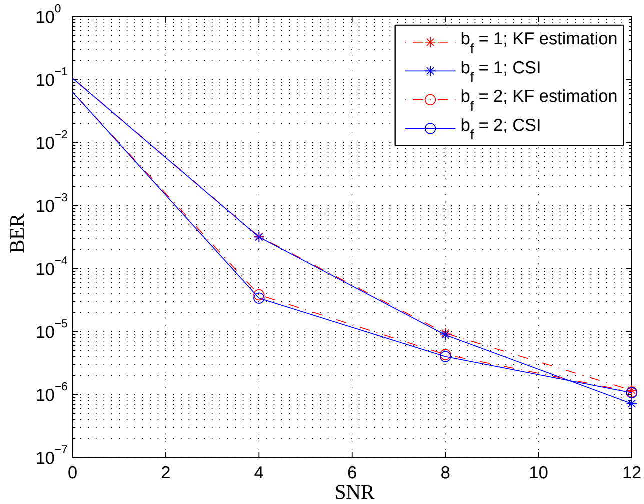

Fig. 3. BER performance for $f_D T = 0.0045$.

receiver. Before any data is transmitted, the symbols are coded with the "trivial" group-coherent codes. We insert 250 training codewords for every 750 GGCC data codewords. We assume the receiver operates in decision-directed mode, where after the end of the training sequence, the channel estimator employ the decisions provided by the space-time decoder. Note that these decisions are based on the channel estimates generated by the estimation algorithms in the previous iteration. The transmission rate is $T = $ 1Mb/s and we consider a carrier frequency of 1.9GHz. Assuming these parameters, we simulated three conditions of mobility: i) normalized Doppler frequency $f_D T = 0$ (time-invariant); ii) normalized Doppler frequency $f_D T = 0.0015$ ($v = 60$ Km/h); iii) normalized Doppler frequency $f_D T = 0.0045$ ($v = 120$ Km/h). For each mobility condition we simulated two different quantized feedback scenarios: $b_f = 1$ and $b_f = 2$ feedback bits. We also suppose no spatial correlation between the transmit antennas. The simulation results, presented in the sequel, represent the average behavior of 10 channel realizations[1].

Figure 1 compares the BER $\times$ SNR performance of the proposed semiblind Kalman filter-based channel estimator to the perfect channel state information for $f_D T = 0$ (no time variation), $b_f = 1$, and $b_f = 2$. As we can observe, the proposed estimator provides an error performance very close to the one using perfect channel knowledge. And, in both quantized feedback scenarios, the KF channel estimator presents practically the same loss of performance when compared to the perfect channel estimator.

Figure 2 compares the BER $\times$ SNR performance of the proposed KF channel estimator to the perfect channel knowledge for $f_D T = 0.0015$, $b_f = 1$, and $b_f = 2$. Contrasting Figures 1 and 2, we see that, for $b_f = 1$ or $b_f = 2$, the KF channel estimator presents practically the same loss of performance when compared to the perfect channel estimator. The BER performance loss due to mobility is not observed here because the simulations were ran for only ten channel realizations.

Looking at Figures 1–3, it is evident the performance losses of the proposed algorithm because of the no-relative mobility ($v = 0$km/h) between transmitter and receiver. This occurs because the KF algorithm is better adapted for time-varying channels. On the other hand, observing the results for $b_f = 1$ and $b_f = 2$ feedback bits, it is clearly noticeable that the performance of the proposed kalman filter-based algorithm is approximately the same in both conditions of feedback use, suggesting that the use of the proposed estimator could be applied in others space-time systems with quantized feedback channel.

V. CONCLUSIONS AND FINAL REMARKS

In this paper we proposed a Kalman filter-based channel estimator for generalized group-coherent codes in Rayleigh, flat,

[1]Resulting curves are not very smooth because of the small number of channel realizations.

and time-varying MIMO channels. The proposed algorithm, based on the kalman filter, is able to track the channel coefficients of flat, and time-varying MIMO channels. The proposed algorithm is based on the channel estimator presented in [10] and adapted for generalized group-coherent codes applications. Simulation results reveal that the BER performance of the GGCC codes when we consider the proposed Kalman filter-based channel estimator, under different Doppler conditions, is very close to the one that assumes a perfect channel state information, indicating that the proposed KF estimator has a good tracking robustness. Moreover, as we could observe in all figures, the KF channel estimator presents practically the same loss of performance for $b_f = 1$ and $b_f = 2$, suggesting that the proposed estimator could be used in others MIMO systems with quantized feedback channel.

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