Performance Evaluation over Indoor Channels of an Unsupervised Decision-Aided Method for OSTBC Systems

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Abstract. Unsupervised algorithms can be used in digital communications to estimate the channel at the receiver without using pilot symbols, thus obtaining a considerable improvement in terms of data rate, spectral efficiency, and energy consumption. Unfortunately, the computational load is considerably high since they require to estimate Higher Order Statistics. For addressing this issue, it has been recently presented a decision-aided channel estimation strategy, which implemented a decision rule to determine if a new channel estimate was required or not. If channel estimation is not needed, a previous estimate was used to recover the transmitted signals. Based on this idea, we propose a lower-complexity decision criterion and we evaluate its performance over real-world indoor channels measured using a hardware platform working at the Industrial, Scientific and Medical band at 5 GHz.

1 Introduction

In 1998, S. M. Alamouti proposed a popular Orthogonal Space Time Block Coding (OSTBC) scheme for transmitting in systems with two antennas at the transmitter and a single one at the receiver [1]. This code provides spatial and temporal diversity, while the decoding scheme is very simple because the Maximum Likelihood (ML) criterion is reduced to a matrix-matched filter followed by a symbol-by-symbol detector. Due to such advantages, the Alamouti code has been incorporated in some of the latest wireless communication standards, like IEEE 802.11n [2] or IEEE 802.16 [3].

The decoding procedure performed in the Alamouti scheme requires to estimate a 2×2 channel matrix. For this purpose, current standards define the inclusion of pilot symbols in the data frame. Pilot symbols are used by supervised algorithms to estimate the channel matrix with good precision, but as it is well-known, they reduce the maximum achievable data rate and the spectral efficiency. An alternative is to use unsupervised (also called blind) algorithms to decrease the overhead associated with pilot transmission [4]. Most unsupervised

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algorithms exploit the statistical independence of the transmitted signals and require to estimate Higher Order Statistics (HOS). For this reason, the computational load of unsupervised decoders is considerably higher than that exhibited by the supervised ones.

In order to reduce the computational load of decoding, different strategies to estimate channel variations have been proposed in [5,6]. The method presented in [6] uses the preambles –included in current digital communication standards– to obtain a coarse channel estimation. Such an estimation is used to decide if the channel has suffered a considerable variation that requires to re-estimate its coefficients. In other case, a previously-estimated channel matrix is used to recover the transmitted signals. The evaluation performed with simulated channels shows a good performance for such a scheme.

In this paper, we present a decision-aided decoding scheme similar to that proposed in [6] but with a different preamble structure. The main contribution of this paper is to present a performance evaluation in realistic scenarios using a hardware testbed. This testbed, configured as a Multiple Input Single Output (MISO) 2×1 system, operates in the Industrial, Scientific and Medical (ISM) band at 5 GHz. Channel coefficients have been acquired in real transmissions performed in indoor scenarios and they are later on plugged in a multilayer software, specifically designed to ease the evaluation of channel estimation algorithms.

This paper is organized as follows. Section 2 presents the Alamouti scheme. Section 3 explains the decision-aided method proposed in this work. Section 4 describes the testbed used for experimental evaluation and also shows the results obtained from the testbed. Finally, Section 5 is devoted to the conclusions.

2 Alamouti Coded Systems

Figure 1 shows the baseband representation of an Alamouti-based system with two antennas at the transmitter and one antenna at the receiver. A digital source in the form of binary data stream, b_i, is mapped into symbols which are split into two substreams, s_1 and s_2. We assume that s_1 and s_2 are independent equiprobable discrete random variables that take values from a finite set of symbols belonging to a real or complex modulation (PAM, PSK, QAM...). The path from the first transmit to the receive antenna is denoted by h_1 and the path from the second transmit antenna to the receive antenna is denoted by h_2. The received signals are given by

$$\texttt{Even instants} \quad r_1 = h_1 s_1 + h_2 s_2 + v_1, \tag{1}$$

$$\texttt{Odd instants} \quad r_2 = h_2 s_1^* - h_1 s_2^* + v_2. \tag{2}$$

The observations are obtained using $x_1 = r_1$ and $x_2 = r_2^*$.

The vector $\mathbf{x} = [x_1\ x_2]^T = [r_1\ r_2^*]^T$ of the received signals (observations) can be written as $\mathbf{x} = \mathbf{H}\mathbf{s} + \mathbf{v}$, where $\mathbf{s} = [s_1\ s_2]^T$ is the source vector, $\mathbf{v} = [v_1\ v_2]^T$ is the additive white Gaussian noise vector, and the 2×2 channel matrix has the form

$$\mathbf{H} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \tag{3}$$

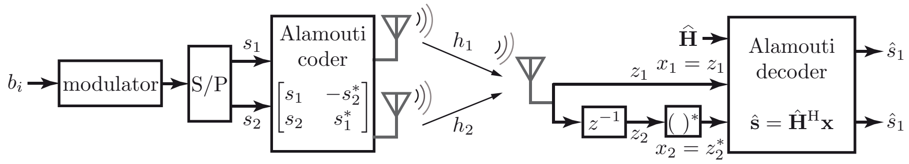

Fig. 1. Alamouti coding scheme

The matrix $\mathbf{H}$ is unitary up to a scalar factor, i.e., $\mathbf{H}\mathbf{H}^{\mathrm{H}} = \mathbf{H}^{\mathrm{H}}\mathbf{H} = \|\mathbf{h}\|^2\mathbf{I}_2$, where $\|\mathbf{h}\|^2 = |h_1|^2 + |h_2|^2$ is the squared Euclidean norm of the channel vector, $\mathbf{I}_2$ is the 2×2 identity matrix, and $(\cdot)^{\mathrm{H}}$ is the Hermitian operator. It follows that the transmitted symbols can be recovered applying $\hat{\mathbf{s}} = \hat{\mathbf{H}}^{\mathrm{H}}\mathbf{x}$, where $\hat{\mathbf{H}}$ is a suitable channel matrix estimate. As a result, this scheme supports maximum likelihood detection based only on linear processing at the receiver.

3 Decision-Aided Scheme

In static environments, it is common to assume that the channel remains constant during the transmission of several frames (block fading). On the contrary, in mobile environments, channel variations happen faster (for each frame or even within the transmission of a frame). In order to reduce the computational complexity of decoder, in [6] it has been proposed a simple method to detect channel variations from the preambles transmitted before each data frame. The decoder estimates the channel coefficients only when the decision criterion detects a channel variation. In this work we propose a decision-aided scheme similar to that presented in [6], but using a simpler preamble scheme.

We denote by p_1 and p_2 the orthogonal preambles transmitted by each antenna. Unlike the scheme presented in [6], these preambles are not coded with Alamouti. From Equation (1), the receive signal has the form

$$r = h_1\, p_1 + h_2\, p_2 + v. \tag{4}$$

Multiplying each sample of this signal by the preamble samples and summing up over the preamble length P, we obtain

$$c_1[k] = \sum_{n=1}^{P} r[n]p_1[n]^* = h_1 \sum_{n=1}^{P} |p_1[n]|^2 + \sum_{n=1}^{P} v[n]p_1^*[n], \tag{5}$$

$$c_2[k] = \sum_{n=1}^{P} r[n]p_2[n]^* = h_2 \sum_{n=1}^{P} |p_2[n]|^2 + \sum_{n=1}^{P} v[n]p_2^*[n]. \tag{6}$$

Considering that the preamble length is large enough to eliminate the term corresponding to the noise, we have that each result obtained from such a "correlation" is a coarse estimate of each one of the channel coefficients. Comparing the values c_1 and c_2 to a threshold value, the decoder can determine if it is needed to re-estimate the channel matrix or not.

The proposed decision-aided scheme can be summarized as follows:

1: Compute $c_1[k]$ and $c_2[k]$ from the preambles transmitted for the k-th frame.
2: Compute the error
$\text{Error}_1[k] = |c_1[k] - c_1[k-1]|$ and $\text{Error}_2[k] = |c_2[k] - c_2[k-1]|$.
3: Use the decision criterion

$$(\text{Error}_1[k] > \beta) \text{ OR } (\text{Error}_2[k] > \beta) \rightarrow \text{Channel estimate is required},$$

where β is a real-valued threshold.

In order to avoid the transmission of pilot symbols, we propose to estimate the channel matrix using an unsupervised algorithm like the Joint Approximate Diagonalization of Eigen-matrices (JADE) algorithm or the Blind Channel Estimation based on Eigenvalue Spread (BCEES) method proposed in [9]. BCEES is a simplification of JADE [7], where the matrix to be diagonalized is selected taking into account the absolute difference between the eigenvalues (eigenvalue spread).

4 Performance Evaluation Based on Measured Indoor Channels

A testbed developed at the University of A Coruña [10] (see Figure 2) was used to extract 2×1 channel matrices corresponding to a realistic indoor scenario in which the transmitter and the receiver were separated approximately 9 m, whereas the antenna spacing at the transmitter was set to 7 cm. In this section we describe the measurement procedure followed to obtain the indoor wireless channel coefficients that are later on plugged in the simulations in order to evaluate the performance of the proposed approaches under real-world indoor channels.

4.1 Measurement Procedure

The testbed is used to estimate the 2×1 MISO channel. For that purpose, we design a frame structure consisting of a preamble sequence (119 symbols) for time and frequency synchronization; a silence (50 symbols) for estimating at the receiver the noise variance; and a long training sequence (4 000 symbols per transmit antenna) for estimating the channel. Note that the preamble length is considerably higher than the preamble introduced in Section 3. The resulting signals are modulated (single carrier) and pulse-shape filtered using a squared root-raised cosine filter with 12 % roll-off, and the resulting signal bandwidth is 1.12 MHz, which leads –according to our tests– to a frequency-flat channel response.

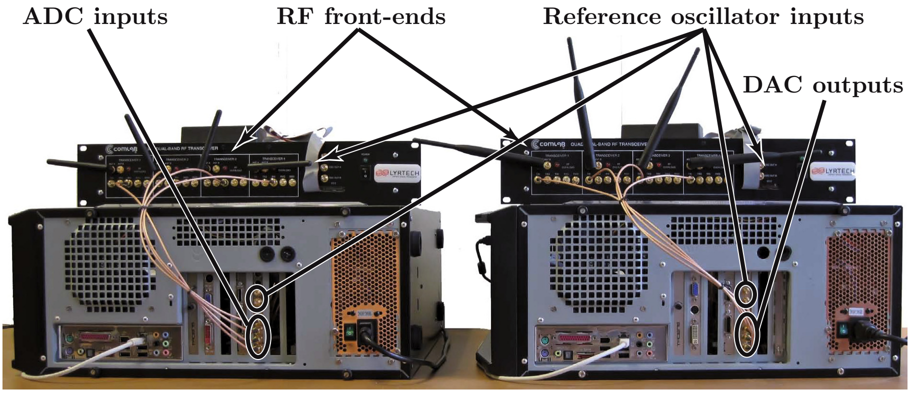

Fig. 2. Picture of the testbed

With the aim of obtaining statistically rich channel realizations, and given that the Lyrtech RF front-end is frequency-agile, we measure at different RF carriers (frequency hopping) in the frequency interval ranging from 5 219 MHz to 5 253 MHz and from 5 483 MHz to 5 703 MHz. Carrier spacing is 4 MHz (greater than the signal bandwidth), which results in 65 different frequencies. Additionally, we repeat the whole measurement procedure for four different positions of the transmitter, giving as a result 260 channel realizations. Note that we have these 260 realizations per each pair of transmit antennas for a given receiver position and therefore, taking into account four receiver locations, a maximum number of 1 040 channel realizations is available for the Alamouti system.

In order to be able to plug the estimated channel coefficients in a simulation, all of them from each of the four sets of 65 channel matrices are normalized, giving as a result unit mean variance channels, but preserving the same statistical distribution as the original channel matrices.

4.2 Experimental Results

A thousand channel realizations have been used to evaluate the performance of the proposed decision-aided scheme. The experiments have been performed using QPSK source symbols coded with the Alamouti scheme. A total of 20 frames consisting of 200 symbols per transmit antenna, i.e. 8 000 QPSK coded symbols (4 000 source symbols), are transmitted in 20 frames. The channel matrix remains constant during the transmission of 5 frames; hence the 20 frames experience 4 different channel realizations.

First, we consider the problem that arises from selecting the threshold value used for the decision criterion. In order to obtain a good estimate of the cross–correlations, the simulations performed in these tests contained a preamble with 100 symbols per antenna. To quantify the difference –in terms of Symbol Error Rate (SER) versus Signal-to-Noise Ratio (SNR)– between the BCEES and the Decision-Aided BCEES scheme (DA-BCEES), the following expression is introduced

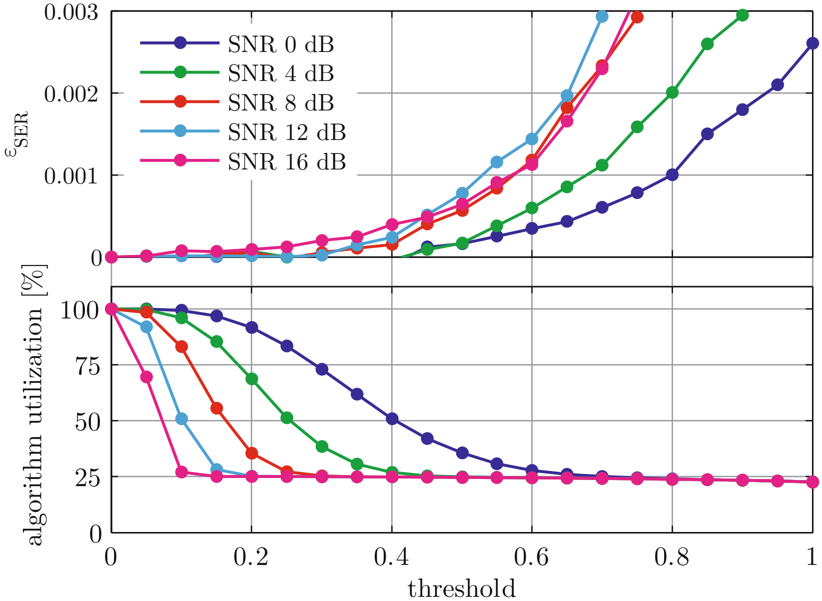

Fig. 3. SER and algorithm utilization for the DA-BCEES approach versus threshold β given several SNR values for measured channels

$$\epsilon_{\mathrm{SER}} = \frac{\mathrm{SER}_{\text{DA-BCEES}} - \mathrm{SER}_{\mathrm{BCEES}}}{1 + \mathrm{SER}_{\text{DA-BCEES}}}. \tag{7}$$

Figure 3 plots ϵ_{SER} as well as the percentage of algorithm utilization, defined as the number of frames in which the channel was estimated divided by the total number of frames. We can see that a value of $\beta = 0.6$ gives a good tradeoff between SER and channel estimation, since SER is almost zero and the channel estimation is equal to 25 %, which corresponds to estimate the channel only 5 times per 20 transmitted frames (for the first frame and for each channel variation), which corresponds to the optimum value.

Figure 4 shows the SER and the algorithm utilization percentage for the unsupervised algorithms (JADE and BCEES) when the channel is estimated for all the frames (100 % of algorithm utilization). Observing the curves of the decision-aided schemes (DA-JADE and DA-BCEES), we can conclude that both schemes achieve the same performance as, respectively, JADE and BCEES, in terms of SER versus SNR, but with a considerable reduction of the algorithm utilization percentage. Note also that the SER obtained with DA-BCEES presents an insignificant loss compared to DA-JADE. For comparison reasons, this figure also plots the results obtained with the Least-Squares (LS) algorithm (denoted as *Supervised* in the figure), which estimates the channel using 8 pilots. Note that the curve of SER vs SNR is equal to that obtained with JADE and DA-JADE.

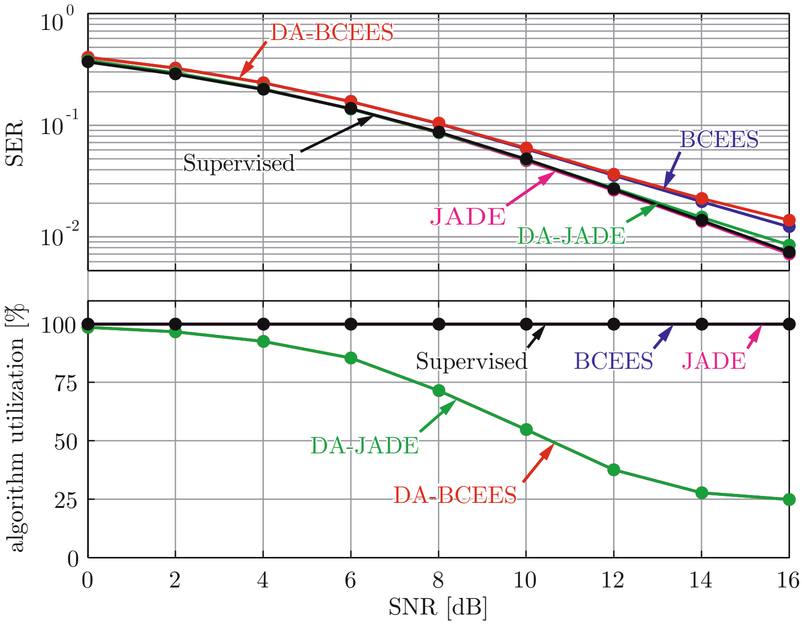

Fig. 4. SER and algorithm utilization versus SNR

5 Conclusions

We present a simple scheme to detect channel variations in Alamouti coded systems. The proposed approach uses information obtained during the synchronization procedure to determine channel variations. When channel variations are significant, the system estimates the channel matrix using an unsupervised method. The experimental results —obtained from real-world channel coefficients measured in indoor scenarios— show that the proposed scheme presents several important benefits: the utilization of an unsupervised algorithm increases the spectral efficiency and the utilization of the proposed decision rule reduces the computational load. Consequently, the unsupervised decision-aided approach arises as a promising method to avoid the transmission of training sequences and thus reducing power consumption in wireless communication devices.

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