BLIND CHANNEL RECOGNITION FOR 2X1 ALAMOUTI CODED SYSTEM

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ABSTRACT

In this paper the experimental evaluation of several blind channel estimation techniques making use of multiple-antenna test bed and software defined radio implementations in MATLAB. This paper is partly based on the publications [6, 7, 19, 20] and a short introduction to Space-Time Block Codes (STBCs) is provided. Different channel estimation strategies suitable for Alamouti Orthogonal Space-Time Block Code (OSTBC) are described the 2x1 Multiple-Input Multiple-Output (MIMO) case . In this cases, several channel estimation approaches are included as benchmarks and/or references. The description of the set-up, the procedures followed to measure the channel, and the results obtained – including computer simulation results – are explained for the 2x1 MIMO case.

Key word- STBC, Alamouti, MIMO

I. Introduction

Space–time block coding is a technique used in wireless communications to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer. The fact that the transmitted signal must traverse a potentially difficult environment with scattering, reflection, refraction and so on and may then be further corrupted by thermal noise in the receiver means that some of the received copies of the data will be 'better' than others. Multiple-antenna systems have been considered in the literature to drastically improve the performance of wireless communications systems by adding a spatial dimension to the existing code, frequency and time dimensions [9, 16, 17, 24]. STBCs have emerged as good mechanisms to exploit spatial diversity in MIMO systems [8,13]. STBC is very popular due to the work of Alamouti [1] becoming one of the most famous MIMO transmission techniques and motivating a great variety of research [3, 6, 7, 10, 11, 15, 18, 19, 20]. Other STBC schemes have been proposed for more than two transmit antennas, but they suffer from severe spatial rate losses [14, 23]. Among space-time coding schemes, OSTBCs are one of the most attractive because they are able to provide full diversity gain without any Channel State Information (CSI) knowledge at the Transmitter (TX), and this with very simple encoding and decoding procedures. The specific structure of OSTBCs makes it possible to convert the optimal Maximum Likelihood (ML) decoder into a simple linear Receiver (RX), which can be seen as a matched filter followed by a symbol-by-symbol detector. According to [5], such a linear RX maximizes the Signal to Noise Ratio (SNR) for each data symbol based on the CSI at the RX side. Moreover, it should be noted that from an information theory perspective, OSTBCs are far from being capacity approaching codes. However, the Alamouti 2x1 OSTBC scheme is optimal. Blind channel estimation techniques can exploit the algebraic structure of OSTBCs while overcoming the limitations of DSTBC . In the paper, there is a great variety of blind channel estimation proposals [2, 22]. Such proposals can be classified into two groups depending on whether they exploit the Higher-Order Statistics (HOS) or the Second-Order Statistics (SOS) of the acquired signals.

II. Alamouti's code

Alamouti invented the simplest of all the STBCs in 1998 although he did not **coin** the term "space–time block code" himself. It was designed for a two-transmit antenna system and has the coding matrix:

$$C_2 = \begin{bmatrix} c_1 & c_2 \\ -c_2^* & c_1^* \end{bmatrix},$$

where * denotes complex conjugate.

It is readily apparent that this is a rate-1 code. It takes two time-slots to transmit two symbols. Using the optimal decoding scheme discussed below, the bit-error rate (BER) of this STBC is equivalent to $2n_R$-branch maximal ratio combining (MRC). This is a result of the perfect orthogonality between the symbols after receive processing — there are two copies of each symbol transmitted and n_R copies received. This is a very special STBC. It is the **only** orthogonal STBC that achieves rate-1. That is to say that it is the only STBC that can achieve its full diversity gain without needing to sacrifice its data rate. Strictly, this is only true for complex modulation symbols. Since almost all constellation diagrams rely on complex numbers however, this property usually gives **Alamouti's code** a significant advantage over the higher-order STBCs even though they achieve a better error-rate performance. See 'Rate limits' for more detail.

The design of STBCs is based on the so-called diversity criterion. Orthogonal STBCs can be shown to achieve the maximum diversity allowed by this criterion.

Diversity criterion

Call a codeword
$$\mathbf{c} = c_1^1 c_1^2 \cdots c_1^{nT} c_2^1 c_2^2 \cdots c_2^{nT} \cdots c_T^1 c_T^2 \cdots c_T^{nT}$$
and call an erroneously decoded received codeword

$$\mathbf{e} = e_1^1 e_1^2 \cdots e_1^{nT} e_2^1 e_2^2 \cdots e_2^{nT} \cdots e_T^1 e_T^2 \cdots e_T^{nT}.$$

Then the matrix

$$B(c,e) = \begin{bmatrix} e_1^1 - c_1^1 & e_2^1 - c_2^1 & \cdots & e_T^1 - c_T^1 \\ e_1^2 - c_1^2 & e_2^2 - c_2^2 & \cdots & e_T^2 - c_T^2 \\ \vdots & \vdots & \ddots & \vdots \\ e_1^{nT} - c_1^{nT} & e_2^{nT} - c_2^{nT} & \cdots & e_T^{nT} - c_T^{nT} \end{bmatrix}$$

has to be full-rank for any pair of distinct code words $\mathbf{c}$ and $\mathbf{e}$ to give the maximum possible diversity order of $n_T n_R$. If instead, $\mathbf{B}(\mathbf{c},\mathbf{e})$ has minimum rank b over the set of pairs of distinct code words, then the space–time code offers diversity order bn_R. An examination of the example STBCs shown below reveals that they all satisfy this criterion for maximum diversity.

STBCs offer only diversity gain (compared to single-antenna schemes) and not coding gain. There is no coding scheme included here — the redundancy purely provides diversity in space and time. This is contrast with space–time trellis codes which provide both diversity and coding gain since they spread a conventional trellis code over space and time. The significance of Alamouti's proposal was the first demonstration of a method of encoding which enables full diversity with ***linear*** processing at the receiver. Earlier proposals for transmit diversity required processing schemes which scaled *exponentially* with the number of transmit antennas. Furthermore, it was the first open-loop transmit diversity technique which had this capability. Subsequent generalizations of Alamouti's concept have led to a tremendous impact on the wireless communications industry.

III. 2x1 Alamouti Channel Estimation

In this section the channel estimation techniques used in both computer simulations and testbed measurements for the 2x1 Alamouti code. The adaptation of the notation introduced for the case of the 2x1 Alamouti code. Next, a SOS-based blind channel estimation approach as well as two different HOS-based blind channel estimation techniques as a reference. When the 2x1 Alamouti OSTBC is used the relationship between the vector of observations x = [x1 x2]T and the vector of sources s = [s1 s2]T is given by

x = Hs + n …………………………… 1

where H is the 2x2 effective channel matrix resulting from coding the two channel coefficients according to the Alamouti code:

$$H = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}$$
……………………………… 2

Where n= $[n_1\ n_2^*]^T$ is the AWGN. Note that H is an orthogonal matrix satisfying $HH^H = H^H H = \|h\|^2 I_2$ where $\|h\|^2 = |h_1|^2 + |h_2|^2$ is the squared Euclidean norm of h. Filtering a vector x with the matrix matched filter yields the following decision statistics

$y = H^H X = \|h\|^2 S + \tilde{n}$
…………………….. 3

where $\tilde{n} = H^H$ n is the output noise vector, with the same statistical distribution as the input noise n. It is apparent from Equation detection of s1 and s2 can be calculated by applying y to a pair of independent scalar slicers. Consequently, the correct detection of the transmitted symbols s requires an accurate estimation of the channel matrix H from the received data x.

The channel estimation methods considered in this section are based on the computation of a 2x1 matrix G containing SOS or HOS of the acquired signals. The basic premise of the methods considered is that G has an algebraic structure with the form $H\Delta H^H$ where Δis a diagonal matrix. Due to the orthogonal structure of H, if the diagonal entries of Δ are different, the channel matrix can be identified from the eigenvectors of G with a possible scaling and/or permutation.

SOS-Based Blind Channel Estimation

According to the signal model in Equation 1, the autocorrelation matrix of the observations can be written as

$$G_{sos} = E[XX^H] = HR_sH^H + N_0I_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 4$$

where N_0 is the variance of the complex-valued noise and R_s = E$[SS^H]$ is the correlation matrix of the transmitted signals. Given that H is orthogonal, Equation can be rewritten as the following eigen value decomposition:

$$G_{sos} = H\left(R_s \frac{N_0}{\|h\|^2} I_2\right) H^H \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 5$$

Notice that if the two transmitted sources have the same power, then GSOS is diagonal, and therefore H is not identifiable from an eigen value decomposition.

HOS-Based Blind Channel Estimation

The orthogonal MIMO channel matrix H can be estimated blindly from the eigen decomposition of matrices made up of HOS of the received signals without the need to unbalance the power value of the sources. Indeed, for a 2x1 vector of observations x, the 4-th order matrix of cumulants GHOS(M) is a 2x2 matrix, and its elements are given by

$$[G_{HOS}\,(M)]_{ij} = \sum_{k,l=1}^{2} cum\left(x_i {x^*}_j\, x_k {x^*}_l\right) m_{kl} \;\ldots\ldots\ldots\ldots\ldots\ldots \; 6$$

where mkl k; l = 1; 2, denote the entries of a 2x2 matrix M, and the 4th-order cumulant is defined by the following equation:

cum(^x1; ^x2; ^x3; ^x4) = E[^x1^x2^x3^x4] - E[^x1^x2]E[^x3^x4] - E[^x1^x3]E[^x2^x4] - E[^x1^x4]E[^x2^x3] ……………… 7

For the particular case of zero-mean signals, the cumulant matrix admits the following decomposition :

$$G_{HOS}(M) = H\Delta_{HOS}\,(M)H^H \;\ldots\ldots\ldots\ldots\ldots\ldots \; 8$$

Another way of estimating the mixing matrix consists in performing a simultaneous diagonalization of several fourth-order cumulant matrices, such the Joint Approximate Diagonalization of Eigenmatrices (JADE) algorithm . This algorithm provides an excellent performance but, unfortunately, its computational cost is very high. From now on, the JADE algorithm will be employed solely as a benchmark for the blind channel estimation schemes.

IV. 2x1 Alamouti Evaluation

The evaluation is completed with computer simulation results. BER vs SNR – of five different channel estimation schemes for the 2x1 Alamouti code: the proposed SOS-based approach and finally the proposed HOS-based approach The Channel carried out two different experiments –the TX and the RX were at a distance of 5m from each other, with a clear line of sight between them. The TX antennas were spaced about 30 cm apart in order to ensure a good spatial diversity. Note that such distance is easy to achieve in e.g. a laptop computer, by placing the two antennas on different corners of the lid. The TX and the RX were placed about 9m from each other, with no line of sight between them. In all cases, the TX antennas and the RX antenna were typical rod antennas with a gain of 3 dB, similar to those utilized by WiFI access points.

Testbed Measurements

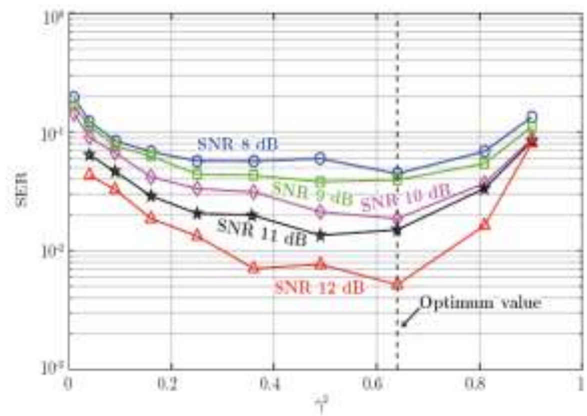
For the experimental evaluation, chose to carry out narrowband (7MHz of bandwidth2) 2x1 MISO measurements making use of the second version of the GTEC MIMO testbed. In our measurement approach, all signal processing operations were implemented in MATLAB. The data was generated off-line, transmitted in real-time through the wireless channel at a rate equal to 5 M Baud, and stored in the hard drives at the RX. In a later step, the measurement data was evaluated off-line. A different way – and probably offering the same results – of evaluating the above-mentioned methods would be to employ a channel sounder and then utilize the channel coefficients in a computer simulation.

Computer Simulation Results

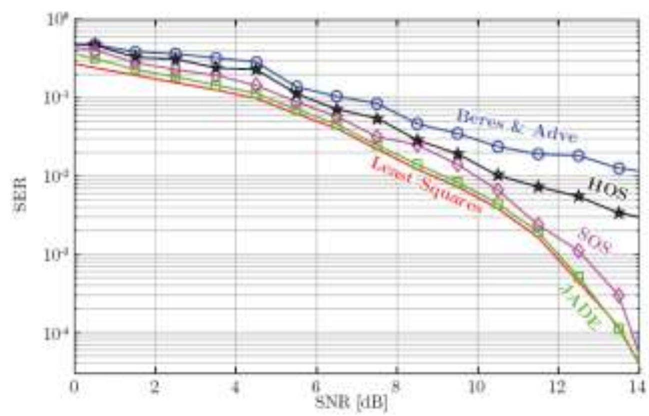
The five different channel estimation methods to be measured are previously evaluated by means of computer simulations. The simulations randomly generate 4 QAM signals that are transmitted through Rayleigh-distributed randomly generated flat-fading channels affected by AWGN. We assume block fading, i.e. the channel remains constant during the transmission of a block of K = 500 symbols. The statistics in Equations have been calculated by averaging over each block of symbols and the performance has been measured in terms of the SER.

Measurement Results

In order to be able to use the SOS-based the optimum power unbalance factor γ^2 must be found. To this end, the SER is evaluated for different values of γ^2 using exactly the same set-up as for Experiment .

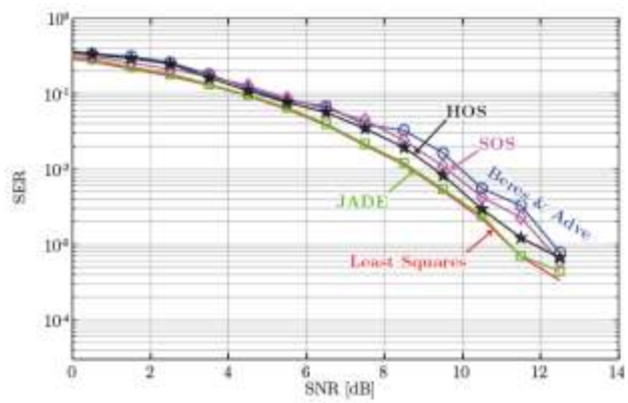


performance of the SOS-based method as a function of γ^2



SER performance versus SNR with clear line of sight.

and show that the optimal value is around γ^2= 0.64. This value is in accordance with that obtained by simulations over an uncorrelated Rayleigh channel .The measured SER versus SNR in Experiment for the five different channel estimation methods: JADE, Beres and Adve, the SOS-based approach with γ^2 = 0.64, and the HOS-based approach with λ = -1. Similarly to computer simulation results, the JADE algorithm achieves the same performance as with LS estimation while the SOS-based only loses about 0.5 dB. The poor performance of HOS methods since they present a floor effect for SNR values greater than 10 dB.



SER performance versus SNR without line of sight

V. Conclusion

In this paper, two different blind channel estimation schemes, namely SOS-based approach and an HOS-based approach, evaluated by computer simulations and by test bed measurements .Both simulations and realistic experiments in LOS and NLOS scenarios show that the SOS-based estimation suffers from a loss of less than 1 dB compared to the perfect CSI (or the LS) case. Given the low computational requirements demanded by the SOS-based approach, it exhibits an excellent tradeoff between channel estimation accuracy and computational complexity. The performance of several 2x1 MIMO-STBC systems was also measured in different realistic indoor scenarios . In particular, Alamouti code for two RX antennas with coherent and non-coherent demodulation was measured. On the one hand, such blind methods reveal a slight increase in the effective data rate and a moderate increase in the computational complexity of the detector. On the other hand, the DSTBC evaluated as a reference presents, as expected, a penalty of about 3 dB with respect to coherent schemes. The measurement results presented in this paper were carried out using the first versions of the GTEC MIMO test bed. If we repeated the measurements again, then we would modify the measurement procedure in such a way that we could present the results with respect to the SNR as well as with respect to the TX power value. We would also provide confidence intervals for the resulting curves to show the accuracy of the measurements.

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