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On channel estimation for spatial modulated systems over time-varying channels

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ABSTRACT

Spatial Modulation (SM) has been proposed recently for multiple-input multiple-output (MIMO) systems to cope with the interchannel interference and to reduce the detection complexity as compared to the conventional MIMO systems. In SM system, the data symbols are transmitted by a randomly selected active antenna of a MIMO transmitter to the receiver through a wireless channel. The information is carried both by the data symbol from any signal constellation such as M-ary phase shift keying (M-PSK) or M-ary quadrature amplitude modulation (M-QAM), by the index of the selected antenna. The channel estimation is a critical process at the receiver during the coherent detection of the transmitted symbol and the antenna index, randomly selected. Recently, the channel estimation of channel for SM systems has been investigated by the recursive least square (RLS) algorithm for only quasi-static fading channels. In this paper, a novel channel estimation is proposed for SM systems in the presence of rapidly time-varying channels. The Bayesian mean square error (MSE) bound has been derived as a benchmark and the performance of the proposed approaches is studied in terms of MSE and bit-error rate (BER). Computer simulation results have confirmed that the proposed iterative channel estimation technique has significant BER/MSE performance advantages compared with existing channel estimation algorithm proposed earlier in the literature.

1. Introduction

Conventional multiple-input multiple-output (MIMO) systems use all transmit antennas to transmit multiple data streams. Therefore, its performance depends on some important parameters such as the distance between receiver and transmitter antennas [1,2], inter-channel interference (ICI) at the receiver and inter-antenna synchronization (IAS) at the transmitter [3,4]. For example, it was shown that uncorrect IAS causes performance degradation for MIMO systems [3,4].

Spatial modulation (SM) is a promising MIMO transmission technique that has been recently proposed [5–7]. The basic principle of the SM is to use the indices of multiple antennas to convey information in addition to the conventional two-dimensional signal constellations such as M-ary phase shift keying (M-PSK) and M-ary quadrature amplitude modulation (M-QAM), where M is the constellation size. Optimal SM decoder at the receiver searches jointly for all M-ary constellation points and transmit antennas to decide on both the transmitted symbol and the index of the transmitted antenna over which the symbol is transmitted. Consequently, it is an effective way to remove the intercarrier interference (ICI) completely between the transmitter antennas of a MIMO link. Furthermore, SM does not require IAS of the MIMO link and only one radio frequency chain (RF) is needed at the transmitter.

The SM technique is different from the transmit antenna selection (TAS) since TAS is a closed-loop mechanism and provides spatial-multiplexing while the SM is open-loop with transmit-diversity [8]. SM technique adds a third dimension to the two-dimensional signal space which is the spatial dimension and it maps multiple information bits into one symbol and the corresponding antenna index. Therefore, the number of total transmitted information bits depends on the constellation diagram and the total number of transmitter antennas [9]. Consequently, the spatial modulation has a very flexible mechanism that provides high spectral efficiency with low complexity [10].

The receiver has to detect both the transmitted symbol and the active antenna index since the desired information carried by the modulated signal and the transmit antenna index, chosen at random. In the literature, the antenna index and symbol detection are realized by means of optimal and non-optimal detection

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methods [5,11]. It has been shown in [11] and [9] that SM can achieve better error performance than V-BLAST (Vertical-Bell Lab Layered Space–Time) in some cases under the assumption that perfect channel information (CSI) is available at the receiver. However, in practice, we hardly have a perfect CSI at the receiver and thus a channel estimator is employed to provide unknown channel parameters. Recently, the effect of imperfect channel estimation on the SM-MIMO systems has been investigated [12,13]. In [12], the least square (LS) estimation technique is employed for MIMO systems operating over quasi-static Rayleigh flat fading channels and its mean-square error (MSE) performance is investigated. In [13], a joint channel estimation with data detection is proposed while assuming the channel correlation matrix is available at the receiver.

Pilot symbol assisted modulation (PSAM) has been generally employed to achieve coherent detection performance in wireless environments [14]. Based on this approach, in [15] the channel estimation for SM systems has been investigated by means of a pilot-based recursive least square (RLS) method while assuming the wireless channel is quasi-static for a duration of at least one frame length. The RLS algorithm is known to possess fast convergence, but also to yield high channel estimation errors on fast fading channels mainly because it solely depends on the pilot symbols and does not take the mobility into account [16]. In communication systems, pilot symbols, known to the receiver, can be inserted periodically, usually in the beginning of each frame consisting of several transmitted symbols. However, when the channel varies rapidly, pilot symbol sequence cannot be effective to implement the channel estimation efficiently.

In this work, the pilots are sent out through only one transmit antenna at each time instant. Hence, using pilot-based channel estimation, only the CSI of the active transmit antenna can be obtained at the receiver. This leads to a challenging task for the channel estimation in SM systems over fast time-varying channels. In [17], performance bounds for training and superimposed training-based channel estimation for time-varying flat-fading channels have been discussed. It was shown that the regular periodic placements (RPPs) perform better at high SNR and for slowly varying channels, whereas the superimposed scheme is superior for relatively fast time-varying channels. However, in MIMO systems it is required that the pilot sequences transmitted from each transmit antenna should be orthogonal to each other to prevent inter-antenna interference. This a challenging design problem in general. On the other hand, this problem can be easily handled in spatial modulated MIMO systems since the pilot sequences transmitted from each transmit antenna are surely orthogonal each other due to the fact that they are mutually disjoint at all the time.

Channel coefficients in a real mobile environment change smoothly in time. This smoothness helps us to employ well designed curve fitting methods in order to further improve the channel estimation accuracy [18]. In [19], the rectangular-windowed recursive least squares algorithm where each tap of the frequency selective fading channel modeled as a polynomial in time is proposed. On the other hand, all channels could not be observed within the duration of a symbol transmission since only one antenna is active at the given signaling interval. This also motivates us to use curve fitting methods to interpolate unknown channel durations [20]. It is clear that to track the channel coefficients for data duration we need to employ a decision directed channel estimation scheme. Different methods based on decision directed are also proposed to enhance the tracking capability of the RLS algorithm in [21] for MIMO systems. In [21], optimizing the involved window size and forgetting factor and the initialization of the autocorrelation matrix of RLS are also investigated.

To the best of our knowledge, there is not any efficient and computationally feasible channel estimation algorithm, in the presence of a rapidly varying channel, exists for the SM-MIMO systems in the literature. Motivated by the existing correspondences between the RLS, the decision directed channel estimation and the polynomial fitting, in this paper a novel channel estimation technique and an iterative receiver design are proposed based on the curve fitting and the detected symbols employed in a decision-directed mode that ensure excellent tracking for SM-MIMO systems. We insert periodic pilot blocks to cope with the errors, introduced in decision-directed channel estimation mode, due to the accumulate over bits. The data block length between adjacent pilot blocks can be adjusted based on the channel mobility in our proposed scheme. This results in minimum overhead for pilot symbols. It is known that the iterative receivers provide significant advantages [22–24] over conventional receivers and shown that the SM receiver employing the proposed channel estimator has superior performance as compared to the conventional RLS channel estimation-based receivers. Moreover, we derived analytically an overall Bayesian MSE lower bound for the channel estimator proposed in this work to serve as a benchmark. We performed new computer simulations to determine how the MSE performance of our channel estimation algorithm can approach this lower bound.

Notation: Throughout the paper, the following notations and assumptions are used. Bold and capital letters '$\mathbf{A}$' denote matrices. Bold and small letters '$\mathbf{a}$' denote vectors. diag$\{\mathbf{a}\}$ is a diagonal matrix with $\mathbf{a}$ on its main diagonal. $E_{x,y}[.]$ is the expectation over x and y. The notations, $(.)^*$, $(.)^T$, $(.)^\dagger$, $(.)^+$, $(.)^{-1}$ and $\|.\|_F$ denote conjugate, transpose, Hermitian, pseudoinverse, inverse and Frobenius norm, of a matrix or a vector respectively.

2. System model

An SM-MIMO system with N_t transmit antennas and N_r receive antennas is considered. In general, the total number of bits that is transmitted by a M-ary SM-MIMO system is

$$k = \log_2(N_t) + \log_2(M) \tag{1}$$

where M represents the total number of bits per transmitted symbol. At the nth symbol interval the SM mapper takes a random sequence of k bits and maps them into an N_t-dimensional signal vector as

$$\mathbf{x}(n) = \left[x_1(n), x_2(n), \cdots, x_{N_t}(n)\right]^T. \tag{2}$$

Only one of $x_j(n)$ that is active in $\mathbf{x}(n)$ is nonzero. Then, at the nth symbol interval, the output of the SM-MIMO system at the transmitter can be expressed as

$$\mathbf{x}_j(n) \triangleq \big[0 \cdots \underbrace{x_q(n)}_{j.\ \text{transmitted antenna}} \cdots 0\big]^T \tag{3}$$

where j is the active antenna index and $x_q(n)$ is the qth symbol from the M-ary constellation diagram. The other antennas remain silent over this symbol duration. The symbol $x_q(n)$ is transmitted from antenna j over an $N_r \times N_t$ MIMO channel. The observation model at receiver can be expressed as

$$\begin{bmatrix} y_1(n) \\ \vdots \\ y_r(n) \\ \vdots \\ y_{N_r}(n) \end{bmatrix} = \begin{bmatrix} h_{1,1}(n) & h_{1,2}(n) & \cdots & \cdots & h_{1,N_t}(n) \\ h_{2,1}(n) & h_{2,2}(n) & \cdots & \cdots & h_{2,N_t}(n) \\ \vdots & \vdots & \ddots & & \vdots \\ \vdots & \vdots & & \ddots & \vdots \\ h_{N_r,1}(n) & h_{N_r,2}(n) & \cdots & \cdots & h_{N_r,N_t}(n) \end{bmatrix}$$