Proceedings of the 4th WSEAS Int. Conf. on Information Security, Communications and Computers, Tenerife, Spain, December 16-18, 2005 (pp478-481)

The performance of multi-mode spatial MIMO system with imperfect CSI

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Abstract: In this paper we describe and analyze a simple but effective algorithm for selecting transmit antennas and their coding-modulation schemes in multiple input multiple output (MIMO) communication systems. The algorithm selects the most suitable antennas among those available at the transmitter by observing the signal to self-generated noise ratio obtained, applying pseudoinverse on the MIMO channel matrix and adjusts the coding and modulation of each selected antenna according to the instantaneous channel conditions, maintaining the average BER of the system below the target value. The performance of the proposed adaptive MIMO system is tested in imperfect channel state information (CSI). The simulation results show, that the algorithm is not sensitive to small channel estimation errors.

Key–Words: multiple input multiple output (MIMO) system, adaptive coding and modulation (ACM), quadrature amplitude modulation (QAM), antenna selection, spatial multiplexing, linear detection

1 Introduction

One of the most important topics in radio communications research is to develop efficient methods to increase the spectral efficiency of the system. A resent fundamental breakthrough in this research area has been made by Bell Labs researchers [1], who proposed the use of multiple antennas at the transmitter and at the receiver. The system was named multiple input multiple output (MIMO) system.

An alternative method to increase the system throughput exploits the knowledge of the channel characteristic at the transmitter site. The method adjusts the coding and modulation scheme to the instantaneous channel condition and it is known as an adaptive coding and modulation (ACM) [2]. Various ACM schemes were described and analysed in literature for single input single output (SISO) systems, mainly developing an adaptive method in the time and frequency domain. In MIMO systems, of course, the adaptation technique should be further extended to the spatial domain.

In this paper, we analyze the sensitivity of communication system, which applies the algorithm proposed in [3, 4] on time variation of the channel caused by imperfect channel state information at the transmitter.

The paper is organized as follows. The proposed adaptive MIMO system is described in the second section. The algorithm which determines the set of transmit antennas and selects the CM scheme for each antenna separately is described next. The performance of the algorithm when criteria is target BER, and its sensitivity to imperfect channel knowledge are studied by computer simulations. And finally in conclusion further work is proposed.

2 Adaptive MIMO system

In a MIMO system with M_T transmit and M_R receive antennas there exists in principle $M_T * M_R$ subchannels between transmitter and receiver, which in general exhibits frequency selective fading. In this paper we shall hereafter assume a quasistatic channel and flat fading. Then the received signal on the j-th receive antenna is

$$y_j = \sum_{i=1}^{M_T} h_{ij} x_i + n_j, \tag{1}$$

where x_i is the transmitted signal from i-th transmit antenna and y_j is the received signal at j-th receive antenna. Variable n_j denotes samples of circularly symmetric complex Gaussian noise with variance σ_n^2 at the j-th receiver. The fading channel is described as a sum of complex paths h_{ij} between receive and transmit antennas. In the Rayleigh channel the complex gain coefficient h_{ij} follows the Gaussian distribution. The matrix form of Eq. (1) is

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n}, \tag{2}$$

where $\mathbf{y}$ is the column vector of received signals, $\mathbf{H}$ the channel matrix, $\mathbf{x}$ the column vector of transmitted signals and $\mathbf{n}$ the column vector of additive white Gaussian noise.

Accurate detection of the MIMO signal requires knowledge of the CSI at the receiver. The CSI is estimated from the received signal using training sequences added to the transmitted signal. If the CSI is known only at the receiver, the MIMO system is non-adaptive, because the transmitter uses the same set of transmit antennas and CM schemes regardless of the channel characteristic. The system may become unreliable, in spite of a high signal to noise ratio (SNR) when subchannels are correlated. We can cope with this problem by adaptive principle in MIMO system, which adjusts the subset of transmit antennas and coding modulation scheme for each active antenna to the estimated channel state information [4].

The properties of the adaptive system mainly depend on the three algorithms: channel estimation, channel prediction and transmission scheme selection. In this paper we limit our analysis only to the essential part of the adaptive MIMO system, the transmission scheme selection block, which selects transmit antennas and their CM schemes.

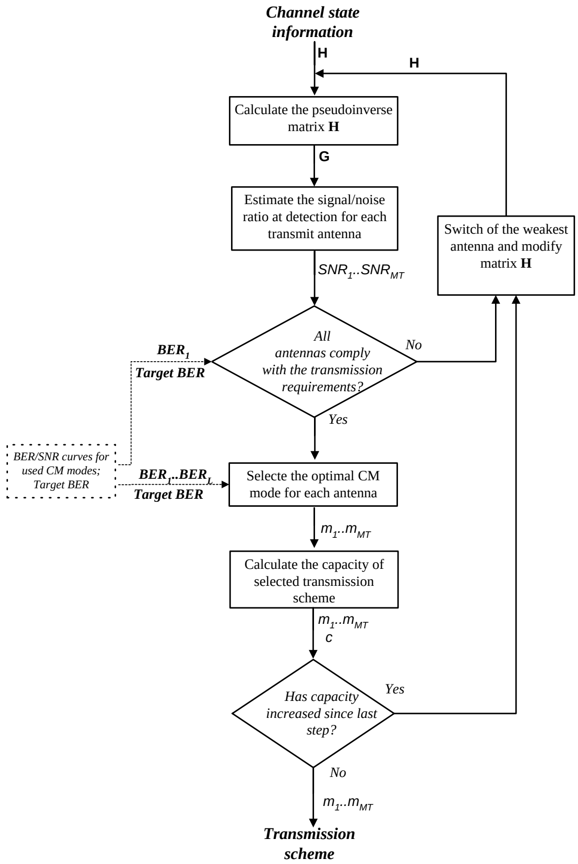

Figure 1: Block diagram of the algorithm for selecting transmit antennas and their CM schemes.

3 Algorithm description

The criterion for transmission mode selection is based on estimated self-generated noise using ZF demodulator [4]. A block diagram of the algorithm is shown in Fig. 1. The algorithm input is the estimated or predicted channel matrix $\mathbf{H}$. The pseudoinverse of the channel matrix is calculated in the first block. Next for each transmit antenna the signal to self-generated noise ratio is estimated from the pseudoinverse of the channel matrix. If the target BER cannot be achieved by the antenna with the highest self-generated noise, it is switched off and eliminated from the transmission scheme, and the procedure of calculating the SNR of the remaining transmit antennas is repeated. If the switched off antenna is highly correlated the diversity gain of the system is significantly increased and consequently the self-generated noise of the remaining antennas is reduced. The increased SNR may enable the transmission of more efficient CM schemes at the remaining transmit antennas. The whole procedure of finding the optimum modulation scheme with the pseudoinverse calculation is recursively repeated with a new deflated channel matrix $\mathbf{H}$ until all unreliable antennas are eliminated. When the target BER can be achieved for all active antennas in the system, the CM scheme is determined for each antenna separately from the pre-calculated thresholds.

The selected antennas and the estimated CM scheme may not be optimal, and for that reason in the next recursive loop we calculate the system throughput, which is equal to the sum of the bits allocated to each antenna. The weakest antenna is switched off again and the algorithm is restarted with a new set of used transmit antennas to calculate the new system throughput. If calculated system throughput is higher than that of the previous iteration the next weakest antenna is switched off and the whole procedure is repeated, until no increase of system throughput is observed.

4 Simulation results

The algorithm performance is tested for two target BERs, namely 10^{-3} and 10^{-6}, in the Rayleigh fading MIMO channel. The MIMO system consists of

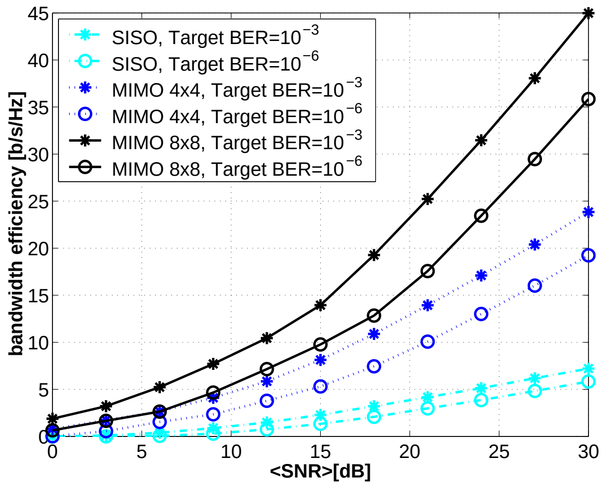

Figure 2: Bandwidth efficiency of adaptive MIMO and SISO systems for target BER 10^{-3} and 10^{-6}.

either four transmit and four receive antennas $M_R = M_T = 4$ or eight receive and eight transmit antennas $M_R = M_T = 8$. The following set of modulation schemes: BPSK, QPSK, $\{8, 16, 32, 64, 128, 256, 512, 1024\}$-QAM are applied in simulations for illustrative purposes only. The power is allocated uniformly to all selected antennas. The simulation results obtained were compared to simulation results for an adaptive SISO system.

The simulation results show that the BER is nearly constant in the SNR range considered for all simulated systems. The average BER is below the target value in all cases because the transmission scheme selection algorithm always selects the modulation that gives expected BER below target value. The BER does not noticeable depend on the number of transmit and receive antennas. The number of transmit and receive antennas have an effect only on the bandwidth efficiency. Nearly linear increase of system throughput with the number of transmit antennas is observed in Fig. 2. The system throughput increases rapidly with the increase in average SNR.

Errors in channel knowledge occur mainly because of channel estimation errors and variation of channel characteristic due to transmitter or receiver movement. The most common reasons for channel estimation errors are Gaussian noise added to the transmitted signal, co-channel and adjacent channel interference and limited calculation precision of the channel estimation algorithm. In communication system there is always some disagreement between the channel knowledge at the transmitter or receiver and the actual channel. Therefore it is important to test the performance degradation of the algorithm due to CSI errors. In the paper we assume that channel estimation error is negligible in comparison to the channel errors which are caused by the channel variation. If the channel is perfectly estimated at the receiver and no channel variations occur, the transmission scheme is determined accurately according to the observed CSI, and therefore no degradation of the system reliability is expected. However, when the channel is changed during the next transmission then the transmission scheme selection is not optimal which causes an increase in BER.

The statistics of channel estimation errors caused by outdated estimates due to the channel variation depend on many factors such as type of predictor, propagation environment geometry, characteristics of transmit and receive antennas, channel estimation technique, etc. In the absence of a detailed analysis of the channel estimation technique, channel prediction technique and propagation environment geometry, we simulate the channel estimation error as an uncorrelated Gaussian process with zero mean and standard deviation σ as a parameter. The simulations give us only an initial guide to channel sensitivity of the proposed antenna selection algorithms.

The results for $\sigma = 0.05$ are plotted in Fig. 3. The detection process uses the CSI obtained from the currently transmitted signals, while the set of active antennas and corresponding CM schemes have been selected using the CSI estimated previously transmitted signals. For that reason in a time varying channel the selected CM schemes and set of active antennas do not perfectly correspond to the channel state. The simulation results show that the proposed algorithm is insensitive to simulated channel variations for ZF detection. A negligible increase in BER is observed regardless of the number of transmit and receive antennas and target BER for MIMO system. While in SISO systems a significant increase of BER is observed for higher SNR and the lower target BER. When the target BER is low, the BER around switching thresholds become steeper and the overestimation of SNR causes the transmission of a CM mode with BER higher than the target value. MIMO systems are less sensitive to channel variations than SISO systems, because the MIMO systems receive with several antennas so channel variation is averaged and the probability that SNR at all antennas are overestimated is low.

5 Conclusion

A transmit antenna selection and their CM schemes adaptation algorithm is designed and analyzed in the paper. The main advantages of the proposed system are the small amount of information in return chan-

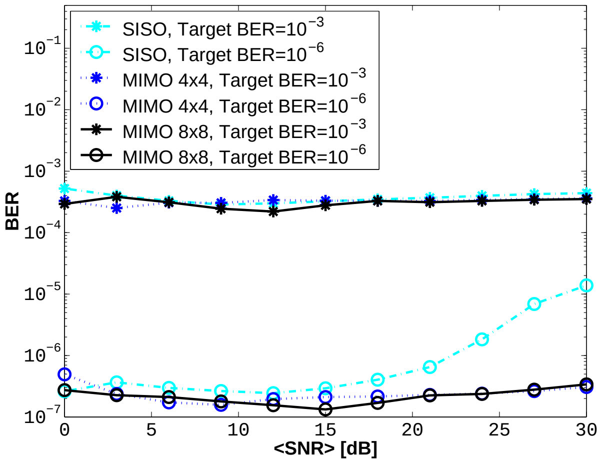

Figure 3: Algorithm performance degradation with ZF detection due channel variation $\sigma = 0.05$.

nel and no increase of peak to average power ratio, which makes the algorithm appropriate for a system with limited power resources. The lower number of transmitter chains also decreases the cost of the system.

The simulated MIMO system is not sensitive to small channel estimation errors. The channel misestimation behaves like co-channel channel interference, while the proposed algorithm is optimized only for additive Gaussian noise, therefore at higher channel estimation error we may expect a degradation of the system performance. A straightforward solution to cope with channel errors would be to back off the all channel thresholds by expected average error in CSI.

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