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Space Time Coded OFDM System with Transmit and Receive Antenna Selection

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Abstract: In this paper, antenna selection both at the transmitter and the receiver is proposed for space-time coded (STC) orthogonal frequency division multiplexing (OFDM) systems. Antennas for all-subcarriers or per-subcarrier are selected to maximize the signal to noise ratio (SNR) at the receiver which knows the channel state information perfectly and the transmitter only knows the indices of the selected antennas. The error performance is evaluated via simulations when space time block and concatenated coding is used. The results indicate that the joint antenna selection can be a highly appealing solution for increasing the performance and reducing the hardware/software complexity in OFDM based systems like WiMAX.

Keywords: OFDM, space-time coding (STC), antenna selection

1. Introduction

Next generation wireless systems are required to provide high data rates as the number of users and applications demanding high speed is increasing. In order to approach to the desired transmission rates reliably, the adverse effects of fading channels can be reduced by increasing diversity gains. Having multiple antennas at the transmitter and the receiver can provide spatial diversity which can be achieved by the use of space time coding (STC) techniques [1,2]. When the STCs are used over frequency-selective channels, the receiver may have to use highly complex equalizers to cancel the effects of intersymbol interference (ISI) which may not be practical.

Orthogonal frequency division multiplexing (OFDM) is a multi-carrier modulation method which can efficiently use the frequency spectrum and also eliminate the need for equalizers over frequency-selective fading channels. Since it is possible to gain high data rates reliably by using STC and OFDM techniques together [3,4,5], the IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX) standard has adopted them [6,7]. On the other hand, when the transmission rates are increased, the implementation and computation complexities may prohibit the practical use of STC-OFDM especially for size and power constrained mobile units.

Antenna selection [8] can be useful to reduce the cost and hardware/software complexity of multiple antenna systems. In this technique, some of the antennas are selected at each frame and used in actual transmission, thus the number of RF chains can be less than the number of antennas. In the literature, various selection criteria have been studied such as maximum capacity, maximum SNR, or minimum error probability. Antenna selection applied at the receiver [9], at the transmitter [10] or both [11,] can utilize the full available diversity order of the MIMO system when full-rank space-time codes are used. The research on STC-OFDM systems with antenna selection are also increasing [12,13].

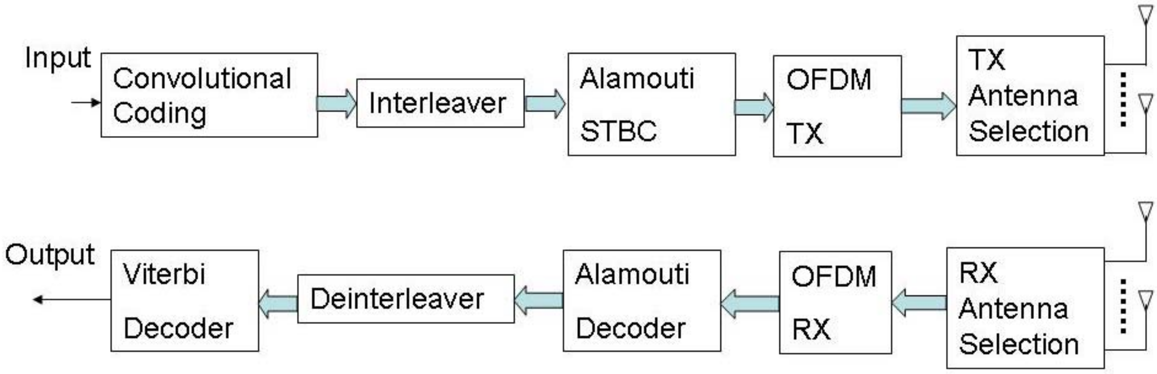

Figure 1: Block diagram of proposed STC- OFDM system with transmit and receive antenna selection

Antenna selection technique has to be well investigated before it can be added into future wireless standards.

In this paper, the error performance of the STC-OFDM systems with joint transmit and receive antenna selection is explored. By utilizing the channel coefficients known at the receiver, the antennas are selected to maximize the average SNR since SNR is a common parameter to be maximized to maximize the channel capacity and minimize error probability. With the help of simulations, the diversity gains are investigated with STBC [1] or with concatenated STC when selection is done for all-subcarriers or per-subcarrier. The results show that joint transmit/receive antenna selection can be quite promising for the OFDM based systems when strong STCs are employed.

This paper is organized as follows. Section 2 describes the STC-OFDM system with antenna selection while Section 3 shows the simulation results and finally Section 4 summarizes the conclusions.

2. STC-OFDM with Transmit and Receive Antenna Selection

The simplified block diagram of the STC-OFDM system with antenna selection is shown in Figure 1. The source bits first pass through a space-time encoder based on concatenated convolutional coding and Alamouti's STBC. Then, space-time symbols are obtained at the output of OFDM modulator which uses inverse fast Fourier transformation (IFFT) and digital to analog conversion. There are M transmit and N receive antennas available in the system, however, $M_S \leq M$ transmit $N_S \leq N$ and receive antennas are selected and used in actual transmission of STC-OFDM symbols. The channel state information (CSI) is assumed to be known perfectly only at the receiver and the transmitter does not have access to this. The antennas are selected at the receiver to maximize the average SNR and only the indices of selected antennas are sent to the transmitter from a feedback channel. The signals passed through frequency-selective quasi-static fading channel are received at the selected antennas and after the OFDM demodulation using FFT operation, the baseband symbols are detected by a maximum likelihood (ML) space-time decoder.

The received signal can be written as,

$$Y_n[k] = \sum_{m=1}^{M_s} H_{n,m}[k] X_m[k] + W_n[k] \qquad (1)$$

where $X_m[k]$ represents the transmitted data symbol with k. sub-carrier (k=1, 2, ... , K), $W_n[k]$ is the additive noise of the symbol in frequency domain, belonging to the n^{th}

($n=1,2,\ldots,N_S$) antenna (zero mean i.i.d. Gaussian distributed) and $H_{n,m}[k]$ shows the channel coefficients between the n^{th} receive and m^{th} transmit antennas ($m=1, 2, \ldots, M_S$) in frequency domain.

$$H_{n,m}[k]=\sum_{l=0}^{L-1} h_{n,m}[l]e^{-j\frac{2\pi}{K}lk} \qquad (2)$$

Here $h_{n,m}[l]$ is zero-mean independent Gaussian distributed, L ($l=0,1,\ldots,L$) shows the channel tap number and K shows the total number of subcarriers. Channel impulse response is assumed to be constant over OFDM symbol interval. Thus the time index is not notified in the system model. The selected N_SxM_S channel matrix H[k] for the k'th sub-carrier is acquired from the NxM complete channel matrix H[k] which is:

$$\hat{H}[k]=\begin{bmatrix} H_{1,1}[k] & \cdots & H_{1,N}[k] \\ \vdots & \ddots & \vdots \\ H_{M,1}[k] & \cdots & H_{M,N}[k] \end{bmatrix} \qquad (3)$$

In this study, two different antenna selection methods described in [13] are considered. The first one selects the same transmit antennas for all OFDM sub-carriers (all-tone selection), and the second method selects antennas for each OFDM sub-carrier (per-tone selection) separately. When all-tone selection is made, the channels that consist of the channel coefficients in the frequency domain *($H_{n,m}[k]$)* having the maximum Frobenius norm are selected for all of the OFDM subcarriers. All possible selection types are calculated and finally the most powerful configuration is selected. Data is transmitted from those selected antennas. Only some part of the antennas is used over the OFDM symbol interval, making the system hardware cost less. In this technique, all possible C(M,M_S).C(N,N_S) combinations are compared (C(i,j) is the number of combinations when j elements are chosen from i elements). The complexity for this comparison can be a high especially if the numbers of antennas are large, however, at the end the computational complexity at the receiver and the hardware cost for the general system will be reduced tremendously. Note that instead of joint transmit/receive selection, selecting the antennas at the transmitter or receiver first and then at the other side separately will reduce the selection complexity with slight performance loss. On the other hand, using per-tone selection, the antennas are selected separately for each subcarrier which can provide better performance at the cost of increased complexity. Furthermore, one can also consider group selection to use the antennas for a group of subcarriers to have a performance and complexity between the above two methods.

Considering the theoretical error analyses in the literature for STC-OFDM systems and antenna selection, one can expect the full diversity to be achieved with per-tone selection. However considering the complicated derivations in antenna selection literature the proof has not been obtained, yet. Therefore, computer simulations may give some idea about the performance and achievable diversity orders.

3. Simulation Results

In this section, the simulation results of the proposed STC-OFDM system with transmit/receive antenna selection are presented. The notation "*(M;N)*" is used denote M transmit and N receive available antennas without antenna selection, and "*(M:M_S;N:N_S)*"

notation represents the system where M_S antennas are selected from M transmit antennas and N_S antennas are selected from N receive antennas. The simple Alamouti STBC or

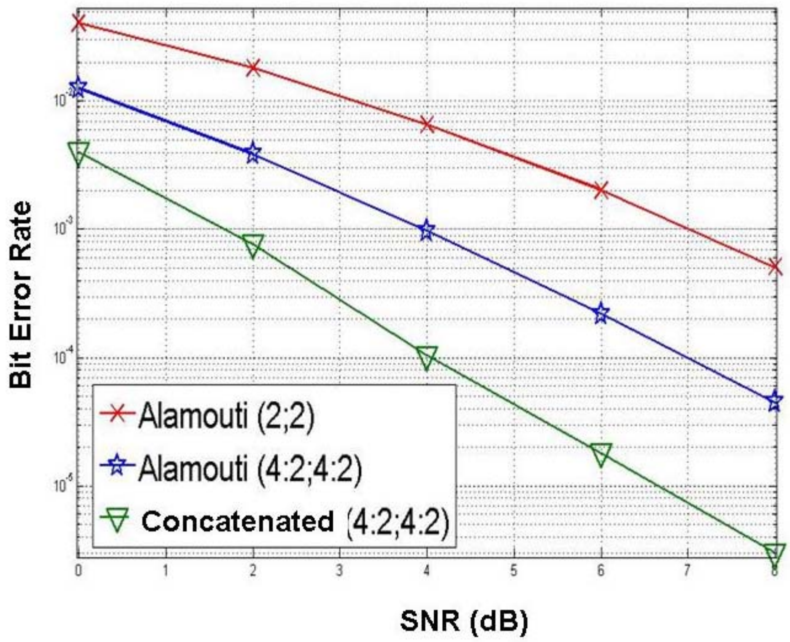

Figure 2: Bit error rates with all-tone antenna selection

concatenated STC made of widely used convolutional coding (with constraint length 3) and Alamouti STBC with a random interleaver in between are used to utilize some of the available diversity in the system. The space time coded bits are modulated by using QPSK signaling and OFDM with $K=64$ sub-carriers. The wireless channel is assumed to be quasistatic Rayleigh frequency-selective fading with $L=2$ taps having identical powers.

Bit error rate (BER) plots are shown for a STC-OFDM system in Figure 2, where all-tone antenna selection technique is employed and STBC (Alamouti) and concatenated STC transmissions are compared. Obviously, there is an improvement in error performance with antenna selection and with stronger coding. Comparing the *(2;2)* with *(4:2;4:2)* systems approximately 3 dB SNR gain can be obtained at the error probability of 10^{-4} with joint antenna selection and concatenated STC requires almost 6 dB less power than Alamouti without antenna selection. On the other hand, it can be seen that Alamouti code cannot achieve full diversity order available in the system since it is specifically designed for flat fading channels. It is possible to increase achievable diversity order with the use of stronger channel codes like concatenated space time codes.

The error performance for per-tone selection is presented in Figure 3. Comparing to the all-tone selection, this technique has much better error performance while selection complexity is increased linearly with the number of subcarriers. When we compare the Alamouti coded systems *(2;1)* with *(4:2;4:1)* and *(2;2)* with *(4:2;4:2)* at bit error rate 10^{-4}, there are 14 dB and 7 dB SNR gains, respectively. These are significant gains and it can also be seen that the diversity gains are increased with this selection technique. Furthermore, unlike all-tone selection using concatenated coding can result in considerably larger diversity gains than simple Alamouti coding. It is quite interesting that one can obtain bit error rate of 10-5 at SNR less than 1 dB with the use of only 2 selected out of 4 antennas both at the transmitter and receiver. Therefore, the joint transmit and receive antenna selection technique can be quite desirable for next generation OFDM based systems like WiMAX.

In the simulations, it is assumed that the receiver knows the channel coefficients perfectly which is not the case in practice. Although not shown here, using erroneous channel estimates in the selection and the decoding processes does not decrease the achievable diversity order but results in loss of antenna selection gain depending on the

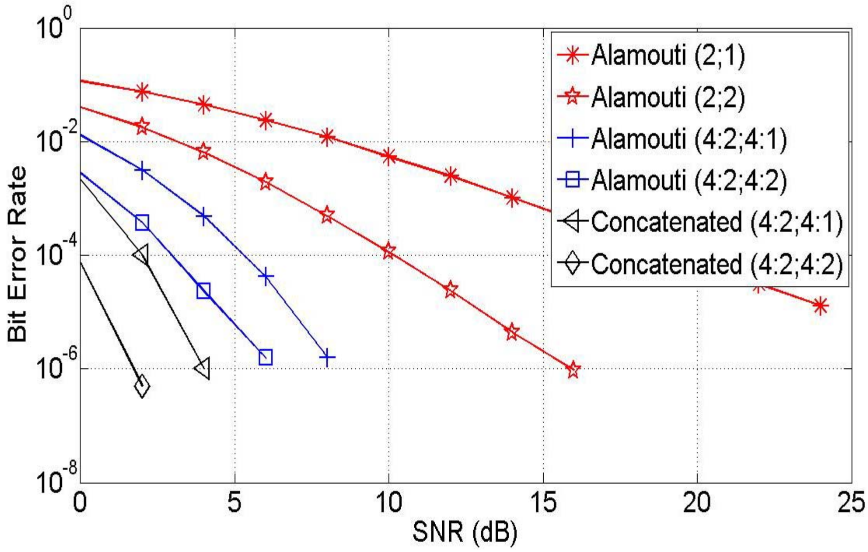

Figure 3: Bit error rate with per-tone antenna selection

correlation of actual and estimated channel coefficients. Moreover, using larger number of subcarriers and more ISI taps improves the performance slightly.

4. Conclusions

In this paper, a joint transmit and receive antenna selection is proposed for space-time coded OFDM systems. Compared to STC systems without antenna selection, when same number of antennas is used in transmission, the simulation results illustrate that there is a significant improvement in error performance due to increased diversity gains with antenna selection. Transmitting STC based on simple Alamouti scheme cannot utilize the multipath diversity, however, concatenated STC can obtain better performance by making use of large diversity available in the system. Our future work will explore the theoretical error rate expressions and achievement of full diversity order with STC-OFDM employing antenna selection.

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