Space Time Turbo Coded OFDM System with Transmit and Receive Antenna Selection

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Abstract

In this paper, a space-time turbo coded (STTC) orthogonal frequency division multiplexing (OFDM) system with QPSK signalling is explored when joint transmit and receive antenna selection is employed. Maximization of signal to noise ratio is used for antenna selection based on per-tone, all-tone or hybrid selection criteria. Simulation results show that applying joint transmit/receive antenna selection techniques for STTC-OFDM systems can improve error rate performances considerably by achieving high diversity orders, thus make it preferable for standards of high speed wireless networks.

1. Introduction

Next generation wireless communication systems are required to have high data rates as the number of users and applications are increasing. The major adverse effect in wireless channels is fading which can increase error rates significantly. In order to mitigate the effects of fading, diversity gains can be increased, for example, by using multiple antennas at the transmitter and/or receiver with the proper selection of space time codes (STC) [1,2,3] Space time codes can be based on simple block codes, trellis codes or turbo codes and are usually designed to achieve full diversity available in the system and as much coding gain as possible. Space time block coding (STBC) [2] is the simplest case where two transmit antennas are used in order to increase the data reliability. Space time turbo codes on the other hand (STTC) are quite effective techniques that are constructed from the parallel concatenation of two recursive systematic convolutional codes with a pseudo-random interleaver between them. STC systems have been widely studied in the literature, however, in practice, as the number of antennas increase in an attempt to improve performance, the design and hardware costs can increase tremendously. Similarly, the computational complexity at the receiver can prohibit the use of STC systems with large number of antennas. Therefore, complexity reduction with minimal performance loss has been a popular research topic.

Antenna selection (AS) [4] can be a useful method to decrease hardware and software complexity in multiple antenna systems. Based on the maximization of SNR, minimization of error rate or maximization of capacity, only some of the available antennas can be selected and used at each frame. In the literature, the number of works on AS is increasing. Antenna selection can be applied at the transmitter, receiver and/or jointly on both sides and it has been shown that the achievable diversity order does not degrade even if there are channel estimation errors [5,6]. Orthogonal frequency division multiplexing (OFDM) technique utilizes closely located narrowband orthogonal subcarriers to convey symbols over long symbol durations to use spectrum efficiently while protecting intersymbol interference (ISI) [7]. With the use of OFDM, the receiver does not have to use channel equalizers which can be quite complex especially if there are large number of ISI taps caused by small symbol duration.

In the literature, OFDM technique can be used with STCs in order to achieve high data rates while keeping the error rates low. In [8], STC-OFDM system is analyzed, and pairwise error probability (PEP) is derived which can help the design of new codes. It is shown that using STC-OFDM in frequency selective channel can achieve full diversity order. In [9], a new space-time – frequency coding for OFDM over frequency – selective fading channels is studied and it is shown that this technique can be capable of maximum diversity and high coding gain. In order to decrease complexity of these systems, STC-OFDM systems with AS are also studied. In [10], the performance of MIMO AS for these systems is analyzed to show that full diversity can be achieved with receive antenna selection. Receive antenna selection for MIMO-OFDM systems with channel estimation error is analyzed in [11]. In [12], Alamouti coded OFDM system with per-tone transmit antenna selection is analyzed and some power constraint to improve performance are developed in [13]. In [14], bulk versus per-tone transmit antenna selection is compared in MIMO-OFDM system and some important insights into codeword construction and performance analysis are presented. The performance of combined bulk and per-tone transmit antenna selection in uncoded OFDM systems is investigated in [15] and shown that the new scheme does not degrade the coding and diversity gains. STC OFDM with joint transmit and receive antenna selection is presented in [16] where the simple Alamouti scheme [2] is not powerful enough to achieve most of the available diversity. The pairwise error probability of a STC-OFDM system is shown in [8] where the result is very similar to that of [1] and indicates that full diversity order of *NML* can be achieved. Although the details are not shown here, it is possible to extend the derivation of upper bound of pairwise error probability as in [5] to claim that full diversity is also achievable with joint transmit and receive antenna selection. Although there are several studies in the literature, the bit error rate performance results for STTC-OFDM systems with per-tone selection have not been presented yet.

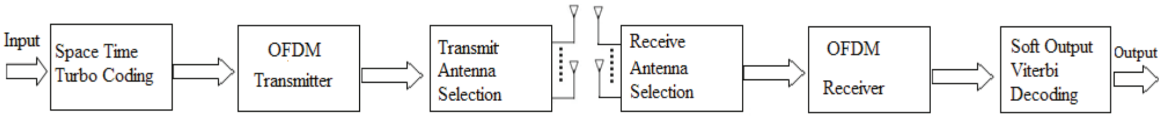

Fig. 1. Block diagram of the STTC-OFDM system with transmit and receive antenna selection

Most of the previous studies have considered some analytical results to investigate performance, however, in order to understand the performance effects of antenna selection, bit error rates should be compared in different scenarios. In this paper, the performance of space-time turbo coded OFDM systems with joint transmit and receive antenna selection is explored over quasi-static frequency selective Rayleigh fading channels. We consider selection of the best antennas to maximize the received power for each subcarrier, for all subcarriers or combined selection. Only the receiver is assumed to know the channel state information and performance comparison of different selection types are presented. In Section 2, system model of the proposed model is described. In the third section, numerical results are provided and final conclusions are given in Section 4.

2. System Model

The block diagram of the STTC-OFDM system with AS is shown in Fig. 1. The input bits are passed through space-time turbo encoder [3] and coded OFDM modulated QPSK symbols are transmitted through the MIMO frequency selective fading channel over the selected transmit and receive antennas. M_S transmit antennas are selected from M possible candidates at the transmitter and N_S receive antennas are selected from N possible candidates at the receiver based on the maximization of the SNR at the receiver. It is assumed that channel state information (CSI) is perfectly known at the receiver to be used for selection, decoding. Only the indices of the selected transmit antennas are fed back thus reduces the data rate. The received symbols pass through the OFDM demodulator which uses Fourier transform. At the decoder side, soft output Viterbi algorithm (SOVA) [17] is used to have lower complexity compared to MAP algorithm.

The block diagram of the space time turbo encoder [3] is given in Fig. 2. The encoder consists of a turbo encoder followed by a symbol interleaver and multiplexer. Each of STTC encoders operates on a block consisting of groups of m information bits. Input sequences of binary vectors [c_1, ..., c_m] is transformed by the convolutional encoders which are shown in Fig.3. One specific property of this scheme is that it can utilize M-ary modulation alphabet unlike many turbo schemes working on binary inputs. The details of the operation can be seen in [3].

The block diagram of a recursive convolutional encoder is given in Fig. 3. The memory cells are capable of storing symbols, multipliers and adders that can perform M–ary multiplication and addition operations respectively. Since we consider QPSK signaling the coefficients in the figure can be taken from the set {0,1,2,3} as explained in [3].

Similar to many MIMO OFDM systems in the literature, the received signal at the output of the MIMO OFDM channel can be written as,

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

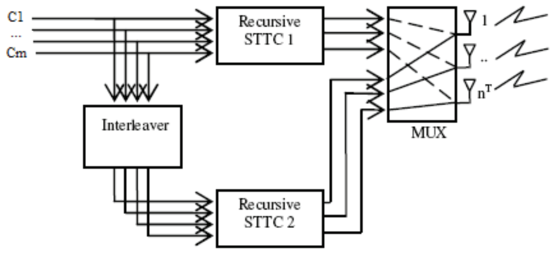

Fig 2. Block diagram of the space time turbo encoder.

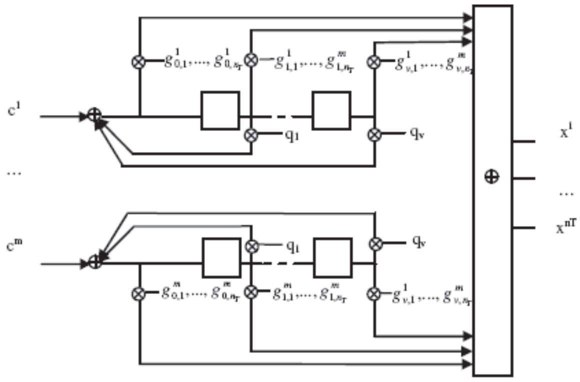

Fig. 3 Block diagram of a recursive STTC encoder for M-ary modulation

where $X_m[k]$ represents the transmitted data symbol with k. sub-carrier ($k=1, 2, \ldots, K$), and K shows the total number of subcarriers. $W_n[k]$ is zero mean i.i.d additive white Gaussian noise sample belonging to the n-th ($n=1,2,\ldots,N_S$) antenna and $H_{n,m}[k]$ shows the channel coefficients between the n-th receive and m-th transmit antennas

$$H_{n,m}[k] = \sum_{l=0}^{L-1} h_{n,m}[l] e^{\frac{-j2\pi lk}{K}} \qquad (2)$$

Here $h_{n,m}[l]$ is a zero-mean independent Gaussian distributed random variable, L (l=0,1,...,L) shows the number of taps. The selected N_SxM_S channel matrix is acquired from the NxM complete channel matrix

$$\boldsymbol{H}[\boldsymbol{k}] = \begin{pmatrix} h_{1,1}[k] & \cdots & h_{1,N}[k] \\ \vdots & \ddots & \vdots \\ h_{M,1}[k] & \cdots & h_{M,N}[k] \end{pmatrix} \qquad (3)$$

Three different antenna selection methods are employed with STTC-OFDM system and our major focus is the comparison of performance results in the next section. The first selection method is called all-tone selection which performs the selection by maximizing the received power considering all OFDM sub-carriers [13]. The second method is called per-tone selection where the best antennas are selected for each sub-carrier individually [14]. The third method combines all-tone selection with per-tone selection which is called hybrid (or combined) selection. In this method, first all-tone method is used to reduce the number of selectable antennas and then per-tone selection is used based on the rest of the antennas [15].

3. Simulation Results

In this section, the simulation results of the STTC-OFDM system with joint transmit/receive antenna selection are provided. The notation "*(M;N)*" is used to denote M total antennas at the transmitter and N total antennas at the receiver. "$(M{:}M_S;N{:}N_S)$" 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 space time coded bits are modulated by using QPSK signaling and OFDM with $K=128$ sub-carriers. Bit error rate (BER) plots are shown for the STTC-OFDM system described in the previous section. We compare all-tone, per-tone and hybrid antenna selection performances on different channel models.

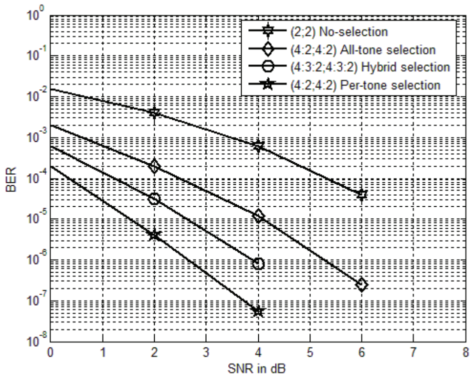

Fig. 4. Comparison of different selection methods in STTC-OFDM system

(4:2;4,2) all-tone selection is compared with (4:3:2;4:3:2) hybrid and (4:2;4:2) per-tone selection cases in Fig. 4. where the wireless channel is assumed to be quasi-static Rayleigh frequency-selective fading with $L=2$ taps having identical powers. Compared to no-selection, all-tone selection achieves 2.5 dB SNR gain at 10^{-4} BER. Moreover, if per-tone selection is used instead, the gain increases to 5 dB when compared to no selection case. Compared to all-tone selection, per-tone selection achieves 2 dB SNR gain at 10^{-4} with BER with a cost of increased selection complexity. Therefore hybrid selection can be used if we want to decrease selection complexity with the cost of slight performance loss. In this figure, the performance of hybrid selection is 1 dB lower than per-tone selection at the 10^{-4} BER. Moreover, as the highest diversity gain can be achieved by using per-tone selection, hybrid selection can also achieve high diversity orders.

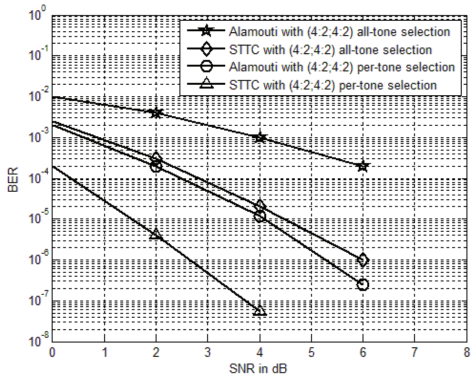

Fig. 5. Comparison of all-tone and per-tone antenna selection using STBC and STTC

STTC-OFDM system with (4:2;4:2) all-tone and per-tone antenna selection is compared with STBC-OFDM system in Fig. 5 where quasi-static Rayleigh frequency-selective fading wireless channel is used with $L=2$ taps having identical powers. In this figure, it can be seen that the diversity gain and error performance of the STTC is much better than that of STBC as expected since turbo coding is better error correcting codes. For example, at 10^{-6} error rate, 3 dB SNR gain can be achieved if we compare per-tone selections.

Obviously, there are considerable performance improvements with antenna selection and with stronger coding like STTC in MIMO OFDM systems. As expected, we observe that antenna selection gains with per-tone selection can be larger than all-tone and hybrid selection methods.

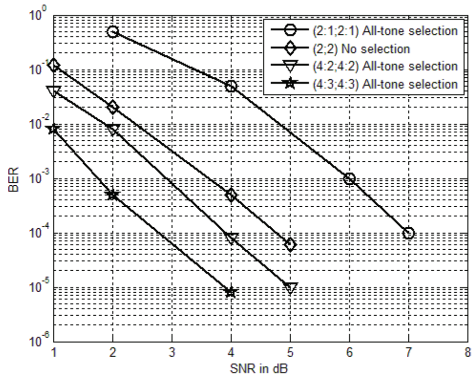

Fig. 6. STTC-OFDM system with all-tone transmit/receive antenna selection over WLAN (E) channel

Performance of the STTC-OFDM system with all-tone selection over WLAN (type E) channel is depicted in Fig. 6. To generate channel matrix H, we used narrowband Kronecker model [18]. To compute channel matrix, we used a method that employs correlation matrix [19]. We observe that the (2:1;2:1) selection performs worse than the (2;2) system by about 2 dB at 10^{-4} BER. However, when we compare the systems (4:2;4:2) and (4:3;4:3) with the (2;2) system without antenna selection then there are 1 dB and 2 dB SNR gains, respectively, at the bit error rate of 10^{-4}. We observe that, the simplest all-tone selection improves BER but does not increase diversity gains noticeably.

4. Conclusions

In this paper, space-time turbo coded MIMO-OFDM channel model with joint transmit/receive antenna selection is studied. The performances with all-tone, per-tone and hybrid antenna selection methods are compared. Per-tone selection has the best performance and achieves high diversity gains at the cost of increased computational complexity. On the other hand, hybrid selection decreases selection complexity with a slight loss in performance. Moreover, STTC is compared with STBC while per-tone and all-tone antenna selection is applied to both of them. Simulation results verify that STTC-OFDM with transmit and receive antenna selection can decrease error rates significantly by exploiting high diversity orders. Therefore, the considered transmission model can appear in the next generation high speed OFDM based systems.

5. References

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