Transmission Control Scheme for Throughput Maximization in MIMO Systems

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Abstract

We introduce our throughput maximization transmission control scheme for multiple input multiple output (MIMO) systems [1][2]. The proposed scheme selects a transmission scheme (a set of transmit antennas, modulation, and coding rate) to maximize throughput based on received signal-to-interference-plus-noise ratio (SINR). The proposed scheme achieves high throughtput under any channel conditions and any number of transmit and receive antennas. The simulation results show that the proposed transmission control scheme always keeps higher throughput than conventional MIMO systems in both singlecarrier and multicarrier systems.

I. INTRODUCTION

Recently, multiple input multiple output (MIMO) systems have been intensively investigated for high data rate communications. Especially, space division multiplexing (SDM) is considered as a key technology to achieve high spectral efficiency [3]–[5]. In a SDM system, input signals are individually transmitted from multiple transmit antennas and the signals are separated by a receiver using array signal processing.

When the receiver has more antennas than the transmitter, good spatial multiplexing transmission can be realized in usual receiver beamforming [4]. However, in actual wireless communications, the transmitter sometimes has more antennas than the receiver. Under such environments, signals independently transmitted from all transmit antennas cannot be separated by the receiver, and the signal quality deteriorates. Rather, stopping the transmission from some transmit antennas may achieve better performance. Thus, it is possible to attain high quality data transmission by controlling a transmission scheme of signals.

Previously, transmission control schemes for MIMO systems have been considered under the same modulation and coding for all transmit antennas [6][7]. In [6], a scheme to selects an set of transmit antennas is reported and in [7] a scheme to control transmit power is studied.

In this paper, we introduce our throughput maximization transmission control scheme for MIMO systems proposed in [1][2]. The proposed transmission control scheme selects a transmission scheme (a set of transmit antennas, modulation scheme, and coding rate) with maximum throughput based on output signal-to-interference-plus-noise ratio (SINR). The proposed system requires only a few feedback information, because the information of selected transmission scheme is fed back to the transmitter. We show that the proposed transmission control scheme attains high throughput in both singlecarrier and multicarrier MIMO systems with any number of antennas by computer simulations.

II. SPACE DIVISION MULTIPLEXING

A singlecarrier MIMO system with N transmit and M receive antennas is shown in Fig. 1, where h_{mn} denotes the channel response from the n-th transmit antenna to the m-th receive antenna. When the signal $s_n(t), n = 1, \cdots, N$ is transmitted from the n-th transmit antenna at time t, the received signal $\boldsymbol{x}(t) = [x_1(t), \cdots, x_M(t)]^T$ is given by

$$\boldsymbol{x}(t) \quad = \quad \sum_{n=1}^{N} \boldsymbol{h}_n s_n(t) + \boldsymbol{z}(t), \qquad \boldsymbol{h}_n = [h_{1n} \cdots h_{Mn}]^T \qquad \boldsymbol{z}(t) = [z_1(t) \cdots z_M(t)]^T$$

where $x_m(t)$ and $z_m(t)$ denote the received signal and the noise in the m-th receive antenna, respectively. At the receiver, the received signal is combined by the weight vector $\boldsymbol{v}_m = [v_{1m}, \cdots, v_{Nm}]^T$ to yield an output $y_k(t)$ of

$$y_k(t) = \boldsymbol{v}_k^\dagger \boldsymbol{x}(t) = \sum_{n=1}^{N} \left(\boldsymbol{v}_k^\dagger \boldsymbol{h}_n \right) s_n(t) + \boldsymbol{v}_k^\dagger \boldsymbol{z}(t). \tag{1}$$

where † is the complex conjugate transpose. There are various weight decision schemes for $\boldsymbol{v}_k$. For example, the minimum mean square error (MMSE) weight is given by

$$\boldsymbol{v}_k = \left(\sum_{n=1}^{N} \boldsymbol{h}_n \boldsymbol{h}_n^\dagger + P_z \boldsymbol{I} \right)^{-1} \boldsymbol{h}_k \tag{2}$$

where P_z denotes the noise power per receiver antenna.

Spatial division multiplexing (SDM) works well when the multiplexed signals can be separated by the weight $\boldsymbol{v}_k$. However, the multiplexed signals are not sufficiently separated in case of $N > M$. Then, the signal quality degrades even if the MMSE weight is used. Therefore, we need a scheme that attains high quality data transmission under such environments.

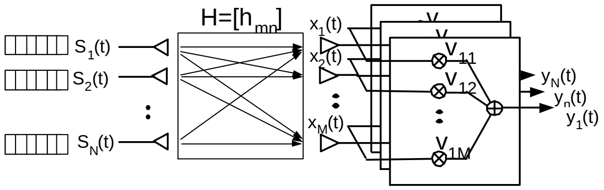


Fig. 1. SDM scheme.

TABLE I

LOOKUP TABLE OF ADAPTIVE MODULATION AND CODING (AMC).

SINR [dB]	Modulation	Coding Rate	Throughput
∼ 0	No use	No use	0.000
0 ∼ 1	QPSK	1/8	0.250
1 ∼ 2	QPSK	1/7	0.285
2 ∼ 3	QPSK	1/6	0.333
⋮	⋮	⋮	⋮
25 ∼	16QAM	3/4	3.000

III. TRANSMISSION CONTROL

Our transmission control scheme for singlecarrier MIMO systems selects a set of transmit antennas, modulation scheme, and coding rate based on output SINR at the receiver. The algorithm has the following processes:

1) Channel Estimation
The pilot sequences are transmitted simultaneously from all transmit antennas. The pilot sequences $s_i(t)$ $(E[|s_i(t)|^2] = 1)$ for the i-th transmit antenna are orthogonal with other sequences in period T_0 as $\sum_{t=1}^{T_0} s_i^*(t)s_j(t) = 0(i \neq j)$. At the receiver, the channel response is estimated as

$$\tilde{\boldsymbol{h}}_n \;=\; \frac{1}{T_0}\sum_{t=1}^{T_0} \boldsymbol{x}(t)\boldsymbol{s}_n^*(t) = \boldsymbol{h}_n + \frac{1}{T_0}\sum_{t=1}^{T_0} \boldsymbol{z}(t)\boldsymbol{s}_n^*(t) \tag{3}$$

2) SINR Estimation
Assuming a subset of transmit antennas $n \in \boldsymbol{U}$, the MMSE weight $\boldsymbol{v}_n$ and the output SINR γ_n corresponding to the signal from the n-th transmit antenna are estimated as

$$\boldsymbol{v}_n \;=\; \boldsymbol{R}^{-1}\boldsymbol{h}_n, \qquad \gamma_n = \frac{|\boldsymbol{h}_n^\dagger \boldsymbol{v}_n|^2}{\boldsymbol{v}_n^\dagger \boldsymbol{R}\boldsymbol{v}_n - |\boldsymbol{h}_n^\dagger \boldsymbol{v}_n|^2} \tag{4}$$

respectively, where $\boldsymbol{R} = \sum_{n\in\boldsymbol{U}} \boldsymbol{h}_n\boldsymbol{h}_n^\dagger + P_z\boldsymbol{I}$. If only one transmit antenna (n-th) is selected, the output SINR(=SNR) is given by $\gamma_n = ||\tilde{\boldsymbol{h}}_n||^2/P_z$. If two transmit antennas (n_1-th, n_2-th) are selected, the output SINR of the signal from the n_1-th transmit antenna is given by $\gamma_{n_1} = \tilde{\boldsymbol{h}}_{n_1}^\dagger(\tilde{\boldsymbol{h}}_{n_2}\tilde{\boldsymbol{h}}_{n_2}^\dagger + P_z\boldsymbol{I})^{-1}\tilde{\boldsymbol{h}}_{n_1}$.

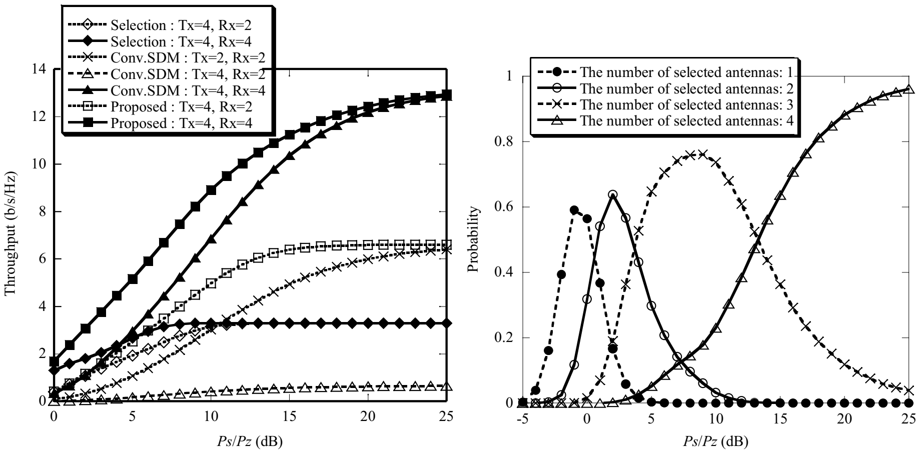
3) Computation of Total Throughput
Based on the estimated SINR, throughput of the n-th transmit antenna is computed using the lookup table of adaptive modulation and coding (AMC). Table I shows an example of the lookup table. The lookup table, which is prepared in advance, lists modulation schemes, coding rates, and throughputs to achieve the target packet error rate (PER) under various SINRs. As SINR becomes larger, the throughput increases. System throughput is given by the sum of throughputs corresponding to all transmit antennas.

4) Selection of Transmission Scheme
Steps 2) and 3) are performed for all possible subsets of transmit antennas. Finally, the transmission scheme with the maximum system throughput is selected among all transmission schemes. The information of the selected transmission scheme is fed back to the transmitter.

In case of 4 transmit and 2 receive antennas, the all possible subsets are given by (1, 2), (1, 3), (1, 4), (2, 3), (2, 4), (3, 4), (1), (2), (3), (4), where the number in the bracket represents the transmit antenna number. Using the proposed algorithm, maximum system throughput is selected among all possible subsets of transmit antennas. The proposed system requires only a few feed back information about selected transmission scheme.

IV. PERFORMANCE OF SINGLECARRIER MIMO

The performance of the proposed scheme is evaluated by computer simulations. In the simulations, adaptive modulation among QPSK, 8PSK, and 16QAM, convolutional coding with K= 7 and adaptive coding rate $R = 1/2, 2/3, 3/4, 5/6$, packet length of 120 symbols, target PER of 10^{-2}, ideal channel estimation, and ideal feedback are assumed. Also, we consider a constant power P_s for selected transmit antenna.



(a) (b)

Fig. 2. Performance of the proposed scheme, the selection transmit diversity, and the conventional SDM (a) throughput versus P_s/P_z (b) probability that $n \in \{1,2,3,4\}$ transmit antennas.

Fig. 2 (a) shows the system throughput versus P_s/P_z for the proposed scheme, the selection transmit diversity scheme, and the conventional SDM scheme. The selection transmit diversity scheme selects a single transmit antenna based on output SNR and modulation scheme and coding rate are determined by the output SNR. The conventional SDM scheme selects all transmit antennas, and modulation scheme and coding rate of each transmit antenna are individually determined by output SINR.

From the numerical results, the proposed transmission control scheme with Tx = 4 and Rx = 4 has higher throughput than the conventional SDM scheme with Tx = 4 and Rx = 4, especially in case of small P_s/P_z. This is because, in small P_s/P_z, the conventional SDM scheme has very small SINR and little throughput for each transmit antenna, while the proposed scheme achieves much higher SINR by decreasing the number of transmit antennas. Also, the proposed scheme with Tx = 4 and Rx = 2 has higher throughput than the conventional SDM schemes with Tx = 4 and Rx = 2, and Tx = 2 and Rx = 2. In this case, the proposed scheme selects at most two transmit antennas that is the maximum separable number of signals for receiver. The proposed scheme also outperforms the selection diversity scheme, because the proposed scheme has larger number of candidates to select a subset of transmit antennas.

Fig. 2(b) shows the probability to select 1 to 4 transmit antennas in the proposed scheme under 4×4 MIMO channel. In small P_s/P_z, limited number of transmit antennas are selected to obtain large SINR. On the other hand, in large P_s/P_z, signals are transmitted from all four transmit antennas.

V. PERFORMANCE OF OFDM-MIMO

Next, we present the transmission control algorithm and the performance for MIMO–OFDM system.

A. Transmission Control Algorithm

Consider MIMO–OFDM system which uses individual receive weights for all subcarriers. In our transmission control, the same subset of transmit antennas is selected for all subcarriers and one transmit antenna use the same modulation and coding rate for all subcarriers. We extend our transmission cotrol scheme in **III.** to OFDM systems, by averaging output SINR over all subcarriers. In step 2), the average SINR Γ_n for the n-th transmit antenna is given by $\Gamma_n = \frac{1}{L}\sum_{l=1}^{L} \gamma_n^l$ where L denotes the number of subcarriers and γ_n^l is the estimated SINR for the l-th subcarrier of the n-th transmit antenna. In step 3), the lookup table of AMC is prepared against various average SINRs. Thus, replacing the SINR by average SINR, the same process for transmission control algorithm can be applied to OFDM-MIMO system. The performance of MIMO–OFDM system with 4 transmit and 4 receive antennas is evaluated by simulations. Table II shows the simulation parameters. In the simulations, exponential decay 18-path channel model with RMS delay spread of 50ns is employed, where each path has Rayleigh fading.

B. AMC Selection Table

In the proposed scheme, the lookup table of AMC is prepared in advance. To make the lookup table, PER performances of single input single output (SISO)-OFDM system with actual channel estimations is evaluated under frequency selective fading. Based on the performance evaluation, we pick up three AMC sets to achieve PER=1% considering channel estimation effect as listed in Table III. Generally, in OFDM system with selective fading , a notch of frequency response can be compensated with the interleave and channel coding, and PER performance is greatly dependent on average SINR. Therefore, we can get PER $\leq$ 1% using this lookup table.

C. System Throughput

Fig. 3(a) shows the system throughput performance. In the figure, the conventional schemes always use fixed modulations and coding rates of (QPSK R=1/2), (16QAM R=3/4), (64QAM R=3/4), for all transmit antennas. From these results, the system throughput can be improved effectively by the proposed scheme. Therefore, it is confirmed that the proposed transmission control scheme can be also applied to MIMO-OFDM system.

TABLE II

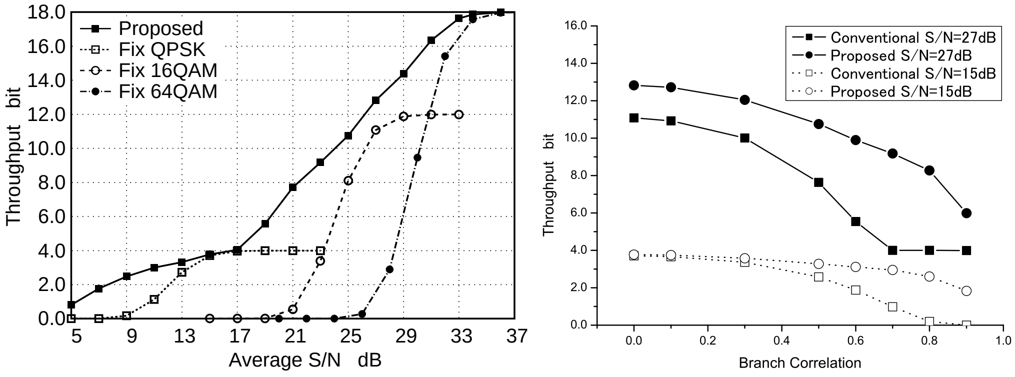
SIMULATION PARAMETERS FOR OFDM-MIMO.

Modulation method	QPSK, 16QAM, 64QAM	Channel Coding	Convolutional, R=1/2, 3/4
FFT points / Guard interval	64 / 16	Number of subcarriers	52
FFT clock	25MHz	Pilot length	4 OFDM symbols
Packet length	1 frame =12 OFDM symbols	Number of antennas	Tx: 4, Rx: 4

TABLE III

LOOKUP TABLE OF AMC IN OFDM SYSTEMS.

Avg. SINR threshold	Modulation	Coding rate	Throughput
∼ 11.8dB	No use	No use	0.0
11.8dB ∼ 23.8dB	QPSK	1/2	1.0
23.8dB ∼ 29.5dB	16QAM	3/4	3.0
29.5dB ∼	64QAM	3/4	4.5



(a) (b)

Fig. 3. Performance of MIMO–OFDM system (a) System throughput (b) Throughput comparison in the correlated fading environment.

D. Evaluation in the Correlated Fading Environment

In MIMO–OFDM systems, system throughput rapidly degrades as the branch correlation increases. The branch correlation α between two branches is defined as

$$\alpha = |E\left[f_a(t) \cdot f_b^*(t)\right]|/\{\sqrt{E[|f_a(t)|^2]} \cdot \sqrt{E[|f_b(t)|^2]}\} \tag{5}$$

where f_a and f_b are the path gains of the two branches which have the same delay time. There is no correlation between the paths with deferent delay time.

Fig. 3(b) shows the system throughput in the correlated fading environment when the SNR=15dB and 24dB. In this figure ”Conventional” means the 4 channel parallel transmission with the fixed modulation which has the maximum throughput in each condition. We see that the proposed scheme has superior throughput compared with conventional one as the branch correlation increases.

VI. CONCLUSIONS

We presented our throughput maximization transmission control scheme that selects a transmission scheme (a set of transmit antennas, modulation scheme, and coding rate) with maximum throughput based on output SINR for MIMO systems. The proposed transmission control scheme attains higher throughput than the conventional SDM scheme using a little feed back information. It is shown that the transmission control scheme can be applicable to OFDM-MIMO system replacing output SINR by average output SINR over subcarriers. The proposed transmission control scheme always keeps good performance, regardless of the number of the transmit and the receive antennas. Therefore, the proposed transmission control scheme is effective to achieve high throughput in MIMO systems.

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