Throughput Maximization Transmission Control Scheme for MIMO systems

Kenji Suto† Yoshitaka Hara†† Tomoaki Ohtsuki†
† Dept. of Electrical Engineering, Tokyo University of Science
2641 Yamazaki, Noda, Chiba 278-8510 Japan
Phone: 81-4-7124-1501, Fax: 81-4-7125-8651
E-mail : j7302644@ed.noda.tus.ac.jp
†† Mitsubishi Electric Corporation

Abstract— **Recently, multiple-input multiple-output (MIMO) systems that realize a high bit rate data transmission with multiple antennas at both transmitter and receiver have drawn much attention for high spectral efficiencies. In MIMO systems, space division multiplexing (SDM) has been researched widely. In SDM, the input data symbols are transmitted from multiple transmit antennas at the transmitter, respectively, and the output data symbols are extracted by the signal processing at the receiver. In recent wireless communications, the environments that the number of transmit antennas is larger than that of receive antennas often exist. Under such environments, the MIMO system that transmits independent data streams from each transmit antenna simultaneously cannot separate the received signals, and the signal quality deteriorates largely. Therefore, we need the scheme that attains high quality and high throughput data transmission under such environments. In this paper, we propose a throughput maximization transmission control scheme for MIMO systems. The proposed transmission control scheme selects a transmission scheme (a set of transmit antennas, modulation schemes, and coding rates) with maximum throughput based on signal to interference and noise ratio (SINR). We show that the proposed transmission control scheme attains high throughput by our computer simulation.**

I. Introduction

Recently, multiple-input multiple-output (MIMO) systems that realize a high bit rate data transmission with multiple antennas at both transmitter and receiver have drawn much attention for high spectral efficiencies. MIMO systems are known to have larger capacity than single-input single-output (SISO) systems with single antenna. In MIMO systems, space division multiplexing (SDM) has been researched widely [1]–[3]. In SDM, input data symbols are transmitted from multiple transmit antennas at the transmitter, respectively, and output data symbols are extracted by the signal processing at the receiver. Undesired signals are suppressed out of multiple signals with beamforming at the receiver, and the systems can realize spatial multiplexing transmission.

When the number of transmit antennas is smaller than that of receive antennas, good spatial multiplexing transmission can be realized in usual beamforming scheme [2]. In recent wireless communications, the environments that the number of transmit antennas is larger than that of receive antennas often exist. Under such environments, the MIMO system that transmits independent data streams from each transmit antenna simultaneously cannot separate the received signals, and the signal quality deteriorates largely. Therefore, we need the scheme that attains high quality and high throughput data transmission under such environments. When the number of transmit antennas is smaller than that of receive antennas, the schemes that transmit signals with all the transmit antennas cannot necessarily attain high quality data transmission. That is, the schemes with stopping the transmission from some transmit antennas may perform better than the schemes with all the transmit antennas. Thus, it is possible to attain high quality data transmission by controlling a transmission scheme of signals.

As the scheme that controls the transmission scheme of signals for MIMO systems, the scheme that selects an optimum set of transmit antennas based on channel state information (CSI) are reported [4]–[6]. In [4] the scheme that selects an optimum set of transmit antennas so that the channel capacity is maximized is reported. In [5][6] the scheme that selects an optimum set of transmit antennas and controls power adaptively so that the throughput of the system is maximized is reported.

In this paper, we propose a throughput maximization transmission control scheme for MIMO systems. The proposed transmission control scheme selects a transmission scheme (a set of transmit antennas, modulation schemes, and coding rates) with maximum throughput based on signal to interference and noise ratio (SINR) and signal to noise ratio (SNR). The feedback information in the proposed transmission control scheme is less than that in MIMO systems with singular value decomposition (SVD), because the information on which transmission scheme is selected is only fed back to the transmitter in the proposed transmission control scheme. We show that the proposed transmission control scheme attains higher throughput than the SDM schemes and the selection transmit diversity schemes by our computer simulation.

II. Space Division Multiplexing

A MIMO system with N transmit antennas and M receive antennas is shown in Fig. 1 where h_{mn} denotes the channel response from the transmit antenna n to the receive antenna m and $\mathbf{H} = [h_{mn}]$ denotes the channel matrix between the transmitter and the receiver. The transmitted signal $s_n(t), n = 1, \cdots, N$ is transmitted from the transmit antenna n at time t. The received signal is multiplied by the weight vector $\mathbf{v}_m = [v_{1m} \cdots v_{Nm}]$ at the receiver. The received signal vector $\mathbf{x}(t) = [x_1(t) \cdots x_M(t)]^T$ is given as follows where $x_m(t)$ denotes the received signal from the receive antenna m and ^{T} denotes transpose.

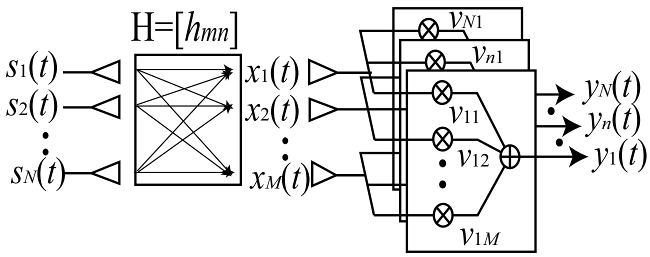

Fig. 1. SDM scheme

$$\mathbf{x}(t) = \sum_{n=1}^{N} \mathbf{h}_n s_n(t) + \mathbf{z}(\mathbf{t}) \tag{1}$$

$\mathbf{h}_n = [h_{1n} \cdots h_{Mn}]^T$ denotes the channel vector from the transmit antenna n to M receive antennas, $\mathbf{z}(t) = [z_1(t) \cdots z_M(t)]^T$ denotes the noise vector, and $z_m(t)$ denotes the noise at the receive antenna m. At the receiver, the suitable weight vector $\mathbf{v}_k = [v_{k1} \cdots v_{kM}]^T$ to $s_k(t)$ is decided. The weighted signal $y_k(t)$ is given by

$$\begin{aligned} y_k(t) &= \mathbf{v}_k^T \mathbf{x}(t) \\ &= \sum_{n=1}^{N} \left(\mathbf{v}_k^T \mathbf{h}_n\right) s_n(t) + \mathbf{v}_k^T z(t). \end{aligned} \tag{2}$$

There are various deciding schemes for the receive weight vector $\mathbf{v}_k$. Each receive weight vector $\mathbf{v}_k$ is decided so that the output $y_k(t)$ approaches the signal $s_k(t)$. For example, the weight vector is decided so that the weight vector $\mathbf{v}_k$ satisfies the eq. (3) in the weight decision based on the Zero-Forcing (ZF) criterion.

$$\mathbf{v}_k^T \mathbf{h}_n = \begin{cases} 1, & n = k \\ 0, & n \neq k \end{cases} \tag{3}$$

Eq. (3) shows the condition that the desired signal $s_k(t)$ is received strongly and the undesired signal $s_n(t)$ ($n \neq k$) is suppressed. The receive weight vector based on the ZF criterion is expressed as

$$\mathbf{v}_k = \left(\sum_{m=1}^{M} \mathbf{h}_m \mathbf{h}_m^H\right)^{-1} \mathbf{h}_k \tag{4}$$

where ^{H} denotes Hermitian transpose. In the Minimum Mean Square Error (MMSE) criterion, the weight vector is decided so that E $\left[||y_k(t) - \mathbf{v}_k^T \mathbf{x}(t)||^2\right]$ is minimized. The receive weight vector based on the MMSE criterion is expressed as

$$\mathbf{v}_k = \left(\sum_{m=1}^{M} \mathbf{h}_m \mathbf{h}_m^H + P_z \mathbf{I}\right)^{-1} \mathbf{h}_k \tag{5}$$

where P_z denotes the noise power and $\mathbf{I}$ denotes an identity matrix. The multiplex signal is separated and extracted by receiving signal with each weight vector $\mathbf{v}_k$ to each desired signal index k, and we can realize spatial multiplexing transmission.

When the number of transmit antennas N is smaller than or equal to that of receive antennas M ($N \leq M$), eq. (3) can be satisfied. However, when the number of transmit antennas N is larger than that of receive antennas M ($N > M$), eq. (3) cannot be satisfied. When $N > M$, the undesired signal cannot be suppressed enough and the signal quality is degraded even if the MMSE criterion is used. Therefore, we need a scheme that attains high quality data transmission under such environments.

III. Throughput Maximization Transmission Control Scheme

In the proposed transmission control scheme, a set of transmit antennas is selected based on SINR. The modulation schemes and coding rates are also selected based on SINR. We explain the selection algorithm of the proposed transmission control scheme (a set of transmit antennas, modulation schemes, and coding rates).

Selection Algorithm of The Proposed Transmission Control Scheme

1) In the training section, specific pilot sequences are transmitted from each transmit antenna. The channel response is estimated at the receiver.
2) The SINRs for each set of transmit antennas are calculated with the estimated channel response.
3) The throughput of each transmission scheme (a set of transmit antennas, modulation schemes, and coding rates) that satisfies the target packet error rate (PER) per transmit antenna is calculated based on the calculated SINR. The lookup table for the modulation schemes and the coding rates is prepared in advance.
4) The transmission scheme with the maximum throughput is selected and the information on which transmission scheme is selected is fed back to the transmitter.

Fig. 2 shows a flow chart of the selection algorithm of the transmission control scheme. At the receiver, a set of transmit antennas is searched and output SINR is estimated. The throughput of each transmission scheme (a set of transmit antennas, modulation schemes, and coding rates) based on SINR is calculated. Throughput is calculated for all the transmission schemes (a set of transmit antennas, modulation schemes, and coding rates). The transmission scheme with the maximum throughput is selected and the information on which transmission scheme is selected is fed back to the transmitter.

1) Estimation of Channel Response
In the training section, orthogonal sequences are transmitted as pilot sequences from all the transmit antennas. The channel response between the transmit and the receive antennas is estimated at the receiver. The channel matrix between the transmit and the receive antennas is expressed as

$$\mathbf{H} = [\mathbf{h}_1 \cdots \mathbf{h}_N]. \tag{6}$$

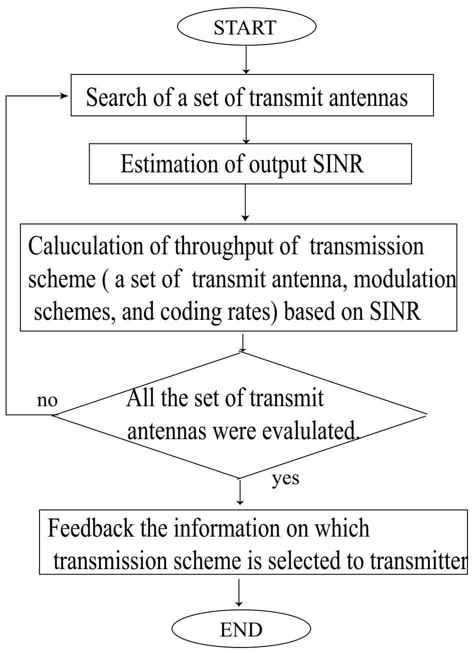

Fig. 2. A flow chart of the selection algorithm of the transmission control scheme

The received signal is expressed as

$$\mathbf{x}(t) = \mathbf{H} \begin{bmatrix} s_1(t) \\ \vdots \\ s_N(t) \end{bmatrix} = \sum_{n=1}^{N} \mathbf{h}_n \mathbf{s}_n(t) + \mathbf{z}(t) \qquad (7)$$

where $s_i(t), i = 1, \cdots, N$ denotes the pilot signal from the transmit antenna i. The condition for the correlation between pilot signals is expressed as

$$\frac{1}{T_0} \sum_{t=1}^{T_0} s_i^*(t) s_j(t) = \begin{cases} 0, & i \neq j \\ 1, & i = j \end{cases} \qquad (8)$$

where T_0 denotes the pilot length and $*$ denotes the complex conjugate. The received signal is multiplied by the pilot signal and the channel is estimated.

$$\tilde{\mathbf{h}_n} = \frac{1}{T_0} \sum_{t=1}^{T_0} \mathbf{x}(t) \mathbf{s}_n^*(t) = \mathbf{h}_n + \frac{1}{T_0} \sum_{t=1}^{T_0} \mathbf{z}(t) \mathbf{s}_n^*(t) \qquad (9)$$

2) SINR Estimation

In calculation of the estimated SINR, the receive weight vector $\mathbf{v}_n$ is calculated with the estimated channel vector $\tilde{\mathbf{h}_n}$. In the MMSE criterion, the receive weight vector $\mathbf{v}_n$ is expressed as

$$\mathbf{v}_n = \left(\sum_{m=1}^{M} \mathbf{h}_m \mathbf{h}_m^H + P_z \mathbf{I} \right)^{-1} \mathbf{h}_n. \qquad (10)$$

The output SINR is expressed as

$$\gamma_n = \frac{|\mathbf{h}_n^H \mathbf{v}_n|^2}{\mathbf{v}_n^H \left(\sum_{m=1}^{M} \mathbf{h}_m \mathbf{h}_m^H + P_z \mathbf{I} \right) \mathbf{v}_n - |\mathbf{h}_n^H \mathbf{v}_n|^2}. \qquad (11)$$

TABLE I

AN EXAMPLE OF THE LOOKUP TABLE TO SELECT A MODULATION SCHEME AND A CODING RATE SO THAT THE THROUGHPUT IS MAXIMIZED BASED ON SINR

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

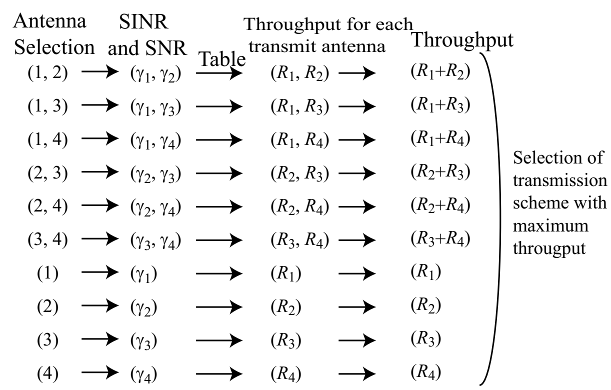

Fig. 3. The selection process of the proposed transmission control scheme for MIMO system with four transmit antennas and two receive antennas

3) Calculation of Throughput

The throughput of each transmission scheme (a set of transmit antennas, modulation schemes, and coding rates) that satisfies the target PER per transmit antenna is calculated based on SINR. Table 1 shows an example of the lookup table to select a modulation scheme and a coding rate so that the throughput is maximized based on SINR. As SINR becomes larger, the throughput becomes higher.

4) Selection of Transmission Scheme

The transmission scheme with the maximum throughput is selected out of all the transmission schemes. The information on which transmission scheme is selected is fed back to the transmitter.

For example, we consider the system with four transmit antennas and two receive antennas. Fig. 3 shows the selection process of the proposed transmission control scheme, where γ_i denotes SINR from the ith transmit antenna, and R_i denotes the transmission rate from the ith transmit antenna.

1.) The orthogonal sequences as the pilot sequences are transmitted from each transmit antenna and the channel responses between the transmit and receive antennas are estimated.

2.) When only one transmit antenna (kth) is selected, $\mathrm{SNR} = \gamma_k$ of the receive signal is calculated as follows.

$$\gamma_k = P_s ||\tilde{\mathbf{h}}_k||^2 / P_z, \quad k = 1, \ldots, 4 \qquad (12)$$

TABLE II

SIMULATION PARAMETERS

Number of Transmit Antennas	2, 4
Number of Receive Antennas	2, 4
Modulation	QPSK, 8PSK, 16QAM
Error Correcting Codes	Convolutional Code (constraint length = 7)
Coding Rate	1/2, 2/3, 3/4, 5/6
Channel	Quasi-Static Fading
Packet Lenght	120
Target PER	10^{-2}
Channel Estimation	ideal
Feedback	ideal

where $\tilde{\mathbf{h}}_k$ denotes the estimated channel vector from the kth transmit antenna to the receive antennas, P_s denotes the signal power per transmit antenna, and P_z denotes the noise power per receive antenna. When two transmit antennas (lth, mth) are selected, SINRs of the receive signal are calculated as

$$\gamma_l = P_s\tilde{\mathbf{h}}_l^H(P_s\tilde{\mathbf{h}}_m\tilde{\mathbf{h}}_m^H + P_z\mathbf{I})^{-1}\tilde{\mathbf{h}}_l, \quad (13)$$

$$\gamma_m = P_s\tilde{\mathbf{h}}_m^H(P_s\tilde{\mathbf{h}}_l\tilde{\mathbf{h}}_l^H + P_z\mathbf{I})^{-1}\tilde{\mathbf{h}}_m. \quad (14)$$

3.) The throughput of each transmission scheme (a set of transmit antennas, modulation schemes, and coding rates) that satisfies the target PER per transmit antenna is calculated based on the calculated SINRs. The lookup table for the modulation schemes and the coding rates is prepared in advance. For the system with four transmit antennas and two receive antennas, the proposed transmission control scheme has ten sets of transmit antennas: (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.

4.) The transmission scheme with the maximum throughput is selected and the information on which transmission scheme is selected is fed back to the transmitter.

IV. Simulation Results

We present the results of our computer simulation. Table 2 shows the simulation parameters. Fig. 4 shows the throughput versus P_s/P_z per transmit and receive antennas for the proposed transmission control scheme, the selection transmit diversity scheme, and the SDM scheme. The selection transmit diversity scheme selects a transmission scheme (one transmit antenna, modulation schemes, and coding rates) based on SNR. The SDM scheme selects a transmission scheme (modulation schemes and coding rates) based on SINR. In condition that the power per transmit antenna is constant, the total transmit power changes according to the number of selected transmit antennas. When the power per transmit antenna is constant, we can use an amplifier with narrow dynamic range. In addition the signal transmission with the power as large as possible from each transmit antenna according to the channel attains higher throughput. Tx = i denotes that the number of transmit antennas is i. Rx = j denotes that the number of receive antennas is j. The throughput of the proposed transmission control scheme with Tx = 4 and Rx = 4 is higher than that of the SDM scheme with Tx = 4 and Rx = 4. When the P_s/P_z is small, an improvement is found notably. This is because when the P_s/P_z is small, in the SDM scheme, the signals are transmitted from four transmit antennas, which results in small SINR and the low throughput, while, in the proposed transmission control scheme, the signals are transmitted from a part of transmit antennas so that the SINR becomes large and the throughput becomes high. Moreover, when the P_s/P_z is large, the throughput of the proposed transmission control scheme is higher than that of the SDM scheme. When the P_s/P_z is large, even if the correlation of the channels is large and the interference between antennas is large, the signals are transmitted from a part of transmit antennas so that the SINR becomes larger and the throughput becomes higher in the proposed transmission control scheme. The throughput of the pro-

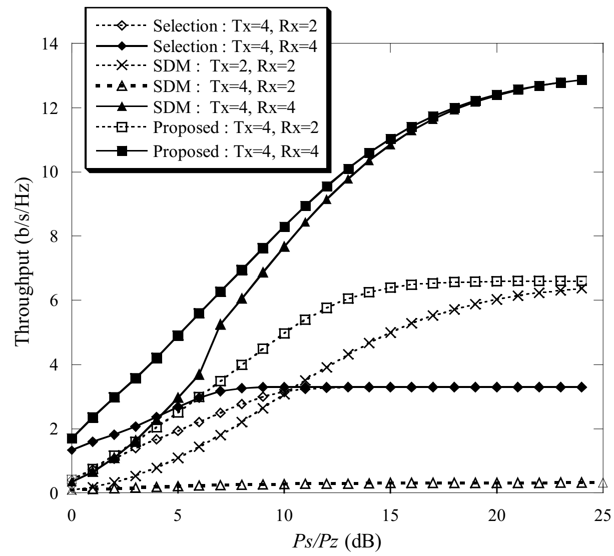

Fig. 4. Throughput versus P_s/P_z per transmit and receive antennas for the proposed transmission control scheme, the selection transmit diversity scheme, and the SDM scheme.

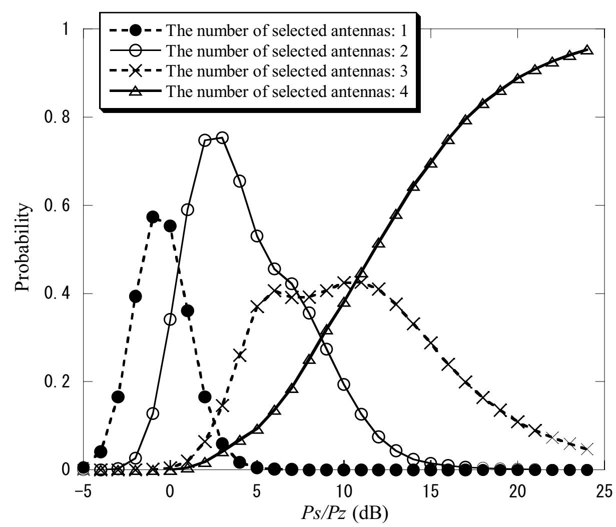

Fig. 5. The selection probability for each set of antennas versus P_s/P_z for the proposed transmission control scheme with Tx = 4 and Rx = 4.

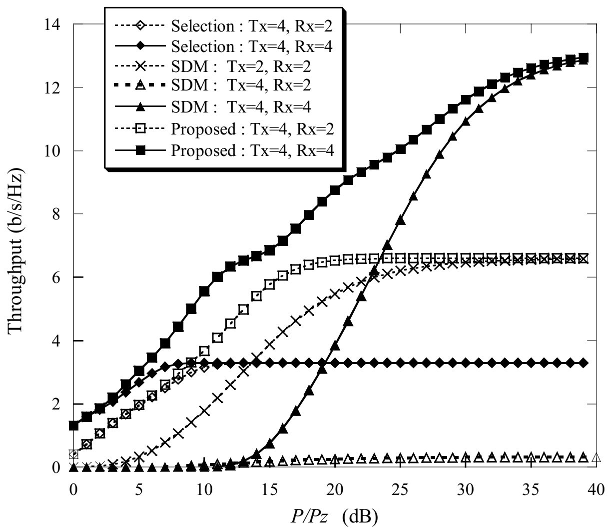

Fig. 6. The throughput versus P/P_z at the constant total transmit power for the proposed transmission control scheme, the selection transmit diversity scheme, and the SDM scheme, where P denotes the total transmit power.

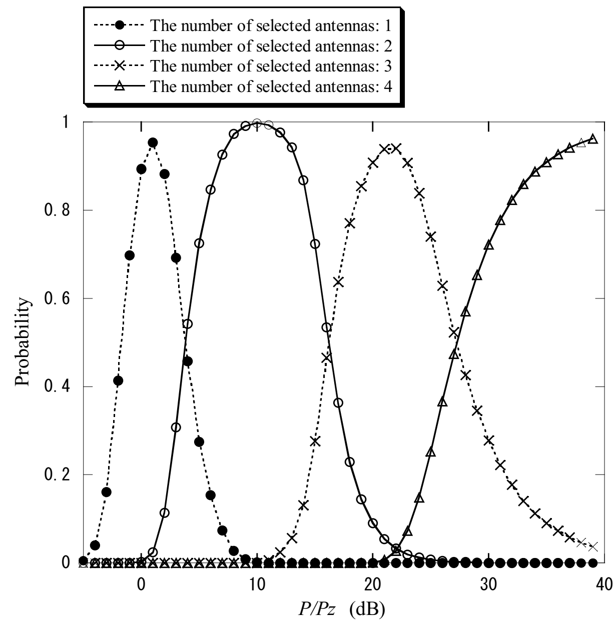

Fig. 7. The selection probability for each set of antennas versus P/P_z at the constant total transmit power for the proposed transmission control scheme with Tx = 4 and Rx = 4.

posed transmission control scheme with Tx = 4 and Rx = 2 is also higher than that of the SDM schemes with Tx = 4 and Rx = 2, and Tx = 2 and Rx = 2 . When the P_s/P_z is small, in the proposed transmission control scheme, the signals are transmitted from two transmit antennas that is the separable maximum number for two receive antennas so that the SINR becomes larger and the throughput becomes higher. The throughputs of the proposed transmission control schemes with Tx = 4 and Rx = 4, and Tx = 4 and Rx = 2 are higher than those of the selection diversity schemes with Tx = 4 and Rx = 4, and Tx = 4 and Rx = 2, respectively. This is because the number of sets of transmit antennas in the proposed transmission control scheme is large compared with that in the selection diversity scheme.

Fig. 5 shows the selection probability for each set of antennas versus P_s/P_z for the proposed transmission control scheme with Tx = 4 and Rx = 4. As P_s/P_z becomes larger, more transmit antennas are selected. When the P_s/P_z is small, the signals are transmitted from a part of transmit antennas so that SINR becomes large and the throughput becomes higher. When the P_s/P_z is large, signals are transmitted from four transmit antennas so that the SINR becomes larger and the throughput becomes higher.

Fig. 6 shows the throughput versus P/P_z at the constant total transmit power for the proposed transmission control scheme, the selection transmit diversity scheme, and the SDM scheme, where P denotes the total transmit power. In condition that the total transmit power is constant, as the number of selected antennas increases, the power per each transmit antenna decreases. The performance similar to Fig. 4 is found. The throughputs of the proposed transmission control schemes with Tx = 4 and Rx = 4, and Tx = 4 and Rx = 2 are higher than those of the SDM scheme with Tx = 4 and Rx = 4, and Tx = 4 and Rx = 2, respectively. The throughput of the proposed transmission control schemes with Tx = 4 and Rx = 4, and Tx = 4 and Rx = 2 are higher than those of the selection diversity schemes with Tx = 4 and Rx = 4, and Tx = 4 and Rx = 2, respectively.

Fig. 7 shows the selection probability for each set of antennas versus P/P_z at the constant total transmit power for the proposed transmission control scheme with Tx = 4 and Rx = 4. The performance similar to Fig. 5 is found. As P/P_z becomes larger, more antennas are selected.

V. Conclusions

We have proposed a throughput maximization transmission control scheme that selects a transmission scheme (a set of transmit antennas, modulation schemes, and coding rates) with maximum throughput based on SINR and SNR for MIMO systems. We have shown that the proposed transmission control scheme attains higher throughput than the SDM scheme and the selection transmit diversity scheme by our computer simulation. The proposed transmission control scheme attains high throughput, 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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