순차적인 간섭제거를 사용하는 공간 다중화 전송 MIMO 시스템의 전송 안테나 선택 방법에 관한 연구

정회원 문 철*, 정 창 규*

Transmit Antenna Selection for Spatial Multiplexing with Per Antenna Rate Control and Successive Interference Cancellation

Cheol Mun, Chang-Kyoo Jung* *Regular Members*

요 약

본 논문은 순차적인 간섭제거와 전송 안테나 별 전송률을 제어하는 공간 다중화 전송 MIMO 시스템에서 채널 환경에 따라 전송에 사용되는 안테나를 선택하고 데이터 율을 조절하는 알고리즘을 제안한다. 수신기에서 전송에 사용될 송신 안테나 및 전송률을 결정하고, 이는 각 송신 안테나 별 전송률에 대한 피드백 채널을 통해 송신기로 전송된다. 본 연구에서는 각 단계에서 최소의 SINR을 가지는 안테나를 제거해가는 연속적인 단계들로 이루어진 직렬 결정 방식을 제안한다. 또한, 각 연속적인 심볼 추정 단계에서 가장 낮은 신호 대 간섭 비를 갖는 심볼을 먼저 추정하는 "reverse detection ordering"이 각 안테나에 할당되는 용량 차이를 증가시킴으로서 안테나 선택에 의한 이득을 증가시킴을 보인다. 시뮬레이션 결과는 제안된 "reverse detection ordering"을 기반으로 하는 직렬 결정 방식이 낮은 복잡도을 가지면서 heuristic 방식과 비슷한 용량을 제공함을 보여준다.

Key Words : MIMO, spatial multiplexing, transmit antenna selection, successive interference cancellation.

ABSTRACT

This paper proposes an algorithm for transmit antenna selection in a multi-input multi-output(MIMO) spatial multiplexing system with per antenna rate control(PARC) and an ordered successive interference cancellation (OSIC) receiver. The active antenna subset is determined at the receiver and conveyed to the transmitter using feedback information on transmission rate per antenna. We propose a serial decision procedure consisting of a successive process that tests whether antenna selection gain exists when the antenna with the lowest pre-processing signal to interference and noise ratio(SINR) is discarded at each stage. Furthermore, we show that ''reverse detection ordering'', whereby the signal with the lowest SINR is decoded at each stage of successive decoding, widens the disparities among fractions of the whole capacity allocated to each individual antenna and thus maximizes a gain of antenna selection. Numerical results show that the proposed reverse detection ordering based serial antenna selection approaches the closed-loop MIMO capacity and that it induces a negligible capacity loss compared with the heuristic selection strategy even with considerably reduced complexity.

* 국립 충주대학교 전기전자정보공학부 ({chmun, ckjung}@chungju.ac.kr)
논문번호 : KICS2005-01-032, 접수일자 : 2005년 1월 17일
※본 연구는 2004학년도 충주대학교 학술연구조성비에 의하여 연구되었습니다.

I. Introduction

Spatial multiplexing, used in multiple transmit and receive antennas, has recently been shown to be the most effective way to increase transmission rates[1]. Recently, there has been increasing interest in optimizing the mode of spatial multiplexing to a given propagation environment. There are several motivations for this, including reducing hardware cost and complexity[2], increasing reliability[3]-[5] and increasing data rate[6],[7]. These efforts may be classified into two categories according to whether this decision on the optimal mode is made at the transmitter or the receiver. In most approaches to adapt the active antenna subset and its transmission rate to varying channel conditions, this decision is made at the transmitter[2],[3],[6], which results in the requirement of CSI at the transmitter. Due to practical limitations on the feedback delay and load, partial CSI such as a channel correlation matrix is preferred for feedback[2],[3],[6]. One exception is [7], where the author has proposed a decremental strategy for selection of the receive antenna in spatial multiplexing without CSI at the transmitter. Other contributions develop a mode selection algorithm where the optimal mode decision is made at the receiver[4],[5]. Mode selection at the receiver can limit the amount of feedback because there are typically a small number of modes.

Recently, there have been efforts to expand the dimensions of link adaptation to space in MIMO systems[8]-[10]. An extended vertical Bell Labs layered space-time(V-BLAST) with both rate and power adaptation per-antenna has been proposed in [10], demonstrating that the closed-loop MIMO capacity can be approached by conventional single-dimensional coding using OSIC and PARC. In practice, it is desirable to allocate equal power to each transmit antenna in order to limit the overhead in the feedback channel, although the achievable transmission rate is limited to the open-loop MIMO capacity. The trade-off between capacity gain and amount of feedback can be compromised by antenna selection: turning antennas "on" or "off" without per antenna power control, which can approach the closed-loop MIMO capacity with limited feedback.

In this paper, we propose an algorithm for transmit antenna selection in a spatial multiplexing system with PARC and an OSIC receiver. The active antenna subset is determined at the receiver under equal power allocation to the active antennas and conveyed to the transmitter using on transmission rate per antenna. Our study is motivated by link adaptation to channel realization in MIMO systems[8],[10]. Its scope is further extended to maximization of the capacity of the spatial multiplexing with nonlinear receivers by an effective antenna selection scheme with limited feedback. Previous studies considering nonlinear receivers disregard detection ordering[6],[10]or borrow "forward detection ordering"[7], where the signal with the highest SINR is extracted at each stage. This consequently ensures the highest worst-case SINR over the whole set of layers[1], which is optimal for the case of equal power and rate allocation to all antennas. On the other hand, in a spatial multiplexing system with rate adaptation per antenna and antenna selection, we show that antenna selection gain can be maximized through capacity concentration: concentrating most of the total capacity in a limited number of antennas and discarding noncontributory antennas. Furthermore, "reverse detection ordering", whereby the signal with the lowest SINR is extracted at each stage, widens the disparities among fractions of the whole capacity allocated to each individual antenna without changing the total capacity. As such, the best capacity concentration among all possible detection orderings is achieved. This allows us to derive a "reverse detection ordering" based antenna selection procedure consisting of a successive process that tests whether transmit antenna selection gain exists when the antenna with the lowest pre-processing SINR is discarded at each stage. This technique leads to a near-optimal mode with considerably reduced complexity.

The remainder of this paper is organized as follows. We outline a spatial multiplexing system with PARC and an OSIC receiver in Section II.

In Section III, a serial decision procedure is proposed to optimize the active antenna subset, its decoding order, and its modulation and coding scheme (MCS). Simulation results are presented and discussed in Section IV. Finally, a summary concludes this paper.

Ⅱ. System Model

We consider an MIMO spatial multiplexing system with PARC and an OSIC receiver, which employs n_T transmit and n_R receive antennas. Let us define an ordered active transmit antenna set A in which the K_A indices of the antennas are selected among n_T indices of available transmit antennas and are arranged in the order of detection.

The high-speed data stream for a given user is demultiplexed into several K_A independent substreams. The number of simultaneous substream is adjusted up to $\min(n_T, n_R)$, according to the fading environments. The substreams are then separately coded and mapped to symbols. The coding and modulation per antenna are subject to the feedback information $M_{A,i}$, which denotes a specific MCS of the substream transmitted via the i th antenna in A The total transmit power P_T is uniformly distributed over K_A independent substreams. The symbols $\{x_i\}_{i=1,\cdots,K_A}$ are sent from the corresponding active transmit antennas.

We further assume that the channel is flat fading and quasi-static. The signal at the receiver is given by

$$y=\sqrt{\frac{P_T}{K_A}}\, H_A x + n \qquad (1)$$

where $\boldsymbol{x}$ is a $K_A\times 1$ vector in which the ith element represents the symbol transmitted from the ith antenna in A An MIMO channel of K_A selected transmit antennas and n_R receive antennas is denoted by a $K_A\times n_R$ matrix $\boldsymbol{H}_A$ in which the column vectors $\{h_{A,i}\}_{i=1,\cdots,K_A}$ represent the vector channel transmitted from the ith antenna in A They are selected from the MIMO channel matrix $\boldsymbol{H}$ of n_T transmit and n_R receive antennas according to A The received signal is an $n_R\times 1$ vector denoted by $\boldsymbol{y}$ and is an $\boldsymbol{n}$ additive white complex Gaussian noise vector with variance σ^2.

The MIMO channel of n_T transmit and n_R receive antennas is represented by an $n_R\times n_T$ matrix $\boldsymbol{H}$ in which elements are modeled as zero-mean and unit variance complex Gaussian random variables. The correlated channel matrix can be written as[11]

$$H=K_R^{\frac{1}{2}}\, H_w K_T^{\frac{1}{2}} \qquad (2)$$

where H_w is an $n_R\times n_T$ matrix with uncorrelated complex Gaussian entries. K_R and K_T are the correlation matrices at the receiver end and the transmitter end, respectively.

The received signal vector $\boldsymbol{y}$ is decoded with a minimum mean square error (MMSE) receiver with OSIC. Besides symbol detection, the active antenna subset, its decoding order, and the corresponding MCS set are determined and MCS per antenna is fed back to adjust the corresponding transmission parameters.

The signals radiating from the active antennas are decoded in the order of A Let us define $H_A(m)=[\,h_{A,m+1}\ h_{A,m+2}\cdots h_{A,K_A}]$. For a practical coding scheme with a non zero error rate, the rate supported by the th ordered antenna in is given by[12]

$$T_{A,m}=\log_2\left(1+\frac{\gamma_{A,m}}{\Gamma}\right) \qquad (3)$$

where the post-processing SINR of the mth ordered antenna in A $\gamma_{A,m}$ is given by

$$\gamma_{A,m}=h^H_{A,m}\left(H_A(m)H^H_A(m)+\frac{K_A}{\rho}I_{n_R}\right)^{-1}h_{A,m} \qquad (4)$$

Here, ρ denotes the average signal to noise ratio(SNR) per receive antenna. Γ is a gap reflecting the capacity loss resulting from a finite-length coding with non-zero error rates, and is a function of target bit error rate(BER) and coding method. If we assume a block turbo coded M-QAM with a target BER 10^{-5}, Γ is 1.95 (2.9dB)[13].

We consider a simple rate adaptation scheme based on rounding off the rate from a continuous set. The available rates are assumed to be 0, q, $2q$, and so on. q is the interval between rate quantization levels. Given the rate $T_{A,m}$ in (3), the quantized rate $R(M_{A,m})$ and the corresponding MCS, $M_{A,m}$ are given by

$$R(M_{A,m}) = q\lceil T_{A,m}/q \rceil, \quad (5)$$

where $\lceil x \rceil$ denotes the largest integer that is smaller than or equal to x. The sum rate supported by the active transmit antennas in A is given by

$$T_A = \sum_{m=1}^{K_A} R(M_{A,m}) \quad (6)$$

The MCS set M_A, which includes the MCSs of the n_T antennas, and, in which the unselected antennas are assigned to the lowest MCS level denoting no transmission via the corresponding antenna, is fed back. Assuming negligible delay and error in the feedback channel, the achievable rate by A becomes T_A.

Ⅲ. Transmit Antenna Selection

For a spatial multiplexing system with an OSIC receiver, the signals radiating from the active transmit antennas are decoded in an agreed-upon order. Notably, the detection ordering has no impact on the sum capacity attained by all n_T antennas under equal power allocation to all n_T transmit antennas. However, the ordering does impact a fraction of the capacity that is allocated to each individual antenna[12]. Thus, the detection order ultimately affects the sum rate attained by the selected antennas. Therefore, the active antenna subset, its decoding order, and its transmission rate should be jointly determined in order to maximize the transmission data rate.

3.1 Heuristic Decision Strategy

To find the optimal active antenna subset and the decoding order for maximizing the transmission data rate, all possible decoding orders over all possible antenna subsets should be considered. Let the ordered antenna subset $\{A_j\}_{j=1,\cdots,2^{n_T}-1}$ be a permutation of the indices of the antennas specifying the detection order. A_j is an ordered set in which the K_{A_j} indices are selected among n_T indices of available transmit antennas and are arranged in the order of one among all possible K_{A_j} detection orders. For all A_j, the transmission rate possible for A_j, T_{A_j} is calculated by (3), (5), and (6). We determine the optimal ordered antenna subset A and the corresponding MCS set M_A, maximizing the sum rate as follows

$$A, M_A = \arg\max_{A_j, M_{A_j}} T_{A_j} \quad (7)$$

Although this exhaustive search makes it possible to find the optimal active transmit antenna subset and its decoding order that maximizes the capacity, a full search over all possible cases is prohibitive for practical implementations.

3.2 Low Complexity Serial Decision Strategy

Maximization of data rate can be achieved by maximizing a gain of antenna selection. We now theoretically show that antenna selection gain can be maximized by concentrating most of the total capacity in a limited number of antennas and not selecting noncontributory antennas. Based on the observation that "reverse detection ordering" can yield the best capacity concentration among all possible detection orderings, we derive a "reverse detection ordering" based antenna selection procedure with low complexity.

3.2.1 Capacity Concentration

The criterion used for optimization of the active antenna subset is maximization of the capacity gain of antenna selection over no antenna selection and is expressed as

$$A = \arg\max_{A_j} \Delta T(A_j, A_0), \qquad (8)$$

where A_0 denotes an ordered index set that includes indices of all available n_T transmit antennas and thus $K_{A_0} = n_T$. Further, the capacity gain obtained by selecting K_{A_j} antennas from A_0 is defined as

$$\Delta T(A_j, A_0) = T_{A_j} - T_{A_0} \qquad (9)$$

where the order of indices in A_j is identical with those in A_0. If, and only if, $\Delta T(A_j, A_0) > 0$ when $K_{A_j} < n_T$, a gain of antenna selection exists. Searching A with maximum selection gain over all possible A_j is identical with the heuristic decision strategy. A closed form solution for the criterion (8) cannot be found analytically and, furthermore, an exhaustive search over all possible A_j is too complicated to be conducted in real time. Thus, based on the criterion given in (8), we derive a key principle that leads to a near-optimal solution with low complexity.

A spatial multiplexing with an MMSE-OSIC receiver can approach the open-loop MIMO capacity irrespective of the detection order as long as the rate of each transmit antenna can be appropriately adjusted under equal power allocation[12]. Therefore, if we assume the use of a very sophisticated coding (e.g.,Turbo codes) that makes Γ be close to 1 and a minute level of rate quantization, the transmission data rates T_{A_j} and T_{A_0} become the open-loop capacity of $\mathbf{H}_{A}$ and $\mathbf{H}_{A}$, and can be expressed as $C(\mathbf{H}_{A_j}, \rho/K_{A_j})$ and $C(\mathbf{H}_{A_0}, \rho/K_{A_0})$. Here, $C(\mathbf{H}_{A_n}, \rho/K_{A_n}) = \log_2 \det(\mathbf{I}_{n_R} + \rho/K_{A_n} \mathbf{H}_{A_n} \mathbf{H}^H_{A_n})$ and denotes the capacity of $\mathbf{H}_{A_n}$ when equal transmit power of P_T/K_{A_n} is allocated to K_{A_n} transmit antennas. Thus, the capacity gain obtained by selecting K_{A_j} antennas from A_0 can be refined as

$$\Delta C(A_j, A_0) = C\left(\mathbf{H}_{A_j}, \frac{\rho}{K_{A_j}}\right) - C\left(\mathbf{H}_{A_0}, \frac{\rho}{n_T}\right) \qquad (10)$$

The capacity of $\mathbf{H}_{A_0}$ becomes the sum of $C_{A_0,i}$ [16] where $C_{A_0,i}$ denotes the capacity supported by the ith antenna in A_0 and is given by

$$C_{A_0,i} = \log_2(1 + \gamma_{A_0,i}) \qquad (11)$$

Here, $\gamma_{A_0,i}$ denotes the post-processing SINR of the ith ordered antenna in A_0.

The capacity gain $\Delta C(A_j, A_0)$ can be rewritten by dividing $C(\mathbf{H}_{A_0}, \rho/K_{A_0})$ into two parts, the sum capacity of the antennas which belong to A_j and that of the other antennas, as follows:

$$\Delta C(A_j, A_0) = C\left(\mathbf{H}_{A_j}, \frac{\rho}{K_{A_j}}\right) - C\left(\mathbf{H}_{A_0}(\Delta K_{0,j}), \frac{\rho}{n_T}\right) - \sum_{i=1}^{\Delta K_{0,j}} C_{A_0,i}. \qquad (12)$$

Here, $\Delta K_{0,j} = n_T - K_{A_j}$. Since $\mathbf{H}_{A_0} = [\mathbf{h}_{A_0,1} \cdots \mathbf{h}_{A_0,\Delta K_{0,j}} \mathbf{H}_{A_j}]$, then $\mathbf{H}_{A_0}(\Delta K_{0,j}) = \mathbf{H}_{A_j}$. Consequently, $C(\mathbf{H}_{A_0}(\Delta K_{0,j}), \rho/n_T)$ denotes the channel capacity of $\mathbf{H}_{A_j}$ when equal power of P_T/n_T is allocated to the K_{A_j} selected antennas; this can be rewritten as $C(\mathbf{H}_{A_j}, \rho/n_T)$. Thus, in the case of antenna selection, i.e., $K_{A_j} < n_T$, at the right hand of (12), the difference between the first two terms reflects the increase in channel capacity of $\mathbf{H}_{A_j}$ that results from increasing the transmit power from P_T/n_T to P_T/K_{A_j} to each K_{A_j} selected antenna, while the last term denotes the loss in channel capacity of $\mathbf{H}_{A_0}$ that results from giving up the $\Delta K_{0,j}$ antennas.

Let λ_i denote the eigenvalues of $\mathbf{H}_{A_j}$. Then,

$$\Delta C(A_j, A_0) = \sum_{i=1}^{K_{A_j}} \log_2\left(1 + \frac{\rho}{K_{A_j}}\lambda_i\right) - \sum_{i=1}^{K_{A_j}} \log_2\left(1 + \frac{\rho}{n_T}\lambda_i\right) - \sum_{i=1}^{\Delta K_{0,j}} C_{A_0,i}. \qquad (13)$$

At low SNR, the capacity gain $\Delta C(A_j, A_0)$ can be expressed by Taylor series approximations as follows:

$$\Delta C(A_j,A_0) \approx \sum_{i=1}^{K_{A_j}} \left(\frac{\rho}{K_{A_j}} \lambda_i - \frac{\rho}{n_T} \lambda_i \right) - \sum_{i=1}^{\Delta K_{0,j}} \frac{\rho}{n_T} \| h_{A_0,i} \|^2$$
$$= \frac{\Delta K_{0,j}}{K_{A_j}} \sum_{i=\Delta K_{0,j}+1}^{n_T} \frac{\rho}{n_T} \| h_{A_0,i} \|^2 - \sum_{i=1}^{\Delta K_{0,j}} \frac{\rho}{n_T} \| h_{A_0,i} \|^2 \quad (14)$$

Since $\Delta K_{0,j}/K_{A_j}$ is steadily decreasing with K_{A_j}, selection of only the antennas with high SNR, $\rho \| h_{A_0,i} \|^2/n_T$ can guarantee antenna selection gain by increasing the sum of SNR of the selected antennas and simultaneously decreasing the sum of the post-processing SINR of unselected antennas.

At high SNR, we have an approximated capacity gain, which is given by

$$\Delta C(A_j,A_0) \approx \sum_{i=1}^{K_{A_j}} \log_2 \frac{\rho}{K_{A_j}} \lambda_i - \sum_{i=1}^{K_{A_j}} \log_2 \frac{\rho}{n_T} \lambda_i - \sum_{i=1}^{\Delta K_{0,j}} \log_2 \gamma_{A_0,i}$$
$$= K_{A_j} \log_2 \frac{n_T}{K_{A_j}} - \sum_{i=1}^{\Delta K_{0,j}} \log_2 \gamma_{A_0,i} \quad (15)$$

The capacity gain of selected antennas due to increment of transmit power, $K_{A_j} \log_2 n_T/K_{A_j}$ is steadily decreasing with the number of selected antennas, K_{A_j} when $K_{A_j} > n_T/2$. Thus, removing only the antennas with low post-processing SINR can achieve antenna selection gain by decreasing the product of the post-processing SINR of unselected antennas while increasing the capacity gain of selected antennas. Furthermore, in both approximated cases, the more disparate post-processing SINR between the selected and the unselected antennas increases the difference between the capacity gain due to power concentration and the capacity loss resulting from giving up some antennas, and hence ultimately enhances antenna selection gain. As a result, antenna selection gain can be maximized by concentrating most of the total capacity in a limited number of antennas and removing noncontributory antennas. A fraction of the total capacity that is allocated to each individual antenna can be controlled by detection ordering without impacting the total capacity. By choosing a proper detection ordering scheme, a requirement for maximizing antenna selection gain can be satisfied.

3.2.2 Reverse Detection Ordering

We define an initial antenna set A_0 in which n_T indices of all available antennas are arranged in the order of detection. Let k_i be the index of the antenna decoded at the ith detection stage where $k_i \in \{1,2,\cdots,n_T\}$. At the ith detection stage, k_i is given by the proposed reverse detection ordering policy

$$k_i = \arg\max_{j \in S_i} \gamma_{i,j}, \quad (16)$$

where S_i is a set collecting indices of $n_T - i + 1$ antennas to be detected at the ith detection stage and $\gamma_{i,j}$ denotes the pre-processing SINR of the jth antenna at the ith detection stage[1]. The proposed reverse detection ordering performs "worst first" detection, and thus the antenna with the lowest pre-processing SINR experiences interference from all the other antennas decoded after it. That results in the lowest post-processing SINR among those of all possible orderings. With increasing detection order, an antenna with better pre-processing SINR than those of antennas decoded at an earlier stage experiences diminished interference from the other antennas due to SIC. This leads to far better post-processing SINR than is experienced by antennas at an earlier stage. As a result, reverse detection ordering widens the disparities among fractions of the whole capacity allocated to each individual antenna without changing the total capacity and ultimately provides better conditions to satisfy the requirement for the maximization of antenna selection gain.

The post-processing SINR of the antenna decoded at each detection stage show a steady increase in accordance with the decoding order, as follows:

$$\gamma_{A_0,k_1} \le \gamma_{A_0,k_2} \le \cdots \le \gamma_{A_0,k_{n_T}}, \quad (17)$$

which enables a serial procedure for transmit antenna selection. From the antenna with the lowest post-processing SINR in A_0, the antenna's selection is determined on an individual basis in the order given by the reverse detection ordering policy.

3.2.3 Serial Decision Procedure for Antenna Selection

We propose a serial procedure consisting of a successive process that tests whether antenna selection gain exists when the antenna with the lowest pre-processing SINR is discarded at each stage. For an antenna set given at each stage, since the antenna with the lowest pre-processing SINR produces the lowest post-processing SINR after SIC processing with reverse detection ordering, it is optimal to select all available antennas at each stage with the exception of the antenna with the lowest pre-processing SINR if antenna selection gain exists. At the ith stage, whether antenna selection gain exists or not is determined by comparing $T_{A_{i+1}}$ and T_{A_i}, which are the possible transmission rate of A_{i+1} and A_i when total transmit power is uniformly distributed to A_{i+1} and A_i, respectively. Here, A_{i+1} is the subset of A_i in which the antenna with the lowest pre-processing SINR is discarded in A_i. Antenna selection gain exists only when $\Delta T(A_{i+1}, A_i) > 0$. As long as antenna selection gain exists, the process for antenna selection continues and the final antenna subset becomes the optimal transmit antenna subset maximizing antenna selection gain. The whole algorithm can be described compactly through a recursive procedure as follows:

initialization:

$A_0 = \{k_1, k_2, \cdots, k_{n_T}\}$, where the detection order is given by the reverse detection ordering policy

$H_{A_0} = [\ h_{A_0}, k_1\ \ h_{A_0, k_2} \cdots\ \ h_{A_0, k_{n_T}}]$

$\{P_{A_{0,m}}\}_{m=1,\cdots,n_T} = P_T / n_T$

$i \leftarrow 0$

recursion:

$A_{i+1} \leftarrow A_i - \{k_{i+1}\}$

$H_{A_{i+1}} = H_{A_i, \overline{k_{i+1}}}$

$\{P_{A_{i+1,m}}\}_{m=1,\cdots,K_{A_{i+1}}} = P_T / K_{A_{i+1}}$

$(K_{A_{i+1}} = K_{A_i} - 1)$

Compute $\Delta T(A_{i+1}, A_i)$

if $\Delta T(A_{i+1}, A_i) \leq 0$, transmit antenna selection ends,

A_i becomes the final active transmit antenna subset A,

else

$i \leftarrow i+1$, Repeat the above recursion.

Here, the notation $H_{A_i, \overline{k_{i+1}}}$ denotes the $n_R \times (n_T - i - 1)$ matrix obtained by zeroing out the first column vector $h_{A_{i,1}}$ in H_{A_i}. A serial decision procedure that simply drops the worst antenna at each stage while antenna selection gain exists leads to the optimal active antenna subset A The detection order of the selected antennas in A has a negligible impact on the total rate but does impact a fraction of the transmission rate allocated to each individual antenna. It also affects the corresponding MCS of each antenna. Thus, for the final active antenna subset A the corresponding MCS set M_A can be calculated by (3) and (5) in straightforward manner according to its arbitrary detection order.

Obviously, in a worst propagation environment where the optimal antenna subset contains only one antenna, the serial decision algorithm only requires testing possible antenna subsets sorted by the reverse detection ordering policy. In a favorable environment that needs no antenna selection, the serial decision algorithm requires the testing of only one antenna subset that includes all available transmit antennas. Compared with the heuristic decision strategy, which always requires the testing of $\sum_{k=1}^{n_T} n_T! / (n_T - k)!$ possible ordered antenna subsets regardless of propagation environments, the serial decision algorithm is considerably less complex.

Ⅳ. Simulation Results

We consider an MMSE-OSIC spatial multiplexing system. To model a system with various modulation levels and coding rate combinations, the interval between rate quantization levels is assumed as 1/2, and therefore the available rates are assumed to be 0, 1/2, 1, 3/2, and so on. The average (ergodic) capacity is used as a performance measure and is obtained by averaging a large number of random capacity variables computed in every channel realization when $\Gamma=1.95$. For reference, the open-loop MIMO capacity and the closed-loop MIMO capacity, when the capacity loss from the non-zero error rate and the rate quantization is considered, are presented.

Linear arrangement of the antenna array is assumed at both the transmitter and receiver with the spacing $d_T=4.0\lambda$ and $d_R=0.5\lambda$, respectively. We assume a uniform angular spectrum at both the transmitter and the receiver ends with angular spreads Δ_T and Δ_R when both the angle of departure and the angle of arrival are 0°. We assume that the receive antennas are loosely correlated by letting $\Delta_R=60^\circ$, while the correlation between transmit antennas varies with the angular spread Δ_T. We assume two scenarios $\Delta_T=5^\circ$ and $\Delta_T=60^\circ$, which correspond to highly correlated channels and loosely correlated channels, respectively, at the transmitter end.

The effect of power allocation schemes on the sum rate when $n_T=n_R=2$ in a loosely correlated channel is shown in Fig. 1. We consider optimal power allocation by a heuristic method. The optimal solution is obtained by selecting the one that yields the largest capacity among all possible power distribution over all possible decoding orders while considering the capacity loss from the non-zero error rate and the rate quantization. The effect of power quantization is reflected by considering 2^{N_p} power quantization levels where N_p denotes the required feedback information bits per transmit antenna. Then, our proposed equal power allocation with transmit antenna selection by the heuristic decision algorithm is considered. The results indicate that our proposed equal power allocation with antenna selection scheme shows comparable performance with optimal power allocation schemes even with a large number of power quantization levels. This indicates that equal power allocation to the selected antennas works as well

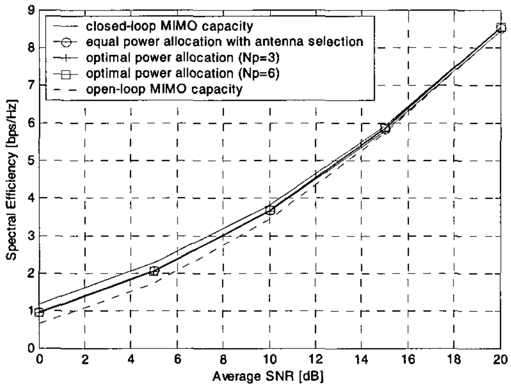

Fig. 1. Capacity comparison between power allocation schemes when $n_T=n_R=2$ in a loosely correlated channel.

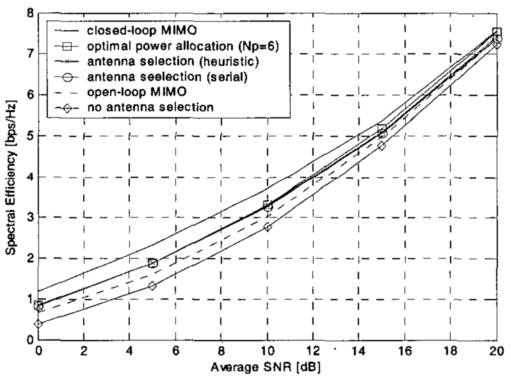

Fig. 2. Capacity comparison between antenna selection schemes when $n_T=n_R=2$ in a highly correlated channel.

as the optimal power allocation but that it doses not require additional feedback information on power allocation.

Fig. 2 shows capacity comparison results between antenna selection schemes when $n_T=n_R=2$ in highly correlated channels. The sum rates between the heuristic decision algorithm and the serial decision algorithm are compared. Also, we consider a no antenna selection scheme with a fixed detection order according to the antenna index under equal power allocation to n_T transmit antennas. The results show that the capacity curves of the serial decision algorithm nearly match those of the heuristic decision algorithm. This result indicates that the serial decision procedure provides an optimal solution even though it has considerably reduced complexity. Our proposed transmit antenna selection and equal power allocation scheme approaches the closed-loop MIMO capacity, while an equal power allocation without antenna selection approaches the open-loop MIMO capacity. The capacity gap between antenna selection and no antenna selection shows that transmit antenna selection can achieve substantial performance enhancement with minimal feedback information.

Capacity comparisons between antenna selection schemes are shown in Fig. 3, when $n_T=n_R=4$ in loosely correlated channels. The result shows the same trend as when $n_T=n_R=2$, except that there is a slight capacity gap between the heuristic and the serial decision algorithms. The capacity gap results from the detection order of the selected antennas. This ordering affects a fraction of the transmission rate allocated to each transmit antenna. As a result, it also affects the amount of loss from rate quantization, thereby affecting the total rate as well. The heuristic decision strategy that considers all possible decoding orders over the selected antennas can choose the ordering of the selected antennas that maximizes the total rate. On the other hand, the serial decision algorithm does not consider the effect of the detection ordering of the selected antennas. This loss is quite acceptable, considering the significant reduction in computation intensity. In the case of a no rate quantization, both algorithms show identical capacity results.

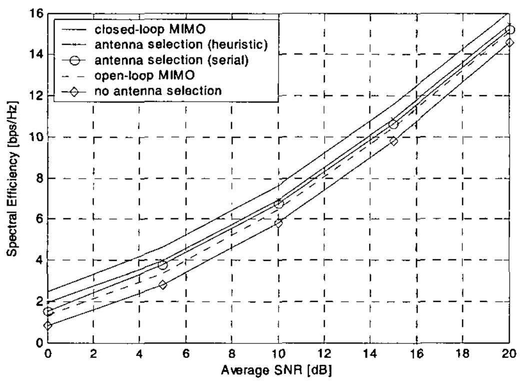

Fig. 3. Capacity comparison between antenna selection schemes when $n_T=n_R=4$ in a loosely correlated channel.

V. Conclusion

In this paper, we focused on designing a low complexity algorithm for an active transmit antenna subset and its transmission rate selection by considering its decoding order in a spatial multiplexing system with PARC and an SIC receiver. A serial decision procedure that simply drops the worst antenna at each decision stage while antenna selection gain exists is proposed and is shown to provide a near-optimal solution with considerably reduced complexity. Numerical results show that for most MIMO configurations and propagation environments, the serial decision algorithm shows comparable performance with the heuristic decision strategy.

REFERENCES

〔1〕 P. W. Wolniansky, G. J. Foschini, and G. D. Golde, "V-BLAST: An architecture for realizing very high data rates over the rich-scattering wireless channel," in *Proc. ISSSA'98*, Pisa, Italy, 1998, pp. 295-300.

〔2〕 D. Gore, R. Heath, and A. Paulraj, "Statistical antenna selection for spatial multiplexing systems," in *Proc. IEEE ICC 2002*, pp. 450-454.

〔3〕 Hairuo Zhuang, Lin Dai, Shidong Zhou, and Yan Yao, "Low complexity per-antenna rate and power control approach for closed-loop V-BLAST ," *IEEE Trans. Commun.*, vol.51, no.11, pp.1783-1787, Nov. 2003.

〔4〕 R.W. Heath Jr., D.J. Love, "Dual-mode antenna selection for spatial multiplexing systems with linear receivers Signals," in *Proc. IEEE Asilomar Conf. Signals, Systems, and Computers*, vol.1, pp.1085-1089, Nov. 2003.

〔5〕 R.W. Heath Jr., D.J. Love, "Multi-mode antenna selection for spatial multiplexing systems with linear receivers Signals," accepted to *IEEE Trans. Signal Processing*.

〔6〕 R. Narasimhan, "Spatial multiplexing with transmit antenna and constellation selection for correlated MIMO fading channels," *IEEE*

Trans. Signal Processing, vol.51, no.11, pp.2829-2838, Nov. 2003.

〔7〕 A. Gorokhov, D. Gore, A. Paulraj, "Receive antenna selection for MIMO flat-fading channels: theory and algorithms,'' *IEEE Trans. Information Theory*, vol.49, no.10, pp.2687-2696, Oct., 2003

〔8〕 S. Catreux, V. Erceg, D. Gesbert, and R. W. Heath Jr., "Adaptive Modulation and MIMO Coding for Broadband Wireless Data Networks," *IEEE Commun. Mag.*, pp.108-115, June 2002.

〔9〕 S. Catreux, P. F. Driessen, and L. J. Greenstein, "Data throughputs using multiple-input multiple-output (MIMO) techniques in a noise-limited cellular environment," *IEEE Trans. Wireless Commun.*, vol.1, pp.226-235, Apr. 2002.

〔10〕 S. T. Chung, A. Lozano, and H.C. Huang, "Low complexity algorithm for rate and power quantization in extended V-BLAST," in *Proc. IEEE VTC 2001 Fall*, pp.910-914.

〔11〕 D. Chizhik, F. Rashid-Farrokhi, J. Ling, and A. Lozano, "Effect of antenna separation on the capacity of BLAST in correlated channels," *IEEE Commun. Letters*, vol.4, no.11, pp.337-339, Nov. 2000.

〔12〕 A. Lozano, "Capacity-approaching rate function for layered multiantenna architectures ," *IEEE Trans. Wireless Commun.*, vol.2, no.4, pp.616-620, July 2003.

〔13〕 R. Pyndiah, A. Picart, and A. Glavieux, "Performance of block turbo coded 16-QAM and 64-QAM modulations," in Proc. *IEEE Globecomm 1995*, pp.1039 -1043.

문 철 (Cheol Mun) 정회원

1995년 2월 연세대학교 전자공학과 졸업
1997년 2월 연세대학교 전자공학과(공학석사)
2001년 2월 연세대학교 전자공학과(공학박사)
2001년 3월~2002년 2월 삼성전자 네트웍 사업부
2003년 8월~현재 충주대학교 전기전자정보공학부 교수
<관심분야> 채널모델링, MIMO, OFDM

정 창 규 (Chang-Kyoo Chung) 정회원

1988년 2월 연세대학교 전자공학과 졸업
1990년 8월 연세대학교 전자공학과(공학석사)
1995년 8월 연세대학교 전자공학과(공학박사)
1995년 9월~현재 충주대학교 전기전자정보공학부 교수
<관심분야> 채널 모델링, MIMO, OFDM