PAPER

A Practical Antenna Selection Technique in Multiuser Massive MIMO Networks*

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SUMMARY In this paper, a practical *antenna selection (AS)* scheme is investigated for downlink multiuser massive multiple input multiple output (MIMO) networks where a base station (BS) is equipped with many antennas (N) and communicates with K mobile stations (MSs) simultaneously. In the proposed antenna selection technique, S antennas ($S \leq N$) are selected for transmission based on the knowledge of channel coefficients of each MS for reducing the number of RF chains which mainly induce cost increase in terms of size, hardware, and power. In the proposed AS technique, a BS first ranks antenna elements according to the sum of their channel gains to all MSs. Then, the BS computes the downlink sum-rate with S consecutive antenna elements in the ordered set, where the subset consisting of S consecutive antennas is called a *window*. The BS selects the window resulting in the highest sum-rate. The selected S antenna elements are used for transmitting signals to multiple users, while the remaining $(N - S)$ antenna elements are turned off for the time slot. Therefore, the proposed AS technique requires only $(N - S + 1)$ sum-rate computations, while the optimal AS technique involves $\binom{N}{S}$ computations. We analyze downlink sum-rate with the proposed AS technique and compare it with that of a reference system with the same number of antenna elements without AS. Our results show that the proposed AS technique significantly outperforms the reference scheme.

key words: *massive MIMO, multiuser MIMO, cellular network, antenna selection, precoding*

1. Introduction

Recently, the demand for mobile data traffic has been explosively increasing [1]. To support this traffic demand, next-generation mobile communication systems, called beyond 4G systems, require significant performance enhancement in spectral efficiency over the conventional communication systems. There are three approaches for improving the throughput performance of the conventional mobile communication systems: smaller cell paradigm, bandwidth expansion technique, and adoption of large number of antennas.

Basic idea of small cell approach is to reduce distance of wireless link between transmitter and receiver, which results in higher-quality links and more spatial reuse [2]. Femtocells or picocells are known as small-sized and low-powered base stations and they are key enabling techniques for implementing smaller cells. Placement of small cells in geographical area is one of the most important technical issues in the small cell approach and some interesting studies on random placement of small cells have been performed [3]. Bandwidth expansion are being applied to 3GPP LTE-Advanced system with carrier aggregation techniques (CA) [4]. Frequency gives a degrees-of-freedom (DoFs), and thus throughput performance of wireless system linearly increases as the bandwidth increases. Major technical challenges for adopting CA technique in LTE-Advanced system are asymmetry of data traffic in uplink and downlink, control signal design, handover control, and guard band setting, etc. In addition, the CA should support non-contiguous carrier aggregation because the spectrum resource in the low frequency band is scarce. Multiple input multiple output (MIMO) technology has been actively studied and incorporated into emerging wireless systems such as 3GPP WCDMA, IEEE 802.16m, IEEE 802.11n/ac, 3GPP LTE, 3GPP LTE-Advanced, etc. For example, in 3GPP LTE-Advanced system, maximum 8 antennas are used for data transmission in order to improve the system throughput. In MIMO technologies, $\min(N_{TX}, N_{RX})$ DoFs can be provided and the throughput can be linearly increased as the number of antennas increases without bandwidth expansion [5], where N_{TX} and N_{RX} represent the number of transmit antennas and receive antennas, respectively.

On the other hand, massive MIMO has received much attention in the past few years and it is regarded as one of the most promising technologies for the next generation wireless networks [6]–[9]. With massive MIMO, hundreds antennas (or more) at a base station (BS) are simultaneously used for transmitting data to much smaller number of mobile stations (MSs). MSs are assumed to have a single antenna in general. However, large number of antennas at BS require high hardware complexity in both digital and radio-frequency (RF)/analog domains. In order to reduce the hardware complexity, antenna selection (AS) technique can be used, in which the number of employed RF chains (consisting of amplifiers, AD/DA converters, mixers, etc.) is smaller than the number of available antenna elements [10]–[12].

Recently, the AS technique has been proposed for massive MIMO networks [13], [14]. However, these studies considered the single-user MIMO network where a BS communicates with a single MS at a time even though studies on massive MIMO consider multiuser MIMO in general. In multiuser MIMO networks, the BS communicates with K users simultaneously [15]. Several AS

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techniques for multiuser MIMO networks have been proposed in [16]–[20]. These previous schemes utilized block-diagonalization (BD) or zero-forcing (ZF) precoding for reducing the co-channel interference (CCI) among users and selects transmit antennas one by one. However, these selection schemes may also be too complex to implement in *massive* MIMO networks with hundreds or thousands of antennas because they requires many iterations and matrix inversion process used in these precoding matrices requires the computational complexity of $O(N^3)$ in general where N represents the number of transmit antennas at BS. In this paper, therefore, we propose a practical AS technique which can perform irrespective of the number of antennas and precoding scheme. In the proposed antenna selection technique, a subset of available antennas ($S \le N$) is selected simultaneously based on the knowledge of channel coefficients of each MS for reducing the number of RF chains which mainly induce cost increase in terms of size, hardware, and power. Unfortunately, obtaining the optimal subset of antennas for maximization of downlink sum-rate is not mathematically tractable because it is a combinatorial problem which involves $\binom{N}{S}$ sum-rate computations. Furthermore, we assume that N is very large and the computation load cannot be negligible. Thus, we choose a heuristic approach in this paper.

The rest of this paper is organized as follows. In Sect. 2, system model for a massive MIMO is explained. In Sect. 3, we propose an adaptive antenna selection scheme. The performance of our proposed scheme is evaluated and compared with that of a reference scheme in Sect. 4. Finally, this paper is concluded in Sect. 5.

2. System Model for Massive MIMO

Figure 1 depicts the block diagram of multi-user beamforming scheme in a massive MIMO system. One base station wjth N transmit antennas simultaneously communicate with K users with single receive antenna. s_i indicates a scalar signal transmitted for user i and is multiplied by $\mathbf{v}_i$ which is $N \times 1$ beamforming vector. Overall transmit signal $\mathbf{x}$ is given by $N \times 1$ vector as follows:

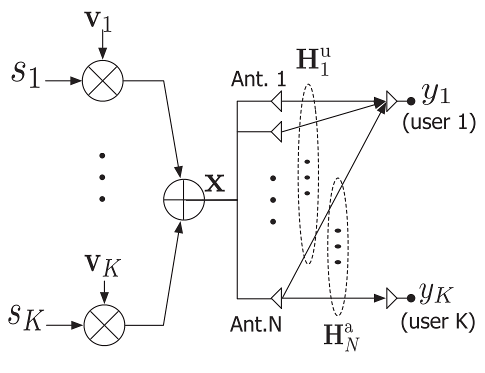


Fig. 1 Block diagram of multi-user beamforming in a massive MIMO system.

$$\mathbf{x} = \sum_{k=1}^{K} \mathbf{v}_k s_k \tag{1}$$

where

$$\mathbb{E}\left[|s_k|^2\right] = p_k, \ \sum_{k=1}^{K} p_k = P, \ \|\mathbf{v}_k\|^2 = 1 \tag{2}$$

On the other hand, the overall channel in multi-user beamforming scheme can be modelled by $K \times N$ matrix $\mathbf{W} = [w_{ij}]_{1 \le i \le K,\ 1 \le j \le N}$ where w_{ij} represents the channel coefficient from j-th transmit antenna of base station to i-th user's receive antenna which is assumed to be complex Gaussian random variable with zero-mean and unit-variance and to be independent and identically distributed (*i.i.d.*). Then, the effective correlated channel matrix is obtained by $\mathbf{H} = \mathbf{W}\mathbf{R}_T^{\frac{1}{2}}$ where $\mathbf{R}_T$ is a correlation matrix for transmit antennas given by [21], [22]

$$\mathbf{R}_T = \begin{bmatrix} 1 & \rho & \cdots & \rho^{N-2} & \rho^{N-1} \\ \rho & 1 & \cdots & \rho^{N-3} & \rho^{N-2} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \rho^{N-2} & \rho^{N-3} & \cdots & 1 & \rho \\ \rho^{N-1} & \rho^{N-2} & \cdots & \rho & 1 \end{bmatrix}, \ 0 \le \rho < 1. \tag{3}$$

Note that the correlation at receivers is not considered because receivers have single antenna. Then, $\mathbf{H}$ can be rewritten by

$$\mathbf{H} = \begin{array}{cccc|c} \mathbf{H}_1^{\mathrm{a}} & & \cdots & \mathbf{H}_N^{\mathrm{a}} & \\ \hline h_{11} & h_{12} & \cdots & h_{1N} & \mathbf{H}_1^{\mathrm{u}} \\ h_{21} & h_{22} & \cdots & h_{2N} & \vdots \\ \vdots & \vdots & \vdots & & \\ h_{K1} & h_{K2} & \cdots & h_{KN} & \mathbf{H}_K^{\mathrm{u}} \end{array} \tag{4}$$

where $\mathbf{H}_i^{\mathrm{u}}$ is a $1 \times N$ row vector which represents entire channel coefficients of i-th user from N transmit antennas, while $\mathbf{H}_j^{\mathrm{a}}$ is a $K \times 1$ column vector which represents entire channel coefficients of j-th transmit antenna for K users. $\mathbf{x}$ is transmitted over the channel and then the signal received at user i can be obtained as

$$\begin{aligned} y_i &= \mathbf{H}_i^{\mathrm{u}} \mathbf{x} + n_i \\ &= \mathbf{H}_i^{\mathrm{u}} \sum_{k=1}^{K} \mathbf{v}_k s_k + n_i \\ &= \mathbf{H}_i^{\mathrm{u}} \mathbf{v}_i s_i + \sum_{k=1, k \ne i}^{K} \mathbf{H}_i^{\mathrm{u}} \mathbf{v}_k s_k + n_i, \end{aligned} \tag{5}$$

where n_i denotes the additive white Gaussin noise with zero-mean and unit-variance. Then, the signal-to-intereference plus noise ratio (SINR) perceived at user i is given by

$$\mathrm{SINR}_i = \frac{p_i \left\|\mathbf{H}_i^{\mathrm{u}} \mathbf{v}_i\right\|^2}{1 + \sum_{k=1, k \ne i}^{K} p_k \left\|\mathbf{H}_i^{\mathrm{u}} \mathbf{v}_k\right\|^2} \tag{6}$$

We assume a slow fading where channel coefficients are quasi-static during one transmission interval and randomly variable for each transmission interval. Based on this assumption, Eqs. (1)~(6) do not include time index.

3. Proposed Antenna Selection Scheme

In this section, we propose an adaptive antenna selection scheme where S antennas out of N are selected to transmit signals and the remaining $(N-S)$ antennas are turned off. The proposed scheme is composed of two steps. Figure 2 shows the first step of the proposed algorithm. First, we rank N antennas according to the sum of their channel gains for all users which can be denoted by $\left\|\mathbf{H}^{\mathrm{a}}_{j}\right\|^{2}$, $j = 1 \cdots N$. The ordered channel vectors are indexed by $\hat{j}$ so that $\left\|\mathbf{H}^{\mathrm{a}}_{\hat{1}}\right\|^{2} \geq \cdots \geq \left\|\mathbf{H}^{\mathrm{a}}_{\hat{N}}\right\|^{2}$.

Then, we introduce a *window* which includes S consecutive antenna elements in the ordered set. We can have $(N-S+1)$ windows and the window shifts one by one element. The SINR of i-th user for w-th window can be obtained as

$$\mathrm{SINR}_{i,w} = \frac{p_i \left\|\mathbf{H}^{\mathrm{u}}_{i,w}\mathbf{v}_{i,w}\right\|^{2}}{1 + \sum_{k=1,k\neq i}^{K} p_k \left\|\mathbf{H}^{\mathrm{u}}_{i,w}\mathbf{v}_{k,w}\right\|^{2}} \tag{7}$$

where $\mathbf{H}^{\mathrm{u}}_{i,w}$ denotes the i-th user's channel coefficient vector from S antenna elements included w-th window and can be described as

$$\mathbf{H}^{\mathrm{u}}_{i,w} = \left[h_{i\widehat{w}}\ h_{i\widehat{(w+1)}} \cdots h_{i\widehat{(w+S-1)}}\right] \tag{8}$$

The sum-rate for w-th window, c_w, can be calculateded by

$$c_w = \sum_{i=1}^{K} \log_2\left(1 + \mathrm{SINR}_{i,w}\right) \tag{9}$$

Then, we can select a window including S consecutive antenna elements with the highest sum-rate as follows:

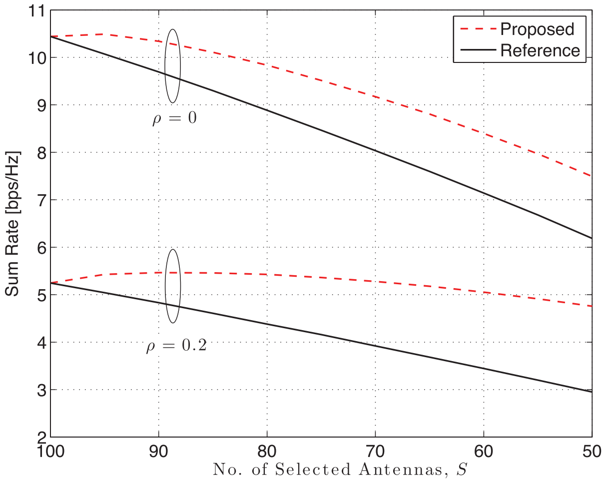
$$w^{*} = \arg_{1\leq w\leq N-S+1} \max c_w \tag{10}$$

and the corresponding capacity is given by c_{w^*}. Finally, overall average sum-rate can be calculated by averaging c_{w^*} over $\mathbf{H}$ as follows:

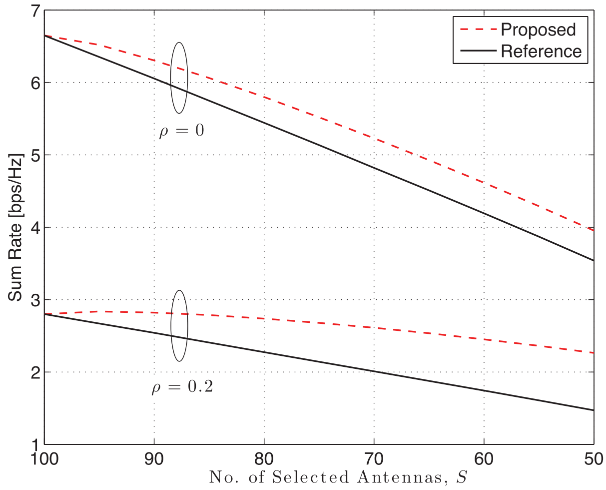
$$C = \mathbb{E}_{\mathbf{H}}[c_{w^*}] \tag{11}$$

4. Performance Evaluation

We evaluate the performance of proposed scheme in terms of the sum-rate defined in Eq. (9) by relying on Monte-Carlo simulation because it is not mathematically tractable to acquire the distribution of SINR defined in Eq. (7). It is infeasible to analyze the performance of the optimal antenna selection scheme in massive MIMO networks because of disastrous computational complexity. We need to calculate and compare sum rates for $\binom{N}{S}$ combinations of transmit an-



(a) $K = 10$



(b) $K = 20$

Fig. 3 Sum rates when $N = 100$ and SNR=0 dB.

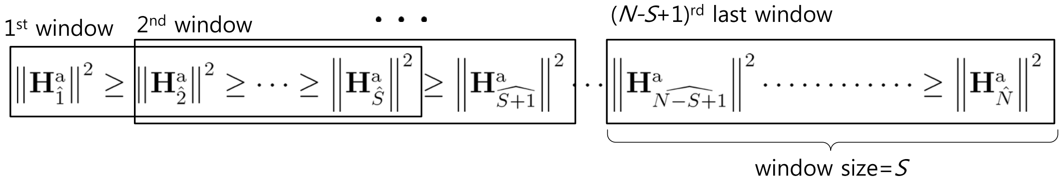
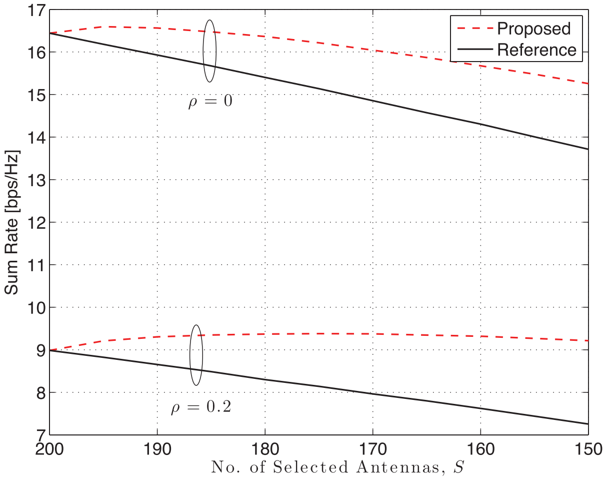
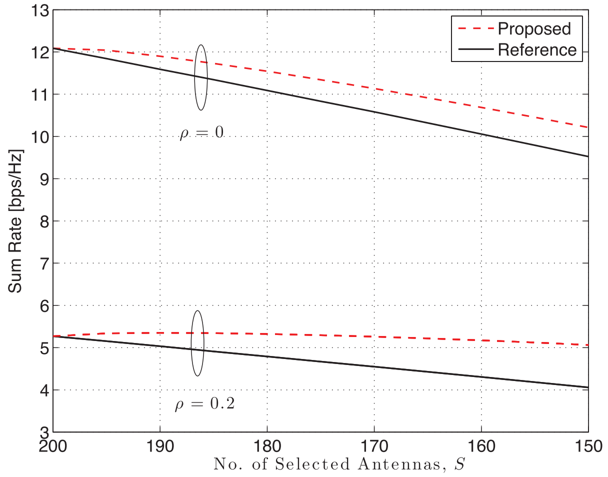


Fig. 2 Antenna ordering and window selection in the proposed scheme.



(a) $K = 10$



(b) $K = 20$

Fig. 4 Sum rates when $N = 200$ and SNR=0 dB.

tennas per one channel realization to select the optimal S transmit antennas. For example, $\binom{200}{195} \approx 2.5 \times 10^9$. Thus, we compare the performance of the proposed scheme with that of a reference system which is assumed to have total S antenna elements and use all of them without any AS because both schemes should use the same number of transmit antennas for fair performance comparison. We also assume that $p_k = \frac{P}{K}$ $(k = 1 \cdots K)$. Based on this equal power allocation for users, we can focus on AS problem. In addition, we consider maximal ratio transmit (MRT) beamforming scheme for its simplicity and feasibility. Thus, the beamforming vector $\mathbf{v}_i$ is given by $\frac{(\mathbf{H}_i^{\mathrm{u}})^\dagger}{\|\mathbf{H}_i^{\mathrm{u}}\|}$, where $()^\dagger$ denotes a Hermittian transpose operation. It should be noted that the proposed scheme can be incorporated into other precoding schemes although performance is evaluated based on the MRT precoding scheme.

Figure 3 shows sum-rates when $N = 100$ and SNR is equal to 0 dB. Total transmit power, P, availabe at base station can be interpreted as SNR because we assumed unit-variance noise. Figure 3(a) shows simulation results when the number of users $K = 10$. Sum-rates of both schemes decrease as S decreases because array gain of base station is reduced. However, sum-rate of our proposed scheme does not decrease when the number of antennas turned off, $(N - S)$, is small. This indicates that the proposed scheme can achieve sufficient array gain by casting transmit power to the selected antennas when $(N - S)$ is small. In addition, it is shown that our proposed scheme significantly outperforms the reference scheme. Figure 3(b) shows sum-rates when $K = 20$. Sum-rates of both schemes decrease more steeply compared with Fig. 3(a) because each user can not achieve sufficient gain because of lack of arrays as the number of users increases. However, our proposed scheme still outperforms the reference scheme. In addition, the sum rate improvement of the proposed antenna selection scheme increases as K decreases because array gain for each user increases for increasing K and thus the effect of antenna selection increases.

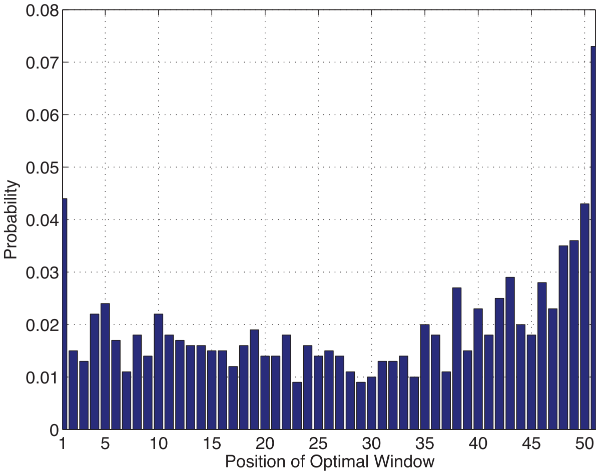


Fig. 5 The probabilities of optimal window positions when $N = 200$, $K = 10$, $S = 150$, and SNR=0 dB.

Figure 4 shows sum-rates when N is 200. It is shown in Fig. 4(a) that the sum-rate of our proposed scheme for $S = 195$ is higher than that for $S = N = 200$. This indicates that the sum-rate of our proposed adaptive antenna selection scheme can be higher than that of a scheme with more antennas without AS because the power allocated to antenna elements with low channel gains can be efficiently exploited by elements with high channel gains.

Finally, Fig. 5 shows the probabilities of optimal window positions which is selected in the proposed scheme when $N = 200$, $K = 10$, $S = 150$, and SNR=0 dB. It is shown that the probability that the first and last windows are selected is high.

5. Conclusion

In this paper, we investigated an AS problem in a multi-user MIMO system where a BS is equipped with massive antenna elements (N) and communicate with K users simultaneously. We proposed a practical and simple AS scheme that can significantly reduce hardware and computational complexity. In the proposed scheme, we rank antenna elements according to the sum of their channel gains for all users. Then, we introduce a *window* including consecutive S antenna elements from the first element in the ordered set and calculated the sum-rate of the window. The window shifts one by one element. Thus, we can have $(N - S + 1)$ windows. Finally, we can select an optimal window resulting in the highest sum-rate. We evaluated the performance of our proposed scheme and compared it with that of a reference scheme with S antennas without AS through Monte-Carlo simulations.

Simulation results showed that our proposed scheme significantly outperforms the reference scheme, while the proposed scheme can remarkably reduce the hardware and computational complexity of a base station.

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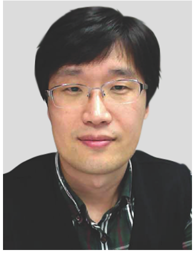

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