Antenna Selection Based on Energy Efficiency of Uplink in Massive MIMO Systems

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Abstract. Massive multiple-input multiple-output (MIMO) system installs a large number of antennas on the base station (BS), which requires one radio frequency (RF) chain for each antenna. When the number of antennas is small, the power consumption of the RF chains is negligible compared with the transmitting power. However, with the increase of antennas and RF chains, the ratio of the RF chains power consumption to the total transmitting power is gradually increasing. Therefore, the energy efficiency (EE) of the system tends to be saturated gradually and decreases with the further increase of antennas. To improve EE in massive MIMO systems, an antenna selection method by switching antenna dynamically with channel state information (CSI) is proposed in this paper, and trade-off between EE and spectral efficiency of the system is addressed.

Keywords: Massive MIMO · Energy efficiency · Antenna selection · Spectral efficiency

1 Introduction

As one of the key technologies of 5G, massive multiple-input multiple-output (MIMO) technology [1–3] can greatly improve the spectral efficiency (SE) of the system by installing a large number of antennas on the base station (BS), this is because the data rates of the system will grow with the increased number of antennas. In communication systems, maximizing system energy efficiency (EE) is expected while improving system SE. However, considering the power consumption of the radio frequency (RF) chains, the EE of the massive MIMO system rises firstly and falls afterwards with the increase of antennas on the BS [4–6]. Therefore, improving EE is a key issue that needs to be addressed urgently in massive MIMO technologies.

Under the ideal power consumption model, [7] and [8] discussed the trade-off between SE and EE and the relationship among the number of BS antennas, users and the transmitting power in massive MIMO systems. The adverseness of using low-cost transceivers in large-scale antennas when adopting non-ideal devices is discussed in [9], the relationship between the number of BS antennas and the system EE is also analyzed. However, most of these studies are not take the power consumption of the RF chains into account in the actual system. Under the actual power consumption model,

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a system energy consumption function of the number of BS antennas and users is obtained in [10], and the optimal number of RF chains was provided according to this energy consumption function to optimize the EE of the system. But the EE of the system can be further improved by antenna selection.

In this paper, an improved antenna selection method is proposed based on EE of massive MIMO systems, the antennas of optimal channel state information (CSI) are selected to reduce energy loss, and the trade-off between EE and SE of the system is illustrated. Finally, the bit error rate (BER) of the system is simulated and analyzed.

2 Energy Consumption Model of the System

This paper considers the uplink of massive MIMO systems in a single cell multi-user scenario. The bandwidth of the system is B, and M antennas are installed on the BS to serve K single-antenna users. In a flat fading channel, the channel is quasi-static within the U symbols of the time-frequency coherent block. It is assumed that the BS and the user are fully synchronized in time division duplex (TDD) protocol.

The EE of the uplink with zero-forcing (ZF) processing under perfect CSI in single cell can be modeled as

$$\max_{M \in \mathbb{Z}_+, K \in \mathbb{Z}_+, \rho \geq 0, M \geq K+1} \left(\mathrm{EE}^{(ZF)} \right) = \frac{\sum_{k=1}^{K} \left(E\left\{ R_k^{(\mathrm{ul})} \right\} \right)}{P_{TX}^{(\mathrm{ul})} + P_{CP}^{(ZF)}} = \frac{K\zeta^{(\mathrm{ul})} \left(1 - \frac{\tau^{(\mathrm{ul})} K}{U\zeta^{(\mathrm{ul})}} \right) B \log_2 (1 + \rho (M - K))}{P_{TX}^{(\mathrm{ul}-ZF)} + P_{CP}^{(ZF)}}, \quad (1)$$

where $R_k^{(\mathrm{ul})}$ is the data rate of the kth user that the pilot overhead is not included, $P_{TX}^{(\mathrm{ul})}$ represents the total transmitted power, circuit power consumption $P_{CP}^{(ZF)}$ is the sum of the power consumed by different analog components and digital signal processing using ZF detection. The proportions of the uplink and downlink transmissions are $\zeta^{(\mathrm{ul})}$ and $\zeta^{(\mathrm{dl})}$, and $\zeta^{(\mathrm{ul})} + \zeta^{(\mathrm{dl})} = 1$. In the uplink transmission, $U\zeta^{(\mathrm{ul})}$ symbols are included, the user needs to transmit a pilot signal for channel estimation when the CSI is unknown, and the pilot occupies $\tau^{(\mathrm{ul})}K$ symbols, where $\tau^{(\mathrm{ul})} \geq 1$ to ensure the pilots among users are mutually orthogonal. ρ is the design parameter proportional to the received signal-to interference-and-noise ratio (SINR) [11].

3 Antenna Selection Based on Energy Efficiency

Figure 1 is a block diagram of the antenna selection. It is proposed in [5] when the number of RF chains on the BS is F ($F = M/2$), the EE is optimal considering the overall power consumption on both the transmitter and the receiver.

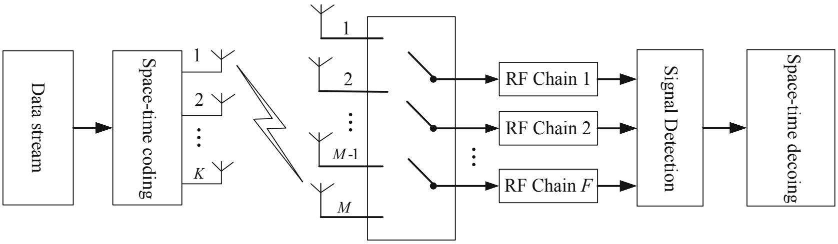

Fig. 1. Antenna selection block diagram ($F < M$)

Based on [5], an improved antenna selection scheme is described in this paper in the following steps.

3.1 Acquisition of CSI

Initialization $i = 1$, the RF chain is switched to the 1st to the Fth antenna, assume $\mathbf{H}_i$ represents the channel matrix between the BS and the users, $\mathbf{H}_i$ is an $F \times K$-dimensional matrix and estimated by the pilot signal. Then, the channel matrix $\mathbf{H}_i$ is subjected to ZF equalization, the ZF equalization matrix is

$$\mathbf{W}_i = \left(\mathbf{H}_i^H \mathbf{H}_i\right)^{-1} \mathbf{H}_i^H, \tag{2}$$

and the corresponding weight matrix $\mathbf{W}_i$ is obtained, $(\cdot)^H$ and $(\cdot)^{-1}$ stand for the conjugate transpose and matrix inversion, respectively. The two-norm of each column of the matrix $\mathbf{W}_i$ can be calculated as

$$\mathbf{k}_i = \underset{l \in \{1,2,\ldots.F\}}{\arg} \left\|(\mathbf{W}_i)_l\right\|^2, \tag{3}$$

where $\mathbf{k}_i$ is the row vector of the F columns, l is the row of $\mathbf{W}_i$. Switch the RF chain to the $(F + 1)$th to Mth antenna, and then repeat channel estimation and equalization. Combine $\mathbf{k}_i$ and $\mathbf{k}_{i+1}$ by row to get $\mathbf{k}$ ($\mathbf{k} = [\mathbf{k}_i, \mathbf{k}_{i+1}]$), $\mathbf{k}$ is the row vector of M columns.

3.2 Evaluation of CSI

We sort the $\mathbf{k}$ in ascending order, then select F antennas with better CSI (the SINR is large when the two-norm is small). The F best CSI of all M antennas are selected to form a new channel matrix $\mathbf{H}_{i'}$, these selected antennas are used for the transmission and reception of next frame. And the mean value of $\mathbf{k}$ is calculated as a threshold for measuring CSI during antenna switching.

3.3 Dynamic Antenna Selection

Similarly, $\mathbf{H}_{i'}$ is subjected to ZF equalization to obtain the corresponding weight matrix $\mathbf{W}_{i'}$, the two-norm of each column of $\mathbf{W}_{i'}$ is calculated to obtain $\mathbf{k}_{i'}$, and all the elements in $\mathbf{k}_{i'}$ are compared with the threshold to find an element larger than the threshold, which the antenna CSI is smaller than the mean value, and the corresponding antenna number is recorded. After the signal detection, the RF chains of the antennas with recorded numbers are randomly switched to the idle antennas. As CSI changes continuously, the mean value of M antenna CSI will fluctuate with time. In general, when the number in $\mathbf{k}_{i'}$ greater than the mean value of $\mathbf{k}$ is more than $M/4$ (more than the half number of used antennas), let $i = i + 1$ to restart.

With the algorithm above, we consider the channel frequency domain response of each user comprehensively, reduce the number of RF chains (reduce the power consumption) to improve the EE of the system.

4 Simulation Results

4.1 Energy Efficiency and Spectral Efficiency

According to the actual power consumption parameters in [11], the exhaustive search method is adopted of the uplink in a single cell, while the number of antennas on the BS is M (340 or 384) and the number of users is K (from 1 to 150). Each combination of M and K is simulated, and the relationships between the EE and K, the SE and K of the uplink are obtained. The curve of M = 170 and M = 192 indicate that the proposed antenna selection method is used. Point A, B, D and E in Fig. 2 correspond to the point A, B, D and E in Fig. 3, respectively.

As can be seen from Fig. 2, with the same number of users, the EE of the system can be improved with antenna selection as compare to the system without antenna selection.

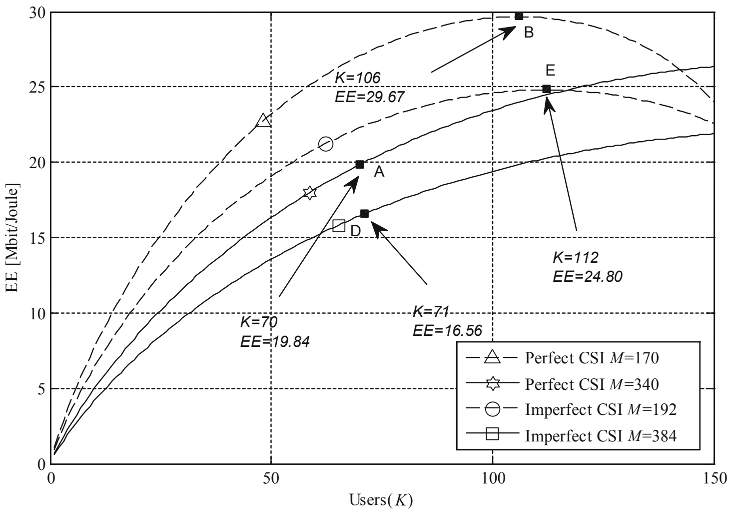

Fig. 2. Relationship of system energy efficiency and K with and without antenna selection

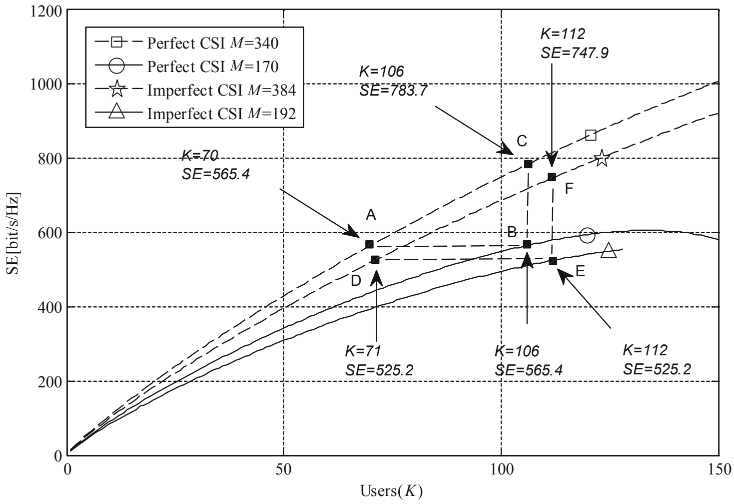

Fig. 3. Relationship of system spectral efficiency and *K* with and without antenna selection

It is shown in Fig. 3 that the system SE of point A and point B is 565.4 bit/s/Hz, while in Fig. 2 the system EE are 19.84 Mbits/J and 29.67 Mbits/J respectively under perfect CSI. Under imperfect CSI, the system SE of point D and point E is 525.2 bit/s/Hz, while the system EE are 16.56 Mbits/J and 24.80 Mbits/J, respectively. From results above, comparing A with B (as well as D with E), the EE of the system can be improved using antenna selection when the SE is equal.

As can be seen from Fig. 3, the SE of the system at point B is 565.4bit/s/Hz, the SE of the system at point C is 783.7 bit/s/Hz. The SE of point B is lower than point C under perfect CSI. The similar as E (SE = 525.2 bit/s/Hz) and F (SE = 747.9 bit/s/Hz), the SE of point E is lower than point F under imperfect CSI. That is because with the same number of users, the SE of the system will be reduced when the number of BS antennas decreases.

Although the SE of the system with antenna selection at point B or E is lower than that of the system without antenna selection at point C or F as shown in Fig. 3, the EE of the system with antenna selection at point B or E is higher than that of the system without antenna selection when the number of users is same.

4.2 System Error Rate

Figure 4 shows the relationship of BER and SNR under imperfect CSI in a single cell. There are 2 users when the BS antennas are 64, 128 and 256, respectively. System bandwidth B is 20 MHz, and sampling interval is $1/B$ with 16 quadrature amplitude modulation (QAM), ZF processing is adopted in multipath fading channels, and the selected antennas are half of the BS antennas (the number of configured RF chains is $M/2$).

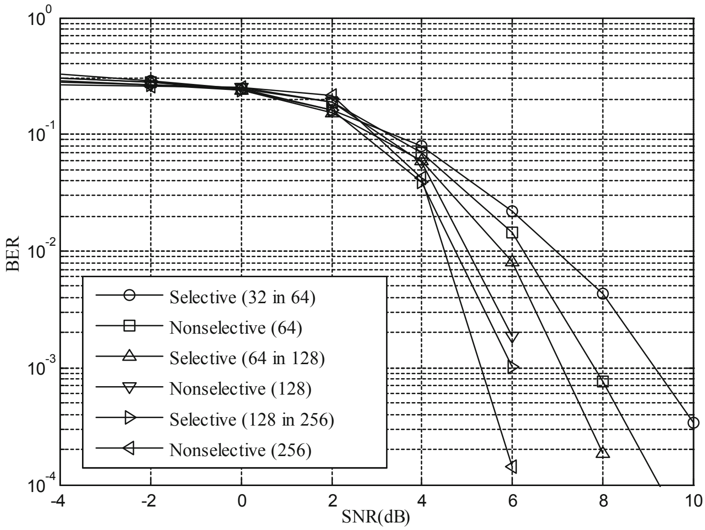

Fig. 4. The BER performance under imperfect CSI

It is shown in Fig. 4, when the antennas on BS are 64, 128 or 256, half antennas are selected in antenna selection system, the BER of system with antenna selection is higher than that of the system without antenna selection. That is because the lower diversity gain of antenna selection system leads to an increase in BER. Although the BER of the system with antenna selection is higher than that of the corresponding system without antenna selection, the EE of the antenna selection system is higher. When the diversity gain is consistent, the BER of the system with 64 or 128 selected antennas is lower than that of the system with 64 or 128 unselected antennas.

5 Conclusion

This paper has analyzed the relationship between EE and SE of the massive MIMO system. Antenna selection is performed to improve EE of the system by reducing the number of RF chains. The simulation results show that when the SE is equal, the EE of the system can be improved with antenna selection. Furthermore, the BER performance of the system with antenna selection is better than that of the system without antenna selection when the RF chains are equal.

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