

# Adaptive Antenna Selection and Power Allocation in Downlink Massive MIMO Systems

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## ABSTRACT

Massive multi-input, multi-output (MIMO) systems are an exciting area of study and an important technique for fifth-generation (5G) wireless networks that support high data rate traffic. An increased number of antenna arrays at the base station (BS) consumes more power due to a higher number of radio frequency (RF) chains, which cannot be neglected and becomes a technical challenge. In this paper, we investigated how to obtain the maximal data rate by deriving the optimal number of RF chains from a large number of available antenna arrays at the BS when there is equal power allocation among users. Meanwhile, to mitigate inter-user-interference and to compute transmit power allocation, we used the precoding scheme zero forcing beamforming (ZFBF). The achievable data rate is increased because the algorithm of ZFBF enables the choosing of the maximum power in relation to the optimal antenna selection. We conclude that the transmit power allocation allows the use of less number of RF chains which provides the maximum achievable data rate depending on the optimal RF chain at the BS.

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## 1. INTRODUCTION

A major challenge for mobile broadband networks is figuring out how to support throughput in 5G networks. Massive MIMO is very important in 5G technology because it allows for the achievement of high data rates [1], [2]. Moreover, an increase in the number of antenna arrays at a BS results in greater power consumption due to a higher number of RF chains. Meanwhile, higher number of radio frequency (RF) chains, in both of BS and active user (UE) consume more of power due to the processing activities in the digital-to-analog converter (DAC), power amplifier, multiplexer, and filter. Consequently, all antennas at the BS need to connect with the RF chains as shown in Figure 1. It has been reported that BSs are responsible for 80 percent of the energy consumed in cellular networks [3]. Meanwhile, the optimal number of RF chains was studied in [4].

The authors considered how many RF chains were optimal for point-to-point in a large scale MIMO channel studied in [5]. The authors determined the optimal antenna selection for when the number of antennas was more than the number of users [11]. In this work, we derived the optimal number of RF chains that maximized data rate in a large-scale antenna arrays based on the downlink channel condition. This is proportional to the number of active users (UEs)  $K$ , where the number of RF chains equals the amount of power allocation according to the number of active users  $K$ . Consequently, obtaining a high performance system required that the number of RF chains be less than the number of transmit antennas that was good

under channel state information (CSI). The authors in [6] proposed an optimal power allocation algorithm for downlink massive MIMO systems with maximum ratio transmission (MRT).

Additionally, the number of antenna at a BS cannot be subjectively increased due to the physical area in a practical system [9]. Furthermore, with regards to the energy resource in the cellular networks, the power allocation algorithms required minimizing the power consumption and maximizing the achievable data rate [7], [8]. The subspace projection for RF is adaptive to spatial correlations and able to mitigate the interference for different user clusters [10]. Moreover, the optimal antenna selection required determined the status of CSI in the forward link channel due to the large number of antenna elements  $M$  in massive MIMO systems. The huge degree of freedom offered by a massive MIMO systems can be used to reduce the amount of transmitted power, allow for larger hardware impairments, and provide the system with the ability to increase multiplexing and diversity gain [12], [13]. The optimal power allocation in a massive MIMO system requires using power allocation for control, which reduces the interference and beamforming algorithm through use of the required linear precoding schemes.

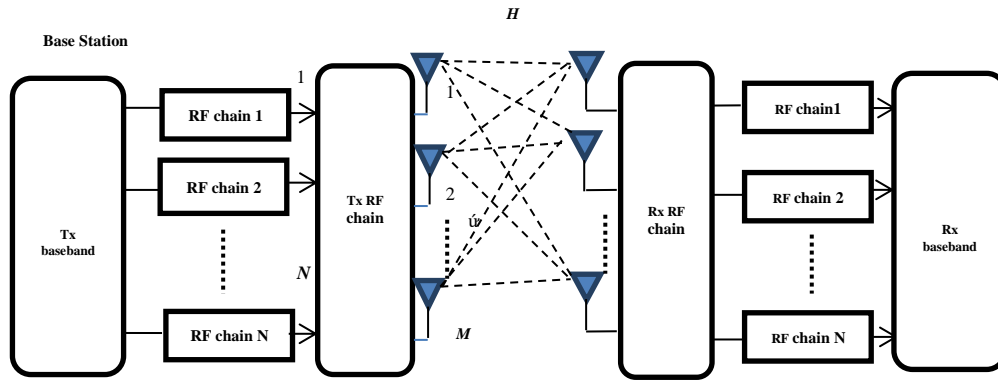


Figure 1. Transmitted signal with RF chains in massive-MIMO channel

## 2. SYSTEM MODEL

The downlink signal multi-user-MIMO system includes the BS, which contains many antenna arrays  $M$  and receives data from many random active users  $K$ , where every user still receives a high data rate; the received signal from BS to UEs ( $K$ ) is given by

$$z_k = \sum_{i=1}^L \sqrt{Q_t} \gamma_k x_k \tag{1}$$

where  $Q_t^{dl}$  is the downlink transmit power for every user,  $x_k$  represents the data symbol signal of the  $k^{th}$  user and  $\gamma_k$  represents the beamforming matrix.

The signal received in terms of UEs is given by:

$$r_k = \underbrace{\sum_{i=1}^L \sqrt{Q_k} h_k^H \gamma_k x_k}_{\text{desired signal}} + \underbrace{\sum_{t=1, t \neq k}^K \sqrt{Q_t} h_k \gamma_t x_t}_{\text{interference}} + \underbrace{n_k}_{\text{noise}} \tag{2}$$

where,  $h_k$  is a matrix channel of  $K \times M$  and  $n_k$  is the receive noise with zero mean and variance. The received signal-to-interference noise ratio (SINR) used to describe the achievable data rate at every UE  $K$  is:

$$SINR_k = \frac{\frac{Q_k}{k} \sum_{k=1}^K |h_k \gamma_k|^2}{\frac{Q_t}{k} \sum_{i=1}^L \sum_{t=1}^K |h_k \gamma_t|^2 + \sigma^2} \tag{3}$$

The transmit beamforming is used to maximize the performance transmitted power and reduce the inter-user-interference; the purpose of using SINR for each user is to provide the optimal of beamforming  $\sum_{k=1}^K \|\gamma_k\|^2$ , the optimal beamforming matrix ZFBF is expressed as:

$$\gamma_k^{opt} = \left( I_N + \frac{1}{\tau^2} H A H^H \right)^{-1} H \sqrt{Q_k} \tag{4}$$

where  $\tilde{Q}_k = \text{diag} (Q_k / \|(\tau^2 I_k + HAH^H)^{-1} h_k\|)$  according the power allocation,  $\tau^2$  is the noise power at transmitted signal,  $I_N$  bethe  $M \times M$  identity matrix, and  $A = \text{diag} [\vartheta_1, \dots, \vartheta_k]$  is the diagonal matrix in Lagrange multiplier associated with many of UEs  $K$ .

The corresponding power allocation matrix when  $\tau^2 \rightarrow 0$  and  $\tilde{Q}_{k\tau^2 \rightarrow 0}$ , the asymptotic power allocation with ZFBF channels, is given as:

$$\gamma_k^{opt} = (0 I_N + HAH^H)^{-1} H \tilde{Q}_{k\tau^2 \rightarrow 0} = H(HH^H)^{-1} A^{-1} \tilde{Q}_{k\tau^2 \rightarrow 0} \quad (5)$$

The optimal zero forcing beamforming  $\gamma_k$  is:

$$\begin{aligned} \min_{\gamma_1, \dots, \gamma_k} \sum_{k=1}^K \|\gamma_k\|^2 \\ \text{subject to } SINR_k \geq \gamma_k \end{aligned} \quad (6)$$

where,  $\gamma_k$  represent SINRs the parameter  $\gamma_1, \dots, \gamma_k$ , in every active user.

Using transmit power beamforming to maximize SINR in every active user required in this case the maximum data rate to ensure the fixing of the SINR, where the optimal beamforming is smaller than the total transmit power.

$$\max_{\gamma_1, \dots, \gamma_k} \sum_{k=1}^K f(\gamma_1, \dots, \gamma_k) \quad (7)$$

$$\text{subject to } \sum_{k=1}^K \|\gamma_k\|^2 < Q_k \quad (8)$$

The achievable data rate in terms of SINR is given by

$$R_k = \log_2(1 + \gamma_k) \quad (9)$$

The output of the transmit power is dependent on the amount of circuit power consumed by the RF chain, such as multiplexer, filter amplifier, and DAC. To obtain the optimal power allocation for users  $Q_k^{opt}$ , is given by water filling algorithm [14].

$$Q_{out}^{max}(\zeta_m) = \sum_{i=1}^M Q_k^{opt} \quad (10)$$

where  $\zeta_m$  is the antenna coefficient,  $m=[1, \dots, M]$ , and  $Q_k^{opt}$  is optimization power of the  $K^{th}$  active user. The constraint for circuit power consumption is given by

$$\frac{Q_{out}}{\varepsilon} + \sum_{m=1}^M \zeta_m Q_{ct} \leq Q_{max} \quad (11)$$

where  $\varepsilon$  is the efficiency of power allocation and the consumption power  $Q_{ct} = Q_{UT} + Q_{OSC} + Q_S$  can be divided by the consumption power at user  $Q_{UT}$ , the power consumed by the local oscillators  $Q_{OSC}$ , and the fixed power  $Q_S$ .

Based on the conventional antenna selection, in order to get the optimal subset of antennas for the RF chains that maximizes the data rate, the chosen antenna coefficient  $\zeta_m$  is expressed as.

$$\zeta_m = \arg \max_{k \in I} \mathcal{F}_{m,k} \quad (12)$$

where  $I$  is the set of not chosen transmit antennas, where  $\zeta_m$  is the index of  $m_{th}$  selected antenna coefficient.

The coefficient antenna selection assists in giving the high performance transmission, when the channel matrix is the uncorrelated coefficient. Where the spatial correlation effect of the performance of a multi-antenna transmits power, the channel capacity allows an increase in the amount of data that can be transmitted; the effect of norms of columns and uncorrelated channel matrix  $\varphi_k$  is given by

$$\varphi_k = \sum_{i=k}^K \sqrt{1 - \frac{|h_k^H h_k|}{\|h_k\|^2}} \quad (13)$$

The cost function  $\mathcal{F}_{m,k}$  is given by

$$\mathcal{F}_{m,k} = \frac{h_k}{\sqrt{y_r}} + \sum_{m=1}^{M-1} \varphi_{m,k} \quad (14)$$

where  $y_r$  represents the receive antennas.

To get a higher sum capacity requires decreasing the total power consumption at the transmitter. Where the power constraint that limits the total consumption circuit power is  $Q_{out} \leq Q_{max}$

$$Q_{out}^{max}(\zeta_m) = \varepsilon(Q_{max} - \zeta_m Q_{Ct}) \quad (15)$$

The efficiency of power allocation acts to constrain the consumption power when transmitting the number of available antennas using  $Q_{max}$ . Depending on the state channel matrix, we supposed that the RF chain is active to all antennas; otherwise the power must be consumed by the state channel and the transmitter power, which minimizes the BS consumption circuit power dependent on the knowledge of the state of channel denoted as  $H_{\zeta_m}$ .

The main contribution can be obtained by deriving the optimal number of RF chains from the large number of available antenna arrays at the BS to maximize data rate.

$$R = \max_{\zeta_m} \mathbb{E}_H [R_k(H_{\zeta_m})] \quad (16)$$

$$Q_{out}^{max} : \max_{Q_i^{opt}, R_k} R_k(H_{\zeta_m})$$

$$S. t, R_k(H_{\zeta_m}) \cong \mathbb{E}[\log_2(1 + \gamma_k)] \geq H_{\zeta_m, R_k}, \forall k; \quad (17)$$

$$Q_i^{opt} \in \cup^{M \times x_m}, O_m \geq K_m, \forall m; \sum_{m=1}^M O_m \leq O \quad (18)$$

$$\sum_{m=1}^M \zeta_m \geq K \quad (19)$$

where the average data rate constraints in equation (17). The knowledge of the state of channel denoted  $H_{\zeta_m, R_k}$  and used to provide the quality of service for different users, the  $O_m$  is the RF chains allocation and  $\zeta_m$  is the antenna coefficient  $m = [1, \dots, M]$ .

Depend on the optimal of beamforming  $\gamma_k$  and a CSI  $h_k$ , in addition to permit to decrease the number of transmitted RF chains under equal received power, the achievable data rate is expressed as

$$R_k(h_k, \gamma_k) = Q_k |h_k, \gamma_k|^2 \quad (20)$$

At transmitted power to cells, initially must be checking the status of channel is good. In this case, we can approximate the multi-user interference at  $K$ ,  $|h_k, \gamma_k| \rightarrow \infty$ . The number of schedule users must be not increasing more than the number of antenna selection according to equation (19). Consequently, the total transmit power, which cannot be increasing, is expressed as

$$\sum_{k=1}^K Q_k \leq Q \quad (21)$$

where  $Q$  the total power is transmitted according to Convex optimization in [14]; the transmit RF chain chooses the performing antenna selection when an equal power allocation including users as

$$Q_k = \left( \omega - \frac{1}{|h_k, \gamma_k|^2} \right)^T = \left( \omega - \frac{\tau^2}{\rho \alpha_k^2} \right)^T \quad (22)$$

The power constraint can be satisfied as

$$\sum_{k=1}^K \left( \omega - \frac{\tau^2}{\rho \alpha_k^2} \right)^T = Q_{out}^{max}(\zeta_m) \quad (23)$$

where  $\omega$  is the path loss exponent satisfying the constraint power,  $\tau$  is the noise power at receiver,  $\rho$  is the propagation loss and  $\alpha$  represents the diagonal matrix in data rate, which contains singular values  $\alpha_k$ .

To get the optimal number of RF chains to maximize the achievable data rate in the channel, requires equaling the power allocation which is used only in terms of active users, where  $Q_k =$

$Q_{out}^{max}(\zeta_m)/K$ . Moreover, reducing the transmitted power from the BS depend on select the optimal number of RF chains for choosing the best performing antenna selection as

$$\max_{Q_i^{opt}, R_k} R_k(H_{\zeta_m}) = \log_2 \left( 1 + \sum_{m=1}^M \frac{\mathbb{E}\|h_k h_l\|^2}{\alpha_i^2} Q_{out}^{max}(\zeta_m) \right) \quad (24)$$

$$\mathbb{E}\|h_k^H h_l\|^2 = \mathbb{E} \left[ |h_{k,1}^H h_{l,1} + h_{k,2}^H h_{l,2} + \dots + h_{k,m}^H h_{l,m}|^2 \right] \quad (25)$$

$$= M \mathbb{E}|h_{k,m}^H h_{l,m}|^2 + M Q_k^{dl} \mathbb{E}(h_{k,m}^H h_{l,m} h_{k,i} h_i^H) \quad (26)$$

$$\mathbb{E}\|h_k^H h_l\|^2 = \frac{Q_k}{K} \quad (27)$$

$$\beta = \sum_{m=1}^M \zeta_m \quad (28)$$

where  $\beta$  is the select antenna and  $\zeta_m$  is the coefficient antenna selection, from the SINR requires the optimal antenna selection satisfied as

$$\beta^{opt} = \arg \max_{\beta} R_k(H_{\zeta_m}) < \frac{Q_{max}}{Q_{ct}} \quad (29)$$

where  $\frac{Q_{max}}{Q_{ct}}$  represents the total number using the RF chain at transmit power at BS.

The optimal antenna selection using to determine the power consumed by the RF chains. The performance of the selected antenna in terms of equal power allocation is given by

$$\beta^{opt} = \frac{Q_{out}^{max}(\zeta_m) - Q_k K}{Q_{ct}} \quad (30)$$

### 3. NUMERICAL RESULT

In this section, we present numerical results that show the performance antenna for RF chains using Monte-Carlo simulations; the simulation parameters are shown in Table 1 where the number of antennas in the BS =220 ( $M$ ) and the number of users =15 ( $K$ ).

Table 1. System Parameters

Symbol	Description	Value
$K$	number of active users	15
$M$	number of antennas	220
$Q_c$	consumption power RF chains	0.05
$\omega$	path losses exponent	3.7
	cell radius for a circular cell	250
	minimum distance between UE and BS	35
	bandwidth	10KHz
	carrier Frequency	2.5GHz

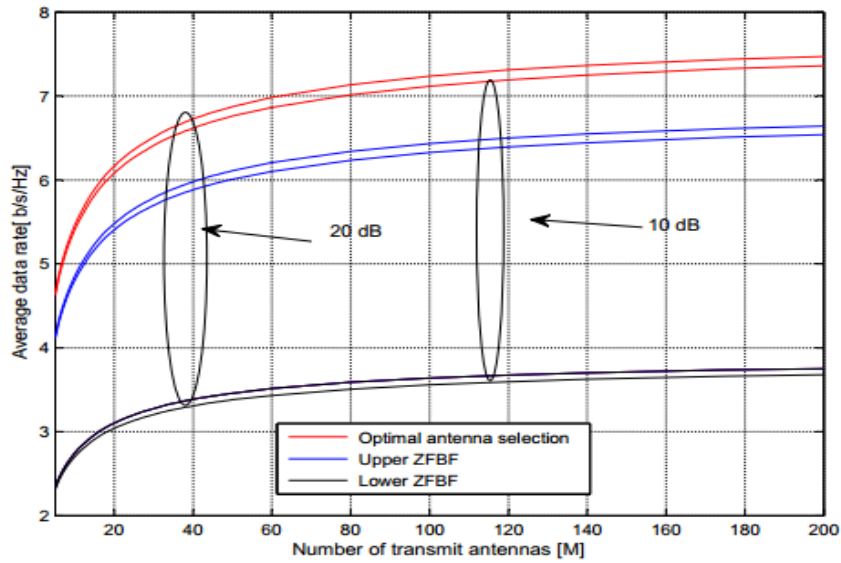


Figure 2. Averagedata rate with increased number of antenna array  $M$

In Figure 2, the average data rate increases with the number of antennae  $M$ , showing that the number of active users should be scheduled in each cell due to the transmitted power under the performance antenna selection at different SINR. We assume that the optimal antenna selection maximizes the achievable data rate and reduces the inter-user-interference subject to the linear precoding ZFBF. The achievable data rates increased because ZFBF enables the choosing of maximum power in relation to optimal antenna selection and is capable of working at high SINRs. Consequently, when the SINR=20 dB, the achievable data rate is higher than when the SINR=10 dB.

Figure 3 shows that when the number of RF chains increased, the transmitted power also increased. Consequently, increasing the number of RF chains increased the achievable data rate, allowing for a decrease in the number of transmitted RF chains under equal received power and distributed power among users. In Figure 3, the conjugate ZFBF gave the nearest value of the optimal beamforming using the equal power allocation, which enhanced the system performance and increased the data rate when the power was allocated to equal users in the same cluster.

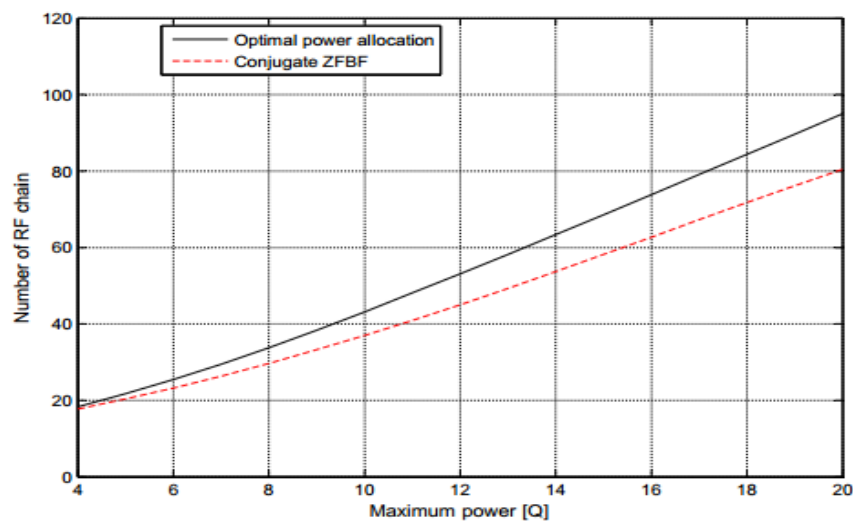


Figure 3. Effect of transmit number of the RF chain in the BS with maximum power

In Figure 4, the achievable data rate is dependent on how many antennas can be selected, where the number of RF chains depended on the number of best performing antennas, selected for different values of total accessible power transmitted from the BS to cells and distributed power among users. In Figure 4, the maximal data rate that can be obtained depended on allowing for a decrease in the number of transmitted RF chains under equal received power. This depended on selecting the highest performing antennas at maximum power = 8 dB, while the average data rate decreased with the increased number of RF chains at the lower maximum power = 4 dB. Consequently, the average data rate increase when using fewer RF chains was dependent on the best performing antenna selection and distributed power among users.

In Figure 5, the limited RF chain gave the better result at using optimal ZFBF  $\gamma_k^{opt}$ . The receiver of the RF chain depended on the equal received power allocation, which reduces the effect channel where the ZF baseband precoding is closed to the optimal massive MIMO system. Consequently, with an increased number of RF chains using ZFBF at  $M=128$ , transmit antennas give the high data rate. While reducing the number of RF chains using optimal ZFBF gives  $M=64$ , we noted that the achievable data rate is smaller than compared with  $M=128$ . Meanwhile, the optimal number of RF chains was equipped with 128 antennas serving active users  $K=8$ , which was able to suppress high SINR in order to get high average data rates by using equal power allocation beamforming.

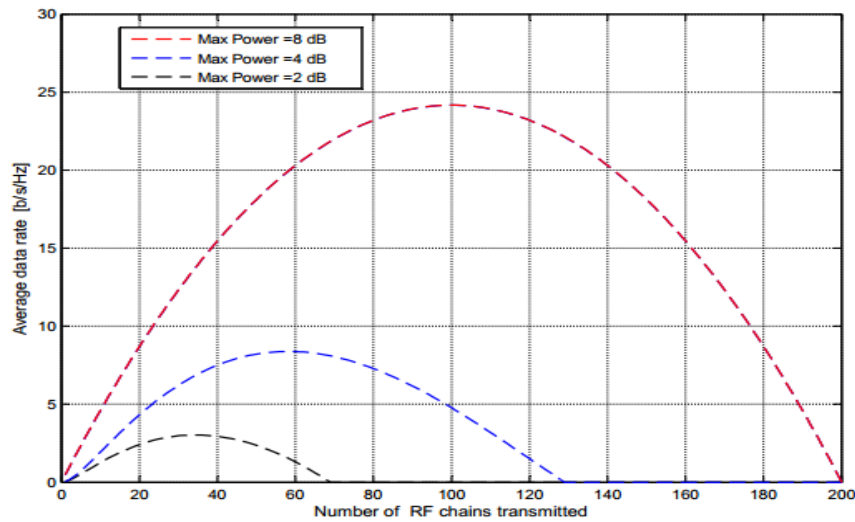


Figure 4. Effect of increased RF chains on the data rate at increased power

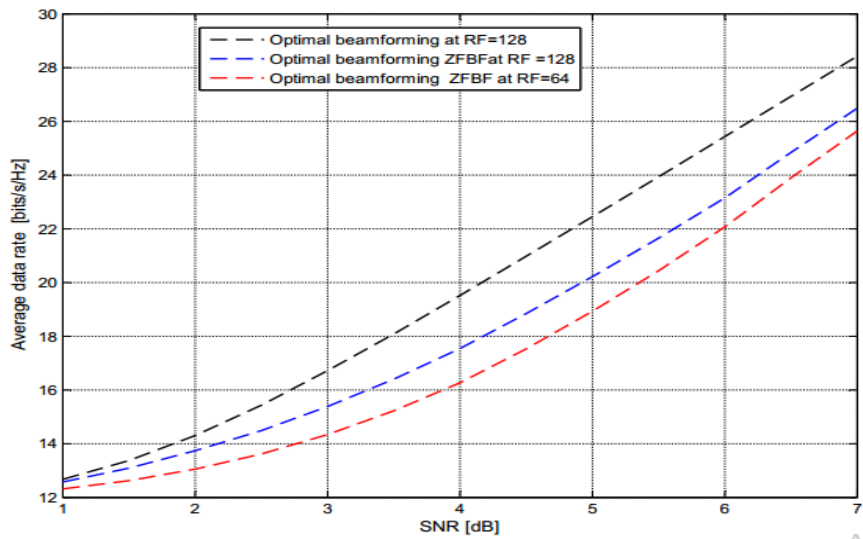


Figure 5. Effect of SNR on the increase of average data rate

#### 4. CONCLUSION

This paper presented the number of RF chains required to reduce the consumption of circuit power to provide the maximum data rate with a limited number of RF chains by performing antenna selection and good CSI for equal received power among the active users. Consequently, performing antenna selection with a limited number of antenna arrays and using equal received power allocation for lower and upper ZFBF at different SINRs provided the maximum data rate. The maximal data rate that can be obtained depended on allowing for a decrease the number of transmitted RF chains under equal received power among users, which depends on selecting the highest performance antennas selection.

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