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Performance analysis of joint transmit antenna selection and user scheduling for massive MIMO systems

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Abstract: To alleviate the problem of hardware complexity, energy wastage and increased cost of deployment in massive multiple input multiple output (MIMO) system, joint antenna selection and user scheduling (JASUS) algorithms are proposed which reduce the computational complexity of optimal exhaustive search algorithm with a scarification of some spectral efficiency (SE). These algorithms remove the worst performance antenna greedily and results in best set of antennas and users at the same time. But all JASUS algorithms use semi-orthogonal user scheduling (SUS) to select users and zero forcing (ZF) precoding to mitigate co-channel interferences. A semi-orthogonal user scheduling scheme generates a high computational complexity for massive MIMO systems. Therefore, in this work with the objective of reducing the complexity of SUS, we implement two low complexity user scheduling in JASUS algorithm. These are norm-based user scheduling (NUS) and random user scheduling (RUS). Also, we apply minimum mean square error (MMSE) and maximum ratio transmission (MRT) precoding techniques along with user scheduling schemes to examine their SE and computational complexity performance when implemented in JASUS algorithm. Compared with the originally implemented SUS user scheduling technique, NUS showed a slightly better SE performance under all precoding schemes with a much reduced complexity. RUS shows around 3 bits/s/Hz performance decrement with much less computational complexity as compared to SUS in JASUS algorithm. Also, performance

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PUBLIC INTEREST STATEMENT

Wireless communication systems are the noticeably emergent technologies of these decades. 5 G communication system has benefits of high communication speed, low latency and supports connectivity for a number of devices. Massive multiple input multiple output systems have been considered or addressed as a promising candidates in 5 G generation networks and are expected to play a key roles in future communication system too. Currently, researchers are very interested to improve the spectral and energy efficiency and alleviate the problem of hardware complexity of the system. One of the state-of-art in this emerging technology is to propose an algorithm on user scheduling and antenna selection of massive multiple input and multiple output system.

comparison of precoding techniques showed that MMSE results in best SE performance in most considered scenarios with all considered user scheduling schemes.

Subjects: Technology; Electrical Engineering Communications; Telecommunication

Keywords: JASUS; massive MIMO; precoding

1. Introduction

In Massive multiple input multiple output (Ma-MIMO), the base station (BS) is equipped with large number of antennas to serve several users simultaneously in the same frequency band. It is also known as large-scale antenna systems and promises significant gains in terms of spectral efficiency (SE) and energy efficiency (EE) to accommodate a large number of users at extraordinarily high data rates with better reliability while consuming much less power. Ma-MIMO is one of the exciting technologies enabling the fifth generation (5 G) and beyond fifth generation (B5G) wireless cellular networks (Khandaker & Wong, 2018; Ngo et al., 2013).

However, the benefits of Ma-MIMO come with a cost of some price. Using large number of transmitter antennas at the BS requires radio frequency (RF) equipment for individual antennas which greatly increase the energy consumption and hardware complexity. Therefore, when there are a large number of transmit antennas but a limited number of RF chains, the system performance can be optimized by selecting a subset of transmit antennas with good channel conditions. User selection should be performed with antenna selection to restrict the maximum number of users from surpassing the selected antenna number. A brute force search (BFS) algorithm which selects the best set of antennas and users from all possible sets of antennas and users guarantee optimum performance. But it cannot be used in practical scenario because of its high computational complexity. Variants of greedy-based joint antenna selection and user scheduling (JASUS) algorithm are proposed to reduce the computational complexity of BFS with a close SE performance. In the work by Xu et al., (2014), the authors proposed a joint antenna selection and user scheduling scheme for the downlink-distributed massive MIMO systems. In this paper, the joint antenna selection and user scheduling is formulated as a sum-rate maximization problem under backhaul capacity constraint. In the work by Liu & Wang, (2016) the authors investigated the antenna selection and user scheduling problems in massive MIMO non-orthogonal multiple access (NOMA) system. This paper is on massive MIMO-NOMA transmission scheme where a successive interference cancellation scheme is implemented to solve inter user interference problem. In the work by Benmimoune et al., (2015), a greedy-based sum-rate maximizing JASUS algorithm is proposed which greatly reduces the computational complexity of BFS with a few amount of SE scarification. The authors Dong et al., (2017) proposed two variants of JASUS algorithm which improve the SE of the work by Benmimoune et al., (2015) by 0.5b/s/HZ with reduced complexity. The papers by Benmimoune et al., (2015); Dong et al., (2017) use a semi-orthogonal user scheduling (SUS) scheme to select users and zero forcing precoding for interference cancellation. In the work by Li et al., (2018), JASUS algorithm is proposed which incorporates matrix Gaussian elimination method to schedule users which results in a better SE and higher computational complexity when compared with SUS. Olyaee et al., (2017) proposed JASUS algorithm with the aim of maximizing energy efficiency. In this paper, SE of the algorithm is not considered. SUS with computational complexity of $\mathcal{O}(M^3K)$ (Mao et al., 2012) generates a high computational complexity for massive MIMO systems. The computational complexity rises with a cubic scale as the number of antenna increases. The authors Sheikh et al., (2019a, 2019b, 2020, , 2021) proposed a variety of antenna and user selection schemes. They implement their algorithms under different scenarios. In these papers, MMSE, MRT and ZF are used to mitigate interferences. Also, they used SUS and RUS user scheduling methods along with antenna selection. But the antenna selection mechanism is dependent on the norm of user channel rather than the iterative capacity maximizing method. In this paper, with the aim of reducing the computational complexity of greedy-based capacity maximizing JASUS algorithm due to SUS, we implement two low complexity conventional user scheduling schemes (NUS and RUS) in the greedy-based JASUS algorithm. Also, we use minimum mean square error (MMSE) and maximum ratio transmission (MRT) precoding techniques along with user scheduling schemes for interference cancellation.

Greedy-based capacity maximizing JASUS algorithm removes antennas with worst SE performance at each iteration by simultaneously selecting users. The greedy-based algorithms are good in reaching the capacity of an optimal BFS algorithm with scarification of some SE values. But the proposed greedy-based JASUS algorithms previously used semi-orthogonal user scheduling schemes which result in a high computational complexity when used in JASUS algorithm. In this paper, we showed the spectral efficiency of low complexity user scheduling techniques, especially NUS is comparable with SUS when implemented in greedy-based JASUS algorithm. In this paper, the computational complexity of JASUS algorithm is decreased without degrading SE of the system. Moreover, the performance of different precoding techniques combined with user scheduling techniques is analyzed when they are used in capacity maximizing greedy-based JASUS algorithm under different scenarios.

This paper is organized as follows. Section 2 explains system model and algorithms, precoding techniques and user scheduling schemes. In section 3, computational complexity is analyzed in detail. Finally, simulation results and discussion are demonstrated in section 4 and concluding remarks are made in section 5.

2. System model and algorithms

In this paper, a single cell multi-user MIMO system, which consists X total users each with a single antenna, is considered. A BS is equipped with M antennas and N RF chains as depicted inFigure 1.

A JASUS algorithm at the transmitter selects $K \leq N$ users and N antennas with the objective of maximizing broadcast sum-rate. The selected N antennas are then connected to the N RF chains through the RF switch. In other words, the transmitter chooses two sets **A** and **U**, defined as sets of selected transmit antennas and scheduled users, respectively. The scheduled users' data are then processed by the precoder and transmitted by the N selected transmit antennas through the channel (Benmimoune et al., 2015).

2.1. Precoding techniques

In this work, we consider a multi-user massive MIMO system with total M antennas at the BS and K users which are served at the same time by the available antennas. The transmission channel model from antenna $'m'$ to user $'k'$ is assumed to be Rayleigh fading so that the channel gain $|h_{mk}|$ is a Rayleigh distributed random variable.

In multi-user system, linear precoding techniques are implemented to reduce the effect of inter-user interference. When the number of antennas is large as compared to the number of users, linear precoding system in the downlink and linear detection in the uplink result in optimal performance (Ngo, 2015). In this paper, we implement three conventional precoding techniques which are MMSE, MRT and zero forcing (ZF) precoding. The linear precoder apply linear processing on the users' data before transmission so that inter-user interference becomes negligible or totally canceled in the desired spatial direction. Each user symbol s_k is multiplied by its respective weight vector $\mathbf{w_k}$; then the weighted symbols are added together to form a transmitted vector $\mathbf{x}$ (Ngo et al., 2013).

$$\mathbf{x} = \sum_{k=1}^{K} s_k \mathbf{w_k} = \mathbf{W}\mathbf{S_d} \tag{1}$$

where $\mathbf{x} \in \mathbb{C}^{MX1}$

Table 1. Approximate computational complexity of JASUS algorithm under different user scheduling and precoding implementation

Combination of precoding and scheduling in JASUS	Asymptotic computational complexity
SUS-channel inversion	$\sum_{i=1}^{M-N} M-i+1((M-i+1)^3 S+N^3)$
SUS-MRT	$\sum_{i=1}^{M-N} M-i+1(\left(M-i+1)^3 S+(M-i+1)N\right)$
NUS-channel inversion	$\sum_{i=1}^{M-N} M-i+1((M-i+1)S+N^3)$
NUS-MRT	$\sum_{i=1}^{M-N} M-i+1((M-i+1)(S+N))$
RUS-channel inversion	$\sum_{i=1}^{M-N} M-i+1(N^3)$
RUS-MRT	$\sum_{i=1}^{M-N} M-i+1((M-i+1)N)$

$$\mathbf{S_d} = [s_1, s_2, \ldots.., s_K]^T, \quad \text{and} \quad \mathbf{W} = [\mathbf{w_1}, \mathbf{w_2}, \ldots..\mathbf{w_K}]$$

Each users symbol s_k is a complex independent identical distribution (iid) random variable with $E\left\{|s_k|^2\right\} = 1$. $\mathbf{W}$ is normalized to fulfil the total transmission power constraint $P = tr(\mathbf{W}^H\mathbf{W})$, where $tr(*)$ is a trace function. After a signal is transmitted through the available antennas, the received signal vector $\mathbf{y}$ is expressed as (Ngo et al., 2013)

$$\mathbf{y} = \mathbf{H^T x} + \mathbf{n} \tag{2}$$

$$\mathbf{n} \in \mathcal{N}\left(\mathbf{0}, \sigma^{\mathbf{2}}\right),$$

$$\mathbf{y} \in \mathbb{C}^{KX1}$$

where n is additive white Gaussian noise vector with zero mean and variance σ^2 and $\mathbf{H}$ is total channel matrix. Each users' received vector $\mathbf{y_k}$ can be obtained from Equation (2) and expressed as

$$\mathbf{y_k} = \mathbf{h_k^T w_k} + \sum_{i \neq k} \mathbf{h_k^T w_i s_i} + n \tag{3}$$

The second term in Equation (3) represents inter-user interference. The noise power σ^2 is assumed to be the same for all users.

2.1.1. Zero forcing (ZF) precoding

In ZF precoding, all the interferences in the desired direction are effectively cancel out. The ZF matrix $\mathbf{W}$ can be found from the pseudo inverse of channel coefficient matrix $\mathbf{H}$ (Bjornson et al., 2015).

$$\mathbf{W} = \mathbf{H}(\mathbf{H}^H\mathbf{H})^{-1} \tag{4}$$

The second term of Equation (3) will be zero for ZF precoding case as it cancels all interferences from other users. The received signal and signal-to-noise plus interference ratio (SINR) for each user can be expressed as Equations (5) and (6), respectively.

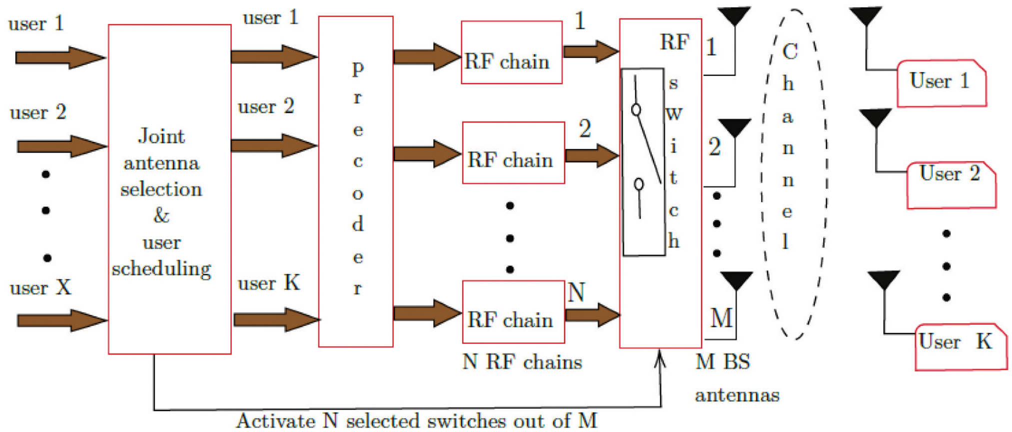

Figure 1. System model of a single cell MU-MIMO system that selects N antennas from M BS antennas and at the same time schedules $K \leq N$ users from X total users.

$$y_k^{zf} = \mathbf{h}_\mathbf{k}^\mathbf{T}\mathbf{w}_\mathbf{k}s_k + n \tag{5}$$

$$SINR_k^{zf} = \frac{|h_k^T w_k|^2}{\sigma^2} \tag{6}$$

We can derive the average broadcast sum-rate that can be achieved by users available in the user set **U** when ZF precoding is applied and shown in Equation (7).

$$R_{sum}^{ZF}(\mathbf{A}, \mathbf{U}) = E\left[\sum_{k\in\mathbf{U}} \log_2(1 + SINR_k^{ZF}(\mathbf{A}, \mathbf{U}))\right] \tag{7}$$

where $R_{sum}(\mathbf{A}, \mathbf{U})$ implies the broadcast sum rate achieved by the users in the user set **U** simultaneously served by antennas in the set **A** (when ZF precoding is applied) and $SINR_k(\mathbf{A}, \mathbf{U})$ is the signal to interference plus noise ratio of each user in the set **U** served by antennas in the set **A**.

With the objective of maximizing Equation (7) and under the total transmit power constraint P at the BS, the optimal power allocation strategy is achieved by means of water-filling algorithm for ZF precoding (Sanguinetti & Poor, 2009). In this power allocation strategy, the total power P is allocated to each user according to

$$p_k = [\mu\gamma_k - 1]^+ \tag{8}$$

where γ_k, μ and p_k represent the effective channel gain at the k^{th} user, a water level and power allocated to each user, respectively.

2.1.2. Minimum mean square error (MMSE) precoding

MMSE approach introduces a regularization term before the channel inversion that allows for a balance to be found between the noise covariance and the transmit power. It is sometimes also referred as regularized zero-forcing (RZF). It is the optimized version of the pseudo-inversion which addresses the poor performance of ZF precoding at low SNRs. The un-normalized MMSE precoding matrix is given by (Peel et al., 2005)

$$\widetilde{W} = H(H^H H + \frac{|U|\sigma^2}{P} I)^{-1} \tag{9}$$

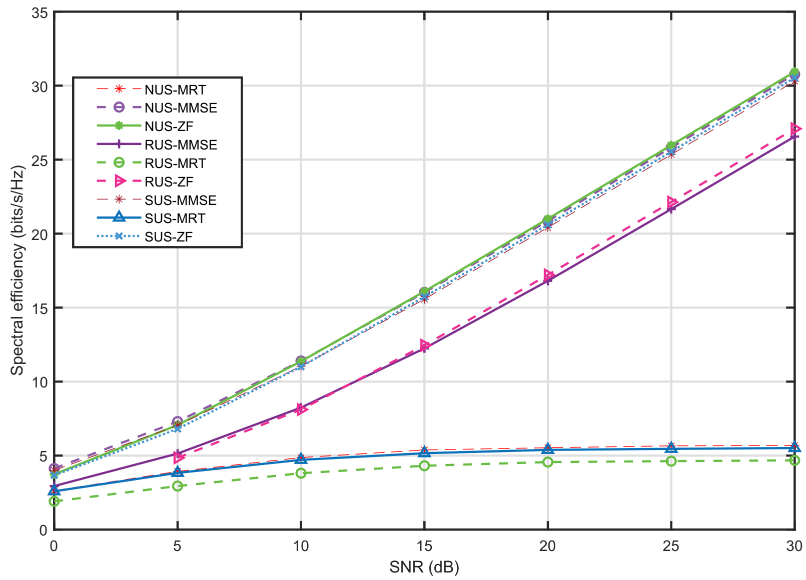

Figure 2. Spectral efficiency performance comparison of user scheduling schemes in JASUS algorithm using different precoding type. M = X = 10 and N = K = 3.

$|U|$ and P represent the number of users in the user set $\mathbf{U}$ and the total available power at the BS, respectively. $\mathbf{I}$ is an identity matrix.

$\widetilde{\mathbf{W}}$ is normalized by normalization factor η with the aim of satisfying the power constraint. Thus, the SINR and average sum-rate achieved by users in the set $\mathbf{U}$ for MMSE precoding are given in Equations (10) and (11), respectively.

$$SINR_k^{MMSE} = \frac{\left|\mathbf{h_k}^T\mathbf{w_k}\right|^2}{\sum_{i\neq k}\left|\mathbf{h_k}^T\mathbf{w_i}\right|^2 + \sigma^2} \tag{10}$$

$$R_{sum}^{MMSE}(\mathbf{A},\mathbf{U}) = E\left[\sum_{k\in\mathbf{U}}\log_2(1 + SINR_k^{MMSE}(\mathbf{A},\mathbf{U}))\right] \tag{11}$$

2.1.3. Maximum ratio transmission (MRT) precoding

This precoding technique focuses on magnifying the signal-to-noise (SNR) while it does not consider inter-user interference minimization. Due to this reason, the signal processed with MRT precoding and received at the user suffers with inter-user interference. But, MRT is a low complex technique for implementation because it does not need any channel inversion like that of ZF and MMSE precoding techniques. Similarly, SINR and average sum-rate of MRT precoding are given by

$$SINR_k^{MRT} = \frac{\frac{1}{\eta^2}|\mathbf{h_k}|^4}{\frac{1}{\eta^2}\left(\sum_{i\neq k}\left|\mathbf{h_k}^T\mathbf{h_i^*}\right|^2\right) + \sigma^2} \tag{12}$$

$$R_{sum}^{MRT}(\mathbf{A},\mathbf{U}) = E\left[\sum_{k\in\mathbf{U}}\log_2(1 + SINR_k^{MRT}(\mathbf{A},\mathbf{U}))\right] \tag{13}$$

2.2. User scheduling schemes

In Ma-MIMO systems, antenna selection is the factor that makes user scheduling important. A SUS that is widely used in conventional MU-MIMO system generates a cubic scale of computational complexity as the number of antennas increase. It is obvious that JASUS algorithm that employs SUS will suffer with computational burden. In this section, we provide the description of the two user scheduling schemes which will be implemented in JASUS algorithm which is proposed by Benmimoune et al., (2015).

Norm-Based User Scheduling (NUS) scheme is based on the norm (channel gain) of users' channel and it is a simple scheme as it requires a single iteration. Algorithm 1 shows the pseudo code of NUS. Line 1 of algorithm 1 calculates the norm of each user channel vector from the channel matrix formed by antenna set **A** and user set **U** and sorts in descending order based on the magnitude of the channel vectors. Then, N users with largest channel gain is selected (line 2 of algorithm 1).

Algorithm 1: Steps of norm based user scheduling (Zhang et al., 2009)

Input:

Set of available antennas **A**

Number of available RF chains N

Initialization:

$\mathbf{U} = \{1, 2 \ldots.., K\};$

$S = \emptyset$

1. For $k = 1, 2, \ldots.., K$,sort all $||h_{k,\mathbf{A}}||_2,$, such that

$||h_{\pi(1)} \geq h_{\pi(2)} \geq, \ldots.. \geq h_{\pi(K)}||$

2. $S = \{\pi(1), \pi(2), \ldots.., \pi(N)\}$

Random User Scheduling (RUS) is the simplest user selection method and selects users randomly independent of their channel realizations. Algorithm 2 describes the steps of RUS. It simply picks a random N user index from the available K user index and the set S consists the selected N users (Zhang et al., 2009).

Algorithm 2: Steps of random user scheduling (Zhang et al., 2009)

Input:

Set of available antennas **A**

Number of available RF chains N

Initialization:

$\mathbf{U} = \{1, 2 \ldots.., K\};$

$S = \emptyset$

1. Let $S = \{\pi(1), \pi(2), \ldots.., \pi(N)\}$ be a set of any N random indices from $\{1, 2 \ldots.., K\};$

2. $S = \{\pi(1), \pi(2), \ldots.., \pi(N)\}$

2.3. Joint antenna selection and user scheduling (JASUS) algorithm

The strategy of selecting antennas and schedule users depends on the system performance metrics to be optimized. Since band width is a scarce resource in wireless communications; SE is one of the performance metrics to be optimized in massive MIMO systems. In line with this fact, the goal of most JASUS algorithms is to maximize the SE as much as possible with low computational complexity. The joint antenna selection and user scheduling optimization problem can be written as (Benmimoune et al., 2015)

$$\max_{\mathbf{A},\mathbf{U}} .R_{sum}(\mathbf{A},\mathbf{U}) = \max_{\mathbf{A},\mathbf{U}} .E\left[\sum_{k\in\mathbf{U}} log_2(1+SINR_k(\mathbf{A},\mathbf{U}))\right] \tag{14}$$

subject to

$$|\mathbf{U}| \leq |\mathbf{A}| \leq N; \quad \text{and} \quad \sum_{m\in\mathbf{A}} \sum_{k\in\mathbf{U}} p_k = P$$

For the given applied precoding type, $R_{sum}(\mathbf{A},\mathbf{U})$ expression is substituted by one of the respective broadcast sum-rate equation.

$$R_{sum}(\mathbf{A},\mathbf{U}) = \begin{pmatrix} R^{ZF}_{sum}(\mathbf{A},\mathbf{U}) & \textit{for ZF precoding} \\ R^{MMSE}_{sum}(\mathbf{A},\mathbf{U}) & \textit{for MMSE precoding} \\ R^{MRT}_{sum}(\mathbf{A},\mathbf{U}) & \textit{for MRT precoding} \end{pmatrix}$$

Algorithm 3 describes the steps of JASUS algorithm. Lines 4 and 5 of algorithm 3 are the sections of algorithm where we apply low complexity user scheduling schemes (line 4) and two different precoding techniques (line 5). The original JASUS algorithm proposed by Benmimoune et al., (2015) uses SUS for user selection and ZF precoding as interference cancellation.

Algorithm 3: Steps of JASUS Algorithm

Input:

Channel coefficients **H**;

Number of RF chains N

InitInitialization:

$t \leftarrow 1$

$\mathbf{A} \leftarrow \{1, \ldots., \mathbf{M}\}$

1 **while** $t<N$ **do**

2 $maxRate \leftarrow 0$;

3 **foreach** $m \in \mathbf{A}$ **do**

4 $U_t \leftarrow$ a set of N users using USS($\mathbf{A}\backslash\{m\}, N$)

5 $R\_m = R_{sum}(\mathbf{A}\backslash\{m\}, U_t)$

6 **if** $maxRate>R\_m$ **then**

7 $maxRate \leftarrow R\_m$;

8 $m_{bad} = m$;

9 $\mathbf{U} = \mathbf{U_t}$

10 **end**

11 **end**

12 $\mathbf{A} \leftarrow \mathbf{A} \backslash \{m_{bad}\}$;

13 $t \leftarrow t + 1$;

14 **end**

Output: The set of antennas given by **A** and the set of users given by **U**

At each iteration, the algorithm removes the worst antenna and schedule users using the three user scheduling schemes. It starts by initializing **A** with the set of all antennas. In each new iteration, the algorithm looks for the antenna to be removed from **A**. To this end, it iterates over all the elements in this set in order to find the worst antenna, i.e. the one without which the system can provide the maximum sum-rate. The algorithm terminates when it performs exactly $M - N$ iterations producing a set of exactly N antennas and a set of at most N users. The sum-rates (line 5 of Algorithm 3) are computed based on one of the three user scheduling schemes taking as input the set **A** deprived of one antenna and the set of all users **U**. The JASUS algorithm selects the user set (U_t) (line 4) by using a set of antennas deprived of one antenna and number of RF chains. Line 12 shows the removal of the worst performance antenna designated by m_{bad} from the current antenna set **A**. Also, to calculate the sum-rates, the channel matrix formed by the selected user set (U_t) is precoded using one of the three precoding types (MMSE, MRT, ZF).

3. Computational complexity

Computational complexity refers to the processing time required to execute a certain algorithm at the transmitter (Castaneda et al., 2016). In this paper, we use a simplified flop count method, “Big-O” ($\mathcal{O}(.)$), to compare the computational complexity performance of the JASUS algorithms with different user scheduling and precoding techniques. The computational complexity of NUS mainly comes from calculating the frobenius norm of an MXS matrix and roughly $\mathcal{O}(MS)$. SUS has a computational complexity of $\mathcal{O}(M^3S)$. RUS simply selects users without any floating operation so it has a complexity of roughly $\mathcal{O}(1)$ (Liu et al., 2015; Mao et al., 2012). The computational complexity of MMSE and ZF precoding is mainly due to the channel inversion operation on MXS matrix and it can be approximated as $\mathcal{O}(S^3)$. MRT can be considered as matched filtering and its computational complexity is given by $\mathcal{O}(MS)$. The computational complexity of JASUS algorithm accounting both scheduling and precoding techniques can be given as

$$\sum_{i=1}^{M-N} M - i + 1(\mathcal{T} + \mathcal{R}) \tag{15}$$

where $\mathcal{T}$ and $\mathcal{R}$ represent the computational complexity of user scheduling schemes and precoding techniques, respectively. After a given user scheduling technique selects at most N users, precoding is performed on N column channel matrix to calculate sum-rate (line 5 of algorithm 3). Therefore, we approximate the computational complexity of MMSE and ZF to matrix channel inversion complexity ($\mathcal{O}(N^3)$) for both techniques. Since one antenna is removed at each outer loop iteration and N user are selected in the inner loop, the channel matrix for scheduling and precoding in the inner loop will have a dimension of $(M - i + 1)XS$ and $(M - i + 1)XN$, respectively. Table 1 shows the asymptotic computational complexity of JASUS algorithms for each

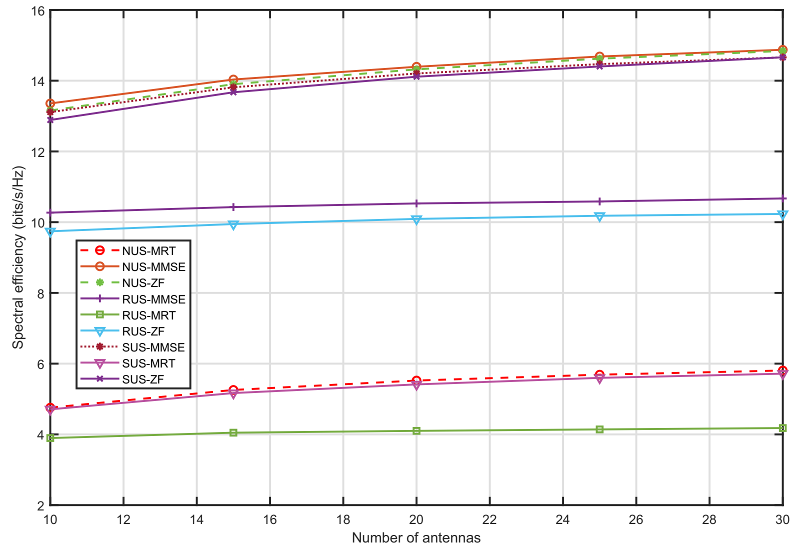

Figure 3. Spectral efficiency performance comparison of user scheduling techniques in JASUS algorithm when the available BS antenna is varied using different precoding. X = 10, N = 4, K = 4 and SNR = 10 dB.

combination of user scheduling and precoding techniques. To eliminate the variable ambiguity, we assume $S = X$ and $K = N$.

4. Results and discussion

In this section we present the SE performance comparison for the combination of two user scheduling and two precoding techniques in JASUS algorithm with a previously implemented SUS-ZF in different scenarios. Also, we provide the computational complexity performance of JASUS algorithm in all combinations of precoding and user scheduling techniques. The performance is simulated for single cell. The number of total antennas and users as well as the number of users considered are the same with the previous work of Benmimoune et al., (2015). The sum-rate for each case is averaged for 1000 channel realizations.

4.1. Spectral efficiency performance evaluation at different SNR values

In this section, the SE performance of JASUS algorithm using a combination of different scheduling and precoding technique for different values of SNR in (dB) is provided. From Figure 2 the upper most results are obtained from the combination of SUS and NUS with ZF and MMSE precoding techniques. NUS shows a slightly higher performance than SUS in the JASUS algorithm with both precoding. The combination of NUS with MMSE gives the highest performance at low SNR values but as SNR increases, ZF precoding takes over the highest Performance. This is due to the optimal water-filling power allocation which allocates power more efficiently as transmit power increases. The middle results are the results from RUS in combination with ZF and MMSE precoding. RUS is expected to have lower performance than NUS and SUS as it selects users randomly. It is almost 3 bits/s/Hz down from SUS and NUS at 10 dB. Also, RUS-ZF shows a slightly better performance than RUS-MMSE for higher SNR values. The bottom results are due to MRT precoding for the three user scheduling schemes. MRT, which is limited by inter-user interference, shows least performance than MMSE and ZF. NUS with MRT have a slightly higher performance than SUS and RUS.

4.2. Spectral efficiency performance evaluation for variable number of antennas

The results in Figure 3 show that the SE performance of the JASUS algorithm increases slowly as the number of total antennas increase. This is due to the spatial selectivity gain of antenna selection. NUS shows a slightly better performance than SUS throughout all regions of total number of antennas in all precoding techniques. The large number of antennas at the BS enables simple user grouping schemes like NUS to have a comparable SE performance with user scheduling schemes that relies on user separability. RUS shows the lowest performance in comparison with

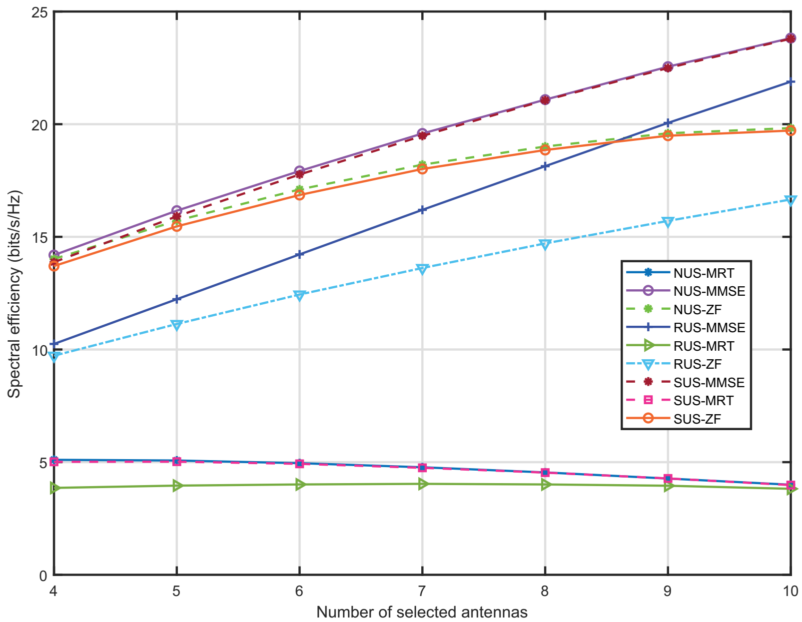

Figure 4. Spectral efficiency performance comparison of user scheduling schemes in JASUS algorithm with different number of selected antenna under different precoding. M = 14, X = 14 and SNR = 10 dB.

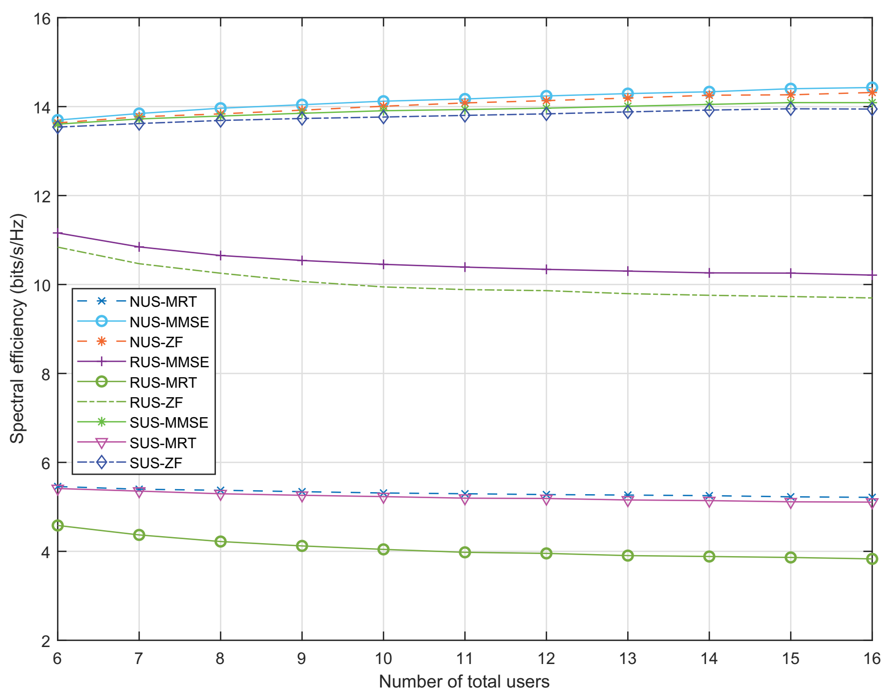

Figure 5. Spectral efficiency performance comparison of user scheduling schemes in JASUS algorithm with various number of users with different precoding. M = 16, N = K = 4 and SNR = 10 dB.

NUS and SUS, and it indicates a performance gap of 3.41 b/s/Hz with NUS at M = 10. Figure 3 also shows that the SE performance of JASUS in MMSE is better than ZF for entire number of antennas in all user scheduling schemes, especially in small number of antennas. But, as the number of antennas increase, the performance gap decreases which verifies that ZF is an optimal precoding for large-scale antenna system.

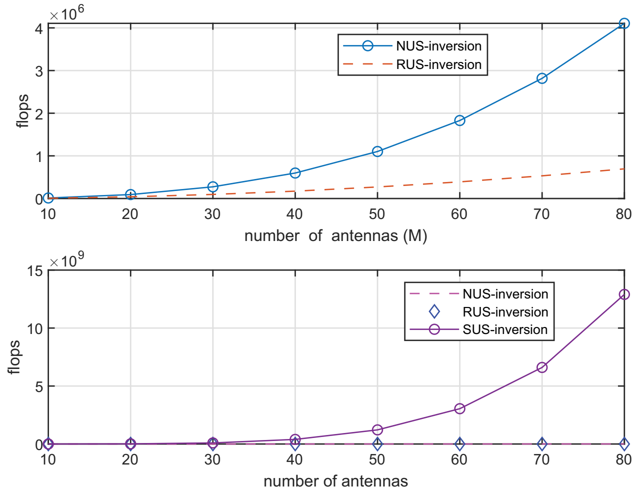

Figure 6. Asymptotic computational complexity of JASUS algorithm with different user scheduling and channel inversion precoding (MMSE and ZF).

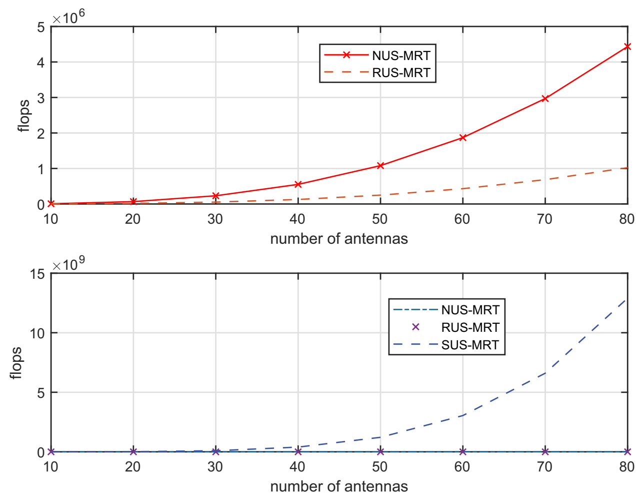

Figure 7. Asymptotic computational complexity of JASUS algorithm with different user scheduling and MRT precoding.

4.3. Spectral efficiency evaluations for different number of selected antennas

Figure 4 reveals the performance comparison of user scheduling schemes in JASUS algorithm when the number of selected antenna is varied for the three precoding techniques. In this case, the number of selected antenna and users are the same. So that, when the selected number of antennas increase, the selected user will also increase. The performance is increasing for all scheduling techniques under MMSE and ZF precoding. The performance gap between MMSE and ZF is increasing as the number of selected antenna increases. ZF shows a slow and saturating increment while MMSE has a constant increasing performance. This is due to the fact that MMSE has a linear increment as the number of users increase. For all user scheduling schemes, MRT shows a decreasing performance due to increased inter-user interference problem as the number of users increase.

4.4. Spectral efficiency versus number of available users

It is clear that as the number of users increases the spatial orthogonality between users diminishes and this increases the inter-user interference between users by increasing the channel correlation. MRT, which does not consider elimination of co-channel interference, is prone to inter-user interference in this scenario. From Figure 5 one can see that the SE performance of JASUS is increasing at a slow rate for NUS and SUS with channel inversion type precoding. As the user number increases, the probability of getting users with good channel conditions will increase for NUS and SUS. With the support of channel inversions which minimize interference in the desired direction, SINR will increase as the total available users increase for SUS and NUS, so that the SE performance of JASUS increases with the number of users. But, RUS shows decreasing performance when the number of users increase as it selects users randomly without any criteria.

4.5. Computational complexity of JASUS for the variations of antenna number

The numerical values are found using Table 1 by setting $S = X$. To plot the computational complexity of JASUS, we varied the number of antennas between 10 and 80 whereas the other parameters are constant with values $X = 20, N = k = 6$. Figure Figure 6 shows the complexity of JASUS algorithm with the combination of user scheduling and precoding types which perform channel inversion (MMSE and ZF). Even though JASUS in NUS and SUS shows a curved scaling, the computational complexity in SUS is rapidly increasing as the the number of antennas increase as compared to NUS. The computational complexity of JASUS algorithm with NUS is in mega flops while that of SUS is in giga flops. This confirms that JASUS algorithm with NUS results in lower computational complexity than JASUS with SUS. Figure 7 compares the complexity of JASUS algorithm under the implementation of MRT precoding with the three user scheduling schemes. Since the number of antennas (M) is the variable parameters by assuming other parameters constant, the computational complexity scaling is dominated by user scheduling complexity. This is why the two figures show the same increment pattern for the channel inversion and MRT precoding.

5. Conclusion

Due to huge computational complexity generated by SUS when implemented in the JASUS algorithm, it is necessary to apply lower complexity user scheduling schemes in massive MIMO systems. In this work, we apply two lower complexity user scheduling schemes (RUS and SUS). From the obtained results it can can be concluded that, in massive MIMO systems selecting users based on their channel magnitude results in a significant reduction in computational complexity with a negligible SE improvement when applied in a greedy-based JASUS algorithm in comparison with a SUS. RUS with its least complexity in the JASUS algorithm shows a SE performance decrement than SUS and NUS. It shows around 2 and 3 bits/s/Hz performance decrement than the other scheduling schemes. Unlike NUS and SUS, RUS does not exploit the benefits of multi-user diversity. Performance evaluation of precoding techniques shows that with a negligible performance gap, MMSE out performs ZF precoding in low SNR values while at higher SNR values ZF gives better performance than MMSE due to the optimal water-filling power allocation.

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