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Channel Gain Based User Scheduling for 5G Massive MIMO Systems

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***Abstract*—Massive multiple-input multiple-output (MIMO) is a key enabling technology for next-generation 5G networks. It groups antennas at both transmitter and the receiver to achieve high spectral efficiency.During downlink, the base station can schedule more than one user at a time to maximize the system capacity of the system. In this paper, we propose a novel channel gain based user scheduling algorithm for massive MIMO system and compare it with conventional scheduling algorithms in terms of error performance, sum rate, throughput, and fairness. The simulation results show that our proposed channel gain based user scheduling algorithm achieves better error performance, improves sum capacity and throughput, and guarantees fairness among users.**

***Index Terms*—Massive MIMO, 5G, spectral efficiency, scheduling, sum capacity, throughput, fairness**

I. Introduction

Over the last few decades, wireless communication technology has advanced significantly and wireless data traffic is increasing exponentially. With the swift progression of the new technologies like Internet of Things (IoT) and machine to machine communication (M2M), the surge in wireless data traffic is expected for the next few decades as well. The future generation network 5G is expected to accommodate this massive influx in data traffic and provide the user with higher data rate and quality of service (QoS). MIMO is a key technology for current wireless communication systems, and it has been adopted by Long Term Evolution (LTE) and Third Generation Partnership Project (3GPP) [1]. Recently, Massive MIMO technology has been proposed, which is an advancement of contemporary MIMO technology, and it is considered as a key technology for implementing 5G networks. In massive MIMO systems, the base station is equipped with hundreds and even of thousands of antennas. These antennas can serve tens of user simultaneously to provide better spectral efficiency and throughput [2] [3].

Since massive MIMO base station communicates with multiple users simultaneously, the performance of massive MIMO system degrades due to multi-user interference. Precoding is done at the base station to reduce the multi-user interference, and on top of that, it also simplifies the receiver by reducing the overall computational complexity. Due to the limited number of antennas at the base station, if the number of the users become more than the number of antennas at the base station, proper user scheduling scheme is also required before precoding. Addition of the user scheduling algorithm will ensure the better system throughput. The precoding and user scheduling usually depend upon each other and have a significant impact on the overall performance of the system [4].

There has been an extensive investigation in the last few decades to find optimal precoding and scheduling algorithm. Several non-linear and linear methods have been used for precoding. Non-linear methods such as Maximum Likelihood (ML) and Dirty Paper Coding (DPC) [5] can achieve sum capacity, but they have higher computational complexity, which makes them infeasible to implement for larger antenna system. Linear precoder like Zero Forcing (ZF) and MMSE (Minimum Mean Square Error) [6] have lower computational complexity and can achieve near-optimal sum capacity. Semi Orthogonal User Selection (SUS) and Signal to Leakage Plus Noise Ratio (SLNR) methods have been proposed in [7] [8], and their performance is close to ZF beamforming. Proportional Fair (PF) and Maximum Fairness (MF) scheduling were proposed in [9] but their complexity increases on a multi-user system. The algorithms in [10] [11] achieve sum capacity, but fairness measurement is not considered on those algorithms. The well known fair scheduling algorithms, Proportional Fair (PF), Greedy, and Round-Robin (RR) have been presented on [12] [13] to guarantee fairness among users. In this paper, we pro-

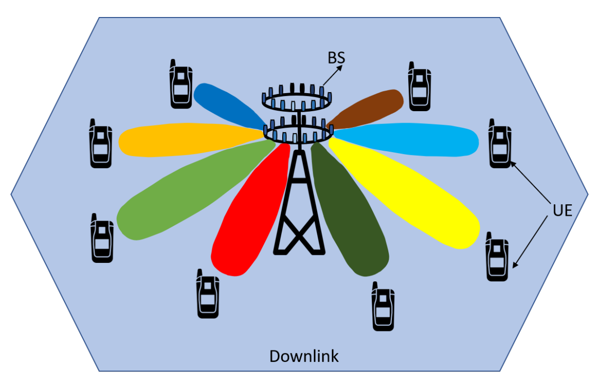

Fig. 1. Downlink Massive MIMO System.

pose a novel user scheduling algorithm which achieves higher sum capacity, better throughput and error performance, and guarantees fairness among the users. We are only focusing on the downlink massive MIMO system, and the ZF beamforming is used at the massive MIMO base station.

The rest of the paper is organized as follows. Section II presents the downlink system model, and Section III presents the proposed scheduling algorithm. Section IV describes the simulation results, and section V concludes the paper.

II. System Model

We consider a downlink massive MIMO system, where base station equipped with M antennas and it is serving N users having a single antenna simultaneously. We have used Rayleigh Fading channel for signal transmission between the base station and the user, where the channel gain from any base station antenna to a user is described by a zero-mean circularly symmetric Gaussian random variable [14]. The base station sends independent information to multiple users simultaneously. The signal received, $y_k \in \mathbb{C}^{M\times 1}$ at the k_{th} user is:

$$y_k = h_k x_k + w_k \tag{1}$$

Where, h_k is channel vector between k_{th} user and base station, whose elements are independent and identically distributed (i.i.d) with zero mean and unit variance, i.e., $h \sim \mathcal{CN}(0,1)$ [15] [16].$x_k \in \mathbb{C}^M$ is the signal transmitted by base station for user k And, w_k is Additive White Gaussian Noise (AWGN) and each element of $w_k \in \mathbb{C}^M$ is i.i.d with zero mean and finite variance, i.e., $w \sim \mathcal{CN}(0,\sigma^2 I)$. The transmitted user signal x_k is product of beamforming vector b_k and user symbol s_k.

$$x_k = b_k s_k \tag{2}$$

These beamforming vectors are stacked to get precoding matrix B, which is done to reduce inter-user interference. In the case, where the number of users is less than the number of base station antenna, ZF precoding can achieve the maximum sum rate, which involves inversion of channel matrix at the base station to create orthogonal channels between the base station and the user, without any cooperation from the users [17]. The ZF precoding eliminates the interference but suffers from noise enhancement. All the channel vector are stacked to get channel matrix H. The ZF precoding matrix $B \in \mathbb{C}^{M\times M}$ is given by:

$$B = H^H (HH^H)^- 1 \tag{3}$$

Thus, using (1), (2), and (3) the received signal vector y can be represented as:

$$y = HBs + w \tag{4}$$

Where s is the user symbol vector, and w is a noise vector. If we consider uniform power allocation between all the users, the achievable sum rate of the system is given as :

$$R = \sum_{k=1}^{K} \log_2 \left(1 + \frac{|b_k h_k|^2}{1 + \sum_{i=1, i\neq k}^{N} |b_k h_i|^2}\right) \tag{5}$$

where, b_k is the k_{th} row of precoding matrix B and h_k is the k_{th} row of the channel matrix H.

The ZF beamforming only works if numbers users are less or equal to the number of antennas at the base station. However, in practice, the number of active users can be more than the number of antennas at the base station. Thus, there is a need to integrate ZF beamforming with a proper scheduling mechanism to achieve better sum rate and throughput from the system. The scheduling mechanism selects suitable M users from active N users and transmits data to selected users simultaneously. In this paper, we are proposing an algorithm for user scheduling in massive MIMO systems.

III. Proposed Scheduling Algorithm

This section presents the proposed massive MIMO scheduling algorithm, which is based on mean channel gain. This algorithm selects the user to maximize the sum rate. The ZF beamforming technique is used along with the proposed algorithm to reduce interference among users. The proposed algorithm is summarized in five steps as follows:

Step-1 (Initialization): A set containing all the active users present in a cell is initialized. The base station transmits to M users at a time thorough M antenna.

$$G_0 = [1, 2, 3, 4...N] \tag{6}$$

$$i = 1 \tag{7}$$

$$S = \{\phi\} \tag{8}$$

where, G_0 is set containing all the users, S is the set of the selected user which is empty at the beginning. The selected users will be added to this set.

Step-2 (Mean Channel Gain Calculation): For each user k, ($k \in G_i$), calculate channel gain g_k and find mean channel gain μ as:

$$g_k = ||h_k||^2 \tag{9}$$

$$\mu = g_k / N \tag{10}$$

Step-3 (Selection Criteria): For each user, the magnitude of difference between the user's channel gain and mean channel gain, ψ_k is calculated. All the users will be selected based upon this selection criteria:

$$\psi_k = |g_k - \mu| \tag{11}$$

Step-4 (User Selection): The users are selected based upon the channel gain, i.e., the user having channel gain closest to the mean channel gain is selected first. After a user is selected, both the set having all the users and the selected users are updated. The value of i is also updated after each user is selected.

$$\pi(i) = arg\, min ||v_k|| \tag{12}$$

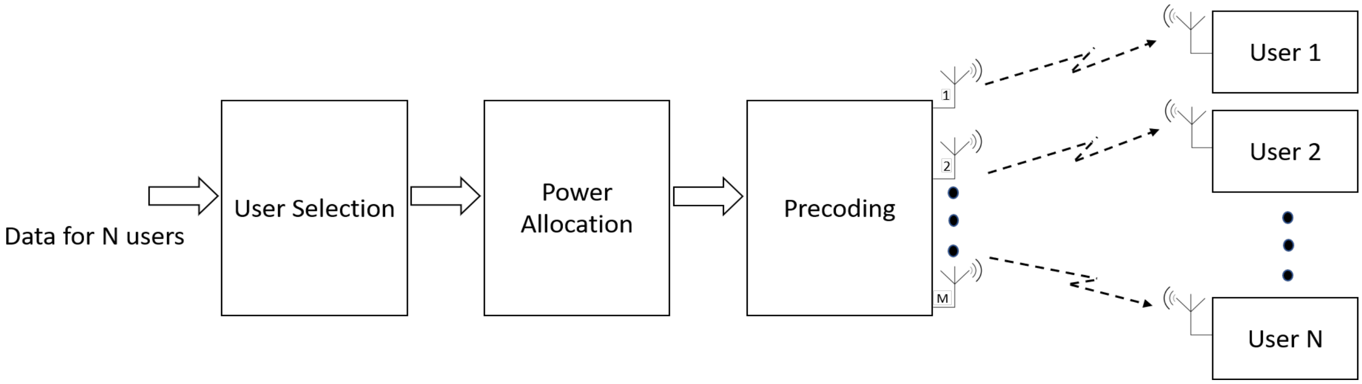

Fig. 2. System Model: Massive MIMO Downlink

$$S = S \cup \pi(i) \tag{13}$$

$$G = G - S \tag{14}$$

$$i = i + 1 \tag{15}$$

Step-5 (Stopping Criterion): The step-4 is repeated until all the users are selected.

$$Repeat\ until\ G \neq \{\phi\} \tag{16}$$

IV. Numerical Results

In this section, the simulation results of the proposed scheduling algorithm are presented and compared with conventional scheduling algorithms like Round-Robin (RR), Proportional Fair (PF), and Greedy algorithm. All the simulation parameter are shown in Table I. The most commonly used Rayleigh fading channel is assumed between the base station and the user to transmit the generated symbols. The AWGN noise is considered, and 16-Quadrature Amplitude Modulation (QAM) scheme is used for the simulation. A massive MIMO system with 16 antennae at the base station is considered, and it is supporting 100 users having a single antenna. In general, these users in the cell may have more than one antenna, but for the simplicity, it is assumed that they have a single antenna system. The system bandwidth of 5 MHz is used, and SNR values are varied from 0 dB to 30 dB. All the simulations were done in Matlab.

TABLE I
Simulation Parameters

Parameters	Value
System Bandwidth	5 MHz
Signal to Noise Ratio	0 to 30dB
Signal Variance	2
Noise Variance	Controlled by SNR
Modulation Scheme	16-QAM
Channel Model	Rayleigh Fading Channel
Number of Antenna at the base station	16
Number of Antenna at user terminal	1
Number of Users	100

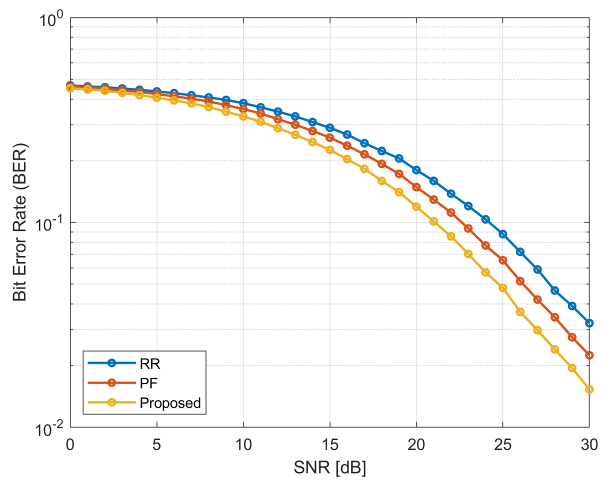

Fig. 3. Comparison of bit error rate performance of different scheduling algorithms with M=16, N=100, and 16-QAM Modulation

A. Bit Error Rate and Sum-Rate Performance

In this section, we access the Bit Error Rate (BER) and sum-rate performance of the proposed scheduling algorithm and compare with similar algorithms like PF and greedy. The plots are obtained by averaging over 100000 independent channel realizations. Fig. 3 shows the BER vs. SNR performance of the proposed scheduling algorithm. The results show that the proposed algorithm outperforms both PF and the Greedy algorithm. At BER = 10^-1, the proposed algorithm gets 2 dB gain when compared to the PF algorithm, and an additional 2dB gain is obtained when compared to the RR algorithm. Fig. 4 shows the comparison of the average sum rate (bits/s/Hz) of all compared scheduling algorithms for various SNR values. The results show that the proposed algorithm is better than the Greedy and PF algorithm in terms of the average sum rate.

We can conclude that the average sum rate increases with the number of users. This increment is majorly due to multi-user diversity with more number of users. However, this sum rate doesn't always increase with more number of users. After we reach a certain number of users, the sum rate will saturate.

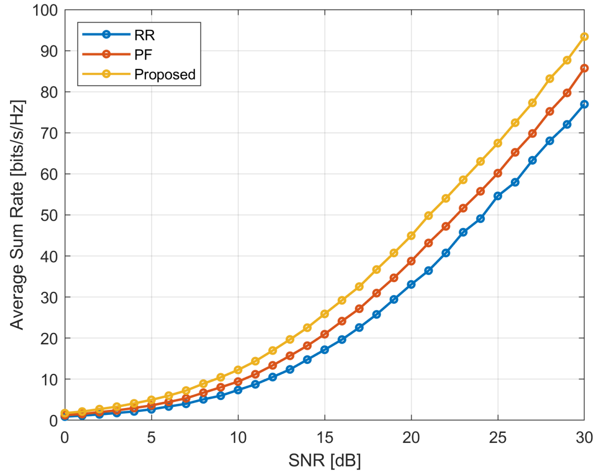

Fig. 4. Comparison of average sum rate of different scheduling algorithms with M=16, N=100, and 16-QAM Modulation

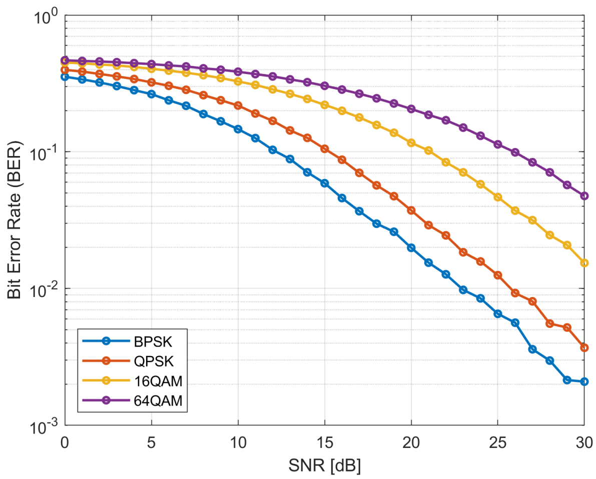

Fig. 5. Comparison of bit error rate performance of the proposed algorithm with different modulation schemes (BPSK, QPSK,16-QAM, and 64-QAM) with M=16 and N=100

Fig.5 shows the BER performance of the proposed scheduling algorithm with various modulation schemes. The Binary Phase Shift Keying(BPSK) modulation achieves the best performance, whereas 64-QAM modulation has the worst BER performance. At BER value $10^{-}1$ changing modulation scheme from BPSK to Quadrature Phase Shift Keying (QPSK) has an almost 2.5dB loss, and there is further 6dB loss when we move to 16-QAM modulation. Thus, increasing modulation order worsens the error performance as the system becomes more resilient to noise and interference. Although higher modulation schemes have bad error performance, higher modulation order is used when faster data rate and high spectral efficiency are required. Thus, a dynamic and adaptive modulation technique is required for optimum performance.

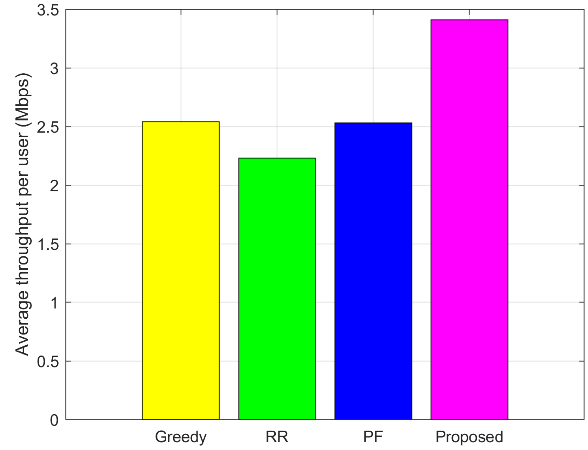

Fig. 6. Comparison of average throughput per user of different scheduling algorithms with M=16, N=100, 16-QAM Modulation, and SNR=20dB

B. *Throughput and Fairness Index Comparison*

We compared the average user throughput fairness of proposed scheduling algorithm with other conventional scheduling algorithms. Fig. 6 shows the average throughput per user(Mbps) for different scheduling algorithms. The Proposed algorithm has the best average user throughput of 3.4 Mbps, whereas PF has the worst per user throughput of 2.3 Mbps. Thus, in terms of average throughput, the proposed scheduling algorithm has the best performance. To evaluate fairness performance, we used Jain's fairness index measurement. The Jain's fairness index is defined in [18], which measures the fairness of a set of values.:

$$\mathcal{J}(X) = \frac{\left(\sum_{j=1}^{N} x_j\right)^2}{\sum_{j=1}^{N} x_j^2} \tag{17}$$

where $0 \leq \mathcal{J} \leq 1$ is fairness index, x_j is throughput for jth connection. A high value of $\mathcal{J}$ indicates high fairness. The Jain's fairness index for all the algorithms was almost similar, as shown in Table II. Although all the algorithms guarantee very high fairness among users, the proposed algorithm outperforms conventional scheduler in terms of sum rate, throughput, and error performance.

TABLE II
FAIRNESS OF SCHEDULING ALGORITHMS

Scheduling Algorithm	Fairness Index
Round Robin	0.973
Proportional Fair	0.983
Greedy	0.984
Proposed	0.991

V. CONCLUSION

In this paper, we introduced a novel user scheduling algorithm based on channel gain for massive MIMO systems. The goal of the proposed algorithm is to select a subset of users which maximizes sum rate capacity, increases throughput, and reduces error rate while keeping the fairness high. The results through simulations show that the proposed user scheduling algorithm outperforms the conventional algorithms in terms of sum rate, throughput, and error performance and also guarantees fairness among users. The results also show that the error performance of the proposed algorithm reduces with higher modulation order, but high data rate and spectral efficiency can be achieved by increasing modulation order. Thus, the proposed algorithm can be advantageous during downlink user scheduling in massive MIMO systems. Future work would be to test this algorithm by introducing several realistic network parameters, and it would be fascinating to test the algorithm with multi-antenna users.

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