Accepted at Texas Symposium on Wireless and Microwave Circuits and Systems, IEEE 2020

An Efficient and Fair Scheduling for Downlink 5G Massive MIMO Systems

Robin Chataut [#1], Robert Akl [#2]
[#]Department of Computer Science and Engineering, University of North Texas, USA
[1] Robin.Chataut@unt.edu, [2] Robert.Akl@unt.edu

***Abstract*—Massive MIMO (multiple-input multiple-output) is one of the key enabling technology for future generation 5G networks, which groups antenna at both base station and the user terminals to provide high spectral and energy efficiency. Massive MIMO throughput can be increased by scheduling users experiencing good channel conditions, but the users at the edge of the cell with poor channel conditions are often ignored. To improve overall system performance, a certain amount of fairness must be ensured among all the users. In this paper, we propose a fair scheduling algorithm based upon user channel gain to provides higher throughput, sumrate, and better error performance. The simulation results of the proposed algorithm, when compared to the traditional scheduling algorithms, show that the proposed algorithm provides better throughput, sumrate, error performance, and ensures fairness among all users.**

***Index Terms*—5G, massive MIMO, spectral efficiency, hardware architecture, scheduling, fairness**

I. Introduction

There has been an enormous increase in wireless data traffic and the number of connected devices in the past few years. Along with mobile broadband service, services like the Internet of Things (IoT) and Machine to Machine (M2M) communication are also contributing to the increased wireless data traffic. According to Cisco, the total wireless data traffic will be 76 exabytes per month by 2022, which is huge when compared to 25 exabytes per month in 2019 [1]. By 2022, there will be 4.1 billion internet users and 29 billion connected devices, which is almost 52 percent of the world population, and nearly 82 percent of internet traffic will be video [2]. This massive amount of wireless data traffic is difficult to manage with the current wireless system. The fifth-generation (5G) network is expected to address the wireless data traffic challenge and provide each wireless user with high data and reliability.

Efficient wireless access technology is essential to address the current challenges faced by wireless carriers. Massive MIMO (Multiple-Input-Multiple-Output) is the most enthralling sub-6 GHz wireless access technology to deliver the needs of future wireless networks. Massive MIMO brings together antennas, radios, and spectrum to enable higher capacity and speed for incoming 5G world [3]-[6]. Massive MIMO is an extension of MIMO technology, and it involves using hundreds of antennas attached to a base station to improve spectral efficiency and throughput. Massive MIMO provides immense benefits to wireless networks such as high data rate, improved energy and spectral efficiency, low latency, low power consumption, and user tracking [7]-[10].

Since there are a limited number of antennas in the massive MIMO base station, user scheduling has to be performed if the number of the users is more than the number of antenna terminals at the base station. Massive MIMO system throughput can be increased by only scheduling the users experiencing good channel conditions. But using this scheme, the users at the edge of the cell with poor channel conditions are ignored and never scheduled. To improve overall system performance, a certain amount of fairness must be ensured among all the users. Thus, a fair and efficient scheduling algorithm is required to provide a high data rate and guarantee fairness among users.

Recently, there has been extensive research to find an optimal scheduling algorithm for downlink massive MIMO systems. The well-known scheduling algorithm like Proportional Fair (PF), Greedy, and Round-Robin (RR) guarantee fairness among users, but these algorithms don't provide higher sumrate and throughput performance [11],[12]. The Semi Orthogonal Selection (SUS), Signal to Leakage Noise Ratio (SLNR), Maximum Fairness (MF) methods have been used, but their complexity increases with a large number of antennas [13]-[15].

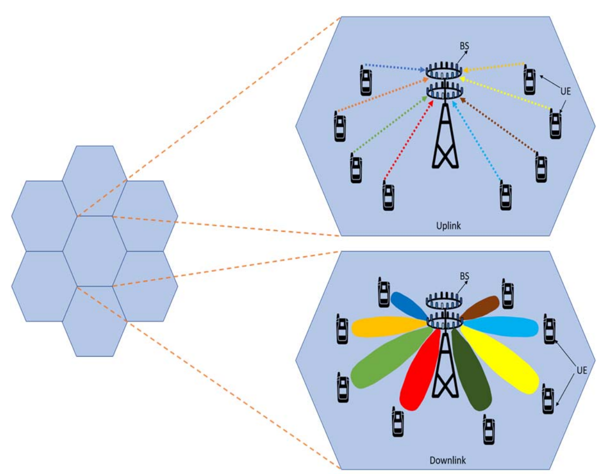

Fig. 1. Massive MIMO downlink and uplink

The linear methods like Zero Forcing (ZF) and Minimum Mean Square Error (MMSE) and non-linear methods like Dirty Paper Coding (DPC) and Maximum likelihood (ML) were used along with various scheduling algorithms, but optimal sum capacity was not achieved [16],[17]. An optimal user scheduling algorithm that addresses both the throughput and the fairness issue is imminent. In this paper, we propose a fair scheduling algorithm for a massive MIMO downlink system based upon user channel gain, which provides higher throughput, sumrate, and better error performance. The simulation results of the proposed algorithm, when compared to the traditional scheduling algorithms, show that the proposed algorithm provides better throughput, sumrate, error performance, and ensures fairness among all users.

A. Contributions

The main contributions of this work are outlined as follows:

- We investigate the user scheduling problem in a downlink massive MIMO system and propose a fair user scheduling algorithm based upon channel gain.
- We assess the error, sum rate, and average per-user throughput performance of the proposed algorithm by comparing it with conventional scheduling algorithms like RR, PF, and Greedy. The simulations results show that the proposed scheduling algorithm can achieve better throughput, sumrate, and error performance compared to conventional algorithms.
- We evaluate the fairness of the proposed algorithm by taking average user throughput as the criterion to measure fairness. The simulation results show that the proposed algorithm guarantees fairness among the users.

B. Outline

The rest of the paper is organized as follows: Section II describes the downlink system model required for conducting the simulations. The proposed channel gain based scheduling algorithm is presented in section III. The numerical results and analysis are provided in section IV, whereas section V presents the hardware architecture of the proposed algorithm. Finally, section V concludes the paper summarizing the key ideas.

C. Notations

In this paper, the lower-case and upper-case letters denote column vectors and matrices, respectively. The superscripts $(.)^{-1}$, $(.)^{'}$, and $(.)^{H}$ denotes inverse, transpose, and Hermitian transpose of a matrix, respectively. $\mathbb{C}^{M}$ denotes the space of the N-element complex vector, and I^{M} indicates the $N \times N$ identity matrix.

II. SYSTEM MODEL

A massive MIMO downlink system is considered having M antennas at the base station serving N single antenna users simultaneously, as shown in Fig. 2. The base station will send an independent data stream towards each user. We have considered the channel between the user and the base station as the Rayleigh fading channel. The channel gain between the user and the base station is represented by a zero-mean circularly symmetric Gaussian random variable [18]. The downlink signal received at the j^{th} user is given as:

$$\mathrm{y_j} = \mathrm{h_j x_j} + \mathrm{n_j} \quad (1)$$

Where $\mathrm{y_j} \in \mathbb{C}^{M}$ is the signal received by the j_{th} user, $\mathrm{x_j}$ is the independent signal transmitted by the base station for user j. h_j is the channel between the base station and the j_{th} user, whose elements are independent and identically distributed with zero mean and unit variance, i.e., $h \sim \mathcal{CN}(0,1)$ and $h \in \mathbb{C}^{N \times M}$. $\mathrm{n_j} \in \mathbb{C}^{M}$ is the additive white Gaussian noise (AWGN), where each element of n_j is independent and identically distributed with zero mean and some finite variance, i.e., $n \sim \mathcal{CN}(1, \sigma^2 I)$.

If N users are waiting to be scheduled, the scheduling algorithm will select J users from available N users (J $<$ N). To precode for the selected J users, the user scheduler will also select the precoding matrix P [19]. Precoding is conducted before user scheduling to reduce multi-user interference and to simplify the receiver. The beamforming vectors $\mathrm{b_j}$ are stacked together to get the precoding matrix, and the user signal is the product of this beamforming vector and the user data symbol $\mathrm{s_j}$.

$$\mathrm{x_j} = \mathrm{p_j} \times \mathrm{s_j} \quad (2)$$

We have used the linear precoders, ZF and MMSE for conducting the simulations. The MMSE precoding matrix is given as:

$$P_{MMSE} = \left(HH^{H} + \frac{W_0}{E_s}\right)^{-1} H^{H} \quad (3)$$

The received signal y with MMSE precoding matrix can be represented using (1), (2), and (3) as:

$$y = HP_{MMSE}s + n \quad (4)$$

The ZF precoding matrix is given as:

$$P_{ZF} = (HH^{H})^{-1}H^{H} \quad (5)$$

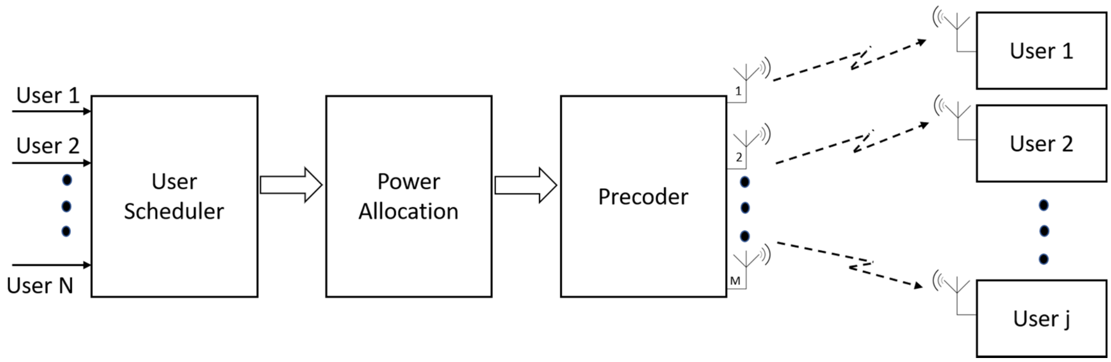

Fig. 2. System model for downlink massive MIMO.

The received signal y with ZF precoding matrix can be represented using (1), (2), and (5) as:

$$y = HP_{ZF}s + n \tag{6}$$

Considering power allocation between the users, the sum rate can be represented as [20]:

$$R = \sum_{j=1}^{J} \log_2\left(1 + \frac{\left|p_j h_j\right|^2}{1 + \sum_{i=1, i\neq j}^{N} \left|b_j h_i\right|^2}\right) \tag{7}$$

Where b_j and h_j are the j^{th} row of the precoding matrix and the channel matrix, respectively.

III. Proposed Algorithm

This section presents the proposed scheduling algorithm for downlink user scheduling in massive MIMO systems. The proposed algorithm is summarized in the steps below:

Step-1 (*Initialization*): During initialization, a set containing all the active users and a set containing all the scheduled users are initialized. Since none of the users are scheduled at the beginning, the set of scheduled users is empty.

$$A = \{1,2,3,4, \ldots N\} \tag{8}$$

$$S = \{\phi\} \tag{9}$$

$$\mathrm{i} = 0 \tag{10}$$

Step-2 (*Channel Gain Computation*): The base station computes channel gain for each active user in set A.

$$g_j = \left|\left|h_j\right|\right|^2 \tag{11}$$

Step-3 (*Selection Criteria*): We divide the available time slots depending upon the number of active users to obtain factor α. Here, the factor α helps to select the group of users waiting to be scheduled.

$$\alpha = ceil\left(\frac{N}{T}\right) \tag{12}$$

Where, T is the number of available time slots, and N is the number of active users.

Step-4 (*User Scheduling*): In the beginning, the base station selects α users with the highest channel gain and schedules them in the first available time slots. If there are more than α users with the same channel gain, then the base station selects α users with the highest channel gain randomly.

$$\pi_1(i) = arg\ max\left|\left|g_j\right|\right| \tag{13}$$

After the first set of α users are scheduled, the set having active users is updated.

$$A_1 = \mathrm{A} - \pi_1(i) \tag{14}$$

From the set of remaining users A_1, α users with lowest channel gain are selected and scheduled in the subsequent time slot. If there are more than α users with the same channel gain, then α users with the least channel gain are selected randomly by the base station. The alternating selection of users with the highest and lowest channel gain guarantees fairness among all the active users.

$$\pi_2(i) = arg\ min\left|\left|g_j\right|\right| \tag{15}$$

After the second set of α users are scheduled, the set having active users and selected users are updated.

$$A_2 = \mathrm{A}_1 - \pi_2(i) \tag{16}$$

$$\mathrm{S} = \mathrm{S} \cup \pi_1(i) \cup \pi_2(i) \tag{17}$$

Step-5 (*Stopping Criterion*): The process in step 4 is repeated until all the users are scheduled.

$\boldsymbol{if}$ $(A_2 \neq \phi)$ **then**
$A = A_2$
$i = i + 1$
Repeat Step 4
else
Stop

IV. Numerical Results and Analysis

In this section, we present the simulation result of the proposed scheduling algorithm. We compare the performance of our algorithm with conventional scheduling algorithms like RR, PF, and Greedy. Table I shows the simulation parameter used during the simulation. A massive MIMO base station with 16 antennas is communicating with 100 users having a single antenna. An uncorrelated Rayleigh fading channel is considered between the base station and the user terminal. The system bandwidth of 20 MHz having 25 subcarriers and a coherence interval of 200 symbols is considered for the simulation. All the plots are acquired by averaging over 100000 independent channel realizations. All the simulations were conducted on Matlab under Mac OS, with 3.4 GHz Intel Core i7 processor with 16 GB of RAM.

Fig. 3 shows the BER performance comparison of proposed and conventional scheduling algorithms. The result through simulation shows that the proposed algorithm has better error performance than both RR and PF algorithm with both MMSE and ZF precoding.

TABLE I
SIMULATION PARAMETERS

Parameters	**Value**
System Bandwidth	20 MHz
Subcarriers	25
Coherence Interval	200 Symbols
Signal Variance	2
Noise Variance	Controlled by SNR
Number of Antenna at the Base Station	16
Number of Antenna at the User Terminal	1
Number of Users	100
Channel Model	Uncorrelated Rayleigh Fading
Modulation Scheme	BPSK, QPSK, 16QAM, 64QAM
Signal to Noise Ratio	0 to 30 dB

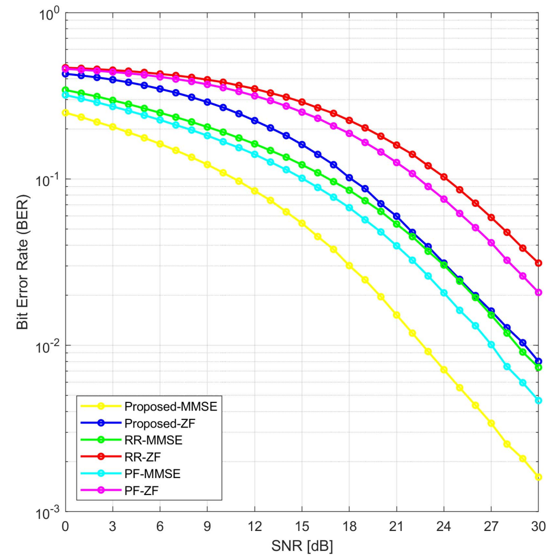

Fig. 3. BER Vs. SNR comparison between the proposed and convention scheduling algorithm for Massive MIMO downlink (M=16, N=100, 16QAM modulation) with ZF and MMSE precoding.

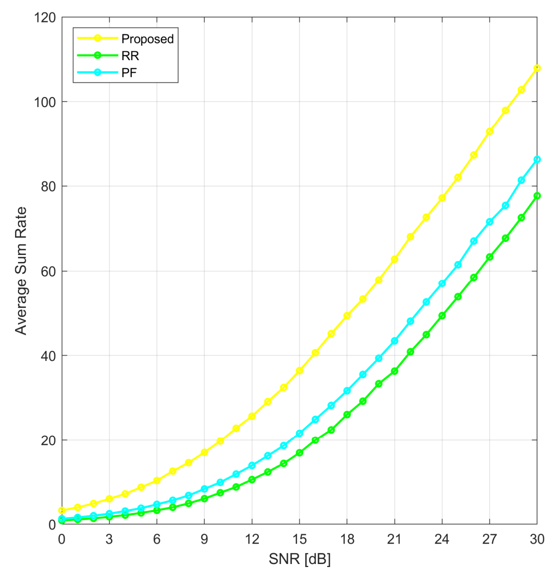

Fig. 4. Average Sum Rate Vs. SNR comparison between the proposed and convention scheduling algorithm for Massive MIMO downlink (M=16, N=100, 16QAM modulation) with MMSE precoding.

At BER $= 10^{-1}$ with MMSE precoding, the proposed algorithm achieves almost 4dB gain when compared to the RR algorithm and 6dB gain when compared to the PF algorithm. Fig. 4 shows the average sum rate comparison between the proposed and the conventional scheduling algorithm with MMSE precoding. The acquired simulation result shows that the proposed algorithm has a better average sum rate performance compared to RR and PF algorithms. At 15dB, the proposed algorithm has a sum rate of 38 bits/s/Hz, whereas the RR and PF have a sum rate of 17 bits/s/Hz and 21 bits/s/Hz respectively. The improvement in the sum rate is predominantly due to the multi-user diversity that massive MIMO gets with a more significant number of antennas and users. However, this sum-rate will saturate once we reach a certain number of users in that specific base station.

Fig.5 shows the performance of the proposed algorithm with different modulation schemes with MMSE precoding. We have used BPSK (Binary Phase Shift Keying), QPSK (Quadrature Phase Shift Keying), 16QAM (Quadrature Amplitude Modulation), and 64QAM modulation schemes for this experiment. At BER = 10^{-1}, BPSK achieves 14 dB, 9dB, and 3 dB gain when compared to QPSK, 16QAM, and 64QAM modulation, respectively. Thus, the BPSK modulation has the best error performance, whereas 64QAM modulation has the worst error performance. This is because, with higher modulation, the channel becomes more sensitive to noise and interference. The higher modulation orders are used in applications where we are not much concerned about the error performance and only focus on achieving higher data rates and spectral efficiency.

The average throughput per user comparison between the proposed and the conventional scheduling algorithm with MMSE precoding is shown in Fig. 6. The best average throughput per user performance amongst all the algorithms was shown by the proposed algorithm with per-user throughput of 3.17 Mbps, whereas the RR algorithm had the worst performance with an average per-user throughput of 2.17 Mbps. The PF and Greedy algorithm had almost similar performance with per average user throughput of 2.58 Mbps and 2.45 Mbps, respectively.

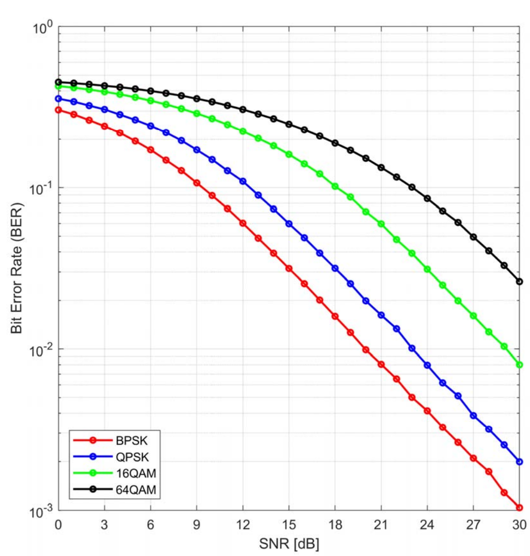

Fig. 5. BER Vs. SNR comparison for the proposed scheduling algorithm for Massive MIMO downlink (M=16, N=100, 16QAM modulation) with different modulation schemes.

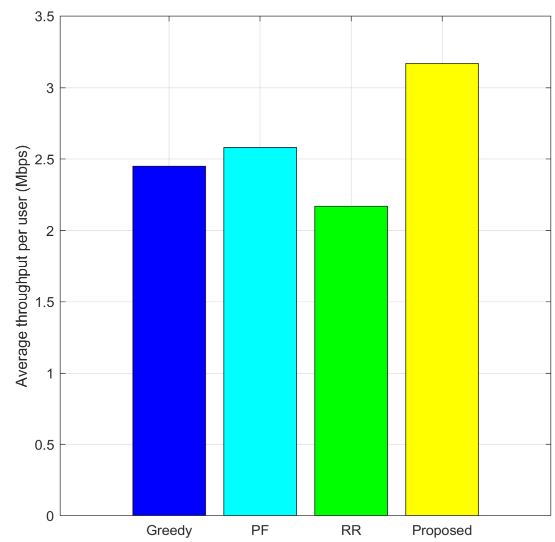

Fig. 6. Average throughput per user comparison between the proposed and convention scheduling algorithms for Massive MIMO downlink (M=16, N =100, 16QAM modulation) with MMSE precoding.

We evaluated the fairness of the proposed scheduling algorithm and compared it with traditional scheduling algorithms. We evaluate Jain's fairness index for each algorithm which is defined in [21]:

$$\mathcal{J}(x_1, x_2, , \ldots., x_n) = \frac{\left(\sum_{j=1}^{n} x_j\right)^2}{\sum_{j=1}^{n} x_j^2} \qquad (18)$$

This equation rates the fairness of a set of values with n users with x_j being throughput for the j_{th} user. The worst-case fairness is $\frac{1}{n}$, whereas the best-case fairness would be 1. Table II shows the fairness value obtained for each scheduling algorithm by taking average user throughput as the criterion to measure fairness. The fairness of the proposed algorithm was almost similar to the fairness of conventional scheduling algorithms, but the proposed algorithm outperforms the traditional algorithm in terms of error performance, sum rate, and average per-user throughput.

V. Conclusion

In this paper, we proposed a novel scheduling algorithm for scheduling users during downlink in massive MIMO

TABLE II
FAIRNESS COMPARISON OF SCHEDULING ALGORITHMS

Scheduling Algorithm	**Fairness Index**
Round Robin	0.963
Proportional Fair	0.973
Greedy	0.981
Proposed	0.998

systems. The results from the simulation show that the proposed algorithm has a better error, sum rate, and average per-user throughput performance when compared to the conventional algorithm like RR, PF, and Greedy. The proposed algorithm also guarantees fairness among all the users. We further analyzed the influence of the modulation scheme on the proposed algorithm, and we found out that the proposed algorithm has the best error performance with BPSK, whereas 64QAM can be used in applications where the high data rate is essential. Thus, the proposed algorithm is an up-and-coming candidate for user scheduling in downlink massive MIMO systems. In the future, we plan to test this algorithm with multi-antenna users by incorporating other realistic network parameters.

REFERENCES

[1] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2017-2022, Accessed on Jan. 2020. Available:https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/ white-paper-c11-738429.pdf

[2] Infographic: The number of internet users by 2020., Accessed on Jan. 2020. Available: https://www.gemalto.com/review/Pages/ infographic-the-number-of-internet-users-by-2020.aspx

[3] A closer look at Massive MIMO., Accessed on Jan. 2020. Available: https://business. sprint.com/blog/massive-mimo

[4] F. Rusek, D. Persson, B. K. Lau, E. G. Larsson, T. L. Marzetta, O. Edfors, and F. Tufvesson, "Scaling up MIMO: Opportunities and Challenges with Very Large Arrays," *IEEE Signal Process. Mag*., vol. 30, no. 1, pp. 40-60, Jan. 2013.

[5] E. G. Larsson, F. Tufvesson, O. Edfors, and T. L. Marzetta, "Massive MIMO for Next Generation Wireless Systems," *IEEE Commun. Mag*., vol. 52, no. 2, pp. 186-195, Feb. 2014.

[6] T. L. Marzetta, "Massive MIMO: An Introduction," in *Bell Labs Technical Journal,* vol. 20, pp. 11-22, 2015.

[7] R. Chataut and R. Akl, "Optimal pilot reuse factor based on user environments in 5G Massive MIMO," *2018 IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC),* Las Vegas, NV, 2018, pp. 845-851.

[8] R. Chataut, R. Akl and U. K. Dey, "Least Square Regressor Selection Based Detection for Uplink 5G Massive MIMO Systems*," 2019 IEEE 20th Wireless and Microwave Technology Conference (WAMICON),* Cocoa Beach, FL, USA, 2019, pp. 1-6.

[9] J. Hoydis, K. Hosseini, S. Ten Brink, and M. Debbah, "Making smart use of excess antennas: Massive MIMO, small cells, and TDD*," Bell Labs Technical Journal,* vol. 18, no. 2, pp. 5-21, Sep. 2013.

[10] T. L. Marzetta, "Noncooperative cellular wireless with unlimited numbers of base station antennas," *Wireless Communications, IEEE Transactions* on, vol. 9, no. 11, pp. 3590-3600, 2010.

[11] Jinsu Kim, Sungwoo Park, Jae Hong Lee, Joonho Lee, and Hanwook Jung, "A scheduling algorithm combined with zero-forcing beamforming for a multi-user MIMO wireless system," *VTC-2005-Fall. 2005 IEEE 62nd Vehicular Technology Conference,* 2005., Dallas, TX, USA, 2005, pp. 211-215.

[12] Mohammed Farooq Hamdi, Rashid Abdelhaleem Saeed, and Ahmed Saleem Abbas, 126 2018, "Downlink Scheduling in 5G Massive MIMO", *Journal of Engineering and Applied Sciences*, vol. 13, no. 6, 2018, pp. 1376-1381.

[13] K. Djouani, G. Maina, M. Mzyece, G. MuriithiA, "Low Complexity Greedy Scheduler for Multiuser MIMO Downlink," *Southern African Telecommunications Networks and Applications, (SATNAC),* South Africa, 2010.

[14] Wang Hongyu, Meng Weixiao, Nguyen Trungtan, "User Fairness Scheme with Proportional Fair Scheduling in Multi-user MIMO Limited Feedback System," *Communications and Network Scientific Research Publishing,* vol. 5, no. 03, pp. 113, 2013

[15] Yueming Cai, Jiang Yu, Youyun Xu, and Mulin Cai, "A comparison of packet scheduling algorithms for OFDMA systems," *2008 2nd International Conference on Signal Processing and Communication Systems*, Gold Coast, QLD, 2008, pp. 1-5.

[16] D. L. Colon, F. H. Gregorio, and J. Cousseau, "Linear precoding in multi-user massive MIMO systems with imperfect channel state information," *2015 XVI Workshop on Information Processing and Control (RPIC)*, Cordoba, 2015, pp. 1-6.

[17] K. Lyu, "Capacity of multi-user MIMO systems with MMSE and ZF precoding," *2016 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, San Francisco, CA, 2016, pp. 1083-1084.

[18] Kuenyoung Kim, Hoon Kim, and Youngnam Han, "A proportionally fair scheduling algorithm with QoS and priority in 1xEV-DO," *The 13th IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications*, Pavilhao Atlantico, Lisboa, vol. 5, 2002, pp. 2239-2243.

[19] S. K. Burra and R. P. R. Yendrapalli, "User Scheduling Algorithm for MU-MIMO System with limited feedback," *Dissertation*, 2010.

[20] R. Chataut and R. Akl, "Channel Gain Based User Scheduling for 5G Massive MIMO Systems," *2019 IEEE 16th International Conference on Smart Cities: Improving Quality of Life Using ICT & IoT and AI (HONET-ICT)*, Charlotte, NC, USA, 2019, pp. 049-053.

[21] R. Jain, D. Chiu, and W. Hawe, "A Quantitative Measure of Fairness and Discrimination for Resource Allocation in Shared Systems, Digital Equipment Corporation," *Technical Report DEC-TR-301*, Tech. Rep., 1984.