An Adaptive User Scheduling Algorithm for 6G Massive MIMO Systems

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***Abstract*—Massive Multiple-input Multiple-output (MIMO) is a sub-6GHz wireless access technology and is one of the key enabling technology for current 5G and upcoming 6G networks. Massive MIMO technology is also considered crucial for realizing the potential capacity of upcoming 6G and beyond networks. However, with hundreds of antenna terminals, user scheduling during downlink communication is one of the major challenges in massive MIMO system deployment. In this paper, we propose a novel scheduling algorithm that improves the area throughput and error performance and ensures fairness among all users. Our scheduling method uses the average channel rate as the scheduling criteria, which is obtained from the channel state information provided by the users during the uplink communication. The results from the Matlab simulations convey that the proposed algorithm based on channel rate is fair and better than the conventional scheduling algorithms as it provides better sumrate, throughput, and bit error performance.**

***Index Terms*—— Massive MIMO, 5G, 6G, user scheduling, sumrate, fairness**

I. INTRODUCTION

The demand for high data rates has increased over the past few decades, and mobile data traffic has increased exponentially. With the inception of novel applications like the blockchain, cyber-security, Smart Vehicles, the Internet of Things, augmented reality, virtual reality, and extended reality, the demand for next-generation wireless systems has increased. The next-generation wireless systems, 5G, beyond 5G, and 6G networks, should handle this colossal amount of data and provide the user with a high data rate and better quality of service. The MIMO technology is the basis of older generation networks such as 3G, and 4G networks [1]- [3]. This technique provides ways to tackle the effects of fading and achieves high multiplexing and diversity gains. To handle more users with better quality of service, a MIMO technique called massive MIMO plays an essential role. Massive MIMO uses hundreds of antennas at the base station and serves tens of users at the same time. Massive MIMO provides high spectral and energy efficiency with low latency [3]- [10]. A massive MIMO system is shown in Fig. 1. The uplink pilot signal is sent by users toward the base station during the uplink. The beamforming provided by massive MIMO during the downlink helps to direct the signal toward the users. With more antennas, these beams become narrower and spatially focused on the user.

A proper user scheduling method during the downlink is required to increase the throughput of the massive MIMO system when the number of active users is more than the number of base station antenna terminals. The total area throughput can be improved by scheduling users with better channel conditions. However, a proper fairness level should also be maintained to guarantee that users with bad channel conditions get scheduled in a timely manner. Significant research has been going to develop an optimal user scheduling algorithm. The greedy algorithms are discussed in [11] - [13]. These greedy algorithms provide better fairness performance, but optimal throughput is not achieved. The traditional algorithms, Round Robin (RR) and Proportional Fair (PF) are better in terms of fairness but do not achieve optimal fairness. [14]-[15] considered linear methods such as Zero Forcing(ZF) and Minimum Mean Square Error (MMSE). The authors in [16]-[18] have investigated user scheduling methods for downlink MIMO systems. However, optimal performance in terms of both throughput and fairness has not been achieved. In this paper, we propose an adaptive user scheduling algorithm based on channel rate to provide the user with optimal throughput and ensure fairness among all the users.

A. Contribution

The main contributions of this paper :

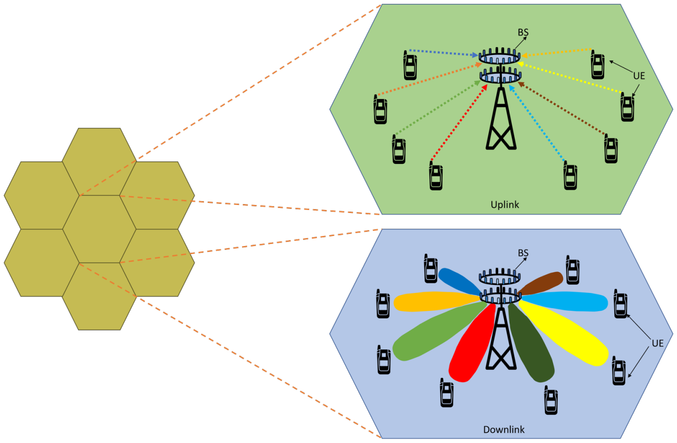

Fig. 1: Massive MIMO uplink and downlink system.

1) The user scheduling issue during the downlink massive MIMO system is investigated, and an adaptive user scheduling scheme based on instantaneous channel rate is proposed.
2) We assess the sum rate, per-user throughput, and error performance of the proposed algorithm.
3) we evaluate the fairness index of the proposed algorithm. We have used Jain's fairness index to compute the fairness index.
4) The results obtained from the Matlab simulations show that the proposed algorithm is fair and performs better than the traditional user scheduling algorithm in terms of sumrate, per-user throughput, and error performance.

B. Outline

The remainder of the paper is structured as follows: Section II defines the downlink system model for massive MIMO with M antennas and N users. The proposed adaptive algorithm is described in III. The simulation steps, required parameters, and algorithm analysis are presented in IV. Finally, V concludes the paper by encapsulating the major concepts of the paper.

II. SYSTEM MODEL

A massive MIMO downlink system is considered with M base station antenna terminals and N users. In the course of the downlink communication, the base station will send an independent and autonomous signal to each active user. If U users are waiting for their turn to be scheduled, the base station selects S users $(S <= U)$ according to the scheduling algorithm. The base station will apply a precoder before sending the downlink signal towards the user. The precoding improves the system throughput. The signal received by user i can be represented as:

$$y_i = Hx_i + n_i \tag{1}$$

Where,

$$x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ . \\ . \\ . \\ x_i \end{bmatrix} \quad and \quad H_i = \begin{bmatrix} h^i_{11} & h^i_{12} & . & h^i_{1N} \\ h^i_{21} & h^i_{22} & . & h^i_{2N} \\ . & . & . & . \\ . & . & . & . \\ h^i_{N1} & h^i_{N2} & . & h^i_{NM} \end{bmatrix}$$

y_i is the signal received by the i_{th} user, and x_i is the signal sent towards the user from the base station i. $H \in \mathbb{C}^{N \times M}$is the channel vector between the user terminals and the base station antenna terminals, where elements of H are independent and identically distributed. n_i is the added white Gaussian noise at the i_{th}.

We do the precoding before scheduling the user to minimize multi-user interference. We get the matrix for precoding by stacking the beamforming vectors and user signals.

$$y_i = HWx_i + n_i \tag{2}$$

Where,

$$W = \begin{bmatrix} p_1 & p_2 & . & . & . & p_j \end{bmatrix}$$

$W \in \mathbb{C}$ is the precoding matrix, which contains a set of precoders. p_j is the vector used for precoding the j_{th} user. For our simulations, we have applied two simple linear precoders, ZF and MMSE [21]:

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

$$W_{MMSE} = H^H(HH^H + \sigma^2 I)^-1 \tag{4}$$

We compute the sumrate by considering the uniform power allocation among each user as [19]:

$$Sumrate = \sum_{i=1}^{N} \log_2 \left(1 + \frac{|b_i h_i|^2}{1 + \sum_{j=1, j \neq i}^{N} |b_i h_j|^2} \right) \tag{5}$$

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.

III. PROPOSED ALGORITHM FOR DOWNLINK USER SCHEDULING

The proposed algorithm is summarized in 1. We initialize the active users set U, including N active users. The set of selected users is S, which is null initially as non of the users are scheduled. Then we calculate the instantaneous channel rate for each user:

$$C_j = log_2 \left(1 + \sqrt{\sum_{j=1}^{N} |h_j|^2} \right) \tag{6}$$

The mean channel rate is computed based on the active users waiting to be scheduled. The calculated mean channel rate will also be the selection criteria for the proposed algorithm.

$$\bar{C} = \frac{\sum C_j}{N} \tag{7}$$

The user with an instantaneous channel rate closest to the mean channel rate is selected first. Once the selected user is scheduled, we update the set containing the remaining active and selected users.

$$\pi(j) = argmin|||A_j| \tag{8}$$

$$S = S \, U \, \pi(j) \tag{9}$$

$$U = U - S \tag{10}$$

The process of user selection is repeated until all the active users are scheduled. Then, the mean channel rate is re-evaluated for the next set of active users.

$$U \neq \{\phi\} \tag{11}$$

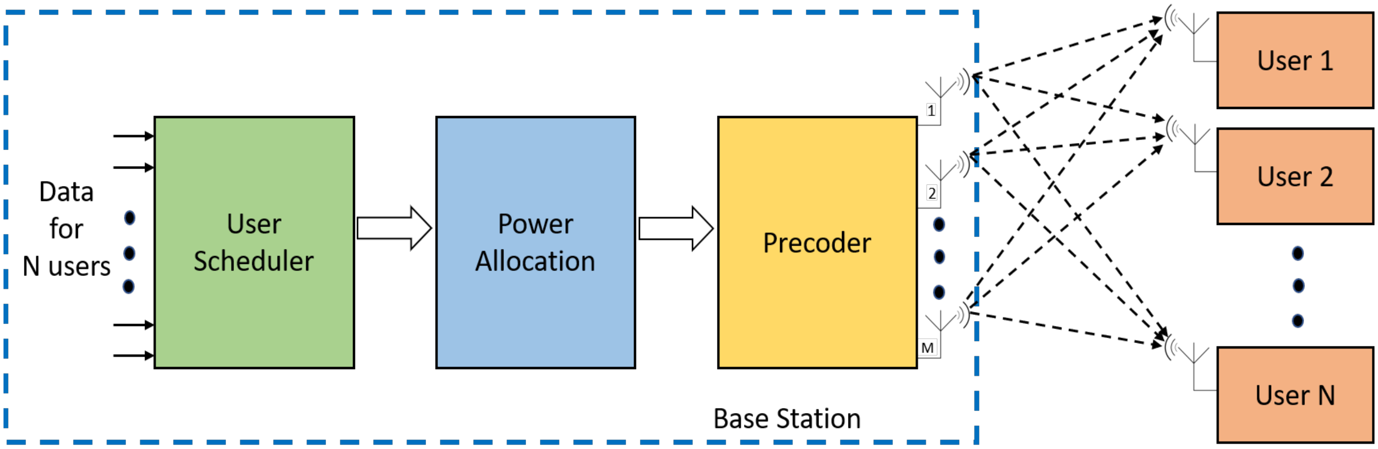

Fig. 2: System Model with M base station antenna serving N users.

IV. SIMULATION RESULTS AND ANALYSIS

In this section, we analyze the results obtained from the Matlab simulations. For simulations, we set up a massive MIMO base station with many antenna terminals (16 to 512). We assume that all the antenna terminals are communicating with 128 single active users simultaneously. We have considered various antenna configurations with different modulation techniques (QPSK, 16QAM, 16QAM) for conducting the simulations. The system's bandwidth is set to 20 MHz, whereas a carrier frequency of 2.5 GHz is used. A perfect channel state information (CSI) is assumed between the user and the base station, and the Rayleigh fading channel model is used for simulations. We have compared our proposed algorithm with traditional schedulers like Proportional Fair (PF) and Round Robin (RR) algorithms for analysis. In addition, we have used ZF and MMSE precoding to reduce the effect of multi-user interference and to simplify the processing required at the receiver. The simulation parameters used are shown in I.

Fig.3 shows the error performance of the proposed algorithm with 16 users, 16 base station antenna terminals, 16QAM modulation, and MMSE precoding. The proposed algorithm has better BER performance than the traditional algorithm within the whole range of SNR users for simulation. For example, at BER 10^{-2}, the proposed algorithm achieved a 6dB gain over the RR algorithm and a 4 dB gain over the PF algorithm. Fig.4 shows the simulation with similar parameters but with ZF precoding. We can see that the performance pattern is similar; however, the overall performance of all the algorithms has reduced. For example, at BER=10^{-1}, the

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Algorithm 1 Proposed Algorithm for Massive MIMO Downlink Scheduling
Initialization:
$U = \{1, 2, 3, 4, ....N\}$
$S = \{\phi\}$
$j = 0$
Channel Rate Calculation:
$C_j = log_2\left(1 + \sqrt{\sum_{j=1}^{N} |h_j|^2}\right)$
$\bar{C} = \frac{\sum C_j}{N}$

Selection Criteria:
$A_j = |C_j - \bar{C}|$

Algorithm iteration:
do
    $\pi(j) = argmin|||A_j|$
    $S = S\, U\, \pi(j)$
    $U = U - S$
    $i = i + 1$
While    $U \neq \{\phi\}$
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TABLE I: Simulation Parameters

Parameter	**Value**
Base Station Antenna Terminal	16 to 512
Number of Users	128
Carrier Frequency	2.5 GHz
Bandwidth	20 MHz
Coherence Internal	200 Symbols
Channel Model	Uncorrelated Rayleigh Fading
Signal Variance	2
SNR	0 dB - 25dB
Modulation	QPSK, 16QAM, 64QAM

proposed algorithm leads the RR algorithm by 5 dB and PF by 3.5 dB. Thus, in terms of BER performance, the proposed algorithm performs better than traditional algorithms.

We analyzed the sumrate performance of the proposed algorithm as shown in Fig.5. This simulation was administered with 16 base station antenna terminals communicating with 16 users using 16QAM modulation and MMSE precoding. The simulation results show that the proposed algorithm's performance is better than the traditional algorithms. For example, at SNR= 21 dB, a sum rate of 60 bits/s/Hz is attained by the proposed algorithm, whereas the PF algorithm achieved a sum rate of 43 bits/s/Hz, and the RR algorithm had the worst performance among all with a sum rate of 38 bits/s/Hz. The high sum rate is mainly due to the increased antenna terminals. However, as the number of active users grows in a cell, this sum rate will saturate at a point. We then considered the performance of our proposed algorithm with several modulation techniques. Again, this simulation was administered with 16 base station antenna terminals communicating with 16 users using 16QAM modulation and MMSE precoding. As shown in Fig. 6, QPSK has the best error performance over the range of SNR, whereas 64 QAM has the best performance. This is because higher modulation orders can carry more data per symbol. On the other hand, higher modulation order has a higher error rate as it is more prone to interference and noise. Thus, a perfect modulation order is always based on the application and the user's requirements.

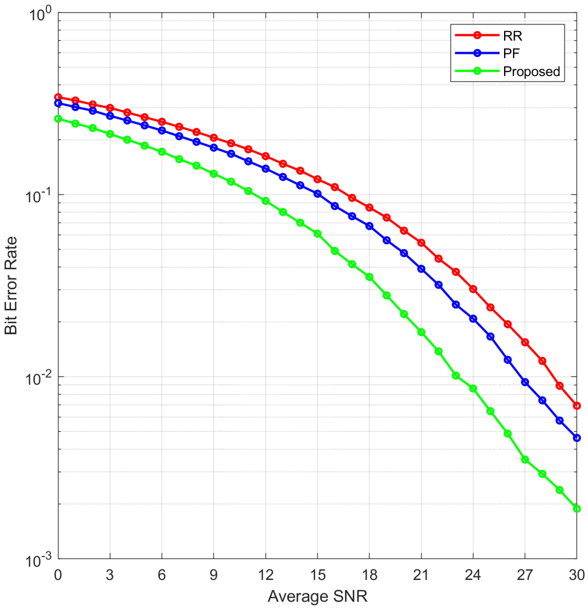

Fig. 3: BER vs. SNR performance with 16 users, 16 base station antennas, 16QAM modulation, and MMSE precoding.

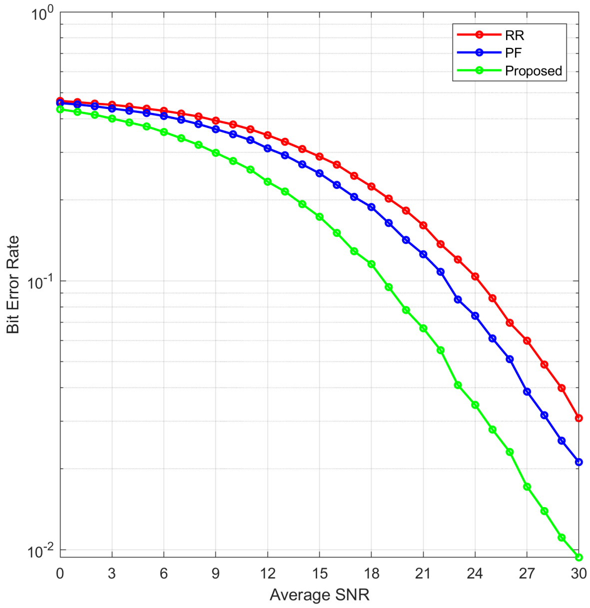

Fig. 4: BER vs. SNR performance with 16 users, 16 base station antennas, 16QAM modulation, and ZF precoding.

We evaluated the proposed algorithm's average throughput per user performance. This simulation was administered with 16 base station antenna terminals communicating with 16 users using 16QAM modulation and MMSE precoding As shown in Fig. 7, the average per-user throughput for the proposed algorithm was best among the compared algorithms. Our algorithm achieved a per-user throughput of 3.14 Mbps, whereas, for RR and PF algorithms, it was found to be 2.33 Mbps and 2.53 Mbps, respectively.

We use Jain's fairness index to evaluate the performance of the proposed algorithm. We measured Jain's fairness index for all the algorithms [20].

$$\mathcal{F}(X) = \frac{\left(\sum_{i=1}^{N} x_i\right)^2}{\sum_{i=1}^{N} x_i^2} \tag{12}$$

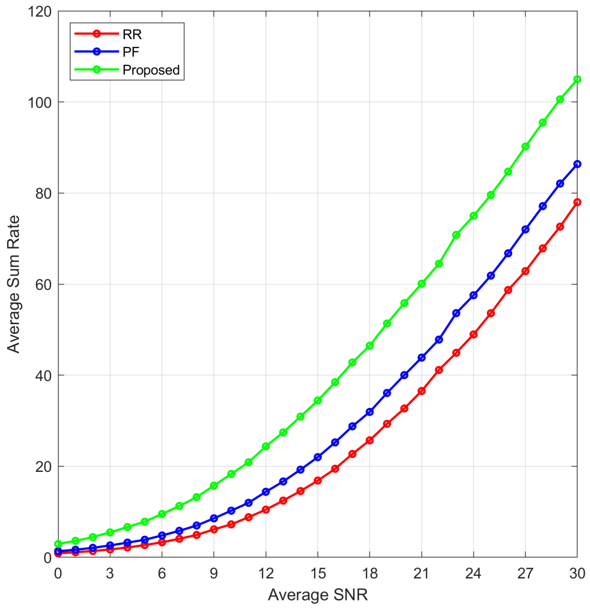

Fig. 5: Sumrate vs. BER performance with 16 users, 16 base station antennas, 16QAM modulation, and MMSE precoding.

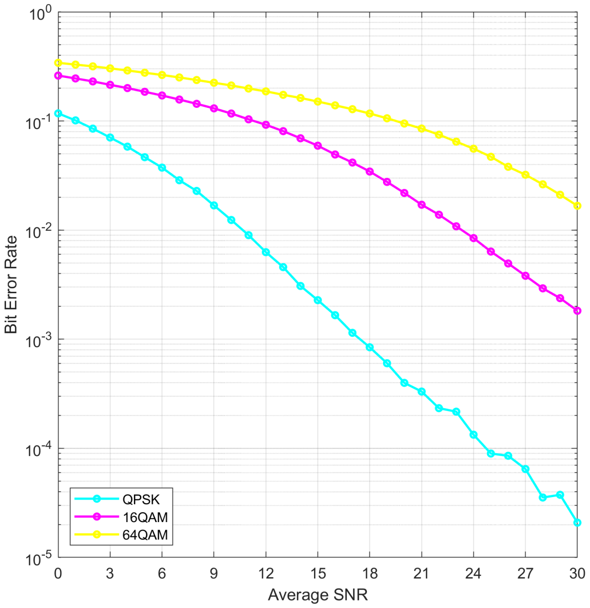

Fig. 6: BER performance of the proposed algorithm with several modulation schemes with 16 users, 16 base station antennas, and MMSE precoding

Where $\mathcal{F}$ is the fairness index whose values are between 0 and 11, and x_j is throughput for ith user. As shown in II, simulation results show that the fairness provided by the proposed algorithm is similar to that of the traditional algorithms.

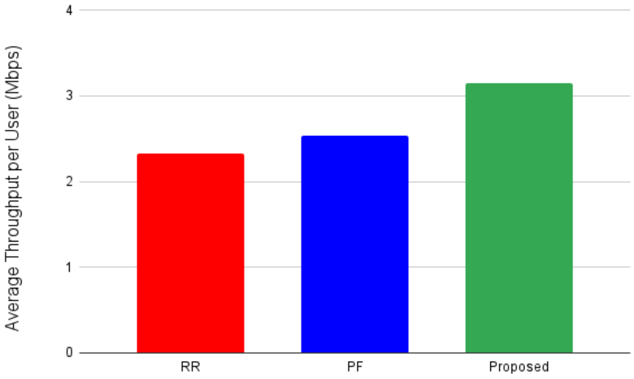

Fig. 7: Average throughput per user with 16 users, 16 base station antennas, 16QAM modulation, and MMSE precoding.

TABLE II: Fairness Index Comparison

Scheduling Algorithm	**Fairness Index**
Round Robin	0.973
Proportional Fair	0.983
Proposed	0.999

V. CONCLUSION

In this paper, we investigated the user scheduling issue during the downlink signaling in a massive MIMO system and proposed an adaptive user scheduling scheme based on instantaneous channel rate. We evaluated the sum rate, per-user throughput, and bit error performance of the proposed algorithm and compared the performance with traditional scheduling algorithms. The results obtained from the Matlab simulations show that the proposed algorithm performs better than the traditional user scheduling algorithm in terms of sumrate and per-user throughput. It also provides better error performance and establishes fairness among all users. We also studied the performance of the proposed algorithm with several modulation techniques and found that 64QAM provides the best data rate, whereas QPSK provides the best error rate. Finally, we assessed the fairness index of the proposed algorithm using Jain's fairness index. We found that the proposed algorithm provides a fairness index of 0.99 and ensures fairness among all the users. Thus, the proposed algorithm is a suitable candidate for downlink user scheduling in a massive MIMO system with a large number of antennas.

REFERENCES

[1] A. Paulraj, R. Nabar, and D. Gore, Introduction to Space-Time Wireless Communications. New York, USA: Cambridge University Press, 2008.

[2] IEEE Draft Standard Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 4: Enhancements for Higher Throughput. P802.11n D3.00, Sept. 2007.

[3] 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (EUTRA); Multiplexing and channel coding (Release 9). 3GPP Organizational Partners TS 36.212 Rev. 8.3.0, May 2008.

[4] 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.

[5] 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.

[6] 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.

[7] 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.

[8] 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.

[9] 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.

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

[11] G Dimic, ND Sidiropoulos, On downlink beamforming with greedy user selection: performance analysis and a simple new algorithm. Signal Process. IEEE Trans. 53(10), 3857–3868 (2005).

[12] J Wang, DJ Love, MD Zoltowski, User selection with zero-forcing beamforming achieves the asymptotically optimal sum rate. Signal Process. IEEE Trans. 56(8), 3713–3726 (2008).

[13] M Kobayashi, G Caire, Joint beamforming and scheduling for a multi-antenna downlink with imperfect transmitter channel knowledge. IEEE J Sel A Commun. 25(7), 1468–1477 (2007).

[14] 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.

[15] 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.

[16] M. Sharif and B. Hassibi, ”On the capacity of MIMO broadcast channels with partial side information,” IEEE Trans. Inf.

[17] T. Al-Naffouri, M. Sharif and B. Hassibi, ”How much does transmit correlation affect the sum-rate scaling of MIMO Gaussian broadcast channels?,” IEEE Trans. Commun., vol. 57, no. 2, pp. 562 -572, Feb. 2009.

[18] Theory, vol. 51, no. 2, pp. 506 -522, Feb. 2005 [5] T. Yoo and A. Goldsmith, ”On the optimality of multi-antenna broadcast scheduling using zero-forcing beamforming,” IEEE J. Sel. Areas Commun., vol. 24, no. 3, pp. 528 - 541, Mar. 2006.

[19] 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 and IoT, and AI (HONET-ICT), Charlotte, NC, USA, 2019, pp. 049-053.

[20] 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.

[21] R. Akl .”An Efficient and Fair Scheduling for Downlink 5G Massive MIMO Systems,” May 2020. 11th IEEE Texas Symposium on Wireless and Microwave Circuits and Systems (TSWMCS 2020).