

PAPER 61 – MITIGATING INTERFERENCE AND IMPROVING RESOURCE USAGE IN A DOWNLINK MU-MIMO TRANSMISSION FOR B5G NETWORKS

D. U. Onyishi¹, A. A. Masud^{1*}

¹Department of Electrical and Electronics Engineering, Federal University of Petroleum, Effurun, Nigeria.

*Email: abdulmujeebakajewole@gmail.com

ABSTRACT

In this paper, an Enhanced Mechanism for Downlink Multi-User Multiple Output Multiple Input (EMD-MU-MIMO) was proposed to improve the resource usage of the resource blocks and mitigate interference in a 5G and Beyond (B5G) network. The modified algorithm considered the mobility of users in the system to make the proposed algorithm adaptable to practical environmental settings. Simulation results showed that the EMD-MU-MIMO algorithm mitigated interference by 7.47% and 2.01% when compared with the conventional IEEE 802.11ax standard and the existing MD-MU-MIMO algorithm, respectively. Additionally, the EMD-MU-MIMO algorithm showed a mean percentage reduction in unnecessary resource usage by 26.13% and 4.67% when compared with the conventional IEEE 802.11ax standard and against the MD-MU-MIMO algorithm, respectively. Future works would delineate the impact of the modified algorithm in mitigating outage probability and showing the general improvement in the spectral efficiency of the system.

KEYWORDS: Outage probability, MIMO, MU-MIMO, Interference, Resource Usage

1. INTRODUCTION

The mobility of users in a downlink MU-MIMO system can have a significant impact on the network, which highly reduces the Quality of Service (Hassan *et al.*, 2020; Adikpe *et al.*, 2023). In this work, we restrict the discussion to the impact of mobile users on resource usage and interference. When users move around in the system, their channel conditions change, which affects the allocation of resource blocks (RBs) and the level of interference in the system (Zhang & Jiang, 2021). As such, it is essential that mobile users are allocated the appropriate number of RBs to maintain a certain quality of service while minimizing interference. If a user is moving away from the Next Generation Node B (gNB), the signal quality may degrade, and the system needs to allocate more RBs to maintain a certain level of quality. Similarly, if a user is moving towards the base station, the signal quality may improve, and the system can allocate fewer RBs to maintain the same quality (Barri *et al.*, 2021).

Due to the randomness of users' movement, the behaviour of users is unpredictable during a defined time gap. If a user moves randomly during the time gap, the wireless channel between the moving user and the transmitting BS or receiving User Equipment (UE) changes with the location of the moving user (Zhang & Jiang, 2021). As such, the instantaneous wireless channel mismatches with the weight of beams derived from measured channel information. Hence, the beams for each receiving node may interfere with each other. The unpredicted inter-beam interference will degrade the performance of an MU-MIMO transmission and consequently increase the probability of an outage in the system. In the work of Lee *et al.*, (2018), the influence of inter-beam interference on the outage probability performance was exploited, but the randomness of interference was not considered. Hassan *et al.*, (2020) proposed several techniques for joint transmit and receive beamforming in downlink multi-user MIMO systems under Rayleigh fading channel. Nonetheless, the mobility of users was not considered. Nalband *et al.*, (2020) evaluated the achievable sum rate and highlighted the energy efficiency properties of mmWave massive MIMO systems. The drawback of the work was that the effect of inter-beam interference was not considered. This could reduce the reliability of the approach in improving the spectral efficiency of the system. Aarsal *et al.*, (2021) identified that the computational complexity of expressions used to compute the outage probability and coverage probability increased as the number of transmit antennas and scheduled users on the same frequency response grew. A primary aspect of the work was focused on minimizing the computational complexity in computing the coverage probability, however, the SIR values of users connected to the same cell were not considered. These drawbacks are likely to reduce the approaches' performance in practical environments. The work of Huh *et al.*, (2021) utilized signal processing optimization to address digital federated learning and over-the-air compression schemes under muMIMO uplink systems. However, the drawback of the approach was that the computational complexity was high, which could affect the reliability of the communication link. In the work Barri *et al.*, (2021), the influence of interference and resource usage was considered, however, the mobility

of users was not taken into account. Kinol *et al.*, (2022) proposed a novel low-complexity radix factorization-based fast Fourier transform multi-beam former and maximal likelihood –multi-user detection (MLMUD) techniques as signal detector and was customized with sub-detector systems which minimized complexity reduction with intolerable error rate performance. The shortcoming of the approach was that the computational complexity was high, which could affect the reliability of the communication link. For most of the literature, users were assumed to be stationary and if the mobility of the users was considered, the approach adopted was computationally complex.

Additionally, the mobility of users in an MU-MIMO system can also impact the channel estimation process. As users move, the channel conditions between the user and the base station change, and the channel estimation needs to be updated to ensure accurate signal transmission. The update rate of the channel estimation process needs to be carefully designed to balance the trade-off between accuracy and overhead. Overall, the mobility of users in a MU-MIMO system presents several challenges for resource usage and interference management. And proffering a balance to mitigate interference and improve resource usage is worth discussing.

Motivated by the discussion above, this paper considers the non-consideration of mobility in the work of Barri *et al.*, (2021) and modifies the existing Mechanism for Downlink in a Multi-User MIMO (MD-MU-MIMO) algorithm to not only consider stationary users but also the randomness of mobile users. Furthermore, the modified algorithm is discovered to minimize unnecessary resources and mitigate interference in the system.

2. MATERIALS AND METHODS

This paper modifies the existing MD-MU-MIMO algorithm in the work of Barri *et al.*, (2021) to improve resource usage and minimize interference in the MU-MIMO system. As such, this work develops a closed-form expression of the outage probability for both mobile and stationary UEs on the downlink MU-MIMO system. As such, it defines the events to identify mobile and stationary UEs at the start of the time frame, which would aid in evaluating the expected outage probability for the weighted probability of UE events on the downlink MU-MIMO as identified in the work of Masud *et al.*, (2023).

In a real-world network environment, UE placement within a coverage area is random. In a MU-MIMO transmission, inter-beam interference and the number of received interference are innately influenced by the mobility state of the UEs. According to (Zhang & Jiang, 2021), continuous measurement of the channel state would probably be computationally challenging because the channel's state, the power delivered, etc., are all dynamic. In this paper, the data transfer to UEs is taken into account within a time frame to reduce this complexity. Additionally, the power transmitted and the channel's condition are thought to remain consistent during this time. These assumptions are adopted in this work. In this discrete time, it is easier to investigate the co-channel interference and inter-beam interference. Furthermore, this consideration makes allowance for the evaluation of a closed-form outage probability of an instantaneous MU-MIMO transmission. As a result, this work considers the placement of UEs in a coverage area to be randomly allocated according to Spatial Poisson Point Process (SPPP) with intensity (λ). The set of BS is represented as $\Omega(\lambda) = \{B_i\}$, where B_i is the position of the BS, at an instant in time, i .

In the data transmission phase of MU-MIMO, the received signal of the receiving UE, k , is mathematically given as (Lee *et al.*, 2018):

$$y_k = \sqrt{\frac{P_t}{K}} D_k^{-\beta} \mathbf{h}_k^H \mathbf{w}_k s_k + \sum_{j \in K, j \neq k} \sqrt{\frac{P_t}{K}} D_k^{-\beta} \mathbf{h}_k^H \mathbf{w}_j s_j + \sum_{\tau \in \Phi/T_k} \sqrt{P_t |\Omega_\tau|^{-\beta}} g_{\tau k} s_\tau + n_k \quad (1)$$

where:

y_k denotes the receiving signal of the receiving UE

k is a receiving UE

P_t represents the transmit power

T_k depicts the BS

$\mathbf{h}_k \in \mathbb{C}^{N_t \times 1}$ represents the channel gain vector between the k and T_k

$\mathbf{g}_{\tau, k} \in \mathbb{C}^{1 \times 1}$ represents the channel gain vector between the k and τ

$\mathbf{s}_k \in \mathbb{C}^{K \times 1}$ denotes the symbol transmitted from the BS

n_k depicts the additive white Gaussian noise (AWGN) with zero mean and variance of σ^2

$$\begin{aligned} \sqrt{\frac{P_t}{K} D_k^{-\beta}} \mathbf{h}_k^H \mathbf{w}_k \mathbf{s}_k &\text{ represents the desired signal} \\ \sum_{j \in K, j \neq k} \sqrt{\frac{P_t}{K} D_k^{-\beta}} \mathbf{h}_k^H \mathbf{w}_j \mathbf{s}_j &\text{ denotes the inter-beam interference signal} \\ \sum_{\tau \in \Phi / T_k} \sqrt{P_t |\Omega_\tau|^{-\beta}} g_{\tau k^s \tau} &\text{ depicts the co-channel interference signal} \end{aligned}$$

For the receiving UE, k , whether the inter-beam interference signal exists or not depends on whether the wireless channels change with respect to the location of the BS during the time frame or not. The orthogonality of the beams and the elimination of inter-beam interference are both possible in a scenario where the UEs remain stationary during a discrete time. In contrast, the beam for a moving UE interferes with the other beams while the beam for a stationary UE interferes with the beams for the moving UEs. To assess the effectiveness of a MU-MIMO transmission, the behaviour of UEs is divided into categories based on the presence or absence of inter-beam interference and the quantity of interference beams that have been received. This paper defines a number of events to illustrate the behaviour of UEs in the following manner, which simplifies the calculations. When the event \mathcal{H}_2 with $0 < M < K$ occurs, the beam for a motionless UE has interfered with the beams for M moving UEs, but the beam of a moving UE has interfered with the beams for $K - 1$ UEs. In light of the aforementioned, the proposed measurement of the instantaneous received SINR for motionless and moving UEs is represented as an event \mathcal{H}_2^s and \mathcal{H}_2^m , respectively. As such, this paper considers two cases. The first case considers an event in which the UEs of an MU-MIMO system are both keep motionless during the time frame and is denoted as an event \mathcal{H}_1 . For case two, an event that the M ($1 < M \leq K$) UEs move during the time frame is denoted by the event \mathcal{H}_2 .

The outage probability of an MU-MIMO transmission is defined as the probability that instantaneous received SINR does not exceed that required SINR threshold. The expected outage probability is the sum of the outage probability weighted by the probability of defined events. Assuming the SINR threshold is ξ_{thres} , hence, the expected outage probability proposed in this research work is given as:

$$\begin{aligned} P_k^{exp}(\xi_{thres}) &= \sum_{i=1}^2 \wp(\mathcal{H}_i) \wp(\xi_{k, \xi_{thres}}^{ins}) \\ &= \wp(\mathcal{H}_1) \wp(\xi_{k, \xi_{thres}}^{ins}) + \wp(\mathcal{H}_2) \times \left[\wp(\mathcal{H}_2^s) \wp(\xi_{k, \mathcal{H}_2^s}^{ins} \leq \xi_{thres}) + \wp(\mathcal{H}_2^m) \wp(\xi_{k, \mathcal{H}_2^m}^{ins} \leq \xi_{thres}) \right] \end{aligned} \quad (2)$$

where $\wp(\mathcal{H}_i)$ represents the probability of the event \mathcal{H}_i and $\xi_{k, \mathcal{H}_i}^{ins}$ depicts the instantaneous received SINR of the receiving node k when the event \mathcal{H}_i occurs. The input parameters required to simulate and model the network topology of the wireless cellular network consider the variables for the mobile and stationary UEs. Before calculating each user's resource block, the work examines the mobility state of events for connected UEs. For the two states, the resources are calculated for one where the interference's impact, that is, when $\phi = 0$ is removed and another where the interference is taken into account, that is $\phi = 1$. The outage probability used to determine the latter and former aforementioned is delineated in (3) and (4), respectively.

$$P_k^{ins}(\xi_{thres}) = \kappa Q \omega^{2/\beta} \left(1 + \sum_{m=1}^{N_t - K} \frac{1}{m!} \prod_{l=0}^{m-1} (m - \delta) \right) \quad (3)$$

$$P_k^{ins}(\xi_{thres}) = 1 - \frac{e^{-\kappa Q \omega^\delta}}{(1 + 2\rho\omega)^\beta} \quad (4)$$

Where β Path loss exponent, N_t is the transmit antenna; m depicts the mobile receiving UEs, K is the receiving UEs, $\delta = 2/\beta$, $Q = \mu \Gamma(\delta) \Gamma(1 - \delta)$, $\rho = 1/KD_k^\beta$ and $\omega = \xi_{thres}/\rho$. $S_k = |\mathbf{h}_k^H \mathbf{w}_k|^2$

2.1 Proposed EMD-MU-MIMO Algorithm

Algorithm 1 delineates the EMD-MU-MIMO algorithm. The algorithm considers a network architecture that considers the mobility states of UEs. The mobility of UEs is an essential factor that influences the overall performance of the MU-MIMO system in a pragmatic environmental setting. As such, the proposed network model considers UEs to be randomly distributed around the coverage area of the BS. This case scenario for this extends the model in Barri *et al.*, (2021). Algorithm 1 considers two cases in the EMD-MU-MIMO algorithm. The first event was denoted as \mathcal{H}_1 indicates that the UEs are stationary at the start of a set time frame and remain

stationary during a duration not less than T_{Frame} . In the second scenario, \mathcal{H}_2 considers the movement of the UE during T_{Frame} . The variables for these mobility events are considered in the input parameters that are needed to simulate and model the network topology of the wireless cellular network. For UEs that are connected to the gNB, the work checks the mobility state of events before computing each user's resource block. Concerning the two states, the resources are computed for one in which the effects of interference are removed, that is, where $\phi = 0$ and another in which the interference is considered, that is $\phi = 1$. The purpose of this modification is to minimize the processing time when considering the conditions to either include inter-beam interference or not. The proposed EMD-MU-MIMO algorithm would lower the probability of an outage in the network.

Algorithm 1 Proposed EMD-MU-MIMO algorithm

Input $\mathcal{H}_i, T_{Frame}, i, \mathcal{H}_2^s$ and \mathcal{H}_2^m

Input Number of MIMO layers, Bandwidth, frequency range, modulation type

Output RBs, SINR, and average data rate

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1   For simulated network topology, users at time instant,  $U_i$  are uniformly or randomly distributed
2       For each  $U_i$ 
3           If  $i$  is connected
4               For each  $U_i$  trying to connect
5                   Calculate the maximum data rate the UE can achieve
6                    $i++$ 
7               End for
8           Else
9                $i++$ 
10              Evaluate the expected outage probability using equation (2)
11              Compute PDF on events  $\mathcal{H}_i$ 
12              If  $\phi = 0$ 
13                  Compute outage probability using equation (3)
14                  Compute Reach user's RB
15              Else
16                  If  $\phi = 1$  and  $0 < M < K$ 
17                      Compute outage probability using equation (4)
18                      Compute each user's RB
19                  End if
20              End if
21          End if
22      For each cell topology
23          Calculate BSs power allocated to the connected users
24          Compare scenarios with conventional allocation
25           $K++$ 
26      End for
27 End for

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The simulation parameters adopted for the EMD-MU-MIMO algorithm are as follows (Barri *et al.*, 2021; Zhang & Jiang, 2021): Transmit antenna, $N_t = 25$; Receiving antenna, $N_r = 4$; Receiver Noise Power, $P_{rn} = -32\text{dBm}$; Link rate, $L_r = 867\text{Mbits/s}$; Resource block frames UL, $RB_{UL} = 275$; Resource block frames DL, $RB_{DL} = 275$; Users for each scenario, $U_i = 200, 250, 300$; Path loss exponent, $\beta = 4$; SINR threshold, $\xi_{thres} = -30\text{dB}$; Average time interval, $\theta = 1\text{s}$; Number of discrete rates, $L = 4$. These values are used to evaluate the performance of the conventional IEEE 802.11ax approach, the mechanism for downlinking MU-MIMO, and the modified Efficient Mechanism for downlinking MU-MIMO (EMD-MU-MIMO) adopted in this work.

3. RESULTS AND DISCUSSION

This section presents and discusses the simulation results implemented to measure the performance of the EMD-MU-MIMO algorithm to mitigate unnecessary resource usage and interference in a MU-MIMO system adopted in the work of Barri *et al.*, (2021). The results obtained using the proposed EMD-MU-MIMO system are compared against the conventional IEEE 802.11ax standard and the MD-MU-MIMO algorithm.

3.1 Interference

Figure 1 shows the result of the performance of the conventional IEEE 802.11ax standard, the MD-MU-MIMO algorithm, and the EMD-MU-MIMO algorithm in mitigating interference in an MU-MIMO system. In this paper, the interference is considered for three use case scenarios for each user. As in the work of Barri *et al.*, (2021) the three scenarios were designed to run at a total of fifty times. In these iterations, the mobility of the user was only considered for the EMD-MU-MIMO algorithm and the distribution of the users was considered to be random to make the scenario more realistic. This was compared against the interference observed from the conventional IEEE 802.11ax standard and the MD-MU-MIMO algorithm that considered the distribution of the UE to be uniform in the later and randomly distributed in the former. However, the mobility of the UE was not considered as in the work of Barri *et al.*, (2021). On this premise, it was observed that the MD-MU-MIMO algorithm and the EMD-MU-MIMO had a mean percentage reduction of 5.56% and 7.47%, respectively, in the interference observed in the MU-MIMO system when compared with the conventional IEEE 802.11ax standard. Additionally, the average percentage improvement of the proposed EMD-MU-MIMO had a 2.01% improvement against the MD-MU-MIMO algorithm in the interference observed in the MU-MIMO system. In the subsequent report, this percentage improvement of the proposed EMD-MU-MIMO algorithm is expected to further increase when the mobility of the UE is also considered in the conventional IEEE 802.11ax standard and the MD-MU-MIMO algorithm.

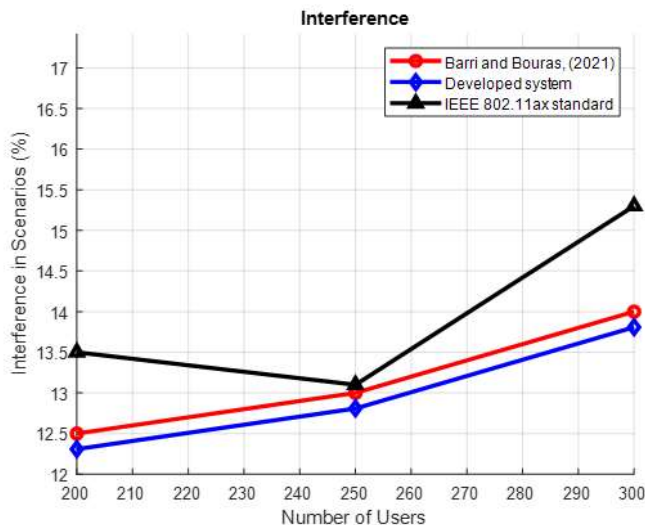


Figure 1: Interference for Three Use Case Scenarios for Each User

3.2 Resource Usage

Figure 2 shows the result of the performance of the conventional IEEE 802.11ax standard, the MD-MU-MIMO algorithm, and the EMD-MU-MIMO algorithm in improving resource usage in MU-MIMO. In this study, resource usage is considered for three use case scenarios for each user. The three scenarios were planned to run a

total of fifty times, similar to the research by Barri *et al.*, (2021). The EMD-MU-MIMO algorithm was the only part of these iterations that took user mobility into account, and to make the scenario more plausible, the distribution of users was assumed to be random. This was compared to the observed resource utilization from the standard IEEE 802.11ax standard and the MD-MU-MIMO method, which assumed the distribution of the user equipment (UE) to be uniform in the latter and randomly distributed in the former. However, the mobility of the UE was not considered as in the work of Barri *et al.*, (2021). On this premise, it was observed that the MD-MU-MIMO algorithm and the EMD-MU-MIMO had a mean percentage reduction of 29.36% and 26.13%, respectively, in the resource usage observed in the MU-MIMO system when compared with the conventional IEEE 802.11ax standard. In comparison, the average percentage improvement in the resource usage observed of the proposed EMD-MU-MIMO against the MD-MU-MIMO had a 4.67% improvement over the MD-MU-MIMO

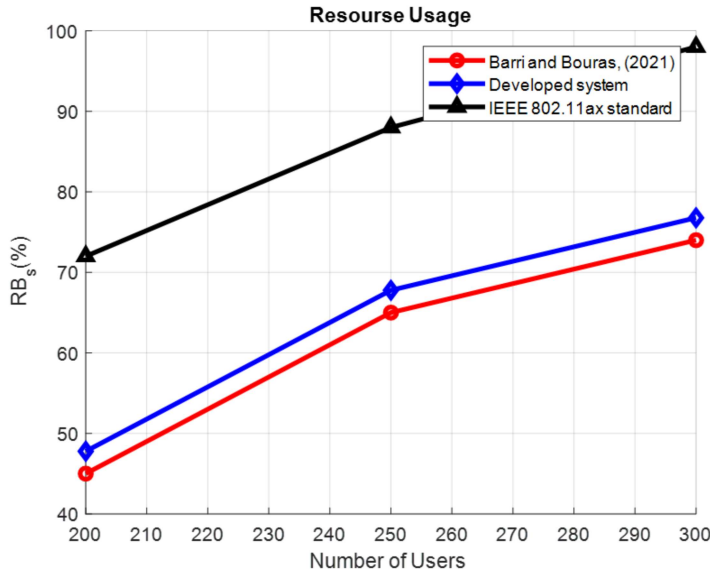


Figure 2: Resource Usage for Three Use Case Scenarios for Each User

4. CONCLUSION

This paper considers the mobility of users to modify an existing MD-MU-MIMO algorithm. As such, the modified algorithm termed EMD-MU-MIMO considers the mobile state of users in addition to the stationary state of users in the algorithm to minimize resources and mitigate interference in the MU-MIMO system. The developed algorithm was compared against the existing MD-MU-MIMO algorithm and the conventional IEEE 802.11ax algorithm. Results showed that the EMD-MU-MIMO algorithm mitigated interference by 7.47% and 2.01% when compared with the conventional IEEE 802.11ax standard and the MD-MU-MIMO algorithm, respectively. Additionally, the EMD-MU-MIMO algorithm showed a mean percentage reduction of 26.13% and 4.67% in resource usage when compared with the conventional IEEE 802.11ax standard and against the MD-MU-MIMO algorithm, respectively. Since mobility is a crucial part of this work, future works would also consider the mobility of the UE in the IEEE 802.11ax standard and the MD-MU-MIMO algorithm. This would aid in delineating the impact of the proposed EMD-MU-MIMO algorithm against the aforementioned algorithms in a more realistic scenario. Additionally, comparisons of the EMD-MU-MIMO algorithm against the conventional IEEE 802.11ax standard and the MD-MU-MIMO algorithm would be carried out with outage probability and spectral efficiency as performance metrics.

REFERENCES

- Adikpe, A. O. Tekanyi, A. M. S. & Yaro, A. S. (2023). Mitigating the Signaling Resources Expended in 5G Location Management Procedures at Millimeter-Wave Frequencies. *Advances in Electrical and Electronic Engineering*, 20(4), 572-583.

- Arsal, A., Civanlar, M. R., & Uysal, M. (2021). Coverage Analysis of Downlink MU-MIMO Cellular Networks. *IEEE Communications Letters*, 25(9), 2859-2863.
- Barri, E., Bouras, C., Kokkinos, V., & Koukouvela, A. (2021). A Mechanism for Improving the Spectral Efficiency in mu-MIMO for 5G and Beyond Networks. In *Proceedings of the 19th ACM International Symposium on Mobility Management and Wireless Access* (pp. 11-16).
- Hassan, A. K., Moinuddin, M., Al-Saggaf, U. M., Aldayel, O., Davidson, T. N., & Al-Naffouri, T. Y. (2020a). Performance Analysis and Joint Statistical Beamformer Design for Multi-User MIMO Systems. *IEEE Communications Letters*, 24(10), 2152-2156.
- Hassan, A. K., Moinuddin, M., Al-Saggaf, U. M., Aldayel, O., Davidson, T. N., & Al-Naffouri, T. Y. (2020a). Performance Analysis and Joint Statistical Beamformer Design for Multi-User MIMO Systems. *IEEE Communications Letters*, 24(10), 2152-2156.
- Kinol, A. M. J., Nisha, A. S. A., Marshiana, D., & Krishnamoorthy, N. R. (2022). Hybrid Multi Beamforming and Multi-User Detection Technique for MU MIMO System. *Wireless Personal Communications*, 124(4), 3375-3385.
- Lee, S., Kim, S., Park, Y., Choi, S., & Hong, D. (2018). Effect of unpredictable interference on MU-MIMO systems in HetNet. *IEEE Access*, 6, 28870-28876.
- Masud *et al.*, (2023, April). Mitigating Interference and Improving the SINR in a Discrete Time Frame of a Downlink MU-MIMO Transmission in 5G and Beyond Wireless Networks. *Paper presented at the 2023 IEEE International Conference of Science, Engineering and Business for Driving Sustainable Development Goals, Omu-Aran, Kwara State.*
- Nalband, A. H., Sarvagya, M., & Ahmed, M. R. (2020). Optimal hybrid precoding for millimeter wave massive MIMO systems. *Procedia Computer Science*, 171, 810-819.
- Zhang, W., & Jiang, S. (2021). Effect of Node Mobility on MU-MIMO Transmissions in Mobile Ad Hoc Networks. *Wireless Communications and Mobile Computing*, 2021.