Nigerian Journal of Technology (NIJOTECH)
Vol. 43, No. 2, June, 2024, pp.328 - 337
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.v43i2.16

A RELIABLE DOWNLINK MIMO ALGORITHM FOR MITIGATING THE EFFECT OF USER EQUIPMENT MOBILITY IN MULTI-USER MIMO IN FIFTH-GENERATION AND BEYOND NETWORKS

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ARTICLE HISTORY:
Received: 21 November, 2023.
Revised: 04 April, 2024.
Accepted: 30 April, 2024.
Published: 12 June, 2024.

KEYWORDS:
Outage Probability, 5G, MU-MIMO, UE Mobility Effect.

ARTICLE INCLUDES:
Peer review

DATA AVAILABILITY:
On request from author(s)

EDITORS:
Patrick Akpan

FUNDING:
None

Abstract
Multiple Input Multiple Output (MIMO) wireless systems offer substantial capacity gains over conventional wireless channels, making them well-suited for future high-speed wireless communications. However, ensuring high Quality of Service (QoS) for users in terms of signal quality, data speed, and reliability are some of the challenges of 5G wireless cellular networks. However, the effect of users' mobility potentially may result in significant inter-beam interference, which increases the probability of outage in a Multi-User-MIMO (MU-MIMO) system. Although several studies have been carried out to mitigate the probability of outage, most of the studies either considered the impact of user mobility or User Equipment (UE) stationarity in determining outage performance or have used methods with high computational complexity that ignore one or both inter-beam interference and interference from the mobile UEs. This paper presents a model that minimizes the outage probability in the downlink of both mobile and stationary UEs in an MU-MIMO system. This proposed model to mitigate the outages encountered by mobile UEs in different scenarios: when a single UE is mobile when half of the UEs are mobile, and when all UEs are mobile within the proposed MU-MIMO system. These scenarios are assessed within a defined time frame to gauge the extent to which they reduce outage probability and enhance the spectral efficiency of the MU-MIMO system. Simulation results showed that the probability of outage in a discrete time frame and for UEs that are mobile in a discrete-time frame increased as the density of M increased. However, the proposed model minimized the probability of outage and improved the spectral efficiency in comparison to existing systems.

HOW TO CITE:
Akajewole, M. A., and Onyishi, D. U. "A Reliable Downlink Mimo Algorithm for Mitigating the Effect of User Equipment Mobility in Multi-User Mimo in Fifth-Generation and beyond Networks", *Nigerian Journal of Technology*, 2024; 43(2), pp. 328 – 337; *https://doi.org/10.4314/njt.v43i2.16*

1.0 INTRODUCTION
The explosive growth in wireless mobile data usage has spurred growing demand for wireless data, with projections suggesting this demand will double every 2.5 years and potentially increase up to 5,000-fold by 2030 [1]. This growing demand has driven the development of fifth-generation (5G) technology, which has technical specifications that surpass legacy fourth-generation (4G) networks. The Third Generation Partnership Project (3GPP) and allied companies are pursuing the objective of nearly 100% coverage with a low likelihood of disruption, which is one of these essential standards [2, 3]. In an effort to improve post-transmission performance, a number of technologies have been adopted, including beamforming, Millimeter Wave (mmWave), Non-Orthogonal Multiple Access (NOMA), massive Multiple Input Multiple Output (mMIMO),

Orthogonal Frequency Division Multiplexing (OFDM), Device-to-Device (D2D), and hybrid precoding [2,4]. Although, this work focuses on MU-MIMO.

Wireless transceiver performance has been greatly enhanced by MIMO technology, which has its roots in third-generation (3G) wireless networks [5]. MIMO is divided into two categories in cellular networks: Single-User MIMO (SU-MIMO) and MU-MIMO, also referred to as multi-user MIMO [6]. The primary focus of current research is on assessing MU-MIMO systems' downlink performance in 5G networks. Based on the quantity of interfering beams received and the presence or absence of interbeam interference, researchers categorize the behaviour of receiving user equipment (UEs) [7]. Also, understanding the contribution of the mobility effect of UEs to this interference is crucial in next-generation wireless communications.

Although the mobility effect significantly affects MU-MIMO systems, many existing studies do not adequately address this phenomenon. In an MU-MIMO system, the mobility effect of UEs can cause transmission degradation, especially in higher frequency bands. Furthermore, beam interference becomes more severe when beam frequencies are assigned to multiple users. Although several studies have attempted to improve the downlink in a MU-MIMO system, a significant challenge when investigating MU-MIMO systems is the computational complexity, which largely derives from the dynamic nature of the factors that must be considered. These elements could result from coexisting technologies that share frequency channels, like Bluetooth, Zigbee, and other WLAN systems [8]. Such coexistence has a number of negative implications, including capacity, power consumption, connection dependability, interference, outages, and security problems. In addressing these complexities, many researchers inadvertently compromise computational efficiency to investigate these effects [7, 9, 10] or exclude factors such as the mobility effect of UEs to reduce complexity while investigating MU-MIMO downlink [4].

To adapt to changing user demands and optimize spectrum utilization, it is essential to evaluate interference and the probability of outage resulting from the mobility effect. This paper extends our previous work [11], which demonstrated a reduction in interference in the proposed MU-MIMO system. This extends the application of the system model to mitigate the probability of outage resulting from UE mobility. The proposed model addresses outages experienced by mobile UEs in various scenarios, including cases where a single UE, half of the UEs, or all UEs are mobile within the MU-MIMO system. These scenarios are evaluated within a defined time period to evaluate their impact on reducing the probability of outages and improving spectral efficiency. As such, multiple events, contingent on the mobility or steady state of the transmitting and receiving user devices within an instantaneous time period, play a pivotal role in the performance of MU-MIMO systems.

1.1 Related Work

This subsection presents a review of recent literature that attempts to improve the downlink performance of received UEs in an MU-MIMO system. The insights gathered from the literature reviewed are used to model an efficient mechanism for MU-MIMO wireless communication systems to mitigate outages in 5G and beyond wireless communications.

The authors of [7] examined the impact of mobile nodes on MU-MIMO transmission in MANETs. The authors evaluated node movement in the proposed network using three mobility scenarios. In the first scenario, both the transmitting and receiving nodes were stationary. In the second scenario, the transmitting node was mobile regardless of the receiving node's mobility state. In the final scenario, the transmitting node was stationary, while the receiving node was mobile. These scenarios assessed the probability of events, the outage probability of instantaneous MU-MIMO transmission, and the probability of outage. MU-MIMO throughput was also evaluated. Simulation results showed that unpredictable inter-beam interference reduces outage probability performance, suggesting that time gap duration could be improved. While the study developed a model that reduced the computational complexity of analyzing UE mobility in downlink MU-MIMO systems, it did not consider detection techniques. These techniques could further reduce computational complexity and enhance the MU-MIMO system.

To maximize system throughput in sub-band and beam MIMO systems subject to QoS constraints, the authors in [12] developed a Mobility-aware Sub-band and Beam Allocation (MSBA) scheme. The proposed MSBA scheme consists of two phases: (1) Sub-band beam index allocation to reduce inter-beam interference using an iterative genetic algorithm, and (2) beamwidth and beam direction assignment to eliminate residual beam interference in each subband using a novel beam orthogonalization method. The authors employ a mobility-aware beam interference model by constructing the interference matrix for each beam pair based on user mobility information. The authors obtain closed-form formulas for the average throughput of the system and the theoretical upper bound of the SINR signal's Complementary Cumulative Distribution Function (CCDF). The authors also determine the optimal beamwidth and beam direction allocation policy for the single-user interference-free scenario and generalize the result to multiuser beam interference scenarios. The suggested MSBA system surpasses previous schemes in terms of both throughput and complexity, as demonstrated by the simulation results, which also support the theoretical analysis. The work's restriction is the assumption of perfect CSI at the base station.

The authors of [13] proposed a system model for a mixed free-space radio frequency and optics (FSO/RF) system that includes a ground Central Unit (CU), multiple Ground Users (GUs), and an Unmanned Aerial Vehicle (UAV) that serves as a decoding and forwarding aerial relay. Statistical techniques are utilized to predict the fading channels on the FSO and RF links, and three-dimensional geometry-based placement is utilized for the CU, air relay, and GUs. Additionally, the closed-form equations for the End-to-End (E2E) system's outage probability as well as the PDF and CDF of the instantaneous SNR received at the overhead relay and GUs were provided. Their findings indicate that the proposed system can achieve a high level of reliability under various channel conditions and that the use of MU-MIMO channels with Transmission Aperture Selection (TAS) and Orthogonal Space-Time Block Coding (OSTBC) can significantly reduce the outage performance of the system. However, the work neglects the UE mobility effect, which could impact channel conditions and consequently increase the probability of outage.

In their work, [14] delved into the impact of multi-cell association on downlink MU-MIMO systems' performance. Employing a realistic system model with arbitrary beamforming and Rayleigh fading channels, the authors devised a novel analytical framework to derive closed-form expressions for the coverage probability of a given user in a multi-cell association regime. An Indefinite Quadratic Form (IQF) formulation was utilized to model the multi-cell association problem, effectively capturing the intricate interactions between cells and users within the system. Leveraging the IQF formulation, the authors derived closed-form expressions for the coverage probability of a given user. The results revealed that multi-cell association can substantially enhance coverage probability in downlink MU-MIMO systems. Moreover, the benefits of multi-cell association were more pronounced for users with lower Signal-to-Interference-Plus-Noise Ratios (SINRs). However, the work neglects the UE mobility effect, which could impact channel conditions and consequently increase the probability of outage.

The work in [15] proposed and analysed various RRM schemes for NOMA and MU-MIMO, and demonstrated that they can significantly improve the performance of cellular networks in terms of spectral efficiency, fairness and energy efficiency. The work achieved a number of important results, including a simple static coordinated power allocation scheme that can improve performance by 80% compared to equal power allocation for NOMA RRM, and a simple practical scheduler for MU-MIMO that achieves 97% performance for near-optimal greedy-to-end (GDAW) strategy with Full Drop (FD) strategy. The main limitation of the work is that it only considers two multi-user transmission technologies and assumes that the channel is perfectly known by the base station. However, the work does not explicitly consider the UE mobility effect. It is important to consider the mobility effect of UEs when designing RRM schemes for multi-user transmission systems. Since then, UE mobility can cause changes in channel conditions, which can affect system performance.

In an attempt to improve the downlink performance to receiving UEs in an MU-MIMO system, some of the works considered the mobility effect of the UEs and the probability of outage. However, some work only considered stationary UEs, which are not ideal for practical environments. Additionally, some of the approaches were computationally complex. To address these challenges, this paper proposes a Reliable Downlink MU-MIMO (RD-MU-MIMO) mechanism to mitigate the outage probability and improve the spectral efficiency of the MU-MIMO system. The previous paper [11] had already shown that the developed RD-MU-MIMO mechanism mitigated interference and improved SINR when compared to an existing system. The extension of the work, which is discussed in the next section is presented to mitigate the probability of outage in a discrete time frame and for mobile users in a determined time frame. This is expected to further improve the spectral efficiency of MU-MIMO transmissions.

2.0 SYSTEM DESIGN FOR THE RD-MU-MIMO ALGORITHM

The RD-MU-MIMO algorithm fundamentally considers two cases for the MU-MIMO system. In the first case, the UEs in an MU-MIMO system are kept motionless during the time frame is denoted as the event H_1. In the second case, UEs (M) move during the time frame, which is denoted as the event H_2. In this case, $M \geq 0$ since there is a mobile user at any point in the time frame considered. When considering UE mobility, it is essential to take into account several factors that could contribute to increased cases of signal quality degradation or unreliable connections. These factors include interference, fading, and varying channel conditions, which together contribute to what is known as outage probability. The utilization of multiple antennas and the integration of single-antenna users within the MU-MIMO framework play a crucial role in improving spectral efficiency and ensuring more robust communication links, as demonstrated by findings from previous literature. In a MIMO system, the deployment of multiple transmitting and receiving antennas is common practice. Each antenna, while intended to receive specific components of the signal, also captures indirect components intended for other antennas on the same channel. To maximize system performance, data intended for transmission is divided into separate, independent data streams, a number that is typically equal to or less than the number of available antennas. This design results in a linear increase in system capacity as the number of flows grows, aligning with the principles described in the Shannon-Hartley theorem for MIMO, denoted as (1) [4].

$$C \leq MB \log_2\left(1 + \frac{S}{N}\right) \quad (1)$$

where C is the channel capacity in bits per second, B is the bandwidth in hertz, S is the average received signal power in Watts, and N is the average power of the noise in Watts. The maximum attainable data rate of a system is calculated by taking the product of the number of pulse levels (M), the system's bandwidth, and the base-2 logarithm of the Signal-to-Noise Ratio (SNR) plus 1 [4].

$$MaxDR = B \log_2\left(1 + \frac{S}{N}\right) \quad (2)$$

Whereas a low SNR results in a nearly linear increase in The Maximum Data Rate (MaxDR), solely focusing on maximizing SNR is not the most effective approach. Instead, distributing SNR across multiple streams multiplies the maximum available data rate. Spread spectrum techniques like CDMA achieve this distribution by multiplexing transmissions over a broader bandwidth. MU-MIMO mode is particularly beneficial for the uplink, minimizing complexity by employing only one antenna for transmission in user equipment. Leveraging diverse antennas on the end of the user and that of the Base Station (BS) enhances spectral efficiency and overall communication system reliability. Spectral Efficiency (SE), measured in bits/s/Hz, represents the cumulative transmission efficiency within a cellular network cell. Achieving higher spectral efficiency is essential to ensure the system effectively serves the maximum number of UEs within the cell, utilizing the same bandwidth [4].

$$SE = \frac{Throughput(bps)}{Channel\ bandwidth(Hz)} \quad (3)$$

The topology of the RD-MU-MIMO mechanism comprises 25 antennas catering to a variable several users. The number of users differs in relation to the deployment environment in the 5G NR Frequency Radio 2 (FR2) type. The proposed topology takes into account microcells and metro cells, resulting in a maximum capacity of 256 users for microcells, whereas metro cells can serve more than 250 users. This RD-MU-MIMO algorithm aims to determine the optimal number of UEs to be scheduled and served for each cell in the network to enhance and maximize its spectral efficiency.

The Downlink employs a MU-MIMO system, wherein the base station communicates with user equipment (UE) deployed with M_a single antennas while using N antennas. A number of processing strategies are investigated: zero-forcing (ZF), a revolutionary full-pilot zero-forcing (P-ZF) strategy, and maximum ratio (MR) combining/transmission. Inter-cell interference in a fully distributed coordinated beamforming system is efficiently mitigated by P-ZF. It uses the presumption that every scheduled user has a substantially identical precoding matrix, therefore in-queue scheduled users can use the same matrix. Single-user detection is carried out by each UE, and its bit rate is set by its bandwidth (B) and Signal-to-Noise Ratio (SNR), and the function (F_l) measures the performance of the link [4].

$$R_b = B\ X\ F_l(SNR) \quad (4)$$

This paper seeks to enhance network performance by tackling the challenges posed by multi-cell systems, taking into account various parameters and processing schemes within the simulated network topology. The SINR(x) function can be used to calculate the SINR based on the location of the user. The bit rate divided by the user's bandwidth at a given location yields the spectral efficiency at the User Equipment (UE) location. Each Base Station (BS) servicing a cell distributes subcarriers from the available bandwidth to individual customers in accordance with the previously described methodology. By allocating these subcarriers, the BS makes sure that different users within the same cell are serviced by different subsets of subcarriers. As a result, since each BS transmits at a constant power, users within the cell experience interference from their respective base stations.

Modifying the above equations to consider events ($\mathcal{H}_2^M$) that take into account the mobility of the UEs, Equation (1) is redefined as:

$$C \leq M_a B \log_2\left(1 + \xi_{k,\mathcal{H}_2^m}^{ins}\right) \quad (5)$$

Where $\xi_{k,\mathcal{H}_2^m}^{ins}$ is the instantaneous received SINR at the receiving node, K, for events ($\mathcal{H}_2^M$).

Since $\xi_{k,\mathcal{H}_2^m}^{ins}$ is defined as (6) [7].

$$\xi_{k,\mathcal{H}_2^m}^{ins} = \frac{P_t/KD_k^{-\beta}\left|\boldsymbol{h}_k^H \boldsymbol{w}_k\right|^2}{\sigma^2 + \phi\sum_{j\epsilon U}(P_t/K)D_k^{-\beta}\left|\boldsymbol{h}_k^H \boldsymbol{w}_j\right|^2 + \sum_{\tau\epsilon\Phi/T_k} P_t|Z_\tau|^{-\beta}\left|g_{\varphi,k}\right|^2} \quad (6)$$

where $P_t/K\,D_k^{-\beta}$ represents desired signal power, $|\boldsymbol{h}_k^H \boldsymbol{w}_k|^2$ denotes the squared magnitude of the channel coefficient between the transmitter and the intended receiver, multiplied by the squared magnitude of the weight vector for the intended user, σ^2 represents noise power, $\phi\sum_{j\epsilon U}(P_t/K)D_k^{-\beta}\left|\boldsymbol{h}_k^H \boldsymbol{w}_j\right|^2$ represents the interference caused by other users in the system, and $\sum_{\tau\epsilon\Phi/T_k} P_t|Z_\tau|^{-\beta}\left|g_{\varphi,k}\right|^2$ represents the interference caused by other cells in the system, particularly focusing on the antennas in those cells that interfere with the intended receiver.

As such, the $MaxDR$ computed is redefined as (7).

$$MaxDR = B \log_2\left(1 + \xi_{k,\mathcal{H}_2^m}^{ins}\right) \quad (7)$$

Additionally, the spectral efficiency (SE) is redefined as:

$$\text{SE} = \frac{iThr_{tot}^{exp}}{\text{Channel Bandwidth (Hz)}} \quad (8)$$

Since the proposed expected throughput (Thr_{tot}^{exp}) proposed is denoted as:

$$iThr_{tot}^{exp} = \sum_{k=1}^{K}\left(\wp(\mathcal{H}_1)Thr_{k,\mathcal{H}_1}^{exp} + \wp(\mathcal{H}_2)\left(\wp(\mathcal{H}_2^s)Thr_{k,\mathcal{H}_2^s}^{exp} + \wp(\mathcal{H}_2^m)Thr_{k,\mathcal{H}_2^s}^{exp}\right)\right) \quad (9)$$

As such, substituting (9) into (8) yields:

$$\text{SE} = \frac{\sum_{k=1}^{K}\left(\wp(\mathcal{H}_1)Thr_{k,\mathcal{H}_1}^{exp} + \wp(\mathcal{H}_2)\left(\wp(\mathcal{H}_2^s)Thr_{k,\mathcal{H}_2^s}^{exp} + \wp(\mathcal{H}_2^m)Thr_{k,\mathcal{H}_2^s}^{exp}\right)\right)}{\text{Channel Bandwidth (Hz)}} \quad (10)$$

The resource block (R_b) usage is given as (11):

$$R_b = B \times F_l\left(\xi_{k,\mathcal{H}_2^m}^{ins}\right) \quad (11)$$

Equations (5) to (11) form some of the fundamental algorithms used to model the RD-MU-MIMO mechanism.

Equation (12) provides the estimated probability of outage for the instantaneous MU-MIMO transmission. The average of the outage probabilities for the cases of the UEs' events is known as the expected outage probability.

$$P_k^{exp}(\xi_{thres}) = \sum_{i=1}^{2}\wp(\mathcal{H}_i)\wp(\xi_{k,\xi_i}^{ins} \leq \xi_{thres}) = \wp(\mathcal{H}_i)\wp(\xi_{k,\xi_{thres}}^{ins}) + \wp(\mathcal{H}_2) \times \left[\wp(\mathcal{H}_2^s)\wp(\xi_{k,\mathcal{H}_2^s}^{ins} \leq \xi_{thres}) + \wp(\mathcal{H}_2^m)\wp(\xi_{k,\mathcal{H}_2^m}^{ins} \leq \xi_{thres})\right] \quad (12)$$

Where $P_k^{exp}(\xi_{thres})$ is the outage probability (P_{outage}) based on a given threshold (ξ_{thres}), $\wp(\mathcal{H}_i)$ represents the probability of event $\mathcal{H}_i$ given as $P(M)$ and $\xi_{k,\mathcal{H}_i^s}^{ins}$ depicts the instantaneous received SINR of the receiving node (k) when the event $\mathcal{H}_i$ occurs given as $P((SINR < \xi_{thres}) \mid M)$.

The ramifications of the reduced weighted sum impact the probability of events and the performance factors measured. Outage probability represents the probability that a wireless communication link will fail due to various factors, including interference and signal quality.

Equations (13) and (14) evaluates the PDF on event $\mathcal{H}_i$ using equations (13) and (14) [7].

$$\wp(\mathcal{H}_1) = \left(P_{state}e^{-\theta T_{frame}}\right)^{K+1} \quad (13)$$

Where $\wp(\mathcal{H}_1)$ represents the outage for $\mathcal{H}_1$, P_{state} is a parameter denoting the probability that a specific state (e.g., a certain channel state or interference level) occurs during the communication. $e^{-\theta T_{frame}}$ denotes the exponential function where T_{frame} represents the duration of time for which the communication is observed. And $K+1$ is the exponent that models the outage probability for K+1 receiving users.

$$\wp(\mathcal{H}_2) = \left(P_{state}e^{-\theta T_{frame}}\right)^{K-M+1}\left(1 - P_{state}e^{-\theta T_{frame}}\right)^{M} \quad (14)$$

Equation (14) models the outage probability for a more complex scenario where there are K+1 users in the MU-MIMO system, and it depends on the probability of a specific state (P_{state}), the time duration (T_{frame}), the number of users (K+1), and the Mobile UEs. These equations are crucial for assessing the system's performance and understanding the probability of outage in complex wireless scenarios.

These equations are the equations for the PDFs on event $\mathcal{H}_i$. The PDFs are the probabilities that the UEs are in good or bad channel condition, given that the UEs are in event $\mathcal{H}_i$. The outage probability of instantaneous MU-MIMO transmission using the appropriate equation, depending on the value of ϕ. If ϕ = 0, then the outage probability is obtained using Equations (15) [7].

$$P_k^{ins}(\xi_{thres}) = 1 - \sum_{m=0}^{N_t-K}\frac{(-\omega)^m}{m!}\frac{(d)^m}{d\omega^m}\mathcal{L}_{I_{k,CCI}}(\omega) \quad (15)$$

Where $P_k^{ins}(\xi_{thres})$ denotes the outage probability for the *k-th* user, given a threshold SINR (ξ_{thres}). N_t is the total number of transmit antennas and K is the number of users. $\mathcal{L}_{I_{k,CCI}}$ denotes the Laplace transform of the interference seen by user K due to CCI.

If ϕ is equal to 1 and 0<M<K, then the outage probability is the expected to be obtained using equation (16) [7].

$$P_k^{ins}(\xi_{thres}) = 1 - \sum_{m=0}^{N_t-K} \frac{(-\omega)^m}{m!} \frac{(d)^m}{d\omega^m} \mathcal{L}_{\rho I_{k,IBI}}(\omega) \mathcal{L}_{I_{k,CCI}}(\omega) \quad (16)$$

Where $\mathcal{L}_{\rho I_{k,IBI}}(\omega)$ signifies the Laplace transform of the interference seen by user K due to Inter Block Interference (IBI), scaled by ρ. Equation (16) combines both IBI and ICI to compute the outage probability for ξ_{thres}. It quantified the probability that ξ_{thres} experiences by the *k-th* user when it falls below the defined ξ_{thres} due to interference.

To enhance the pragmatism of the simulation studies, additional complex channel models that account for realistic propagation condition, including Non-Line-of-Sight (NLOS) components and variable mobility patterns were considered by further modifying the Laplace transforms $\mathcal{L}_{\rho I_{k,IBI}}(\omega)$ and $\mathcal{L}_{I_{k,CCI}}(\omega)$. As such, the parameter ρ_{NLOS} was introduced to capture the effects of NLOS components and $f_{mobility}(t)$ was introduced to represent the mobility patterns of users over time (t). Hence, the redefined Laplace are:

$$\mathcal{L}_{\rho_{LOS} I_{k,IBI}}(\omega) = \mathcal{L}\{\rho_{NLOS}. I_{k,IBI}(t)\} \quad (17)$$

$$\mathcal{L}_{I_{k,CCI}}(\omega, t) = \mathcal{L}\{I_{k,CCI}(t). f_{mobility}(t)\} \quad (18)$$

Hence, equation (16) is redefined as:

$$P_k^{ins}(\xi_{thres}) = 1 - \sum_{m=0}^{N_t-K} \frac{(-\omega)^m}{m!} \frac{(d)^m}{d\omega^m} \mathcal{L}\{\rho_{NLOS}. I_{k,IBI}(t)\} \mathcal{L}\{I_{k,CCI}(t). f_{mobility}(t)\} \quad (19)$$

2.1 Flowchart of the RD-MU-MIMO Algorithm

This is the RD-MU-MIMO algorithm flowchart in Figure 1. The network design in the flowchart takes into account the mobility states of the user equipment. The MU-MIMO system's overall performance in a realistic environmental context is significantly influenced by the movement of the user equipment. Consequently, the suggested network model regards UEs as being distributed at random over the BS's coverage area. Both of the RD-MU-MIMO algorithm's cases are examined in Figure 1. The first event denoted as $\mathcal{H}_1$ indicates that the UEs are immobile at the start of a set time frame and do not move during the duration not less than T_{Frame}. The second scenario, $\mathcal{H}_2$ considers the movement of the UE during T_{Frame}. The input parameters required to simulate and model the network topology of the wireless cellular network encompass the variables associated with mobility events. In the case of UEs linked to the gNB, the work assesses the mobility state of these events prior to calculating the resource block of each user. 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, $\phi = 1$. Whether inter-beam interference is taken into account or not, the goal of this modification is to reduce processing time. An outage in the network would be less likely using the suggested RD-MU-MIMO mechanism.

The input parameters, such as the number of MIMO layers, bandwidth, frequency range, and modulation type are initialized. Then, it loops through all the users in the simulated network topology. For each user, it checks if the user is connected. If the user is connected, the pseudocode calculates the maximum data rate the user can achieve. Otherwise, the user is not connected and the pseudocode moves on to the next user.

After looping through all the users, the pseudocode evaluates the expected outage probability using Equation (11) and computes the PDF on events $\mathcal{H}_1$. Then, it checks if the value of ϕ is equal to 0. If it is, the pseudocode computes the outage probability using Equation (15) and computes the number of RBs used by users either stationary or mobile using Equations (4) and (10), respectively. Otherwise, the pseudocode checks if the value of ϕ is equal to 1 and if the number of users in the cell is less than the number of RBs available. If both of these conditions are met, the pseudocode computes the outage probability using Equation (16) and computes the number of RBs used by each user. Otherwise, the pseudocode moves on to the next cell.

Finally, the pseudocode loops through all the cells in the simulated network topology and calculates the power allocated to the connected users. Then, it compares the results from the proposed allocation method with the conventional allocation method.

Table 1: Extracted parameters [4;7]

S/No	Parameters	Values
1	Antennas, N_t	25
2	Bandwidth, B	160 MHz
3	Capacity speed, V_c	3.39 Gbits/s
4	Carrier bandwidth, B_c	400 MHz
5	Downlink rates	20 Gbps
6	Link rate	867 Mbits/s
7	Path loss exponent	4
8	Mobile receiving nodes	1, *K/2*, *K*
9	Receiver Noise power	-32dBm
10	Resource block frames DL	275
11	Resource block frames UL	275
12	Number of discrete rates	4
13	Average time interval	1s
14	Scenario	Four Antennas AP
15	SINR threshold	-30dB

16	Sub Carrier Spacing	120 KHz
17	Users for each scenario	200, 250, 300
18	Distance between Tx and Rx, R_k	100m

2.2 Simulation Parameters

The simulation parameters adopted for the RD-MU-MIMO mechanism are presented in Table 1. These values are used to evaluate the performance of the conventional IEEE 802.11ax approach, the mechanism for downlink MU-MIMO, and the modified RD-MU-MIMO mechanism adopted in this research.

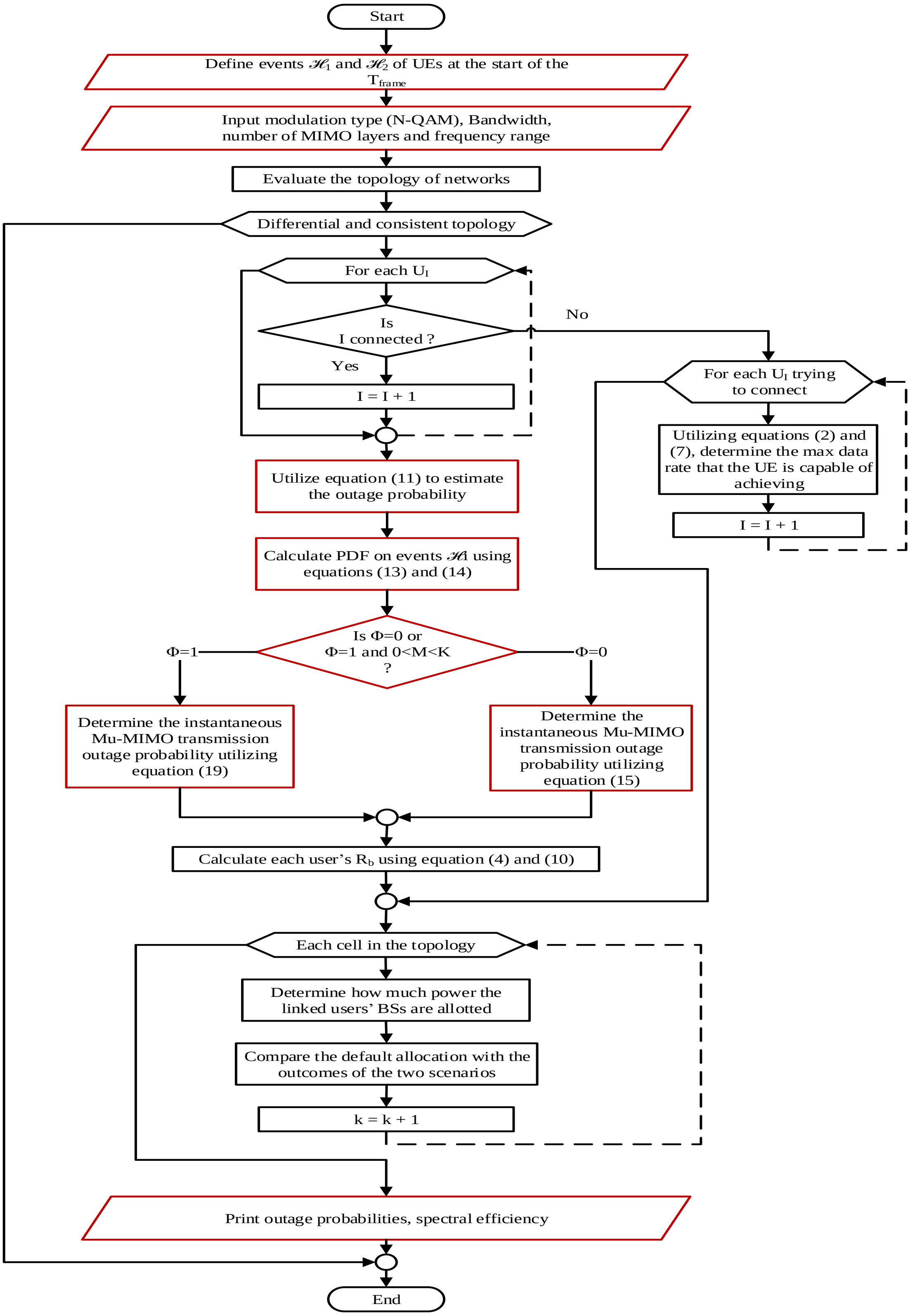

Figure 1: Proposed flowchart for the RD-MU-MIMO Algorithm

3.0 SIMULATION RESULTS AND DISCUSSION

The probability of outage of the instantaneous MU-MIMO transmission within the duration of a determined time frame is considered under the conditions M=1, M=K/2, and M=K. Where M=1, when one UE is mobile, M=K/2 when half of the UEs are mobile, and M=K where all the UE are mobile. These three conditions aid in determining the impact of the expected outage probability of the instantaneous MU-MIMO transmission for event $\mathcal{H}_2^M$ within a determined time frame. As identified in Figure 2, the performance of receiving UEs during the time gaps showed some overlaps. The likely reasons for these overlaps are due to interference variability, user mobility, channel fading, user distribution, and transmit power control. In the case of interference variability, interference plays a significant role in determining the quality of the received signal. The interference experienced by a receiving UE depends on the spatial arrangement of transmitting users and their channel conditions. As the positions and channel conditions of user's change, the level of interference at a receiving UE can fluctuate, impacting the outage probability.

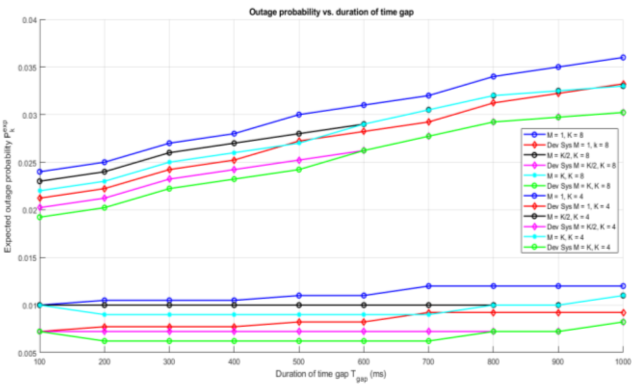

Figure 2: Outage probability vs duration of time frame

This is observed in time frame from 600ms to 1000ms when the number of receiving nodes (K=8). These fluctuations also show from 700ms to 1000ms in the case where K=4. As for the other likely causes of fluctuations within the time frame aforementioned. The other factors aforementioned can likely influence the outage probability in the following ways. In the case of UE mobility, if the users are mobile, their positions and relative distances to the Next Generation Node Bs (gNBs) will change over time. As a result, the channel conditions and received signal strength at the receiving nodes will vary, leading to fluctuations in outage probability. In the case of channel fading, wireless channels are subject to fading due to multipath propagation and other environmental factors. Channel fading causes the received signal power to vary over time, which can result in fluctuations in the outage probability.

Figure 2 shows how the probability of outage and the duration of the time frame relate to each other. In regards to the events $\mathcal{H}_1$ and $\mathcal{H}_2^M$, the probability of the event, $\mathcal{H}_1$ decreases since at any point within the time frame considered there is at least one user that is mobile in the considered MU-MIMO system. As such, the event for $\mathcal{H}_2^M$ always increases within the duration of the time frame as M increases in the MU-MIMO system. Although, the outage probability as observed in Table 5.7 increases with the increase in receiving K. As such, the increase in outage probability in K=8 at $M \geq 0$ is higher than in K=4 at $M \geq 0$. Also, since the M in event $\mathcal{H}_2^M$ is susceptible to inter-beam interference with other K-1 receiving UEs, the outage probability when M>0 are higher in event $\mathcal{H}_2^M$ than in event $\mathcal{H}_1$ where M=0.

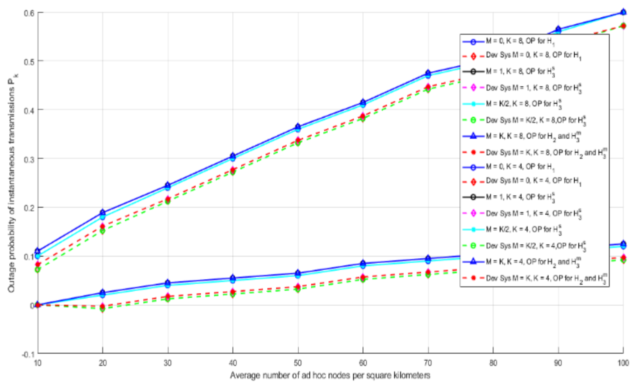

Figure 3: Probability of instantaneous MU-MIMO transmission with the possibility of outage compared to the average number of users per square kilometers

In Figure 3 the probability of outage increases in relation to the number of receiving UEs, that is, K=8 is higher than K=4. Additionally, the outage probability also increases with the number of users that are mobile in the MU-MIMO system. Within the time frame, the increase in the outage probability results from inter-beam interference with the remaining K-1 stationary UEs in the case of M=1 and M=K/2 and between the beams of the mobile UEs (M) in the case of M=K.

In regards to the events $\mathcal{H}_1$ and $\mathcal{H}_2^M$, the probability of the event, $\mathcal{H}_1$ decreases since at any point within the time frame considered there is at least one user that is mobile in the considered MU-MIMO system. As such, the condition for $\mathcal{H}_2^M$ always increases within the duration of the time frame as M increases in the system. The observed increase in M increases cochannel interference signals. Conversely, the increase in M results in a decrease in the desired signal power and also leads to an increase in inter-beam interference power with the remaining K-1 receiving UEs. Hence, the outage probability as observed in Figure 3 increases with the increase in receiving K. Also, since the M in event $\mathcal{H}_2^M$ is susceptible to inter-beam interference with other K-1 receiving UEs, the outage probability when M>0 is higher in event $\mathcal{H}_2^M$ than in event $\mathcal{H}_1$ where M=0.

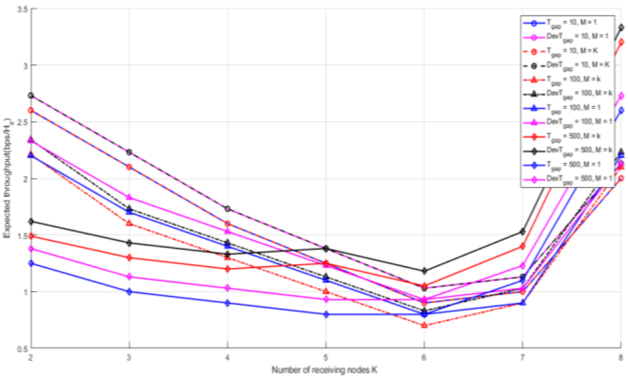

Figure 4: Spectral efficiency of MU-MIMO transmissions vs number of receiving UEs

The effects of an increasing number of receiving nodes on the spectrum efficiency of a MU-MIMO transmission are shown in Figure 4. The predicted throughput of each receiving UE and the total expected throughput decrease as the number of receiving UEs falls below a threshold. This is seen for values of M=1 and M=k for Tg=10 and Tg=100. The total expected throughput increases as the number of receiving K increases and surpasses the threshold.

The term Spectral Efficiency (SE) really refers to the total spectral efficiency of all communications occurring within a network cell. The cell throughput, which is measured in bit/s, is obtained by multiplying the SE's bit/s/Hz value by the bandwidth. Since it is clear that the bandwidth cannot be increased, increasing cell throughput is a better and more desirable alternative. Spectral efficiency needs to be improved and increased in order to do this. Ensuring that the proposed system can service as many UEs in the cell at once while utilizing the same bandwidth is the system to increase spectral efficiency. Additionally, utilizing the RD-MU-MIMO mechanism for this enhancement and growth.

The Spectrum Efficiency (SE) for M receiving UEs at $\mathrm{T}_g = 10, \mathrm{T}_g = 100, and\ at\ \mathrm{T}_g = 500$ all showed that the SE of the modified RD-MU-MIMO mechanism showed a higher increase in throughput than the existing system.

4.0 CONCLUSION

In summary, MIMO wireless systems offer significant enhancements in capacity for high-speed wireless communications, a crucial factor for the future of wireless networks. However, the pursuit of high QoS and the mobility of UEs in a MU-MIMO system introduce the risk of severe inter-beam interference, consequently increasing the likelihood of outages in a MU-MIMO system within 5G wireless cellular networks. This paper presents a modified model designed to minimize downlink outage probabilities for both mobile and stationary UEs in a MU-MIMO system. The proposed model was systematically evaluated in various scenarios, including instances where a single UE, half of the UEs, or all UEs are mobile within the MU-MIMO system, each considered for a defined period. The simulation results revealed that the probability of outages increased with increasing UE density within a discrete time frame for mobile UEs. However, the newly proposed model effectively reduced outage probabilities and improved spectral efficiency compared to existing systems.

These findings highlight the potential of the proposed model to enhance the reliability and efficiency of MU-MIMO systems, particularly in the context of 5G wireless networks, where maintaining a consistent QoS remains a top priority. Future work is recommended to investigate the impact of increasing the number of receiving UEs (K) when computing the outage probability over a defined time frame and over a defined area, as well as determining the spectral efficiency under the conditions considered for a higher number of receiving UEs. Additionally, Machine Learning (ML) approaches can be adopted to modify the RD-MU-MIMO algorithm to dynamically adjust to varying network conditions and UE densities in real-time to maximize performance under varying conditions.

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