IMPROVED FAIR POWER ALLOCATION IN NOMA SYSTEM FOR USER FAIRNESS IN 5G NETWORK

BY

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF ENGINEERING IN COMMUNICATION ENGINEERING

JUNE, 2023

DECLARATION

I hereby declare that this thesis titled: "**Improved Power Allocation in NOMA System for User Fairness in 5G Network**" is a collection of my original research work and has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

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SIGNATURE/DATE

CERTIFICATION

The thesis titled: "**Improved Power Allocation in NOMA System for User Fairness in 5G Network**" by: CHIKEZIE, Chekwas Ifeanyi (MEng/SEET/2019/9518) meets the regulations governing the award of the degree of MEng of the Federal University of Technology, Minna. It is approved for its contribution to scientific knowledge and literary presentation.

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ABSTRACT

Non-orthogonal multiple access (NOMA) has been presented as an alternative technology due to its ability to accommodate immense connectivity and enhances spectral efficiency in 5G and future wireless networks. In contrast to orthogonal systems, NOMA allows numerous users to share the same radio resource simultaneously, breaking the orthogonality of traditional multiple access. However, power allocation is a critical challenge in designing an effective NOMA system. This study investigated the Fair Power Allocation and considered it pertinent to improve the scheme further. To ensure user fairness, this study proposed an improved fair power algorithm that can be modified dynamically based on target rate requirements and channel state information. The simulation results show that Improved Fair Power Allocation outperformed the Fair Power Allocation by 35.80% in terms of outage probability and achieved a 48.14% higher achievable rate than the Fixed Power Allocation. The performance of the downlink NOMA for the BPSK transmission system in a Rayleigh fading was also analyzed in this study using MATLAB. The findings demonstrated that NOMA offers users 77.56% fairness while minimizing interference at 0.01 BER.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
5G	Fifth Generation
BPSK	Binary Phase-shift Keying
BS	Base Station
BER	Bit Error Rate
CSI	Channel State Information
FTPA	Fractional Transmit Power Allocation
FSPA	Full Search Power Allocation
GPA	Generalized Power Allocation
I-FTPA	Improved Fractional Transmit Power Allocation
LP	Linear Programming
MIMO	Multiple Input Multiple Output
NOMA	Non-orthogonal multiple access
OMA	Orthogonal Multiple Access
OPA	Optimal Power Allocation
OFDMA	Orthogonal Frequency Division Multiple Access
OMA	Orthogonal Multiple Access
PSO	Particle Swarm Optimization
PD	Power Domain
QoS	Quality of Service
SINR	Signal-To-Interference Plus Noise Ratio
SNR	Signal-To-Noise Ratio
SIC	Successive Interference Cancellation
SC	Superposition Coding
UE	User Equipment

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

Non-orthogonal multiple access (NOMA) is a promising technology for 5G and future wireless networks that boost spectral efficiency and allow massive connections (Cai *et al*., 2018; Maeng *et al*., 2022; Wei, 2019). The main concept of NOMA is to break the orthogonality of conventional multiple access by allowing multiple users to share the same radio resource simultaneously. NOMA improves the system's spectral and energy efficiency while supporting more users (Tang and Liao, 2020). Despite NOMA's advantages, the performance of the NOMA is heavily dependent on the power allocation and decoding order within the users. Power allocation should be improved to ensure acceptable performance and fairness among NOMA users (Ali *et al*., 2022; Pishvaei *et al*., 2022).

Power allocation influences the system's performance, such as interference control and user rate distribution. If the power allocation is not properly done, it might result in an unfair rate distribution and outage. In this circumstance, the power allocation of users becomes a critical consideration in designing a NOMA system. Channel State Information availability, maximizing objective function, channel conditions, total power constraint and Quality of Service (QoS) requirements are important aspects to consider while designing power allocation schemes. Sum rate, fairness, energy efficiency, number of acceptable users, and number of antennas are performance metrics utilized in power allocation schemes. (Ali *et al*., 2022; Campos, 2019).

1.2. Statement of the research problem

In order to fulfill the requirements of numerous services in the next generation of cellular networks, effective data transmission across wireless networks is essential (Ahmed *et al*., 2018). In recent years, multiple techniques have been introduced to meet these demands.

NOMA is a new technology that has gotten much interest because it enhances spectral efficiency, user fairness, and cell-edge throughput (Mahmoudi *et al*., 2021). NOMA systems perform better than orthogonal multiple access (OMA) counterparts (Tang and Liao, 2020). NOMA can support multiple users via non-orthogonal resource allocation by simultaneously using time, frequency, and code domains and multiplexing them at various power levels (Abdel-Razeq *et al*., 2022; Huang *et al*., 2020).

Signals from multiple users are merged at the transmitter using superposition coding (SC) and transmitted in the same frequency block concurrently in power-domain NOMA. Each user employs a successive interference cancellation (SIC) at the receiver to detect their signal. Despite the NOMA's benefits, its performance is greatly influenced by how power is allocated among its users and by which users decode data first. It is crucial to improve the power allocation parameters and user decoding order in order to guarantee adequate performance and fairness among NOMA users. (Ali *et al*., 2022; Pishvaei *et al*., 2022). By assigning various power levels to various users, the NOMA system can modify the number of connections and the quality of service (QoS). When designing a NOMA system, the users' power allocation becomes crucial.

Power allocation significantly impacts overall throughput in the Power Domain (PD) NOMA system; however, user fairness must be addressed. Most existing studies on Fair Power Allocation have not completely accounted for the fairness of the near and far users. To resolve this, this study proposed an improved fair power allocation.

1.3. Aim and Objectives of the Research

This study aims to improve the Fair Power Allocation algorithm in the NOMA system for efficient communication in 5G networks.

The following objectives are to be achieved:

(i) Development of an Improved Fair Power Allocation algorithm for NOMA systems,

(ii) Evaluation of power allocation algorithm in (i) based on outage probability and sum rate

(iii) Comparison of (i) with other existing power allocation algorithms of a NOMA system based on outage probability and sum rate.

1.4 Scope of the study

This study is centred on improving the Fair Power Allocation scheme to enhance user fairness. The performance of the Improved Fair Power Allocation scheme will be compared with the existing Fixed Power Allocation and Fair Power Allocation algorithm in terms of outage probability and Sum Rate Maximization.

1.5 Justification for the Study

Performance factors like interference management and user rate distribution are impacted by power allocation. An unjust rate distribution and outage will occur if the power allocation is not done properly. Implementing an effective power algorithm results in nearly perfect SIC at the transmitter. To this end, the fair power allocation scheme was proposed to be improved to ensure fair rate distribution and minimized outage probability of both the weak and strong users in a NOMA system.

1.6 Thesis Outline

The rest of the thesis is structured as follows. Chapter two reviews the Non-Orthogonal Multiple Access power allocations, various NOMA power allocation algorithms and mathematical models, and related literature on NOMA performance. Chapter three presents the research system model and methodology. Chapter four presents and discusses the MATLAB simulation results in sections. Chapter five states the conclusion and recommendations of the research.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Theoretical Framework

The theoretical framework for this study is a foundational review of existing theories that serves as a roadmap for developing the arguments utilized in this work.

2.1.1 Fixed Power Allocation

In Fixed Power Allocation, users are allocated power depending on their channel gains. More power is allocated to a user who has a weak channel gain than to a user who has a strong channel gain. The simplest technique is the Fixed Power Allocation alogrithm, This can considerably lower the base station's and the user equipment's communication overhead.

2.1.2 Fair Power Allocation

In a Fair Power Allocation, more power is given to the weaker user and less to the stronger user in an effort to promote user fairness.The aim is to choose between α_n and α_f in such a way that $R_f = R^*$.

$$R^* = \left(1 + \frac{|h_f|^2 P\alpha_f}{|h_f|^2 P\alpha_n + \sigma^2}\right) \tag{2.1}$$

where α_n is the near user's coefficient for power allocation, α_f is the far user's coefficient for power allocation, h_f is the far user's coefficient for channel gain, P is the total transmit power and σ^2 is the Noise power

Unlike Fixed Power Allocation, the power allocation coefficients are adjusted dynamically with respect to target rate requirements and channel state information (Lee, 2019).

2.1.3 Waterfilling algorithm for power allocation

The allocation of water-filling power is dependent on channel coefficients. The SNR is proportional to the quantity of power allocated or the water-filled volume. It also relies on the overall amount of power available, the level of interference, and the channel gain matrix. The inverse of each channel gain is taken after it is organized in decreasing order. Equation (2.2) gives the original water level or power assigned (Kumar and Singh, 2016; Sinduja and Janani, 2019).

$$PA = \frac{P + \sum_{i=1}^{n} 1 + \frac{1}{h_i}}{\sum channels} - \frac{1}{h_i} \tag{2.2}$$

where P represents the entire available power, h is the channel gain, and n is the number of users. Up until the power value drops below zero, this process is repeated. This mechanism appears to provide more power to users with higher channel gains. When there is no water-filling and a sequential water-filling procedure, the system with water-filling has a higher mean capacity. This strategy outperforms Fair Power Allocation in terms of the fairness index; however, it suffers from changes in outage probability.

2.1.4 Fractional Transmit Power Allocation (FTPA)

Although this approach is preferable to Fixed Power Allocation, it is a less ideal solution. The power is distributed according to equation (2.3), which depends on channel gain.

$$P_i = \frac{|h_i|^{-2\beta} \times P}{\sum_{i=1}^{n} |h_i|^{-2\beta}} \tag{2.3}$$

where β is a fractional number between 0 and 1, such that if β is equal to zero, the user pair receives equal power. The amount of electricity provided to users with poor channel conditions increases if β is raised. It is more sophisticated than Fixed Power Allocation and involves signalling overhead (Alghasmari and Nassef, 2020). P is the total amount of power that is allocated, n is the entire number of cluster users and $|h_i|^2$ is the magnitude square of channel gain. Despite being a dynamic power allocation scheme, it does not change for various user channel conditions because just one decay factor is used for all users. If one of the users has a poor channel, the performance can deteriorate. Assigning power levels based on the channel conditions makes fractional transmit power allocation preferable to fixed transmit power allocation.

2.1.5 Improved Fractional Transmit Power Allocation (I-FTPA)

In improved fractional transmit power allocation, the decay factor, which acts as an exponent in fractional transmit power allocation, changes according to channel gain.

$$P_i = \frac{P \times \left(\frac{|h_i|^2}{N_{0,i}}\right)^{-\beta_i}}{\left(\frac{|h_i|^2}{N_{0,1}}\right)^{-\beta_1} + \cdots + \left(\frac{|h_i|^2}{N_{0,i}}\right)^{-\beta_i}} \tag{2.4}$$

where P_i is the power allotted to the i^{th}user, h_i is channel, N is noise variation, and β_i is determined by channel gain. The total of the power allocation coefficients for all users should equal 1 when added together (Bai *et al.*, 2019). In terms of bit error rate, this technique performs better than NOMA Fixed Power Allocation, NOMA fractional transmission power allocation, and orthogonal frequency division multiple access (OFDMA). Improved channel flexibility comes with careful consideration of the various decay variables. The detection precision of each user is impacted by several of decay factors. Based on the application, this can be altered to match the user's demands. In contrast to fractional transmit power allocation, where the decay factor cannot be altered based on the channel, the decay factor may be modified based on the channel. As a result, improved fractional transmit power allocation outperforms fractional transmit power allocation in NOMA.

2.1.6 Generalized Power Allocation (GPA)

Generalized Power Allocation is a basic power allocation algorithm used in NOMA. The idea of GPA is represented by equation. (2.5) (Ahmed *et al.*, 2018).

$$P_i = \frac{n!}{i! \times (n-1)!} \times C^i \tag{2.5}$$

where *C* is the Choice Factor, which is calculated as:

$$C = P^{\frac{1}{n}} - 1 \tag{2.6}$$

The power of all individual users, $P_1, P_2, P_3 \ldots, P_i$ has been allotted using equation (2.4), where $i = 1, 2, 3 \ldots. n$. The equation demonstrates that all users' power allocation cannot be the same, which is a fundamental condition of the NOMA system. The total power allotted to each user must fulfill the equation below.

$$P \approx \sum_{i=1}^{n} P_i \tag{2.7}$$

Although GPA-based power allocation is a simpler approach, it performs similarly to conventional power allocation schemes. It's important to note that neither of the parameters is optimized for calculating power. On the other hand, GPA's performance is stable across different modulation schemes.

2.1.7 Optimal Power Allocation (OPA)

With a constraint on the fairness index, this technique maximizes the sum rate and total system throughput. First and foremost, the target fairness index is determined, and the power matrix is set to all feasible values. Iterative calculations determine the capacity and fairness index for any probable power allocation scheme. The power is set to zero if the fairness index is below the desired value. The maximum power is initially set to zero, which is then compared to each expected power value. If the power value is greater than the maximum power value, the maximum power value must be changed to the current power value.

$$maximum\ sum\ capcity = \sum_{i=1}^{n} BW \times log_2\left(1 + \frac{P_i \times |h_i|^2}{N + \sum_{k=1}^{i-1} P_k \times |h_k|^2}\right) \tag{2.8}$$

where BW is the available transmission bandwidth, N is the total noise power N = N_0W, h_k is the channel attenuation gain, P_k is the power allocation attenuation

$$\sum_{i-1}^{n} P_i \leq P, \qquad P_i > 0 \tag{2.9}$$

Fairness index F is given

$$F = \frac{(\sum R_i)^2}{n \times \sum {R_i}^2} \tag{2.10}$$

where R is the total power and n is the noise variance (Manglayev *et al*., 2017). Sum capacity performance is contrasted with that of orthogonal multiple access (OMA) for various fairness indexes, and it is determined to be superior in terms of throughput. The total capacity decreases as the fairness index rises, and there are no substantial performance variations between OMA and NOMA. Under a fairness constraint, OPA does an extensive search for optimal performance.

2.1.8 Target SNR-based Power Allocation

Power allocation in Target SNR-based Power Allocation is done such that it maximizes the signal-to-interference plus noise ratio (SINR) for strong users and raises it over the minimal level for weak users. Additionally, it is thought that both the transmitter and the receiver have perfect channel state information (CSI). Symbol power, target SNR, channel gain, and Noise variance are used to calculate power allocation. The user that has a high gain is allotted a low power factor, whereas the user that has a low channel gain is alloted a high-power factor (Narengerile and Thompson, 2019). This technique has the advantage of considering target SNR and channel gain while determining power allocation variables. This guarantees that the quality of service (QoS) is maintained.

2.1.9 Full Search Power Allocation (FSPA)

The Full Search Power Allocation uses extensive search to determine the power level of users sharing subchannels. This method generates any possible set of power levels to find an ideal, computationally optimal solution. By considering multiplexed pairs in subchannels and generating all possible sets of power levels for each pair of channel conditions, an optimal set of power levels can be selected based on the gain in system performance.

2.1.10 Particle Swarm Optimization (PSO) based Power Allocation

Using the optimization technique known as "particle swarm optimization," until the optimum solution is obtained, the search space is filled with numerous randomly created particles. The channel gain and population size are inputs into the PSO algorithm. It is an iterative process in which each particle is started at its ideal location before being swarmed at that location and at random locations (positions that reflect the potential power allocation values of a user pair). Iterations are carried out until a condition is met or a preset number of them have been finished. Each iteration involves changing the particle's location and speed to increase or reduce the fitness function. The fitness function for energy efficiency (data rate to transmission power ratio) is maximized when power is allocated in NOMA. Finally, the user's optimal power allocation is updated according to the optimal position of the swarm (Pliatsios and Sarigiannidis, 2019). The fitness feature is provided.

$$f = \sum_{s-1}^{s} log_2 \left(1 + \frac{h_s^2 P_s}{\frac{B}{s} N_0}\right) - 100 \times \max\left(0, \sum_{s-1}^{s} (P_s - P_{max})^2\right) \tag{2.11}$$

where N_0 is noise variance, B is bandwidth, and S is the number of channels. Due to its quicker convergence and global optimum, It is an optimal power allocation strategy for maximizing energy efficiency. On the basis of the population, the variety of subcarriers, and the channel gain of each user, the appropriate power allocation coefficients are computed. The restrictions of the optimization problem are enforced via a fitness function. It is a time-consuming, iterative process that produces excellent outcomes.

2.2 Review of related literature

Increasing the performance of NOMA, especially in network capacity, is the primary purpose of resource allocation in terms of user pairing and power allocation. On the other hand, although improving NOMA capacity to variable degrees, conventional user pairing and power allocation algorithms frequently fall short in simultaneously enhancing other critical performance metrics like UE fairness and outage probability. Additionally, computational complexity is a crucial factor when designing resource allocation algorithms because it decreases computing efficiency and the speed at which allocation choices are made (Pliatsios and Sarigiannidis, 2019).

To increase the proportional fairness of UEs, Chen *et al*., (2019) presented a hybrid user pairing and power allocation algorithm for uplink NOMA systems. A simple scenario in which UEs are disseminated across a single base station (BS) and a complex one in which interfering UEs users are dispersed randomly outside the BS is considered. In the basic situation, tabu search is used to identify a near-optimum solution to the user pairing problem. In contrast, stochastic programming is employed to solve the power allocation problem in a complex scenario.

Do and Nguyen, (2019) presented a novel downlink cooperative communication system for outage analysis, combining NOMA and AF relaying approaches. The proposed scheme was evaluated for outage performance while considering the effects of different factors in cooperative NOMA systems.

In a downlink non-orthogonal multiple access system, Lee, (2019) investigated and proposed a power allocation technique to achieve fair data rates for two users.

In order to find the most energy-efficient parameters of transmission power, data transmission rate and subchannel allocation, taking into account the constraint of the client's maximum and minimum throughput ratio, Uddin, (2019) formulated a fractional optimization problem. To make the factional optimization problem tractable, the problem is defined as a linear programming (LP) problem. The optimization program CPLEX was used to quantitatively solve the LP issue for various wireless cellular networks. Numerical results show that the simultaneous optimization of transmission scheduling and resource allocation of the NOMA system outperforms the resource allocation algorithms currently used in Orthogonal Multiple Access (OMA) systems.

For heterogeneous downlink NOMA networks, Song *et al*., (2019) an imperfect CSI-based power allocation scheme to maximize energy efficiency. To solve optimization problems, probabilistic problems are relaxed into non-probabilistic problems. A gradient-based binary search method examines energy efficiency trends as a function of small cell power to assign power to each small cell. Sequential convex programming transforms nonconvex problems into convex ones. The Lagrange multiplier method determines the closed-form solution of the power distribution ratio problem. The simulation results show the superiority and efficiency of the proposed scheme compared to conventional methods. Bai *et al*., (2019) proposed an improved Fractional Transmission Power Allocation (I-FTPA) algorithm. The simulation results show that I-FTPA outperforms the previous fixed and partial transmission power allocation.

Khan *et al*., (2020) proposed a multi-objective optimization technique for resource allocation in multi-user downlink NOMA systems to increase spectrum efficiency and energy efficiency. The SIC process is guaranteed by keeping the constraint of the minimal gap among UE transmit powers articulated and addressed via dual decomposition.

For NOMA downlink multi-user, Alghasmari and Nassef, (2020) studied some resource allocation techniques such as full search power allocation, partial transmission capacity allocation and fixed capacity allocation. Fractional transmit power allocation and fixed capacity allocation are worse than full search capacity allocation. The results show that the system has little effect on user alignment with different channel conditions.

To enhance the system's sum rate, Alghasmari and Nassef, (2021) presented power allocation as a downlink NOMA optimization problem. Using a genetic algorithm that uses heuristics to find practical solutions, a genetic algorithm-based power allocation was proposed to address the issue. The proposed power allocation algorithm outperformed the full search power allocation. The results reveal that genetic algorithm-based power allocation achieves a performance similar to full search power allocation while reducing complexity. Genetic algorithm-based power allocation also ran simulations with a variety of user-paring algorithms. The better outcomes are achieved by channel state sorting-based user pairing with genetic algorithm-based power allocation, which outperforms exhaustive user pairing and random user pairing methods.

The basic idea behind Yuan *et al*., (2021) unique power allocation algorithm based on greedy policy is to maximize the system's total throughput performance by using the concept of optimal local discrimination in the greedy algorithm. Despite being suboptimal, this algorithm exhibits a variety of benefits when compared to other suboptimal algorithms.

Sanjana and Suma, (2021) introduced Eigenvalue-based power allocation. They employed a symbol error rate against a signal-to-noise ratio plot to investigate the performance of several power allocation algorithms under various random Rayleigh channel conditions to analyze their performance. The simulation results show that Eigenvalue-based power allocation performs better than other power allocation schemes and is close to optimal power allocation for a Rayleigh channel.

To optimize the fairness utility function, Wang *et al*., (2021) investigated the power allocation problem in multi-cluster downlink MIMO-NOMA systems. The optimization problem was initially defined as a problem of maximizing the weighted-sum rate using a long-term fairness function. Adding two sets of auxiliary variables gave the problem a convex shape and presented an iterative method for updating the weight factors and auxiliary variables. A problem of maximizing minimum data rate with instantaneous fairness posed the optimization challenge. After iteratively reducing the problem to a one-dimensional optimization problem, a closed-form power allocation statement was constructed. The simulation findings show that, in terms of edge user rate, the two presented Fair Power Allocation technques outperform other comparable schemes.

2.3 Research Benchmark

After investigating the Fair Power Allocation scheme, this study picks its benchmark from Lee, (2019), aiming to reduce the probability of power outage of near users whenever the limiting operation was executed.

Table 2. 1: Summary of Related Literature

S/N	Author	Year	Aim and Approach	Strength	Weakness
1	Do	2019	The downlink Fixed Power Allocation NOMA network's outage performance under Rayleigh fading was evaluated using numerical examples to validate the derived formula.	It is easy to implement	It lacks a defined power allocation algorithm to determine the amount of power to be alloted to various users depending on their channel gain. It is static and suboptimal.
2	Lee	2019	Investigated and proposed a power allocation scheme to achieve fair data rates for two users	The power allocation coefficients are adjusted dynamically with respect to target rate requirement and channel state information	The weak user is given utmost priority over the strong user. The strong user always goes on an outage when the weak user's target rate exceeds 1
3	Bai *et al.*	2019	Investigation of improved Fractional Transmit Power Allocation in downlink NOMA. An iterative technique was employed.	In terms of bit error rate, this technique outperforms fractional transmit power allocation. It has enhanced channel conditions adaptation.	Different decay factors affect the detection accuracy of each user. The power allocation of each user varies as SNR changes
4	Alghasmari and Nassef	2020	Investigation of Fractional Transmit Power allocation in downlink NOMA. Comparative analysis of Fractional	Fractional Transmit Power Allocation achieved good performance with less	It is more sophisticated and involves signalling overhead.

			Transmit Power Allocation to Full Search Power Allocation was carried out.	complexity than Full Search Power Allocation	It does not consider the channel condition. It has one decay factor for power regulation. It is suboptimal.
5	Sanjana and Suma	2021	An iterative technique was employed to investigate the water-filling algorithm for power allocation in downlink NOMA.	More power is alloted to users with higher channel gain..	This scheme does not perform well in terms of fairness index and has variations in outage probability.
6	Yuan *et al.*,	2021	Full Search Power Allocation was investigated.	It can achieve optimal performance. It can be dynamically adjusted.	Due to Full Search Power Allocation's unacceptably high computational complexity, it is difficult to apply to a practical system
7	Garbhapu *et al.*,	2021	Target SNR-based power allocation was investigated.	Perfect channel state information (CSI) is assumed to be known to both the transmitter and receiver. It takes into account the target SNR and channel gain to ascertain the power allocation factors. It can be dynamically adjusted.	The weak user is given utmost priority over the strong user. SINR is maximized for stronger users, and SINR for weaker users exceeds the minimum level

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

Power allocation is crucial in non-orthogonal multiple access for ensuring user fairness. There are many dynamic power allocation algorithms, each with a distinct aim. This could be to maximize the sum rate, increase energy efficiency, or decrease the outage probability. This study investigated and improved the fair power allocation. In Fair Power Allocation, the weak users are prioritized, and the power allocation coefficients are selected to meet the weak user's target rate while giving the residual power to the strong user.

Table 3. 1: Simulation Parameters

Parameters	Simulation Values
N (Users)	50
η (path Loss Exponent)	40
P (BS Tx Power)	30dBm
$\boldsymbol{\sigma}$ (Noise Power)	-114dBm
Power Allocation Factor	
$\boldsymbol{\alpha_f}$	0.75
$\boldsymbol{\alpha_n}$	0.25
Distance	
$\mathbf{d}_f$	1000m
$\mathbf{d}_n$	500m

3.1 Signal model

This study investigated the power domain downlink NOMA transmission between a base station (BS) and two users. (for this work, the strong user will be interchanged for the near user and the weak user for the far user) where α_n and α_f are the power allocation factors respectively ($\alpha_n + \alpha_f = 1$).

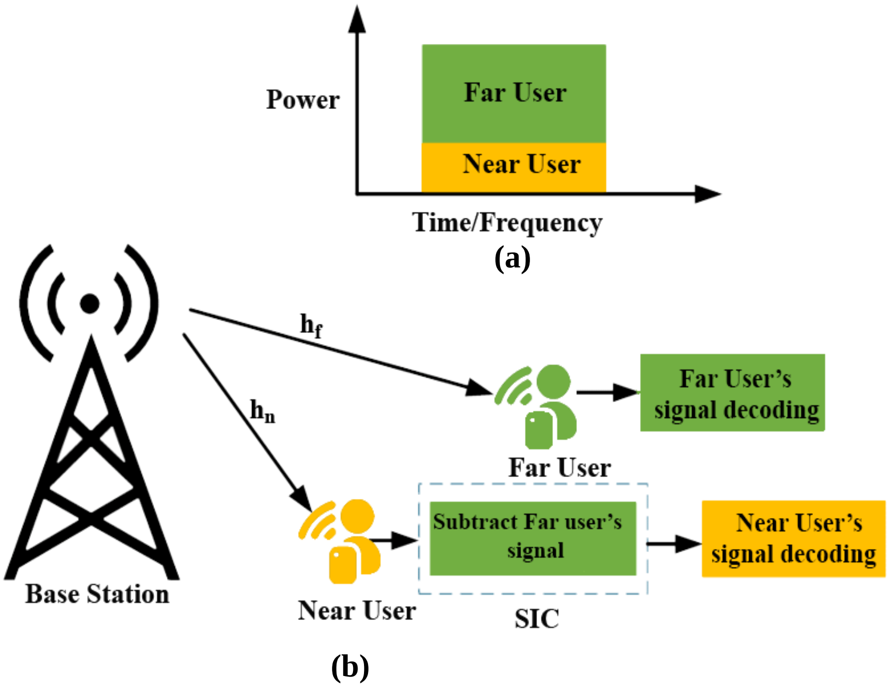

Figure 3. 1: NOMA downlink transmission

3.2 NOMA Capacity

The following are the capacity formulae for NOMA far and near users (Yang *et al.*, 2017) :

$$R_f = \log_2\left(1 + \frac{|h_f|^2 P\alpha_f}{|h_f|^2 P\alpha_n + \sigma^2}\right) \tag{3.1}$$

$$R_n = \log_2\left(1 + \frac{|h_n|^2 P\alpha_n}{\sigma^2}\right) \tag{3.2}$$

R_n is derived once the far user has implemented SIC.

where:

α_n is the near user's coefficient for power allocation

α_f is the far user's coefficient for power allocation

h_n is the near user's coefficient for channel gain

h_f is the far user's coefficient for channel gain

P is the total transmit power

σ^2 is the Noise power

From equation (2.1), the power allocation coefficients were driven as :

$$\frac{|h_f|^2 P\alpha_f}{|h_f|^2 P\alpha_n + \sigma^2} + 1 = 2^{R^*} \tag{3.3}$$

$$\frac{|h_f|^2 P\alpha_f}{|h_f|^2 P\alpha_n + \sigma^2} = 2^{R^*} - 1 \tag{3.4}$$

Let ξ be the target SINR

$\xi = 2^{R^*} - 1$

$$\frac{|h_f|^2 P\alpha_f}{|h_f|^2 P\alpha_n + \sigma^2} = \xi \tag{3.5}$$

$$|h_f|^2 P\alpha_f = \xi |h_f|^2 P\alpha_n + \xi\sigma^2 \tag{3.6}$$

Since $\alpha_n + \alpha_f = 1$,

$$|h_f|^2 P\alpha_f = \xi |h_f|^2 P(1 - \alpha_f) + \xi\sigma^2 \tag{3.7}$$

$$|h_f|^2 P\alpha_f = \xi |h_f|^2 P - \xi |h_f|^2 P\alpha_f + \xi\sigma^2 \tag{3.8}$$

collecting all the α_f terms to the LHS,

$$|h_f|^2 P\alpha_f + \xi |h_f|^2 P\alpha_f = \xi |h_f|^2 h_f|^2 P + \xi\sigma^2 \tag{3.9}$$

$$\alpha_f |h_f|^2 P(1 + \xi) = \xi(|h_f|^2 P + \sigma^2) \tag{3.10}$$

$$\alpha_f = \frac{\xi(|h_f|^2 P + \sigma^2)}{|h_f|^2 P(1 + \xi)} \tag{3.11}$$

after computing α_f, α_n can be written as

$$\alpha_n = 1 - \alpha_f \tag{3.12}$$

3.3 Improved Fair Power Allocation

One of the problems with the Fair Power Allocation scheme is that when the limiting operation was executed, the far-user had a weak channel from equation (3.11), and whenever α_f is greater than 1, α_f is set to 1. By setting $\alpha_f = 1$, α_n will be automatically set to 0, which sets the near user on outage since no power was allocated to him. This was the foundation for improving the Fair Power Allocation scheme.

To enhance Fair Power Allocation, whenever the rate of the far user exceeds 1, instead of limiting α_f to 1, α_f was set to 0. Which will automatically set $\alpha_n = 1$. Setting $\alpha_f = 0$ will not affect the far user's outage since it cannot get out of an outage even if α_f is set to 1 (allocating the entire power to α_f).

3.3.1 Improved Fair Power Allocation flowchart

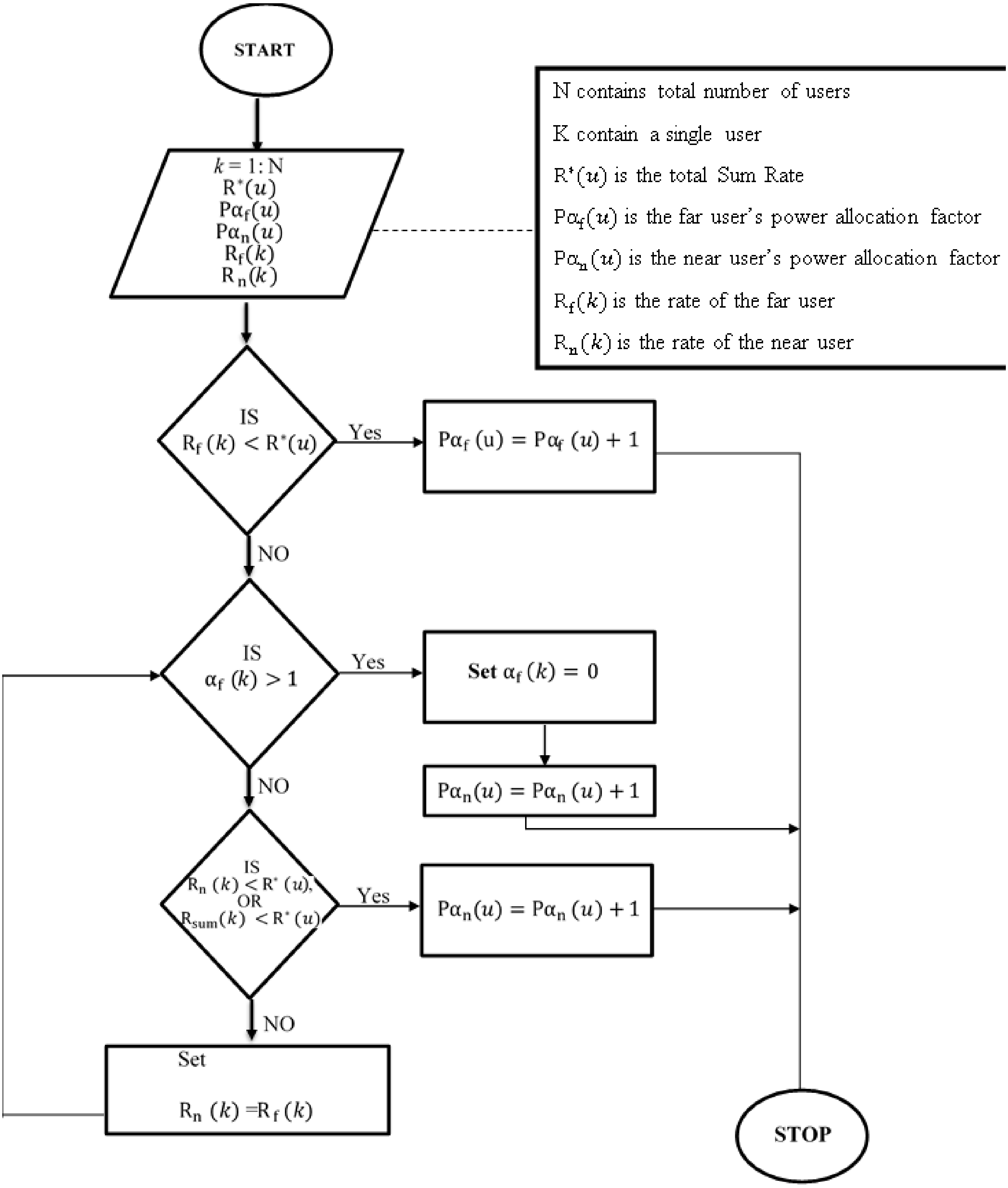

Figure 3. 2: Improved Fair Power Allocation flowchart

3.4 NOMA Bit Error Rate Analysis over a Rayleigh Fading Chanel.

The fundamental idea behind NOMA is to utilize the power domain for multiple access in contrast to previous generations of mobile networks, which depend on the time/frequency/code domain. The fundamental drawback of orthogonal multiple access (OMA) approaches is that they have a low spectral efficiency when some bandwidth resources, like subcarrier channels, are given to users with low channel state information (CSI). However, while employing NOMA, every user has access to every subcarrier channel. Thus, the bandwidth resources allotted to users with low CSI can still be accessed by users with high CSI, thus increasing spectral efficiency (Ding *et al*., 2017). Superposition coding at the transmitter and Successive Interference Cancellation (SIC) at the receivers are the key components of NOMA, which is anticipated to outperform Orthogonal Multiple Access (OMA) in terms of spectral efficiency (Saito *et al*., 2013).

For optimal performance, signal transmission attenuation, distortion, and noise must be minimized. The transmitting and receiving signals must therefore be accurately measured. Factors, coding, features, and various digital modulation techniques can impact the reliability of the received signal and the transmission quality. In contrast to its wired counterpart, wireless technology has several advantages, such as enhanced mobility, higher productivity, reduced costs, simpler installation, and scalability (Attaran, 2021). As a result of reflection, diffraction, and scattering effects, transmitted signals arrive at the receiver with varying power and delay, which is one of the limitations and drawbacks of different transmission channels in the wireless medium between the transmitter and receiver.

The Bit Error Rate (BER) value for the wireless medium is relatively high. The efficiency of wireless data transfer may suffer from these problems. Error management is therefore required for many applications.

Using discrete signals, a carrier wave is modified using the digital modulation approach. High carrier frequencies are employed in digital modulation to facilitate signal transmission over long distances using existing long-distance communication methods, such as radio channels (Bala *et al*., 2021). The received demodulated signal is not adversely affected by channel noise. Conversely, the demodulated signal is distorted if the analogue signal contains noise. Applications that run on the fifth generation (5G) radio access networks have extremely high speeds, low latency, mass connectivity, and good mobility. (Iradier *et al*., 2022; Liu *et al*., 2022). NOMA enables high-density networks and great spectral efficiency by allowing users to access the same radio resources (Li *et al*., 2022). Multiple users are served by conventional Orthogonal Multiple Access (OMA) schemes by assigning them to various radio resources, such as frequency and time. Unlike OMA, which splits users into power domains, NOMA services large numbers of User Equipment (UE) concurrently on the same resource blocks. The fundamentals of a NOMA technique are superposition coding and successive interference cancellation at the transmitter and the receiver respectively.(Azam and Shin, 2022; Hamza *et al*., 2022).

Figure 3.3 details the operation of a digital communication network.

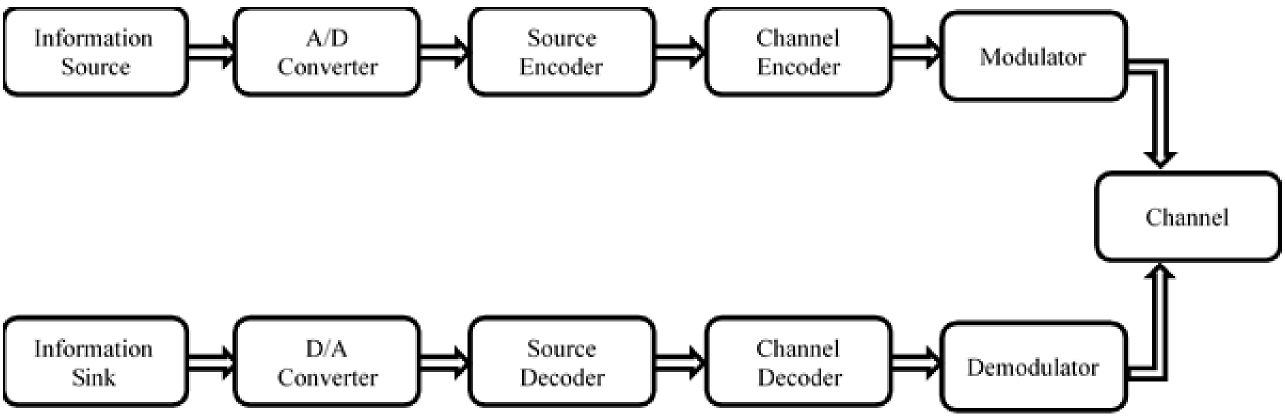

Figure 3. 3: A digital communication system's block diagram

A wireless channel is vulnerable to fading and multipath propagation. Numerous channel models can be used to capture the effects of fading. Every model aims at a specific circumstance. When a line of sight (LOS) path cannot be established between the transmitter and the receiver, one example of a model that may be employed is the Rayleigh fading model. As a result of reflection, scattering, diffraction, and shadowing, all multipath components undergo small-scale fading. In an extreme form of Rayleigh fading, caused by multipath transmission, every bit transmitted experiences a different attenuation and phase shift. In other words, the channel changes for every bit. The weak user in NOMA is given additional transmission power. By interpreting the messages of other users as noise, the weak user can decode its message (Ding *et al*., 2017). On the other hand, the strong user will first identify its message partner under a stronger channel state, subtract the message from the weak user, and last decode its own message. This method explains the successive interference cancellation.

The Base Station sends two discrete messages x_f to the far user, and x_n to the near user. The power allocation factors are α_f and α_n, for the far and the near user, respectively (where $\alpha_f + \alpha_n = 1$). In a NOMA system, more power is allocated to the far user and less to the near user to promote user fairness ($\alpha_f > \alpha_n$).

3.4.1 NOMA Encoding and Transmission

The Base Station transmits a superposition-coded NOMA signal that is:

$$x = \sqrt{P}\left(\sqrt{a_f x_f} + \sqrt{a_n x_n} \right) \tag{3.13}$$

where P is the transmit Power.

After propagating through the channel h_f, the copy of x that the near user receives is given as:

$$y_f = h_f w + w_f \tag{3.14}$$

where w is noise.

Similarly, the copy of x that was propagated through h_n and received by the far user is given as:

$$y_n = h_n w + w_n \tag{3.15}$$

3.4.2 NOMA Decoding at the Far User

Expanding the signal received by the far user:

$$y_f = h_f x + w_f \tag{3.16}$$

$$= h_f \sqrt{P} \left(\sqrt{\alpha_f x_f} + \sqrt{\alpha_n x_n}\right) + w_f \tag{3.17}$$

$$= h_f \sqrt{P} \left(\sqrt{\alpha_f x_f} + h_f \sqrt{P}\sqrt{\alpha_n x_n}\right) + w_f \tag{3.18}$$

where:

$h_f \sqrt{P}\sqrt{\alpha_f x_f}$ is the desired and dominating signal,

$h_f \sqrt{P}\sqrt{\alpha_n x_n}$ is the interference and low power signal,

w_f is noise.

Direct decoding of y_f would yield x_f since $\alpha_f > \alpha_n$. The term x_n component was considered as an interference. For the far user, the signal-to-interference noise ratio is given as follows;

$$\gamma_f = \frac{|h_f|^2 P\alpha_f}{|h_f|^2 P\alpha_n + \sigma^2} \tag{3.19}$$

and its achievable data rate is given as follows:

$$R_f = log_2\left(1 + \gamma_f\right) = log_2\left(1 + \frac{|h_f|^2 P\alpha_f}{|h_f|^2 P\alpha_n + \sigma^2}\right) \tag{3.20}$$

3.4.3 NOMA Decoding at the Near User

Expanding the signal received by the near user:

$$y_n = h_{fn} x + w_n \tag{3.21}$$

$$= h_n \sqrt{P} \left(\sqrt{\alpha_f x_f} + \sqrt{\alpha_n x_n}\right) + w_n \tag{3.22}$$

$$= h_n \sqrt{P} \left(\sqrt{\alpha_f x_f} + h_n \sqrt{P} \sqrt{\alpha_n x_n} \right) + w_n \tag{3.23}$$

where:

$h_n \sqrt{P} \sqrt{\alpha_f x_f}$ is the interference and dominating signal,

$h_n \sqrt{P} \sqrt{\alpha_n x_n}$ is the interference and low power signal,

w_n is noise.

Before decoding his own signal, the near User must first perform successive interference cancellation (SIC). The SIC procedures are as follows;

1. direct decoding of y_n obtains x_f or more specially, an estimate of x_f, which is $\bar{x}$
2. $y'_n = y_n - \sqrt{\alpha_f \bar{x}_f}$ is computed
3. y'_n is decoded to obtain an estimate of x_n

Before SIC, the signal-to-interference noise ratio at the near user for decoding the signal of the far user is given as;

$$\gamma_{f,n} = \frac{|h_n|^2 P \alpha_f}{|h_n|^2 P \alpha_n + \sigma^2} \tag{3.24}$$

The corresponding achievable data rate is given as follows;

$$R_{f,n} = log_2 \left(1 + \gamma_{f,n} \right) = log_2 \left(1 + \frac{|h_n|^2 P \alpha_f}{|h_n|^2 P \alpha_n + \sigma^2} \right) \tag{3.25}$$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

Using the acquired knowledge in chapters 2 and 3, the Improved Fair Power Allocation algorithm was simulated in this chapter. The objective is to evaluate the Improved Fair Power Allocation based on outage probability and compare it with other power allocation algorithms using Matlab.

4.1 Fixed Power Allocation

In Fixed Power Allocation, the Users' power allocation factors are constant because power is allocated based on a set of values. The Fixed Power Allocation prioritizes the user with the lower channel gain.

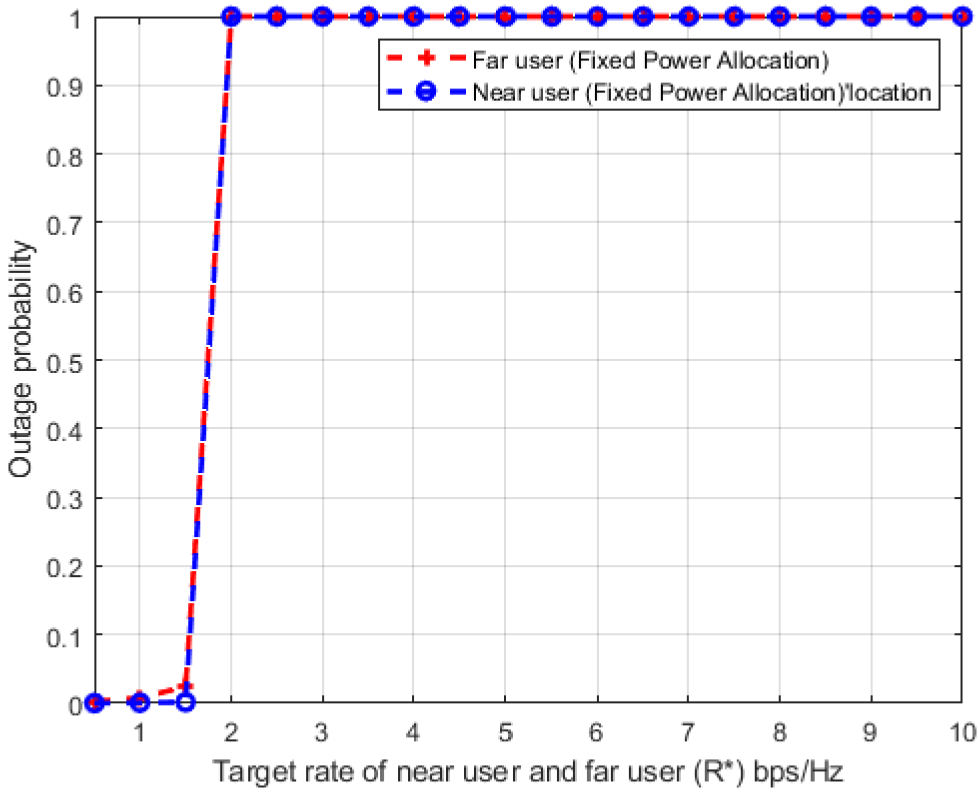

Figure 4. 1: Outage probability vs. R* for Fixed Power Allocation

The main flaw of the Fixed Power Allocation is that it lacks a defined power allocation algorithm for determining how much power should be provided to various users depending on their channel gain. Fixed Power Allocation is deemed inefficient since power levels are set without considering the channel condition.

Table 4. 1: Result Analysis for Fix Power Allocation Outage Probability

Outage Probability for Fix Power Allocation		
Target Rate (R*) bps/Hz	Far User	Near User
0	0.00043	0.00043
1	0.00837	0.00108
2	1.00	1.00
3	1.00	1.00
4	1.00	1.00
5	1.00	1.00
6	1.00	1.00
7	1.00	1.00
8	1.00	1.00
9	1.00	1.00
10	1.00	1.00

The Fixed Power Allocation doesn't perform well when the target rate (R^*) approaches 1.5 bps/Hz, and the outage probability falls to 1. The scheme does not consider the instantaneous channel state information and the target rate requirement. Fixed Power Allocation is not ideal though it's easy to implement.

4.2 Fair Power Allocation

In a Fair Power Allocation, the power allocation coefficients α_n and α_f can be adjusted dynamically with respect to target rate requirements and channel state information.

The outage probability of the far user increases in lockstep with the target rate requirement. The chances of a far user obtaining the target rate decrease as the target rate increases. This would increase the probability of an outage. The near user's outage is fairly sharp around the target rate of 4 to 7 bps/Hz. For any value above this, the near user will experience a continuous outage; however, this scheme is preferable to Fixed Power Allocation.

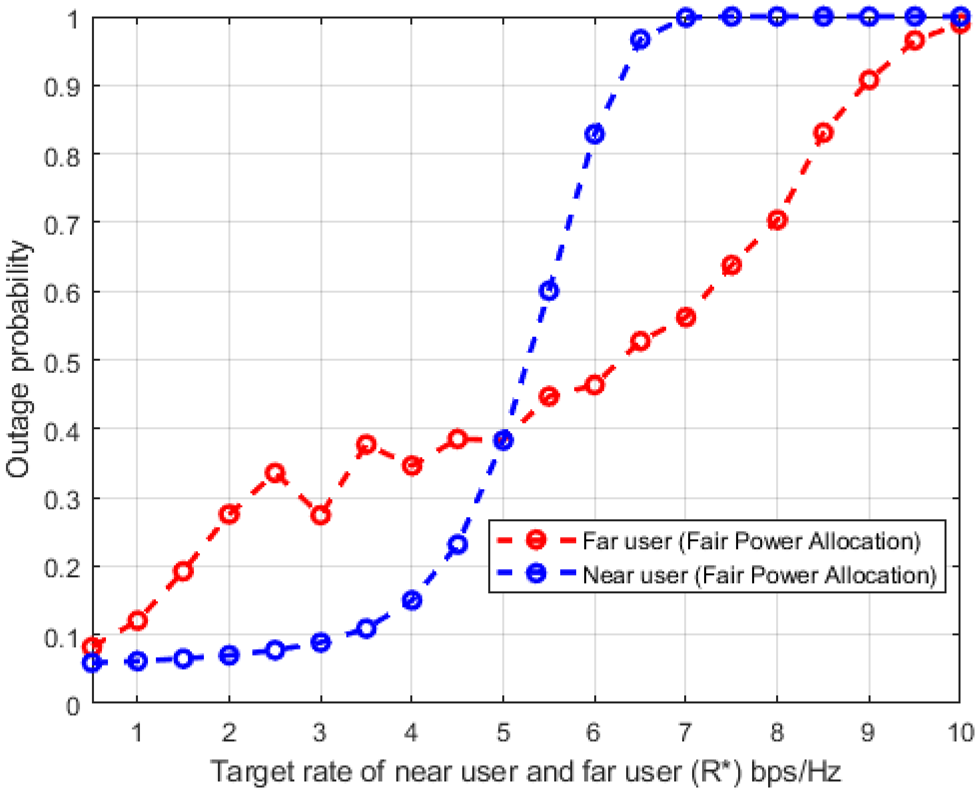

Figure 4. 2: Outage Probability vs. R* for Fair Power Allocation

Table 4. 2: Result Analysis for Fair Power Allocation Outage Probability

Outage Probability for Fair Power Allocation		
Target Rate (R*) bps/Hz	Far User	Near User
0	0.08641	0.05948
1	0.12054	0.06187
2	0.27588	0.07074
3	0.27339	0.08953
4	0.34679	0.14835
5	0.38471	0.38267
6	0.46356	0.82861
7	0.5601	0.99864
8	0.7001	1.0
9	0.90416	1.0
10	0.9894	1.0

From table 4.2, at the rate 0, the far user had an outage probability of 0.08641while the near user had an outage probability of 0.05948. At rate 1, the far user had an outage probability of

0.12054 while the near user had an outage probability of 0.06187. At rate 2, the far user had an outage probability of 0.027588 while the near user had an outage probability of 0.07074.

At rate 3, the far user had an outage probability of 0.27339 while the near user had an outage probability of 0.08953. At rate 4, the far user had an outage probability of 0.34679 while the near user had an outage probability of 0.14835. At rate 5, the far user had an outage probability of 0.38471 while the near user had an outage probability of 0.38267. At rate 6, the far user had an outage probability of 0.46356 while the near user had an outage probability of 0.082861. At rate 7, the far user had an outage probability of 0.5601 while the near user had an outage probability of 0.99864. At rate 8, the far user had an outage probability of 0.7001 while the near user had an outage probability of 1.0. this indicated that the near user is on outage. At rate 9, the far user had an outage probability of 0.90416 while the near user had an outage probability of 1.0 At rate 10, the far user had an outage probability of 0.9894 while the near user had an outage probability of 1.0.

4.3 Improved Power Allocation Algorithm

Compared to Fair Power Allocation, Improved Fair Power Allocation has a lower outage probability and can be modified dynamically depending on target rate requirements and channel state information. Whenever α_f exceeds 1, Instead of limiting $\alpha_f = 1$, α_f is set to 0, which automatically sets $\alpha_n = 1$. When $\alpha_f = 0$, it does not affect the far user's outage since setting $\alpha_f = 1$ cannot get it out of outage.

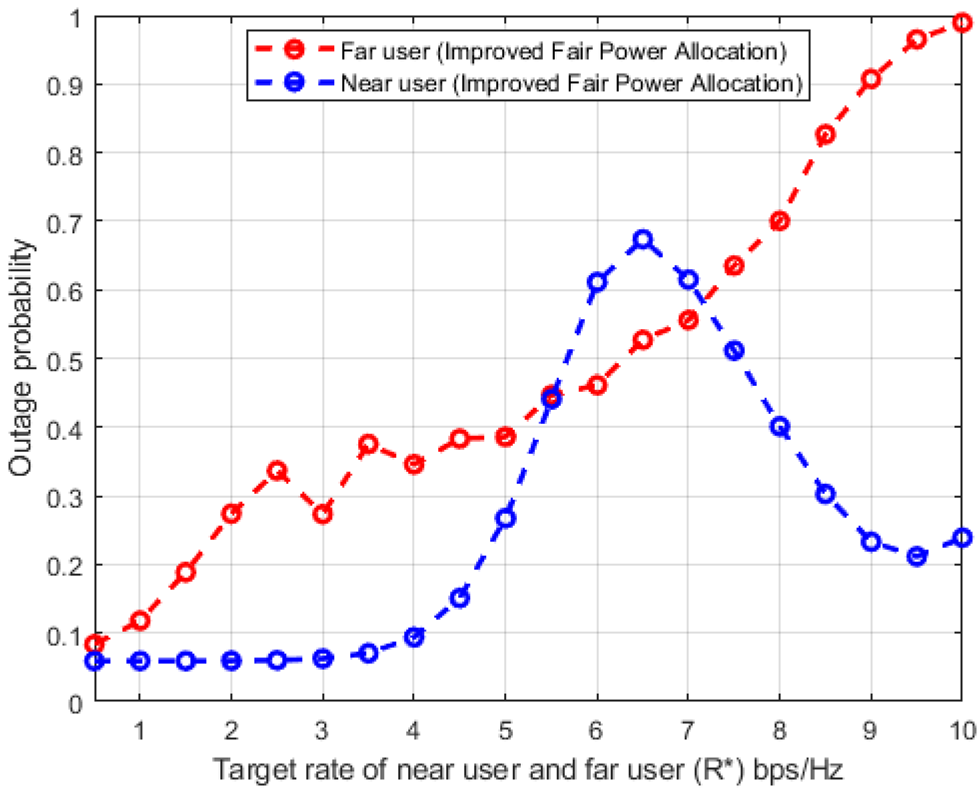

Figure 4. 3: Outage Probability vs. R* for Improved Fair Power Allocation

The outage pattern of the far user is depicted in figure 4.2. This indicates that setting $\alpha_f = 0$, will not affect the far user's outage. The probability of an outage for a near user rises, peaks, and then steadily declines.

When, R^* is between 0 and 6.5 bps/Hz, more power was allocated to the far user at the expense of the near user's performance. Any value more than 6.5 bps/Hz, may not entirely satisfy the target rate. Rather than allocating all power to the far user, priority is given to the near user. This reduces the near user's outage for a target rate above 1.5 bps/Hz while having no effect on the far user's outage.

Table 4. 3: Result Analysis for Improved Fair Power Allocation Outage Probability

Outage Probability for Improved Fair Power Allocation		
Target Rate (R*) bps/Hz	Far User	Near User
0	0.08235	0.05948
1	0.11941	0.05948
2	0.27702	0.05968
3	0.27318	0.063
4	0.34668	0.09315
5	0.38417	0.26736
6	0.4609	0.6105
7	0.5589	0.61348
8	0.69893	0.40341
9	0.90679	0.23494
10	0.98896	0.23778

From table 4.3, at the rate of 0, the far user had an outage probability of 0.08235 while the near user had an outage probability of 0.05948. At rate 1, the far user had an outage probability of 0.11941 while the near user had an outage probability of 0.05948. At rate 2, the far user had an outage probability of 0.27702 while the near user had an outage probability of 0.05968. At rate 3, the far user had an outage probability of 0.27318 while the near user had an outage probability of 0.063. At rate 4, the far user had an outage probability of 0.34668 while the near user had an outage probability of 0.09315. At rate 5, the far user had an outage probability of 0.38417 while the near user had an outage probability of 0.26736. At rate 6, the far user had an outage probability of 0.4609 while the near user had an outage probability of 0.6105. At rate 7, the far user had an outage probability of 0.5589 while the near user had an outage probability of 0.61348. At rate 8, the far user had an outage probability of 0.69893 while the near user had an outage probability of 0.40341. At rate 9, the far user had an outage probability of 0.90679 while the near user had an outage probability of 0.23494. At rate 10, the far user had an outage probability of 0.98896 while the near user had an outage probability of 0.23778.

4.4 Outage Probability Comparison

From figure 4.4, The outage pattern of the far user was depicted in figure 4.2 and figure 4.3. This study compared the near user's outage probabilities for Fair Power Allocation and Improved Fair Power Allocation since the far user's outage probabilities are the same.

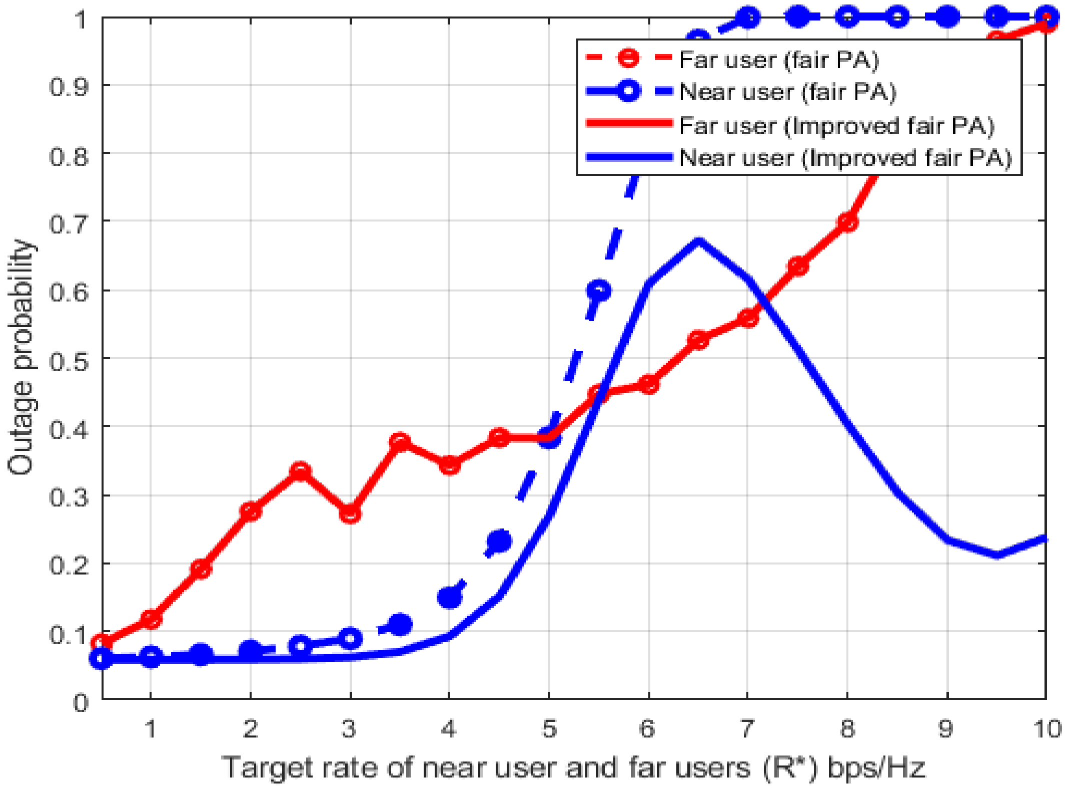

Figure 4. 4: Outage Probability vs. R* for Compared Fair and Improved Fair PA

Table 4. 4: Result Analysis for Compared Fair and Improved Fair Power Allocation

Outage Probability		
Target Rate (R*) bps/Hz	Fair Power Allocation	Improved Fair Power Allocation
0	0.05948	0.05948
1	0.06187	0.05948
2	0.07074	0.05968
3	0.08953	0.063
4	0.14835	0.09315
5	0.38267	0.26736
6	0.82861	0.6105
7	0.99864	0.61348
8	1.0	0.40341
9	1.0	0.23494
10	1.0	0.23778

From Table 4.4, At R* of 0, Fair Power Allocation had a 5.95% outage probability, and Improved Fair Power Allocation had 5.95% also. When compared, there is no performance difference for both power allocation schemes. At R* of 1, Fair Power Allocation had a 6.19% outage probability, and Improved Fair Power Allocation had 5.95%. Improved Fair Power Allocation outperformed Fair Power Allocation at R* of 1 by 3.86%. At R* of 2, Fair Power Allocation had a 7.07% outage probability, and Improved Fair Power Allocation had 5.97%. Improved Fair Power Allocation outperformed Fair Power Allocation at R* of 2 by 15.63%. At R* of 3, Fair Power Allocation had an 8.95% outage probability, and Improved Fair Power Allocation had 6.30%. Improved Fair Power Allocation outperformed Fair Power Allocation at R* of 3 by 29.63%. At R* of 4, Fair Power Allocation had a 14.84% outage probability, and Improved Fair Power Allocation had 9.32%. Improved Fair Power Allocation outperformed Fair Power Allocation at R* of 4 by 37.21%. At R* of 5, Fair Power Allocation had 38.27% outage probability, and Improved Fair Power Allocation had 26.74%. Improved Fair Power Allocation outperformed Fair Power Allocation at R* of 5 by 30.13%. At R* of 6, Fair Power Allocation had 82.86% outage probability, and Improved Fair Power Allocation had 61.05%. Improved Fair Power Allocation outperformed Fair Power Allocation at R* of 6 by 26.32%.

At R* of 7, Fair Power Allocation had a 99.86% outage probability, and Improved Fair Power Allocation had 61.35%. Improved Fair Power Allocation outperformed Fair Power Allocation at R* of 7 by 38.75%. At R* of 8, Fair Power Allocation had a 100.00% outage probability, and Improved Fair Power Allocation had 40.34%. Improved Fair Power Allocation outperformed Fair Power Allocation at R* of 8 by 59.66%. At R* of 9, Fair Power Allocation had a 100.00% outage probability, and Improved Fair Power Allocation had 23.49%. Improved Fair Power Allocation outperformed Fair Power Allocation at R* of 9 by 76.51%. At R* of 10, Fair Power Allocation had a 100.00% outage probability, and Improved Fair Power Allocation had 23.78%. Improved Fair Power Allocation outperformed Fair Power Allocation at R* of 10 by 76.22%.

Improved Fair Power Allocation averagely outperformed Fair Power Allocation by 35.80% in terms of outage probability.

4.5 BER Analysis of a Downlink NOMA System

NOMA's non-orthogonality has been a concern in both academia and the industry. Since its access is not orthogonal, interference between users is a fundamental disadvantage of the NOMA technology. An interference cancellation approach, such as successive interference cancellation (SIC) at the receiver, is typically used to resolve this. Contrarily, inter-user interference in the SIC process cannot be completely eliminated and is usually due to wrong decisions at the receiver caused by the channel. The performance of the downlink NOMA for the BPSK transmission system in a Rayleigh fading was analyzed using MATLAB.

Firstly, the values of the parameters was declared. For the distances, $D_f = 1000\ meters$, and $D_n = 500\ meters$. Then the power allocation factors was set as $\alpha_f = 70$ and $\alpha_n = 30$. For user fairness, more power was allocated to the far user. For the transmit power, a range of 0dBm to 40dBm was initialized. The system's bandwidth was then set to $B = 1MH_z$. According to the formulae, $N_0 = kTB$, where $k = 1.38 \times 10^{-23}$ (Boltzmann constant),

$T = 300K$, the thermal noise power was calculated. The Rayleigh fading coefficients for h_f and h_n was then generated. The path loss exponent was set as $\eta = 4$. Next, the noise samples for the far user and the near user and a randomized binary data for the users was generated. The superposition-coded signal x was calculated after using BPSK to modulate the data. y_f and y_n was also calculated and then equalized by diving h_f and h_n respectively. From the equalized version of y_f, direct BPSK demodulation was performed to obtain $\bar{x}_f$. The biterrr function was used to estimate BER and compared x̄ with the original data from the far user. To estimate x_f, y_n was directly decoded. The signal was decoded to obtain, $\bar{x}_n$ by remodulating x_f and subtrahend the remodulated x_f element from the equalized version of y_n. $\bar{x}_n$ and the near user's initial data was further compared. The BER was estimated using the biterrr function. Finally, the BERs was plotted in relation to transmit power using MATLAB.

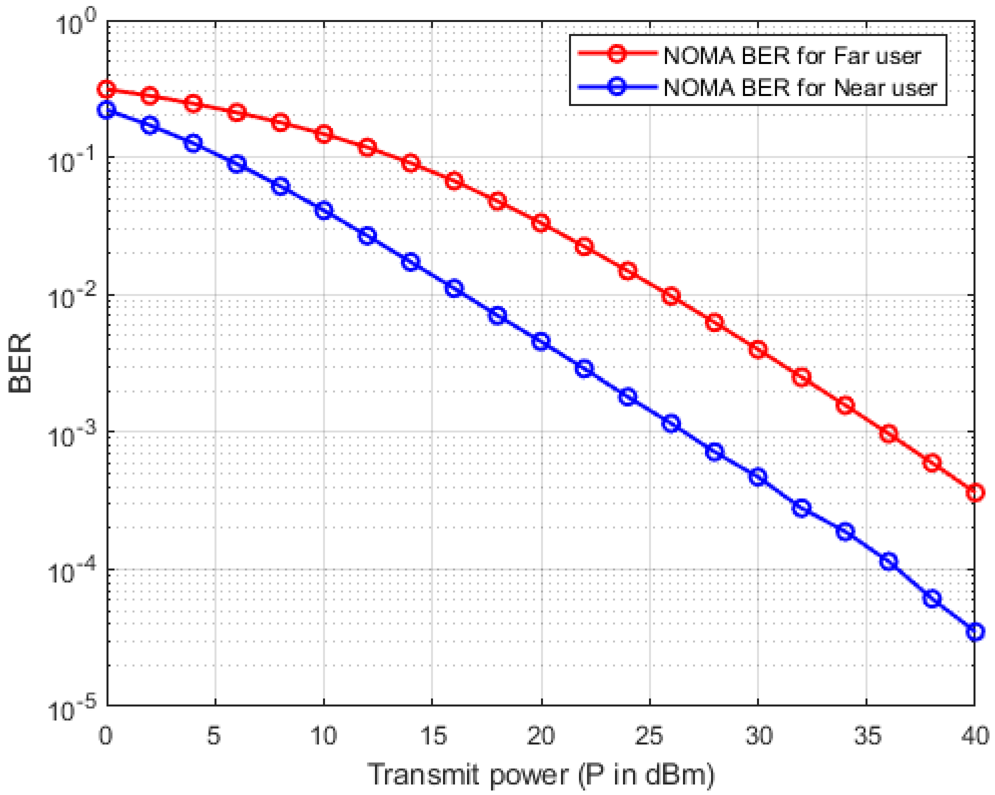

Figure 4. 5: BER Performance vs. Transmit Power (dBm)

The BER performance for a two-user scenario is shown in Figure 4.4. The near and far users were allocated 0.75 and 0.25 power, respectively, with a 1MHz bandwidth using the BPSK modulation technique. According to the figure above, interference from the near user causes the far user to have a greater BER. With no interference, the near user has the lowest BER. This shows that NOMA performs as expected. The near user has an average BER of 0.01, while the far user has an average BER of 0.05.

Table 4. 5: NOMA Bit Error Rate Analysis

Bit Error Rate		
Transmit Power (dBm)	Far User	Near User
10	0.14857	0.040852
20	0. 033698	0.00449
30	0.004079	0.000422
40	0.000447	0.000037

4.6 Sum Rate Comparison

The sum rate is frequently used to evaluate the SIC performance for downlink NOMA systems. Depending on the channel gains, the downlink NOMA can continuously switch users from weak to strong and vice versa. However, the sum rate is a viable factor in determining NOMA's effectiveness. Given that a user's rate rises with an increase in SINR, where the power level is crucial, this study have demonstrated that capacity in sum rates can be maximized, provided appropriate power levels are selected.

NOMA's Sum Rate is given from equations 3.1 and 3.2 as:

$$R_{sum} = R_n + R_f$$

Table 4. 6: Sum Rate Analysis for Fixed and Improved Fair Power Allocation

Transmit Power (dBm)	Sum Rate (bps/Hz)	
	Fixed Power Allocation	Improved Fair Power Allocation
0	0.08604	0.29923
5	0.24599	0.73446
10	0.62395	1.5176
15	1.3411	2.6494
20	2.4351	4.0369
25	3.858	5.5713
30	5.5569	6.9926

As shown in figure 4.6, in terms of achievable rate, Improved Fair Power Allocation performed fared better than the Fixed Power Allocation by 35.11%.

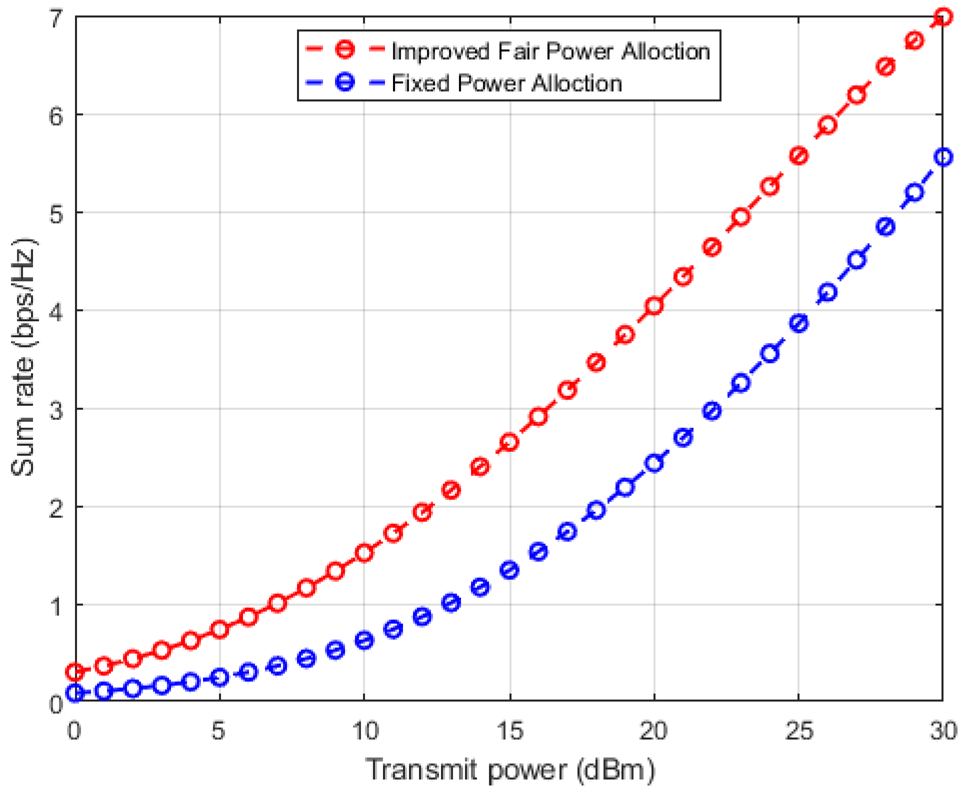

Figure 4. 6: Sum Rate vs. Transmit Power for the Improved Fair Power Allocation

From Table 4.6, at a transmit power of 0dBm, the sum rate for Fixed Power Allocation was 0.09bps/Hz, and the sum rate for Improved Fair Power Allocation was 0.30bps/Hz. When compared, Improved Fair Power Allocation had an achievable rate of 71.25% higher than fixed power. At a transmit power of 5dBm, the Fixed Power Allocation had a sum rate of 0.25bps/Hz, and Improved Fair Power Allocation had a sum rate of 0.73bps/Hz. When compared, Improved Fair Power Allocation had a 66.51% higher achievable rate than Fixed Power Allocation. At a transmit power of 10dBm, the Fixed Power Allocation had a sum rate of 0.62bps/Hz, and Improved Fair Power Allocation had a sum rate of 1.52bps/Hz. When compared, Improved Fair Power Allocation had a 58.98% higher achievable rate than Fixed Power Allocation. At a transmit power of 15dBm, Fixed Power Allocation had a sum rate of 1.34bps/Hz, and Improved Fair Power Allocation had a sum rate of 2.65bps/Hz. When compared, Improved Fair Power Allocation had a 49.38% higher achievable rate than Fixed Power Allocation. At a transmit power of 20dBm, Fixed Power Allocation had a sum rate of 2.44bps/Hz, and Improved Fair Power Allocation had a sum rate of 4.04bps/Hz. When compared, Improved Fair Power Allocation had a 39.68% higher achievable rate than Fixed Power Allocation. At a transmit power of 25dBm, the Fixed Power Allocation had a sum rate of 3.86bps/Hz, and Improved Fair Power Allocation had a sum rate of 5.57bps/Hz. When compared, Improved Fair Power Allocation had a 30.75% higher achievable rate than Fixed Power Allocation. At a transmit power of 30dBm, the Fixed Power Allocation had a sum rate of 5.56bps/Hz, and Improved Fair Power Allocation had a sum rate of 6.99bps/Hz. When compared, Improved Fair Power Allocation had a 20.53% higher achievable rate than the Fixed Power Allocation.

Improved Fair Power Allocation has an average 48.14% higher achievable rate than Fixed Power Allocation.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Aiming to further enhance the system efficiency and quality of service, especially at the cell edge in the future radio access network, this study improved the Fair Power Allocation scheme, analyzed the BER of a NOMA system over a Rayleigh Fading Chanel and finally, the sum rate maximization.

The simulation and a comparison of the outage probability of Improved Fair Power Allocation was carried out using MATLAB software, guided by the concepts of NOMA and system parameters. The Improved Fair Power Allocation results, as presented in this study, indicated that Improved Fair Power Allocation outperformed Fair Power Allocation in terms of outage probability by 35.80% and outperformed the Fixed Power Allocation in terms of sum rate maximization by 48.14%. The simulation results show that Improved Fair Power Allocation performs well for a Rayleigh fading channel than other state-of-art power allocation schemes.

5.2 Recommendation

This study serves as a strong theoretical and simulation foundation for further studies using the NOMA technology. Future studies can be carried out for different channel models of a NOMA system.

5.3 Contribution to Knowledge

This study developed an Improved Power Allocation Scheme for a NOMA System to enhance User Fairness in 5G Networks. It also provided an analysis of the BER of a Downlink NOMA System over a Rayleigh fading channel.

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APPENDIX A

Simulation Files Description

This appendix briefly describes each of the MATLAB simulation files.

- **Fixed_Power_Alloction**: This file contains the Matlab simulation code for the Fixed Power Allocation. For each user, a fixed distance and fixed power value were allocated.
- **Fair_Power_Allocation**: This file presents the Matlab simulation code for the Fair Power Allocation with a far distance of 100 m and a near distance of 500 m, path loss exponent of 4 and -114dbm of Noise power.
- **Improved_Fair_Power_Alloction:** This file presents the Matlab simulation code for a graphic comparison of the Improved Fair Power Allocation. This code shows that the outage pattern of the far user is depicted in Fair Power Allocation, and setting the far users power allocation factor to zero, will not affect the far user's outage as the probability of an outage for a near user rises, peaks, and then steadily declines.
- **NOMA_BER_Rayleigh:** This file presents the Matlab simulation code for analysing the BER of a NOMA system over a Rayleigh fading channel. This code shows that NOMA offers users reasonable fairness while minimizing interference at a reasonable BER.
- **SumRate_for_Improved_fair_Power_Alloction:** This file presents the Matlab simulation code for a graphic comparison of the Sum Rate of the Improved Fair Power Allocation. In terms of achievable capacity.

APPENDIX B

Simulation Codes

```
%% FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE
% NOMA-FIXED POWER ALLOCTION
% By: CHIKEZIE, Chekwas Ifeanyi
% Supervisors: Engr. Dr. M. David, Engr. Dr. A.U. Usman
% Simulation assisted by: Engr.Dr. I Abideen

clc; clear variables; close all;

N = 10^5;
Pt = 30;                    %Max BS Tx power (dBm)
pt = (10^-3)*db2pow(Pt);        %Max BS Tx power (Linear scale)
No = -114;                  %Noise power (dBm)
no = (10^-3)*db2pow(No);        %Noise power (Linear scale)


r = 0.5:0.5:10;              %Far user target rate range (R*)

df = 1000; dn = 500;            %Distances

eta = 4;                     %Path loss exponent

p1 = zeros(1,length(r));
p2 = zeros(1,length(r));
pa1 = zeros(1,length(r));
pa2 = zeros(1,length(r));

af = 0.75; an = 0.25;       %Fixed PA (for comparison)



hf = sqrt(df^-eta)*(randn(1,N) + 1i*randn(1,N))/sqrt(2);
hn = sqrt(dn^-eta)*(randn(1,N) + 1i*randn(1,N))/sqrt(2);

g1 = (abs(hf)).^2;
g2 = (abs(hn)).^2;

for u = 1:length(r)
    epsilon = (2^(r(u)))-1;         %Target SINR for far user


    gamma_f = pt*af*g1./(pt*g1*an + no);
    gamma_nf = pt*af*g2./(pt*g2*an + no);
    gamma_n = pt*g2*an/no;
```

```
    Cf = log2(1 + gamma_f);
    Cnf = log2(1 + gamma_nf);
    Cn = log2(1 + gamma_n);

    for k = 1:N
        if Cf(k) < r(u)
            p1(u) = p1(u) + 1;
        end
        if (Cnf(k)<r(u))||(Cn(k) < r(u))
            p2(u) = p2(u) + 1;
        end

    end
end
pout1 = p1/N;
pout2 = p2/N;



figure;
plot(r,pout1,'--+r','linewidth',2); hold on; grid on;
plot(r,pout2,'--ob','linewidth',2);

xlabel('Target rate of near user and far user (R*) bps/Hz');
ylabel('Outage probability');
xlim([r(1) r(end)]);
legend('Far user (Fixed Power Allocation)','Near user (Fixed Power Allocation)');
```

```
%% FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE
% NOMA-FAIR POWER ALLOCTION
% By: CHIKEZIE, Chekwas Ifeanyi
% Supervisors: Engr. Dr. M. David, Engr. Dr. A.U. Usman
% Simulation assisted by: Engr.Dr. I Abideen

clc; clear variables; close all;
N = 10^5;
Pt = 30;                    %Max BS Tx power (dBm)
pt = (10^-3)*db2pow(Pt);        %Max BS Tx power (Linear scale)
No = -114;                  %Noise power (dBm)
no = (10^-3)*db2pow(No);        %Noise power (Linear scale)


r = 0.5:0.5:10;             %Far user target rate range (R*)

df = 1000; dn = 500;            %Distances

eta = 4;                    %Path loss exponent

p1 = zeros(1,length(r));
p2 = zeros(1,length(r));
pa1 = zeros(1,length(r));
pa2 = zeros(1,length(r));

af = 0.75; an = 0.25;       %Fixed PA (for comparison)

hf = sqrt(df^-eta)*(randn(1,N) + 1i*randn(1,N))/sqrt(2);
hn = sqrt(dn^-eta)*(randn(1,N) + 1i*randn(1,N))/sqrt(2);

g1 = (abs(hf)).^2;
g2 = (abs(hn)).^2;

for u = 1:length(r)
    epsilon = (2^(r(u)))-1;        %Target SINR for far user

        %BASIC FAIR PA%
        aaf = min(1,epsilon*(no + pt*g1)./(pt*g1*(1+epsilon)));
        aan = 1 - aaf;


    gamma_f = pt*af*g1./(pt*g1*an + no);
    gamma_nf = pt*af*g2./(pt*g2*an + no);
    gamma_n = pt*g2*an/no;

    gamm_f = pt*aaf.*g1./(pt*g1.*aan + no);
    gamm_nf = pt*aaf.*g2./(pt*g2.*aan + no);
```

```
    gamm_n = pt*g2.*aan/no;


    Cf = log2(1 + gamma_f);
    Cnf = log2(1 + gamma_nf);
    Cn = log2(1 + gamma_n);

    Ca_f = log2(1 + gamm_f);
    Ca_nf = log2(1 + gamm_nf);
    Ca_n = log2(1 + gamm_n);

    for k = 1:N
        if Cf(k) < r(u)
            p1(u) = p1(u) + 1;
        end
        if (Cnf(k)<r(u))||(Cn(k) < r(u))
            p2(u) = p2(u) + 1;
        end

        if Ca_f(k) < r(u)
            pa1(u) = pa1(u) + 1;
        end
        if aaf(k) ~= 0
            if (Ca_n(k) < r(u)) || (Ca_nf(k) < r(u))
                pa2(u) = pa2(u) + 1;
            end
        else
            if Ca_n(k) < r(u)
                pa2(u) = pa2(u) + 1;
            end
        end
    end
end
pout1 = p1/N;
pout2 = p2/N;
pouta1 = pa1/N;
pouta2 = pa2/N;

figure;
plot(r,pouta1,'--or','linewidth',2); hold on; grid on;
plot(r,pouta2,'--ob','linewidth',2);
xlabel('Target rate of near user and far user (R*) bps/Hz');
ylabel('Outage probability');
xlim([r(1) r(end)]);
legend('Far user (Fair Power Allocation)','Near user (Fair Power Allocation)','location','best');
```

```
%% FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE
% NOMA-IMPROVED FAIR POWER ALLOCTION
% By: CHIKEZIE, Chekwas Ifeanyi
% Supervisors: Engr. Dr. M. David, Engr. Dr. A.U. Usman
% Simulation assisted by: Engr.Dr. I Abideen

clc; clear variables; close all;
N = 10^5;
Pt = 30;                    %Max BS Tx power (dBm)
pt = (10^-3)*db2pow(Pt);        %Max BS Tx power (Linear scale)
No = -114;                  %Noise power (dBm)
no = (10^-3)*db2pow(No);        %Noise power (Linear scale)


r = 0.5:0.5:10;             %Far user target rate range (R*)

df = 1000; dn = 500;            %Distances

eta = 4;                    %Path loss exponent

p1 = zeros(1,length(r));
p2 = zeros(1,length(r));
pa1 = zeros(1,length(r));
pa2 = zeros(1,length(r));

af = 0.75; an = 0.25;       %Fixed PA (for comparison)

hf = sqrt(df^-eta)*(randn(1,N) + 1i*randn(1,N))/sqrt(2);
hn = sqrt(dn^-eta)*(randn(1,N) + 1i*randn(1,N))/sqrt(2);

g1 = (abs(hf)).^2;
g2 = (abs(hn)).^2;

for u = 1:length(r)
   epsilon = (2^(r(u)))-1;        %Target SINR for far user


    %IMPROVED FAIR PA%
    aaf = epsilon*(no + pt*g1)./(pt*g1*(1+epsilon));
    aaf(aaf>1) = 0;
    aan = 1 - aaf;

   gamma_f = pt*af*g1./(pt*g1*an + no);
   gamma_nf = pt*af*g2./(pt*g2*an + no);
   gamma_n = pt*g2*an/no;
```

```
    gamm_f = pt*aaf.*g1./(pt*g1.*aan + no);
    gamm_nf = pt*aaf.*g2./(pt*g2.*aan + no);
    gamm_n = pt*g2.*aan/no;
    Cf = log2(1 + gamma_f);
    Cnf = log2(1 + gamma_nf);
    Cn = log2(1 + gamma_n);

    Ca_f = log2(1 + gamm_f);
    Ca_nf = log2(1 + gamm_nf);
    Ca_n = log2(1 + gamm_n);

    for k = 1:N
        if Cf(k) < r(u)
            p1(u) = p1(u) + 1;
        end
        if (Cnf(k)<r(u))||(Cn(k) < r(u))
            p2(u) = p2(u) + 1;
        end

        if Ca_f(k) < r(u)
            pa1(u) = pa1(u) + 1;
        end
        if aaf(k) ~= 0
            if (Ca_n(k) < r(u)) || (Ca_nf(k) < r(u))
                pa2(u) = pa2(u) + 1;
            end
        else
            if Ca_n(k) < r(u)
                 pa2(u) = pa2(u) + 1;
            end
        end
    end
end
pout1 = p1/N;
pout2 = p2/N;
pouta1 = pa1/N;
pouta2 = pa2/N;

figure;
plot(r,pouta1,'--or','linewidth',2); hold on; grid on;
plot(r,pouta2,'--ob','linewidth',2);
xlabel('Target rate of near user and far user (R*) bps/Hz');
ylabel('Outage probability');
xlim([r(1) r(end)]);
legend('Far user (Improved Fair Power Allocation)','Near user (Improved Fair Power Allocation)''location','best',);
```

```
%% FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE
% NOMA BER ANALYSIS
% By: CHIKEZIE, Chekwas Ifeanyi
% Supervisors: Engr. Dr. M. David, Engr. Dr. A.U. Usman
% Simulation assisted by: Engr.Dr. I Abideen

clc; clear variables; close all;

N = 10^6;

d1 = 1000; d2 = 500;    %Distances of users from base station (BS)
a1 = 0.70; a2 = 0.30;   %Power allocation factors
eta = 4;                %Path loss exponent

%Generate rayleigh fading coefficient for both users
h1 = sqrt(d1^-eta)*(randn(1,N)+1i*randn(1,N))/sqrt(2);
h2 = sqrt(d2^-eta)*(randn(1,N)+1i*randn(1,N))/sqrt(2);

g1 = (abs(h1)).^2;
g2 = (abs(h2)).^2;

Pt = 0:2:40;                %Transmit power in dBm
pt = (10^-3)*10.^(Pt/10);   %Transmit power in linear scale
BW = 10^6;                  %System bandwidth
No = -174 + 10*log10(BW);   %Noise power (dBm)
no = (10^-3)*10.^(No/10);   %Noise power (linear scale)

%Generate noise samples for both users
w1 = sqrt(no)*(randn(1,N)+1i*randn(1,N))/sqrt(2);
w2 = sqrt(no)*(randn(1,N)+1i*randn(1,N))/sqrt(2);

%Generate random binary data for two users
data1 = randi([0 1],1,N);  %Data bits of user 1
data2 = randi([0 1],1,N);  %Data bits of user 2

%Do BPSK modulation of data
x1 = 2*data1 - 1;
x2 = 2*data2 - 1;

p = length(Pt);
for u = 1:p
   %Do superposition coding
   x = sqrt(pt(u))*(sqrt(a1)*x1 + sqrt(a2)*x2);
   %Received signals
   y1 = h1.*x + w1;
   y2 = h2.*x + w2;
```

```
    %Equalize
    eq1 = y1./h1;
    eq2 = y2./h2;

    %AT USER 1--------------------
    %Direct decoding of x1 from y1
    x1_hat = zeros(1,N);
    x1_hat(eq1>0) = 1;

    %Compare decoded x1_hat with data1 to estimate BER
    ber1(u) = biterr(data1,x1_hat)/N;

    %----------------------------------

    %AT USER 2-------------------------
    %Direct decoding of x1 from y2
    x12_hat = ones(1,N);
    x12_hat(eq2<0) = -1;

    y2_dash = eq2 - sqrt(a1*pt(u))*x12_hat;
    x2_hat = zeros(1,N);
    x2_hat(real(y2_dash)>0) = 1;

    ber2(u) = biterr(x2_hat, data2)/N;
    %-----------------------------------

    gam_a = 2*((sqrt(a1*pt(u))-sqrt(a2*pt(u)))^2)*mean(g1)/no;
    gam_b = 2*((sqrt(a1*pt(u))+sqrt(a2*pt(u)))^2)*mean(g1)/no;
    ber_th1(u) = 0.25*(2 - sqrt(gam_a/(2+gam_a)) - sqrt(gam_b/(2+gam_b)));

    gam_c = 2*a2*pt(u)*mean(g2)/no;
    gam_d = 2*((sqrt(a2) + sqrt(a1))^2)*pt(u)*mean(g2)/no;
    gam_e = 2*((sqrt(a2) + 2*sqrt(a1))^2)*pt(u)*mean(g2)/no;
    gam_f = 2*((-sqrt(a2) + sqrt(a1))^2)*pt(u)*mean(g2)/no;
    gam_g = 2*((-sqrt(a2) + 2*sqrt(a1))^2)*pt(u)*mean(g2)/no;

    gc = (1 - sqrt(gam_c/(2+gam_c)));
    gd = (1-sqrt(gam_d/(2+gam_d)));
    ge = (1-sqrt(gam_e/(2+gam_e)));
    gf = (1-sqrt(gam_f/(2+gam_f)));
    gg = (1-sqrt(gam_g/(2+gam_g)));

    ber_th2(u) = 0.5*gc - 0.25*gd + 0.25*(ge+gf-gg);

    gamma1(u) = a1*pt(u)*mean(g1)/(a2*pt(u)*mean(g1) + no);
    gamma2(u) = a2*pt(u)*mean(g2)/no;
end

semilogy(Pt, ber1,'r', 'linewidth',1.5); hold on; grid on;
```

```
semilogy(Pt, ber2,'b', 'linewidth',1.5);
semilogy(Pt, ber_th1, '*r','linewidth',1.5);
semilogy(Pt, ber_th2, '*b','linewidth',1.5);
xlabel('Transmit power (P in dBm)');
ylabel('BER');
legend(BER for Far user', 'BER for Near user');
```

```
%%FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE
% SUMRATE FOR IMPROVED NOMA-FAIR POWER ALLOCATION
% By: CHIKEZIE, Chekwas Ifeanyi
% Supervisors: Engr. Dr. M. David, Engr. Dr. A.U. Usman
% Simulation assisted by: Engr.Dr. I Abideen

clc; clear variables; close all;

N = 10^5;
df = 5000; dn = 1000; %Distances

eta = 4;
hf = sqrt(df^-eta)*(randn(1,N) + 1i*randn(1,N))/sqrt(2);
hn = sqrt(dn^-eta)*(randn(1,N) + 1i*randn(1,N))/sqrt(2);

gf = (abs(hf)).^2;
gn = (abs(hn)).^2;

R1 = 1;  %Target rate bps/Hz

epsilon = (2^(R1))-1; %Target SINR

%Transmit power
Pt = 0:30;
pt = (10^-3)*db2pow(Pt);

%Noise power
No = -114;
no = (10^-3)*db2pow(No);

b1 = 0.75; b2 = 0.25; %Fixed PA for comparison
for u = 1:length(pt)
   a1 = epsilon*(no + pt(u)*gf)./(pt(u)*gf*(1+epsilon));
   a1(a1>1) = 0;
   a2 = 1 - a1;

   %Sum rate of fair PA
   C1 = log2(1 + pt(u)*a1.*gf./(pt(u)*a2.*gf + no));
   C2 = log2(1 + pt(u)*a2.*gn/no);
```

```
    C_sum(u) = mean(C1+C2);

    %Sum rate of fixed PA
    C1f = log2(1 + pt(u)*b1.*gf./(pt(u)*b2.*gf + no));
    C2f = log2(1 + pt(u)*b2.*gn/no);
    C_sumf(u) = mean(C1f+C2f);
end

plot(Pt,C_sum,'--or','linewidth',1.5); hold on; grid on;
plot(Pt,C_sumf,'--ob','linewidth',1.5);
legend('Improved Fair Power Alloction','Fixed Power Alloction')
xlabel('Transmit power (dBm)');
ylabel('Sum rate (bps/Hz)');
```

APPENDIX C

Publication:

1. C. I. Chikezie, M. David, and A. U. Usman, "Power Allocation Optimization in NOMA System for User Fairness in 5G Networks," 2022 IEEE Nigeria 4th International Conference on Disruptive Technologies for Sustainable Development (NIGERCON), 2022, pp. 1-4, doi: 10.1109/NIGERCON54645.2022.9803107.

Accepted Publication:

1. M. David, A. U. Usman, and C. I. Chikezie, "BER Analysis Over a Rayleigh Fading Channel: An Investigation using the NOMA Scheme" 2023 ICICT 8th International Congress and Communication Technology, 2023.