Maximization of Users' Fairness in an Imbalanced-NOMA Network scenario with More Far-Users, by means of Multiple Near-Field Relays.

by

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DECLARATION

I, Mario Ligwa, declare that the contents of this thesis represent my unaided work and that it has not been previously submitted for academic examination towards any qualification. Furthermore, it represents my own research work and not necessarily those of the Cape Peninsula University of Technology.

Signed **Date**

ABSTRACT

The development of 5G networks is currently prominent in the mobile network industry. This is due to the need for increased network performances, such as more capacity and reliability (users' fairness); which the current 4G networks fall short of delivering. Non-Orthogonal Multiple Access (NOMA) technology has been identified by others, as key elements for the realization of 5G networks; thus, the design of NOMA networks has recently gained popularity. NOMA technology implies serving 2 or more users in the same frequency band and discriminating their respective information by assigning different power levels to each (PD-NOMA). In the case of 2 users per frequency band, a base-station with N-antennas must serve 2N users at the time. Initial works in the NOMA-networks' design often assumed that the 2N-users to be served consist of N-far field users and N-near field users. This scenario is referred to as the "balanced-NOMA" scenario. Initial power-allocation algorithms (Initial FM-PAA) have been proposed to maximize users' fairness of NOMA networks in this scenario, and have yielded relatively good results. However, there can be a case where there are more far-users than near-users in the 2N set to be served; it is referred to as an "imbalanced NOMA" scenario. In this case, if the "initial FM-PAA" is used straight, it will only serve possible pairs, leaving many far-users unserved. This will result in very poor user fairness for the network.

To address this problem, first, an "intermediate PAA", which executes NOMA combined with OMA, was designed, implemented and tested. The algorithm consists of an inter-beam power-sharing stage, to distribute the base station's power across respective antennas; and an intra-beam power-sharing stage, only applicable to the NOMA pairs formulated. Both stages employed the "OCTR-ratios convergence concept". The results indicated that the proposed "intermediate-PAA" considerably improves the fairness of the imbalanced-NOMA network scenario; compared to when the "initial FM-PAA" is used straight. However, since it does not serve all users, it therefore constitutes an intermediate solution to the problem stated.

Furthermore, the research proposed an "advanced-PAA" solution, to completely address the problem. The solution consists of placing relays in the near-field of the base station. Each relay serves as the near-user to one of the unpaired far-users, and it will be served with the information intended for the other unpaired far-user. This turns the system into a perfectly balanced NOMA scenario. Then, a power-allocation algorithm, which combines an "initial FM-PAA", and a "relay management system", was designed, implemented and tested. The "initial FM-PAA" was designed based on the "OCTR-ratios convergence" concept. The "relay-management system" was based on the "decode and forward" concept. The results demonstrated that the proposed "advanced PAA" maximizes the fairness of the imbalanced-NOMA network scenario; and as such, outshines, both the "intermediate PAA" and the "initial FM-PAA" used straight. Therefore, it provides an optimal solution to the stated problem.

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DEDICATION

- I would like to dedicate this entire PhD to my late parents, may their souls continue to rest in eternal peace.
- Also, to all my family members who left this world before witnessing my achievement (Mbuzeli Ligwa, Kopayi Nelson Ligwa, Ann Nopasika Ligwa, and Mcofani Ligwa), this work is dedicated to you.
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LIST OF ABBREVIATIONS

NOMA	Non-Orthogonal Multiple Access
OMA	Orthogonal Multiple Access
5G	Fifth Generation
E-UTRAN	Evolved Universal Terrestrial Radio Access
IMT	International Mobile Telecommunication
ITU	International Telecommunication Union
URLLC	Ultra-Reliable Low Latency Communication
mMTC	Massive Machine-type communication
eMBB	Enhanced mobile broadband
OFDMA	Orthogonal frequency division multiple access
TDMA	Time-division multiple access
CDMA	Code division multiple access
MIMO	Multiple inputs multiple outputs
SIC	Successive Interference cancellation
FDR	Full-duplex relay
HDR	Half-duplex relay
LTE	Long term evolution
PF	Proportional factor
EP	Error propagation
SU-MIMO	Single user MIMO
SC	Superposition Coding
UE	User Equipment
HD NOMA	Half-duplex NOMA
FD NOMA	Full-duplex NOMA
RSU	Roadside units
V2X	Vehicle to everything
V2I	Vehicle to Infrastructure
GPRS	General packet radio system
SIC	Successive interference cancellation
4G	Fourth generation
WMBA	Wireless mobile broadband access
CD NOMA	Code Domain non-orthogonal multiple Access
PD NOMA	Power Domain non-orthogonal multiple access
IoT	Internet of things
BS	Base Station

FPA	Fraction power allocation
M-ERPA	Multicast-based equal RB power allocation
CNOMA	Cooperative non-orthogonal multiple access
AF	Amplify and forward
DF	Decode and forward
LTE	Long-time evolution
RAN	Radio Access network
OCTR	Offered Capacity to Transfer Request
UGA	User Grouping Algorithm
UGS	User Grouping System
IMS	Interference Mitigation System
CNOMA	Cooperation Non-Orthogonal Multiple Access
PAA	Power Allocation Algorithm
CSI	Channel state information
MRT	Maximum ratio transmission

PUBLICATIONS

1. **A Comprehensive Survey of NOMA-Based Cooperative Communication Studies for 5G Implementation.** By Mario Ligwa and Vipin Balyan Lecture Notes in Networks and Systems - Springer LINKhttps://link.springer.com, More information about this series at https://link.springer.com/bookseries/15179- Published in Lecture Notes. Please, check the link below https://link.springer.com/chapter/10.1007/978-981-16-2126-0_49.

2. Cooperative Power Domain Noma Transmission Using Relays. by Mario Ligwa and Vipin Balyan.
https://intapi.sciendo.com/pdf/10.2478/ijssis-2024-0010. DOI: 10.2478/ijssis-2024-0010

3**. Control power Cooperative Non-orthogonal Multiple access relay networks. By Mario Ligwa and Vipin Balyan.**
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CHAPTER 1:
INTRODUCTION

The ever-growing demand for data content and mobile applications in coming years necessitates a rethinking of advancements in the current multiple access controllers of wireless cellular networks (Marcano & Christiansen, 2017). The deployment of the 5G network promises to provide a solution to key challenges posed by the existing mobile wireless communication technology. Such challenges include massive application connectivity, massive data demand and ultra-reliable low-latency communication (Wu et al., 2018). Recent studies suggest that the deployment of 5G will enable many applications with a much-enhanced user experience including serving multi-user requirements. However, such applications require secure and reliable network connectivity with a very strong error protection mechanism. Currently, the spectrum resources are not fully occupied in the traditional technique such that it has created system constraints which have opened a greater need to move towards the development of a new wireless technique to accommodate this requirement and achieve more efficiency by utilising the available spectrum (Li et al., 2015).

With the exponential growth of data applications, including smartphones and video content, mobile communication has evolved over the past four decades. Enabling and exploiting radio resource schemes in wireless communication can improve spectrum efficiency and data throughput. Various problems of mobile communication exist and arise in many different scenarios and can be classified according to their different occurrences. As a promising multiple-access (MA) technology to improve maximum throughput and spectral efficiency, Non-orthogonal multiple access (NOMA) has been widely studied (Aldababsa et al., 2018) (Yuan & Yan, 2018) (Manglayev et al., 2016). In addition to the superiority of NOMA, the proposed cooperative network promises further reliability enhancements, including improved cell edge network reception. For instance, by introducing high reliability and high spectral efficiency mechanisms, NOMA has been recommended as a suitable technique (Liu et al., 2017). An overview of NOMA schemes is presented with the relevant literature study including existing algorithms.

1.1 Research background.

The benefits of cooperative communication channels and concepts were first introduced by the pioneering work of Gamal (1979). The significance of cooperative communication (CC) in wireless networks especially in multi-user scenarios is to exploit spatial diversity gain and increase reliability without additional resources (antenna nodes at the user terminal), (Mansourkiaie and Ahmed, 2015). With the advancement in wireless communication, the articulated work of Ding *et al*. (2015a) Gendia *et al*. (2017a) Laneman *et al.* (2004) explicitly described some key advantages of cooperative diversity in wireless networks. Studies by Sendonaris *et al*. (2003a) Sendonaris *et al*. (2003b) outlined the key concept of cooperative diversity by looking at both system description and practical issues. Detailed literature regarding the evolution of wireless communication was proposed by Meraj and Kumar (2015). However, both frequency division multiple access (FDMA) and time division multiple access (TDMA) started in the early evolution of wireless communication as 1G and 2G respectively for the past four decades.

Over the past two decades, the network access point has received extensive constraints due to the explosive rise in mobile applications and their popularity. There is an obvious rise in data demand and internet usage, we have witnessed a rise in data demand which saw the implementation of 3G as code division multiple access (CDMA) from the precious TDMA and FDMA techniques respectively. The era of wireless evolution demonstrated the sharp rise in Artificial intelligence (AI) and the Internet of Things (IoT) applications. To support such higher demand and beyond the orthogonality, the OFDMA is incapable of providing higher spectral efficiency, massive connectivity, and higher data throughput while maintaining higher reliability and better quality of service (QoS). Thus, the current studies recommend that NOMA be regarded as the suitable multiple access for 5G and beyond.
For effective NOMA implementation, the users must be paired or grouped according to their gain margin correlation(Han et al., 2023). For instance, for 2M users, the near-base station users must be grouped with far-base station users (Biyoghe & Balyan, 2023). The grouping of pairs might not guarantee the perfect pairing among users meaning they might be odd users in some instances. The odd pairing has never been addressed in the development of the NOMA multiple access scheme, hence authors assume perfect grouping.

1.2 Research Problem

In the traditional NOMA architecture, for the case of 2 users per NOMA beam, each base station antenna serves 2 users simultaneously, utilizing NOMA technology. Due to the complex gain-margin requirement of NOMA technology, one of the two users must be in the network's far field (far user), while the other must be in the near field (near user). Thus, a base station with N-antennas must serve 2N users in each network's service time slot; N near-users and N-far users. Most studies which proposed a design of NOMA-based networks, whether for capacity or fairness maximization, have often assumed to consider this balanced NOMA scenario. For example, Liu et al. (2013), Zhang et al. (2020) and Zuo (2019) all proposed their respective power-allocation algorithms for system capacity maximisation of a balanced NOMA scenario. Similarly, Qi et al. (2021), Biyoghe (2022) and Chikezie et al. (2022) respectively proposed power-allocation algorithms to maximise the users' fairness of the network in the balanced NOMA scenario. The underlying assumption in this network scenario is that there will always be N far-users and N near-users available for servicing, at each network's service timeslot. While that assumption could hold in a scenario where users are evenly distributed across the network's coverage; it is not, however, always true. Because there could be cases where there are more far-users than near-users at a given service time slot. In such a case, the power allocation algorithms proposed for the traditional balanced-NOMA scenario will not be effective, because multiple far-users will not be served. This will result in very poor network user fairness; thus, leaving the problem of poor network reality in an imbalanced NOMA scenario unresolved. **Error! Reference source not found.**.1 below shows the ideal balanced NOMA and proposed research problem statement.

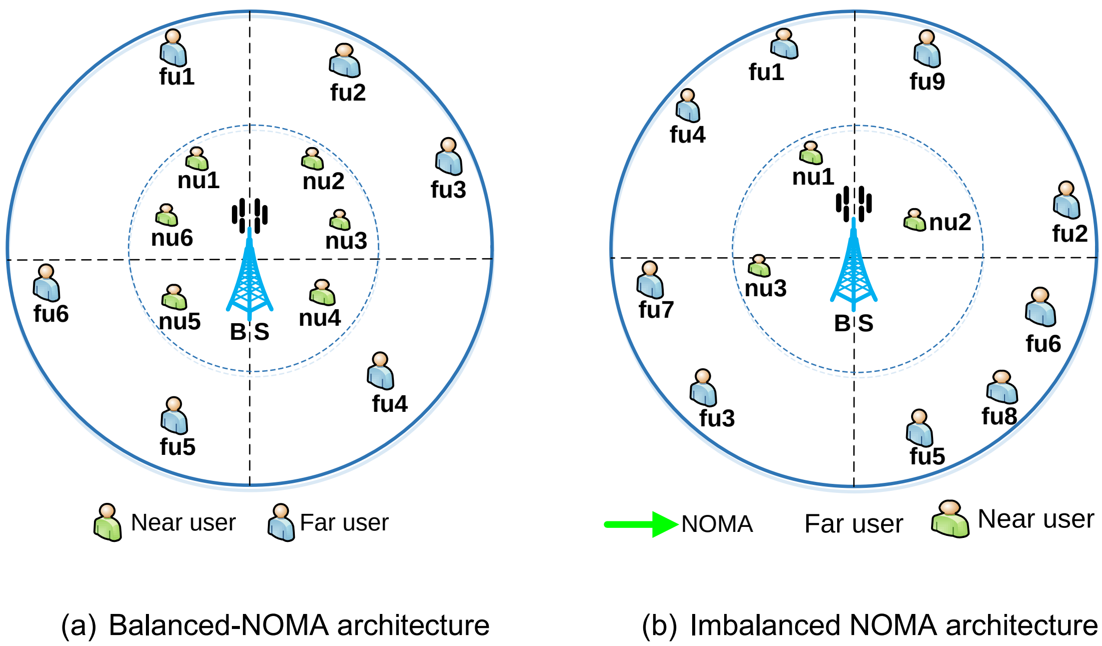

Figure 1.1: User distribution scenarios in NOMA-based networks

1.3 Research Aim and Objectives

This research seeks to contribute to addressing the above-stated problem, by proposing two different solutions, which in each case combine a designated network architecture and its relevant fairness-maximization power-allocation algorithm. The objectives of this research can be outlined as follows:

(i) To demonstrate that the fairness-maximisation power-allocation algorithms used in traditional balanced NOMA scenarios will result in poor networks' fairness in imbalanced NOMA scenarios if used as is.

(ii) To propose an intermediate solution to the network's fairness concern, by combining NOMA- and OMA-technologies; and then derive thereof, a power-allocation algorithm that maximises the OCTR ratio of each user. Thus, improving the network's fairness.

(iii) To propose an advanced solution to the network's fairness concern, by including relays in the near-field of the imbalanced NOMA network; then derive thereof a two-stage power-allocation algorithm which will ensure all users are served and their OCTR-ratios are maximised. In the first state, the power-allocation algorithm serves both the normal users and the relays, by means of a fairness-maximization power-allocation used in a balanced NOMA scenario. Then in the second stage, it uses relay transmission to serve the additional far-users which could not be served in the first stage. This results in servicing all users, and therefore improving their respective OCTR ratios as well as the global fairness of the network.

(iv) To implement, test and validate the two proposed algorithms.

1.4 Research questions.

The following questions are addressed through this research:

(i) What are the key advantages of developing dynamic power allocation over a fixed power-sharing method?

(ii) What are the most optimum concepts for developing power-allocation algorithms which aim at maximizing the network's fairness?

(iii) How can fairness be improved in the imbalanced NOMA network with more far-users, from its poor status obtained when using only the power-allocation algorithm of balanced NOMA?

1.5 Research significance

The solutions proposed by this research are both relevant to the mobile network industry, as they solve two existential problems in current NOMA-based mobile networks. First, they, address the problem of asymmetric user distribution versus the gain margin requirement of NOMA technology. For instance, NOMA requires that there are equal near and far users, for service, at any network's service time slot. However, such is not always possible; thus leading to asymmetric user distributions. This leads to traditional power-allocation algorithms for NOMA only serving the possible pairs; thus, leaving many users unserved. In this regard, the proposition of combining NOMA for possible pairs and OMA for extra far-users (i.e. intermediate solution); or that of including relays in the near-field of the network to serve as near-users (i.e. advanced solution), both address this asymmetric problem. Similarly, the proposed solution addresses the high fairness/reliability requirement in 5G networks. In this regard, the proposed power-allocation algorithms in each of the two solutions, respectively aim at maximizing the network's fairness towards all users. The output of this research may be used by the telecommunication industries which aim to develop 5G mobile networks employing NOMA-technology.

1.6 Research novelty

To the best of the author's knowledge, no reported studies attempted to address the problem of network user fairness in the imbalanced NOMA scenario. Thus, the solutions proposed in this research are novel in that they both attempt to address the outlined problem. As stated otherwise, the contributions of this research in the field of NOMA-based mobile networks for 5G, can be listed as follows:

(i) The idea of combining NOMA and OMA technologies, coupled with a power-allocation algorithm which maximizes user's fairness in this network multi-access configuration, is a novel solution.

(ii) The idea of including relays in the near-field of NOMA-based base-station network, coupled with a power-allocation algorithm which maximizes user's fairness in this network architecture, is a novel solution.

1.7 Delineation of the research

The following delineations have been considered for this research project:

(i) The research focuses on the design of the power-allocation algorithms (i.e. subsystem) for the respectively proposed NOMA-based network architectures.

(ii) The design of other subsystems of the network's multiple-access-controller such as users' channel acquisition, users' scheduling, users' grouping, etc…, are outside the scope of this research.

(iii) For ease of illustration, It is assumed in this research that the Cooperative network relays used and the NOMA-based base stations are entirely in the same designated frequency band; which falls within the 5G spectrum range.

(iv) This research will limit itself to implementing the proposed algorithms on a mobile network's emulation platform, in order to evaluate and validate their respective performances. The implementation of the findings from research on an actual base station falls outside the scope of this research.

1.8 Research Methodology

The following methodology is employed in order to achieve the outlined objectives:

1: Start by demonstrating that the existing fairness-maximization power-allocation algorithms, designed for a balanced NOMA network scenario, will not yield optimal network's fairness in the imbalanced NOMA network scenario if used directly:

(i) Present a description and modelling of a balanced NOMA network scenario;

(ii) Outline a derived initial fairness-maximization power allocation algorithm (initial PA algorithm);

(iii) Implement and test the PA algorithm in the balanced NOMA scenario; and show the results;

(iv) Implement and test the PA algorithm in the imbalanced NOMA scenario; and show the results;

(v) Demonstration from the results is the degrading performance of the initial PA algorithm in the imbalanced NOMA scenario.

2: Then, elaborate on the indeterminate idea which is the combination of NOMA- and OMA technologies in an imbalanced NOMA scenario:

(i) Give a description and modelling of the network scenario;

(ii) Derive a fairness-maximization power allocation algorithm for this scenario (intermediate PA algorithm);

(iii) Implement and test the intermediate PA algorithm in the imbalanced NOMA scenario; and show the results;

(iv) Demonstration from the results that, the intermediate PA algorithm is yielding superior performance than the initial PA algorithm in the imbalanced-NOMA scenario, with respect to resulting network's users fairness.

3: Thereafter, elaborate on the advanced idea which is the inclusion of relays in the near-field of the base station having an imbalanced NOMA scenario:

(i) Give a description and modelling of the network scenario;

(ii) Derive a fairness-maximization power allocation algorithm for this scenario (advanced PA algorithm);

(iii) Implement and test the advanced PA algorithm in the imbalanced NOMA scenario; and show the results;

(iv) Demonstration from the results that, the advanced PA algorithm is yielding superior performance than both the intermediate and initial PA algorithms, in the imbalanced-NOMA scenario; with respect to resulting network's users fairness.

1.9 Thesis organisation

Chapter 1, Begins with a brief introduction, background, and the research problem including the methodology of the study. The significance, research question, and research novelties are also outlined in this chapter. The delineation of the research is listed in this chapter.

Chapter 2, Comprises the comprehensive systematic literature regarding non-orthogonal multiple access NOMA and Cooperative Non-orthogonal multiple access (CNOMA) techniques. The evolution of multiple access and milestones has been outlined in this chapter.

Chapter 3, Focuses on the literature-reviewed work of controlled transmission of two-user and three-user scenarios. At the end of the chapter, we developed the research gaps.

Chapter 4, Develops an initial fairness maximization power-allocation algorithm (initial FM-PAA) for a balanced-NOMA scenario. Then it demonstrates that using this algorithm straight into the imbalanced-NOMA scenario with more far-users will result in a very poor network's users-fairness.

Chapter 5, Presents the design, implementation and testing of an "intermediate PAA" that combines NOMA and OMA technologies; and that thereof improves the users-fairness of the imbalanced NOMA scenario.

Chapter 6, Discusses an advanced solution to the stated problem, which implies using power-relays in the near-field of the network, and then treating the new setup as a balanced-NOMA network. The design, implementation and testing of an "advanced PAA" for this setup are then covered in the chapter. This "advanced PAA" yield optimal fairness results for the imbalanced NOMA scenario.

Chapter 7, Gives the conclusions obtained from this research, and the possible recommendations for future work.

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CHAPTER 2:
LITERATURE REVIEW OF EXISTING STUDIES ON NOMA-BASED TERRESTRIAL NETWORKS

This section provides an overview of similar research work relating to NOMA-based terrestrial networks. Subsequently, it is also aiming to place the main research topic of the proposed study in perspective. The work in literature also provides recent studies based on NOMA and CNOMA access schemes. The primary objective is to demonstrate a comprehensive background to the concept of the evolution of wireless communication technology and its challenges. Subsequently, towards the end of the chapter, the research gaps will be presented.

2.1 Description of the mobile network's multiple access controller (MAC)

The primary objective of wireless communication networks is to provide flexible access and enable seamless connectivity to users without visible physical wires (Rost et al., 2016). This phenomenon has evolved in the past 3 decades from the legacy of 2G to all IP-based wireless networks with the quest for high data demand at the highest speed. The initial mobile network was more focused on coverage and capacity which mobility and communication were the prime objectives. From the basic voice to the deployment of Evolved packet core EPC-based architecture which is a broadband-oriented wireless IP based (Rost et al., 2016). One of the noticeable key evolutions is how the change of the access point to accommodate more users. Both Frequency division multiple access (FDMA) and Time division multiple access (TDMA) were the first multiple access for the earlier generation of mobile networks as shown in the classification diagram below. Due to the high data demand third generation network has introduced a wideband system CDMA. Besides data, the quest for high-speed access and network aggregation has prompted the Orthogonal frequency division multiple access (OFDMA) which is sometimes known as OMA. The requirements for 5G have necessitated the development of new multiple access. Currently, NOMA is recommended as a prepared multiple access due to its non-orthogonality to support multiple access (Nisar & Baseer, 2021).

There are numerous of literature available regarding channel state information acquisition(CSI) User scheduling techniques, User grouping, and Precoding. Those mentioned subsystems are not part of our research objectives, meaning that they are all not in the scope of our research. The following section will illustrate the concept of mobile encoder multiple access block diagrams and their implications in wireless communication. It can be noted that various block diagrams in wireless communication rely upon communication to happen. We selected the one that relates to our power allocation technique. **Error! Reference source not found.** below illustrates mobile multiple access controller with their subsystems which are not limited to. Below demonstrated subsystems are crucial in wireless communication modelling and design

(Yuang & Tien, 2000). Without loss of generality, MAC can be expanded in various network subsystems as an integrated critical wireless communication network. Hence we decided on the MAC integration subsystem overview in our research study as a baseline.

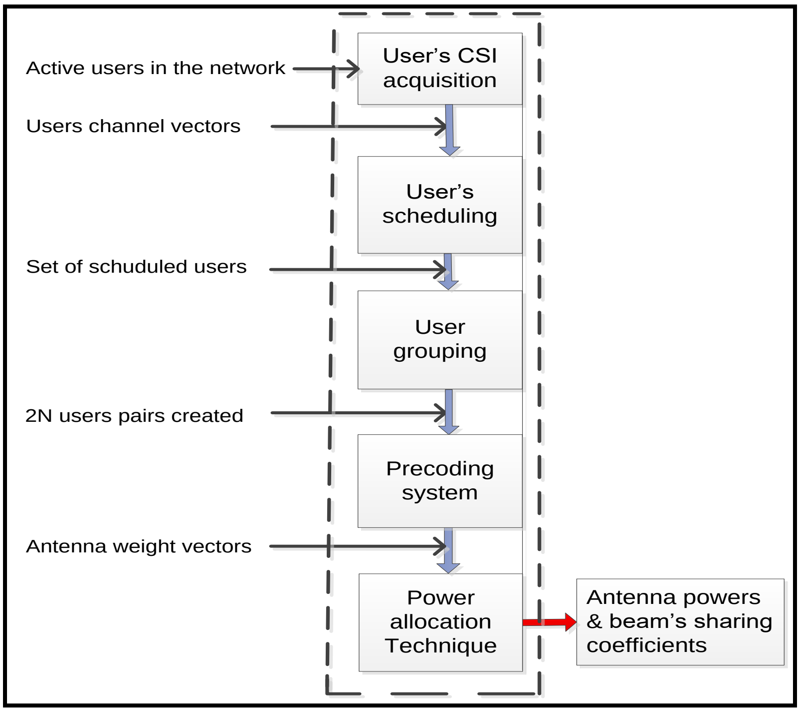


Figure 2.1: Mobile network multiple access controller

(Biyoghe & Balyan 2021)

2.1.1 Channel state information acquisition (CSI).

In wireless communication, channel state information acquisition is undoubtedly the most important component in the network as it determines the property of the channel condition. In the case of Frequency-division duplexing FDD, Zhang *et.al.* (2018) proposed a CSI feedback technique that compares CSI feedback with the reference signal and conventional scheme in terms of spectrum efficiency performance. The channel state information acquisition CSI receives the user channel state information and calculates or estimates user channel gain and phase angle. The preferable method can either utilise a high-tech system through pilot measurements technique or via channel modelling technique also known as statically, or analytical procedure as shown from the expression below:

$$P_r = \frac{P_t G_t G_r (c/f_c)^2}{(4\pi)^2 \ (D)^2} \qquad (2.1)$$

From the above expression, P_r denotes the power of the received antenna; Pt represents the output power of the transmitting antenna. G_t denotes the gain of the transmitting antenna while Gr represents the gain of the receiving antenna and D signifies the distance between the antennas. Wavelength is equal to the speed of light divided by frequency= c/f_c. Before scheduling takes place there is a need and necessity for the network to know and be able to accommodate the users in the beam that require to be served.

2.1.2 User scheduling techniques

Traditionally in the mobile network, not all the active users around the base station can be served by the access point, meaning only a limited number per interval can be served by the base station BS (Moe Thet et al., 2019). Zhong and Yang (2007) proposed two approach algorithm user scheduling schemes that utilise the first and second largest SNR of each user. In the case of minimizing interference, Yi *et.al.* (2011) proposed a new angular technique based on user schedule while the cognitive radio (CR)(Liu et al., 2012) proposed a user scheduling method based on limited feedback to allow a particular number of users to be served by the base station. There is a necessity for scheduling or user planning. The main purpose of user scheduling is to select and schedule the number of users that need to be served by the base station.

User scheduling receives the weight vector matrix of all the users in the beam and selects all the users according to the configured system technique. It can only schedule those users who need to be served by the mobile base station at a particular instance. There are several scheduling techniques that a mobile station can perform, such as using a random scheduling technique or geographical user scheduling and user scheduling algorithm. For instance, the articulated work of Lv *et.al*. (2017) proposed two user scheduling algorithms with partial CSI and full CSI to improve primary and secondary system performance. The user scheduling can consider user channel conditions when scheduling the users.

2.1.3 User grouping system

The user grouping technique has been developed in 5G NOMA for various reasons such as user pairing and energy harvesting(Zhu et al., 2019)(Mounchili & Hamouda, 2020). In this thesis, users are grouped according to design requirements. The following characteristics of two users per relay are being considered with channel gain margin and channel correlation. Strong user-dependent (SUD) and Agglomerative nesting clustering user algorithms two-stage user grouping mechanisms and user location techniques have been considered in various studies (Zhu & Li, 2020). Rubio and Pascual-iserte (2019) studied the two-stage user-grouping and resource allocation as a mechanism that decides which user should be scheduled to receive information and which user should be configured to harvest energy. User grouping can give out 2N pairs of groups per beam.

2.1.4 Precoding system

Serving multiple users at the same time has introduced many challenges in wireless communication which posed the development of linear precoding technique as one of the solutions. Researchers who explicitly provided the precoding literature, precoding techniques, and how to improve system performance include Albreem *et.al.* (2021) Doneriya (2018), and Chandrasekaran (2012). The most popular technique of interference mitigation system is zero-forcing precoding. In a multiuser MIMO system, the multi-antenna transmitter can null the multiuser interference via a precoding channel matrix because the system under development is a multi-antenna and full-frequency reuse system developing an interference mitigation system is necessary. Due to the recent increase in the multiuser multi-antenna system in mobile networks, precoding probably received much attention in modern studies to mitigate interference and improve performance. Chandrasekaran (2012) proposed a precoding matrix indicator PMI technique based on the capacity of SNR.

The Codebook-based and linear precoding as well as maximum ratio transmission including zero forcing are probably the most researched precoding techniques in wireless communication. Zhang *et.al*. (2016) proposed MRT to mitigate interference and obtain more gain while Cheikh *et.al*. (2011) analytically evaluated the zero forcing in terms of outage probability was investigated. Many techniques have already been developed such as zero-forcing and maximum ratio transmission. Recently, many precoding techniques have already been developed for minimizing interference.

The mechanism of interference reduction known as precoding based on max-min fairness MMF was reported in the work presented by Biyoghe and Balyan (2021). Their literature illustrated that the power domain concept of OMA versus NOMA was envisaged as the preferred multiple access to increased users' capacity and improving spectral efficiency in full frequency re-use FFR (Biyoghe & Balyan, 2021). For simplicity, we opted to utilize the concept of precoding techniques in our research.

2.2 Description of the Multiple Access Technologies

Multiple access schemes have been a hot topic for generations in wireless communication and the research community. Various research has done a remarkable job of investigating multiple access according to the network generation. Figure 2.2 below presents a clear view including milestones of how multiple access has played a crucial role in wireless communication by grating access to users (access point). It demonstrates the OMA multiple access and the NOMA multiple access as well as an indication of the year the multiple access has been developed. Additionally, **Error! Reference source not found.** illustrates multiple access technology NOMA and OMA, it further depicts the power domain NOMA scheme. To be consistent with our research alignment our study focuses on Power domain NOMA (P-NOMA). The multiple access is very crucial for multi-user detection and scheduling. The perfect CSI is not guaranteed in NOMA, for simplicity our study assumes perfect CSI.

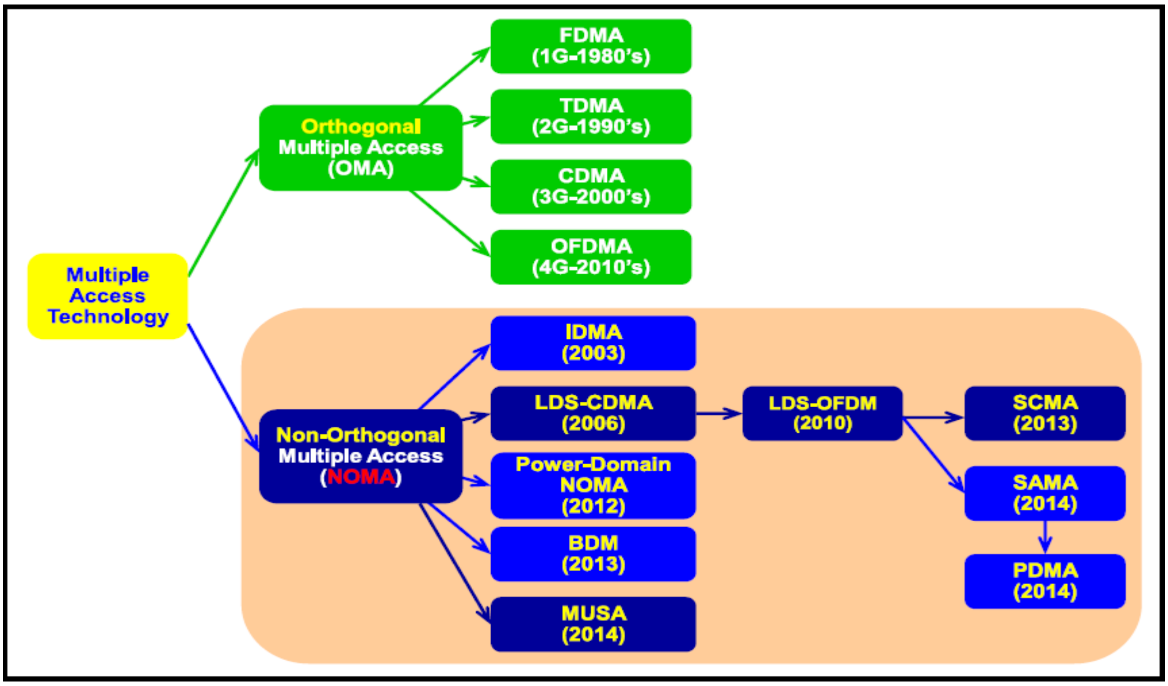


Figure 2.2: The classification of mobile network's multiple access technologies (Adapted from Dai et al., 2018)

2.3 Overview of NOMA and OMA

Due to the robustness and reliability required in wireless communication, non-orthogonal multiple access (NOMA) is recommended and preferred for 5G and beyond multiple access (Ligwa & Balyan, 2022). Due to its non-orthogonality and the ability to support multiple users at the same time with the same resources (frequency and time). NOMA can simultaneously serve multiple users at the same time and frequency with different power levels as illustrated in Figure 2.3 below with this resource utilization, NOMA has been regarded as the suitable multiple access for 5G and beyond. The key difference between the traditional multiple access OMA over NOMA is that NOMA can serve more than one user per resource block (frequency) (Aldababsa *et.al*., 2018) (Dai *et.al*., 2018) (Patel *et.al*., 2021)(Wang et al., 2016). What makes NOMA more proficient and effective and recommended compared to the conventional OMA technique is that NOMA supports a multi-user technique, meaning users can share the same frequency band utilizing the same resources (Keating *et.al*., 2017). Secondly, NOMA employs the power domain concept rather than relying on time, frequency, and code which has limitations in terms of supporting more users(Liu et al., 2017). Some other advantages of NOMA over OMA were also presented in the research of Shivhare *et.al*. (2021). Unlike the conventional orthogonal frequency division multiplexing technique where user access can be granted either utilizing time, frequency, or code. The concept of NOMA is different as users can be separated by their power levels (Sari *et.al*., 2018).

The research work presented by Dai *et.al.* (2015) and Saito, Kishiyama *et.al*. (2013) demonstrates the traditional implementation of the NOMA technique which requires a set-up of near user and far user to be served by the access point. For effectiveness, the NOMA concept to be served in the scenario assumes that the number of near users and far users is the same such that NOMA pairs are aligned as presented by Kassir *et.al*. (2023) demonstrating NOMA with user pair without considering the ideal part which can result in the far users being more than far or alternately near users might be more than the far user. The power comparison of NOMA and OMA is shown in **Error! Reference source not found.** below. Additionally, the clear classification of NOMA and OMA are presented below. The Non-orthogonality approach is shown in Figure 2.3(a) where 2users utilize the same available bandwidth but different power levels so the system can serve more users at the same time. In the Orthogonal concept, two users share bandwidth with the near user receiving more power while the far user receives less power as shown in Figure 2.3(b)

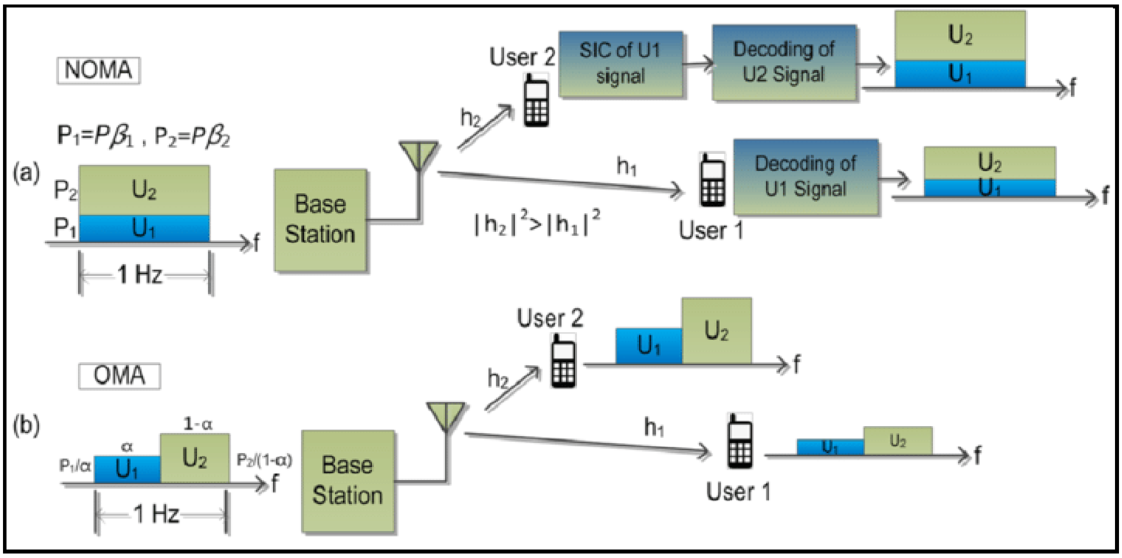


Figure 2.3: System structure of NOMA and OMA

(Adapted from Islam et al., 2017)

The concept and principle of NOMA in terms of power distribution are illustrated in **Error! Reference source not found.** below for the case of 2user power domain NOMA (PD-NOMA). The near user applies the SIC for the far-user signal before it decodes its signal. On the other hand, a far user decodes its signal first. **Error! Reference source not found.** below demonstrates the basic principles of NOMA where the power levels between the near user and the far user are being distributed(Dai et al., 2018).

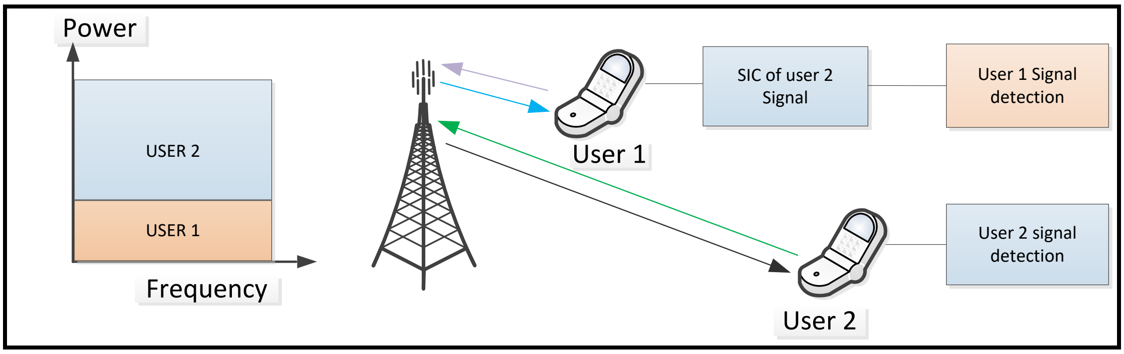


Figure 2.4: Power domain of NOMA with SIC detection technique (PD-NOMA) (Dai et al., 2018)

2.3.1 The power efficiency and energy consumption in the NOMA networks

To maximise the system battery life and improve energy consumption, various studies consider energy efficiency (EE) and energy harvesting (EH) to guarantee reliability for critical communication (Tang et al., 2019), while Deng *et al*. (2017) developed an algorithm that minimises energy consumption. Ding, Peng, and Poor (2015) proposed a cooperative NOMA scheme. Their research objective was to evaluate the significance of user's prior information about the messages of other users and the cooperative technique is one of the key technologies for 5G (Ding, Peng, and Poor, 2015). Their analytical results indicate a gain a performance in the cooperative scheme, and they recommended a simultaneous wireless information and power transfer to NOMA in an attempt to alleviate practical constraints on energy consumption.

In 2016, a study investigated the NOMA multicast technique as a novel and efficient algorithm to find an optimal pair user assignment and transmission power vector for NOMA multicast to improve scalability (Gau & Chiu et al., 2016). The study objective was to increase the system throughput of wireless multicast. The simulation demonstrates that the proposed approach performs better and provides improved network performance results. As expected from the findings, the proposed technique performed optimally for users' assignment and transmission power control for NOMA multicast.

Zhang *et al*. (2018) evaluated and proposed transmission techniques for two MG's which are both relay selection (RS) and performance analysis. In the same study, NOMA based on two multicast groups (MGs) joint cooperative opportunistic multicast scheme was proposed. The aim and objective were to investigate the system efficiency approach method and to improve the coverage ratio. The findings indicate that simulation and numerical results showed an improvement in the performance of the cooperative opportunistic multicast scheme (COM-NOMA), especially power efficiency when the number of users is greater than 10, system coverage ratio improved compared to the OFDMA-based CM technique.

Also, Xung and Yang (2018), investigated and discussed the optimal relay selection (RS) for NOMA, and proposed a method that functions as a two-stage weighted max-min (MWM) and max-weighted harmonic means (MWHM). The study addressed some key elements regarding outage probability and also compared and examined the containment of fixed and adaptive PAs at the relay. Furthermore, simulation results from the study indicated that the proposed scheme outperforms the existing RS schemes, especially under the constraints of fixed and adaptive PA respectively.

Another incredible work was proposed by Yang *et.al.* (2019), and these were two novel cooperation strategies for different scenarios of channel information and availability. The diversity orders of each proposed scenario were analysed, which are based on the energy-saving mechanism. The simulation results indicate that the proposed technique/scenario demonstrated significant performance over the ideal NOMA system in terms of energy-saving as well as gain over the direct NOMA multicast strategy. The study's numerical results validate the analysis.

Similarly, Li *et. al* (2019) conducted a study about layer video NOMA multicast scheme and developed the algorithm for a wireless power transfer relay system. The study formulated constraints concave-convex optimisation problems (Li et al., 2019). The findings showed that the proposed scheme can minimise the power consumption from the base station (BS). Furthermore, in 2019, a study proposed similar work as a cooperative NOMA transmission scheme for a user downlink system intending to investigate and evaluate the algorithm to detect the impact of the user's transmission powers and to achieve a better sum rate of the cooperative NOMA scheme with a fixed decoding method (Fang et al., 2019). The proposed scheme achieves a higher sum rate, and this can be done by changing the decoding order at the direct-link users. The simulation results conducted under different power allocations indicate that the proposed scheme can function in the presence of strong inter-user interference (IUI) and can significantly perform well and outperform existing techniques in terms of sum rate.

2.3.2 Performance analysis of Cooperative NOMA networks (CNOMA)

What constitutes a good network performance is both reliability and latency, while the quality of experience (QoE) and QoS are the key measures of the overall performance of the network's effectiveness (Liu, Wang & Hu, 2019). Figure 2.5 below demonstrates the key function of the new radio (NR) to support vehicle-to-everything (V2X) to deliver adequate low latency requirements *(Ghosh et al., 2020)*. In 2017 Di *et.al.* proposed how NOMA can be exploited to minimise latency while improving packet reception probability (Di et al., 2017). Similarly, a study by Di et al., (2017) provided a systematic utilisation of NOMA in a dense vehicle communications network. Their study, which covered V2X communication techniques aimed to minimise latency while improving system performance and packet reception(Host-Madsen & Zhang, 2005). Furthermore, the study developed a novel matching algorithm that converges to an L-rotation stable matching. The findings indicate that the proposed scheme outperforms the existing orthogonal multiple access in terms of reliability and latency. Figure 2.5 below demonstrates the key function of the new radio (NR) to support vehicle-to-everything (V2X) to deliver adequate low latency requirements which attributes the desired reliability in a V2V scenario.

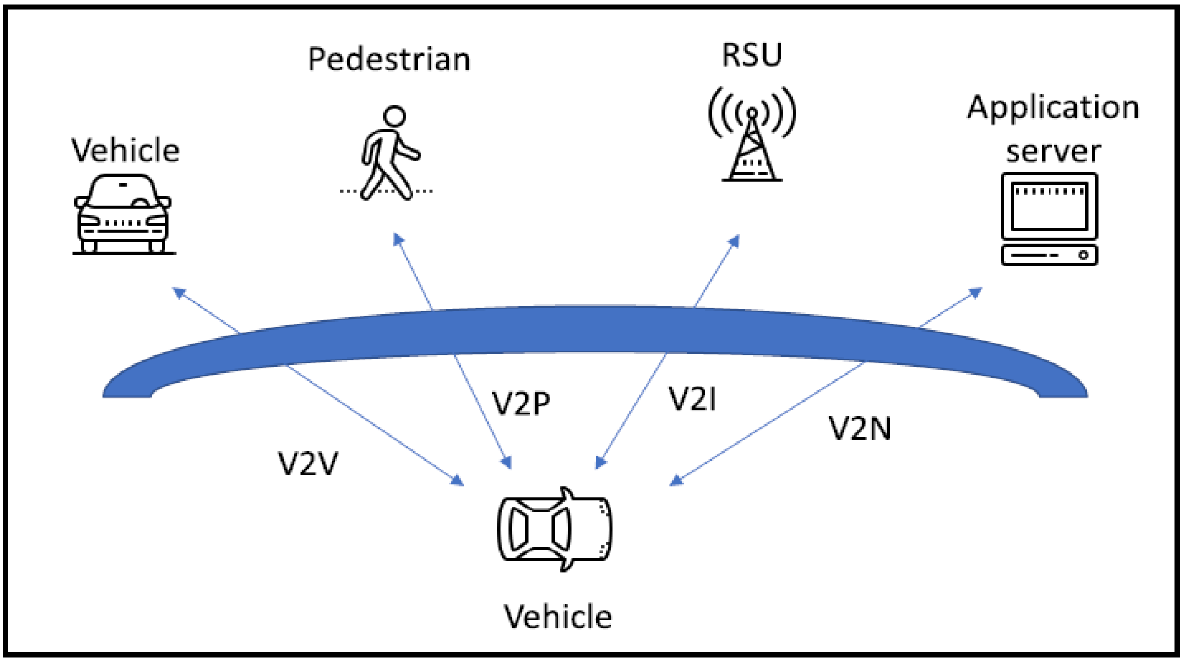


Figure 2.5: An illustration model of vehicle-to-everything (V2X) architecture (adapted from Ghosh et al, 2019)

In 2017, Yang *et. al.* proposed an efficient two-phase cooperation strategy to improve the reliability of users. In the proposed study, the key objective was to demonstrate that in the first phase of the base station (BS) broadcasts, a superposed message consists of all users' information while in the second phase, multicast users are selected to inform a decoded information of unsuccessful users. This strategy also outlined the power allocation approaches which are the key fundamental aspects of NOMA. The results indicated the superiority and advantage of the proposed scheme. Another study investigated and discussed a novel cooperative NOMA multicast scheme *(Zhang et al.*, 2017). In their findings, they also outlined other important aspects and approaches such as noise ratio, sum multicast, and the number of served users to evaluate the proposed scheme. The study investigated the performance of the multicast mm-wave wireless network in conjunction with NOMA.

The simulation results indicate that the proposed scheme can further improve the NOMA mm-wave multicasting and also reveal that cooperative communication improves network reliability and QoS *(Zhang et al.*, 2017). Yang *et al.* (2018) proposed an opportunistic cooperative NOMA multicast method to improve the system reliability of layered multicast. From the proposed strategy, the study outlines two key multicast users, regular users (RU's) and advanced users (AU). Both methods played a key role in the proposed strategy. The numerical results indicate the significant performance of the proposed strategy.

Kader *et.al.*(2018) presented a study that focuses on full-duplex NOMA in cooperative relay sharing for 5G. The study investigated the advantages and comparison of full-duplex NOMA resource sharing and half-duplex NOMA resource sharing. The study's simulation results indicate that full-duplex NOMA performs better than half-duplex NOMA relay sharing (HD NOMA RS). As expected, the full-duplex NOMA relay sharing (FD NOMA RS) outperforms its counterpart strategy half-duplex resource sharing.

The NOMA-based V2X communication utilises a broadcast/multicast communication mechanism for sending critical information was investigated by (Wang *et al.*, 2018). The study envisioned to demonstrate a model and an approach to how the BS sends information to roadside units (RSU) where RSU communicates to vehicles. The study intended to address the power allocation issue of fractional transmission power allocation (FTPA), which has been formulated to increase the minimum achievable vehicles with the purpose of fairness. The study results also indicate that the proposed scheme performs better than the existing fixed NOMA and optimised TDMA. (Balyan & Daniels, 2020) Presented a similar concept as the proposed study (Cooperative communication) where relays are placed at the cell centre and at the cell edges to reduce outage probability as well as improve system performance.

Moreover, Wang *et al*. (2018), also observed that the model can achieve better improvement to the fractional transmission power allocation (FTPA) method. A study by Xiao et al. (2019) focused on the network layer performance bounds and cross-layer power control for downlink MIMO-NOMA to achieve ultra-reliable low latency communication (URLLC). The study demonstrated a high level of knowledge and suitable research contribution to wireless communication. The key objective of the research study was to derive a suitable mechanism to achieve consistently low latency and reliability in MIMO-NOMA while transmission power is at a minimum. The study reveals that due to path losses, the transmit power varies as a result of sustaining reliability and latency. These findings indicate some improvement over the existing schemes such as low delay violation probability.

2.3.3 Analysis of spectral efficiency in NOMA networks

To achieve optimum network performance and minimum error rate probability, the spectrum efficiency trade-off needs to be considered (Kara, 2020). The spectral efficiency is an important measure in a 5G network and it should be at least 3 times more than a 4G network according to the survey by (Wang et al., 2018). A study by (Men & Ge, 2015) on NOMA-based downlink cooperative cellular systems including the outrage performance investigated the ergodic sum rate of the two paired users and the upper bound (Men & Ge, 2015). The simulated study results demonstrated that NOMA could obtain a similar diversity order with conventional multiple access (MA) where the user with good channel conditions is scheduled. Also, it was observed that the sum rate is like conventional multiple access, but NOMA can perform better in spectral efficiency and user fairness.

Both 3G and 4G networks were proficient with the OMA traditional technique offering better system performance due to lower demand in user requirements and standards(Balyan and Saini, 2011, 2014; Balyan et al., 2018; Saini and Balyan, 2012). With the increase in system capacity and spectrum efficiency in 5G and beyond it appears that the OMA technique is unable to deal with such demand. Current studies recommend NOMA technology as is suitable technique to handle high-capacity demand(Balyan, 2021)

The optimum power allocation NOMA-based was investigated to determine the power allocation ratio as well as maximizing system sum capacity. Manglayev et al. (2016) proposed an optimum power allocation scheme for NOMA with the SIC technique for downlink. Their study evaluated and classified the technique in three different categories of fairness index 0.5, 0.7. and 0.9 respectively. Their findings indicated that the sum capacity with NOMA decreases as the fairness index increases. More equivalent to previous studies, NOMA with SIC can improve user spectral efficiency. The study also recommended NOMA be implemented in future radio access. As demonstrated in Figure 2.6 below, the Robust Resource Allocation Using Edge Computing for vehicle-to-infrastructure (V2I) has been demonstrated.

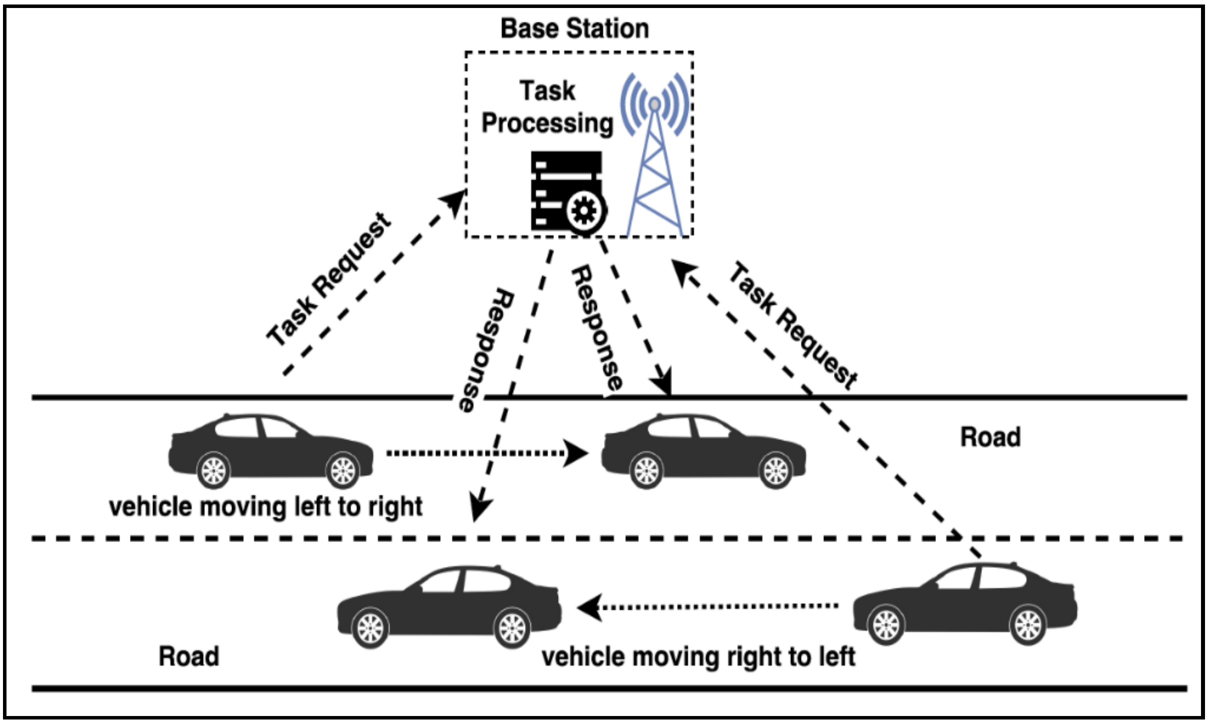


Figure 2.6: Vehicle to infrastructure (V2I) system model

(Adapted Kovalenko et al., 2019).

In 2017, Zhang *et.al* proposed a joined transmission scheme based on NOMA intended to improve spectral efficiency where the average ratio for users was also classified. The proposed method aims to divide each multicast group into different subgroups. It also seeks to combine NOMA with multicast and to utilise the full use of spectrum resources (Zhang *et al*., 2017). The findings indicated that MS-NOMA outperforms OMA-based multicast schemes. The results show that MS-NOMA can improve spectral efficiency and can serve all UE`s with a higher attach success rate (ASR).

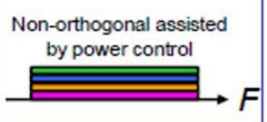
Another incredible research study in 2017 was proposed by Islam *et.al*. They investigated some key elements of the NOMA technique, and their study also classified some key valuable aspects of wireless communication techniques that can be integrated with NOMA such as cooperative communication MIMO, beamforming and network coding (Islam et al., 2017). Their study presented a simulation capacity comparison between NOMA and OMA. From the results, it can be observed that when NOMA is integrated with proven communication networks, it outperforms ideal NOMA as predicted and those performances are achievable rate outage performance, sum-rate performance, spectral efficiency, achievable rate performance of NOMA with relay outage performance of MIMO NOMA system sum-rate performance of NOMA in 5G with random users in the cell as well as outage performance of a cooperative NOMA. Young Song and Hyeon Kang proposed a comprehensive mechanism that improves spectral efficiency and data rate. In 2019, another study investigated and classified two decoding strategies which are the conventional SIC without catch-aided interference cancellation and SIC with aided interference cancellation and each both were discussed to analyse the proposed strategy. The study examines and evaluates coverage probability. The simulation results indicate that the proposed technique can significantly improve the performance of NOMA-based multicast.

2.3.4 Data transmission for NOMA networks

The objective of bandwidth improvement can simultaneously enhance the system performance and opportunistically allow the data transmission process to improve as well (Chen et al., 2015). To this extent, most research studies are considering system capacity and data transmission such as the multicast technique (Zhang *et al.*, 2018). The implementation of hybrid beamforming in the MIMO system increases system data transmission (Xiao et al., 2017). In 2019, Liu, Wang, Hu, Ding & Fan proposed another remarkable study like the proposed work. They jointly proposed a study on Cooperative NOMA (CNOMA) for multicast broadcasting to improve system low latency and high reliability. In the same study, they proposed two relay-assisted mechanisms: full-duplex relay FDR and half-duplex relay HDR. The study objective was to develop a technique to assist users with poor reception and to improve the QoS. The study also indicated the issue of power allocation to maximise the minimum achievable rate *(Liu et al., 2019)*.

The simulated results indicate that the proposed technique significantly performs better than the ideal NOMA scheme. Another key finding was that full-duplex NOMA (FDR NOMA) performs at a max-min achievable rate than half-duplex NOMA (HDR NOMA) when its interference is reduced to its minimal. The purpose of the proposed schemes is to achieve a better transmission rate for the vehicle with poor channel conditions at the expense of the transmission rate of the vehicle with better transmission conditions (Liu, Qin, and Elkashlan, 2018).

Table 2.1:Evolution of Cellular Multiple access from 3G, 3.9G/4G, and FRA

	3G	3.9/4G	FRA (expected)
User multiplexing	Non-orthogonal (CDMA)	Orthogonal (OFDMA)	Non-orthogonal with SIC (NOMA)
Signal waveform	Single carrier	OFDM (or DFT-s-OFDM)	OFDM (or DFT-s-OFDM)
Link adaptation	Fast TPC	AMC	AMC + Power allocation
Image			

(Adapted from Saito et al., 2013)

As observed from Table 2.1 above, the evolution of multiple access (MA) has been a key enabler for wireless communication system efficiency as well including supporting multiple users and growing and explosive data demand respectively. To improve robustness and increase the achievable data rate the evolution of wireless communication has emerged as the key enabler for the highest detection technique in the near-far and fast transmission mechanism.

2.4 Conclusion

This chapter has provided a detailed literature and comprehensive review of different concepts including previous similar research work. Another important consideration outlined in the chapter is the gaps in the current literature that the study is intended to fill, especially from the performance point of view. Additionally, it also highlighted significant parameters in the mobile network which are key aspects of wireless communication. Another key consideration in this section is that the work provided in this chapter also provided research insights by outlining questions that add to formulate the gaps in this area of research which ultimately justified the motivation for the research problem.

CHAPTER 3:
COOPERATIVE NOMA-BASED TRANSMISSION TECHNIQUE FOR TWO-USER AND THREE-USER

This chapter considers and examines the concept of cooperative NOMA-based transmission where two users and three users are being compared in controlled power and uncontrolled power. The main objective of this section is to highlight and demonstrate the differences between controlled and uncontrolled power-sharing mechanisms. The related work has been presented followed by a cooperative broadcasting channel. Lastly, this section provides the results that were simulated and validated using the MATLAB platform.

3.1 Introduction

The NOMA multiple access techniques are widely studied due to their non-orthogonality and providing access to users together which have the same frequency and time resource making it a front runner to meet the needs of high traffic requirement networks. In this research study, downlink two-user and three-user, NOMA, and CNOMA were compared with varying different parameters such as source transmit power, user transmit power, and power allocation for achievable sum rates. Simulation results show that the CNOMA achieves a higher sum rate as compared to NOMA for all the parameters.

Current multiple access (OMA) cannot handle the high rise in data demand and smart devices including modern wireless applications (Ding *et al.*, 2017). As promising multiple access, NOMA has been regarded as the most suitable candidate for 5G wireless communication. Cooperative communication is one of the most prominent techniques to enhance system performance, spatial diversity, and user coverage (Naukowe *et al.*, 2017). Cooperative relaying is considered the optimum solution for enhancing small-scale fading which improves system data throughput and spectral efficiency for the users far from the BS. Nabar *et al.* (2004) demonstration of superiority in cooperative networks over non-cooperative techniques in terms of achievable throughput has been investigated. Adam and Bettstetter (2008), examined the energy required to receive data while users are cooperating has been studied.

Hwang and Ko (2007) proposed a mechanism to improve message complexity in the form of developing a solution-based algorithm. This study proposed a cooperative NOMA flexible resource allocation (PA) mechanism. Secondly, this research study investigated the cooperative relay-sharing method that would enhance user reliability and reception in multicast technology and the worst channel condition in the multicast group (MG) and determines how modulation and coding schemes can be selected by (BS). As a result, the worst channel condition constrains the multicast rate. The work regarding dual-stage cooperative multicast (CM) has already been investigated in recent years to tackle this challenge and reach the highest possible multicast coverage comparisons. The multicast coverage ratio is the number of users who can successfully receive better signals compared to the number of MG users. Users with better channel conditions also known as the SU can receive preferential in which BS can send data to those MG in the first stage, using the opportunistic multicast scheme (OMS). Those with a bad channel condition can be regarded as unsuccessful users (USU).

In the second step, some SUs are chosen as user relays (UR’s), which use device-to-device (D2D) technology to pass their reception signals to USUs. The advent of D2D allows MG users to collaborate more effectively. This prevents the cell-edge MG user from experiencing profound fading. Multicast systems' coverage ratio and throughput have been enhanced significantly. However, under the COM-NOMA UR selection scheme for the effective and optimum purpose, each USU chooses the SUs that are within the relay selection range that is most efficient (ERSR) and can ensure effective reception without considering the relationship between SU density and USU position.

Authors (Hwang & Ko, 2007) proposed a mechanism to improve message complexity in the form of developing a solution-based algorithm. In this paper we propose a cooperative NOMA flexible resource allocation (PA) mechanism, secondly, we investigate the cooperative relay-sharing method to enhance user reliability and reception in multicast technology, the worst channel condition in the multicast group (MG) determines how modulation and coding schemes can be selected by base stations (BS). As a result, the worst channel condition constrains the multicast rate. The work regarding dual-stage cooperative multicast (CM) has already been investigated in recent years to tackle this challenge and reach the highest possible multicast coverage comparisons. The multicast coverage ratio is the number of users who can successfully receive compared to the number of MG users. Users with better channel conditions also known as the SU can receive preferential in which BS can send data to those MG in the first stage, using the opportunistic multicast scheme (OMS). Those with a bad channel condition can be regarded as unsuccessful users (USU).

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3.1.1 Cooperative strategy in multi-relay networks

There are two cooperative communications in wireless networks, user-aided cooperative NOMA and relay-aided cooperative NOMA(Ligwa & Balyan, 2024b). The user-aided case is where users with better channel conditions assist users with bad channel conditions. While relay-aided cooperation NOMA is when the base station communicates with the relay such that relays forward the information to the intended farthest users (Lv *et.al.*, 2020). The study by Gendia *et.al*. (2017a) deals with the relay-aided technique with an indication of the advantage of two-stage NOMA relay selection over the conventional max-min approach. In Ding *et.al*.(2015b) the semi-work of a user-aided technique has been presented where users with better channel conditions assist users with bad channel conditions. As key performance metrics, BER expression has been presented by Shen *et.al*. (2021) while Umakoglu *et.al.* (2021) investigated the performance comparison of BER AF and DF-assisted relay selection strategy in NOMA cooperative networks.

In cooperative communications, the transmitting user or relay is not only responsible for forwarding their message but also for relaying information on behalf of other users (Ding *et.al*., 2016). The strategy by which the information is relayed to the destination is known as the relay protocol. The key advantages of cooperative communication are spatial diversity, network coverage, reliability and bit error rate (BER) (Wan *et al.*, 2018). A study by Liau *et al.* (2018) focused on the possibility of amplifying and forward-relaying protocols to enhance user cooperation since it has lower complexity and more flexibility in terms of handling inter-relay interference. The objective of these protocols is to describe how information is handled at the relays before it is sent or forwarded to the desired destination. Figure 3.1 below shows the amplify and forward protocol.

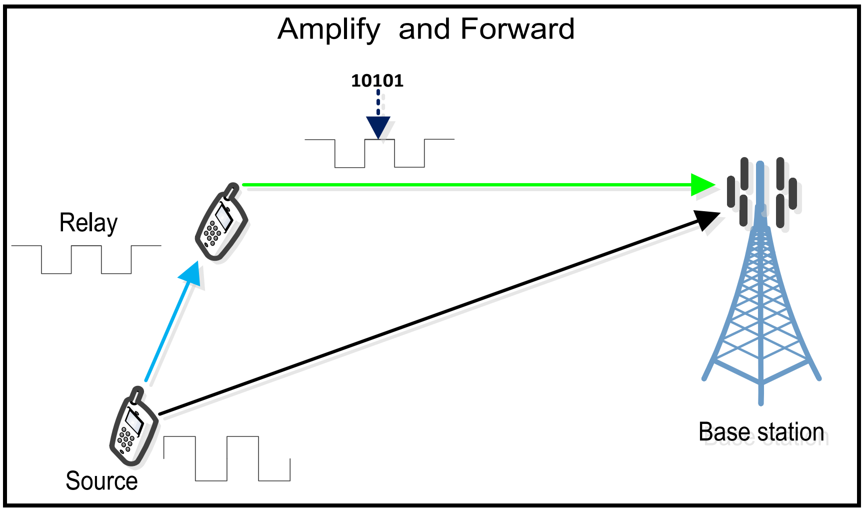


Figure 3.1: Amplify and forward protocol(Kaur & Bhattacharya, 2011)

Both amplify and forward as well as decode and forward protocol was proposed by Laneman *et al*. (2004). The comparison of decode and forward DF and amplify and forward protocol in terms of bit error rate (BER) was proposed by Umakoglu *et al.* (2021) demonstrating that the increase in relay deployment improves BER performance. Pandey *et al*., (2013) examine the outage performance in decode and forward and amplify and forward protocol which reveals that amplify forward performs better when SNR is higher.

In terms of performance analysis, DF outperforms AF in terms of spectrum efficiency especially when all relays are active (Chen & Zhang, 2017). The work presented by Aggarwal *et al.* (2015) detailed the concept of path loss and transmission impairments resulting in the application of an amplify and forward scheme, another observation is that in AF protocol the received signal from the source needs to be amplified before it can be forwarded to the destination without any need for decoding. Figure 3.2 below shows the decode and forward protocol.

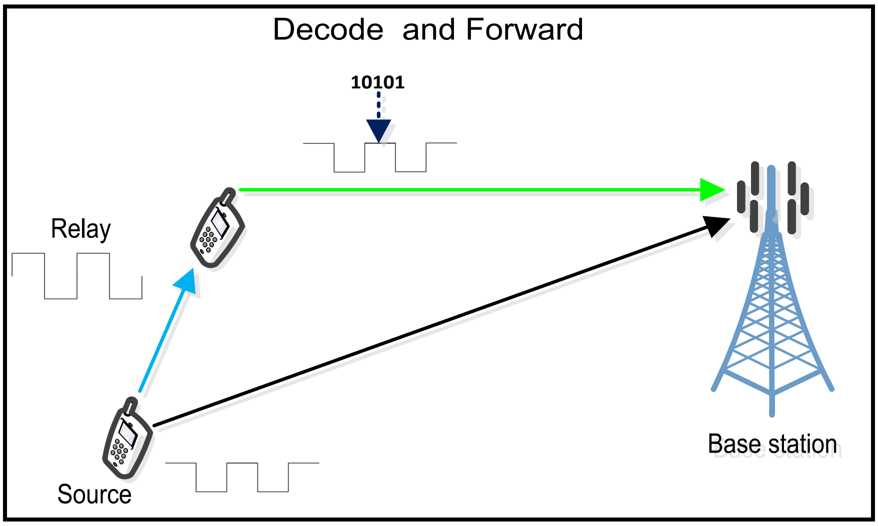


Figure 3.2: Decode and forward protocol (Kaur & Bhattacharya, 2011)

Traditionally in the NOMA application users are paired according to their channel condition and perform each other's decoding process (Ibraheem *et al.*, 2018). In the same prospect, the proposed research is intended to utilise decode and forward protocol since part of system functionalities requires a user to decode the information of the other users and the information meant to it in the NOMA process. To improve outage performance, expression in the decode and forward DF approach was investigated (Ibraheem *et al.*, 2018). With a partial relay selection scheme the study by Satya *et al*. (2023) demonstrates the performance analysis of decode and forward DF schemes in NOMA networks.

The work related to outage probability on both protocols was investigated by (Pandey et al., 2013). with the demonstration that the AF technique provides less complexity compared to the decode and forward protocol.

3.2 Related works

Recent cooperative networks with relay selection mechanisms have been studied as key enablers in enhancing user reception(Ligwa & Balyan, 2024a). To solve the issue of the low coverage efficiency problem, a range division user relay selection scheme has been proposed. To minimise transmission time, (Nam et al., 2008) proposed two relay selection methods. Ikki and Ahmed (2008) investigated the best relay method to achieve fewer resources needed as well as full diversity order. The concept of opportunistic relay selection to improve spectral efficiency was proposed by (Nomikos *et al*. 2020). As an effective means to improve the system efficiency of full-duplex FD-NOMA, the same study explored together with buffer-aided (BA) relay grids, incorporated with NOMA and broadcasting technique. **Error! Reference source not found.** below illuatrate a two-user cooperative NOMA.

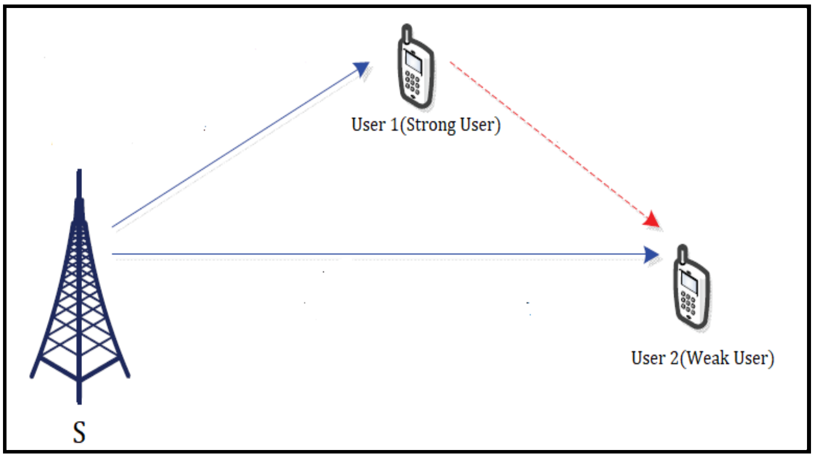


Figure 3.3: Two User Cooperative NOMA

To be consistent with the ability to enhance system efficiency and achievable rate, a study by Huang and Lee (2020) proposed NOMA-based diamond relay cooperative and non-cooperative. To address the problem of reception quality, Kim and Lee (2015) formulated the cooperative relay system (CRS) technique. In Wang *et al.* (2018) resource allocation was proposed to achieve both achievable rate and fairness. Moreover, to minimise human errors and maximise performance in the same study, NOMA has been proposed and considered as a possible solution to the problems of the next-generation wireless radio access network to avoid human error collisions and incident reduction. Proposed exact approaches to serve cell edge users in which the NOMA relay outperforms the OMA relay in both outage probability and outage capacity.

A relay broadcast channel (RBC) for single-antenna users is used. One user denoted as user 1 is the strong user, which has a stronger link or better channel conditions. The other user is denoted as user 2 or a weak user who has poor channel conditions with the transmitter. The transmitter encodes the intended signal for these users depending on their channel conditions. In other words, different power allocation proportions are used for each user. More power is allocated to the weak user as compared to the strong user, which implies that the signal of a weak user has a high signal-to-noise ratio (SNR). By applying this approach, user 1 easily decodes the user 2 signal even before decoding its signal and can subtract it from the total signal to retrieve its signal i.e., SIC is employed. The user's cooperation is used to improve the achievable rate of weak users (Benjebbour et al., 2013). The received signal of User 1 is expressed as follows:

$$y_1=h_1x+w_1 \tag{3.1}$$

And received signal by User 2 is:

$$y_2=h_2x+h_{12}x_1+w_2 \tag{3.2}$$

where h_1, h_2 and h_{12} denotes channel coefficients from the transmitter to User-1, User-2 and between User-1 and User-2 (i.e., cooperative link) respectively. The signal x has information on two users, $x_1$is the message sent by User-1 to User-2. w_1 and w_2 denotes AWGN noise at User 1 and User 2 receivers respectively. The achievable rates (r_1 and r_2) for User-1 and Users-2 respectively, can be expressed as:

$$r_1=\log_2\left(1+\frac{iP|h_1|^2}{\sigma^2}\right) \tag{3.3}$$

$$r_2=\min(r_{1\text{-}2},r_{2\text{-}2})=\min\left\{\begin{array}{c}\log_2\left(1+\frac{(1-i)P|h_1|^2}{iP|h_1|^2+\sigma^2}\right),\\ \log_2\left(1+\frac{(1-i)P|h_2|^2+P_1|h_{12}|^2}{iP|h_2|^2+\sigma^2}\right)\end{array}\right\} \tag{3.4}$$

Where "i" is the power allocation fraction of total transmit power (P) from the source that is allocated to the User-1 signal and P_1 is power used for the cooperation given to User-1 being a strong user.

3.3 Two-user cooperative NOMA

In a setup of two users where cooperative NOMA has been utilised, both users are assumed to be equipped with a single antenna the source is assumed to know the channel coefficients of both users and the strong user is assumed to know the channel coefficient of the cooperative link. There are two possibilities of cooperation power, namely, uncontrolled cooperation for two users and controlled cooperation for two users.

3.3.1 Uncontrolled Cooperative for two users

When the cooperative power given to user-1 for transmission with user-2 has no fixed value, it will dissociate the source transmit power from the cooperation power. The aim is then to maximise the minimum rates of both user-1 and user-2 in the network as:

$$\text{max-}\min(r_1,r_2) \tag{3.5}$$

With conditions: $P \leq$ Threshold power for transmission, and $P_1 \geq 0$.

3.3.2 Controlled Cooperative for two users

When the cooperative power given to user-1 for transmission with user-2 is limited by a threshold or maximum value (i.e. $P_1 \le P_{1,th}$). The equation (3.5) modifies as max-min$\{\log_2\left(1+\frac{iP|h_1|^2}{\sigma^2}\right)$,

$$\min\left\{\log_2\left(1+\frac{jP|h_1|^2}{iP|h_1|^2+\sigma^2}\right), \log_2\left(1+\frac{jP|h_2|^2+\beta P_1|h_{12}|^2}{iP|h_2|^2+\sigma^2}\right)\right\}$$

With conditions: $P \le$ Threshold power for transmission, $P_1 \ge 0$, $P_1 \le P_{1,th}$.

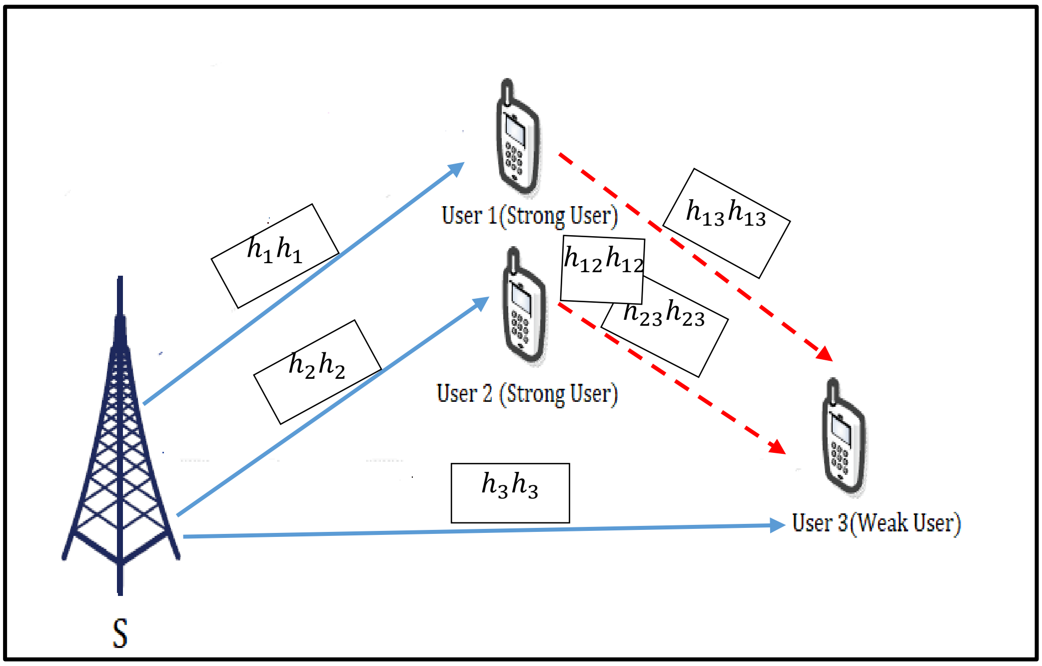


Figure 3.4: Three User Cooperative NOMA

3.4 Three-user cooperative NOMA

In a setup of three users cooperative NOMA, all users are assumed to have single antennas the source is assumed to know the channel coefficients of all the users and the strong users are assumed to know the channel coefficient of a cooperative link between them and the weak users. The three users' cooperative NOMA behaves similarly to the two users' cooperative NOMA, the strong users (user 1 and user 2) decode their signal along with the weak user (user 3) signal. The received signals of user-1, user-2 and user-3 are respectively:

$$y_1=h_1x+w_1 \tag{3.6}$$

$$y_2=h_2x+h_{12}x_1+w_2 \tag{3.7}$$

$$y_3=h_3x+h_{13}x_1+h_{23}x_2+w_3 \tag{3.8}$$

Where h_3 is the channel coefficient of the link between the source and user 3, h_{13} denotes the channel coefficient of the link between user 1 and user 3, h_{23} denotes the channel coefficient of the link between user 2 and user 3, w_3 denotes AWGN noise at user-3 receiver respectively. The signal x has information of three users, x_1 is the message sent by user-1 to user-3 and x_2 is the message sent by user-2 to user-3. It is to be noted that:

$$|h_1|^2 > |h_2|^2 > |h_3|^2 \tag{3.9}$$

The achievable rates (r_1, r_2 and r_3) for user-1, user-2 and user-3 respectively, are:

$$r_1 = \log_2\left(1 + \frac{iP|h_1|^2}{\sigma^2}\right) \tag{3.10}$$

$$r_2 = \min\left\{\log_2\left(1 + \frac{jP|h_1|^2}{iP|h_1|^2 + \sigma^2}\right), \log_2\left(1 + \frac{jP|h_2|^2 + \beta P_1|h_{12}|^2}{iP|h_2|^2 + \sigma^2}\right)\right\} \tag{3.11}$$

$$r_3 = \min\{r_{1\text{-}3}, r_{2\text{-}3}, r_{3\text{-}3}\} \tag{3.12}$$

Where:

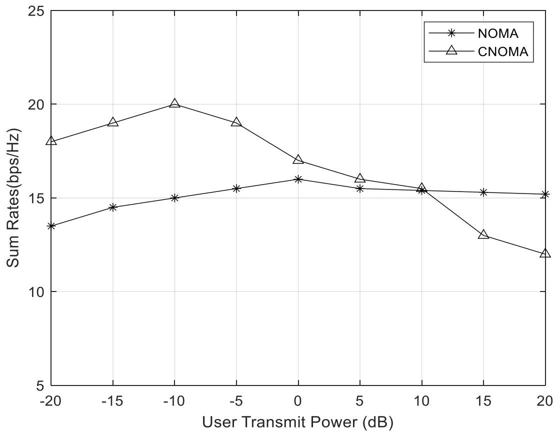
$$r_{1\text{-}3} = \log_2\left(1 + \frac{kP|h_1|^2}{iP|h_1|^2 + jP|h_1|^2 + \sigma^2}\right) \tag{3.13}$$

$$r_{2\text{-}3} = \log_2\left(1 + \frac{kP|h_2|^2 + (1-\beta)P_1|h_{12}|^2}{iP|h_2|^2 + jP|h_2|^2 + \beta P_1|h_{12}|^2 + \sigma^2}\right) \tag{3.14}$$

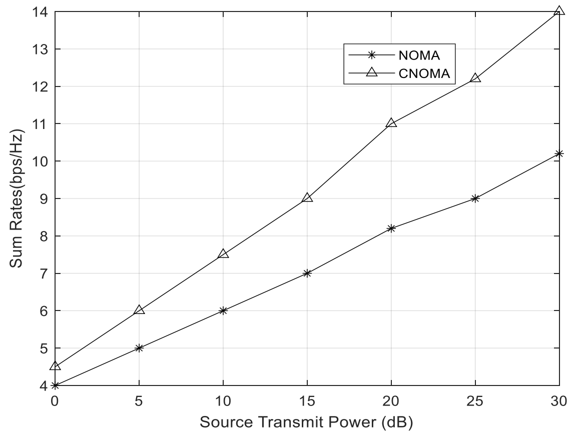
$$r_{3\text{-}3} = \log_2\left(1 + \frac{kP|h_3|^2 + (1-\beta)P_1|h_{13}|^2 + P_2|h_{23}|^2}{iP|h_3|^2 + jP|h_3|^2 + \beta P_1|h_{13}|^2 + \sigma^2}\right) \tag{3.15}$$

Where *i,j,k* denote the power allocation fraction of total transmit power P from the source that is allocated to user 1, User 2 and user 3 signal respectively and P_1,P_2 is the power used for the cooperation given to user 1 and user 2 being a strong user.

Below are the simulation results of NOMA and CMONA illustrating the achievable sum rate in both the user's transmit power and source transmit power. As indicated CMONA outperforms NOMA in both scenarios. Figure 3.5(a) below illustrates the case of the user sum rate against user transmit power. The below results indicate that CNOMA surpasses NOMA below 10dbm user transmit power. Figure 3.5(b) below demonstrates the achievable rate between CMONA and NOMA, as expected that CMONA performs better than NOMA in all source transmitted power respectively.



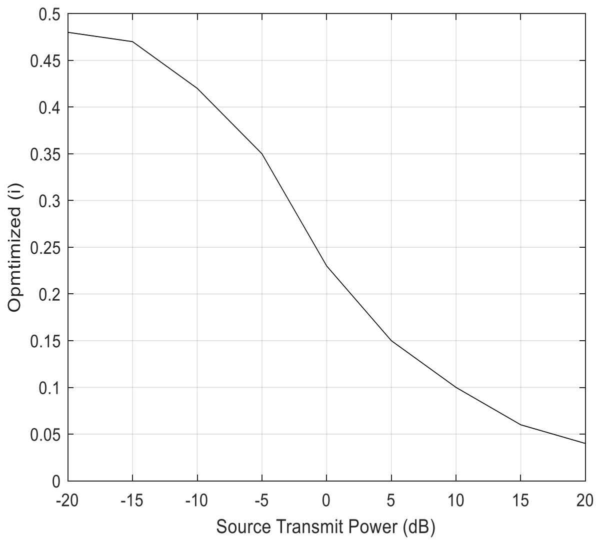
(a) Comparison of the Sum Rate of NOMA and CNOMA against user Transmit power



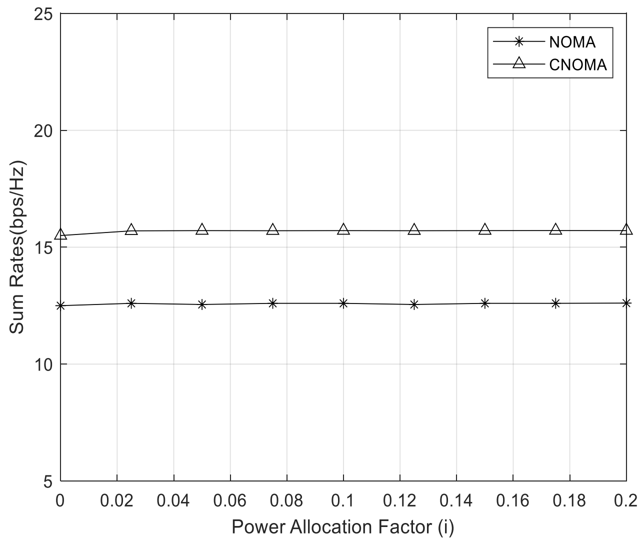
(b) NOMA and CNOMA Sum rate against source transmit power

Figure 3.5: **Sum rate comparison of NOMA and CNOMA**

Figure 3.6 **(**a) below illustrates the system's two-user-optimized behaviour as it drops when the source transmits power increases. Results in Figure 3.6(b)show that the achievable sum rates for both CNOMA and NOMA stay the same for the variable range of power allocation factors. This occurs during the user's data traffic request as well as through the user serving period. Additionally, below illustrative results below indicate the effectiveness of control power over an uncontrolled power scenario.



(a) Illustrative decaying of two-user optimized transmit power



(b) Sum Rate comparison of NOMA and CNOMA against the power allocation factor

Figure 3.6: Comparison of Sum rate Optimized behaviour in CNOMA and NOMA networks

3.4.1 uncontrolled cooperative power for three users

When the cooperative power is given to user 1 and user 2 for transmission with user 3, has no fixed value and will dissociate source transmit power from cooperation power. The aim is then to maximise the minimum rates of user 1, user 2 and user 3 respectively. With the following expression: $\max \min(r_1, r_2, r_3)$, through conditions such that P is less than or equal to threshold power transmission and cooperation power $P_1 \geq 0$, $P_2 \geq 0$, $i + j + k \leq 1$.

3.4.2 Controlled cooperative power for three users

When the cooperative power given to user 1 and user 2 for transmission with user 3, is limited by a threshold or maximum value i.e. $P_1 \leq P_{1,Th}$. With modified expression $\max \min(r_1, r_2)$, Through conditions P≤ Threshold power for transmission, cooperation power $P_1 \geq 0$, $P_1 \leq P_{1,Th}$ and $i+j+k \leq 1$.

3.5 The results discussion

The results obtained and presented in this chapter are for non-fading channels, for example, high-frequency line of sight (LoS) mm-wave, and VLC channels for indoor LoS and THz RF channels. Figure 3.5, demonstrates that as SNR reduces, the strong user power allocation increases because SIC detected at user 1 becomes comparable. Also, as the SNR increases, the power allocation factor needs to be reduced to achieve the same rate. Figure 3.5(a), also demonstrates the sum rate of CNOMA decreases with user transmit power >-10, which is because the user 3 sum rate depends on the links with users 1 and 2 and also due to inter-user interference (IUI) which increases due to increase in user's power. The optimised power allocation is presented in Figure 3.6(a) for the case of two users:

$$\left|h_1\right|^2=10\left|h_2\right|^2,\ |h_{12}|^2=0.5|h_1|^2 \text{ and } \sigma^2=1.$$

In Figure 3.6(b), the sum rate of the NOMA and CNOMA schemes is compared using various source transmit powers for three user scenarios. The cooperative NOMA (CNOMA) performs well for increasing the sum rates as compared to traditional NOMA. As the SNR increases, the difference between NOMA and CNOMA increases too.

Figure 3.6 illustrates both the source's transmit power and power allocation factor which impact the sum rates compared for NOMA and CNOMA, considering two near users (1 and 2) have equal transmit powers in the presence of one far user (user 3). Additionally, Figure 3.6(b) portrays the different power allocation factors used to compare the performance of NOMA and CNOMA. The results show that the achievable sum rates for both CNOMA and NOMA stay the same for the variable range of power allocation factors.

Table 3.1 Notation used in Chapter 3

Important Notations	
i.j,k	Power allocation fraction of total transmit power P from the source.
P_1,P_2	Power allocation
h	System channel coefficients
w_1 and w_2	AWGN noise at user 1 and user 2 receivers
x_1	Denote the message sent by user 1 to user 2

3.6 Research gap

To the best of our knowledge, no studies have investigated this scenario of employing a relay around the base station. Most existing studies employ relays in the network with different setups and configurations. The NOMA-based network did not consider serving far users simultaneously by utilizing NOMA and relay. Prior literature regarding power allocation for mobile networks focused on fixed power to all users which subsequently gives more power to users who do not need it and less power to users who need more power (Thakre, 2022). This has led to two fundamental network problems; namely, very reduced system fairness towards all users as some users were over-satisfied (more power than they need) while others were unsatisfied (less power than they need). This resulted in the unnecessary wastage of network resources (power) which could have been used to improve the services of the under-satisfied users. The optimum efficient power allocation was presented by (Zhu et al., 2017) to solve and avoid equal power allocation problems. The fixed power allocation technique by Shahab *et.al*. (2016) focuses on system sum capacity and minimum bit error rate BER. While the study by Wang *et.al.* (2018) deals with fixed power to formulate the technique to minimize the minimum vehicle achievable rate for fairness. However, in the most practical implementation, there will be cases where the number of near users in quantity is not exactly as the number of far users. This simply means that the traditional NOMA could not be served or implemented, and the farthest users will be served even if the network reverts to the backward capability of OMA wherein the user reliability from cell edge users will not be guaranteed such that QoS might be compromised.

3.7 Conclusion

This chapter has provided an effective comparison and background between the NOMA and CNOMA for two-user and three-user scenarios when power allocation is controlled and uncontrolled. The simulation results indicate that CNOMA outperforms the NOMA for all the simulated parameters with the requirement of a complex receiver. The future work should consist of extended SIC in NOMA to find the complexity of the receiver and delay originated due to the complexity in decoding the received signals. Additionally, the receiver complexity needs to be minimized while improving the decoding system mechanism.

CHAPTER 4:
INITIAL POWER ALLOCATION
ON BALANCED AND IMBALANCED NOMA NETWORK.

The previous chapter presented a comprehensive literature review and the research gaps in the study. Additionally, it has provided a systematic analysis of the first approach of the FM-PAA design which is very significant in our research study. In this chapter, we are seeking to develop our first scientific contribution to the research. Thereafter we intend to evaluate the obtained power allocation algorithm based on the OCTR equalizing concept. The OCTR ratio converges concept can be done in two methods, either by maximising the minimum ratio or by minimising the maximum ratio till both ratios emerge to virtually zero value (Reid *et.al.*, 2001). To be consistent with the research's aim and objectives, the ability to guarantee system reliability which is probably the most critical aspect of the entire study is by minimizing outage probability. The reported work by Balyan has presented the outage probability improvement for all NOMA-based users to increase network fairness (Balyan, 2020).

4.1 Description and Modelling of the Balanced Network Scenario:

An illustration of the traditional NOMA scenario is given in Figure 4.1 below for the case of 2 users per NOMA beam, with 6 antennas at the base station. In a traditional NOMA scenario, the system is assumed to be balanced for the implementation of NOMA technology on all antennas. This means that, with N-antennas at the base station having N-antennas, there are always N near-users and N-far-users. As can be noted in Figure 4.1 below, the number of near users is the same as the number of far users (balanced NOMA).

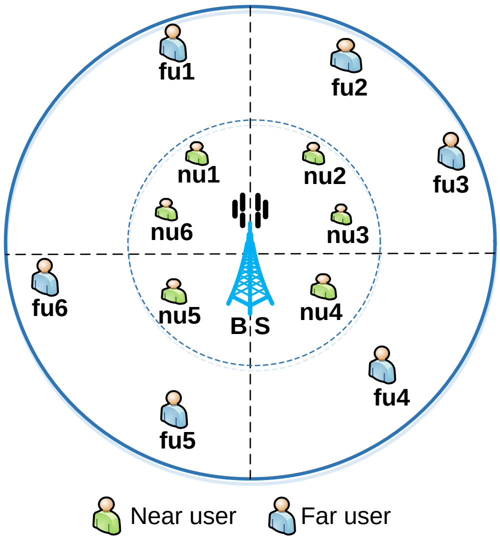


Figure 4.1: Illustrative of a balanced NOMA network

Considering this scenario, authors Biyoghe et.al 2020 provided a PAA that maximizes the network's users-fairness, based on the *OCTR*-ratios convergence concept. Inspired by the later work, in this research, we derive an initial FM-PAA for the traditional NOMA scenario, by adopting the inter-beam and the intra-beam PAAs proposed therein. For convenience's sake, in this document, the indicated inter-beam and intra-team PAAs will be named "PAA-P1" and "PAA-P2", respectively. However, we consider a significant system modification which is that each antenna uses its dedicated sub-frequency band. Thus, there will be no inter-beam interference between users of different beams. Subsequently, the network's MAC will not need to implement precoding at transmission. In this case, the transmitted signal by each antenna (b) will be:

$$S_{\text{tx-b}} = \sqrt{P_b}\left(\sqrt{\alpha_b}\, s_{bn} + \sqrt{1-\alpha_b}\, s_{bf}\right),\ b = 1, 2, \ldots, N \tag{4.1}$$

The total transmitted signal over the entire base-station band will be:

$$S_{\text{tx-tot}} = \sum_{b=1}^{N} \sqrt{P_b}\left(\sqrt{\alpha_b}\, s_{bn} + \sqrt{1-\alpha_b}\, s_{bf}\right),\ b = 1, 2, \ldots, N \tag{4.2}$$

The users in each are only receiving the transmitted signal on their dedicated sub-band while filtering out signals from all other sub-bands. Thus, the received signals at near and far users of each beam (b, b = 1, 2, …, N) can be expressed as:

$$S_{\text{rx-bn}} = h_{bn}^{H} \sqrt{P_b}\left(\sqrt{\alpha_b}\, s_{bn} + \sqrt{1-\alpha_b}\, s_{bf}\right) \tag{4.3}$$

$$S_{\text{rx-bf}} = h_{bf}^{H} \sqrt{P_b}\left(\sqrt{\alpha_b}\, s_{bn} + \sqrt{1-\alpha_b}\, s_{bf}\right) \tag{4.4}$$

Where, h_{bn} and h_{bf} represents the channel vector of the near and far users in beam "b" respectively. According to the NOMA protocol, the near user will decode the information of the far user first, before decoding its own information(Dai et al., 2015),(Wei et al., 2016). As such, it will not suffer any intra-beam interference from the far user. Subsequently, the signal-to-interference-and-noise ratio (SINR) of the near user "*n*" in beam "b" will be:

$$SINR_{bn} = \frac{\left|h_{bn}^{H}\right|^{2} P_b \alpha_b}{P_{noise}} \tag{4.5}$$

Where P_{noise} is the AGWN power. On the other side, the far user will see the near user as noise, and thus, receive some intra-beam interference from it. Thus, the signal-to-interference-and-noise ratio (SINR) of the far user "f" in beam "b" will be:

$$SINR_{bf} = \frac{\left|h_{bf}^{H}\right|^{2} P_b (1-\alpha_b)}{\left|h_{bf}^{H}\right|^{2} P_b \alpha_b + P_{noise}} \tag{4.6}$$

The normalized achievable capacity (C_u) of any user "u" in the network, and the OCTR-ratio (R_u) of this user, can be expressed respectively (Akin & Gursoy, 2010):

$$C_u = log_2(SINR_u + 1) \quad [bps/Hz] \tag{4.7}$$

$$R_u = \frac{C_u}{D_u} \tag{4.8}$$

Where D_u is the traffic request of the user "u" at the time of service. The system's users-fairness of the network servicing 2N-users at the time can be calculated using Jain's fairness metric (Jain et al., 1998):

$$\boldsymbol{J}(R_1, R_2, \ldots, R_{2N}) = \frac{\left(\sum_{u=1}^{2N} R_u\right)^2}{2N \times \sum_{u=1}^{2N} (R_u)^2} \tag{4.9}$$

4.2 Formulation of the Optimisation Problem

The network's users-fairness maximization goal can be described as an optimization problem (P):

$$\boldsymbol{P}: \quad \max_{(P_b, \alpha_b)} \quad \min_{b=1,\ldots,N;\, r=n,f} \quad (R_{b,r})$$

$$\text{s.t.} \quad \sum_{b=1}^{N} P_b \le P_{tot\text{-}BS}$$

$$\underset{b=1,\ldots,N}{P_b} \le P_{b\text{-}max}$$

$$0 \le \underset{b=1,\ldots,N}{\alpha_b} \le 1$$

This problem is non-convex and thus NP-hard, due to the non-linear relationship between the two variables Pb and ab. It is therefore decomposed into two sub-optimal problems; namely, the inter-beam fairness maximization (P1) and the intra-beam fairness maximisation (P2), which are described as follows:

$$\boldsymbol{P_1}: \quad \max_{(P_b)} \quad \min_{b=1,\dots,N} \; (R_b)$$

$$\text{s.t.} \; \sum_{b=1}^{N} P_b \le P_{\text{tot-BS}}$$

$$\underset{b=1,\;\dots,\;N}{P_b} \le P_{\text{b-max}}$$

$$\boldsymbol{P_2}: \quad \max_{(\alpha_b)} \quad \min \; (R_{b,n}, R_{b,f})$$

$$\text{s.t.} \; 0 \le \alpha_b \le 1$$

4.3 Initial Fairness-Maximisation Power Allocation Algorithm

The problem P_1 is solved by an inter-beam power allocation algorithm, which seeks to maximise fairness amongst the respective beams. As indicated earlier, the inter-beam power-allocation algorithm proposed by Biyoghe (2022:72) (see Algorithm-5.2) is adopted in this work; and is referred to herein as PAA-P1. Similarly, problem P_2 is solved by an intra-beam power-allocation algorithm, which seeks to maximise fairness between the far and near users in the beams. In this regard, the intra-beam power-allocation algorithm proposed in Biyoghe (2022:62) (see Algorithm-5.1) is adopted in this work; and is referred to herein as PAA-P2. Finally, a power-allocation algorithm which provides a solution to the original problem (P), is derived in this work, by combining the PAA-P1 and PAA-P2. It is labelled "*initial FM-PAA*" and is presented in Table 4.1 below.

Table 4.1: Initial Fairness-Maximization PA-Algorithm (Initial-FM-PAA) for a traditional 2Users NOMA Network.

Algorithm 1: Initial FM-PAA	
1:	Receive: $\boldsymbol{h_{bn}}$ & $\boldsymbol{h_{bf}}$, $\boldsymbol{D_{bn}}$ & $\boldsymbol{D_{bf}}$, **for all *N*-pairs (b = 1, 2,…, N);**
2:	Specify: $P_{\text{tot-BS}}$, $P_{\text{b-max}}$, $P_{\text{b-init}} = P_{\text{tot-BS}}/\text{N}$, *ce*.
3:	Generate: $\boldsymbol{P_{\text{b-set-init}}} = [P_{\text{1-init}}, \dots, P_{\text{N-init}}]$;
4:	**repeat:**
5:	Receive "$\boldsymbol{P_{\text{b-set-new}}}$" from the previous iteration
6:	Assign $\boldsymbol{P_{\text{b-set-cur}}} = \boldsymbol{P_{\text{b-set-new}}}$
7:	For each beam "*b*", execute "***PAA-P2***".
8:	Get the resulting new R_b and α_b;
9:	Generate new $\boldsymbol{R_{\text{b-set}}} = [R_1, \dots, R_N]$ and $\boldsymbol{\alpha_{\text{b-set}}} = [\alpha_1, \dots, \alpha_N]$;

Verify: if (R_{max}-R_{min}) < *ce*
convergence = Yes;
End if;
If (convergence != Yes)
Execute "***PAA-P1***" by using $\boldsymbol{P}_{\textbf{b-set-cur}}$ and $\boldsymbol{R}_{\textbf{b-set}}$
Get either: $\boldsymbol{P}_{\textbf{b-set-new}}$
End if;
Until: *convergence = Yes.*
Store final powers set: $P_{b\text{-}set\text{-}opt}$ = last $P_{b\text{-}set\text{-}new}$ registered, & "$\alpha_{b\text{-}set\text{-}opt}$" = last $\alpha_{b\text{-}set}$ registered;

The derived "*initial FM-PAA*" was tested under the network's specifications listed in Table 4.2 below.

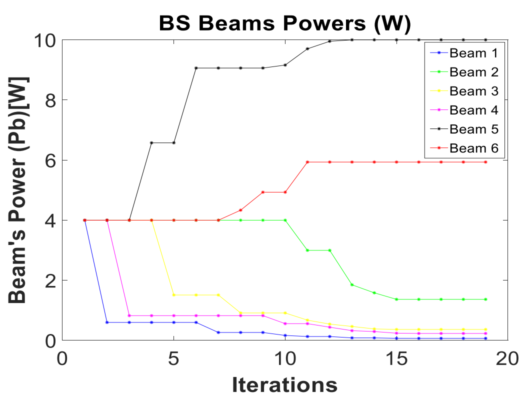
4.4 Algorithm Implementation and Testing

The following network specification has been developed and adopted with clear recommendations for the design testing, and implementation of a 2N user fairness maximization system with six antenna network configurations at 20Ghz carrier frequency.

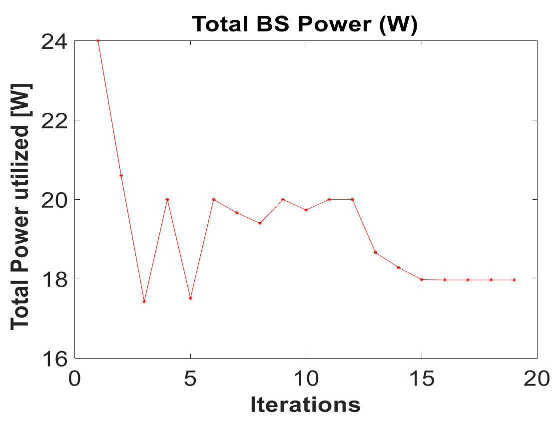
Table 4.2: Mobile Network's Parameters Specification

Parameter	**Specification**
Access-point	Base-Station,
Maximum network coverage	d_{max} = 2km from BS,
Angle-of-Arrival Span	$-\pi,+\pi$, w.r.t the BS's axis.
Number of BS's Antenna	N = 6,
BS's antennas casting technology	No-frequency-reuse (*0FR*),
Frequency of operation	F_c = 20GHz (Ka-Band)
Channel bandwidth	*BW* = 100MHz,
Gain BS' antennas	G_{tx} = 10dBi,
No of the user terminal's antennas	1
Gain of user-terminal antenna	G_{rx} = 0dBi,
Multiple-access technology	NOMA (PD)
No NOMA user's antenna	r = 2,
Total BS power available ($P_{tot\text{-}sat}$)	60W is equal to 48dBm,
Maximal antenna power ($P_{b\text{-}max}$)	20W is equal to 43dBm
Noise Temp & Spectral density	290Kelvin, -174dBm/Hz

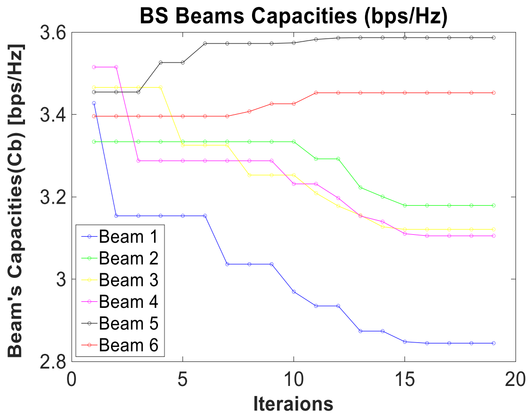
Following these specifications, 100 users were randomly placed across the BS coverage. Since the number of users to be served at a service time slot is 2N, 12 of the 100 users were then randomly selected: with N=6 antennas. The respective channel vectors (h_u) of the 12 users were estimated; their respective traffic requests (D_u) were determined randomly from the range of 1 to 10 bps/Hz. Following this, the 12 users were grouped into 6 NOMA pairs utilizing the users-grouping algorithm (Biyoghe & Balyan, 2023). With all the elements available as required in "line-1" of Algorithm-1 (Table 4.2 above), the "initial FM-PAA" was then executed and tested. The results obtained, for an average traffic request of 4 pbs/Hz across the 12 users, are shown in Figures 4.2 (a) to 4.2(f) below. Figure 4.2(a) shows the power variation of respective beams over iterations of the algorithm; Figure 4.2(d) shows the resulting network's total capacity in each iteration. Figure 4.2(e) shows that the algorithm makes the OCTR ratios of all the users converge around 15 iterations; resulting therefore in the maximization of the network's users-fairness index (see Figure 4.2(f)). Figure 4.2 demonstrates the test results of the initial FM-PAA in the traditional NOMA scenario, For an average traffic request of 4pbs/Hz.

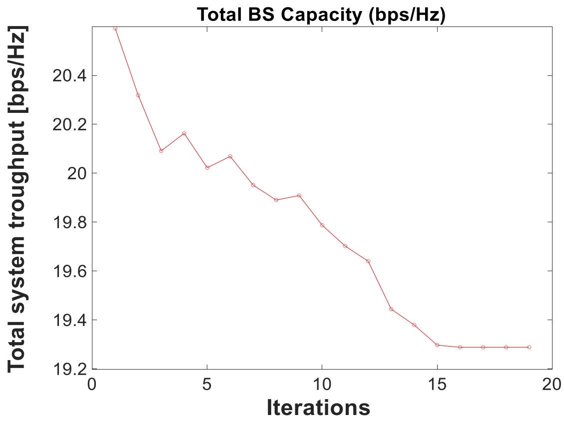


4.2(a)



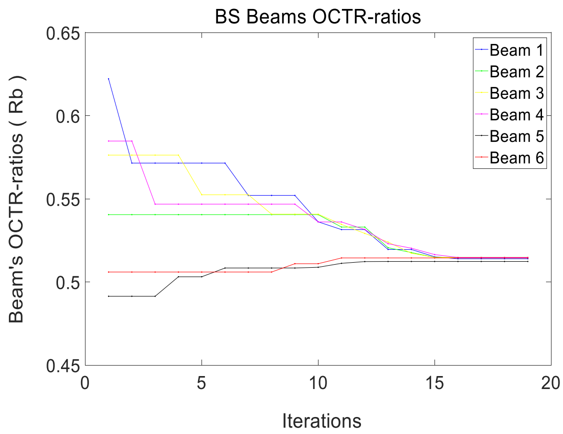
4.2(b)

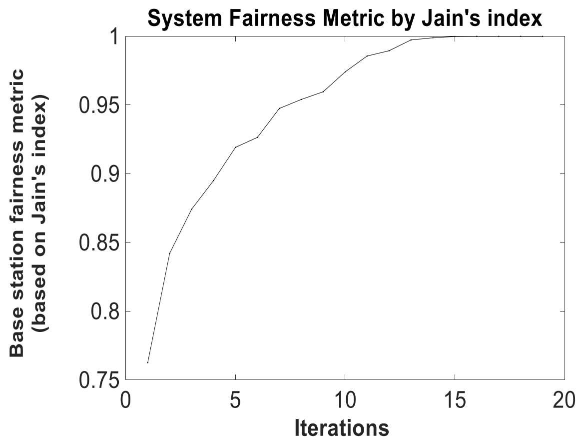




4.2(d)

4.2(c)





4.2(e)

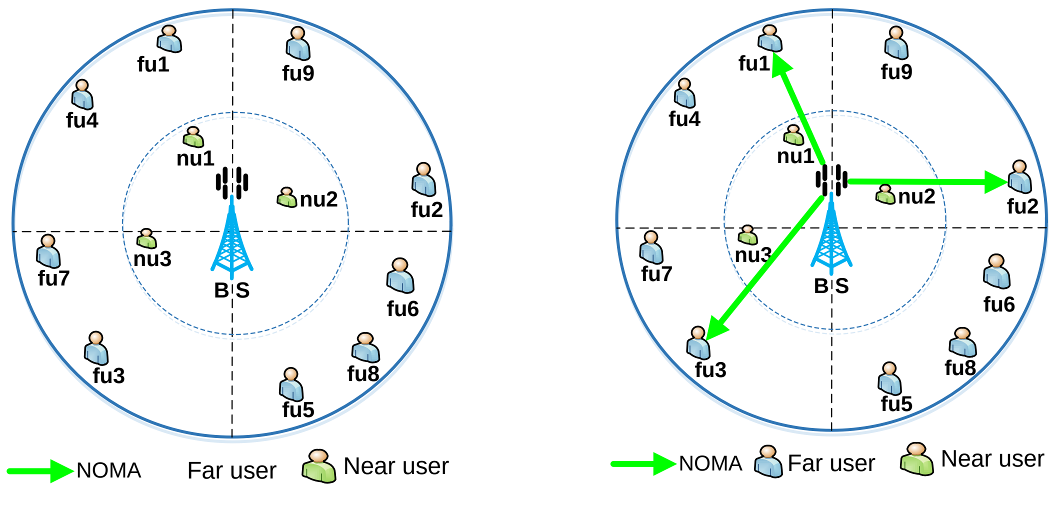
4.2(f)

Figure 4.2: Simulation results of balance network

4.5 Application of the initial FM-PAA on an imbalanced network scenario:

In an imbalanced NOMA scenario, the base station equipped with N-antennas will select 2N users to serve at a given service time slot. However, due to the channel vectors of the users, it will not be feasible to have N far-users and N near-users, for successful NOMA implementation. There will either be more near users, or more far users, out of the 2N users; hence, the imbalanced NOMA scenario. Thus, there will not be N-NOMA pairs, consisting of each of a near and a far user. Subsequently, in these two possible imbalanced scenarios, using the “initial FM-PAA” as is, to maximise the network’s users-fairness will not yield optimal results. Because this algorithm as is, expects to serve two users in each antenna utilizing NOMA; namely, one far and one near the user. Therefore, alternative means of maximising the network’s user-fairness in the imbalanced NOMA scenarios need to be found.

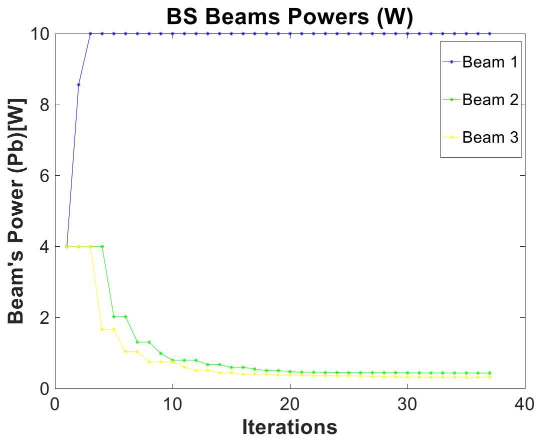
This research focuses on the imbalanced scenario where there are more far users out of the 2N users to be served. For convenience, this scenario will be named “more far-users scenario”. Note that, since there are N-antennas and 2N users to serve, we denote k, the number of near-users (k<N), and the number of far users will be (2N-k). Thus, the number of possible near-far user pairs is k; and the number of extra far-users will be 2x(N-k). Figure 4.3(a) below illustrates the "more far-users scenario" for a base station with 6 antennas. In this case, it is considered that there are 3 near-users; and subsequently, 9 far-users out of the 12 users to be served in the present time slot. The number of possible far-near users NOMA-pairs is 3, and the number of extra far-users is 6; as illustrated in Figure 4.3(b) below. Likewise, Figure 4.3(a) presents the scenario of an imbalanced more far-user scenario for BS with 6 antennas. If the "initial FM-PAA" is used in this scenario as is, it will only be able to serve the k NOMA pairs of near-far users; which means 2k users out of the 2N to be served.



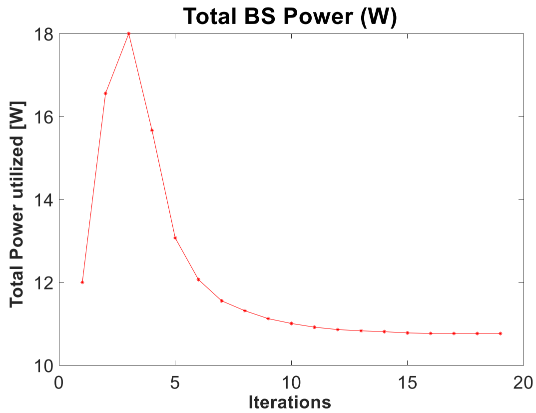
4.3(a) 4.3(b)

Figure 4.3: Illustrates the imbalanced NOMA scenario for the case of more far-users

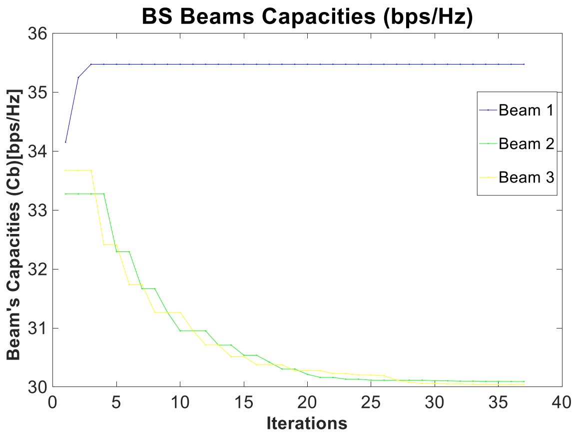
The rest of the 2x(N-k) far-users will be unserved completely, each achieving OCTR-ratios of 0; therefore, yielding an extremely poor network's user-fairness. In the case of the scenario described above, only 3 pairs will be served by the "initial FM-PAA"; which means 6 users; and the rest of the 6 far users will not be served. Figure 4.4 below illustrates the results obtained from testing the "initial FM-PAA" in the described scenario. As can be seen in Figure 4.4(f), the network's fairness index is considerably lower than the one achieved with the "initial FM-PAA", in the traditional (balanced) NOMA scenario. Thus, confirming the earlier observation made. **Error! Reference source not found.** Test results of the initial FM-PAA in the "more far-users" scenario, with 6 antennas, 3 near-users and 9 far-users; as well as an average traffic request of 4bps/Hz.



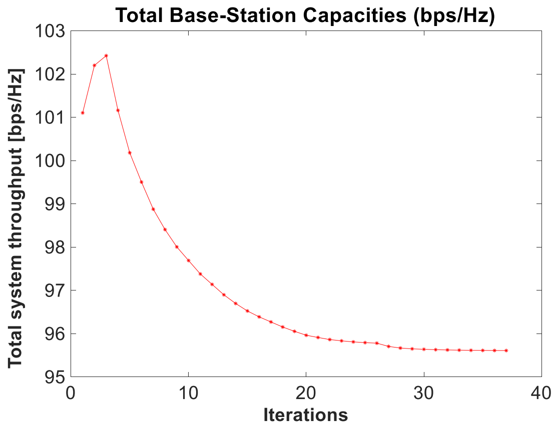
4.4(a)



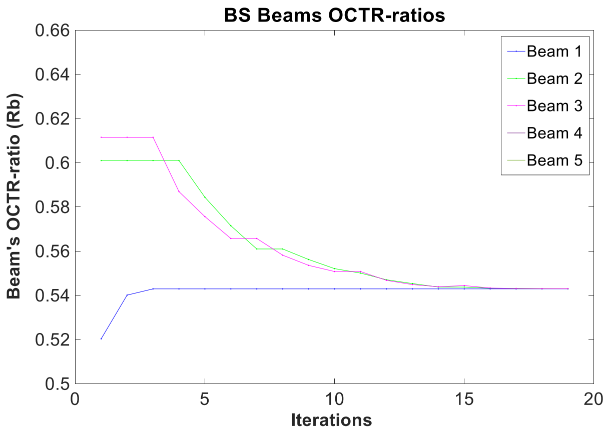
4.4(b)



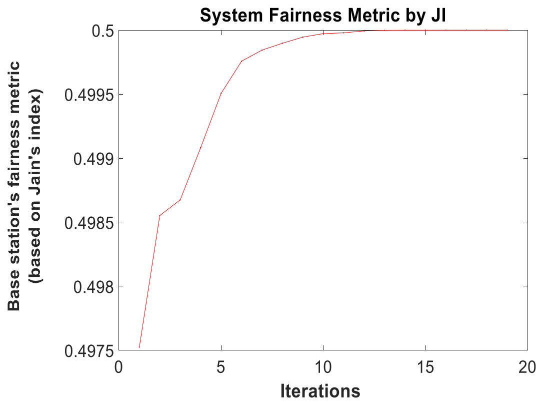
4.4(c)



4.4(d)



4.4(e)



4.4(f)

Figure 4.4: Simulation results of Imbalanced Network

Given the limits of the “initial FM-PAA” in resolving the fairness-maximisation problem in imbalanced NOMA scenarios, two possible solutions are proposed in this research. These include an intermediate solution and a more optimal solution. The intermediate solution consists of combining NOMA and OMA technologies in a single algorithm, so to increase the number of users being served, compared to when the “initial FM-PAA” is being used. The optimal solution consists of placing relays in the near field of the BS and then using the “initial FM-PAA” in combination with some relay algorithm, to serve all the 2N users in a given service time slot. These two solutions are described in more detail below.

4.6 Conclusion

This chapter has presented two main research aspects and research contributions including results simulation at the end, the ideal scenario of the balance concept of near user and far user. The second demonstration in this chapter is an imbalanced scenario, where far users are clustered around the BS more than the near users. The simulation results as expected show that the balance PM-PAA performs better than the imbalance FM-PAA algorithm. The system fairness index by Jain's index demonstrates that at least 50% of the far users cannot receive power share and might be not good in system fairness. Also, for evaluating the system (KPIs) and (QeE) this might have a negative impact likewise to the overall network performance.

CHAPTER 5:
COMBINATION OF NOMA & OMA TO ADDRESS THE LOW FAIRNESS OF THE IMBALANCE NOMA SCENARIO

5.1 Description and modelling of the network scenario

The previous chapter presented the first approach to the FM-PAA design with simulations. This chapter considers the second method of the FM-PAA by combining NOMA and OMA. As a recall, if only NOMA is to be used in the imbalanced scenario illustrated in **Error! Reference source not found.** below, only the "k-pairs" would be served; and the remaining 2x(N-k)-users would not be served. To alleviate this drawback, we introduce the use of OMA technology as a supplement to NOMA, to serve (N-k)-users via the remaining (N-k)-antennas. In this process, instead of only serving the 2k-users from the k-pairs, as obtained when using the "initial FM-PAA" as is; an additional (N-k) far-users will be served effectively. Thus, a total of (N+k) users will be served; and only (N-k) far-users will not be served as opposed to 2x(N-k) when only using the "initial FM-PAA" as is. This concept is illustrated in Figure 5.1 below; where the green arrows indicate the NOMA-beam, and the blue arrows indicate the OMA-beam. We have labelled this concept as "an intermediate solution".

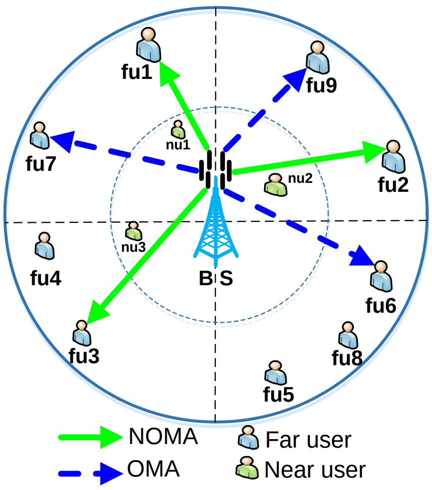


Figure 5.1: NOMA and OMA network system

It is useful to remind that, when OMA technology is used, only one user is served at the time, by the antenna. Thus, the transmitted signal by the antenna b (b = 1, …, (N-k)), the received signal at the designated far user with channel vector (h_{bf}), as well as the SINR of that signal, can all be described as follows:

$$S_{tx\text{-}b} = \sqrt{P_b}\, s_{bf} \text{ , b = 1, 2, …, (N-k)} \tag{5.1}$$

$$S_{rx\text{-}bf} = h_{bf}^{H} \sqrt{P_b}\, s_{bf} \tag{5.2}$$

$$SINR_{\mathrm{bf}} = \frac{\left|h_{\mathrm{bf}}^{\mathrm{H}}\right|^2 P_{\mathrm{b}}}{P_{\mathrm{noise}}} \quad (5.3)$$

5.2 Proposed intermediate algorithm (algorithm 2)

The proposed algorithm to implement this concept can be derived as follows. First, the N-antennas of the BS will be served by the inter-beam power allocation algorithm (PAA-P1) to maximise fairness between antennas. Then, each of the k far-near user pairs will be served utilising NOMA technology, through one of the respective antennas; and the resulting Rb and ab for the beam will be stored. Thereafter, each remaining (N-k) antenna will serve a far-user utilising OMA technology; and the resulting Rb for the beam will be captured. Following this, the OCTR-ratios convergence will be checked. If satisfied, the algorithm will stop and the final results stored; but if not satisfied, another iteration of inter-beam power-allocation will be done. The resulting "Algorithm 2" which we denote as "Intermediate-PAA", is primarily the "initial FM-PAA" with the introduction of OMA implementation for the (N-k) far users that do not have a near-user pair. It is presented in Table 2.1 below.

Table 5.1: Intermediate Fairness-Maximisation PA-Algorithm (PAA-2) for an imbalanced 2Users NOMA Network with more far-users

Algorithm 2: Intermediate-PAA	
1:	Receive: $\boldsymbol{h}_{\mathbf{bn}}$ **&** $\boldsymbol{h}_{\mathbf{bf}}$**,** $\boldsymbol{D}_{\mathbf{bn}}$ **&** $\boldsymbol{D}_{\mathbf{bf}}$**, for all 2*N* users (b = 1, 2,…, N);**
2:	Specify: $P_{\text{tot-BS}}$, $P_{\text{b-max}}$, $P_{\text{b-init}} = P_{\text{tot-BS}}/N$, *ce*.
3:	Generate: $\boldsymbol{P}_{\mathbf{b\text{-}set\text{-}init}} = [P_{\text{1-init}}, \ldots, P_{\text{N-init}}]$; indicate k
4:	**repeat:**
5:	Receive "$\boldsymbol{P}_{\mathbf{b\text{-}set\text{-}new}}$" from the previous iteration
6:	Assign $\boldsymbol{P}_{\mathbf{b\text{-}set\text{-}cur}} = \boldsymbol{P}_{\mathbf{b\text{-}set\text{-}new}}$
7:	For each of the *k*-pairs, execute "**Intra-beam PAA**" for NOMA**.**
8:	Get the resulting new R_{b} and α_{b} from each pair;
9:	For each of the (N-*k*) antennas, serve one far-user using OMA.
10:	Get the resulting new R_{b} from each far-user;
11:	Generate new $\boldsymbol{R}_{\mathbf{b\text{-}set}} = [R_1,\ldots, R_{\mathrm{N}}]$ for all N-antennas, and $\boldsymbol{\alpha}_{\mathbf{b\text{-}set}} = [\alpha_1, \ldots, \alpha_{\mathrm{k}}]$; for all k-pairs.
12:	Verify: if $(R_{\max}-R_{\min}) < ce$
13:	convergence = Yes;
14:	End if;
15:	If (convergence != Yes)
16:	Execute "***PAA-P1***" by using $\boldsymbol{P}_{\mathbf{b\text{-}set\text{-}cur}}$ and $\boldsymbol{R}_{\mathbf{b\text{-}set}}$
17:	Get either: $\boldsymbol{P}_{\mathbf{b\text{-}set\text{-}new}}$
18:	End if;

19:	**Until: *convergence = Yes.***
20:	Store final powers set: $P_{b\text{-set-opt}}$ = last $P_{b\text{-set-new}}$ registered, & "$\alpha_{b\text{-set-opt}}$" = last $\alpha_{b\text{-set}}$ registered;

5.3 Implementation and testing of Algorithm 2

The proposed "Algorithm 2" was tested under the same network description outlined previously. The three far-near user pairs are served utilizing NOMA, on 3 antennas, while an additional 3 far-users are served utilizing OMA, on the remaining 3 antennas. Thus, a total of 9 users out of the 12 available are served; and only 3 far-users remained unserved. The test results obtained are presented in Figure 5.2(a) to Figure 5.2(f) below. These results show that the "intermediate-PAA" serves more users in the imbalanced NOMA scenario than when using the "initial-PAA" alone. Consequently, it provides an improved system of user fairness, as can be noticed by comparing the fairness index graph in Figure 5.2 (f) below and Figure 4.4(f) above.

Error! Reference source not found. test results of the intermediate-PAA in the "more far-users" scenario, with 6 antennas, 3 near-users and 9 far-users; as well as an average traffic request of 4bps/Hz.

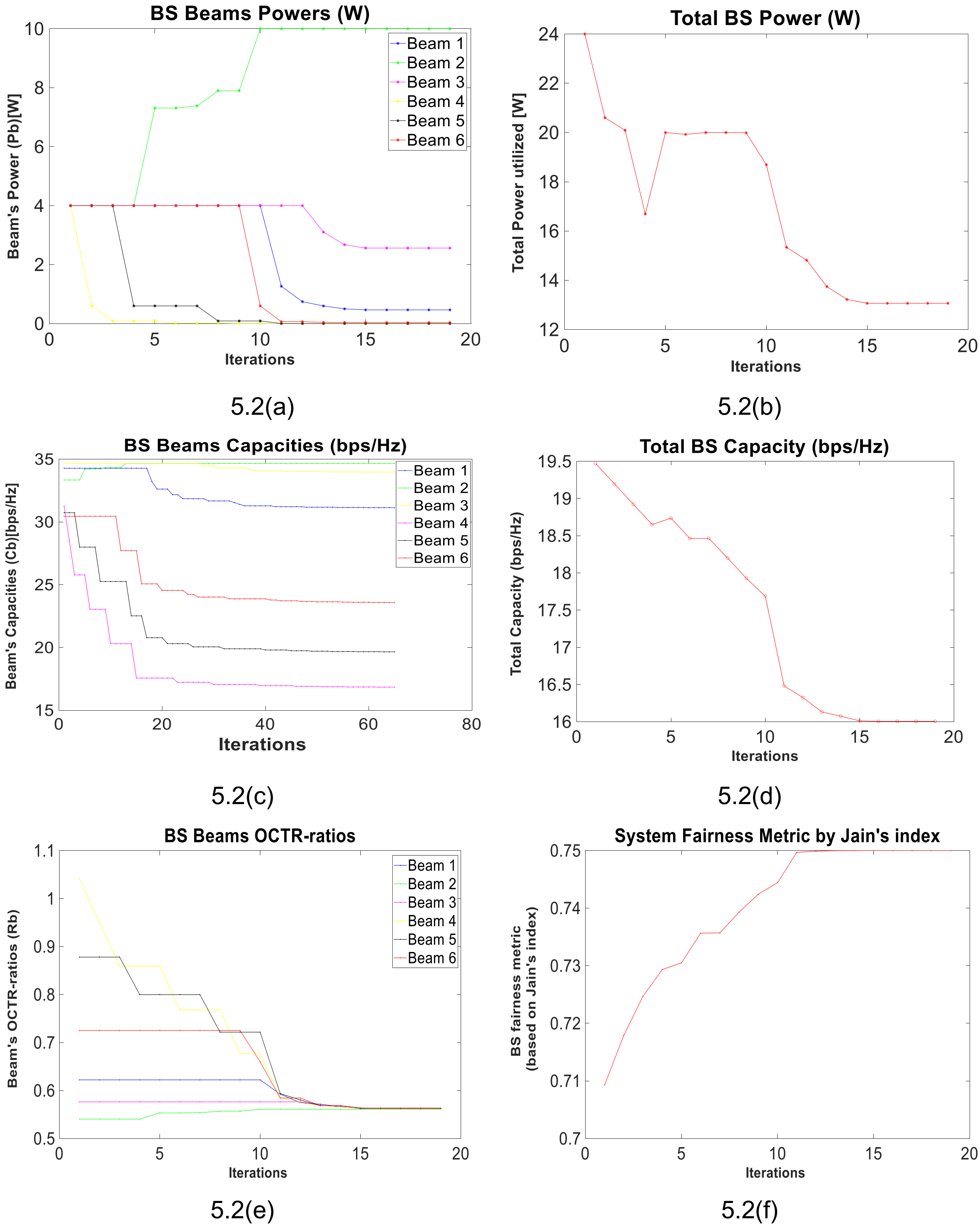


Figure 5.2: Simulation results of both NOMA and OMA

It can be apparent that, even though the intermediate-PAA provides better fairness performance than using the initial-PAA alone in the imbalanced more-far-users' scenario, its users-fairness is still relatively low; because there are still (N-k) far-users not being served at all. Thus, the proposed advanced solution, presented next, attempts to provide better performance.

5.4 Conclusion

This chapter similarly presented two versions of research scenarios, which are part of the research contribution and also an instance where the initial FM-PAA can be utilized with NOMA and OMA. This scenario demonstrates that even though the initial FM-PAA can be applied in NOMA, that would not fully maximise system fairness. Some users will be still served in the form of OMA which can degrade the user fairness and that of the system. Although this combination performs better than the previous imbalance technique about serving 75% of the users are being served as shown by the fairness index by Jain's. This scenario can also be called a fullback scenario; the event is well-expected in wireless communication during network operation.

CHAPTER 6:

COMBINATION OF NEAR-FIELD RELAYS AND INITIAL PAA, TO OPTIMIZE THE FAIRNESS OF THE IMBALANCE NOMA SCENARIO

6.1 Description and modelling of the network scenario

The previous two chapters presented the initial FM-PAA and the combination of NOMA and OMA approaches with their simulations respectively. To further improve the network's user fairness in the imbalanced NOMA scenario with more far-users, this research proposes an advanced solution to the intermediate one presented earlier above. This solution consists of placing relays in the near field of the base station, as illustrated in Figure 6.1 below; and thereafter, doing the following two things. First, some of these relays are used to act as near-users for NOMA implementation on some far-users. In this way, NOMA could be implemented on all N-antennas; and thus, the "initial FM-PAA" could simply be used as is for the task. Secondly, the served relays will convey the information intended for the other unserved far-users. In this regard, a decode-and-forward algorithm could be employed in each relay; since the relay will first decode the information from the NOMA-beam service, and thereafter forward it to the relevant far-user. It can be seen that, through the combination of these two stages, all the 2N users will be served successfully in this service time slot. Figure 6.1 illustrates near-field relays in the imbalanced NOMA scenario with more far-users: all the relays are ON.

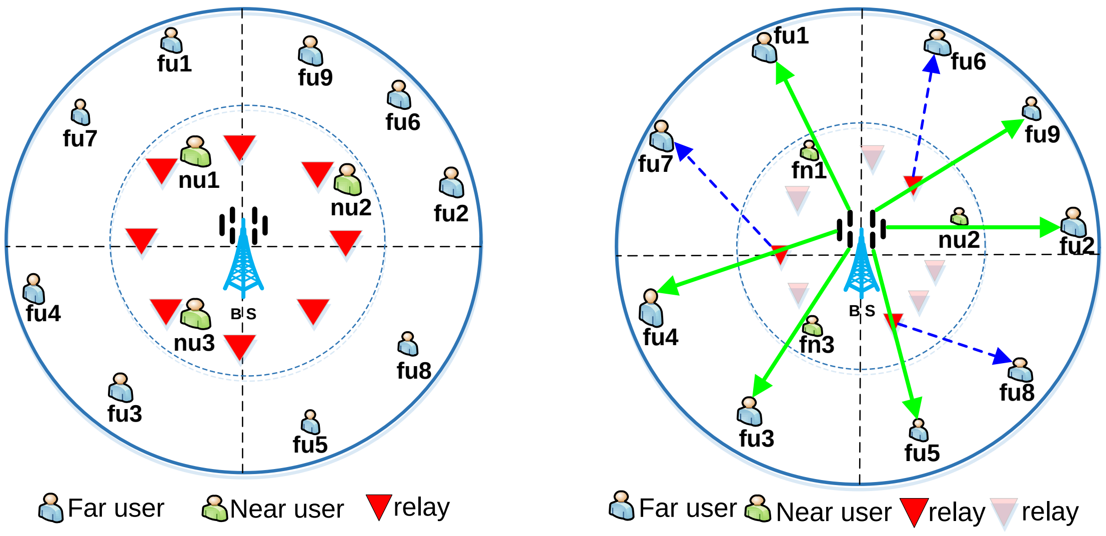


Figure 6.1(a) Figure 6.1(b)

Figure 6.1: Imbalanced technique with the proposed solution

A more detailed elaboration of this concept can be given as follows. It is known that there are *k* near-users (k<N) out of the 2N-users to be served. Thus, there are *k* original near-far user pairs that would be served via *k*-antennas. Subsequently, there are (*N*-*k*) antennas available

to serve the remaining 2x(N-k) far-users. To achieve this, (N-k) relays are selected from the set of relays. These N-k relays will be used to act as near-users for the first group of (N-k) far users; they will be served with the information designated to the second group of (N-k) far-users. In this way, there will be an additional (N-k) pairs of near-far users; each pair consisting of one relay and one far-user from the first group. These additional (N-k) pairs will be served through the (N-k) available antennas. Thus, the base station will be able to implement NOMA technology on all the N-antennas; and subsequently serve 2N-users (k original near-users, N-k relays, and 2N far-users).

At this point, the setup is primarily transformed into the original NOMA scenario; and the fairness maximization problem of this setup can simply be solved utilizing the “initial FM-PAA”. After this stage, the (N-k) relays will respectively forward the decoded information to the designated far-user in the second group. When doing so, the relay serves the far-user with sufficient power so that it can achieve the maximum OCTR-ratio, under the relays’ power constraints. Upon completing the first and second stages, the advanced solution successfully serves all the 2N-users of the imbalanced NOMA scenario; while at the same time maximising the network’s users-fairness. The proposed algorithm “Algorithm 3”, which implements the described concept, is presented in Table 6.1 below. Figure 6.2 below illustrates the described scenario, with the case of 6 antennas (N), 3 near-users (k), and 9 far-users (2N-k). In this case, 3 relays (i.e. N-k) have been selected for service. The green arrows indicate the NOMA implementation between the 6 near users (3 originals, 3 relays) and 6 far users. The blue arrow dots represent the forwarding of information from the 3 relays to the 3 additional far-users, respectively. Figure 6.2 below is an Illustration of the servicing process in the imbalanced “more far-users” NOMA scenario, with near-field relays: only the selected relays are ON; case of 6 antennas, 3 near-users, and 9 far-users.

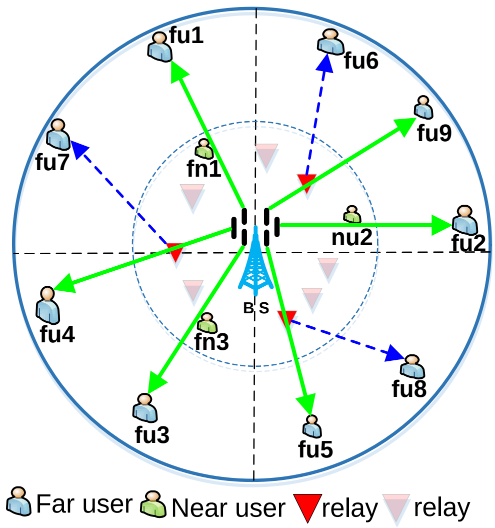


Figure 6.2: Proposed network design

The relay-to-far-user link can be characterized as follows. The relay acts as the access point and transmits the information with a reasonably high power (P_{relay}), for the far-user to achieve a good quality of service; and therefore, a high OCTR ratio. The transmitted signal by the relay (S_{tx-r}), the received signal by the far-user (S_{rx-fu}), as well as the $SINR_{fu}$ of the far-user can respectively be expressed as:

$$S_{\text{tx-relay}} = \sqrt{P_{\text{tx-relay}}}\, s_{\text{fu}} \tag{6.1}$$

$$S_{\text{rx-fu}} = h_{\text{fu}}^{H} \sqrt{P_{\text{tx-relay}}}\, s_{\text{fu}} \tag{6.2}$$

$$SINR_{\text{fu}} = \frac{\left|h_{\text{fu}}^{H}\right|^{2} P_{\text{tx-relay}}}{P_{\text{noise}}} \tag{6.3}$$

Where "h_{fu}" is the channel-vector between the relay and the far-user. With D_{fu} being the traffic request of the far-user, the fairness maximization on this link can be formulated as an optimization problem below:

$$\boldsymbol{P_3}: \quad \max_{(P_{\text{tx-relay}})} \quad (R_{\text{fu}}) \tag{6.4}$$

$$\text{s.t. } P_{\text{tx-relay}} \leq P_{\text{relay-max}} \tag{6.5}$$

Since the maximum useful R_{fu} is 1, where $R_{fu}=C_{fu}/D_{fu}$, the optimisation problem (***P*₃**) can be solved analytically and the solution "$P_{tx-max-relay}$" can be obtained as follows:

$$log_2(SINR_{\text{fu}} + 1) = D_{\text{fu}} \tag{6.6}$$

$$\therefore \; P_{\text{tx-max-relay}} = \frac{(2^{D_{\text{fu}}} - 1)P_{\text{noise}}}{\left|h_{\text{fu}}^{H}\right|^{2}} \tag{6.7}$$

The applicable power by the relay ($P_{tx-relay-app}$) to maximise fairness of the far-user will be the minimum $P_{tx-max-relay}$ and $P_{relay-max}$:

$$P_{\text{tx-relay-app}} = \min(P_{\text{tx-max-relay}}, P_{\text{relay-max}}) \tag{6.8}$$

6.2 Proposed optimal algorithm (algorithm 3)

The proposed optimal algorithm for the study is shown in Table 6.1. To be consistent with the research objectives the proposed optimal algorithm aims to achieve better system performance and fairness of the network. With the simulation results provided indeed the proposed optimal solution outcomes outperform the existing PAA. The results of the advanced PAA indicate how the superiority of the proposed solution behaves.

Table 6.1: Advanced Fairness-Maximisation PA-Algorithm (Advanced-PAA) for an imbalanced 2 Users NOMA Network with more far-users

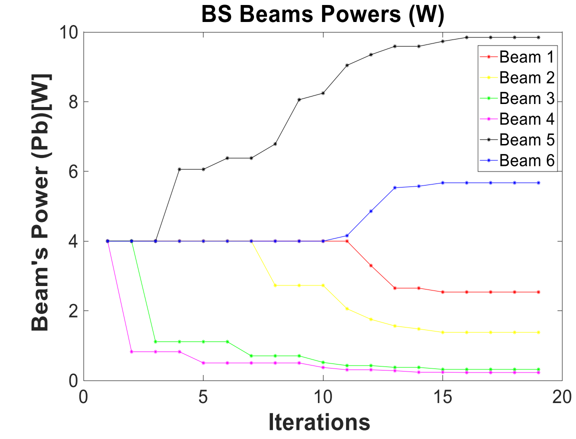
Algorithm 3: Advanced-PAA	
1:	Receive all channel vectors (h_u) and traffic requests (D_u) of all the 2N-users and (N-k) relays.
2:	Receive the formulated N NOMA-pairs and the (N-k) additional far-users.
3:	Specify: $P_{tot\text{-}BS}$, $P_{b\text{-}max}$, $P_{b\text{-}init} = P_{tot\text{-}BS}/N$, ce, and $P_{relay\text{-}max}$.
4:	Execute ***"Initial FM-PAA"*** by giving it $h_{u\text{-}s}$, $D_{u\text{-}s}$ & the N-pairs.
5:	Store the resulting "$P_{b\text{-}set\text{-}opt}$" & "$\alpha_{b\text{-}set\text{-}opt}$", from "Initial FM-PAA".
6:	Execute ***"relay-forwarding"*** (eqt 6.1 & 6.2 above) for each of the additional (N-k) far-users, by giving it all "$h_{fu\text{-}s}$".
7:	Store the resulting "$P_{relay\text{-}app\text{-}set}$" = [$P_{relay\text{-}app\text{-}1}$, …, $P_{relay\text{-}app\text{-}(N\text{-}k)}$], from "relay-forwarding".
8:	Combine "$P_{b\text{-}set\text{-}opt}$", "$\alpha_{b\text{-}set\text{-}opt}$" and "$P_{relay\text{-}app\text{-}set}$" as the final results.
9:	Terminate!

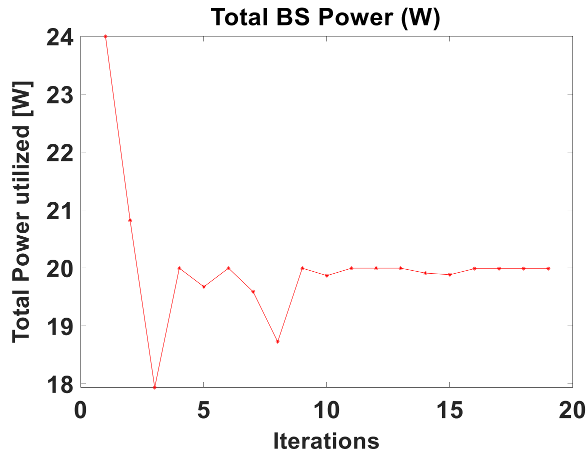
6.3 Implementation and testing of Algorithm 3

The proposed "Algorithm 3" was tested under the same network description earlier in section-1; and with the case scenario described in Figure 6.2 above. As indicated, the relays are first treated as ordinary near-users, for NOMA implementation. Thus, their respective channel vectors and traffic requests are given as part of the user set. Since the relays are implementing "decode and forward", all they need is to get the information designated for their respective additional far-user. As such, the traffic requests of relays are intentionally made to be relatively small, so to favour the fairness of the far user with each relay is sharing NOMA resources. The test results obtained are presented in Figures 6.3(a) to 6.3(f) below. These results show that the "Advanced-PAA" serves more users in the imbalanced NOMA scenario than when using "intermediate-PAA" or the "initial-PAA" alone. Consequently, it provides an improved system of user fairness, as can be noticed by comparing the fairness index graph in Figure 6.3(f) below and Figure 6.2(f) above.

6.4 Superiority of the Advanced PAA

The simulation results below illustrate how the proposed algorithm outperforms other existing algorithms. As per our expectation, the implementation of the relays has a better advantage in the overall fairness of the system and the performance. Figure 6.3 Test results of the intermediate-PAA in the “more far-users” scenario, with 6 antennas, 3 near-users, and 9 far users; as well as an average traffic request of 4bps/Hz





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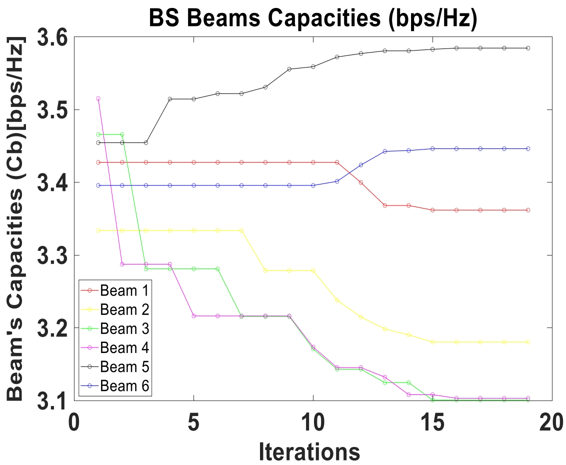
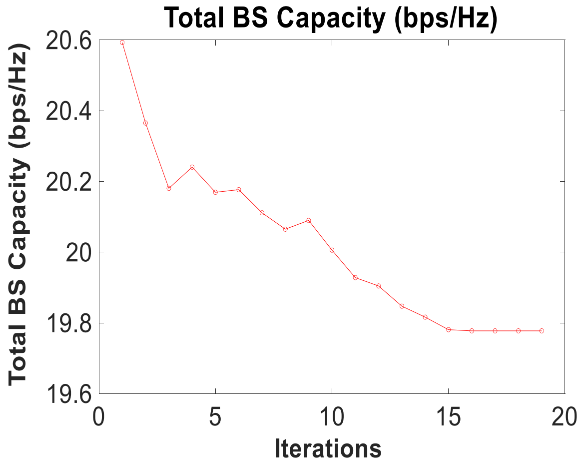
6.3(a)

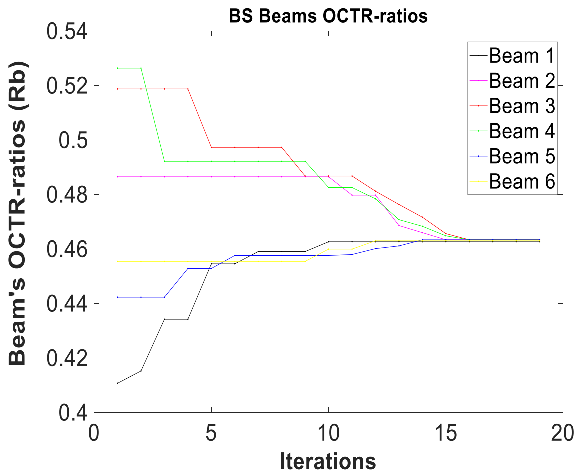
6.3(b)

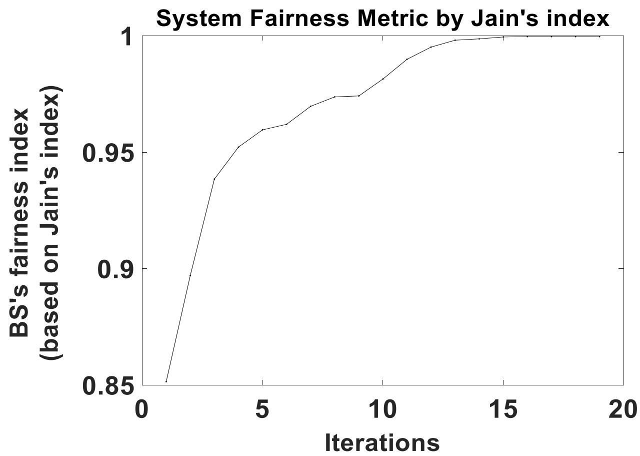




6.3(c)

6.3(d)





6.3 (e)

6.3(f)

Figure 6.3: Simulation results of the proposed solutions

6.5 The superiority of the Advanced-PAA against other Algorithms:

Figure 6.4 below plots the fairness-index graphs for the four discussed solutions, to maximise users-fairness in the imbalanced NOMA scenario (case of more far users). The plots show that the "advanced-PAA" which has been highlighted in "red" outperforms the other existing solutions as it provides the highest fairness index to the imbalanced network (showed in yellow) against (showed in blue) and (showed in green) for "intermediate-PAA" and "initial-PAA alone" respectively. **Error! Reference source not found.** illustrate the users-fairness index for different proposed solutions to demonstrate the optimality of the proposed PAA when combined with other PAA. Additionally, **Error! Reference source not found.** demonstrates the proposed solutions with the initial FM-PAA where all PAA are being simulated in the same figure. The proposed algorithm outperforms all other initial FM-PAA including NOMA and OMA as well as imbalance scenarios.

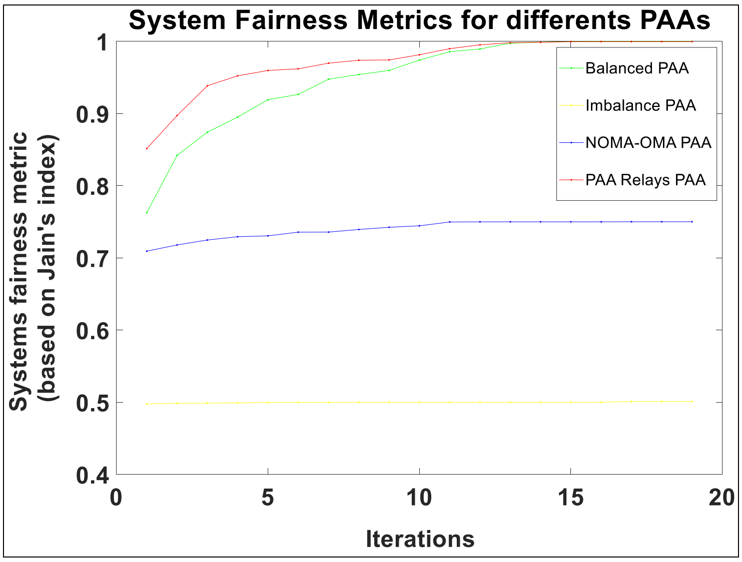


Figure 6.4: Simulation results of all PAA

6.6 Novelty of the proposed solution PAA

The algorithm presented in Table 6.3 above provides some novelty in the research study:

(i) Firstly, to the best of the author's knowledge, to this extent, there is no reported work from the existing literature depicting the development of PAA for imbalanced 2Users NOMA Network with more far-users,

(ii) Secondly, the architecture proposed which presents the near-relay scenario distinct as novelties in the proposed research. This includes both the functionality of the relay presented in the study.

(iii) Thirdly the recommended technique (OCTR equalising concept) for terrestrial environments for both intra-beam and inter-beam approaches represents an appropriate novelty in the research study.

(iv) Lastly, the entire combination of the NOMA-based approach and relay combination as the cooperative method in the terrestrial network is purely a novelty in our research study.

6.7 Conclusion

This chapter has presented the systematic and comprehensive approach for the development of multi-relay and far-user power allocation algorithms to maximise system fairness. We first derived and performed expression modelling to establish system capacity for a near user and far user respectively. We then formulated intra-beam and inter-beam power allocation as well as global power allocation solutions as closed-form expression and optimization problems. And thereafter we executed the simulation. The simulation results once demonstrated that indeed the proposed power allocation solution outperforms the existing power allocations which mostly focus on capacity maximisation and outage behaviour of the network. Additionally, the simulation results not only illustrate the convergence to the optimal solution with a smaller number of iterations but also enhance user reliability of the far user and system effectiveness. We then demonstrated that once the system fairness is maximised in line with our research objective, the far user reliability and availability in the network are guaranteed.

CHAPTER 7:
CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

This research has proposed two conceptual solutions in an attempt to address the fairness problem in NOMA-based base-station networks with imbalanced more far-user scenarios.

First, the research showed that, if the power-allocation algorithms designed for the traditional balanced NOMA scenario, are used straight into the imbalanced NOMA scenario, without any adjustment; they will result in a quite poor network fairness. To come to this conclusion, a power-allocation algorithm intended for a balanced NOMA scenario, labelled “Algorithm 1: Initial fairness-maximization PAA”, was designed, and implemented. The design of this “Initial FM-PAA” was based on the “OCTR-ratios convergence concept”. It was then tested in a balanced NOMA scenario, and the results showed that the network’s fairness was indeed maximized. Thereafter, it was tested straight into the imbalanced NOMA scenario, and the results showed that it yielded relatively poor network fairness. Thus, using “Initial FM-PAAs” straight into the imbalanced NOMA scenario would not be a considerable solution to the problem.

After the above observation, the research proposed an intermediate solution to address the problem. The solution combines OMA and NOMA technologies. NOMA is used to serve the possible far-near users’ pairs in the imbalanced scenario; while OMA is used to serve some far users from the remaining set, which could not be served by NOMA. Thus, a power-allocation algorithm, labelled “Algorithm 2: Intermediate PAA”, which executes NOMA, combined with OMA, was designed, implemented and tested. The algorithm consists of an inter-beam power-sharing stage, to distribute base-station power across respective antennas; and an intra-beam power-sharing stage, only applicable to the NOMA pairs formulated. Both stages employed the “OCTR-ratios convergence concept”, commonly used for the design of fairness-maximization power-sharing algorithms. The results indicated that the proposed “intermediate-PAA” considerably improves the fairness of the imbalanced-NOMA network scenario; compared to when the “initial FM-PAA” is used straight. However, since it does not serve all users, it therefore constitutes an intermediate solution to the problem stated.

Furthermore, the research proposed an advanced solution to address the problem. The solution consists of placing relays in the near-field of the base station; in the imbalanced more-far users’ scenario. Depending on the number of remaining antennas with no NOMA pair, the same number of near-field relays is used. Each relay serves as the near-user to one of the unpaired far-users, and it will be served with the information intended for the other unpaired far-user. This turns the system into a perfectly balanced NOMA scenario. Then, a power-allocation algorithm, which combines an “initial FM-PAA”, and a “relay management system”, is designed, implemented and tested. It is named here named “Algorithm 3: Advanced PAA”. The “initial FM-PAA” was designed based on the “OCTR-ratios convergence” concept, both in its inter-beam and intra-beam power allocation stages. The “relay-management system” was based on the “decode and forward” concept. The results demonstrated that the proposed “advanced PAA” maximizes the fairness of the imbalanced NOMA network scenario; and as such, outshines, both the “intermediate PAA” and the “initial FM-PAA” used straight. Therefore, it provides an optimal solution to the stated problem.

7.2 Response to the proposed research questions

(i) What are the key advantages of developing dynamic power allocation over a fixed power-sharing method?

First, dynamic power allocation is more efficient than fixed power allocation, as it would allow the access point to only use the amount of power needed. In addition, it allows for the optimisation of the network’s performances, in terms of achievable total capacity (Sum Rate) or achievable network’s users-fairness (reliability).

(ii) What are the most optimum concepts for developing power-allocation algorithms which aim at maximizing the network’s fairness?

To design power-sharing algorithms with the aim of maximizing the system’s user fairness, the two commonly used fundamental concepts include the “OCTR-ratios convergence” and the “Maximum-Minimum Fairness” concepts. The former implies giving all users the same level of satisfaction and thus producing a total system of user fairness. It is however quite inefficient, as it often implies, leaving a lot of available power unused. This later implies, serving users according to their “deserving right” to the available power; and thereafter adjusting power from those with excess, giving to those in defect. It comes out to be far more power efficient than the former.

(iii) How can fairness be improved in the imbalanced NOMA network with more far-users, from its poor status obtained when using only the power-allocation algorithm of balanced NOMA?

Two possible ways to achieve this goal have been proposed in this research. The first implies generating a power-allocation algorithm which combines NOMA and OMA. It yields lots of improvement when compared to using the power allocation for a balanced scenario straight into an imbalanced scenario. The second implies, making use of relays in the near-field of the network’s base station; and then generating a power-allocation algorithm which combines the balanced-scenario and the relay-management.

7.3 Recommendations

The power-allocation algorithms designed throughout this research for fairness-maximization of the network were all based on the “OCTR-ratios convergence” concept. It is therefore recommended that a similar work be conducted using the “maximum-minimum fairness” concept, to investigate possible improvement in the current results.

In this research, the focus was put on the imbalanced NOMA scenario with more far-users. It is therefore recommended that similar research be conducted for the case of more near-users.

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9. APPENDICES

9.1.1 Appendix-A: Top-Level MATLAB Code for “Algorithm 1:Initial-FM-PAA”

```
%% ****************************************************************%%%
%          Initial Fairness-Maximization PA-Algorithm (Initial-FM-PAA)          %
%                 for a traditional 2Users NOMA Network                          %
%%% ****************************************************************%
function [Pb_set_opt, ab_set_opt] = Initial_FM_PAA(2N_Demands,
         2N_Chanel_Vect, N-pairs, Ptot_BS, Pb_max, Noise_power_W, N)


    %% PROCESS INITIALIZATION
    %define
    cee = 0.01;
    Pb_init = Pb_tot_BS/N;


    %generate Pb_set_init
    for b = 1:N
        Pb_set_init(b) = Pb_init;
    end


    %% ITERATIVE PROCESS UNTIL "OCTR-ratios Convergence" IS OBTAINED
    octr_ratios_convergence = NO;
    Pb_set_new = Pb_set_init;
    while(octr_ratios_convergence == NO)


        %% RECEIVE THE NEW BEAMS-POWERS SET (Pb_set_new)
        Pb_set_cur = Pb_set_new;


        %%DO INTRA-BEAM PA PROCESS TO GET "ab" and "Rb" FOR EACH BEAM(b):
        %I.E. CALL INTRA-BEAM PA-ALGORITHM BASED ON "OCTR-ratios-CONV"
        for b = 1:N
            [ab, Rb] = intra_beam_paa_ORC(2N_Demands,2N_Chanel_Vect,
                          N-pairs, Noise_power_W,);


            ab_set(b) = ab;
            Rb_set(b) = Rb;
        end


        %% DO INTER-BEAM PA PROCESS TO DET IF CONV-REACH OR NEW-Pb_set:
        %I.E. CALL INTER-BEAM PA-ALGORITHM BASED ON ""OCTR-ratios-CONV"
```

```
        [Pb_set_new, conv_reached] = inter_beam_paa_ORC(Pb_set_cur,
                                     Rb_set, BS, Pb_max);

        %% CHECK WHETHER TO TERMINATE OR LOOPBACK
        if(conv_reached == 1)
            octr_ratios_convergence = YES;
        elseif(conv_reached == 0)
            octr_ratios_convergence = NO;
        end
    end

    %% OUTPUT RESULTS
    Pb_set_opt = Pb_set_new;
    ab_set_opt = ab_set;
end
```

9.1.2 Appendix-B: Top-Level MATLAB Code for "Algorithm 2: Intermediate-FM-PAA"

```
    % ************************************************************* %
    %   Intermediate Fairness-Maximisation PA-Algorithm (Intermediate-PAA)   %
    %     for an  imbalanced 2Users NOMA Network with more far-users      %
    %% *************************************************************%
function [Pb_set_opt, ab_set_opt] = Intermediate_FM_PAA(2N_Demands,
         2N_Chanel_Vect,2N_users,k-pairs,Ptot_BS,Pb_max,Noise_power_W)

    %% PROCESS INITIALIZATION
    %define
    cee = 0.01;
    Pb_init = Pb_tot_BS/N;

    %generate Pb_set_init
    for b = 1:N
        Pb_set_init(b) = Pb_init;
    end

    %% ITERATIVE PROCESS UNTIL "OCTR-ratios Convergence" IS OBTAINED
    octr_ratios_convergence = NO;
    Pb_set_new = Pb_set_init;
    while(octr_ratios_convergence == NO)

        %% RECEIVE THE NEW BEAMS-POWERS SET (Pb_set_new)
        Pb_set_cur = Pb_set_new;

        %%DO INTRA-BEAM PA PROCESS TO GET "ab" and "Rb" FOR EACH k-BEAM:
        %I.E. CALL INTRA-BEAM PA-ALGORITHM BASED ON "OCTR-ratios-CONV"
        for b = 1:k
            [ab, Rb] = intra_beam_paa_ORC(2k_Demands,2k_Chanel_Vect,
                        k-pairs, Noise_power_W,);

            ab_set_k(b) = ab;
            Rb_set_k(b) = Rb;
        end

        %%SERVE REMAINING (N-k) antennas utilizing OMA.
        for u = 1:(N-k)
            [Ru] = OMA_paa(user-Demand,user_Chanel_Vect,Noise_power_W,);
```

```
            Rb_set_N_k(s) = Ru;
        end

        %% GENERATE THE Rb_set FOR ALL ANTENNAS
        Rb_set = [Rb_set_k & Rb_set_N_k];

        %% DO INTER-BEAM PA PROCESS TO DET IF CONV-REACH OR NEW-Pb_set:
        %I.E. CALL INTER-BEAM PA-ALGORITHM BASED ON ""OCTR-ratios-CONV"
        [Pb_set_new, conv_reached] = inter_beam_paa_ORC(Pb_set_cur,
                                         Rb_set, Ptot_BS, Pb_max);

        %% CHECK WHETHER TO TERMINATE OR LOOPBACK
        if(conv_reached == 1)
            octr_ratios_convergence = YES;
        elseif(conv_reached == 0)
            octr_ratios_convergence = NO;
        end
    end

    %% OUTPUT RESULTS
    Pb_set_opt = Pb_set_new;
    ab_set_opt = ab_set;
end
```

9.1.3 Appendix-C: Top-Level MATLAB Code for “Algorithm 3: Advanced-PAA”

```
% *************************************************************** %
%       Advanced Fairness-Maximisation PA-Algorithm (Advanced-PAA)       %
%       for an  imbalanced 2Users NOMA Network with more far-users        %
%% ***************************************************************%
function [Pb_set_opt, ab_set_opt, P_relay_app_set] = Advanced_FM_PAA
(2N_Demands,2N_Chanel_Vect,2N_users,k-pairs,Ptot_BS,Pb_max,Noise_power_W)


    %% PROCESS INITIALIZATION
    %defin
    cee = 0.01;
    Pb_init = Pb_tot_BS/N;
    P_relay = Pb_init;


    %generate Pb_set_init
    for b = 1:N
        Pb_set_init(b) = Pb_init;
    end
    %% FORMULATE THE 2N-PAIRS = k_pairs(normal) + (N-k)_pairs(fu+relay)
    2N_pairs = k-pairs + (N-k)_pairs;

    %% CALL THE “INITIAL-FM-PAA” TO SERVE THE 2N-PAIRS
    [Pb_set_opt, ab_set_opt] = Intermediate_FM_PAA(2N_Demands,
     2N_Chanel_Vect,2N_users,N-pairs,Ptot_BS,Pb_max,Noise_power_W);

    %% CALL THE “RELAY-FORWARDING” TO SERVE THE ADDITIONAL (N-k)_far_users.
    [P_relay_app] = Relay_forwarding((N-k)_users, users-demand,
                    user-vector, noise_power_W);


    %% OUTPUT RESULTS
    Pb_set_opt = Pb_set_new;
    ab_set_opt = ab_set;
    P_relay_app_set= P_relay_app;
end
```

10. Appendix-D: Supplementary Information

D1: **Recommended convergence minimum value.**

The optimum design consideration of OCTR power allocation begins by evaluating the other crucial aspects such as convergence error. The second assessment is the user's achievable capacity which can range between the lowest value bits per second per hertz. For eminent design consideration, a trade-off need is required to be made and be selected appropriately and the assumption ranges between 0.1 to 10 bps/Hz. Apart from that, the lowest values 0.01 or 0.02 are both values that are well-suitable and recommended minimum values where both ratios reaching minimum is convenient and acceptable as the OCTR converge concept has been achieved. This value is called convergence error and is the value once all ratios converge then the process terminates as per the developed algorithm.

D2: Analytical modelling of convergence error value

The convergence error value is the most critical component in computer networks and computer programming. This value sets a minimum acceptable threshold for the power allocation algorithm to terminate the program. The convergence error needs to be defined clearly as it sets all beam ratios to be equal. The definition of the convergence error for the power allocation process is dependent on several system specifications. In this application, as it will be presented later in the simulation section, the users' traffic requests are assumed to be in the range of 0.2 to 20 bps/Hz; and the achievable capacities of users are in practice usually greater than 0.1 bps/Hz. Thus, from this observation, it is reasonable to estimate that, the minimum possible OCTR ratio in the worst-case scenario, would be of the order (0.2/20) = 0.01. On feasibility, there does not seem to be a possible practical case where the OCTR ratio of a user would be less than 0.01. For this reason, we decided to use the value of 0.01 as the sensitivity of the OCTR-ratio; and we subsequently set the convergence-error value to be ce = 0.01. This therefore means that we will consider that the OCTR ratios within the beam are converging when their difference is less than 0.01. Note however that, if the extreme conditions assumed for the maximum traffic request (20bps/Hz) and minimum offered capacity (0.2bps/Hz) are relaxed, the convergence error (ce) could be increased; and that will improve the convergence time of the system performance.

D3: **Classification and modelling of decrement values step size**

For decrement step value formulation, we opt to use a similar approach as the increment above can be used in reverse. Instead of adding the step new now in this case we need to subtract the value as we are working in reverse to determine the value for decrement.

New step in $_{\alpha b}$ = beam_intial - $Step_{new}$

Verification steps of R_{bn} and R_{bf} if achieved.

This section only verifies if the ratio of the near user and the far user has been achieved in the beam or if there are any adjustments needed to be carried out by the search method. Once verification is completed and no further adjustment is needed, neither increment nor decrement is applicable based on the new move that was discussed in the previous section. The new alpha relay can be expressed in terms of decrement and increment as follows:

$\alpha_{b\_new}=\alpha_b+Step_{new}$ the increment step size

$\alpha_{b\_new}=\alpha_b-Step_{new}$ the decrement step size

The first step of the methodology is increasing the power of the minimum beam ratio. R_{beam_min}, once the value reaches the minimum point the value will be recorded down as step new increment. The second step is to adjust the power down from R_{beam_max} until the power reaches the minimum value. Once this value is obtained it will then be recorded down as step new decrement. Another important consideration can be made in terms of equivalences were $Step_{new\_incre}$ can be noted as equivalent to P_{b_incre} and subsequently $Step_{new\_decre}$ can be made equivalent to P_{b_decr} , in terms of power and ratio adjustments. Once those values are recorded, the only important analytical aspect is stepping verification. For instance, there is a need to check if both adjustment methods are optimum alternatively if there is no need to adjust down or up. If the verification process is correct, all values can be recorded, the process can be terminated, and the results can be saved.

D4**: NOMA and imbalance network**

The traditional NOMA technique requires the user pairing or grouping, for instance near user has to be grouped with a far user with both channel conditions taken into consideration. It is critical for NOMA implementation to utilize a grouping technique hence in this research the existing paring technique has been utilized. In other words, the user grouping algorithm has been utilized in this research.

As it was stated prior in the previous section while defining the problem statement there is always an assumption that the number of near users is similar to far users but in practical circumstances or in the real world that is not the case. In some cases or instances, you will find more far users than near users or vice versa hence our research problem stated. In those cases where imbalance users occurred NOMA would not be fully applied otherwise NOMA and OMA will be applicable. The origin of our proposed study triggers in cases where imbalance among users needs to be served by the BS, in such cases we assign the near-field relay to serve as a near user and support far user in paring.

D5: **NOMA implementation**

Non-orthogonal multiple access NOMA can be incorporated with various networks such as software-defined radio SDR, including communication networks such as Multiple input multiple output MIMO, beamforming, cooperative communication as well as millimetre-wave(Xiong et al., 2015)(Khan & Sohaib, 2021).