**REPUBLIC OF TURKIYE**
**ISTANBUL GELISIM UNIVERSITY**
**INSTITUTE OF GRADUATE STUDIES**

Department of Electronics and Electrical Engineering

# INVESTIGATING THE BIT ERROR RATE PERFORMANCE OF THE MIMO-NOMA NETWORK WITH MAJORITY-BASED TAS/MRC SCHEME

Master Thesis

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Supervisor
Asst. Prof. Dr. Mahmoud HK. ALDABABSA

**Istanbul – 2023**

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## DECLARATION

I hereby declare that in the preparation of this thesis, scientific ethical rules have been followed, the works of other persons have been referenced in accordance with the scientific norms if used, there is no falsification in the used data, any part of the thesis has not been submitted to this university or any other university as another thesis.

Princewill Kum KUMSON
__/__/2023

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The thesis study of **PRINCEWILL KUM KUMSON** titled as **Investigating The Bit Error Rate Performance Of The MIMO-NOMA Network With Majority-Based TAS/MRC Scheme** has been accepted as MASTER THESIS in the Department of **Electrical & Electronics Engineering** by our jury.

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# SUMMARY

This thesis focuses on examining the performance of downlink MIMO-NOMA networks using the TAS-maj/MRC technique. It addresses the limitations of previous studies and explores the advantages of combining NOMA and MIMO technologies. Previous research has mainly focused on evaluating SISO NOMA networks and has overlooked the error rate performance of MIMO-NOMA systems. Finding an optimal transmit AS solution remains a challenge in NOMA networks.

To overcome these limitations, this thesis makes significant contributions. Firstly, it investigates the bit error rate (BER) performance of the downlink MIMO-NOMA network with the TAS-maj/MRC scheme under the Nakagami-m fading channel model. By considering the Nakagami-m fading model, which better represents real-world fading channel conditions, a more accurate assessment is achieved. The thesis provides an exact closed-form expression for the BER, offering insights into the system's performance.

Additionally, asymptotic analysis is conducted in high signal-to-noise ratio (SNR) regions to evaluate the diversity and array gains achieved by the TAS-maj/MRC scheme. This analysis enhances our understanding of the system's behavior and the benefits of employing the TAS-maj/MRC scheme in MIMO-NOMA networks. Theoretical results are validated through extensive Monte Carlo simulations, demonstrating significant BER improvements with increasing receive antennas and improved channel conditions.

The research findings contribute to a comprehensive understanding of the BER performance of MIMO-NOMA systems with the TAS-maj/MRC scheme under various channel conditions. This understanding is valuable for the design and optimization of practical wireless communication applications. By identifying the limitations of MIMO-NOMA systems and proposing strategies to enhance their performance, this research aims to advance wireless communication systems.

The thesis structure is as follows: Chapter 1 provides an overview of OMA radio access techniques, introduces NOMA concepts in downlink and uplink networks, and discusses the emergence of MIMO-NOMA systems. Chapter 2 presents a literature review, analyzing previous research on MIMO-NOMA systems, emphasizing the need to investigate the error rate performance.

Chapter 3 describes the theoretical framework of the MIMO-NOMA system with the TAS-maj/MRC scheme, including the Nakagami-m fading channel model, transmit AS schemes, and MRC on the receiver side. The derivation of the closed-form expression for the BER is explained in detail.

Chapter 4 presents simulation results and analyzes the BER performance under different channel conditions. Various parameters, such as receive antennas and channel conditions, are examined through Monte-Carlo simulations, confirming the improvements in BER performance and validating the theoretical findings.

Finally, We summarize the research findings, discuss the study's contributions, and suggest directions for future research. The summary highlights the significance of this research in bridging the gap between NOMA and MIMO technologies, exploring the benefits of the TAS-maj/MRC scheme in MIMO-NOMA networks, and providing insights into the system's behavior under different channel conditions.

**Key Words:** Non-Orthogonal Multiple Access (NOMA), MIMO-NOMA, Transmit Antenna Selection (TAS), Majority-Based TAS, Maximal Ratio Combining (MRC), Bit Error Rate (BER), Wireless communication systems, Capacity and spectral efficiency, Antenna diversity, System performance Optimization, Channel conditions.

# ÖZET

Bu tez, TAS-maj/MRC tekniği kullanılarak uydu-yer bağı MIMO-NOMA ağlarının performansını incelemeye odaklanmaktadır. Önceki çalışmaların sınırlamalarını ele alır ve NOMA ile MIMO teknolojilerini birleştirmenin avantajlarını araştırır. Önceki araştırma, temel olarak SISO NOMA ağlarını değerlendirmeye odaklanmış ve MIMO-NOMA sistemlerinin hata oranı performansını göz ardı etmiştir. NOMA ağlarında optimal bir iletim AS çözümü bulmak bir sorun olmaya devam ediyor.

Bu sınırlılıkların üstesinden gelmek için bu tez önemli katkılar sağlamaktadır. İlk olarak, Nakagami-m sönümleme kanalı modeli altında TAS-maj/MRC şeması ile aşağı bağlantı MIMO-NOMA ağının bit hata oranı (BER) performansını araştırır. Gerçek dünyadaki sönümlemeli kanal koşullarını daha iyi temsil eden Nakagami-m sönümleme modeli dikkate alınarak daha doğru bir değerlendirme elde edilir. Tez, sistemin performansına ilişkin içgörüler sunarak, BER için tam bir kapalı form ifadesi sağlar.

Ek olarak, TAS-maj/MRC şeması tarafından elde edilen çeşitliliği ve dizi kazanımlarını değerlendirmek için yüksek sinyal-gürültü oranı (SNR) bölgelerinde asimptotik analiz yapılır. Bu analiz, sistemin davranışına ilişkin anlayışımızı ve MIMO-NOMA ağlarında TAS-maj/MRC şemasını kullanmanın faydalarını geliştirir. Teorik sonuçlar, kapsamlı Monte Carlo simülasyonları aracılığıyla doğrulandı ve artan alıcı antenler ve iyileştirilmiş kanal koşulları ile önemli BER iyileştirmeleri gösterdi.

Araştırma bulguları, çeşitli kanal koşullarında TAS-maj/MRC şemasına sahip MIMO-NOMA sistemlerinin BER performansının kapsamlı bir şekilde anlaşılmasına katkıda bulunur. Bu anlayış, pratik kablosuz iletişim uygulamalarının tasarımı ve optimizasyonu için değerlidir. Bu araştırma, MIMO-NOMA sistemlerinin sınırlamalarını belirleyerek ve performanslarını artırmaya yönelik stratejiler önererek, kablosuz iletişim sistemlerini geliştirmeyi amaçlamaktadır.

Tezin yapısı şu şekildedir: Bölüm 1, OMA radyo erişim tekniklerine genel bir bakış sağlar, aşağı bağlantı ve yukarı bağlantı ağlarında NOMA kavramlarını tanıtır ve MIMO-NOMA sistemlerinin ortaya çıkışını tartışır. Bölüm 2, MIMO-NOMA sistemleri üzerine önceki araştırmaları analiz eden ve hata oranı performansını araştırma ihtiyacını vurgulayan bir literatür taraması sunar.

Bölüm 3, Nakagami-m sönümlemeli kanal modeli, iletim AS şemaları ve alıcı tarafında MRC dahil olmak üzere TAS-maj/MRC şemasına sahip MIMO-NOMA sisteminin teorik çerçevesini açıklamaktadır. BER için kapalı form ifadesinin türetilmesi ayrıntılı olarak açıklanmaktadır.

Bölüm 4, simülasyon sonuçlarını sunar ve farklı kanal koşullarında BER performansını analiz eder. Alıcı antenler ve kanal koşulları gibi çeşitli parametreler Monte-Carlo simülasyonları aracılığıyla incelenerek BER performansındaki iyileştirmeler doğrulanır ve teorik bulgular doğrulanır.

Son olarak, araştırma bulgularını özetliyoruz, çalışmanın katkılarını tartışıyoruz ve gelecekteki araştırmalar için yönler öneriyoruz. Özet, bu araştırmanın NOMA ve MIMO teknolojileri arasındaki boşluğu doldurma, MIMO-NOMA ağlarında TAS-maj/MRC planının faydalarını keşfetme ve farklı kanal koşulları altında sistemin davranışına ilişkin içgörü sağlama açısından önemini vurgulamaktadır.

**Anahtar Kelimeler:** Non-Orthogonal Multiple Access (NOMA), MIMO-NOMA, Transmit Antenna Selection (TAS), Majority-Based TAS, Maximal Ratio Combining (MRC), Bit Hata Oranı (BER), Kablosuz iletişim sistemleri, Kapasite ve spektral verimlilik, Anten çeşitliliği, Sistem performansı, Optimizasyon, Kanal koşulları.

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# ABBREVIATIONS

| | | |
|---|---|---|
| **3GPP** | : | 3rd Generation Partnership Project |
| **AS** | : | Antenna Selection |
| **BS** | : | Base Station |
| **CDMA** | : | Code Division Multiple Access |
| **CDF** | : | Cumulative Distribution Function |
| **DoF** | : | Degrees Of Freedom |
| **FDMA** | : | Frequency Division Multiple Access |
| **GSM** | : | Global System for Mobile communication |
| **LDS-CDMA** | : | Low-Density Spreading Code Division Multiple Access |
| **LDS-OFDM** | : | Low-Density Spreading Orthogonal Frequency-Division Multiplexing |
| **MUD** | : | Multi-User Detection |
| **OFDM** | : | Orthogonal Frequency-Division Multiplexing |
| **DMA** | : | Pattern Division Multiple Access |
| **PDF** | : | Probability Density Function |
| **QoS** | : | Quality Of Service |
| **SMS** | : | Short Messaging Service |
| **SDMA** | : | Space-Division Multiple Access |
| **SCMA** | : | Sparse Code Multiple Access |
| **TDMA** | : | Time Division Multiple Access |

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# PREFACE

I am thrilled to share my thesis with you, which showcases the results of my research and hard work in wireless communication systems. Specifically, my thesis delves into exploring the performance of downlink MIMO-NOMA networks, utilizing the Transmit Antenna Selection TAS-maj/MRC (Maximum Ratio Combing) technique. This journey has been an amazing one, full of exploration, obstacles, and breakthroughs.

The motivation driving this research stems from the growing demand by users for high-capacity and efficient wireless communication systems. Traditional Orthogonal Multiple Access (OMA) technologies face limitations in terms of capacity and spectral efficiency. Consequently, Non-Orthogonal Multiple Access (NOMA) has emerged as a promising solution. NOMA enables multiple users to share the same time-frequency resource through power-domain multiplexing, leading to increased capacity and spectral efficiency. Additionally, the combination of NOMA with Multiple-Input Multiple-Output (MIMO) technology has shown potential for further enhancing system performance.

The primary objective of this thesis is to address the limitations identified in previous studies and explore the benefits of integrating NOMA and MIMO technologies. Previous research has predominantly focused on SISO (Single-Input Single-Output) NOMA networks, disregarding the error rate performance of MIMO-NOMA systems. Furthermore, determining the optimal transmit Antenna Selection (AS) solution remains a challenge in NOMA networks. These research gaps have motivated me to conduct an in-depth analysis of MIMO-NOMA systems, specifically utilizing the TAS-maj/MRC scheme.

Without Asst. Prof. Dr. Mahmoud HK. ALDABABSA, this thesis wouldn’t have been a success. I therefore owe him gratitude for his invaluable guidance, support, and profound insights throughout this research journey. His expertise and encouragement have played a pivotal role in guiding this thesis and widening my scope in this field.

I am extremely grateful for the unwavering support, understanding, and encouragement from my family and friends throughout this demanding undertaking. Their unwavering belief in my abilities and constant encouragement have been a continuous source of motivation.

Ultimately, my hope is that this thesis will contribute to the existing knowledge base in wireless communication systems and inspire further research in this field. May the findings and insights presented here lay a strong foundation for future advancements and innovations.

# INTRODUCTION

Wireless communication systems has for the past few years seen improvement in its capaicy and spectral efficiency due to the emergence of new technologies like NOMA. NOMA permits the sharing of time-frequency resources by more than one user simultaneously through the modulation of their signals via different power levels and superimposing them at the receiver's end thereby, resulting in increased capacity and spectral efficiency compared to OMA technologies. For example, TDMA and FDMA (Mahmoud A. et al., 2018; Ding, Z., Peng, M., & Poor, H. V, 2015).

MIMO technology has the potentials to increase wireless system capacity while decreasing error probability. To mitigate the impact of fading channels, MIMO utilizes employment of antenna diversity techniques. Despite the ability to upgrade system performance and capacity, through the use of multiple radio frequency (RF) chains they consequently increase the complexity of the hardware. However, antenna selection (AS) schemes like TAS/MRC, Receive Antenna Selection (RAS), Joint Transmit and Receive Antenna Selection (JTRAS), and Transmit Antenna Selection (TAS) can overcome these limitations without taking away the benefits of morethan multi-antenna systems with fewer RF chains (A. Molisch & M. Win, 2004).

The performance of wireless communication systems has recently been studied with an eye toward integrating NOMA and MIMO technologies. This has given birth to the development of MIMO-NOMA system, which allows for more than one user to share the same time-frequency resources while employing multiple antennas for transmission and reception (Mahmoud Aldababsa & Oğuz Kucur, 2020).

While some research has made valuable addition to NOMA systems, we have identified some noteworthy observations that we would like to highlight.

It is important to note that some NOMA studies perform network evaluation using Rayleigh fading. Meanwhile, the Nakagami-m fading model is better suited for fitting empirical data compared to the later model. It can represent a diverse interval of fading channel conditions, including Rayleigh fading as a specific case when m=1.

It should be highlighted that some NOMA studies mainly duel on single-input single-output (SISO)-NOMA networks by examining their error rate performance and do not explore that of MIMO-NOMA networks. It's important to bear in mind that utilizing AS schemes and MIMO technology can greatly enhance NOMA performance.

Though some AS techiniques have been implemented in NOMA networks, it remains a challenge to find the most optimal transmit AS solution. An example of this is the TAS scheme, which has been mentioned in studies by A. P. Shrestha et al. (2016), S. Ustunbas and U. Aygolu (2017), H. Lei et al. (2017 and 2018), and D. -D. Tran et al. (2020). However, this scheme is unable to decide which transmit antenna offers the best channel condition between users and the base station. The best antenna selection is done by a series of factors amongst which is high sum-rate (A. P. Shrestha, et al., 2016), equity amongst users (S. Ustunbas & U. Aygolu, 2017), or safety between users (H. Lei et al., 2017; D. -D. Tran, et al., 2020; H. Lei et al., 2018). Finding the ideal TAS solution in NOMA networks is still difficult. Finding the ideal AS solution may not always be attainable due to the complexity of NOMA networks, which is why some scholars suggest sub-optimal AS systems. Several studies, including those by (Mahmoud Aldababsa and O. Kucur, 2019; Mahmoud Aldababsa and Oğuz Kucur in 2020), propose majority based AS schemes that improve performance for over half of users. However, sub-optimal AS schemes proposed by Y. Yu et al. in 2018 and Q. Li et al. in 2017 only enhance performance for either near or far users.. The MRC scheme is a well-known diversity technique that can provide both diversity and array gains and can be employed on the receiver side. In addition, combining the TAS maj solution with the MRC can achieve higher performance due to the benefits mentioned above. Thus, in this study, we adopt the TAS maj /MRC scheme.

The thesis aims to address the issues mentioned above and look into BER performance of downlink MIMO-NOMA network using the TAS maj/MRC solution. The following are the main contributions of this study:

We investigate the BER performance for binary phase shift keying (BPSK) in the downlink network with the TAS maj/MRC scheme under the Nakagami-*m* fading channel model.An exact closed-form BER express is derived.

To assess the array gains and diversity achieved by use of TAS maj/MRC, We conducted an asymptotic analysis in high SNR regions. This helped us to gain more insight on BER performance of the system.

We are able to verify how accurate the theoretical results is, via  conducting Monte-Carlo simulation. The simulation outcome reveals that BER performance improved significantly with increased  number of receive antennas or better channel conditions.

The outcome of this research will contribute to the understanding of the BER performance for MIMO-NOMA systems with majority based TAS/MRC solution under different channel conditions.This knowledge will be useful in the designing as well as optimization of MIMO-NOMA systems for practical wireless communication applications. In addition, the results will provide insights into the limitations of MIMO-NOMA systems and identify strategies for improving their performance.

The remainder of this thesis is organized as following manner: First chapter expands on a general overview of older OMA radio access techniques and introduces the basic concepts of NOMA with aprticular attention to both downlink and uplink networks and the existence of MIMO-NOMA. In Chapter 2, we provide a comprehensive review of pertinent research in the filed of MIMO-NOMA systems. Chapter 3 describes the theoretical framework of the system model for the MIMO-NOMA with a majority-based TAS/MRC scheme. Chapter 4 presents the simulation results and analyses the BER performance of the MIMO-NOMA system under different channel conditions. Chapter 5 summarizes the research results, discusses the research contributions, and provides directions for future research.

# CHAPTER ONE

# BACKGROUND

## 1.1. Introduction

The journey towards achieving 5G networks, recognized as the future of mobile communication, demanded an understanding of its building blocks. The scope of this chapter provides a broad panorama of these elements, discussing the key technologies that were seen as game-changers in the advancement towards 5G. Additionally, it introduces the concept of  NOMA why it was seen as a prospective candidate for fulfilling the ambitious goals of 5G and beyond.

## 1.2. Evolution of Mobile Networks

Mobile radio communication has consistently witnessed considerable evolution since its inception. Spanning several decades, we have seen the deployment of five generations of cellular communication systems, each succeeding generation emerging approximately every ten years since 1980. The chronological development began with the first-generation (1G) analog cellular systems in 1981, followed by the second-generation (2G) that embraced digital technology in 1992. The third generation (3G) made its debut in 2001, followed by the fourth generation Long-Term Evolution Advanced (LTE-A) in 2011 (J. G. Andrews, S. Buzzi & C. W., 2014) and today's 5G.

The 1G network, the inaugural generation of mobile phones, utilized analog systems. Despite pioneering mobile communication, these systems offered suboptimal and costly services. To mitigate these challenges, a paradigm shift towards digital communication techniques heralded the emergence of second generation, embodied by the Global System for Mobile Communication (GSM). Predicated on digital transmissions, GSM facilitated secure data transmission, reinforcing its global acceptance. It further nurtured the ubiquity of mobile communication, enabling users to make calls from virtually anywhere, in addition to the capacity to send short messages (SMS limited to 80 characters).

The primary objective of the 3G standard was to unlock the potential for multimedia applications, such as video dissemination, video conferencing, and high-bandwidth internet access. The advent of the fourth generation, often called 4G and embodied by the LTE-A technology, leveraged OFDM. This innovation supported transmission spectral bandwidth of up to 20 MHz and incorporated multiple transmit antennas. Although the theoretical data rates had a range from 100 Mb/s to 1 Gb/s, the practical speeds have been observed to be tens of Mb/s (Mahmoud A. et al., 2018; Ding Z. et al., 2015).

This evolutionary journey has underscored mobile networks' immense potential and rapid progression, setting the stage for the revolutionary leap toward 5G and beyond.

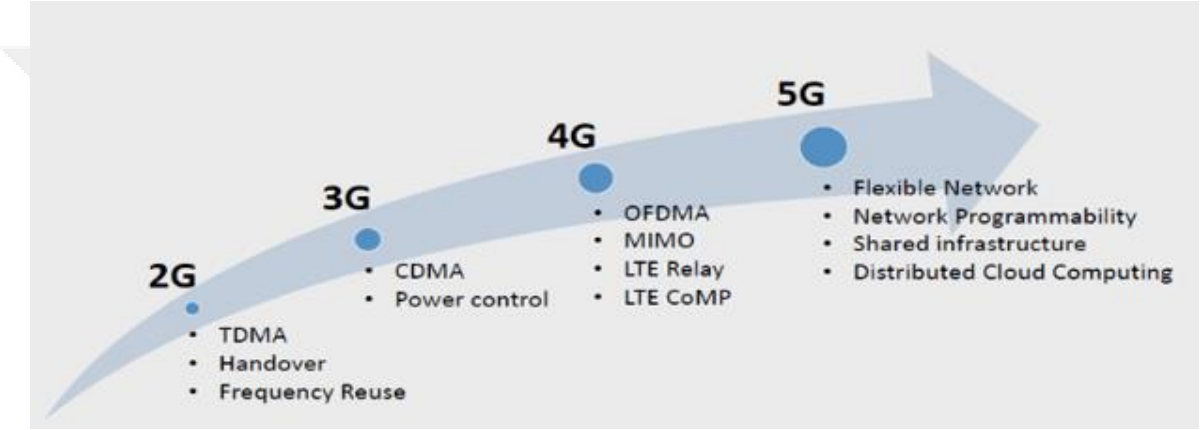

**Figure 1.** evolutional Journey of Mobile Networks

### 1.3. The Rationale Behind 5G

The deployment of 4G LTE-A networks only commenced in 2011 in a handful of countries. Transitioning to a new 5G network warranted additional investments at a time when operators were already managing two networks—2G/3G or 3G/4G. So, why was there already talk of 5G by then?

The meteoric rise in data traffic and the parallel evolution of mobile devices have pushed mobile communication systems to confront a surge in mobile traffic and congestion in the radio spectrum dedicated to cellular networks. These ranged between 700 MHz and 2.6 GHz. This predicament necessitated researchers to devise high-capacity systems and exploit a scope beyond the 4G standard with a broader bandwidth to accommodate higher data rates and meet subscriber demands. Today, the conceptualization and implementation of 5G is principally defined by a consensus on the comprehensive specifications and requirements that were to be completed by communication systems beyond 2020.

The key distinctions between this emerging generation and 4G will revolve around highly directional antenna networks at the base station and mobile terminals, higher binary rates, and a greater overall capacity for a substantial number of simultaneous users. By assimilating various research initiatives, the specifications for a 5G system can be outlined in eight key features (J. G. Andrews, S. Buzzi & C. W., 2014; Mahmoud A. et al., 2018)

- Applicable data rates range from 1 to 10 Gb/s, which is nearly ten times greater than the optimal data rate of the LTE-A network, which stands at 150 Mb/s.
- Latencies around 1ms, thus reducing those of 4G by a factor of 10.
- A broader spectral bandwidth per unit area: enabling mobile terminals within a cell to leverage a wider spectral bandwidth than that utilized in 4G (20 MHz) is imperative.
- An immense number of connected terminals: the new 5G network must guarantee connectivity to thousands of devices (IoT - Internet of Things).
- 99.999% availability: 5G envisages that the network should always be available.
- 100% coverage "anytime, anywhere": a 5G network must ensure comprehensive coverage, regardless of the user's location.
- Energy usage reduction by nearly 90%: Energy management will be far more critical with the elevated data rates and massive connectivity of the 5G network.
- Improved battery life: Reducing battery consumption of terminals is a fundamental criterion in emerging 5G networks.
- This highlights the ambitious agenda that the 5G technology aspires to achieve, positioning it at the vanguard of the future of mobile communications.

## 1.4. Concepts Based on Radio Access Technology

To archive a physical connection within a cellular network system, Radio Access Network (RAN) technology guarantees that. Essentially, RAN utilizes a method of channel access to guarantee connect between mobile terminals and the core network. Upgrading system capacity greatly depends on designing an appropriate multiple-access technique. We recognize two distinct multiple access techniques, namely OMA radio access technologies and NOMA radio access technology (A. Molisch & M. Win, 2004). Therefore to manage simultaneous communications in mobile networks, we need to employ these two techniques with each having their unique characteristics and advantages.

### 1.4.1. Orthogonal Multiple Access (OMA) Radio Access Technologies

OMA represents a scheme that permits a receiver to completely isolate the desired signal from undesired signals using distinct base functions. This simply means that, the signals from different users are orthogonal. Current cellular networks implement techniques that rely on OMA, however, to meetup with the high demand of future 5G network and beyond, these techniques need to be revised.

Existing cellular communication systems radio access technologies are characterized by orthogonal multiple access systems (Mahmoud A. et al., 2018). Though they have been foundational in operating current networks, these systems will need evolution to meet future requirements. They are:

*1- Frequency Division Multiple Access (FDMA):* Mobile phone service used this technology to works by partitioning the allocated frequency band for cellular communication into channels. With this technology, a channel can be assigned to one and only one user at a time be it for carrying digital data or transmitting voice conversation (Mahmoud A. et al., 2018; Ding Z., et al., 2015).

*2- Time Division Multiple Access (TDMA):* In this system, more than one user share the same frequency slot by taking turns at different times. They are able to avoid overlap, a user’s information is therefore transmitted during a non-overlapping time interval, that meaning TDMA-based networks require precise synchronization. Something very difficult to archive, especially in the uplink (Mahmoud A. et al., 2018).

*3- Code Division Multiple Access (CDMA):*In this system, users on the same channel are separated by means of codes. With this distinctive code sequence users are able to occupy the same frequency channel simultaneously. That means, the receiver then makes use of the unique code to identify and extract their desired signal from that of other users (Mahmoud A. et al., 2018; Meng S. et al., 2021).

*4- Orthogonal Frequency Division Multiple Access (OFDMA):* With this technique, multi-user communication is feasible by means of OFDMA that employs orthogonal subcarriers. Multiple users are able to transmit signals simultaneously over the same frequency bandwidth without interference due to the fact that, frequencies are orthogonal  to each other (Mahmoud A. et al., 2018; Meng S. et al., 2021).

### 1.4.2. Non-Orthogonal Multiple Access (NOMA) Radio Access Technologies

In this section, we concisely look into NOMA techniques as used in cellular network systems.

The surfacing of NOMA was introduced by the 3rd Generation Partnership Project (3GPP-LTE), as a viable  component of 5G mobile networks and beyond. There exist two branches of NOMA techniques: Power domain that makes use of varying channel benefits between users to activate multiplexing through energy allocation. Meanwhile on the other hand, Code domain rely on personalized spreading sequence to share the entire resource (Dai L. et al., 2015).

The NOMA technique greatly differs from OMA, which grands orthogonal access to users of the system through frequency, time or code.  NOMA allows for multiple users to share the frequency and time, thereby resulting in a boost to spectral efficiency(SE) as opposed to traditional OMA (Mahmoud Aldababsa & Oğuz Kucur, 2020).

Moreover, NOMA is a the future of radio access technique having the potentials to upgrade the performance of present and yet to come cellular communications. In comparison to OMA, it able to guarantee various desirable benefits, some of which include; increasing the number users to be served as well assuring user fairness. Furthermore, several scholars have proven that NOMA can be effectively used to meet the data rate requirements of the fifth generation (5G) and to provide low transmission latency (Dai L. et al., 2015; Mahmoud A. et al., 2018)

#### 1.4.2.1. Advantages of NOMA

In this section, we delve into the distinct advantages that NOMA offers to enhance wireless communication, which is as follows:

- *Mass Connectivity:* In all OMA techniques, the number of users to be served is constrained by the available number of resource blocks. However, NOMA possess the capability to accommodate an infinite number of users within every resource block by overlaying all user signals. This makes NOMA best fit for IoT applications where many devices desired to transmit small packets (Dai L. et al., 2015).
- *User Fairness Improvement:* More than ever, a balance can be reached between user fairness and system throughput in NOMA. This is so because, radio resources can be managed with flexibility thereby leading to user fairness through appropriate resources allocation (Mahmoud Aldababsa & Oğuz Kucur, 2020).
- *Adaptability to Various QoS Requirements:* With varying Quality of Service (QoS) requirements, NOMA is highly adaptable, making it easy to cater for varying users demands on a single subcarrier. This property of NOMA comes to reinforce the candidature its candidature as best fit for IoT, which links a vast number of electronic devices and sensors hungry for different data rates (Dai L. et al., 2015).
- *High Spectral Efficiency:* Talking about spectral efficiency and user fairness, NOMA most definitely surpasses OMA. This can be explained by the fact that, each NOMA user is able to utilize the entire bandwidth by employing the power domain for user multiplexing, while OMA users are limited within a smaller fraction of the spectrum whose capacity reduces as the number of users increases (Dai L. et al., 2015; Mahmoud Aldababsa & Oğuz Kucur, 2020)

- *Better Utilization of Channel Condition Heterogeneity:* It is with purpose that NOMA combines strong and weak users to benefit from the varying channel state. With a distinct multiplexed channel gain, NOMA outperforms OMA (Dai L., et al., 2015).
- *Low Latency Rate:* The turnaround time or latency rate demands of 5G applications are pretty wide. Regrettably, OMA is unable to secure this as each device has to wait for a resource block to become free just so it can transmit its data. On the contrary, NOMA can accommodate various devices with diverse QoS requirements (Dai L. et al., 2015; Mahmoud Aldababsa & Oğuz Kucur, 2020).

#### *1.4.2.2. NOMA Limitations*

- To archive a successful SIC decoding order, the base station must have perfect Channel State Information (CSI).
- The signaling system overhead increases because the strong users need to be aware of the power allocation of weaker users to utilize SIC.
- Weak users, most especially those at the edge of cells, if given more power, this could lead to an increased cellular interference throughout the system (Dai L. et al., 2015).

## 1.5. Comparison And Coexistence Of NOMA And OMA

### 1.5.1. Comparison between NOMA and OMA

With conventional OFDMA as an example, the main problem with OMA techniques is that fact that its spectral efficiency can be low when allocating defined bandwidth resources, such as subcarrier channels to users with poor channel conditions. Contrarily, when using NOMA each user has the possibility to access all different subcarrier channels. This way, allocated bandwidth resources to users with weak channel conditions can be accessed by those with better channel conditions. Figure 2 contrast the frequency band sharing between NOMA and OFDMA technique (Dai L. et al., 2015).

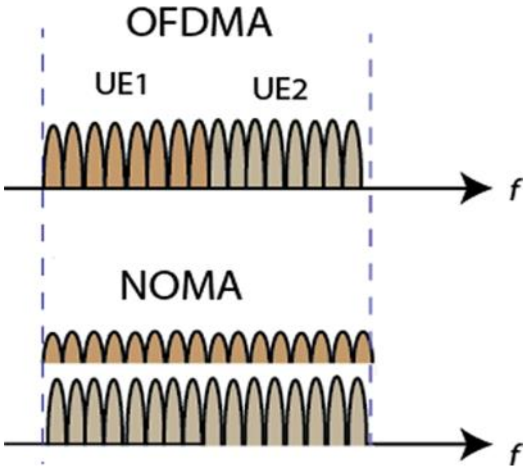

**Figure 2.** Contrast of frequency band Sharing for OFDMA and NOMA for Two users.

Unlike traditional OMA, NOMA shares degrees of freedom (DoF) among users through superposition, consequently necessitating Multi User Detection (MUD) to separate interfering users. As illustrated in Figure 3, NOMA proves beneficial in enhancing the number of connections by introducing a manageable symbol collision (Mahmoud  Aldababsa & Oğuz Kucur, 2020).

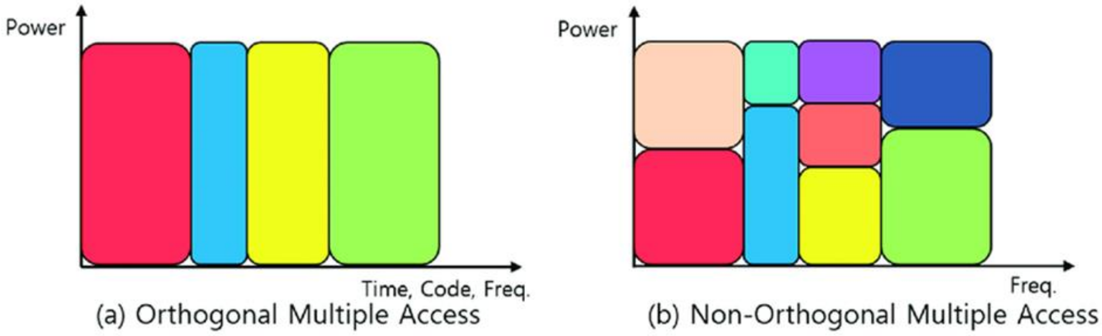

**Figure 3.** Comparing OMA and NOMA

As a result, NOMA can sustain high-traffic transmission, thereby boosting overall system capacity. This allows multiple users with diverse traffic requirements to be multiplexed for simultaneous transmission on the same degree of freedom, enhancing both latency and fairness.

**Table 1.** Comparison of OMA and NOMA

| COMPARISON ASPECT | OMA | NOMA |
|---|---|---|
| **Resource Utilization** | Allocates distinct resources (time/frequency) to each user, which may lead to inefficient resource usage. | Allows simultaneous sharing of the same resource (time/frequency) amongst multiple users, improving resource efficiency |
| **System Complexity** | Generally lower, as each user is allocated a distinct resource and does not need to decode other users' information. | Generally higher as a result of due to the use of SIC which requires users to decode and subtract signals from other users. |
| **User Fairness** | This can lead to unfairness, as users with better channel conditions are typically served first. | Promotes user fairness by allowing simultaneous serving of multiple users, regardless of their channel conditions. |
| **Latency** | Higher latency is due to the scheduling of user transmission in different time/frequency resources. | Lower latency due to simultaneous transmission from multiple users. |
| **Connectivity** | Limited capacity to support massive connectivity, which is essential for IoT applications. | Better equipped to handle massive connectivity due to the simultaneous use of resources, making it more suitable for IoT applications. |
| **Spectral Efficiency** | Low spectral efficiency due to orthogonal allocation of resources | Higher spectral efficiency due to non-orthogonal allocation of resources and overlapping user transmissions. |

### 1.5.2. Coexistence of OMA and NOMA

In the quest to improve capacity within 5G networks, NOMA has emerged as an outstanding contender for radio access. However, it is worth noting that this is not a claim that NOMA will completely replace OMA. Ultimately, the coexistence of both to cater to the varying needs of diverse services and applications in 5G and its future landscape. The coexisting ability of both systems is as crucial as the existence of 5G network and beyond (Ding, Z., Peng, M., & Poor, H. V, 2015).

## 1.6. Classification of NOMA Techniques

There exist different type of NOMA techniques that could be classified based on their domain of multiplexing. They can be primarily categorized on two main fronts. Figure 4 depicts a clear classification of the existing NOMA techniques.

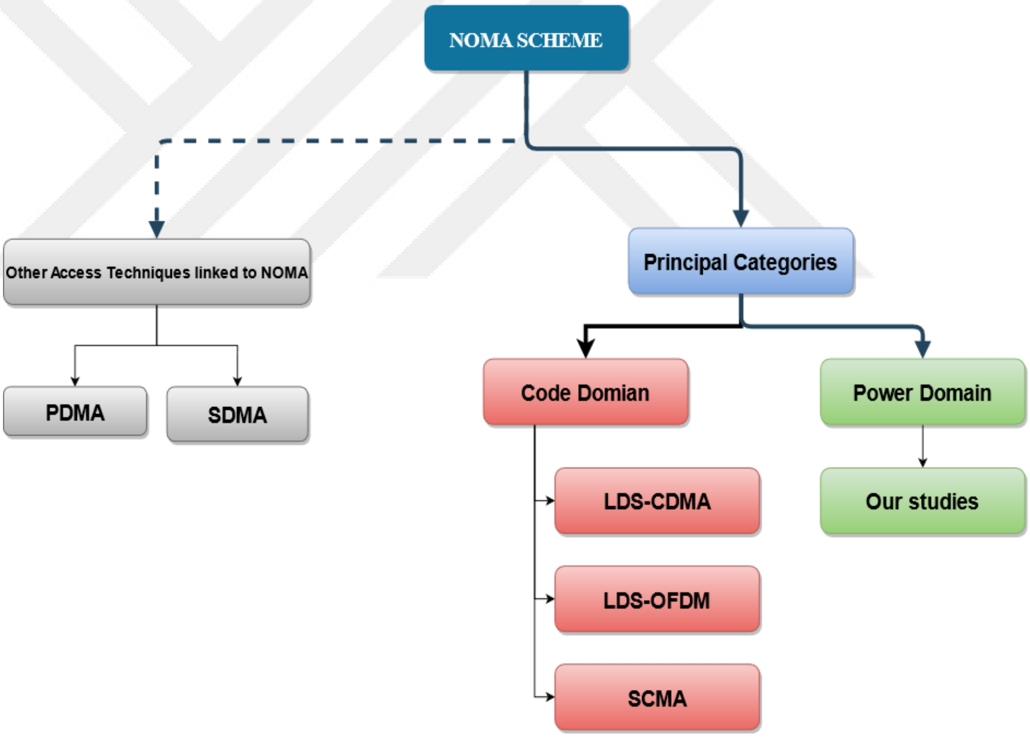

**Figure 4.** Ideal Classification of NOMA techniques

Power Domain Non-Orthogonal Multiple Access (PD-NOMA) is our area of focus, exploring its fundamental concepts, unique characteristics, current progress, and future research bottlenecks. One of the way by which NOMA operate is by the use of Superposition Coding (SC) while transmitting and Successive Interference Cancellation (SIC) at the receiving end. At the transmitting end, more than multiple users are overlaid by the use of SC, taking advantage of the channel gain difference that exist between them. The signals aimed for different users is merged into one and transmitted over the same channel, making use of the same frequency-time resource. On the receiving side, Multi-User Detection (MUD) algorithms such as SIC are used to differentiate the different individual signals (Mahmoud A. et al., 2018).

Code domain NOMA differ from power domain NOMA in that, it is capable to achieve multiplexing in code domain. The operation of code domain NOMA is similar to that of CDMA where they share available resources like frequency and time. Code domain will stand out unique in that it make use of user-specific spreading sequences that could either be non-orthogonal cross-correlation sequences or sparse with low correlation coefficients. It can be categorized into a few different classes, such as :

1. *Low Density Spreading Code Division Multiple Access (LDS-CDMA):* To mitigate the impact of interference on base CDMA systems, LDS-CDMA uses low density spreading sequence.
2. *Low Density Spreading Orthogonal Frequency-Division Multiplexing (LDS-OFDM):* This transmission method can be seen as a blend between LDS-CDMA and OFDM. For a start, the information symbols will be dispersed via low density spreading sequences before subsequently being sent over a group of subcarriers.
3. *Sparse Code Multiple Access (SCMA):* The most recent code domain NOMA technique known is the SCMA technique based on LDS-CDMA. SCMA when compared to LDS-CDMA, provides a reception technique that is less complex and can improve performance.

Some other multiple access techniques related to NOMA, including:

1. *Pattern Division Multiple Access (PDMA):* The implementation of PDMA cuts across different areas. To start off, it lay emphasis on enhancing diversity while bridging overlap between users on the transmitting end, which results in the creation of non-orthogonal designs. Multiplexing is then carried out in the space domain, code domain, or by combing both.
2. *Space-Division Multiple Access (SDMA):* SDMA runs on a working principle similar to CDMA system, but for that it uses user-specific channel impulse response (CIR) rather than the spreading sequence to distinguish users employed in CDMA. This method has an upper hand in situations where uplink users outnumber the reception antennas at the base station. Being able to estimate CIR accurately can be challenging with numerous users present. A walkaround this challenge is the introduction of a technique that leverages a customizable installation to use multiple access schemes. This permits therefore the support of diverse services and applications within the 5G (Z. Ding et al., 2017).

## 1.7. Downlink NOMA Network

Figure 5 illustrate how in the downlink NOMA network, the base station (BS) dispatches a merged signal at the transmitting side. This signal is a superposition of the intended signals for multiple users, each bearing a unique power allocation coefficient. All mobile users receive this combined signal.

On the side of each user (receiver), it's assumed that a SIC process is deployed until the user’s specific signal is retrieved. Power coefficients are assigned to users in an inversely proportionate manner based on their unique channel conditions. In other words, customers with less favorable channel characteristics receive greater transmission power than users with more favorable channel conditions.

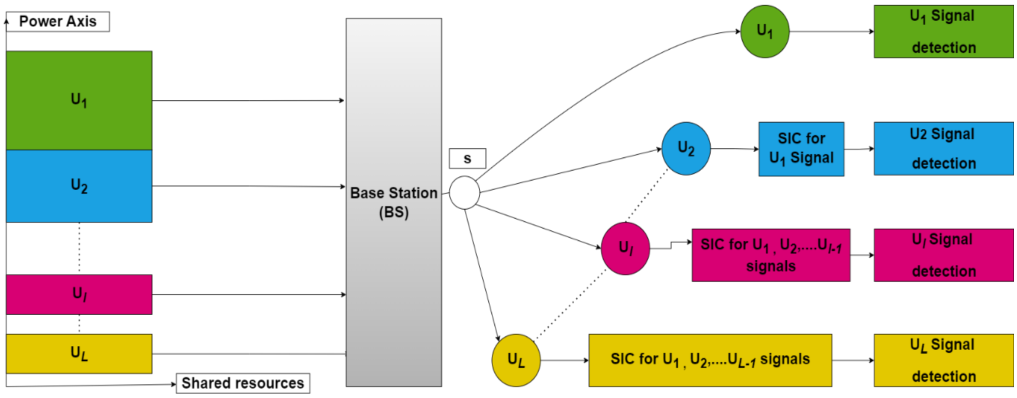

**Figure 5.** Downlink NOMA network

Therefore, if a user has the greatest transmission power, it is much easier for them to identify signals from other users and recover them without the use of SIC processes. Users with unappreciated transmission power, on the other hand, must therefore employ SIC procedures to remove noise and recover the desired signals.

By the principles of SIC, the receiver on the user's system or device at the first time detects signals that are stronger than their own desired signal. The stronger signals identified are removed from the overall received signal until the user's specific signal is isolated. To proceed with decoding their signal at the end, the user consider other users with low power coefficients as noise. The transmitted signal from the BS can be express as such:

$$s = \sum_{i=1}^{L} \sqrt{a_i P_s} x_i, \tag{1}$$

In this equation, $xi$ represents the information from user $i$ ($Ui$), assuming unit energy. $Ps$ stands for the transmission power at the BS, and $ai$ stands for the power coefficient allocated to user $i$, subject to the condition that $\sum_{i=1}^{L} ai = 1$ and $a_1 \geq a_2 \geq \cdot \cdot \cdot \geq a_L$. Assuming that the channel gains are arranged as $|h_1|^2 \leq |h_2|^2 \leq \cdot \cdot \cdot \leq |h_L|^2$, the analysis proceeds without any loss of generality. Here, $h_l$ denotes the channel coefficient of the $l^{th}$ user according to the NOMA principle. Therefore, the signal received at the $l^{th}$ user can be described as follows:

$$y_l = h_l s + n_l = h_l \sum_{i=1}^{L} \sqrt{a_i P_s} x_i + n_l, \qquad (2)$$

It has been identified that $n_l$ is a complex additive Gaussian noise with a mean of zero and variance indicated by $\sigma^2$. This implies that $n_l$ follows a complex normal distribution with the parameters of (0, $\sigma^2$).

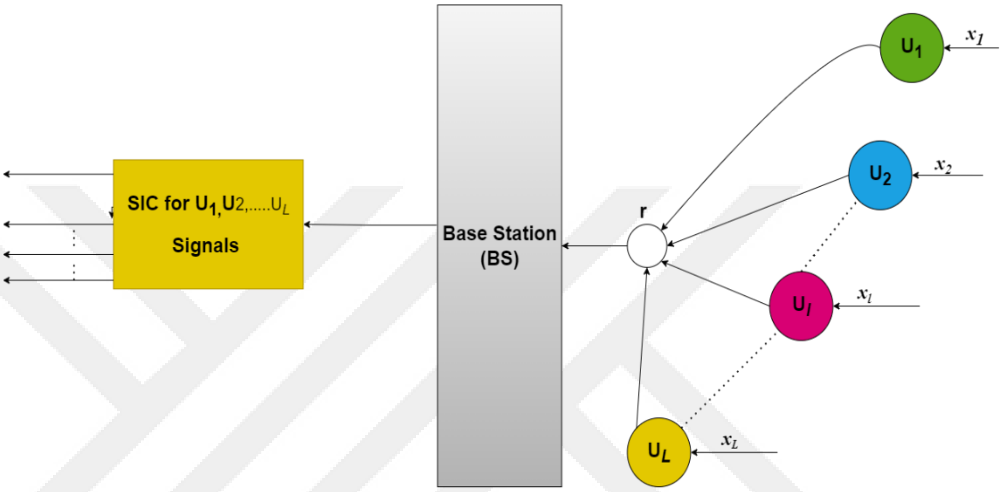

**Figure 6.** Uplink NOMA Network

### 1.8. Uplink NOMA Network

Unlike in downlink NOMA, here each mobile user transmits a signal to the BS. The BS then performs SIC cycles to identify each user's own signal. The signal received at the BS for synchronous uplink NOMA can be represented if the downlink and uplink channels are reciprocal and the BS provides power allocation coefficients to mobile users.:

$$r = \sum_{i=1}^{L} h_i \sqrt{a_i P} x_i + n \qquad (3)$$

From the (3), $h_i$ represents the channel coefficient of the $i^{th}$ user, the maximum transmission power $P$, is assumed to be the same for all users. Meanwhile, $n$ represents zero-mean complex additive Gaussian noise having a variance of $\sigma^2$, implying that $n$ follows a complex normal distribution, CN(0, $\sigma^2$).

### 1.9. MIMO-NOMA Technology

A radio access technique called NOMA is widely used in the field of 5G communication systems with the goal of enhancing spectral efficiency and supporting massive connectivity. In addition to this technology, MIMO increases a radio link's capacity by taking advantage of the presence of multiple BS and receive antennas.

Due to the unique characteristic of both technologies, we can boost of high-performance wireless communication system. A lot of theoretical and practical research has been done on aspects of MIMO-NOMA, revealing its capacity to offer users better spectral efficiency and superior connectivity (A. Benjebbour et al., 2015)..

In this initial chapter, we provided a brief history of the evolution of cellular networks and discussed the requirements for transitioning to 5G. Subsequently, we delved into the essential concepts surrounding Orthogonal Multiple Access (OMA) and Non-Orthogonal Multiple Access (NOMA) radio access techniques and an overall classification of the NOMA technique. In the upcoming chapters, we will focus our studies on the Power Domain NOMA type.

# CHAPTER TWO

# LITERATURE REVIEW

In this chapter, we will review the literature on MIMO-NOMA technology and its signal processing techniques, focusing on the majority-based TAS/MRC scheme. We will also discuss the performance evaluation of MIMO-NOMA systems under different channel conditions.

## 2.1. Relevant research on MIMO-NOMA systems

A key aspect of our day-to-day life, communication has evolved. There has been significant growth in different wireless communication systems due to the ever-growing demand for high performance data rate.

Wireless communication services have seen significant growth, with the potential to offer high-level connectivity and reliability. Furthermore, the endless demand for improved internet connectivity, fast response time, and enhanced data rates have led to the deployment of 5G networks. J. G. Andrews, S. Buzzi, and C. W. (2014) investigated the potential characteristics and features of 5G networks, including extensive connectivity, fast data rates, and the least latency rate.

With the changing phase of events in the world today, the growth of innovative technologies like autonomous driving cars, reception robots, IoT, and virtual reality requires a network capable of handling a large number of interconnected devices, guaranteeing low latency and high speed data transmission.

Despite the existence of advanced technologies like millimeter-wave, NOMA, and massive MIMO that are being studied to meet the increase in the worlds demand for modern communication, MIMO-NOMA standout as a breakthrough as it guarantees to offer exceptional SE and permit extensive connectivity.

The technology permit more than one user to transmit their signals at the same time all within the same frequency band making use of the power domain rather than time or frequency domain (Z. Ding et al., 2017). By utilizing a non-orthogonal approach, the system can allow users to share the same time-frequency resources, thus achieving higher spectral efficiency.

MIMO-NOMA has made it name on list of promising technologies for next-generation wireless communication systems, such as 5G and beyond (Mohammadi et al., 2019). To better enhance SE and capacity of a system, especially in wireless networks with high density, this system has to be implemented. Additionally, MIMO-NOMA can attain a superior energy efficiency level, delay constraints and reliability (Z. Ding et al., 2017).

Much effort has been put in place to enhance the performance of MIMO-NOMA systems via the implementation of advanced signal processing techniques. Advanced signal processing techniques are taking advantage of the inherent diversity present in MIMO channels to be able to employ suitable detection algorithms to help reduce interference and as well improve how reliable the system can be (H. Zhang et al., 2020).

With the exception of SIC and Joint Maximum Likelihood Detection (JMLD), there exist alternative signal processing techniques proposed for MIMO-NOMA systems. L. Yang et al. (2018), proposed the usage of Minimum Mean Square Error (MMSE) Detection which works by minimizing the mean square error between the transmitted and received signals, and Maximum Likelihood Detection (MLD) has as objective to detect all user signals by maximizing the likelihood function.

Moreover, seeking to enhance the performance of MIMO-NOMA technique, researchers have proposed that beamforming technique be incorporated. Where beamforming is a signal processing technique that makes sure that, transmitting signals be concentrated towards the specific user meanwhile at the same time minimizing interference from other users(Z. Ding et al., 2017). To design the beamforming vector and enhance system performance, optimization algorithm such as MMSE and SNR are used.

To sum it up, the effective implementation of a MIMO-NOMA system strongly depends on the technique used for signal processing and to that effect, several methods have been proposed in the literature. Some of which are; SIC, JMDL, MLD, MMSE as well as beamforming. To decide what signal processing method to use strongly depends on the specific requirements of the systems and channel properties.

## 2.2. Performance evaluation of MIMO-NOMA

It is vital that the performance of MIMO-NOMA systems be evaluated in the process of development so as to determine whether or not improvements are necessary and Know the system's overall performance. Capacity, outage probability, and BER are just a handful of performance metrics that can be used to assess the performance of MIMO-NOMA systems. With these different metrics, we are able to get information about the system's error performance, the highest possible data rate, and as well how dependable it is under varying circumstances. With these in mind, researchers or engineers are able to make sound decisions after optimizing and improving the overall performance of MIMO-NOMA systems. We use the BER performance metric to calculate the number of bitwise errors between the transmitted and received signals.

Meanwhile, probability failure measures the likelihood that the quality of the signal will drop below a specified threshold. Aldababsa et al. (2023) did a STAR-RIS (Simultaneously Transmitting And Reflecting Reconfigurable Intelligent Surface) assisted performance analysis on NOMA networks. Primarily, the study aimed at calculating the outage probability (OP) and BER performance on users in the NOMA networks. while doing this, they considered a series of factors like the non-integer fading parameter (m) and an abstract number of STAR-RIS parameters to be able to establish a closed-form expression for the performance metric on each user in the network. An in-depth examination was conducted to evaluate the SNR and obtain asymptotic OP expressions as part of the analysis. The analysis gave prime details on the performance of the system. A closely related study on the OP of the NOMA system having its receiver antenna selection under α-μ fading channels was performed (Rusul Abbas A.S and Mahmoud Aldababsa, 2023). This resulted in the derivation of a closed-form expression used to analyze the system performance with different fading channel conditions and as well assess the OP. In all, the study aimed at deepening the understanding of performance characteristics of NOMA network systems under different receive antenna selections in a realistic fading environment. Results of the simulation have proven that the performance of the system gets better with increasing values of α and μ alongside an increased number of receiver antennas. The highest possible volume of data that can pass through a channel within a specific timeframe is referred to as capacity.

The performance of MIMO-NOMA systems has been analyzed via several performance metrics and compared with that of other communication systems(Z. Ding et al.,2017). In a real life environment with various users, a study conducted showed how, MIMO-NOMA systems drive high SP and capacity better than other wireless systems. In the process, the authors found out that, a better performing MIMO -NOMA systems largely depends on a couple of factors such as number of users, channel conditions, and the signal processing techniques used.

To evaluate how MIMO-NOMA networks perform, several other studies have focused on specific performance metrics. For instance, in a study by T. M. Hoang, et al., (2021), the authors evaluated the performance of MIMO-NOMA networks using the OP metric in Nakagami-m fading channels. To be able to reduce the OP of the systems, the authors proposed a new power assignment algorithm. Similarly, (Mahmoud Aldababsa & Ertugrul Basar, 2021) studied the behavior of of MIMO-NOMA networks using the BER metric and revealed how majority based TAS/MRC scheme outperforms other signal processing techniques but the research focused on energy harvesting.

In summary, the behavior of MIMO-NOMA networks largely depends on the number of users, channel conditions, and the signal processing techniques used. It is therefore essential to study the system's behavior using various performance metrics to identify areas for improvement. By so doing, scholars are able to design new algorithms and signal processing techniques to better improve the behavior of of MIMO-NOMA systems.

## 2.3. Bit Error Rate (BER) Performance of MIMO-NOMA

Researchers have extensively studied how the BER of MIMO-NOMA networks behave which happens to be a crucial aspect of wireless communication. The BER metric is a key indicator of signal transmission quality, that measures the proportion of erroneous bits in a total transmitted bits. It is essential to minimize BER to improve the functioning of communication systems.

In the MIMO-NOMA context, minimizing BER is particularly challenging due to the superposition coding and SIC principles. Few studies (Y. Fu, et al., 2018; L. Yang , et al., 2018; Fu et al., 2017; Wang et al., 2018) have attempted to investigate this problem, revealing factors such as power allocation, information of the channel’s state, and user pairing that significantly influence the BER functioning of MIMO-NOMA.

## 2.4. Majority Based TAS/MRC Scheme in MIMO-NOMA

A more recent technique to optimize the behavior of BER performance in MIMO-NOMA networks is the Majority Based TAS/MRC scheme. With TAS having the capacity to select an optimal antenna for transmission based on instantaneous channel conditions and MRC having a diverse combination of techniques used to improve signal quality at the receiver's end, combined benefits can therefore be harvested from a blend of both.

In a recent study conducted by P. K. Kumson, A. Russ, and M. Aldababsa (2022), they analyzed the BER of MIMO-NOMA with a majority-based TAS/MRC scheme in Nakagami-m fading channels. Their study compared the effectiveness of the majority based TAS/MRC technique with other signal processing techniques, which has been further developed in this thesis. The results showed that the majority based TAS/MRC technique performed better in terms of BER performance. Additionally, Mahmoud Aldababsa & Ertugrul Basar (2021) also conducted a study on the majority based TAS/MRC technique and similarly found that it provides superior performance compared to other techniques. Mahmoud Aldababsa (2023) investigated the behavior of the MRT/RAS technique in dual-hop NOMA energy harvesting transmit networks. The researcher derived mathematical equations that could help analyzed the behavior of the system through asymptotic analysis and determine the likelihood of system failure. Results revealed improved performance with increased antenna numbers and enhanced channel conditions.

However, there is a need for further research to gain a full understanding of the topic, particularly in regard to power allocation techniques and user pairing methods. More on this scheme is elaborated in chapter 3.

Overall, the literature review reveals that MIMO-NOMA is a promising technology when talking wireless communication systems today and tomorrow. The performance of wireless communication systems as far as throughput, spectral efficiency, and user capacity is concerned, can greatly be improved by the use of

NOMA-MIMO. However, further research is needed to optimize the functioning of MIMO-NOMA systems under different channel conditions and to design efficient signal processing techniques for these systems.

# CHAPTER THREE

# METHODOLOGY

## 3.1. Theoretical framework of the system model

The theoretical framework for this study is based on the principles of MIMO and NOMA techniques in wireless communication. While NOMA allows for several users to share the same time and frequency resources, the MIMO technique optimizes communication performance by making use of multiple antennas at the transmitter and receiver. In this study, our aim is to evaluate the functioning of MIMO-NOMA systems using various signal processing techniques.

In this study, we propose a conceptual framework that is based on the hypothesis stating that, a majority based TAS/MRC scheme enhances the performance of MIMO-NOMA networks. This hypothesis is supported by the fact that the majority based TAS/MRC technique combines the signals from multiple antennas, which in turn improves the overall signal quality and reduce interference. Thus, the framework is designed to test this hypothesis and evaluate the behaviour of the majority based TAS/MRC technique in comparison to other signal processing techniques in a MIMO-NOMA setting.

### 3.1.1. Assumptions

To proceed with the study, we made a couple of assumptions:

It is assumed that the wireless communication channels undergo flat-fading, which results in the channel coefficient staying constant throughout the transmission process.

It is assumed that in the MIMO-NOMA network, the Channel state information is perfect. This means that the transmitter has a deep understanding of the channel coefficients.

We assumed that in the MIMO-NOMA network, all users have the same power levels, and have statistically independent channels.

It is assumed that there is perfect synchronization between the transmitter and receiver, implying they have precise knowledge of transmission timing.

These assumptions are common in most studies evaluating the functioning of MIMO-NOMA networks.

### 3.1.2. Limitations

In this study, we identified the following limitations:

The TAS/MRC technique that relies on majority based decisions was evaluated under ideal conditions. However, it's worth noting that in real-life setup, outside factors like interference, channel estimation errors, and multipath fading may impact its performance.

As a limitation, the study only pays attention to particular antenna configuration and set of users. Its of importance to remember that the systems behaviour could greatly be influenced by varying antenna configurations and number of users.

The study assumes that the users in the MIMO-NOMA system have equal power levels. In practice, the power levels may vary, which can affect the system's performance.

### 3.1.3. Data Collection Technique

The technique used in this study for data collection is simulation. Where we use MATLAB to simulate a MIMO-NOMA system and evaluate the performance of various signal processing techniques. The simulations are based on the assumptions made earlier. We alternate number of users and antenna configurations to evaluate the system's performance under varying conditions. A common BER performance metric is used to collect data on the system's BER behaviour.

Performance metrics used to evaluate system performance:

BER: A calculation of the ratio between the number of bit errors and total number of bits transmitted.

Outage probability: The likelihood that BER of the system goes beyond a set threshold.

Capacity: A system’s highest possible transmission rate.

We compare the performance of the majority based TAS/MRC technique to other signal processing techniques, including the conventional MRC scheme and the MLD scheme.

### 3.2. System Model

Figure 7, shows a MIMO-NOMA network in downlink with one transmitter $\mathrm{T}_x$ and multiple receivers $\mathrm{R}_l(1 \leq l \leq L)$. The $\mathrm{T}_x$ and $\mathrm{R}_l$ have $N_t$ transmit and $N_r$ receive antennas, respectively. In the majority TAS/MRC technique, the transmission antenna with the highest sum of squared channel gains for over half of the receiver (between the $\mathrm{T}_x$ and $\mathrm{R}_l$) is selected. This can be realized by following **Algorithm 1**

From NOMA principle, the $\mathrm{T}_x$ utilizes the $SC$, i.e.,

$$x = \sum_{l=1}^{L} \alpha_l s_l, \tag{4}$$

where $s_l$ is $\mathrm{R}_l$ 's signal, $\alpha_l = \sqrt{Pa_l}, P$ is $\mathrm{T}_x$'s power and $\alpha_l$ is $\mathrm{R}_l$'s power factor.

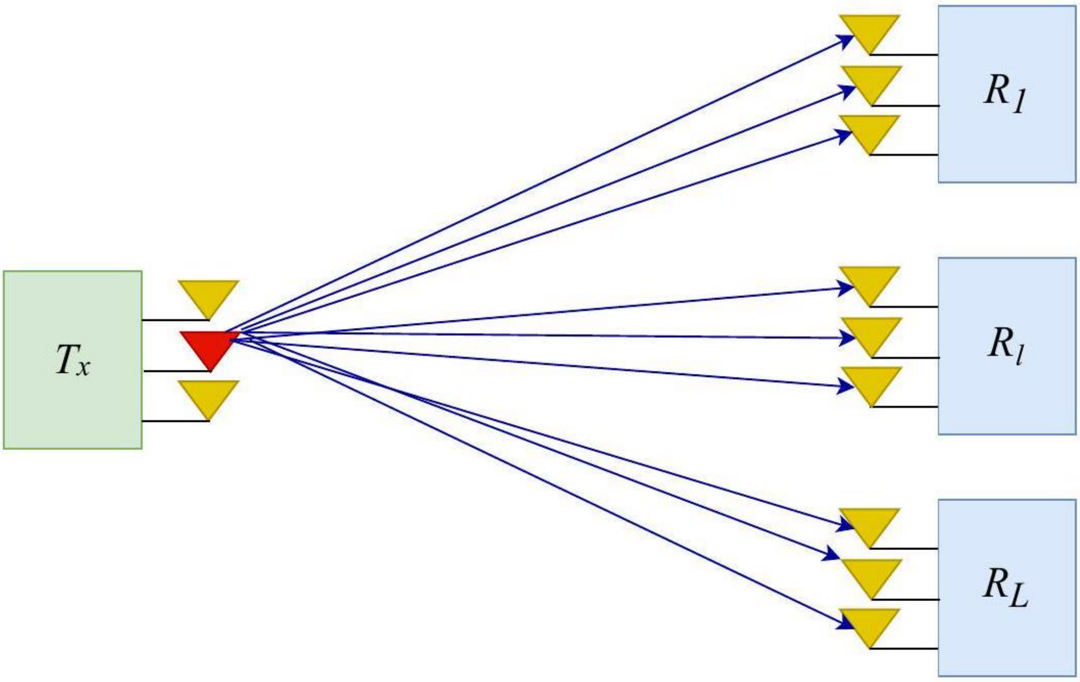

**Figure 7.** System model.

**Algorithm 1** Majority TAS/MRC scheme

---

- The conventional TAS/MRC scheme is applied individually for $R_l$. The transmission antenna $i_l^{\max}$ is selected according to the highest total of squared channel gains at $R_l$, i.e.,

$$i_l^{\max} = \underset{i=1,\ldots,N_t}{\arg\ \max}\left\{\varphi_l^i = \sum_{j=1}^{N_r} \left|h_l^{(i,j)}\right|^2\right\} \tag{1}$$

where $i_l^{\max} \in \{1, \ldots, N_t\}$ and $h_l^{(i,j)}(1 \leq i \leq N_t \text{ and } 1 \leq j \leq N_r)$ represents the dying channel coefficients that exist between the $i$th antenna of the $\mathrm{T}_x$ and the $j$ th receiving antenna of the $\mathrm{R}_l$.

- We apply the rule of majority. From the group of $i_l^{max}$, the reference of the majority transmission antenna $i^{\mathrm{maj}}$ is determined, i.e.,

$$i^{\mathrm{maj}} = \mathrm{Maj}\ (i_l^{\max}) \tag{2}$$

where $Maj(.) is\ the\ majority\ function\ which\ determines\ the\ i^{maj}$.

---

The received signal of the $\mathrm{R}_l$ can be written as

$$\begin{aligned} \boldsymbol{r}_l &= \boldsymbol{h}_l^{maj} x + \boldsymbol{w}_l \\ &= \boldsymbol{h}_l^{maj} \sum_{l=1}^{L} \alpha_l s_l + \boldsymbol{w}_l \\ &= \boldsymbol{h}_l^{maj} \sum_{i=1}^{l-1} \alpha_i s_i + \boldsymbol{h}_l^{maj} \alpha_l s_l + \boldsymbol{h}_l^{maj} \sum_{i=l+1}^{L} \alpha_i s_i + \boldsymbol{w}_l \end{aligned} \tag{6}$$

where $\boldsymbol{h}_l^{\mathrm{maj}}$ denotes the dying channel coefficient of the selected majority transmission antenna between the $\mathrm{T}_x$ and $\mathrm{R}_l$ with $\Omega_l = E\left[\left\|\boldsymbol{h}_l^{\mathrm{maj}}\right\|^2\right]$ and $\boldsymbol{w}_l$ is the noise with a variance of $\sigma_l^2$. With the optimal receive weight vector $\boldsymbol{Q}_l = \frac{\left(\boldsymbol{h}_l^{maj}\right)^H}{\left\|\boldsymbol{h}_l^{maj}\right\|}$, $\|\boldsymbol{Q}_l\| = 1$, the $\boldsymbol{r}_l$ are combined using MRC, i.e.,

$$\begin{aligned} y_l &= \boldsymbol{Q}_l \boldsymbol{r}_l \\ &= \boldsymbol{Q}_l \boldsymbol{h}_l^{\mathrm{maj}} \sum_{i=1}^{l-1} \alpha_i s_i + \boldsymbol{Q}_l \boldsymbol{h}_l^{maj} \alpha_l s_l + \boldsymbol{Q}_l \boldsymbol{h}_l^{\mathrm{maj}} \sum_{i=l+1}^{L} \alpha_i s_i + \boldsymbol{Q}_l \boldsymbol{w}_l \\ &= \frac{\left(\boldsymbol{h}_l^{maj}\right)^H}{\left\|\boldsymbol{h}_l^{\mathrm{maj}}\right\|} \boldsymbol{h}_l^{\mathrm{maj}} \sum_{i=1}^{l-1} \alpha_i s_i + \frac{\left(\boldsymbol{h}_l^{\mathrm{maj}}\right)^H}{\left\|\boldsymbol{h}_l^{\mathrm{maj}}\right\|} \boldsymbol{h}_l^{\mathrm{maj}} \alpha_l s_l + \frac{\left(\boldsymbol{h}_l^{\mathrm{maj}}\right)^H}{\left\|\boldsymbol{h}_l^{\mathrm{maj}}\right\|} \boldsymbol{h}_l^{\mathrm{maj}} \sum_{i=l+1}^{L} \alpha_i s_i + \frac{\left(\boldsymbol{h}_l^{maj}\right)^H}{\left\|\boldsymbol{h}_l^{\mathrm{maj}}\right\|} \boldsymbol{w}_l \\ &= \left\|\boldsymbol{h}_l^{\mathrm{maj}}\right\| \sum_{i=1}^{l-1} \alpha_i s_i + \left\|\boldsymbol{h}_l^{\mathrm{maj}}\right\| \alpha_l s_l + \left\|\boldsymbol{h}_l^{\mathrm{maj}}\right\| \sum_{i=l+1}^{L} \alpha_i s_i + \frac{\left(\boldsymbol{h}_l^{\mathrm{maj}}\right)^H}{\left\|\boldsymbol{h}_l^{\mathrm{maj}}\right\|} \boldsymbol{w}_l. \end{aligned} \tag{7}$$

The $\mathbf{R}_l$ applies SIC and for perfect SIC, the $\left\|\boldsymbol{h}_l^{maj}\right\| \sum_{l=1}^{l-1} \alpha_l s_l$ is eliminated, i.e.,

$$\boldsymbol{r}_l = \|\boldsymbol{h}_l^{maj}\|\phi_l + \boldsymbol{w}_l \tag{8}$$

where $\phi_l = \alpha_l s_l + \sum_{i=l+1}^{L} \alpha_i s_i$. Suppose that the information signal is modulated by using BPSK modulation, i.e.,

$$\phi_l^* =* \alpha_l + \sum_{i=l+1}^{L} \alpha_i s_i \tag{9}$$

In (7), $* \in +, -$ once $s_l = +1$ or -1 , respectively. $s_i$ may be +1 and/or -1

$$\phi_l^* =* \alpha_l + \sum_{i=l+1}^{L} \pm \alpha_i \tag{10}$$

This means that we have multiple combinations of $\phi_l^*$, where $\phi_{l,v}^*$ is the $\phi_l^*$ 's $v$th combination and $v = 1, \dots, \delta_l = 2^{L-l}$

### 3.2.1. Channel Model

The noise is modelled as $\boldsymbol{w}_l \sim CN\left(0, \boldsymbol{I}_{N_r}\sigma_l^2\right)$ and has probability density function (PDF) which can be can be stated as

$$f_{\boldsymbol{w}_l}(x) = \frac{1}{\sqrt{2\pi\sigma_l^2}} e^{-\frac{x^2}{2\sigma_l^2}} \tag{11}$$

The fading channel is Nakagami- $m$ and the cumulative distribution function (CDF) and PDF of its square an be written, respectively

$$F_R(x) = \frac{\Psi\left(m, \frac{mx}{\Omega}\right)}{\Gamma(m)} \tag{12}$$

$$f_R(x) = \frac{(m/\Omega)^m x^{m-1}}{\Gamma(m)} e^{-\frac{mx}{\Omega}} \tag{13}$$

where $\Omega = E[|R|^2]$ and $m$ are Nakagami's parameters. In this study, we try to avoid the complexity of the majority function and assume the special case of three users and two transmission antennas. The CDF of the majority TAS/MRC can be expressed as (12)

$$F_{\varphi_l^2}(x) = \sum_{q=1}^{6} \zeta_{(l,q)} (F_X(x))^q \tag{14}$$

where

$$F_X(x) = \frac{\Psi\left(mN_r, \frac{mx}{\Omega}\right)}{\Gamma(mN_r)} \tag{15}$$

taking the derivative of $F_{\varphi_l^2}(x)$ in 14 , the PDF that matches this can be stated as

$$f_{\varphi_l^2}(x) = \sum_{q=1}^{6} \zeta_{(l,q)} q f_X(x) (F_X(x))^{q-1} \tag{16}$$

where

$$f_X(x) = \frac{(m/\Omega)^{mN_r} x^{mN_r - 1}}{\Gamma(mN_r)} e^{-\frac{mx}{\Omega}} \tag{17}$$

and the values of $\zeta_{(m,q)}$ can be labeled as

$$\zeta = \begin{bmatrix} 1.5 & 1.5 & -4.5 & 3.75 & -1.5 & 0.25 \\ 0 & 0 & 3 & -3/4 & -2.25 & 1 \\ 0 & 0 & 0 & 0 & 1.5 & -0.5 \end{bmatrix} \tag{18}$$

### 3.2.2. BER ANALYSIS

**Theorem 1.** *The exact BER for the* $R_l$

$$\begin{aligned} P_l(E) \quad &= \sum_{v=1}^{\delta_l} \sum_{q=1}^{6} \sum_{p=0}^{q-1} \sum_{k=0}^{p(mN_r-1)} \binom{q-1}{p} (-1)^p \zeta_{(l,q)} \\ &\times \frac{q\mu_k(p, mN_r) \left(2\left(\psi_{l,v}^*\right)^2 \gamma\right)^{-(mN_r+k)} \Gamma(2(mN_r+k)+1)}{\delta_l \Gamma(mN_r)(m/\Omega)^{-mN_r}} \\ &\times {}_2\boldsymbol{F}_1\left(mN_r + k, mN_r + k + \frac{1}{2}, mN_r + k + 1, \frac{2(p+1)}{\left(\psi_{l,v}^*\right)^2 \gamma\Omega}\right) \end{aligned} \tag{19}$$

where ${}_2\boldsymbol{F}_1(a, b, c, z)$ denotes regularized Gauss hypergeometric function.

Proof. The conditional PDF of $y_l$ given $\left(\varphi_l, \phi_{l,v}^*\right)$

$$f\left(y_l/\varphi_l, \phi_{l,v}^*\right) = \frac{1}{\sqrt{2\pi\sigma_l^2}} e^{-\frac{\left(y_l - \varphi_l \phi_{l,v}^*\right)^2}{2\sigma_l^2}} \tag{20}$$

where $\varphi_l = \left\|\boldsymbol{h}_l^{\mathrm{maj}}\right\|$. Integrating $(20)$, then the error probability

$$P_r\left(E/\varphi_l, \phi_{l,v}^*\right) = Q\left(\frac{\varphi_l \phi_{l,v}^*}{\sqrt{\sigma_l^2}}\right) \tag{21}$$

where

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{x^2}{2}} dx \tag{22}$$

Note that $\sigma_l^2 = \sigma^2$ is assumed as well as $\gamma = \frac{P}{\sigma^2}$ is the SNR and $\beta_{l,v}^* = \frac{\phi_{l,v}^*}{\sqrt{P}}$

$$
\begin{aligned}
P_r\left(E/\varphi_l,\phi_{l,v}^*\right) &= Q\left(\sqrt{\frac{\varphi_l^2\left(\phi_{l,v}^*\right)^2}{\sigma^2}}\right)\\
&= Q\left(\sqrt{\varphi_l^2\left(\phi_{l,v}^*\right)^2\frac{P}{P\sigma^2}}\right)\\
&= Q\left(\sqrt{\left(\beta_{l,v}^*\right)^2\gamma\varphi_l^2}\right) \qquad (23)
\end{aligned}
$$

With $P_r\left(\phi_{l,v}^*\right)=\frac{1}{\delta_l}$ and (23)

$$
\begin{aligned}
P_r(E/\varphi_l,\phi_l^*) &= \sum_{v=1}^{\delta_l} P_r\left(E/\varphi_l,\phi_{l,v}^*\right)P_r\left(\phi_{l,v}^*\right)\\
&= \frac{1}{\delta_l}\sum_{v=1}^{\delta_l} Q\left(\sqrt{\left(\beta_{l,v}^*\right)^2\gamma\varphi_l^2}\right). \qquad (24)
\end{aligned}
$$

If $\psi_{l,v}^*=\sqrt{\left(\beta_{l,v}^*\right)^2}$ and $P_r(\phi_l^*)=0.5$

$$
\begin{aligned}
P_l(E/\varphi_l) &= \sum_{*} P_r(E/\varphi_l,\phi_l^*)P_r(\phi_l^*)\\
&= \sum_{*}\frac{1}{\delta_l}\sum_{v=1}^{\delta_l} Q\left(\sqrt{\left(\psi_{l,v}^*\right)^2\gamma\varphi_l^2}\right)\times 0.5\\
&= \frac{1}{\delta_l}\sum_{v=1}^{\delta_l} Q\left(\sqrt{\left(\psi_{l,v}^*\right)^2\gamma\varphi_l^2}\right) \qquad (25)
\end{aligned}
$$

Then

$$
\begin{aligned}
P_l(E) &= \int_0^\infty P_r(E/\varphi_l)f_{\varphi_l}(x)dx\\
&= \int_0^\infty P_r\left(\frac{E}{\varphi_l^2}\right)f_{\varphi_l^2}(x)dx. \qquad (26)
\end{aligned}
$$

Using (25) and (16) in (26), then

$$\begin{aligned} P_l(E) &= \sum_{v=1}^{\delta_l}\sum_{q=1}^{6}\frac{q\zeta_{(l,q)}(m/\Omega)^{mN_r}}{\delta_l\Gamma(mN_r)}\int_0^\infty Q\left(\sqrt{\left(\psi_{l,v}^*\right)^2\gamma x}\right)x^{mN_r-1} \\ &\times e^{-\frac{mx}{\Omega}}\left(\frac{\Psi\left(mN_r,\frac{mx}{\Omega}\right)}{\Gamma(mN_r)}\right)^{q-1} dx \\ &= \sum_{v=1}^{\delta_l}\sum_{q=1}^{6}\frac{q\zeta_{(l,q)}(m/\Omega)^{mN_r}}{\delta_l\Gamma(mN_r)}\int_0^\infty Q\left(\sqrt{\left(\psi_{l,v}^*\right)^2\gamma x}\right)x^{mN_r-1} \\ &\times e^{-\frac{mx}{\Omega}}\left(1-e^{-\frac{mx}{\Omega}}\sum_{k=0}^{mN_r-1}\left(\frac{mx}{\Omega}\right)^k\frac{1}{k!}\right)^{q-1} dx. \end{aligned} \tag{27}$$

The binomial term in 27

$$\begin{aligned} &\left(1-e^{-\frac{mx}{\Omega}}\sum_{k=0}^{mN_r-1}\left(\frac{mx}{\Omega}\right)^k\frac{1}{k!}\right)^{q-1} = \\ &\sum_{p=0}^{q-1}\sum_{k=0}^{p(mN_r-1)}\binom{q-1}{p}(-1)^p\mu_k(p,mN_r)x^k e^{-\frac{mp}{\Omega}x} \end{aligned} \tag{28}$$

where $\mu_a(b,c_d)$ is multinomial coefficient 29, eq.(0.314)]

$$\mu_a(b,c_d) = \sum_{u=1}^{a\geq 1}\frac{(u(b+1)-x)g_u\mu_{a-b}(b,c_d)}{ag_0}, \tag{29}$$

where $g_u = \frac{(c_d/\Omega_c)^u}{u!}$, $\mu_0(b,c_d) = 1$, and $\mu_a(b,c_d) = 0$ if $u > c_d - 1$.

By substituting (28) into (27), then

$$\begin{aligned} P_l(E) &= \sum_{v=1}^{\delta_l}\sum_{q=1}^{6}\sum_{p=0}^{q-1}\sum_{k=0}^{p(mN_r-1)}\binom{q-1}{p}\frac{(-1)^p\zeta_{(l,q)}\mu_k(p,mN_r)}{\delta_l\Gamma(mN_r)(m/\Omega)^{-mN_r}} \\ &\times q\underbrace{\int_0^\infty Q\left(\sqrt{\left(\psi_{l,v}^*\right)^2\gamma x}\right)x^{mN_r+k-1}e^{-\frac{m(p+1)}{\Omega}x}dx}_{\Lambda}. \end{aligned} \tag{30}$$

Using [30, eq.(15.2.2)],

$$\begin{aligned} \Lambda &= \left(2\psi_{l,i}^*\gamma\right)^{-(mN_r+k)}\Gamma(2(mN_r+k)+1) \\ &\times {}_2\mathbf{F}_1\left(mN_r+k, mN_r+k+\frac{1}{2}, mN_r+k+1, \frac{2(p+1)}{\psi_{l,i}^*\gamma\hat{\Omega}}\right). \end{aligned} \tag{31}$$

With some substitution, the $P_l(E)$ is obtained.

**Theorem 2.** *The asymptotic BER expression*

$$P_l^{as}(E) = \sum_{v=1}^{\delta_l}\sum_{q=1}^{6} \frac{\zeta_{(l,q)} q \left(\frac{m}{\Omega}\right)^{mqN_r-1} 2^{mqN_r-\frac{1}{2}}}{\delta_l \Gamma(mN_r)\Gamma(mN_r+1)^{q-1}\sqrt{2\pi}(mqN_r)} \frac{\Gamma\left(mqN_r+\frac{1}{2}\right)}{\left(\psi_{l,v}^{*}\right)^{2mqN_r}} \gamma^{-mqN_r}. \quad (32)$$

Proof. From [31] and [32, eq. (45.9.1)]

$$\Psi\left(mN_r, \frac{mx}{\Omega}\right) \approx \frac{\left(\frac{mx}{\Omega}\right)^{mN_r}}{mN_r}. \quad (33)$$

Thus,

$$F_X^{\infty}(x) = \frac{\left(\frac{m}{\Omega}\right)^{mN_r} x^{mN_r}}{\Gamma(mN_r+1)} \quad (34)$$

and

$$f_X^{\infty}(x) = \frac{\left(\frac{m}{\Omega}\right)^{mN_r} x^{mN_r-1}}{\Gamma(mN_r)} \quad (35)$$

Therefore

$$\begin{aligned} f_{\varphi_l^2}^{\infty}(x) &= \sum_{q=1}^{6} \zeta_{(l,q)} q f_X^{\infty}(x)\left(F_X^{\infty}(x)\right)^{q-1} \\ &= \sum_{q=1}^{6} \zeta_{(l,q)} q \frac{\left(\frac{m}{\Omega}\right)^{mN_r} x^{mN_r-1}}{\Gamma(mN_r)} \left(\frac{\left(\frac{m}{\Omega}\right)^{mN_r} x^{mN_r}}{\Gamma(mN_r+1)}\right)^{q-1} \\ &= \sum_{q=1}^{6} \frac{\zeta_{(l,q)} q \left(\frac{m}{\Omega}\right)^{mqN_r-1}}{\Gamma(mN_r)\Gamma(mN_r+1)^{q-1}} x^{mqN_r-1} \quad (36) \end{aligned}$$

As a result

$$\begin{aligned} P_l^{as}(E) &= \int_0^{\infty} P_r(E/\varphi_l^2) f_{\varphi_l^2}^{\infty}(x)dx \\ &= \sum_{v=1}^{\delta_l}\sum_{q=1}^{6} \frac{\zeta_{(l,q)} q \left(\frac{m}{\Omega}\right)^{mqN_r-1}}{\delta_l \Gamma(mN_r)\Gamma(mN_r+1)^{q-1}} \int_0^{\infty} Q\left(\sqrt{\left(\psi_{l,v}^{*}\right)^2 \gamma x}\right) x^{mqN_r-1}dx. \quad (37) \end{aligned}$$

By using [29], the $P_l^{as}(E)$ is obtained.

### 3.3. Signal processing algorithm

Here, we keep an eye on the signal processing algorithm utilized for MIMO-NOMA networks having a majority TAS/MRC technique. We will focus on this system's detection, precoding, and decoding techniques.

**Detection Techniques:** A majority TAS/MRC scheme that employs maximum likelihood (ML) detection technique is used in MIMO-NOMA networks. This is a technique that is commonly used in multi-antenna systems since it has the prowess to achieve optimal performance. The ML detection technique searched for the signal with the highest chance of being transmitted based on likelihood of observing the received signal.

The ML detector requires better understanding of the channel matrix and noise statistics. The channel matrix for MIMO-NOMA network with majority TAS/MRC technique, is estimated using pilot symbols. The transmitter dispatches pilot symbols which are used by the receiver to estimate the channel matrix. The ML detector becomes available to detect the transmitted signal, once the channel matrix has been estimated.

**Precoding Techniques:** This is a technique used in signal processing to better the functioning of the MIMO-NOMA system implementing the majority TAS/MRC technique. Before transmitting a signal, the desired transmitted signal is first of all multiplied by a matrix as part of precoding. The objective of precoding is to adjust the transmitted signal which further optimizes the SNR .

In MIMO-NOMA systems making use of majority TAS/MRC techniques, the precoding matrix is caved using the channel matrix and detected signal to improve SNR at the receiver's end, while ensuring that the power constraint at the receiver is met.

**Decoding Techniques:** In MIMI-NOMA systems employing the majority TAS/MRC technique, the decoding scheme used is based on SIC. Where SIC is the multiple-user signals decoding technique used in NOMA networks. This consists of detecting and cancelling signals of strong users one after another until all of the user's signals are decoded.

The receiver first detects the signal of the strongest user using ML detection. The detected signal of the user with good channel condition is subtracted from the overall received signal, and the receiver moves on to detect the signal of the next strongest user. This is a recursive process until all the users' signals are decoded.

In all, the signal processing algorithms used in the MIMO-NOMA network employing majority TAS/MRC scheme are designed to achieve better functioning in terms of BER yet ensuring efficient use of resources such as power and bandwidth.

# RESULTS

Here, we present the numerical results to ascertain the effectiveness of the MIMO-NOMA network that implements majority TAS /MRC scheme in Nakagami-m fading channels. Analytical expressions provided in chapter three are validated through Monte Carlo simulations. The simulation assumes parameter values of $\{a_1, a_2, a_3\} = \{0.75, 0.2, 0.05\}$ and $\Omega = 1$.

The influence of the number of receive antennas $(N_r)$ on the BER behavior in Rayleigh fading channels with $m = 1$ has been illustrated in figure 8. Meanwhile, Figure 9 demonstrates the impact of the fading parameter $m$ on the BER behavior when each receiver is fitted with a single receiving antenna $(N_r = 1)$. These results show that the analytical expressions align well with the simulation results, validating the theoretical BER performance for all receivers. Furthermore, it is observed that the BER behavior improves as the number of receive antennas $(N_r)$ increases and channel condition becomes better. To simplify things, we have provided Table I and Table II, which display the necessary SNR values to attain $\mathrm{OP} = 10^{-3}$ and as such, the SNR gain the advantage of different parameters of $(m, N_r)$ for each receiver. Specifically, under the condition of $m = 1$ (Figure 9), for a BER of $10^{-4}$, there are SNR gain advantages of 16 dB, 7 dB, and 3 dB for the $\mathrm{R}_1, \mathrm{R}_2$, and $\mathrm{R}_3$, respectively, when $N_r = 2$ compared to $N_r = 1$. Similarly, when $N_r = 2$ (Figure 9), there are SNR gain advantages of 5 dB, 1 dB, and 1 dB for the $\mathbf{R}_1, \mathbf{R}_2$, and $\mathbf{R}_3$, respectively, when compared to $m = 1$, in order to archive a BER of $10^{-4}$, depending on different channel parameters. Conclusively, the BER behavior of NOMA with the majority TAS/MRC technique is improved more by augmenting the number of receiving antennas $(N_r)$ than by enhancing the channel condition.

The asymptotic and analytical results have been validated by comparing them with the simulation results in figure 10. Grounded on the graph, it is evident that the analytical results corresponds with results from the simulation. However, it is clear that the asymptotic result converges toward the analytical and simulated results at high values of SNR. From the figure, we depict that, the order of diversity of the system is affected both by the number of receiving antenna $(N_r)$ and channel condition $(m)$, which aligns with the outcomes of chapter three. As $(N_r)$ or $(m)$ increases, the diversity order and system performance improve significantly.

**Table 2.** SNR (Db) values that are required to Achieve Ber $= 10^{-4}$ for each receiver with varying parameters of$(m, N_r)$

| $(m, N_r)$ | $R_1$ | $R_2$ | $R_3$ |
|---|---|---|---|
| (1,1) | 48 | 30 | 25 |
| (1,2) | 32 | 23 | 22 |
| (2,2) | 27 | 22 | 21 |

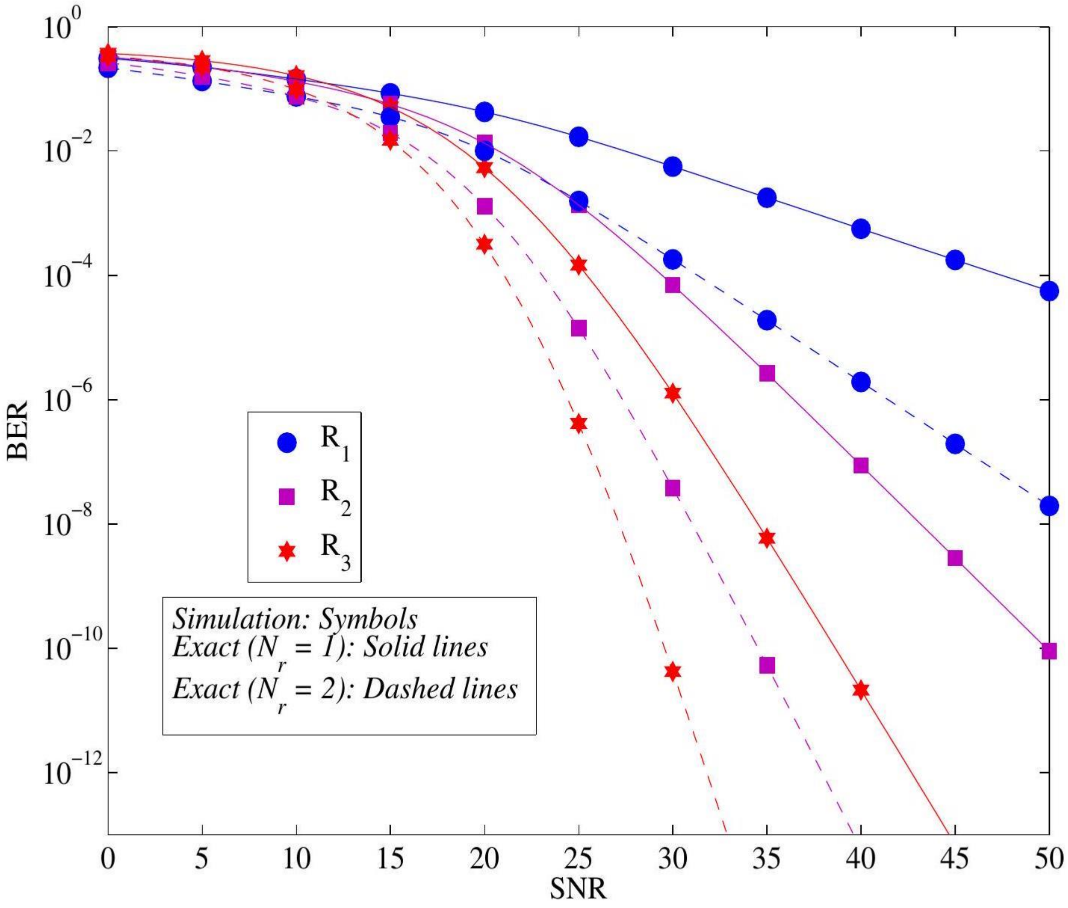

**Figure 8.** How $N_r$ affects BER performance of NOMA network.

**Table 3.** SNR gain advantage of different parameters $(m, N_r)$ per receiver.

| SNR gain advantage of (in dB) | $R_1$ | $R_2$ | $R_3$ |
|---|---|---|---|
| (1,2) over (1,1) | 16 | 7 | 3 |
| (2,2) over (2,1) | 5 | 1 | 1 |

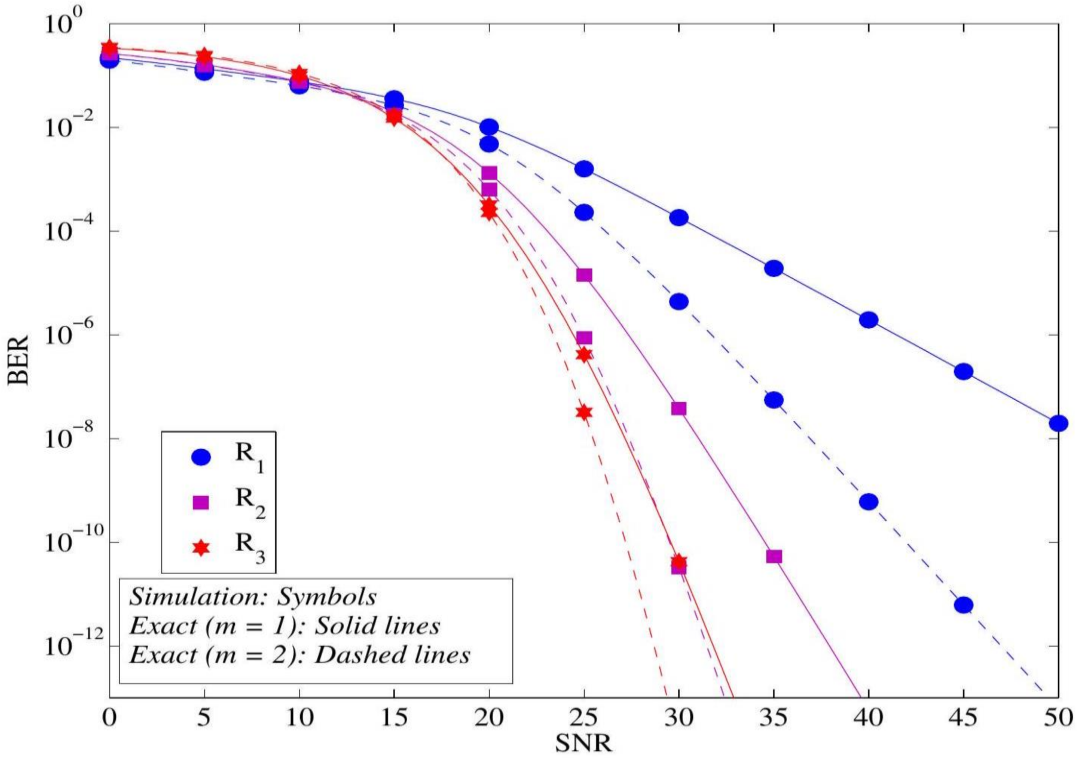

**Figure 9.** How $m$ affects BER performance of NOMA network.

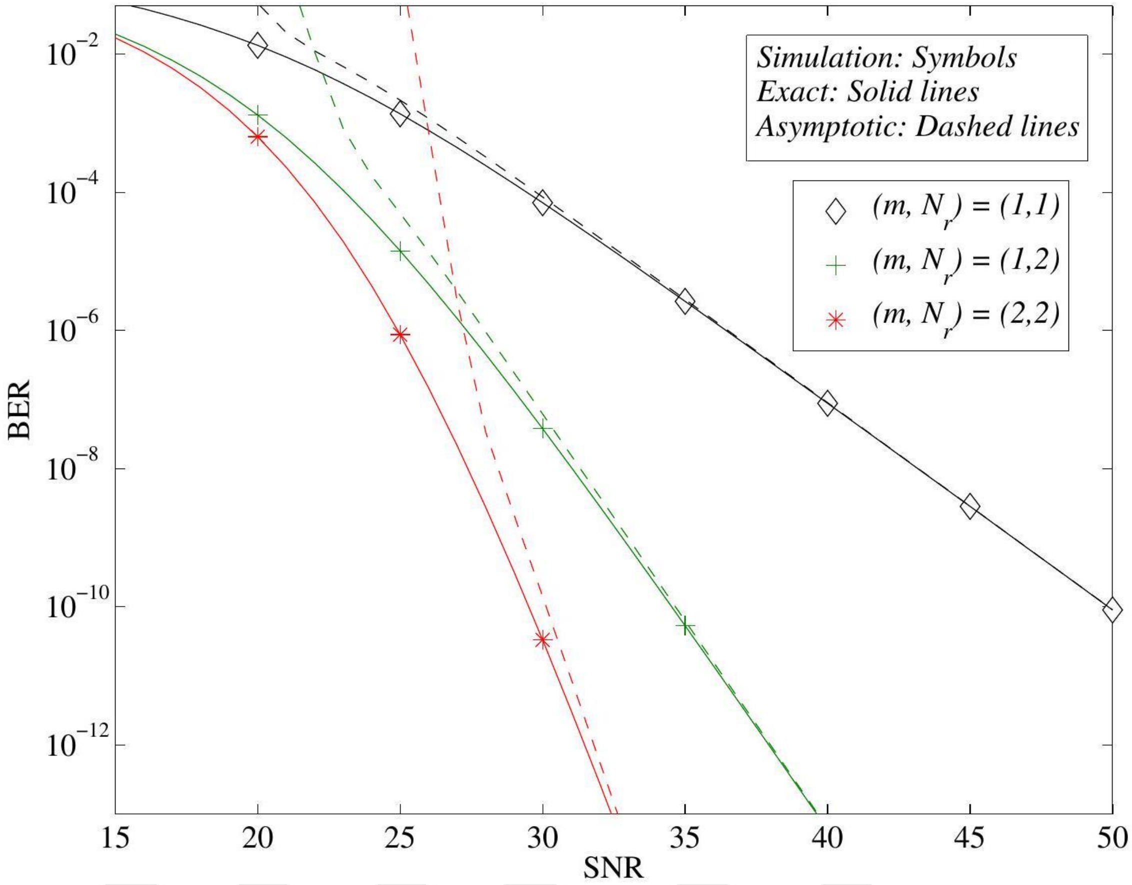

**Figure 10.** Asymptotic BER with different parameters of $(m, N_r)$ for each receiver

# CONCLUSION AND RECOMMENDATIONS

We explored how various radio access technologies have been used to categorize different access schemes in cellular communication. Our energy was concentrated on NOMA and MIMO which are highly touted for 5G and future cellular communication networks. We had as objective to do a literature review of these innovative approach and design a MATLAB simulation program to evaluate and compare it with already established OMA techniques like OFDMA.

In recent times, MIMO-NOMA has taken the central stage in research trying to meet the demands of 5G. As per information presented in this thesis, MIMO-NOMA has the ability to enrich spectral efficiency, while ensuring user fairness, still facilitating vast connectivity with varying quality of service need. With these attributes, MIMO-NOMA is unarguably the most promising multiple access technology for yet to come generation.

From three different approaches, this study has made significant contributions. Firstly by verifying the accuracy of the obtained theoretical BER expression by conducting Monte Carlo simulations. Secondly, the study has revealed the advantages of using majority TAS/MRC techniques in MIMO-NOMA networks, with receiving antennas and improved channel conditions that result in enhanced BER functionality.

Looking forward, there are various possibilities for future research to make use of. To start with, it would be of great advantage to adventure into diverse fading channel models or rather assess the effects of different impairments such as non-linearities and interference. This could lead to a better analysis of the system's performance. Furthermore, exploring various transmission antenna selection schemes or a combination of techniques could uncover an alternative method to enhance BER functionality in MIMO-NOMA networks. Having in mind the existence of practical limitations and system overheads such as hardware complexity and power consumption, would be of great benefit in assessing the feasibility and implementation of the suggested scheme. Finally, expanding the analysis to large-scale networks or accounting for multi-cell scenarios will be of great importance. This will therefore reveal valuable insights into how MIMI-NOMA networks perform in a more realistic working environment.

# REFERENCES

A. Benjebbour, Y. Saito, Y. Kishiyama, A. Li, A. Harada & T. Nakamura. (2013). Concept and practical considerations of non-orthogonal multiple access (NOMA) for future radio access., (pp. 770-774). Naha.

A. Molisch & M. Win. (2004). MIMO systems with antenna selection. IEEE Microwave Magazine, 46-56.

A. P. Shrestha, Tao Han, Zhiquan Bai, J. M. Kim & K. S. Kwak. (2016). Performance of transmit antenna selection in non-orthogonal multiple access for 5G systems. 8th ICUFN, (pp. 1031-1034). Vienna.

Aldababsa, M. (2023). Performance analysis of MRT/RAS scheme in dual-hop NOMA energy. AEU - International Journal of Electronics and Communications, 1-9.

Aldababsa, Mahmoud & Kucur, Oğuz. (2020). Majority based antenna selection schemes in downlink NOMA network with channel estimation errors and feedback delay. IET Communications, 2931 – 2943.

D. -D. Tran, H. -V. Tran, D. -B. Ha & G. Kaddoum. (2020). Secure Transmit Antenna Selection Protocol for MIMO NOMA Networks Over Nakagami-m Channels. IEEE Systems Journal, 253-264.

Dai, Linglong & Wang, Bichai & Yuan, Yifei & Han, Shuangfeng & I., Chih-Lin & Wang, Zhaocheng. (2015). Non-Orthogonal Multiple Access for 5G: Solutions, Challenges, Opportunities, and Future Research Trends. Communications Magazine, IEEE, 74-81.

Ding, Z., Peng, M., & Poor, H. V. (2015). Cooperative Non-Orthogonal Multiple Access in 5G Systems. EEE Communications Letters, 1462-1465.

H. Lei et al. (2017). On Secure NOMA Systems with Transmit Antenna Selection Schemes. IEEE Access, 17450-17464.

H. Lei et al. (2018). Secrecy Outage of Max–Min TAS Scheme in MIMO-NOMA Systems. IEEE Trans. Veh. Techno, 6981-6990.

H. Zhang, H. Zhang, W. Liu, K. Long, J. Dong & V. C. M. Leung. (2020). Energy Efficient User Clustering, Hybrid Precoding and Power Optimization in Terahertz MIMO-NOMA Systems. IEEE Journal on Selected Areas in Communications, 2074-2085.

J. G. Andrews, S. Buzzi & C. W. (2014). What will 5G be? IEEE Journal on Selected Areas in Communications, 32.

L. Yang , Y. Huang, C. Zhang, J. Wang, Y. Jing and X. You. (2018). Signal Processing for MIMO-NOMA: Present and Future Challenges. IEEE Wireless Communications, 32-38.

M. Aldababsa & O. Kucur. (2019). Majority Based TAS/MRC Scheme in Downlink NOMA Network with Channel Estimation Errors and Feedback Delay. arXiv preprint arXiv, 1904.01885.

M. Aldababsa & O. Kucur. (2019). Outage Performance of NOMA with Majority Based TAS/MRC Scheme in Rayleigh Fading Channels. IEEE 27th SIU, (pp. 1-4). Sivas.

Mahmoud Aldababsa, Allam Abu Mwais & Mahmoud Obaid. (2023). Performance of STAR-RIS assisted NOMA networks in Nakagami-m fading channels. AEU - International Journal of Electronics and Communications, 1-7.

Mahmoud Aldababsa, Mesut Toka, Selahattin Gökçeli, Güneş Karabulut Kurt, Oğuz Kucur. (2018). A Tutorial on Nonorthogonal Multiple Access for 5G and Beyond. Wireless Communications and Mobile Computing, 24.

Mahmoud, Aldababsa & Ertugrul, Basar. (2021). Joint Transmit and Receive Antenna Selection System for MIMONOMA with Energy Harvesting. IEEE Systems Journal, 1-10.

Meng Shen, Zihao Huang, Xianfu Lei, & Lisheng Fan. (2021). BER Analysis of NOMA with Max-Min Relay Selection. China Communications, 172-182.

Mohammadi, Mohammadali and Shi, Xiaoyan and Chalise, Batu K. and Ding, Zhiguo and Suraweera, Himal A. and Zhong, Caijun and Thompson, John S. (2019). Full-Duplex Non-Orthogonal Multiple Access for Next Generation Wireless Systems. IEEE Communications Magazine, 110-116.

P. K. Kumson, A. Russ & M. Aldababsa. (2022). Bit Error Rate Performance of MIMO-NOMA with Majority Based TAS/MRC Scheme in Nakagami-m Fading Channels. 30th Signal Processing and Communications Applications Conference (SIU), (pp. 1-4). Safranbolu.

Q. Li, J. Ge, Q. Wang & Q. Bu. (2017). Joint antenna selection for MIMO-NOMA networks over Nakagami-m fading channels. IEEE ICCC, (pp. 1-6). Qingdao.

Rusul Abbas Al Safah, Mahmoud Aldababsa. (2023). Outage probability of NOMA systems with receive antenna selection in $\alpha$-$\mu$. AEU - International Journal of Electronics and Communications, 1-6.

S. M. R. Islam, N. Avazov, O. A. Dobre and K. & -s. Kwak. (2017). Power-Domain Non-Orthogonal Multiple Access (NOMA) in 5G Systems: Potentials and Challenges. IEEE Communications Surveys & Tutorials, 721-742.

S. Ustunbas & U. Aygolu. (2017). Transmit antenna selection based on sum rate and fairness for downlink NOMA. 225th TELFOR, (pp. 1-4). Belgrade.

T. M. Hoang, B. C. Nguyen, X. N. Tran and L. T. Dung. (June 2021). Outage Probability and Ergodic Capacity of User Clustering and Beamforming MIMO-NOMA Relay System With Imperfect CSI Over Nakagami-$m$ Fading Channels. IEEE Systems Journal, 2398-2409.

Y. Fu, Z. Shi, G. Yang, H. Wang & S. Ma. (2018). Performance Analysis of MIMO-NOMA Systems with Randomly Deployed Users. IEEE Global Communications Conference (GLOBECOM), (pp. 1-7). Abu Dhabi.

Y. Yu, H. Chen, Y. Li, Z. Ding, L. Song & B. Vucetic. (2018). Antenna Selection for MIMO Nonorthogonal Multiple Access Systems. IEEE Transactions on Vehicular Technology, 3158-3171.

Z. Ding et al. (2017). Application of Non-Orthogonal Multiple Access in LTE and 5G Networks. IEEE Communications Magazine, 185-191.