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Kurdistan Region – Iraq
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# Non-Orthogonal Multiple Access (NOMA)

A graduation project submitted to
Department Of Communication and Computer Engineering
Bachelor degree in
Communication and Computer Engineering

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2023 – 2024

# Certification

This is to certify that this research paper is my work and is not previously published or written by another person and contains material which to a substantial extent has been accepted for the award of a bachelor's degree in Cihan University - Kurdistan region of Iraq, under supervision of my respected guide Lect.Yazen Saif Aldeen Mahmood

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بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

﴿يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ﴾

صَدَقَ اللهُ العَلِيُّ العَظِيمْ

سورة المجادلة أية ﴿ ١١ ﴾

# Abstract

In the rapidly evolving landscape of wireless communication, Non-Orthogonal Multiple Access (NOMA) has emerged as a promising paradigm to address the ever-increasing demand for higher spectral efficiency. This graduation project delves into the implementation and optimization of NOMA techniques with the aim of enhancing the overall performance of wireless networks.

The primary objectives of this project include the investigation of NOMA's impact on spectrum utilization, the development of novel algorithms for user pairing and power allocation, and the evaluation of its efficacy in diverse communication scenarios. Leveraging advanced simulation tools and real-world experimentation, the project seeks to provide valuable insights into the practical applicability of NOMA in next-generation wireless networks.

Key findings from the project shed light on the significant improvements in spectral efficiency achieved through NOMA, thereby validating its potential as a key enabler for 5G and beyond. The project contributes to the body of knowledge in wireless communication by offering practical insights into the deployment and optimization of NOMA techniques.

This graduation project not only advances our understanding of NOMA but also provides a foundation for future research and development in the field of wireless communication. As the demand for higher data rates and efficient spectrum utilization continues to grow, NOMA stands out as a crucial technology to meet the challenges of the evolving communication landscape.

# Dedication

This study is wholeheartedly dedicated to our beloved parents, who have been our source of inspiration and gave us strength when we thought of giving up, who continually provide their moral, spiritual, emotional, and financial support. To our sisters, relatives, mentor, friends, and classmates who shared their words of advice and encouragement to finish this study. And lastly, we dedicated this book to the Greatest **Lect. Yazen Saif Aldeen Mahmood**, thank you for the guidance, strength, power of mind, protection and skills and for giving us a Powerful support. All of these, we offer to you.

# Acknowledgment

Praise to Allah, the Almighty, for uncountable help and guidance, and peace be upon his messenger Mohammed. We would like to thank our helper and keeper, the One Great GOD who has given us blessing. It is a great pleasure to thank our honorable supervisor **Lect. Yazen Saif Aldeen Mahmood** for his invaluable guidance, helpful suggestions and showing great academic interest in our project in spite of his hard schedule.

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# INTRODUCTION

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# INTRODUCTION

## 1.1 Introduction

Recently, according to the increasing of smart phones, wireless internet applications and multimedia services, mobile network traffic has been explosively increasing. This trend will be expected to be mobile traffic volume 1000 times larger than todays by 2024. In this reason, the importance and research of 5G system to drastically enhance the capacity, compared with 4G system including long term evolution – advanced (LTE-A) have paid attention. In the third-generation partnership project (3GPP) workshop on release 12 and onwards in June 2012, 1000-fold capacity enhancement has emerged as one of the most crucial challenges in order to handle the rapid increase in data traffic and improve the system capacity in 5G. Various basic technologies for increased spectral efficiency in a huge tiny cell environment have been introduced in this workshop. One of the possible technologies that can increase capacity in 5G systems has been presented, in particular the non-orthogonal multiple access (NOMA) method. In NOMA, all users utilize superposition coding to share finite resources (time and frequency). When compared to orthogonal multiple access (OMA), such as orthogonal frequency division multiple access (OFDMA), the sum capacity can be increased since the communication resources in NOMA are shared by all users. However, resource pooling causes inter-user interference, which lowers performance. The receiver must have a successive interference cancellation (SIC) mechanism for this to work. SIC performance is dependent on the transmission power of each user in downlink (DL) NOMA systems. In, the authors proposed the optimal power allocation scheme to maximize edge-user throughput under the condition that total user throughput in NOMA is the same as that in OMA. In, the authors proposed a power allocation method based on proportional fairness scheduling and in, a suboptimal power allocation method to reduce complexity was proposed.

In these previous works, SIC is assumed to be perfectly performed without SIC error. However, SIC errors do happen in real-world systems, which lowers performance. Additionally, even though SIC is flawlessly executed, residual interference still occurs. Because SIC's transmission power is lower than that of the targeted signal, this interference is not eliminated... Therefore, as the number of the total users increases, total capacity is degraded by the residual interference.

## 1.2 Aim

The aim of this research project is to investigate the performance and efficiency of Non-Orthogonal Multiple Access (NOMA) compared to Orthogonal Multiple Access (OMA) in wireless communication systems. Through comprehensive analysis and simulation, this study seeks to demonstrate the advantages of NOMA over OMA in terms of spectral efficiency, system capacity, and user fairness. Furthermore, this research aims to propose and evaluate novel NOMA algorithms and techniques to enhance its performance, addressing challenges such as user pairing, power allocation, and interference management. By providing a thorough comparative analysis and presenting innovative solutions, this research aims to contribute to the advancement of next-generation wireless communication systems.

## 1.3 The Motivation

NOMA allows for simultaneous connections of multiple users in the same frequency band, enhancing connectivity. This can lead to improved user experiences, reduced latency, and increased system capacity, which are critical factors in the design of next-generation wireless networks.

NOMA is considered a key technology for 5G and beyond. Investigating NOMA can contribute to the development of advanced communication systems, meeting the requirements of high data rates, massive connectivity, and low-latency communication envisioned for future wireless networks.

## 1.4 Problem Statement

As telecommunications networks continue to advance and handle a wider range of services, it becomes vital to efficiently allocate resources like power and spectrum. The current multiple access methods may not fully optimize these resources, resulting in potential inefficiencies. Non-Orthogonal Multiple Access (NOMA) has shown promise as a solution, but there are key challenges that need attention, including user pairing, interference management, and maintaining quality of service in diverse environments. This research aims to explore and overcome these challenges for maximizing the advantages of NOMA in modern tele-communications networks.

# CHAPTER TWO
# NOMA FUNDAMENTALS

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# NOMA FUNDAMENTALS

## 2.1 Non-Orthogonal Multiple Access (NOMA)

Non-Orthogonal Multiple Access (NOMA) is a multiple access method proposed by NTT DoCoMo for the next generation (5G) mobile network. NOMA is a type of non-orthogonal multiplexing where users are multiplexed in the power domain, which is not sufficiently utilized by previous wireless mobile systems. Specifically, signals from different users are superposed at transmitter side and separated at receiver by using successive interference cancellation (SIC).

We consider orthogonal frequency division multiplexing (OFDM) as the modulation scheme and NOMA as the multiple access scheme. In conventional 4G networks, as natural extension of OFDM, orthogonal frequency division multiple access (OFDMA) is used where information for each user is assigned to a subset of subcarriers. In NOMA, on the other hand, all of the subcarriers can be used by each user. Figure 2.1 illustrates the spectrum sharing for OFDMA and NOMA for two users. The concept applies both uplink and downlink transmission.[1]

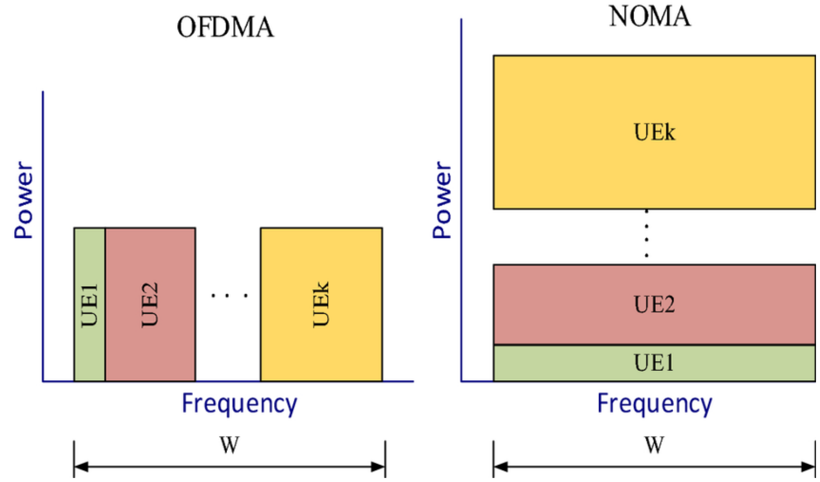


*Fig 2- 1spectrum sharing for OFDMA and NOMA*

Superposition coding at the transmitter and successive interference cancellation (SIC) at the receiver makes it possible to utilize the same spectrum for all users. At the transmitter site, all the individual information signals are superimposed into a single waveform, while at the receiver, SIC decodes the signals one by one until it finds the desired signal. Figure 2.2 illustrates the concept. In the illustration, the three information signals indicated with different colors are superimposed at the transmitter. The received signal at the SIC receiver includes all these three signals. The first signal that SIC decodes is the strongest one while others as interference.[1]

The first decoded signal is then subtracted from the received signal and if the decoding is perfect, the waveform with the rest of the signals is accurately obtained. SIC iterates the process until it finds the desired signal

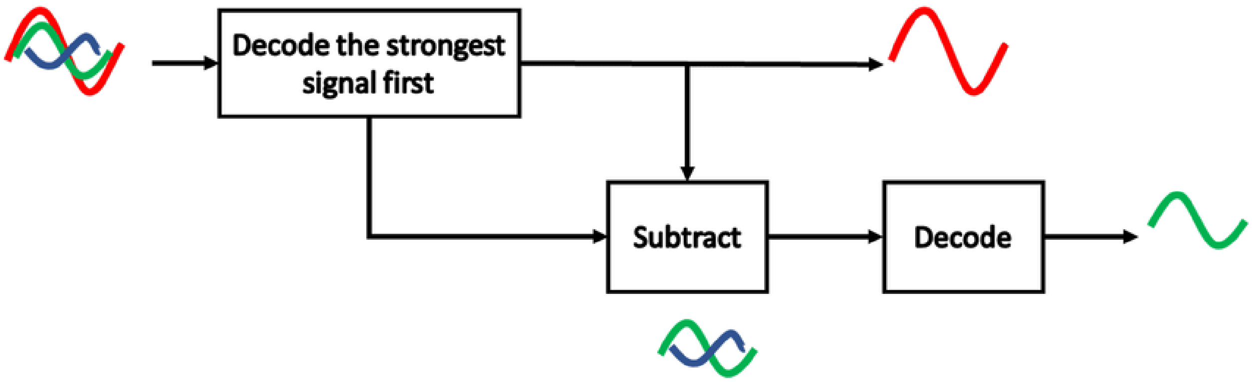


*Fig 2-2 successive interference cancellation*

The success of SIC depends on the perfect cancellation of the signals in the iteration steps. The transmitter should accurately split the power between the user information waveforms and superimpose them. The methodology for power split differs for uplink and downlink channels.[1][8]

## 2.2 NOMA for downlink

In NOMA downlink, the base station superimposes the information waveforms for its serviced users. Each user equipment (UE) employs SIC to detect their own signals. Figure 2.3 shows a BS and K number of UEs with SIC receivers. In the network, it is assumed that the $UE_1$ is the closest to the base station (BS), and $UE_K$ is the farthest.

The challenge for BS is to decide how to allocate the power among the individual information waveforms, which is critical for SIC. In NOMA downlink, more power is allocated to UE located farther from the BS and the least power to the UE closest to the BS. In the network, all UEs receive the same signal that contains the information for all users. Each UE decodes the strongest signal first, and then subtracts the decoded signal from the received signal. SIC receiver iterates the subtraction until it finds its own signal. UE located close to the BS can cancel the signals of the farther UEs. Since the signal of the farthest UE contributes the most to the received signal, it will decode its own signal first. [1][9][7]

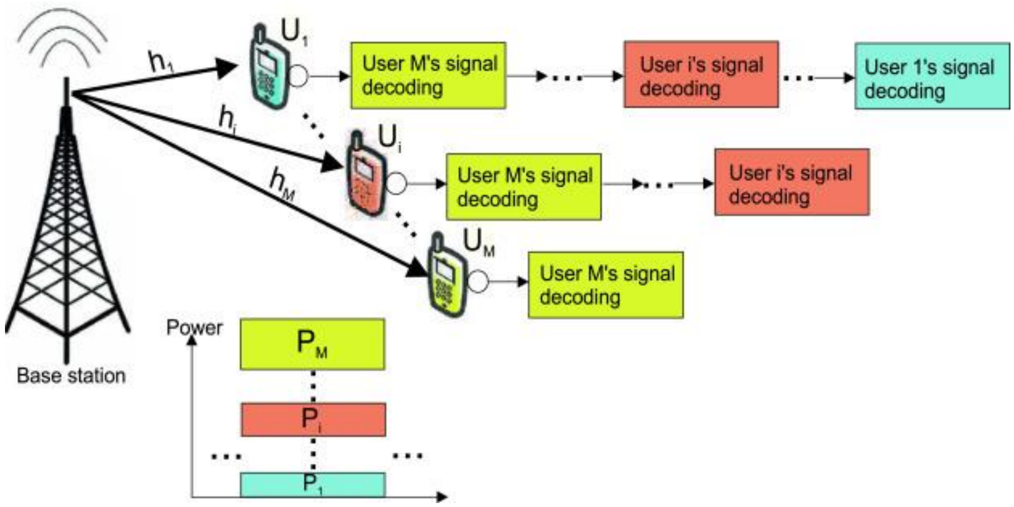


*Fig 2-3 Downlink NOMA for K users.*

The transmitted signal by the BS can be written:

$$x(t) = \sum_{k=1}^{K} \sqrt{\alpha_k P_t}\; x_k(t) \qquad 2\text{-}1$$

Where x(t) is the individual information conveying OFDM waveform $\alpha_k$ is the power allocation coefficient for the $UE_k$, and $P_t$ is the total available power at the BS. The power allocated to each $UE_k$ then becomes $P_k = \alpha_k P_T$, the power is allocated according to the distance of UEs to the BS: $UE_1$ is the closest to the BS, so it is allocated the least power, whereas $UE_K$ is the farthest one, therefore it has the highest power.

The received signal at the $UE_k$ is:

$$Y(t) = x(t)\, g_k + w_k(t) \qquad 2\text{-}2$$

Where is the channel attenuation factor for the link between the BS and the $UE_k$, and x(t) is the additive white Gaussian noise at the $UE_k$ with mean zero and density $N_0$ (W/Hz).

Let us consider the farthest user first. The signal it decodes first will be its own signal since it is allocated the most power as compared the others. The signals for other users will be seen as interference. Therefore, the signal-to-noise ratio (SNR) for $UE_K$ can be written as :

$$SNR_K = \frac{P_K\, g_K^2}{N_0 W + \sum_{i=1}^{K-1} P_i\, g_K^2} \qquad 2\text{-}3$$

where $W$ is the transmission bandwidth. For the closest $UE_1$, the last signal it decodes will be its signal.

Assuming perfect cancellation, the SNR for $UE_1$ becomes:

$$SNR_1 = \frac{P_1 g_1^2}{N_0 W} \quad \text{2-4}$$

In general, for the $UE_k$, the SNR becomes:

$$SNR_k = \frac{P_k\, g_k^2}{N_0 W + \sum_{i=1}^{k-1} P_i\, g_k^2} \quad \text{2-5}$$

When NOMA is used, the throughput (bps) for each UE can be written as:

$$R_k = W log_2(1 + \frac{P_k\, g_k^2}{N + \sum_{i=1}^{k-1} P_i\, g_k^2}) \quad \text{2-6}$$

In OFDMA, on the other hand, UEs are assigned to a group of subcarriers in order to receive their information. When the total bandwidth and power are shared among the UEs equally, the throughput for each UE for OFDMA becomes:

$$R_k = W_k log_2(1 + \frac{P_k\, g_k^2}{N_k}) \quad \text{2-7}$$

$$\textit{where } W_k = \frac{W}{K} \textit{ and } N_k = N_0 W_k. \quad \text{2-8}$$

The sum capacity for both OFDMA and NOMA can be written as:

$$R_T = \sum_{k=1}^{K} R_k \quad \text{2-9}$$

## 2.3 NOMA for uplink

Uplink implementation of NOMA is slightly different than the downlink. Figure 2.4 depicts a network that multiplexes K UEs in the uplink using NOMA. This time, BS employs SIC in order to distinguish the user signals.[1][9]

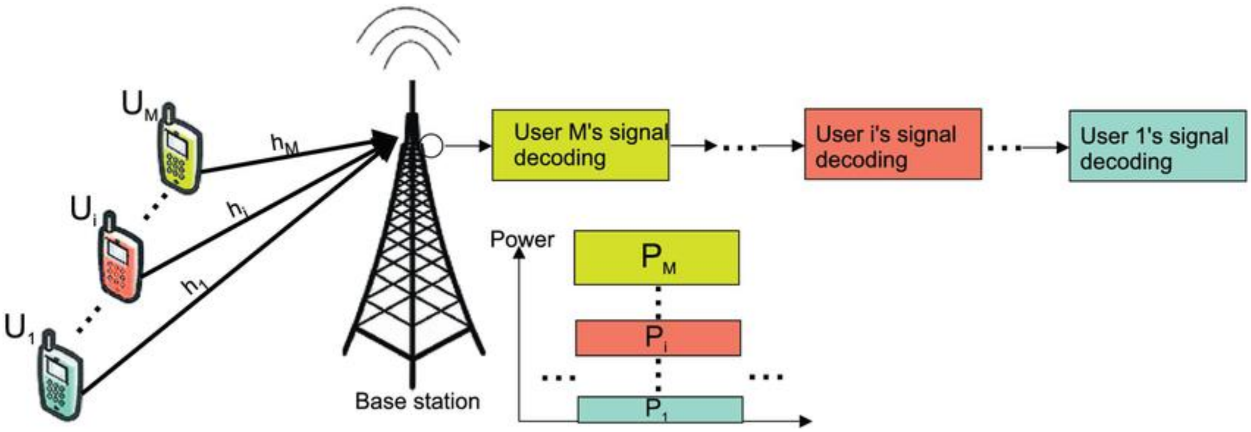


*Fig 2-4 Uplink NOMA for K users.*

In the uplink, the received signal by the BS that includes all the user signals is written as:

$$y(t) = \sum_{k=1}^{K} x_k(t) g_k + w(t) \tag{2-10}$$

Where $g_k$ is the channel attenuation gain for the link between the BS and the $UE_k$, $x_k(t)$ is the information waveform for the kth UE, and *w(t)* is the additive white Gaussian noise at the BS with mean zero and density $N_0$ (W/Hz). In the uplink, the UEs may again optimize their transmit powers according to their locations as in the downlink. However, here we assume that the users are well distributed in the cell coverage, and the received power levels from different users are already well separated. This assumption is more natural from practical point of view, since power optimization requires connection between all the UEs which may be difficult to implement.

At the receiver, the BS implements SIC. The first signal it decodes will be the signal from the nearest user. The SNR for the signal for the UE1 can be written as, including others as interference

$$R_1 = \frac{P g_1^2}{N + \sum_{i=2}^{K} P g_1^2} \qquad \text{2-11}$$

where P is the transmission power of UEs and N = $N_0 W$.

The last signal that the BS decodes is the signal for the farthest user $UE_K$. Assuming perfect cancellation, the SNR for $UE_K$ can be written as:

$$SNR_K = \frac{P g_K^2}{N} \qquad \text{2-12}$$

Generally, for the kth UE, the SNR becomes:

$$SNR = \frac{P g_k^2}{N + \sum_{i=k+1}^{K} P g_i^2} \qquad \text{2-13}$$

The throughput (bps) for each UE can be written as:

$$R_k = W \log_2 [1 + \frac{P g_k^2}{N + \sum_{i=k+1}^{K} P g_i^2}] \qquad \text{2-14}$$

# CHAPTER THREE
# PERFORMANCE ANALYSIS

# CHAPTER THREE
# PERFORMANCE ANALYSIS

## 3.1 NOMA & OMA - Capacity Comparison

As a candidate multiple access technology for 5G, non-orthogonal multiple access (NOMA) offers greater transmission capacity than current orthogonal multiple access (OMA) techniques. This increase in achievable rate is possible because NOMA allows simultaneous transmission of multiple user data in the same frequency carrier.

At the transmitter end, the users are multiplexed in the power domain by using superposition coding. At the receiver end, successive interference cancellation (SIC) is carried out to remove interference and to separate the individual user messages.[4]

### 3.1.1 System Model

Let's consider a downlink communication scenario with a base station (BS) and *N* users. Let $h_{i,}$ denote the channel from the BS to the $i^{th}$ user. There are *N* such channels, h1, h2, ... $h_N$.

Let us assume that user 1, with channel $h_1$ is farthest from the BS and hence, the weakest user. User 2 is the next and so on. User *N* is the nearest/strongest user. This means the channel conditions of the users are arranged as follows:

$$|h_1|^2 < |h_2|^2 < \ldots\ldots |h_N|^2 \qquad 3\text{-}1$$

### 3.1.2 Signal Model for OMA

Next, let's take a look at normal OMA transmission, as an example, let's consider TDMA. To serve N users, TDMA requires N time slots. In the first time slot, user 1's signal is transmitted, in the second time slot, user 2's signal is transmitted and so on. Also, let's assume that all the time slots are of equal duration. Let's say, in the $i^{th}$ time slot, user i's signal is transmitted. Then, the transmit signal is given by

$$X_{i\_OMA} = \sqrt{P}\, X_i \qquad \text{3-2}$$

We see that NOMA has the advantage of simultaneous transmission with controllable interference, while OMA users enjoy interference-free reception. The received signal at user *i* will be

$$y_{i\_OMA} = \sqrt{P}\, X_i\, h_i + \omega_i \qquad \text{3-3}$$

Now, the SNR of the $i^{th}$ OMA user is given by,

$$\gamma_{i\_OMA} = \frac{P\ |\ h_i\ |^2}{\sigma^2} \qquad \text{3-4}$$

The achievable rate for the $i^{th}$ OMA user is given by,

$$R_{i\_OMA} = \frac{1}{N}\log_2(1 + \gamma_{i\_OMA}) \qquad \text{3-5}$$

Finally, the sum rate of OMA is given by,

$$R_{OMA} = \sum_{i=1}^{N} R_{i\_OMA} \qquad \text{3-6}$$

### 3.1.3 Signal Model for NOMA

Let $X_1$, $X_2$ .... $X_N$ denote the messages to be transmitted to the users. The BS performs superposition coding with these messages and transmits the following NOMA signal into the channel:

$$X_{NOMA} = \sqrt{P}\ (\sqrt{\alpha_1}X_1 + \sqrt{\alpha_2}X_2 + \cdots \sqrt{\alpha_N}X_N) \qquad 3\text{-}7$$

where *P* is the total transmit power. $\alpha_1$ …. $\alpha_N$ represent the power allocation coefficients. Since the channels are ordered as

$$|\ h_1\ |^2 <|\ h_2\ |^2 < \ldots..|\ h_N\ |^2$$

the power allocation coefficients must be ordered as

$$\alpha_1\ > \alpha_2 > \ldots..\alpha_N$$

We can represent $X_{NOMA}$ concisely as follows:

$$X_{NOMA} = \sqrt{P}\sum_{i=1}^{N}\sqrt{\alpha_i}\ X_i \qquad 3\text{-}8$$

The received signal at user *i* is given by,

$$y_{i.NOMA} =\ X_{NOMA}h_i + \omega_i \qquad 3\text{-}9$$

where $w_i$ is the AWGN with zero mean and variance = $\sigma^2$

Substituting for $x_{NOMA}$ from **(3-6)**, we get,

$$y_{i.NOMA}\ = \sqrt{P}\left(\sqrt{\alpha_1}X_1 + \sqrt{\alpha_2}X_2 + \cdots \sqrt{\alpha_N}X_N\right)h_i + \omega_i \qquad 3\text{-}10$$

Let's examine how **(3-9)** will look like for user 1 (the farthest user).

$$y_{1\_NOMA} = \sqrt{P}\,\big(\underbrace{\sqrt{\alpha_1}X_1}_{\text{desired and dominating}} + \underbrace{\sqrt{\alpha_2}X_2 + \cdots \sqrt{\alpha_N}X_N}_{\text{interference}}\big)h_1 + \omega_1 \qquad \text{3-11}$$

Since user 1 is allocated the highest amount of power, the message intended for him will be dominating in the received signal. So, he just performs direct decoding, treating the messages intended for all other users as interference. Thus, the SINR for decoding user 1's signal is given by,

$$\gamma_{1\_NOMA} = \frac{\alpha_1 P \mid h_1 \mid^2}{\alpha_2 P \mid h_1 \mid^2 + \alpha_2 P \mid h_1 \mid^2 + \cdots \alpha_N P \mid h_1 \mid^2 + \sigma^2} \qquad \text{3-12}$$

Since the user 1 is allocated the highest power, his message will be dominating the received signal of all the other users. So, first user 2 should directly decode user 1's message, then perform SIC to remove it from $y_{2\_NOMA}$. If the SIC operation is perfect, the resulting signal would be,

$$y_{2\_NOMA} = \sqrt{P}\,\big(\underbrace{\sqrt{\alpha_2}X_2}_{\text{desired and dominating}} + \underbrace{\ldots\sqrt{\alpha_N}X_N}_{\text{interference}}\big)h_2 + \omega_2 \qquad \text{3-13}$$

After SIC, user 2's required message is the dominating term. So, now user 2 can directly decode his message from $y_{2\_NOMA}$ by treating all the remaining users' messages as interference. Thus, the SINR at user 2 to decode his own message is given by,

$$\gamma_{2\_NOMA} = \frac{\alpha_2 P \mid h_2 \mid^2}{\alpha_3 P \mid h_2 \mid^2 + \cdots \alpha_N P \mid h_N \mid^2 + \sigma^2} \qquad \text{3-14}$$

We can extend the same thought process to obtain the decoding rule for users 3, 4 and so on. For example, user 3 has to first decode user 1's signal, perform SIC to eliminate it, then decode user 2's signal, perform SIC again, and then decode his own signal.[4][7]
In general, for any user *i*, the SINR to decode his own signal is given by,

$$\gamma_{i\_NOMA} = \frac{\alpha_i P \mid h_i \mid^2}{\alpha_{i+1} P \mid h_i \mid^2 + \cdots \alpha_N P \mid h_i \mid^2 + \sigma^2} \quad \text{3-15}$$

This expression can be concisely written as:

$$\gamma_{i\_NOMA} = \frac{\alpha_i P \mid h_i \mid^2}{\sum_{j=i+1}^{N} \alpha_j P \mid h_i \mid^2 + \sigma^2} \quad \text{3-16}$$

The achievable rate for any general user *i* can be written as,

$$R_{i\_NOMA} = \log_2(1 + \gamma_{i\_NOMA}) \quad \text{3-17}$$

Finally, the sum rate of all the NOMA users is given by,

$$R_{NOMA} = \sum_{i=1}^{N} R_{i\_NOMA} \quad \text{3-18}$$

## 3.2 Power Allocation in NOMA

Power allocation is very important in non-orthogonal multiple access (NOMA), We used fixed power allocation till now. That is, we fixed the values of $\alpha_1$ and $\alpha_2$ irrespective of the channel conditions. But there are better ways to optimize $\alpha_1$ and $\alpha_2$ dynamically based on the values of channel state information (CSI). A few distinct dynamic power allocation techniques exist, each attempting to achieve a particular objective. The objective can be to maximize energy efficiency, the total rate, etc. This post will discuss a straightforward power allocation strategy that aims to guarantee user fairness. This mechanism called fair power allocation.

The weaker/far user is given priority by our fair PA. In other words, the power allocation coefficients are determined in a way that meets the goal rate for the distant user. All of the available power is only assigned to the near user once the distant user's target rate has been met.[2][6]

### 3.2.1 NOMA Capacity Equations

$$R_f = \log_2(1 + \frac{|h_f|^2 \, P\alpha_f}{|h_f|^2 \, P\alpha_n + \sigma^2}) \tag{3-19}$$

$$R_n = \log_2(1 + \frac{|h_n|^2 \, P\alpha_n}{\sigma^2}) \tag{3-20}$$

$R_n$ is obtained after removing the interference from far user transmission by (SIC)

- $\alpha_n$ - power allocation coefficient for near user
- $\alpha_f$ - power allocation coefficient for far user
- $h_n$ - Rayleigh fading coefficient for near user
- $h_f$ - Rayleigh fading coefficient for far user
- P - Total transmit power
- $\sigma^2$ - Noise power
- $\alpha_n + \alpha_f = 1$
- $\alpha_f > \alpha_n$

### 3.2.2 Derivation of power allocation coefficients $\alpha_n$ and $\alpha_f$

we denote $R^*$ as target rate for far user Choosing αn and αf such that $R_f \geq R^*$ is our aim. will set $R_f = R^*$.

$$\log_2(1+\frac{|\ h_f\ |^2\ \ P\alpha_f}{|\ h_f\ |^2\ \ P\alpha_n+\sigma^2})=R^* \qquad \text{3-21}$$

Now to remove the log will take $2^x$ for both side

$$1+\frac{|\ h_f\ |^2\ \ P\alpha_f}{|\ h_f\ |^2\ \ P\alpha_n+\sigma^2}=2^{R^*} \qquad \text{3-22}$$

$$\frac{|\ h_f\ |^2\ \ P\alpha_f}{|\ h_f\ |^2\ \ P\alpha_n+\sigma^2}=2^{R^*}-1 \qquad \text{3-23}$$

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

ξ is the target SINR for the far user who has target rate $R^*$

$$\frac{|\ h_f\ |^2\ \ P\alpha_f}{|\ h_f\ |^2\ \ P\alpha_n+\sigma^2}=\xi \qquad \text{3-24}$$

$$|\ h_f\ |^2\ \ P\alpha_f=\xi|\ h_f\ |^2\ \ P\alpha_n+\xi\sigma^2 \qquad \text{3-25}$$

$\alpha_n + \alpha_f = 1$, so $\alpha_n = 1 - \alpha_f$.

$$|\ h_f\ |^2\ \ P\alpha_f=\xi|\ h_f\ |^2\ \ P(1-\alpha_f)+\xi\sigma^2 \qquad \text{3-26}$$

$$|\ h_f\ |^2\ \ P\alpha_f=\xi|\ h_f\ |^2\ \ P-\xi|\ h_f\ |^2\ \ P\alpha_f+\xi\sigma^2 \qquad \text{3-27}$$

Collecting all the $\alpha_f$ from to the LHS,

$$| h_f |^2 \; P\alpha_f + \xi | h_f |^2 \; P\alpha_f = \xi | h_f |^2 \; P + \xi\sigma^2 \tag{3-28}$$

$$\alpha_f \; | h_f |^2 \; P(1+\xi) = \xi(| h_f |^2 \; P + \sigma^2) \tag{3-29}$$

$$\alpha_f = \frac{\xi(| h_f |^2 \; P + \sigma^2)}{| h_f |^2 \; P(1+\xi)} \tag{3-30}$$

Now will put a limit to $\alpha_f$ because We don't want to exceed 1

$$\alpha_f = \min\left(1, \frac{\xi\left(| h_f |^2 \; P + \sigma^2\right)}{| h_f |^2 \; P(1+\xi)}\right) \tag{3-31}$$

After utilizing the aforementioned formula to obtain αf, we can effortlessly determine αn.

$$\alpha_n = 1 - \alpha_f \tag{3-32}$$

## 3.3 User Pairing in NOMA

Utilizing hybrid NOMA is the way to support every user. A hybrid NOMA combines any OMA technique with NOMA. Let's use TDMA+NOMA, for instance, as illustrated in Fig. 3-3. Assume that we have a 4 ms time window. Four users need to be supported during this time frame. The four 1 ms slots will now be divided by TDMA, and one slot will be allotted to each user. The four users will each receive a full 4-millisecond slot from NOMA. This is known to increase processing latency and SIC complexity. In contrast, two NOMA users are assigned to each of the two 2 ms slots created by hybrid NOMA.[3][11]

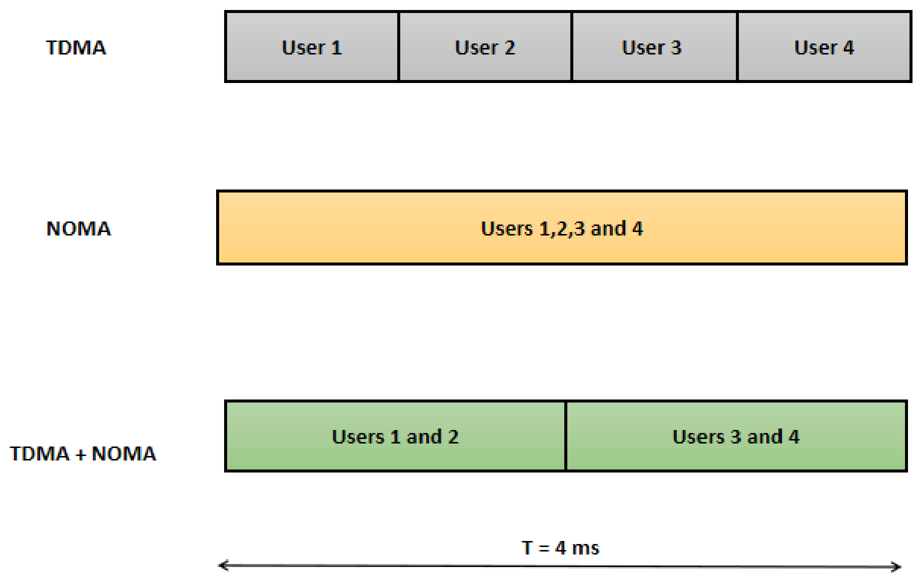


*Fig 3-1 User assignment in different multiple access schemes*

### 3.3.1 Two user pairing strategies in NOMA

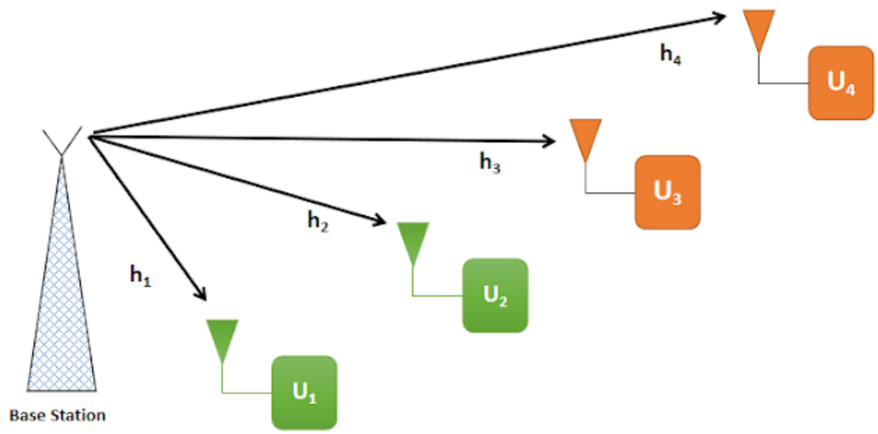


*Fig 3-2 System model*

Let's look at a downlink communication scenario involving four users, as illustrated in figure 3-2 Let's say that $d_1$, $d_2$, $d_3$, and $d_4$ represent $U_1$, $U_2$, $U_3$, and $U_4$'s relative distances from the base station. The closest user is $U_1$, and the furthest away is $U_4$. Their channel conditions are therefore arranged as follows: $|h_1|^2 > |h_2|^2 > |h_3|^2 > |h_4|^2$. We must assign two users to each of the two orthogonal resource blocks (time, frequency, and subcarriers). Based on the distances, we will pair up the users. There are two easy methods for achieving this:

I. Near-far pairing (N-F)

II. Near-near, far-far pairing (N-N, F-F)

### 3.3.2 Near-Far Pairing (N-F)

The closest user to the base station and the furthest user from the base station are matched in this way. The user next in proximity is matched with the user next in distance, and so on. The closest user in our case is U1, and the farthest user is U4. N-F pairing will thus unite U1 and U4 within a single resource block. In the following resource block, U2 and U3 will be matched.

U1 is the near user and U4 is the distant user in the first user pair. Consequently, we must select $\alpha 1 < \alpha 4$ for the power allocation coefficients. So, U1 should handle direct decoding and U4 should handle successive interference cancellation (SIC). In the same way, U2 is the near user and U3 is the distant user in the second user pair. Consequently, we must select $\alpha 2 < \alpha 3$. In this case, U2 should handle SIC and U3 should handle straight decoding.

The users in the first pair can achieve the following rates:

$$R_{1\_nf} = \frac{1}{2}\log_2(1 + \frac{P\alpha_1 \mid h_1 \mid^2}{\sigma^2}) \quad \text{After SIC} \qquad 3\text{-}33$$

$$R_{4\_nf} = \frac{1}{2}\log_2(1 + \frac{P\alpha_4 \mid h_4 \mid^2}{P\alpha_1 \mid h_4 \mid^2 + \sigma^2}) \qquad 3\text{-}34$$

Second Pair

$$R_{2\_nf} = \frac{1}{2}\log_2(1 + \frac{P\alpha_2 \mid h_2 \mid^2}{\sigma^2}) \quad \text{After SIC} \qquad 3\text{-}35$$

$$R_{3\_nf} = \frac{1}{2}\log_2(1 + \frac{P\alpha_3 \mid h_3 \mid^2}{P\alpha_2 \mid h_3 \mid^2 + \sigma^2}) \qquad 3\text{-}36$$

The sum rate of the N-F scheme will be

$$R_{nf} = R_{1\_nf} + R_{2\_nf} + R_{3\_nf} + R_{4\_nf} \qquad 3\text{-}37$$

### 3.3.3 Near-Near, Far-Far Pairing (N-N, F-F)

Putting the closest user together with the next closest user is an additional method of user pairing. Grouped with the next farthest user is the farthest user. In our case, if we stick to this plan, U1 and U2 will share a resource block. U3 and U4 will be paired in the upcoming resource block.[11]

As of right now, in the first user pair, $U_1$ is closer to the base station than $U_2$. Consequently, we must select $\alpha_1 < \alpha_2$. $U_1$ will handle SIC, and $U_2$ will handle straight decoding. In the same way, $U_3$ is nearer the base station than $U_4$. Thus, we must select $\alpha_3 < \alpha_4$. SIC should be handled by $U_3$, while straight decoding is handled by $U_4$.

The users in the first pair can achieve the following rates:

$$R_{1\_nnff} = \frac{1}{2}\log_2(1 + \frac{P\alpha_1 \mid h_1 \mid^2}{\sigma^2}) \text{ After SIC} \qquad \text{3-38}$$

$$R_{2\_nnff} = \frac{1}{2}\log_2(1 + \frac{P\alpha_2 \mid h_2 \mid^2}{P\alpha_1 \mid h_2 \mid^2 + \sigma^2}) \qquad \text{3-39}$$

Second Pair

$$R_{3\_nnff} = \frac{1}{2}\log_2(1 + \frac{P\alpha_3 \mid h_3 \mid^2}{\sigma^2}) \text{ After SIC} \qquad \text{3-40}$$

$$R_{4\_nnff} = \frac{1}{2}\log_2(1 + \frac{P\alpha_4 \mid h_4 \mid^2}{P\alpha_3 \mid h_4 \mid^2 + \sigma^2}) \qquad \text{3-41}$$

The sum rate of the N-N, F-F scheme will be

$$R_{nnff} = R_{1\_nnff} + R_{2\_nnff} + R_{3\_nnff} + R_{4\_nnff} \qquad \text{3-42}$$

## 3.4 Imperfect SIC in NOMA

### 3.4.1 Introduction

Let's first examine the network model we will be using before examining what imperfect SIC actually is. Our network will be configured as follows. Two users are connected to our downlink NOMA network. Each user has two distinct messages that the base station (BS) needs to send. User 1 is the far user/weak user and, user 2 is the near user/strong user.[5][8]

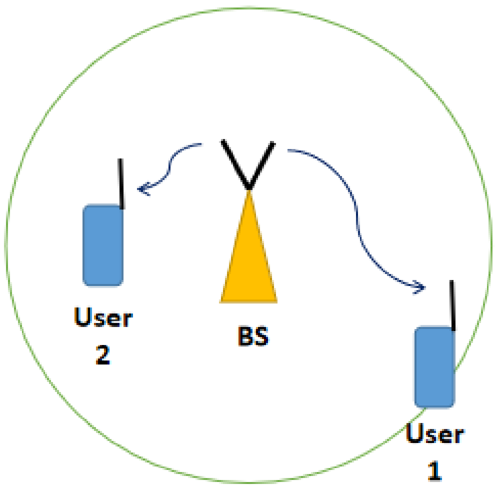


*Fig 3-3 System model*

In case you forgot, the signals received at the close user (y1) and far user (y2) can be depicted as follows:

$$y_1 = h_1 x + \omega_1 = h_1\left[P\left(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2\right)\right] + \omega_1 \quad \text{3-43}$$

$$y_2 = h_2 x + \omega_2 = h_1\left[P\left(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2\right)\right] + \omega_2 \quad \text{3-44}$$

Where

$$x = P\left(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2\right) \quad \text{3-45}$$

According to the rules of NOMA, $\alpha_1 > \alpha_2 >$. Therefore, the far user (user 1) will do direct decoding while, the near user (user 2) must perform SIC to retrieve his data.

### 3.4.2 Imperfect SIC

SIC is perfect if

- User 2 accurately decodes user 1's data from y2 by direct estimation.
- User 2 multiplies the estimate of user 1's data by $\sqrt{\alpha_1}$ accurately.
- User 2 has to deduct from y2 the outcome of the preceding step.

If SIC is flawless, then $y_2$ should become:

$$y_2 = h_2 P\sqrt{\alpha_1}x_1 + h_2 P\sqrt{\alpha_2}x_2 + \omega_2 - h_2 P\sqrt{\alpha_1}x_1 + h_2 P\sqrt{\alpha_2}x_2 + \omega_2 \qquad 3\text{-}46$$

after SIC.

In the event that something goes wrong, SIC would be flawed. When we talk about defective SIC, we mean that $y_2$ still contains a residual of the $x_1$ component following SIC. In other words, following faulty SIC, $y_2$ becomes into

$$y_2' = \underbrace{\sqrt{\epsilon}\, h_2 P\sqrt{\alpha_1}x_1}_{\text{residual term}} + h_2 P\sqrt{\alpha_2}x_2 \qquad 3\text{-}47$$

### 3.4.3 How Imperfect SIC Affects Achievable Data Rate

that the achievable data rate of user 2 for decoding user 1's data is,

$$R_{1,2} = \log_2(1 + \frac{P\alpha_1 \mid h_2 \mid^2}{P\alpha_2 \mid h_2 \mid^2 + \sigma^2}) \quad 3\text{-}48$$

After SIC, the $x_1$ term is totally eliminated and the resulting achievable capacity for user 2 to decode its own data is,[5]

$$R_2 = \log_2(1 + \frac{P\alpha_2 \mid h_2 \mid^2}{\sigma^2}) \quad 3\text{-}49$$

Now, due to imperfect SIC, a residue of user 1's power is still present at interference in the denominator. As a result, the achievable rate reduces to

$$R_2' = \log_2(1 + \frac{P\alpha_2 \mid h_2 \mid^2}{\epsilon\, P\alpha_1 \mid h_2 \mid^2 + \sigma^2}) \quad 3\text{-}50$$

where $\epsilon$ is the proportion of the x1 component residue that remains after SIC mistake. It is evident that $R_2' < R_2$.

Thus, imperfect SIC has a detrimental effect on the data rate of the strong user/the user who is performing SIC.
Note that $R_2'$ equals $R_2$ when $\epsilon$=0 i.e., when SIC is perfect.

# CHAPTER FOUR
# SIMULATION RESULTS AND DISCUSSION

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## 4.1 Rate Pairs Between NOMA & OFDMA

We assume that there are two users in the network for the sake of discussion and analyze the boundaries of the achievable rate regions for these two users

We consider a symmetric downlink channel so that the users are at equal distance to the BS. Let's SNR1= SNR2=10dB shows the boundaries of the achievable rate regions R1 and R1 for NOMA and OFDMA.

NOMA achieves higher rate pairs than the OFDMA except at the corners points (where the rates are equal to the single user capacities).

When the fairness is high, both users experience 1.6 bps/Hz throughputs with both NOMA and OFDMA.

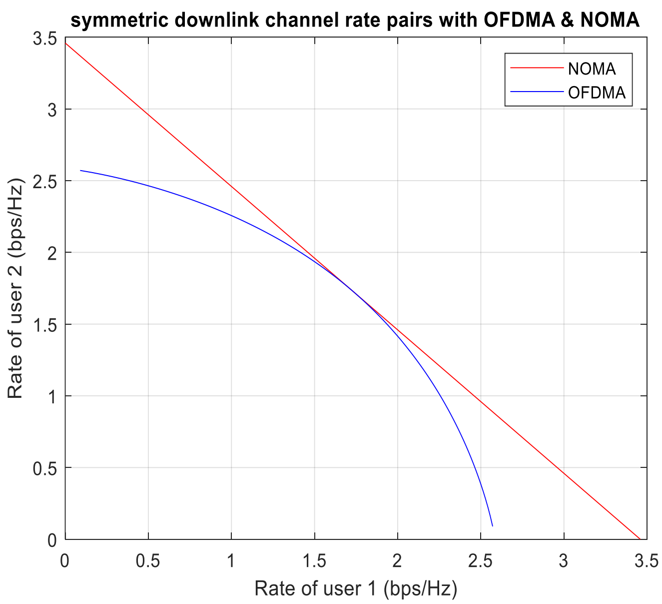


*Fig 4-2 High fairness SNR1=SNR2 = 10 dB*

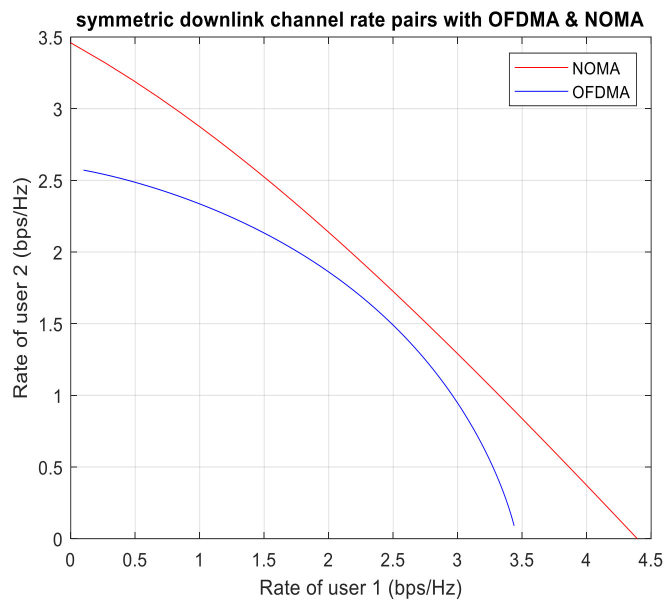


*Fig 4-1 Lower fairness SNR1= 20dB & SNR2 = 10dB*

## 4.2 NOMA & OMA - Capacity Comparison

Now that we have the mathematical expressions, let's plot a graph to compare the capacity of OMA and NOMA. Let us consider a network with N=3 users and compare their performance. The capacity plots look like this:

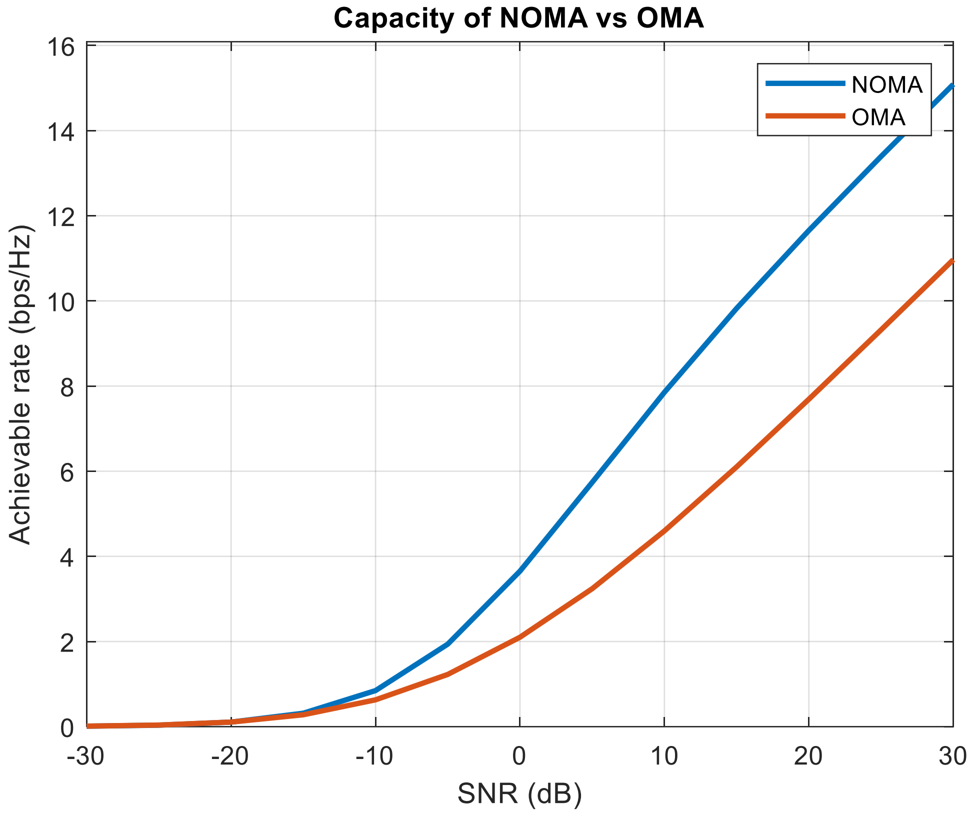


*Fig 4-3 NOMA vs OMA*

At high SNR, however, NOMA outperforms OMA by offering high capacity.

In addition, NOMA accomplishes this while utilizing minimal resources. In this example, TDMA requires 3 times slots to complete the whole transmission. If the duration of 1 time slot is 1 ms, TDMA requires 3 ms to complete the transmission. NOMA, on the other hand, completes the transmission in a single time slot itself (i.e., in 1 ms). This significantly reduces the latency. This demonstrates the usefulness of NOMA in future communication technologies.

## 4.3 Power Allocation in NOMA

Let's contrast the aggregate rate of our enhanced fair PA with the fixed PA we have been utilizing up to this point. Rn + Rf is what we mean by sum rate. This is the graph that results from plotting the sum rate as a function of transmit power.

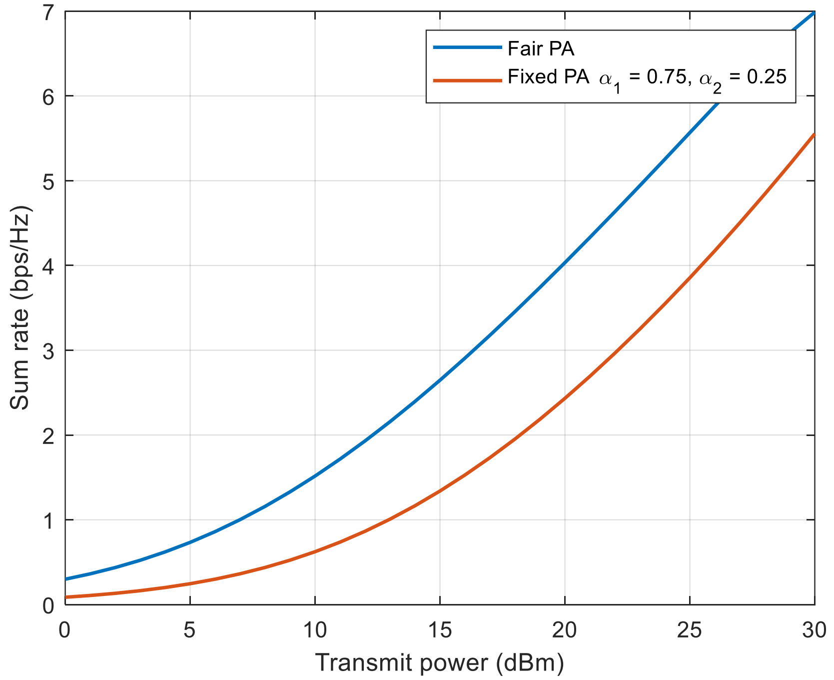


*Fig 4-4 Sum rate vs transmit power of fixed and fair PA*

We are aware of the wireless channel's high degree of dynamic nature. Fixed PA is not concerned with users' immediate channel conditions. Notwithstanding the channel state, αn and αf remain constant. However, our just PA is a flexible plan. In other words, the values of αn and αf are adjusted to comply with the specification whenever the channel changes. Because of this, fair PA outperforms fixed PA in terms of cumulative rate.

## 4.4 User Pairing in NOMA

We take into account N = 4 users in this simulation. Plotting the network's total rate will be done after we use each of the user pairing strategies. Furthermore, we will contrast the network's sum rate performance using only SC-NOMA.

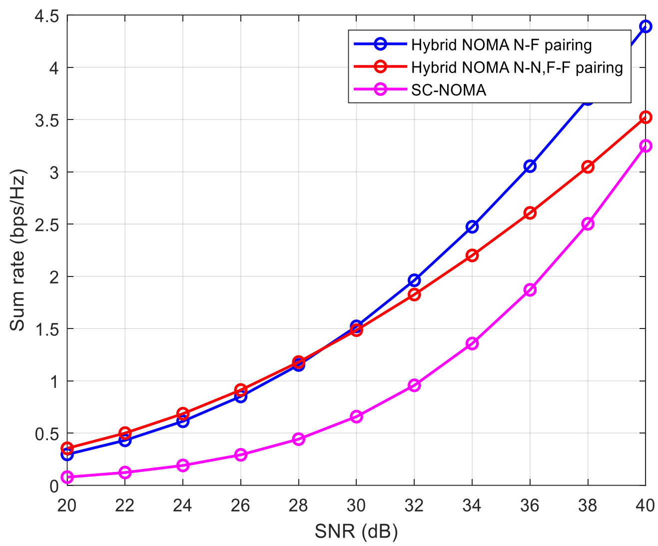


*Fig 4-6 pairing results for 4 users*

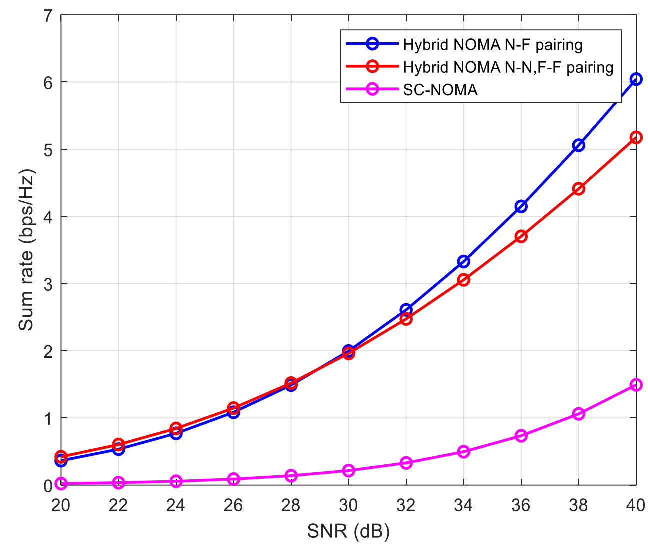


*Fig 4-5 pairing results for 6 users*

A higher sum rate is obtained when the near user and the far user are matched. This validates the well-recognized idea that NOMA functions optimally when there is a difference in the channel conditions between the two users.

## 4.5 Imperfect SIC

We can see that the achievable rate degrades as SIC error increases.

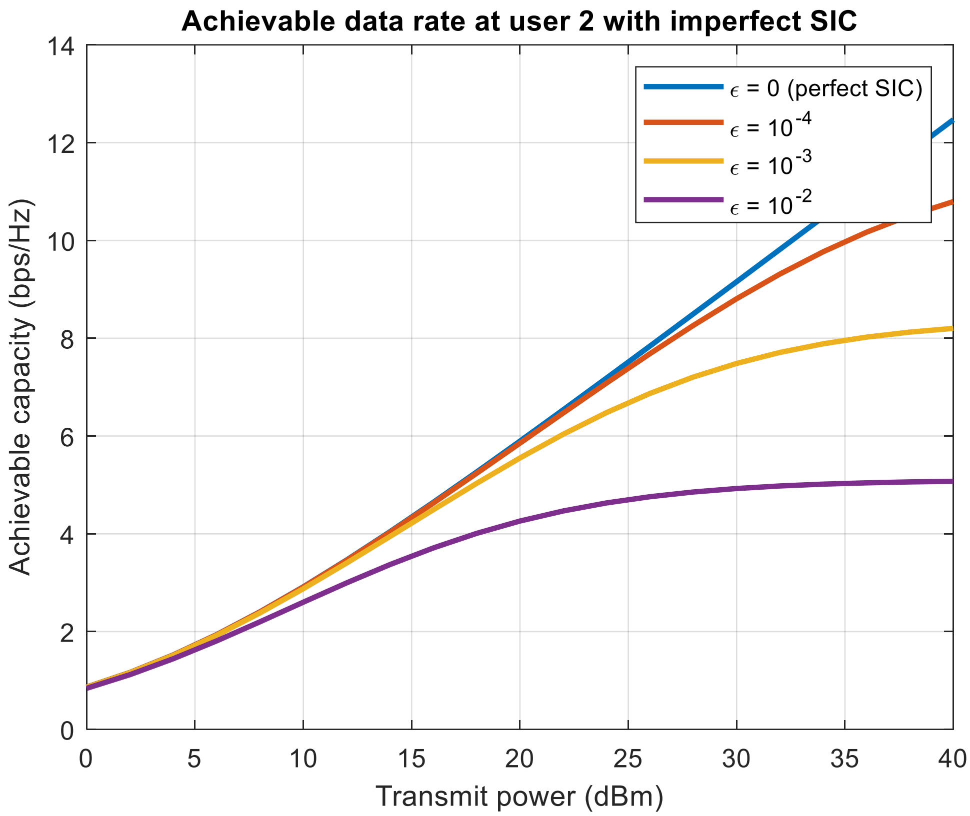


*Fig 4-7 Imperfect SIC*

# CHAPTER FIVE
# CONCLUSION

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# CONCLUSION

In this project, we delved into the realm of Non-Orthogonal Multiple Access (NOMA) and explored various techniques to enhance its performance. Our investigation covered critical aspects such as power allocation, user pairing, and the impact of imperfect Successive Interference Cancellation (SIC) on NOMA systems.

To provide a comprehensive assessment, we conducted extensive simulations and comparisons, particularly focusing on the sum rate of NOMA versus other multiple access techniques. The results demonstrated NOMA's superior performance in scenarios with diverse channel conditions. By achieving higher sum rates, NOMA showcased its potential to meet the growing demands of modern wireless communication.

Power allocation in NOMA played a pivotal role in optimizing spectral efficiency. By intelligently distributing power among users based on their channel conditions, we witnessed significant improvements in the overall system performance. The trade-off between fairness and efficiency in power allocation mechanisms became apparent, shedding light on the importance of striking a balance tailored to specific communication scenarios.

User pairing in NOMA emerged as a strategic approach to exploit the diversity in users' channel conditions. Through effective pairing, NOMA showcased its ability to leverage multiuser diversity, thereby enhancing the system's reliability and throughput. The insights gained from user pairing strategies provided valuable considerations for real-world NOMA deployments.

Moreover, our project not only presented a thorough exploration of NOMA, the findings from power allocation, user pairing, and imperfect SIC shed light on the nuances of NOMA, empowering researchers and engineers to make informed decisions in deploying NOMA for future communication networks. As the demand for higher data rates and spectral efficiency intensifies, the role of NOMA becomes increasingly prominent, marking a significant milestone in the evolution of multiple access techniques.

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