KATHMANDU UNIVERSITY

SCHOOL OF ENGINEERING

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

PROJECT REPORT

PERFORMANCE ANALYSIS OF NON- ORTHOGONAL MULTIPLE ACCESS SYSTEM

A **Final year project** report submitted in partial fulfilment

of the requirements for the degree of

Bachelor of Engineering

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CERTIFICATION

FOURTH YEAR PROJECT REPORT

ON

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ABSTRACT

NOMA uses the power domain for multiple access, where different users are served at different power levels. NOMA allows multiple users to transmit and receive simultaneously using the same resource. This project describes the working of NOMA in ideal condition and also performance analysis of NOMA systems like BER and SNR in AWGN and Rayleigh fading channel. Comparison between OMA and NOMA will be made by observing their achievable rate. We will also be observing the effect on the performance of NOMA with an increasing number of users along with slight understanding of hybrid NOMA.

ACKNOWLEDGEMENT

We are very much grateful to the Kathmandu University for providing us opportunity to undertake this project. I would like to take this moment to express my genuine admiration and appreciation to all those who contributed during the project period. In particular, we are immensely grateful to Department of Electrical and Electronics Engineering for arranging the resources and granting us the opportunity to do the project. We extend our thanks to **Dr. Ram Kaji Budhathoki**, the Head of the Department, for his consistent encouragement, advice, and guidance.

Predominately, we would like to thank our supervisor **Assistant Professor Om Nath Acharya**, for his continued encouragement, advice, and guidance. Mr. Om Nath Acharya insights and feedback have greatly contributed to the success of this project, and his willingness to provide constructive criticism has been instrumental in shaping my understanding and approach to the project

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ABBREVIATION

NOMA : Non- Orthogonal Multiple Access

OMA : Orthogonal Multiple Access

1G : First Generation

2G : Second Generation

3G : Third Generation

4G : Fourth Generation

5G : Fifth Generation

SIC : Successive Interference Cancellation

BS : Base Station

BER : Bit Error Rate

SER : Symbol Error Rate

AWGN : Additive White Gaussian Noise

SCMA : Sparse Code Multiple Access

LDS :Low Density Spreading

LPMA :Lattice Partition Multiple Access

MATLAB: Matrix Laboratory

CHAPTER 1: BACKGROUND AND INTRODUCTION

Since the introduction of the first cellular network in 1970, cellular networks and technology have evolved considerably, from the first emergence of cellular networks in Japan in 1979 commonly known as 1G network , different generations have been developed by increasing capabilities, decreasing latency and improving other parameters. These successive generations are 2G, 3G, 4G utilizing OMA with different modulation techniques. For the latest 5G network to increase efficiency, reliability, decrease latency, different techniques along with different multiple access techniques as OMA is not sufficient and thus NOMA was introduced.

Non-Orthogonal Multiple Access (NOMA) is a candidate multiple access scheme for 5G. The fact that NOMA allows multiple users to transmit and receive simultaneously using the same resource. The two key operations that make NOMA possible are superposition coding which must be done at the transmitter side and successive interference cancellation (also known as SIC) at the receiver side. Superposition coding is a fancy term for power domain multiplexing. Signals from different users are superposed at the transmitter by allocating optimal power to each user and the subsequent signal is then transferred using the same subcarriers.

Multiple accesses (MA) in 5G mobile networks are an emerging research topic, since it is key for the next generation network to keep pace with the explosive growth of mobile data and multimedia traffic. Non-orthogonal multiple access (NOMA) has recently received considerable attention as a promising candidate for 5G multiple access. Particularly, NOMA uses the power domain for multiple access, where different users are served at different power levels. In NOMA, the users with better channel conditions employ successive interference cancellation (SIC) to remove the messages intended for other users before decoding their own . The benefit of using NOMA can be illustrated by the following example. Suppose there is a user close to the edge of its cell, denoted by A, whose channel condition is very poor. For conventional MA, an orthogonal bandwidth channel, e.g., a time slot, will be allocated to this user, and the other users cannot use this time slot. The key idea of NOMA is to squeeze another user with a better channel condition, denoted by B, into this time slot. Since A's channel condition is very poor, the interference from B will not cause much performance degradation to A, but the overall system throughput can be significantly improved since additional information can be delivered between the base station (BS) and B.

1.1 Channel models

In this section, it has described the working principle for Rayleigh fading channel

1.1.1 Rayleigh fading

The Rayleigh fading model uses a statistical approach to analyze the propagation, and can be used in a number of environments. The Rayleigh fading model is ideally suited to situations where there are large numbers of signal paths and reflections. Typical scenarios include cellular telecommunications where there are a large number of reflections from buildings and the like and also HF ionospheric communications where the uneven nature of the ionosphere means that the overall signal can arrive having taken many different paths. The Rayleigh fading model is also appropriate for tropospheric radio propagation because, again there are many reflection points and the signal may follow a variety of different paths. A Rayleigh constrains the total signal at the recipient and can change the probability density Function of Rayleigh fading channel and can be expressed in equation given below

$P(x) = \frac{x}{\sigma^2} exp\left(-\frac{x^2}{2\sigma^2}\right)$ for $x \geq 0$

where $\sigma^2 = variance$,x amplitude of received signal

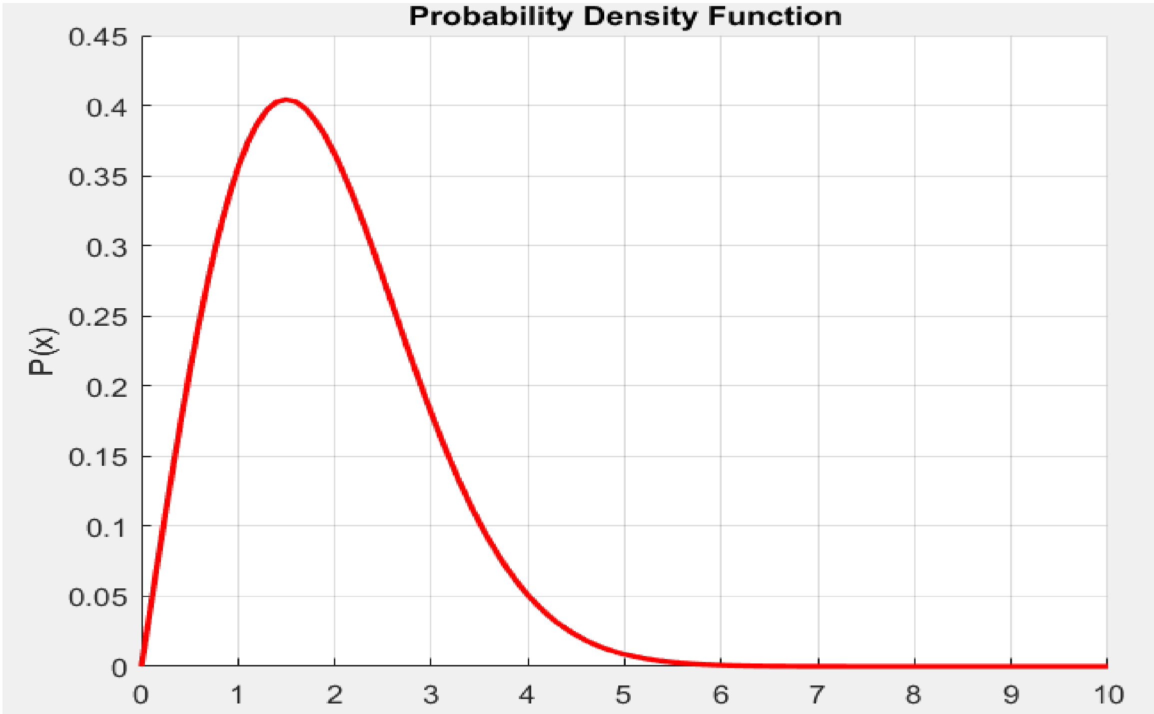

Figure 1: Probability Density Function of Rayleigh Fading Channel

1.2 Performance Metrics

1.2.1 BER (Bit Error Rate)

BER is the percentage of bits that have errors relative to the total number of bits received in a transmission, usually expressed as ten to a negative power. Also, it is an indication of how often a packet or other data unit has to be retransmitted because of error. Too high a BER may indicate that a slower data rate would actually improve overall transmission time for a given amount of transmitted data since the BER might be reduced, lowering the number of packets that had to be resent. It can be expressed as:

$$BER = \frac{Number\ of\ error\ bit}{Number\ of\ transmitted\ bit}$$

1.2.2 SNR (Signal to Noise Ratio)

SNR is a metric that describes the signal performance in the presence of wireless channel noise (interference). In the linear scale, the SNR is the ratio of the signal to the noise power, which tells us the strength of the signal when compared to the channel noise. SNR is measured in db(decibel) units . A positive SNR indicates that the signal power is greater than the noise power while a negative SNR indicates the opposite. It can be expressed as:

$$\text{SNR}= 10log_{10}\left(\frac{Signal\ Power}{Noise\ Power}\right)$$

1.2.3 Achievable Rate and Sum Rate

The achievable rate is the maximum rate at which data can be reliably transmitted over a communication channel using a particular encoding and decoding scheme. The achievable rate is typically calculated based on the properties of the communication channel and the amount of noise or interference present in the channel. The Shannon-Hartley theorem provides a formula for calculating the achievable rate of a communication channel.

The sum rate, on the other hand, is the total rate at which multiple users can communicate over a shared channel. The sum rate takes into account the fact that multiple users may be sharing the same channel, and thus the total capacity of the channel must be divided among them. The sum rate is an important metric in multi-user communication systems such as cellular networks and wireless LANs.

To calculate the sum rate, the achievable rate of each user must be determined, and then the rates are summed over all users. The sum rate is limited by the capacity of the channel and the number of users sharing the channel. As the number of users increases, the achievable rate for each user typically decreases, which can limit the overall sum rate of the system.

Achievable Rate can be expressed as:

$$C = B\ 10log_2(1 + S/N)$$

where, C is the channel capacity in bits per second, B is the bandwidth of the channel in Hertz, S is the average signal power, and N is the average noise power.

The achievable rate R is then given by:

$$R \leq C - \delta$$

where, δ is the coding rate, which is the ratio of the number of information bits to the total number of transmitted bits.

Similarly, the sum rate in a multi-user communication system can be calculated as the total achievable rate of all users sharing the channel. Specifically, if there are K users, each with an achievable rate R_k, then the sum rate R_sum is given by:

$$R_{sum} = \sum_{1}^{k} R_k$$

CHAPTER 2: PROBLEM DEFINITION

The problem defines by the project are:

- Traditional orthogonal multiple access (OMA) assigns separate and orthogonal resources to each user to avoid interference, NOMA allows multiple users to share the same resources
- As bandwidth is divided to multiple users in OMA, the total capacity of the system is lower.
- NOMA can also enhance the fairness of the system by allowing users with weaker channels to access the resources that are otherwise occupied by stronger users.

CHAPTER 3: LITERATURE SURVEY

This article illustrates that the superior spectral efficiency of NOMA is highly promising for 5G radio access. To date, NOMA has been investigated from various viewpoints, including resource allocation and fairness. The potential of NOMA is not limited to only SISO systems; its capacity can be further increased by applying NOMA in MIMO systems. The application of NOMA is also penetrable into other communication systems, including mm Wave and visible light systems. To make NOMA more practical, its limitations such as error propagation and ICI in multi-cell networks should be overcome[1].

Researchers in academia and industry have been recently investigating the error performances and capacity of NOMA schemes. The main drawback of NOMA techniques is the interference among users due to its non-orthogonal access nature, which is usually solved by interference cancellation techniques such as successive interference cancellation (SIC) at the receivers. On the other hand, the interference among users may not be completely eliminated in the SIC process due to the erroneous decisions in the receivers usually caused by channels. In this study, for the first time in the literature, the authors derive an exact closed-form bit error rate (BER) expression under SIC error for downlink NOMA over Rayleigh fading channels. Besides, they derive one-degree integral form exact BER expressions and closed-form approximate expressions for uplink NOMA. Then, the derived expressions are validated by simulations. The numerical results are depicted to reveal the effects of error during SIC process on the performance for various cases such as power allocation for downlink and channel quality difference for uplink[2].

This paper studies the SER and BER with consideration of the downlink/uplink transmission, the number of information streams, and the channel coding jointly. For analyzing the impact of channel coding, gray coding is introduced for the downlink transmission. The derived SER and BER are given by closed-form expressions, by which the transmission performance could be evaluated efficiently. We also show an approximate SER/BER when the transmitter could employ Gray-coding. Additionally, associating with the derived closed-form expressions, we show that there exists no error propagation/error accumulation phenomenon when the successive interference cancellation (SIC) is adopted in signal demodulation, which is treated as a major drawback of SIC demodulation in the NOMA systems. Furthermore, by analyzing the encoding/decoding processes in the current NOMA works, a joint Gray-coding scheme is introduced to reduce the SER and BER in the downlink transmission effectively. Through simulations, we validate the correctness of the derived expressions of SER and BER from different aspects[3].

This paper shows the performance of the considered NOMA based system over Nakagami-m fading channels for the downlink scenario. In particular, we derive the closed-form expression of bit-error rate (BER) at the end users supported by the ad-hoc networks cooperated through the near NOMA user as well as through the far NOMA user. Further, we also derive the closed-form expression for the ergodic capacity and packet error rate for the considered system. Based on the obtained results, the impact of the power allocation coefficient over the performance of the considered system is analyzed to determine the optimal power allocation coefficient. The analytical results are corroborated with the simulations for various parameters to validate the analysis[4].

Non-orthogonal multiple access (NOMA) has become an important principle for the design of radio access techniques for the fifth generation (5G) wireless networks. Although several 5G multiple access techniques have been proposed by academia and industry, including power-domain NOMA , sparse code multiple access (SCMA) , pattern division multiple access (PDMA) , low density spreading (LDS), and lattice partition multiple access (LPMA) , these techniques are based on the same key concept, where more than one user is served in each orthogonal resource block, e.g., a time slot, a frequency channel, a spreading code, or an orthogonal spatial degree of freedom[5].

The upcoming 5G wireless communication systems have unique requirements that need to be met. Non-orthogonal multiple access (NOMA) is a promising technique for addressing these challenges and has been actively researched in recent years. Unlike conventional orthogonal multiple access (OMA), NOMA can support a higher number of users than the number of orthogonal resource slots by using non-orthogonal resource allocation. This is achieved through inter-user interference cancellation, but it increases receiver complexity. This article provides a comprehensive literature survey on NOMA, including its origins, recent developments, and future research directions. It introduces the basic principles of NOMA and compares it to OMA from an information theory perspective. The article discusses prominent NOMA schemes and divides them into two categories: power-domain and code-domain NOMA. The design principles and key features of each scheme are discussed in detail, and a systematic comparison of these schemes is summarized in terms of their spectral efficiency, system performance, and receiver complexity. Finally, the article highlights challenging open problems that need to be addressed in NOMA research, along with corresponding opportunities and future research trends [6].

The article suggests a new approach to solve the limitations of non-orthogonal multiple access (NOMA) by proposing a hybrid access scheme that combines both NOMA and orthogonal multiple access (OMA). As NOMA operates within the power domain, small variations in channel gain or the increase in the number of users can cause issues. To address these limitations, the proposed approach uses a unique combination of NOMA and OMA for multiple access patterns and selects the optimal pattern based on system capacity. Computer simulations are used to demonstrate the effectiveness of the proposed scheme in comparison to conventional hybrid access using NOMA and OMA **[7].**

CHAPTER 4: OBJECTIVE OF THE PROJECT

Objectives of the project are:

- Analysis of basic NOMA structure.
- Analysis of parameters like BER, achievable and sum rate in AWGN channel and Rayleigh fading channel.
- To provide insights into the strengths and limitations of NOMA and to identify the factors that affect its performance.
- Comparing capacity of NOMA and OMA.

CHAPTER 5: SIGNIFICANCE OF THE STUDY

The significance of our project is:

- It achieves superior spectral efficiency by serving multiple users at the same time and with the same frequency resource, and mitigating the interference through SIC.
- It increases the number of simultaneously served users, and thus, it can support massive connectivity.
- Due to the simultaneous transmission nature, a user does not need to go through a scheduled time slot to transmit its information, and hence, it experiences lower latency.
- NOMA can maintain user fairness and diverse quality of service by flexible power control between the strong and weak users; particularly, as more power is allocated to a weak user.

CHAPTER 6: METHODOLOGY

6.1 Basic Structure of NOMA and Project Flow

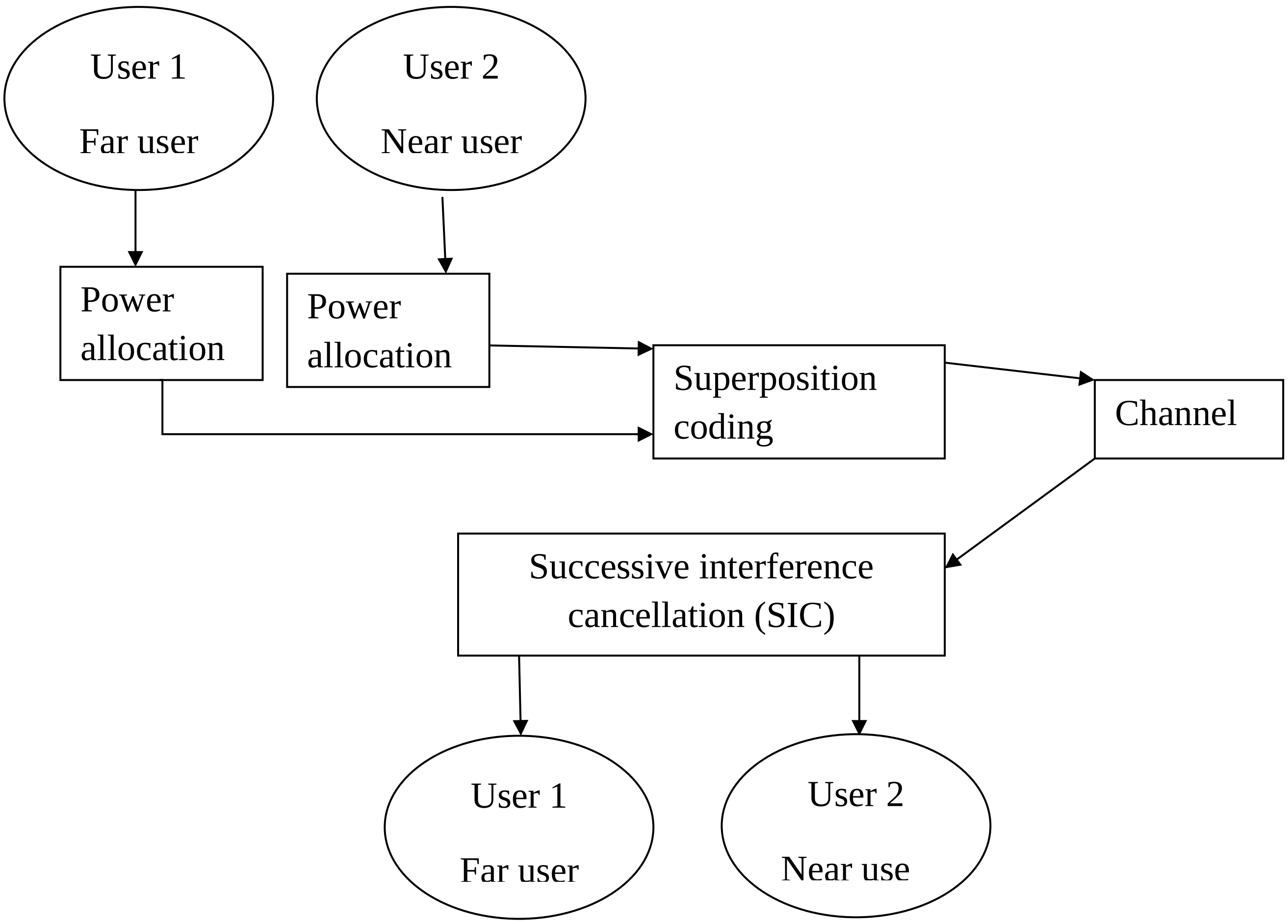

Figure 2: Basic NOMA structure

NOMA allows multiple users to transmit and receive simultaneously using the same frequency. The two key operations that make NOMA possible are superposition coding which must be done at the transmitter side and successive interference cancellation (also known as SIC) at the receiver side.

6.2 Basic flow of Project

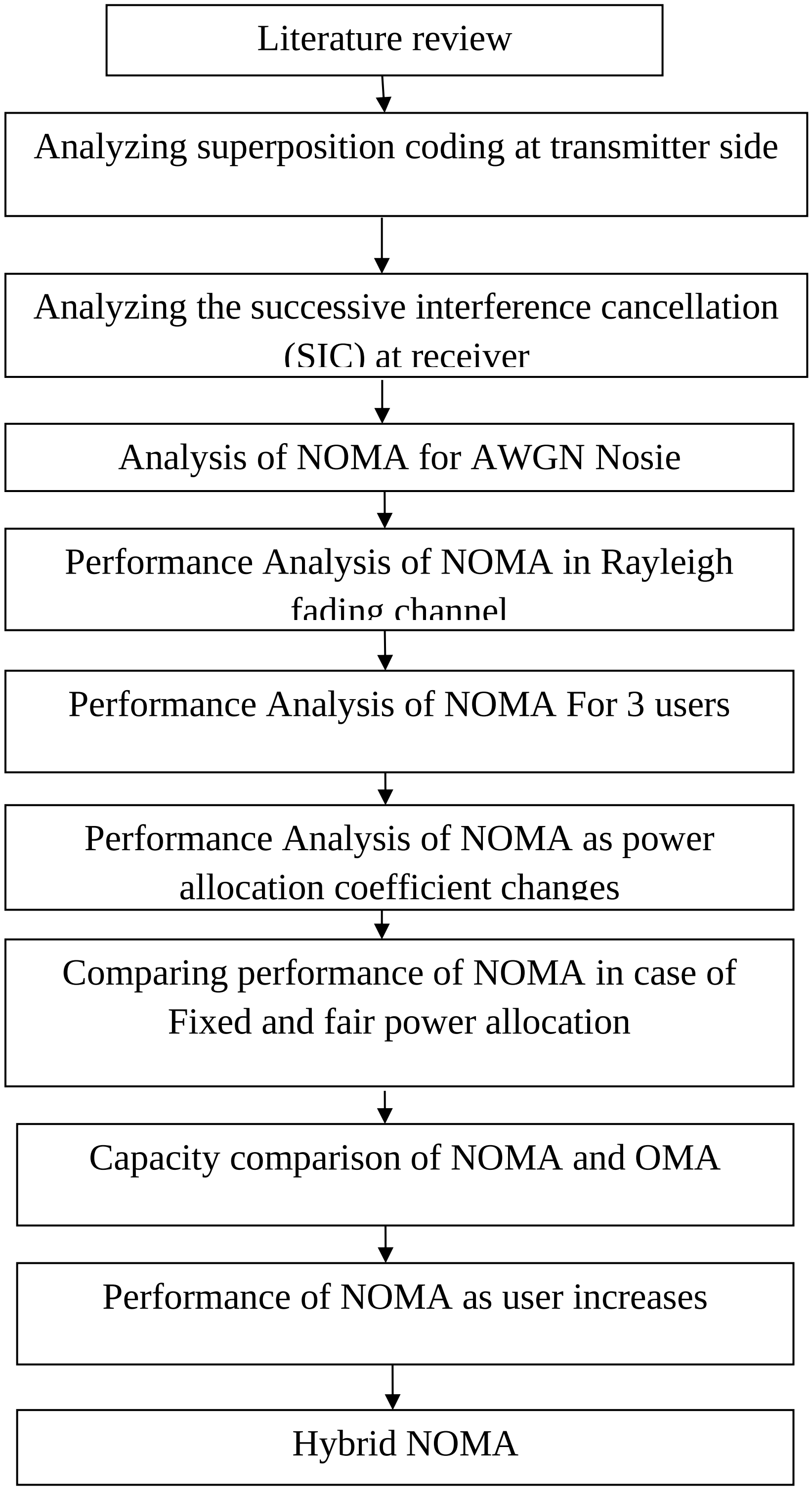

Figure 3: System Flowgraph

The project involves a comprehensive analysis of Non-Orthogonal Multiple Access (NOMA) for wireless communication systems. The first step in the project is a thorough literature review to understand the background and current state of the art in NOMA. The next step is to analyze the performance of superposition coding at the transmitter side and successive interference cancellation (SIC) at the receiver side. The project will also include an analysis of NOMA for Additive White Gaussian Noise (AWGN) noise and performance analysis of NOMA in Rayleigh fading channel. Moreover, the project aims to analyze the performance of NOMA for 3 users and how it performs as the power allocation coefficient changes. The project will also compare the performance of NOMA in the case of fixed and fair power allocation. Additionally, the capacity comparison of NOMA and Orthogonal Multiple Access (OMA) will be studied. Furthermore, the project will explore the performance of NOMA as the number of users increases and the concept of Hybrid NOMA will also be investigated.

6.2.1 Analyzing Superposition Coding at transmitter

Considering two users User 1 and User 2 are going to communicate simultaneously using the same frequency to understand the basics of NOMA. NOMA requires superposition coding at the transmitter side. Superposition coding is also called for power domain multiplexing. To superpose means to add. So, basically, we're going to add data from user 1 and user 2 together. But before doing that, we are going to multiply them with different power levels. Then, we will add them together. And obtain the superposition coded signal in MATLAB.

$$x = \sqrt{a_1}x_1 + \sqrt{a_2}x_2$$

x_1- data to be sent to user 1

x_2 - data to be sent to user 2

a_1 = 0.75 - power weight given to user 1

a_2 = 0.25 - power weight given to user 1

6.2.2 Analyzing Successive Interference Cancellation at receiver

SIC is carried out to decode the superposition coded signal at the receiver side. SIC is an iterative algorithm where data is decoded in the order of decreasing power levels. That is, data corresponding to the user who is given the highest power is decoded first, then the data of the user who is given the next highest power is decoded. This process repeats till we have decoded all the user's data. Plotting the decoded signal using successive interference cancellation techniques in MATLAB. Received signal on ideal channel is given by $y_1 = x$ received by user 1 and $y_2 = x$ received by user 2. By applying direct BPSK modulation to y_1 we get data of user 1,x_1. Now for user 2, first we perform BPSK demodulation to get x_1 and remodulate x_1 into BPSK signal we get $x_1{}'$ and multiply by $\sqrt{a_1}$and subtract it from y_2. That is, $rem = y_2 - \sqrt{a_1}x_1{}'$ .Performing Direct demodulation of rem to obtain x_2.

6.2.3 Simple NOMA system with AWGN noise

NOMA uses superposition coding at the transmitter end and successive interference cancellation at the receiver end. We will see how to simulate a simple two user NOMA system using MATLAB. We will be plotting the BER performance of NOMA in an additive white gaussian noise (AWGN). The AWGN assumption here is made to keep things simple so that we can pay more attention to the actual skeleton of NOMA implementation

As we know already, the superposition coded NOMA signal transmitted by the BS is,

$$x = \sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2)$$

Where P is transmitted power. The copy x received at near user after propagating through AWGN is

$$y_1 = x + w_1$$

Similarly, the copy of x received at far user after propagating through channel h_2 is,

$$y_2 = x + w_2$$

NOMA decoding at user 1(far user)

Expanding the receiver signal at user 1,

$$y_1 = x + w_1$$

$$= \sqrt{P}\left(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2\right) + w_1$$

$$= \sqrt{P}\sqrt{\alpha_1}x_1 + \sqrt{P}\sqrt{\alpha_2}x_2 + w_1$$

Here,

$\sqrt{P}\sqrt{\alpha_1}x_1$ is desired and dominating signal

$\sqrt{P}\sqrt{\alpha_2}x_2$ is interference and low power signal

w_1 is the AWGN noise signal

Since $\alpha_1 > \alpha_2$, direct decoding of y_1 would give x_1. The term containing the x_2 component will be treated as an interference. The signal to interference noise ratio for far user is,

$$\gamma_1 = \frac{P\alpha_1}{P\alpha_2 + \sigma^2}$$

NOMA decoding at User 2 (near user)

Expanding the received signal at user 2,

$$y_2 = x + w_2 \quad = \sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2) + w_2 \quad = \sqrt{P}\sqrt{\alpha_1}x_1 + \sqrt{P}\sqrt{\alpha_2}x_2 + w_2$$

Here,

$\sqrt{P}\sqrt{\alpha_1}x_1$ is interference and dominating

$\sqrt{P}\sqrt{\alpha_2}x_2$ is desired and low power

w_2 is the AWGN noise

User 2 must perform successive interference cancellation(SIC) before decoding its own signal. SIC is carried out as follows:

1. y_2 is directly decoded to obtain x_1 or rather, an estimate of x_1, that is $\widetilde{x_1}$.
2. $y'_2 = y_2 - \sqrt{\alpha_1}\widetilde{x_1}$ is computed.
3. y'_2 is decoded to obtain x_2.

The signal to interference noise ratio at the user 2 for decoding the user 1 signal (before SIC) is

$$\gamma_1 = \frac{P\alpha_1}{P\alpha_2 + \sigma^2}$$

After after cancellation of user 1's signal using SIC, the signal to noise ratio at the user 2 for decoding its own signal is,

$$\gamma_2 = \frac{P\alpha_2}{\sigma^2}$$

Now from the above SNR equation we obtain the graph of BER as the SNR increases.

6.2.4 Performance analysis of Rayleigh Fading Channel

Wireless channel is prone to multipath propagation and fading. Several channel models are available to capture the effects of fading. Each model deals with a particular scenario. One such model is Rayleigh fading model. Rayleigh fading model can be used when there is no line of sight (LOS) path between the transmitter and the receiver. In other words, all multipath components have undergone small scale fading effects like reflection, scattering, diffraction, shadowing etc.

We are going to consider an extreme case of Rayleigh fading where each transmitted bit undergoes a different attenuation and phase shift due to multipath transmission. In other words, the channel changes for every bit. We will first look at the system model and signal model of NOMA and then the MATLAB code for simulating it. We will simulate the bit error rate (BER)
We are considering downlink transmission from base station (BS) to the two users. Our network will look like this.

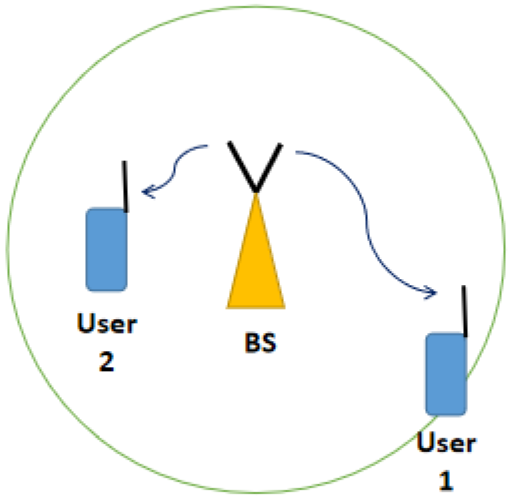

Figure 4: Network Model

User 1 is the far/weak as he is far away from the transmitting BS. User 2 is the near/strong user. Let d1 and d2 denote their distances from the BS

The BS has two distinct messages x1 to user 1 (far user), and x2 to user 2 (near user). α1 and α2 are the power allocation factors for the far and the near user respectively (α1 + α2 = 1). In NOMA, to promote user fairness, more power is given to the far user and less power to the near user. That is, α1 > α2 . Throughout this post, we will use α1 =0.75 and α2 =0.25. This is an arbitrary choice.

Let h1 and h2 denote the channel from the BS to the near and the far user respectively.

NOMA encoding and transmission

As we know already, the superposition coded NOMA signal transmitted by the BS is,

$$x = \sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2)$$

Where P is transmitted power. The copy x received at near user after propagating through channel h_1 is

$$y_1 = h_1 x + w_1$$

Similarly, the copy of x received at far user after propagating through channel h_2 is,

$$y_2 = h_2 x + w_2$$

NOMA decoding at user 1(far user)

Expanding the receiver signal at user 1,

$$y_1 = h_1 x + w_1$$

$$= h_1\sqrt{P}\left(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2\right) + w_1$$

$$= h_1\sqrt{P}\sqrt{\alpha_1}x_1 + h_1\sqrt{P}\sqrt{\alpha_2}x_2 + w_1$$

Here,

$h_1\sqrt{P}\sqrt{\alpha_1}x_1$ is desired and dominating signal

$h_1\sqrt{P}\sqrt{\alpha_2}x_2$ is interference and low power signal

w_1 is the noise signal

Since $\alpha_1 > \alpha_2$, direct decoding of y_1 would give x_1. The term containing the x_2 component will be treated as an interference. The signal to interference noise ratio for far user is,

$$\gamma_1 = \frac{|h_1|^2 P\alpha_1}{|h_1|^2 P\alpha_2 + \sigma^2}$$

NOMA decoding at User 2 (near user)

Expanding the received signal at user 2,

$$y_2 = h_2 x + w_2 \quad = h_2\sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2) + w_2 \quad = h_2\sqrt{P}\sqrt{\alpha_1}x_1 + h_2\sqrt{P}\sqrt{\alpha_2}x_2 + w_2$$

Here,

$h_2\sqrt{P}\sqrt{\alpha_1}x_1$ is interference and dominating

$h_2\sqrt{P}\sqrt{\alpha_2}x_2$ is desired and low power

w_2 is the noise

User 2 must perform successive interference cancellation(SIC) before decoding its own signal. SIC is carried out as follows:

4. y_2 is directly decoded to obtain x_1 or rather, an estimate of x_1, that is $\widetilde{x_1}$.
5. $y'_2 = y_2 - \sqrt{\alpha_1}\widetilde{x_1}$ is computed.
6. y'_2 is decoded to obtain x_2.

The signal to interference noise ratio at the user 2 for decoding the user 1 signal (before SIC) is

$$\gamma_1 = \frac{|h_2|^2 P\alpha_1}{|h_2|^2 P\alpha_2 + \sigma^2}$$

After after cancellation of user 1's signal using SIC, the signal to noise ratio at the user 2 for decoding its own signal is,

$$\gamma_2 = \frac{|h_2| P\alpha_2}{\sigma^2}$$

6.2.5 BER of 3 user Non-Orthogonal Multiple Access(NOMA)

we plotted the bit error rate (BER) of a two user NOMA. There, we used BPSK modulation for both the users.We can multiplex more than two users in a single carrier in NOMA. We are going to multiplex three users, each following QPSK modulation, in a single frequency carrier

Let us consider a wireless network consisting of three NOMA users, numbered U1, U2 and U3.Let d_1,$d_2$and d_3 denote their respective distances from the base station(BS) such that,$d_1 > d_2 > d_3$.

Based on their distances, U1 is the weakest /farther user and U3 is the strongest/nearest user to the BS.

Let h_1,h_2, and h_3 denote their corresponding Rayleigh fading coefficient such that, $|h_1|^2 < |h_2|^2 < |h_3|^2$. The channels are ordered this way because $h_1 \propto \frac{1}{d_i}$

Let α_1,α_2 and α_3 denote their respective power allocation coefficient. According to the principles of NOMA, the weakest user must be allocated the most power and the strongest user must be allocated the least power. Therefore, the power allocation coefficients must be ordered as $\alpha_1 > \alpha_2 > \alpha_3$. The choice of power allocation coefficients has a great significance on the performance of a NOMA network. In this , we are using fixed power allocation.

Let x_1,x_2 and x_3 denote the QPSK modulated message that the BS is given by,

$$x = \sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2 + \sqrt{\alpha_3}x_3)$$

The signal received at i^{th} user is given by,

$$y_1 = h_i x + n_i$$

Where n_i denotes AWGN at receiver of Ui.

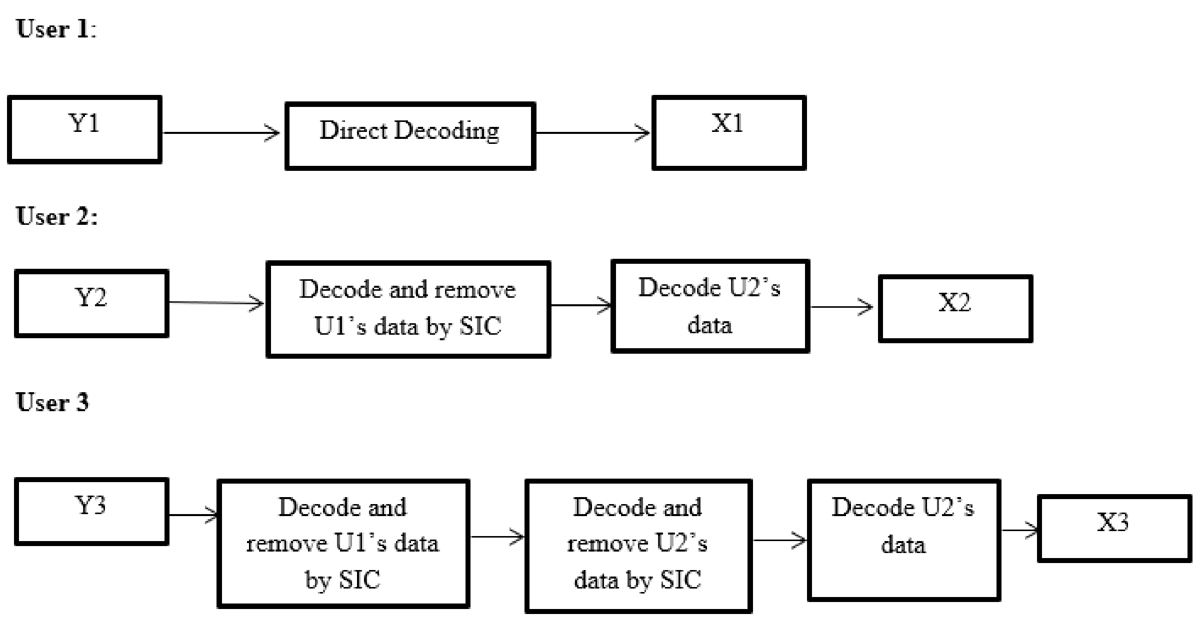

Figure 5: Working of 3 users NOMA

At User 1

Since U1 is allocated the highest power, it will perform direct decoding from y_1, treating the signal of U2 and U3 as interference. Thus, SNR of U1 is,

$$\gamma_1 = \frac{|h_1|^2 P\alpha_1}{|h_1|^2 P\alpha_2 + |h_1|^2 P\alpha_3 + \sigma^2} \quad = \frac{|h_2|^2 P\alpha_1}{|h_2|^2 P(\alpha_2 + \alpha_3) + \sigma^2}$$

Since $\alpha_2 + \alpha_3$ is present at the denominator, now we want α_1 to satisfy $\alpha_1 > \alpha_2 + \alpha_3$. Only then, U1's power will dominate in the transmit signal,x and in the received signal,y_1.

At User 2

Next let's write the rate equation for U2. Since $\alpha_2 < \alpha_1$ and, $\alpha_2 > \alpha_3$,U2 must perform successive interference cancellation to remove U1's data and treat U3 as interference. After removing U1's data by SIC, the SNR for U2 is,

$$\gamma_2 = \frac{|h_2|^2 P\alpha_2}{|h_2|^2 P\alpha_3 + \sigma^2}$$

Since α_3 is present in the interference term at denominator, we want α_2 to satisfy $\alpha_2 > \alpha_3$.

At user 3

Finally,U3 has to perform SIC two times to remove both U1 and U2 data from y_3.Since the α_1 term dominates in y_3,it must be removed first. After that, the α_2 term must be removed. The SNR is,

$$\gamma_3 = \frac{|h_3| P\alpha_3}{\sigma^2}$$

6.2.6 Analyzing the performance of NOMA as power allocation coefficient changes

Bit error rate (BER) of NOMA has a strong relationship with the values of power allocation coefficients. we consider user 1 to be the far user and user 2 to be the near user. We have used fixed power allocation method. That is, we did not alter the coefficients based on channel conditions. We plot the BERs when we fix different values of power allocation coefficients for transmit powers of 50 dBm and 20 dBm.

6.2.7 Comparing Fixed and Dynamic Power Allocation in NOMA

Power allocation is very important in non-orthogonal multiple access (NOMA). The bit error rate (BER) of NOMA has a strong relationship with the values of power allocation coefficients.

We used fixed power allocation till now. That is, we fixed the values of α_1 and α_2 irrespective of the channel condition. But there are better ways to optimize α_1 and α_2 dynamically based on the values of channel state information (CSI).

There are a few different dynamic power allocation schemes each trying to accomplish a specific goal. The goal could be maximizing the sum rate, maximizing the energy efficiency, etc., The power allocation scheme we are going to see in this post is a simple one whose goal is to provide user fairness. Let's call this fair power allocation scheme

Our fair PA gives priority to the weak/far user. That is, the power allocation coefficients are calculated such that the far user's target rate is met. Only after meeting the target rate of far user, all the remaining available power is allocated to the near user. Let's go ahead and derive the power allocation coefficients to meet this specification.

The achievable rate equation can be written as follows:

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

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

Power allocation coefficient α_n and α_f for dynamic power allocation is given by,

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

Here,

ξ is the target SINR for far user.

α_f should not exceed 1. So, let’s set a limit as

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

Sum of all power allocation coefficient must be equal to 1. Therefore,

$$\alpha_n + \alpha_f = 1 \alpha_n = 1 - \alpha_f$$

Now we comparing the fixed allocation scheme by fixing the value of $\alpha_n = 0.25$ and $\alpha_f = 0.75$ and dynamically obtained value of α_n and α_f according to their target rate. Then we plot the sum rate $(R_f + R_n)$ as a function of transmit power.

6.2.8 Comparison between OMA and NOMA

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.

we will compare the achievable rate offered by NOMA and OMA schemes.

Let's consider a downlink communication scenario with a base station (BS) and N users. Let h_i, denote the channel from BS to i^{th} user. There are N such channels, $h_1, h_2, \dots h_N$.

Signal model for NOMA

Let us assume that user 1, with channel h_1. Let us assume that user 1, with channel 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: $|h_1|^2 < |h_2|^2 < \cdots |h_N|^2$

Let $x_1, x_2, \dots x_N$ denote the messages to be transmitted to the users. The BS performs superposition coding with these message and transmits the following NOMA signal into the channel:

$$x_{NOMA} = \sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2 \dots \sqrt{\alpha_N}x_N)$$

Where P is the total transmit power.$\alpha_1, \alpha_2, \dots \alpha_N$ represents the power allocation coefficient. Since the channel are ordered as $|h_1|^2 < |h_2|^2 < \cdots |h_N|^2$, the power allocation coefficient must be ordered as $\alpha_1 > \alpha_2 > \cdots \alpha_N$.

The received signal at user I is given by,

$$y_{i,NOMA} = x_{noma} h_i + w_i$$

Where w_i is the AWGN with zero mean and variance = σ^2

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 SNR for decoding user 1's signal is given by,

$$\gamma_{1,NOMA} = \frac{|h_1|^2 P\alpha_1}{|h_1|^2 P(\alpha_2 + \alpha_3 + \cdots \alpha_N) + \sigma^2}$$

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 $y_{2,NOMA}$. Now user 2 can directly decode its message. If the SIC operation is perfect, the resulting signal would be, The SNR at user 2 to decode its own message is given by,

$$\gamma_{2,NOMA} = \frac{|h_2|^2 P\alpha_2}{|h_2|^2 P(\alpha_3 + \alpha_4 + \cdots \alpha_N) + \sigma^2}$$

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.

In general, for any user i, the SNR to decode his own signal is given by,

$$\gamma_{i,NOMA} = \frac{|h_i|^2 P\alpha_i}{|h_i|^2 P(\alpha_{i+1} + \alpha_{i+2} + \cdots \alpha_N) + \sigma^2}$$

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

$$R_{i,NOMA} = (1 + \gamma_{i,NOMA})$$

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

$$R_{NOMA} = \sum_{i=1}^{N} R_{i,NOMA}$$

Signal model for OMA

Next, let's take a look at normal OMA transmission, As an example, let's consider TDMA. To serve N user, 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. Thus, the transmitted signal is given by,

$$x_{i,OMA} = \sqrt{P}x_i$$

The received signal at user i will be,

$$y_{i,OMA} = \sqrt{P}x_i h_i + w_i$$

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

$$\gamma_{i,OMA} = \frac{|h_i|^2 P}{\sigma^2}$$

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

$$R_{i,OMA} = (1 + \gamma_{i,OMA})$$

Finally, the sum rate of OMA is given by,

$$R_{OMA} = \sum_{i=1}^{N} R_{i,OMA}$$

We plot a graph to compare the capacity of OMA and NOMA by plotting the graph of achievable rate as the function of SNR.

6.2.9 NOMA for multiple users

In above simulation we have increased number of users from two to three to study effect on BER, so what happens to system when we increase user count or how many users can be multiplexed at the same time for that we simulated for different number of user and calculated sum rate of system with different transmit power.

We know that, while performing superposition coding at the transmitter side, the users are ordered according to their channel conditions and the weakest user is allocated the most power. Let's assume we have K users, with U_1 as the weakest user and U_K as the strongest user, and if they are ordered such that,$|h_1|^2 < |h_2|^2 < \cdots |h_K|^2$, then their corresponding power allocation coefficients will be ordered as $\alpha_1 > \alpha_2 > \cdots \alpha_K$ and $\alpha_2 > \alpha_3 + \alpha_4 + \cdots \alpha_K > \alpha_4 + \cdots \alpha_K$ and so on.

At the receiver side, the weakest user U_1 will perform direct decoding. Since $\alpha_1 > \alpha_2 + \alpha_3 + \cdots \alpha_K$, all the other users' data are considered interference.

In the received signal of U_2, U_1's data will be dominating because, $\alpha_1 > \alpha_2 + \alpha_3 + \cdots \alpha_K$. So U_2 has to perform SIC to estimate and remove U_1's data. Once U_1's data is removed, we will have, $\alpha_2 > \alpha_3 > \cdots \alpha_K$. So now U_2's data is dominating. Therefore, U_2 can perform direct decoding, by treating the data of users $U_3, U_4 \ldots U_K$ as interference.

In similar fashion, U_3 must perform SIC to remove U_1 and U_2's data before decoding its own signal.U_4 must remove U_1, U_2 and U_3's data before decoding its own signal. Following the same train of thought,$K-1$ times the stronger user (U_k) should perform SIC before decoding its own data. It must remove every single users' data from his received signal. Only then α_K will be dominating.

if we multiplex 100 users in the same carrier, the 100th user must perform SIC 99 times before decoding his own data. This is not only computationally complex, but also consumes much time leading to processing delay.

U_K must perform SIC for $U_1, U_2, \ldots U_{K-1}$.If U_1's data is decoded in error, then this will lead to a wrong signal being subtracted in the SIC process, which would lead to decoding of U_2's data erroneously and this error propagates on and on to the decoding of U_K own data.

So achievable rate equation for U_1 is

$$R_1 = \left(1 + \frac{|h_1|^2 P \alpha_1}{|h_1|^2 P(\alpha_2 + \alpha_3 + \cdots \alpha_K) + \sigma^2}\right)$$

In the same way achievable rate equation for U_2 will be

$$R_2 = \left(1 + \frac{|h_2|^2 P \alpha_2}{|h_2|^2 P(\alpha_3 + \alpha_4 + \cdots \alpha_K) + \sigma^2}\right)$$

Similarly for achievable rate for $U_3, U_4 \ldots U_K$ can be found out. From calculating achievable rate, we can plot the graph of sum rate as the number of user increases.

6.2.10 Performance Analysis of Hybrid NOMA-OMA for Increased User Capacity

If the number of users is increased beyond a limit, the sum throughput of the network will actually begin to drop. So, we cannot increase the number of users per carrier indefinitely.

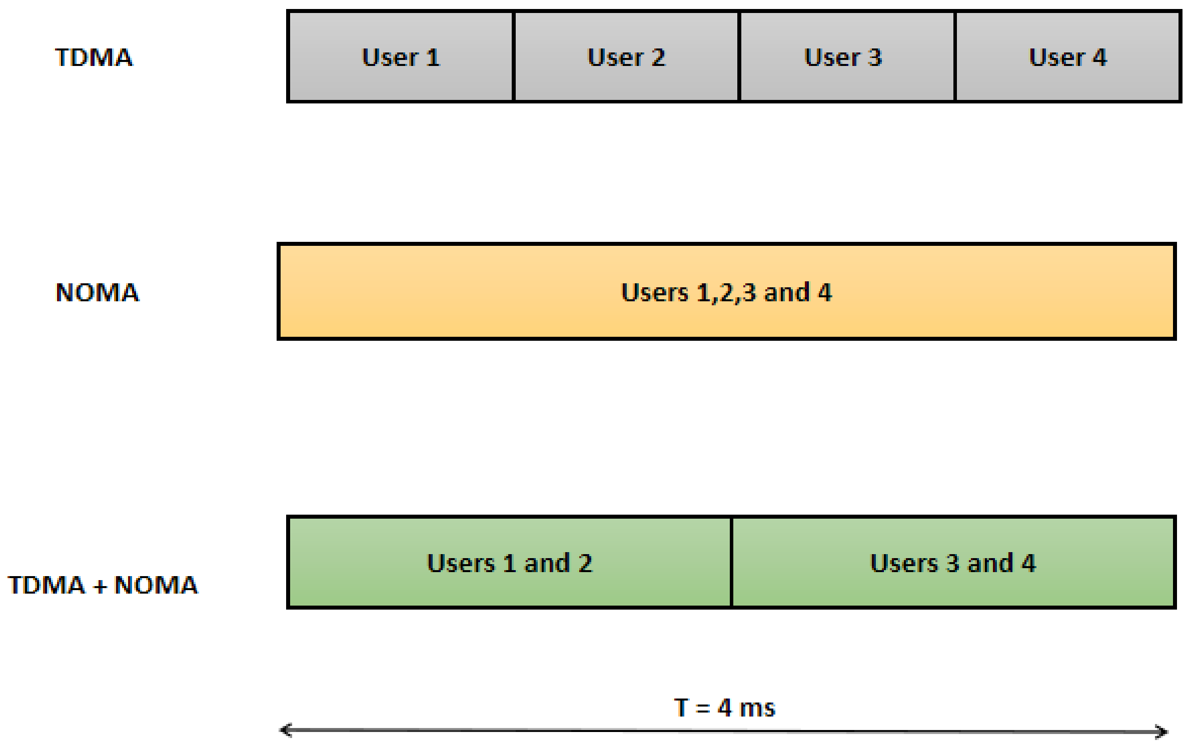

Figure 6: Bandwidth utilization for various OMA/ NOMA schemes

Hybrid NOMA is a combination of NOMA with any OMA technique. For example, let's consider TDMA+NOMA, as shown in Figure 6 Let's say we have a time slot of 4 ms duration. We have to support 4 users within this time slot. Now, TDMA will divide the 4 ms slot into four 1 ms slots and assign one slot to each user. NOMA, will assign the whole 4 ms slot to the four users. As we know, this will increase the SIC complexity and processing delay. Hybrid NOMA, on the other hand, divides the 4 ms slot into two 2 ms slots and assigns two NOMA users to each slot.

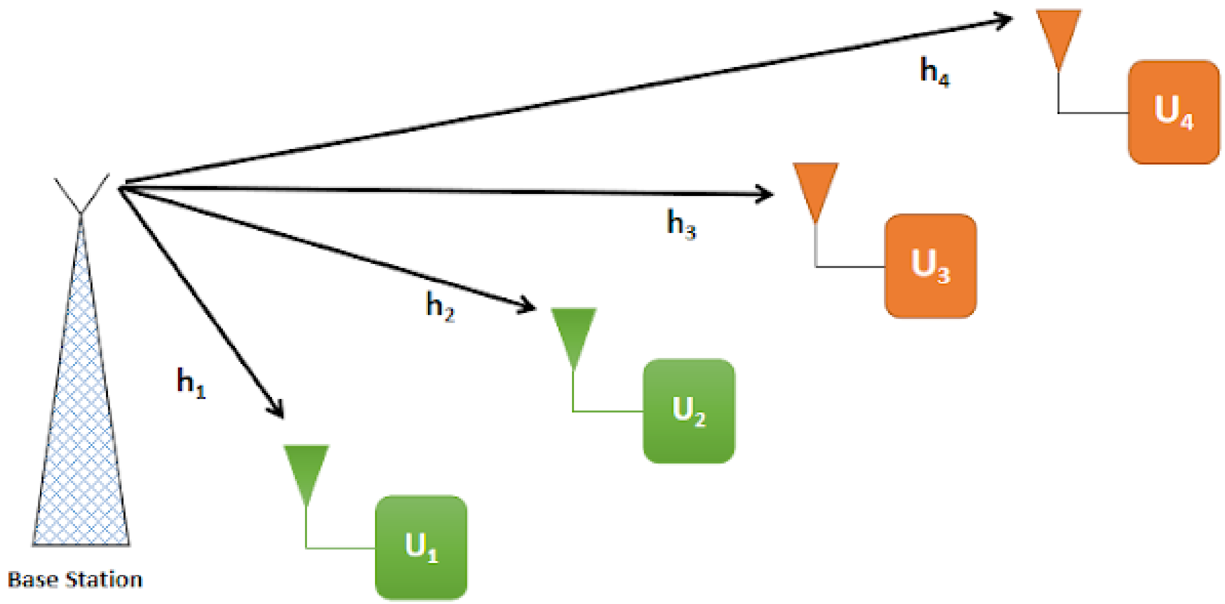

Figure 7: Users at various distance from Base Station

As shown in figure 2, let's consider a downlink communication scenario with 4 users. Let d_1, d_2, d_3, d_4 denote the distances of U1, U2, U3, U4 respectively from the base station. U1 is the nearest user and U4 is the farthest user. Therefore, their channel conditions are ordered as $|h_1|^2 < |h_2|^2 < \cdots |h_K|^2$. We have two orthogonal resource blocks (time/frequency/subcarriers) and we have to assign two users per block. We'll do the user pairing based on the distances. There are two simple ways to do this:

(i) Near-far pairing (N-F)

(ii) Near-near, far-far pairing (N-N, F-F)

(i) Near-far pairing (N-F)

In this method, the nearest user to the base station is paired with the farthest user from the base station. The next nearest user is paired with the next farthest user and so on. In our example, U1 is the nearest user and U4 is the farthest user. So, N-F pairing will pair U1 with U4 in one resource block. U2 will be paired with U3 in the next resource block.

In the first pair of users, U1 is the near user and U4 is the far user. Therefore, we have to choose the power allocation coefficients as $\alpha_1 < \alpha_4$. So, U1 should perform successive interference cancellation (SIC), while U4 will perform direct decoding. Similarly, in the second pair of users, U2 is the near user and U3 is the far user. Therefore, we have to choose $\alpha_2 < \alpha_3$. Here, U2 should perform SIC while U3 will perform direct decoding.

The achievable rates for the users in the first pair are,

$$R_{1,nf} = (1 + \frac{|h_1|^2\alpha_1 P}{\sigma^2})$$

$$R_{4,nf} = (1 + \frac{|h_4|^2\alpha_4 P}{|h_4|^2\alpha_1 P + \sigma^2})$$

Similarly for second pair,

$$R_{2,nf} = (1 + \frac{|h_2|^2\alpha_2 P}{\sigma^2})$$

$$R_{3,nf} = (1 + \frac{|h_3|^2\alpha_3 P}{|h_3|^2\alpha_2 P + \sigma^2})$$

The sum rate of the N-F scheme will be

$$R_{nf} = R_{1,nf} + R_{2,nf} + R_{3,nf} + R_{4,nf}$$

(ii) Near-near, far-far pairing (N-N, F-F)

Another way to perform user pairing is to group the nearest user with the next nearest user. The farthest user is grouped with the next farthest user. If we follow this strategy, in our example, U1 will be paired with U2 in one resource block. U3 will be paired with U4 in the next resource block.

Now, in the first pair of users, U1 is nearest to the base station when compared to U2. Therefore, we have to choose $\alpha_1 < \alpha_2$. U1 should perform SIC, U2 will perform direct decoding. Similarly, U3 is closer to the base station than U4. So, we have to choose $\alpha_3 < \alpha_4$. U3 should perform SIC, while U4 will perform direct decoding.

The achievable rates for the users in the first pair are,

$$R_{1,nn} = (1 + \frac{|h_1|^2 \alpha_1 P}{\sigma^2})$$

$$R_{2,nn} = (1 + \frac{|h_2|^2 \alpha_2 P}{|h_2|^2 \alpha_1 P + \sigma^2})$$

Similarly for second pair,

$$R_{3,nn} = (1 + \frac{|h_3|^2 \alpha_3 P}{\sigma^2})$$

$$R_{4,nn} = (1 + \frac{|h_4|^2 \alpha_4 P}{|h_4|^2 \alpha_3 P + \sigma^2})$$

Finally, the sum rate will be

$$R_{nn} = R_{1,nn} + R_{2,nn} + R_{3,nn} + R_{4,nn}$$

compare the sum rate performance of the network with SC-NOMA, Hybrid NOMA N-F pairing , hybrid NOMA N-N,F-F pairing and TDMA. We make this comparison by plotting the sum rate as the function of SNR.

6.3 LIMITATION

The limitation of our project is:

- Only two channel conditions are observed.
- Research is based on communication for only limited users, one is far from the station and another is near.

CHAPTER 7: RESULT

7.1 Task completed

7.1.1 Simulation of NOMA in Ideal Channel

The basic principle behind NOMA is superposition of data in the transmitting side and Successive Interference Cancellation (SIC) in the receiver side. Through simulation we have shown the basic principle of NOMA in an ideal channel in simulation using MATLAB simulation.

7.1.1.1 For transmitting side:

Let x_1 denote User 1's data and x_2 denote User 2's data Considering 4 bits of data to send. x_1 = 1 0 1 0 0 1 1 0 and x_2 = 0 1 1 0 1 0 1 0

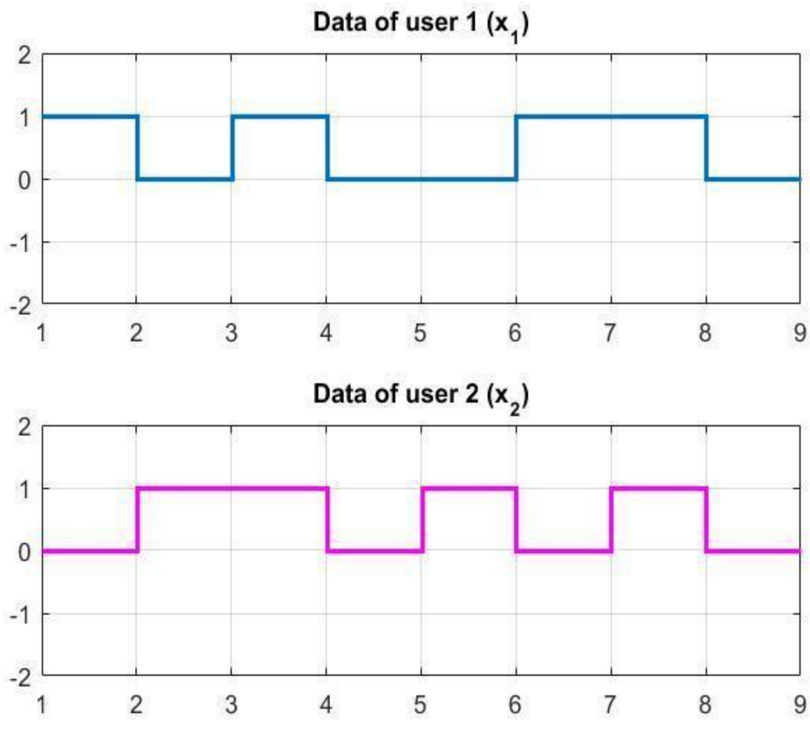

Figure 8: Data from user 1 and 2

Next, we performed BPSK modulation and scale amplitude of x_1 and x_2 with different power level such that total power level is 1. So, scaling factor or power weights for x_1 and x_2 are a_1=0.75 and a_2=0.25 respectively.

Scaling x_1 and x_2 with $\sqrt{a_1}$ and $\sqrt{a_2}$ respectively amplitude scaled versions of the data are,

$\sqrt{a_1}x_1$ = [0.866,-0.866,0.866,-0.866,-0.866,0.866,0.866,-0.866]

$\sqrt{a_2}x_2$ = [-0.5,0.5,0.5,-0.5,0.5,-0.5,0.5,-0.5]

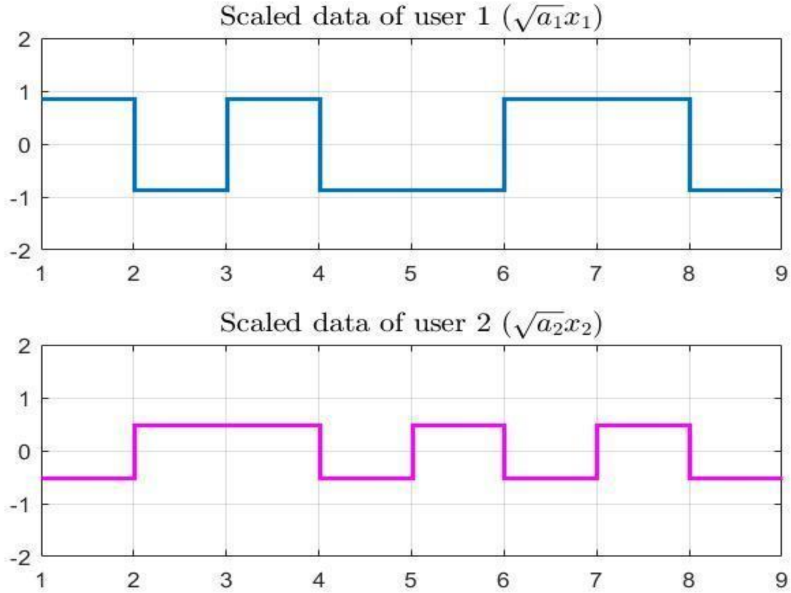

Figure 9: Scaled Data of User 1 and 2

Add both the scales together. The resulting signal is called superposition coded signal and is denoted by,

$x = \sqrt{a_1}x_1 + \sqrt{a_2}x_2$.

x=[0.366,-0.366,1.366,-1.366,-0.366,0.366,1.366,-1.366]

This signal x is the superposition coded NOMA signal that is actually transmitted into the channel

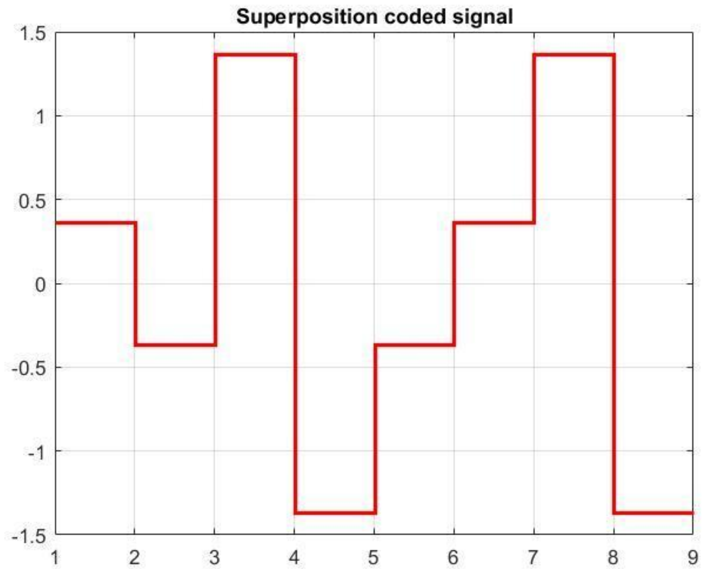

Figure 10: Transmitted Signal

7.1.1.2 For receiving side:

After receiving the transmitted data was decoded in the order of decreasing power levels. That is, data corresponding to the user who is given the highest power is decoded first, then the data of the user who is given the next highest power is decoded. Applying BPSK demodulation directly to x we get [1,0,1,0,0,1,1,0] which is x_1. Ignoring the fact that x had a component of x_2 as allocated a higher power weight to the x_1 component of x. In other words, we treat x_2 as interference and ignore it.

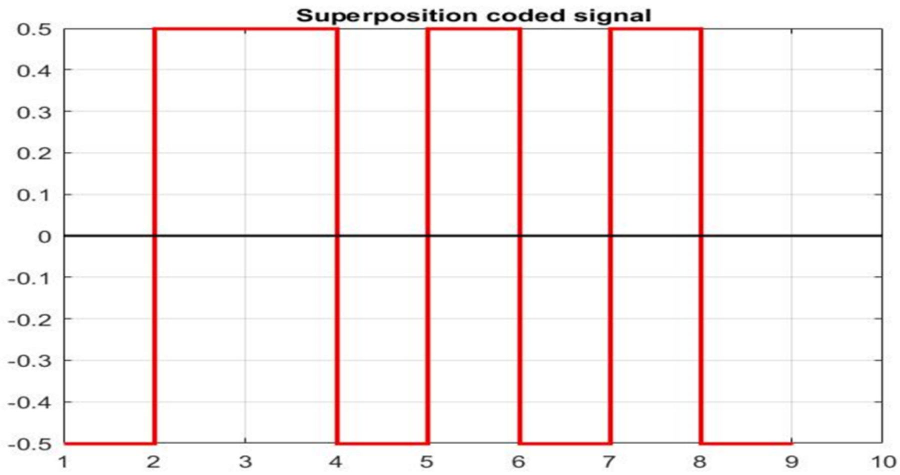

Figure 11: Super coded Received Signal

As we know the scaling weight given to both data, we then multiply the signal decoded x_1 by its corresponding weight and subtract it from x. Decoding of $x-\sqrt{a_1}x_1$ gives x_2. obtained x_1 from demodulation of x. So, if we subtract $\sqrt{a_1}x_1$ from x, we will be left with $\sqrt{a_2}x_2$. Through a similar process we also got the value of x_2.

Thus, utilizing SIC(Successive Interference Cancellation) we get data from both users x_1 and x_2

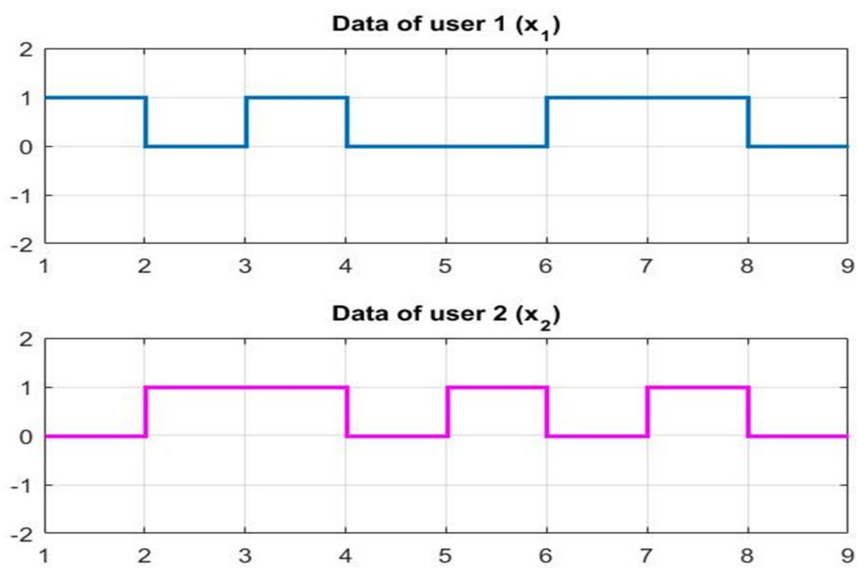

Figure 12: Original Transmitted Data

7.1.2 Simulation of BER of Non orthogonal multiple access (NOMA) in AWGN channel

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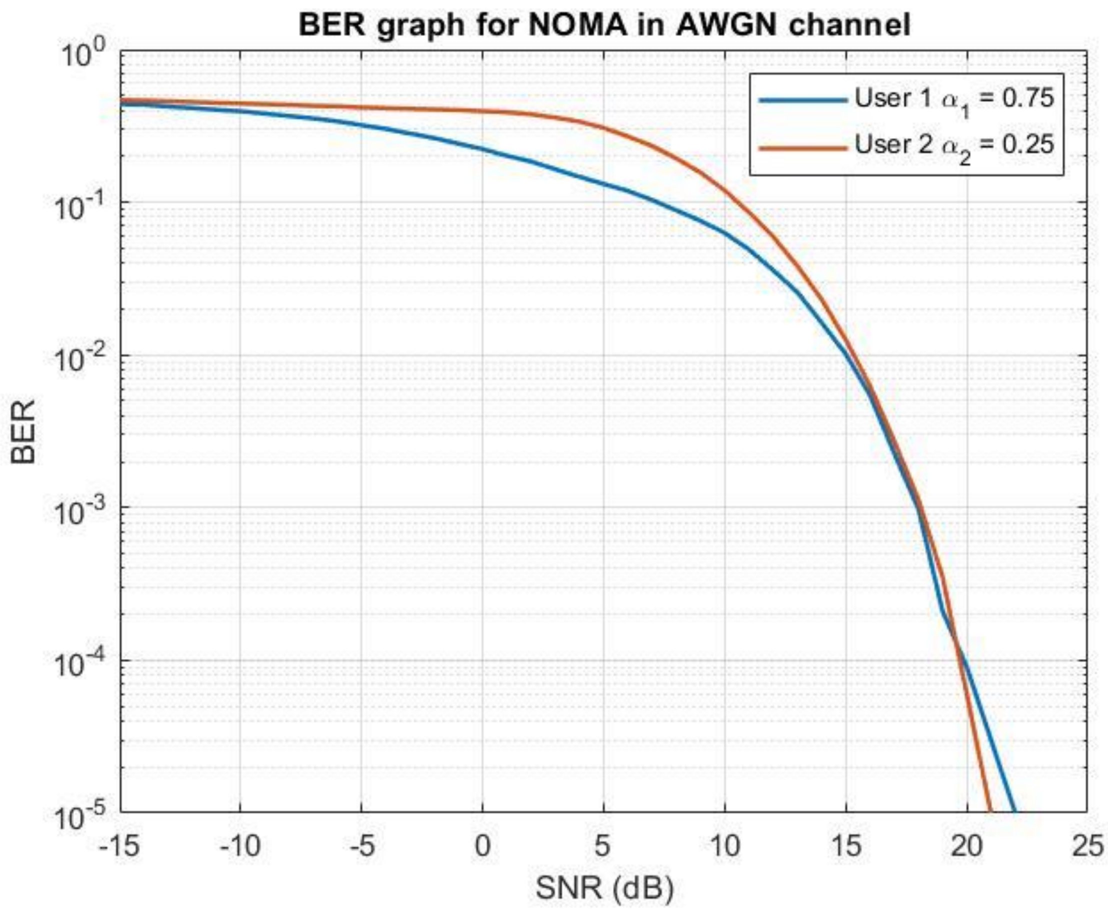

Figure 13: BER vs SNR graph in AWGN channel

The graph shows the BER performance of both users as a function of the signal-to-noise ratio (SNR) in decibels (dB). The x-axis represents the SNR values ranging from -15 dB to 30 dB, while the y-axis represents the BER values on a logarithmic scale. The plot shows two curves, one for each user, with different power weights. User 1 has a power weight of 0.75, while user 2 has a power weight of 0.25. The graph shows that, for a given SNR value, user 1 achieves a lower BER than user 2. This is because user 1 has a higher power weight, which makes its signal more dominant than user 2's signal. As a result, the decoding of user 2's signal is more challenging due to the interference caused by user 1's signal. The BER of both users decreases as the SNR increases, which is expected since the received signals become less affected by noise.

7.1.3 Performance of NOMA in Rayleigh Fading Channel

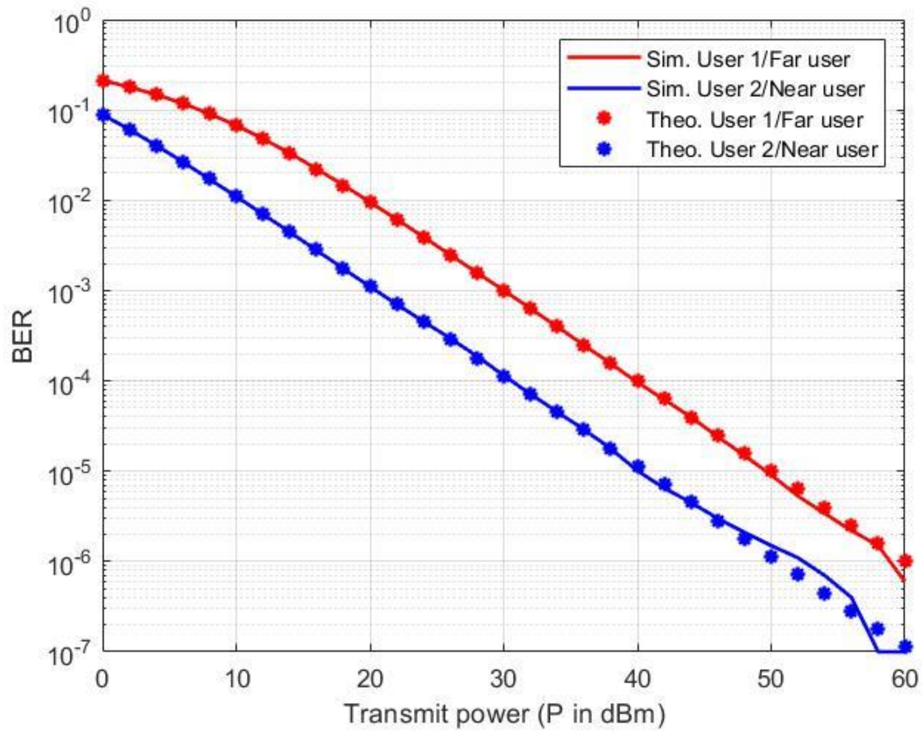

Figure 14: BER vs SNR graph in Rayleigh Fading channel

The curve is showing the BER (bit error rate) performance of two users in a NOMA (non-orthogonal multiple access) system as a function of the transmit power in dBm. The system uses superposition coding, where two users with different power allocation factors transmit their data simultaneously over the same frequency band.

The red curve represents the BER performance of User 1, while the blue curve represents the BER performance of User 2. Both curves are obtained from simulation results using the Monte Carlo method, where the BER is estimated by counting the number of bit errors in the received signal over a large number of iterations (in this case, N=10^7).

The red and blue asterisks (*) on the curve represent the theoretical BER performance of User 1 and User 2, respectively, as obtained from analytical expressions derived based on the NOMA system parameters and assumptions.

The x-axis represents the transmit power in dBm, while the y-axis represents the BER in logarithmic scale. The BER decreases as the transmit power increases, and this is true for both users. However, User 1 has a lower BER than User 2 at all power levels, as indicated by the red curve being below the blue curve. This is because User 1 has a higher power allocation factor than User 2, and hence experiences less interference from User 2's signal.

The simulation and theoretical results show good agreement, indicating that the analytical expressions are valid approximations of the system performance.

7.1.4 Analysis of Power Allocation for NOMA in a Two-User System

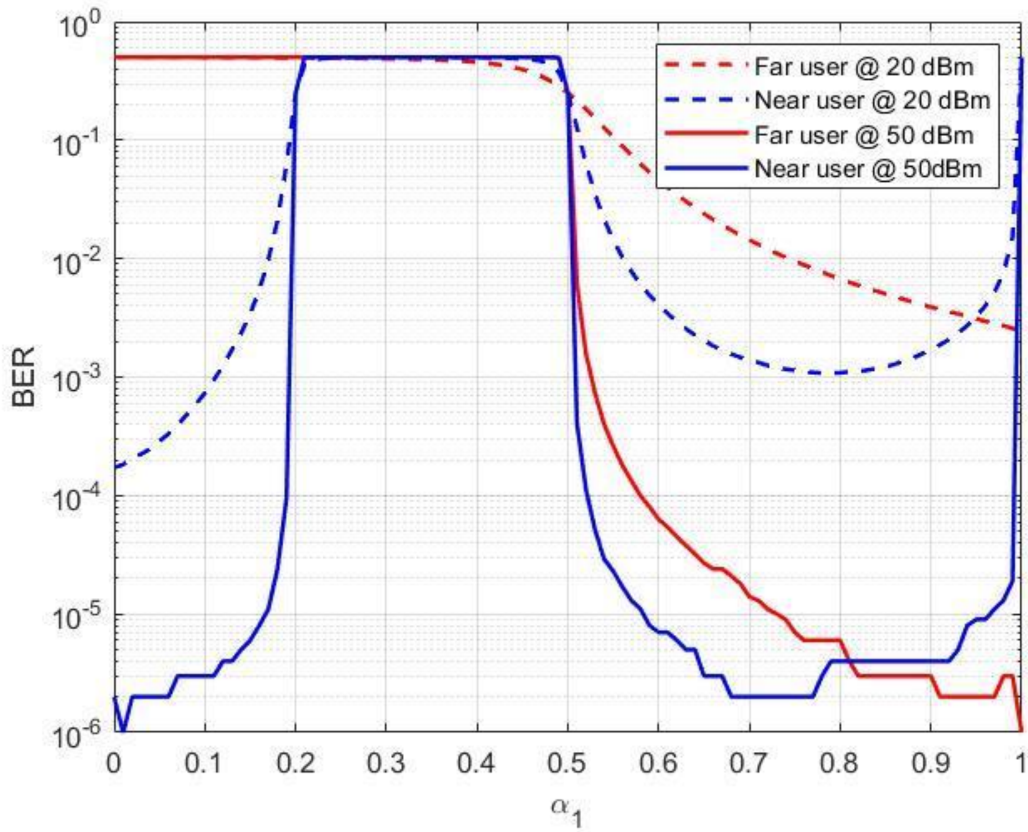

Figure 15: Analysis of Power Allocation for NOMA in a Two-User System

In the context of non-orthogonal multiple access (NOMA), the power allocation coefficients, α1 and α2, determine the relative power allocation between the two users in the system. The aim of power allocation is to maximize the overall system performance, by achieving a good trade-off between the rates of the two users and the bit error rate (BER) performance.

From the given code and analysis, it can be observed that the BER performance of the two users varies depending on the values of the power allocation coefficients, α1 and α2. The optimal power allocation coefficients that minimize the BER for both users are found to be α1∈[0.5,1] and α2∈[0,0.5].

If $\alpha1$ is too small and $\alpha2$ is too large, the near user (user 2) experiences low BER, but the far user (user 1) experiences high BER due to high interference from the near user's signal. Similarly, if $\alpha1$ is too large and $\alpha2$ is too small, the far user experiences low BER, but the near user suffers from high interference and high BER.

Towards the left end of the plot where $\alpha1\approx0$ and $\alpha2\approx1$, the near user receives a very large power allocation, leading to low BER for the near user. However, the far user suffers from high BER as the interference from the near user's signal dominates, and the far user cannot decode its own signal directly.

Towards the right end of the plot where $\alpha1\approx1$ and $\alpha2\approx0$, the far user receives a very large power allocation, leading to low BER for the far user. However, the near user suffers from high BER as the interference from the far user's signal is too large.

Therefore, the optimal power allocation coefficients are those that achieve a good balance between the power allocated to the two users, to ensure fair benefits to both users in terms of BER performance and rates

7.1.5 Analysis of Fair vs Fixed Power Allocation in NOMA

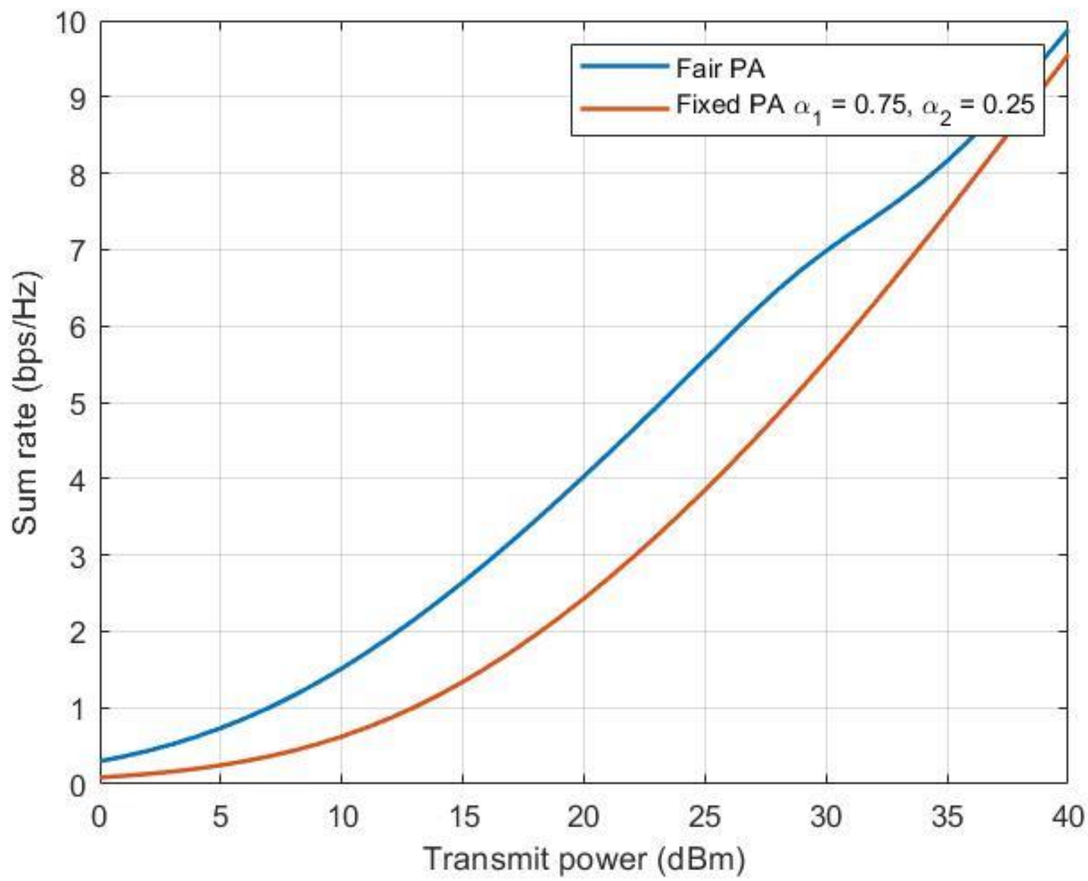

Figure 16: Analysis of Fair vs Fixed Power Allocation in NOMA

The code generates a plot of the sum rate (in bps/Hz) versus the transmit power (in dBm) for a two-user non-orthogonal multiple access (NOMA) system using fair power allocation (PA) and fixed power allocation. The simulation is performed for different values of transmit power ranging from 0 dBm to 40 dBm. The sum rate achieved by each scheme is plotted as a function of transmit power. The plot shows two curves: one for the fair PA and another for the fixed PA where alpha 1 is set to 0.75 and alpha 2 to 0.25.

We can see that as the transmit power increases, the sum rate increases for both fair PA and fixed PA. However, the fair PA curve achieves higher sum rates than the fixed PA curve for all values of transmit power. This is because the fair PA approach allocates power in a way that maximizes the sum rate of both users, while the fixed PA approach allocates power equally to both users, regardless of their channel conditions.

The plot also shows that the fair PA curve increases steeply at low transmit power levels and then gradually levels off as the transmit power increases. On the other hand, the fixed PA curve increases linearly with the transmit power. This indicates that fair PA approach is more effective at low power levels, while the fixed PA approach becomes more competitive at high power levels.

7.1.6 Comparing NOMA and OMA Capacities

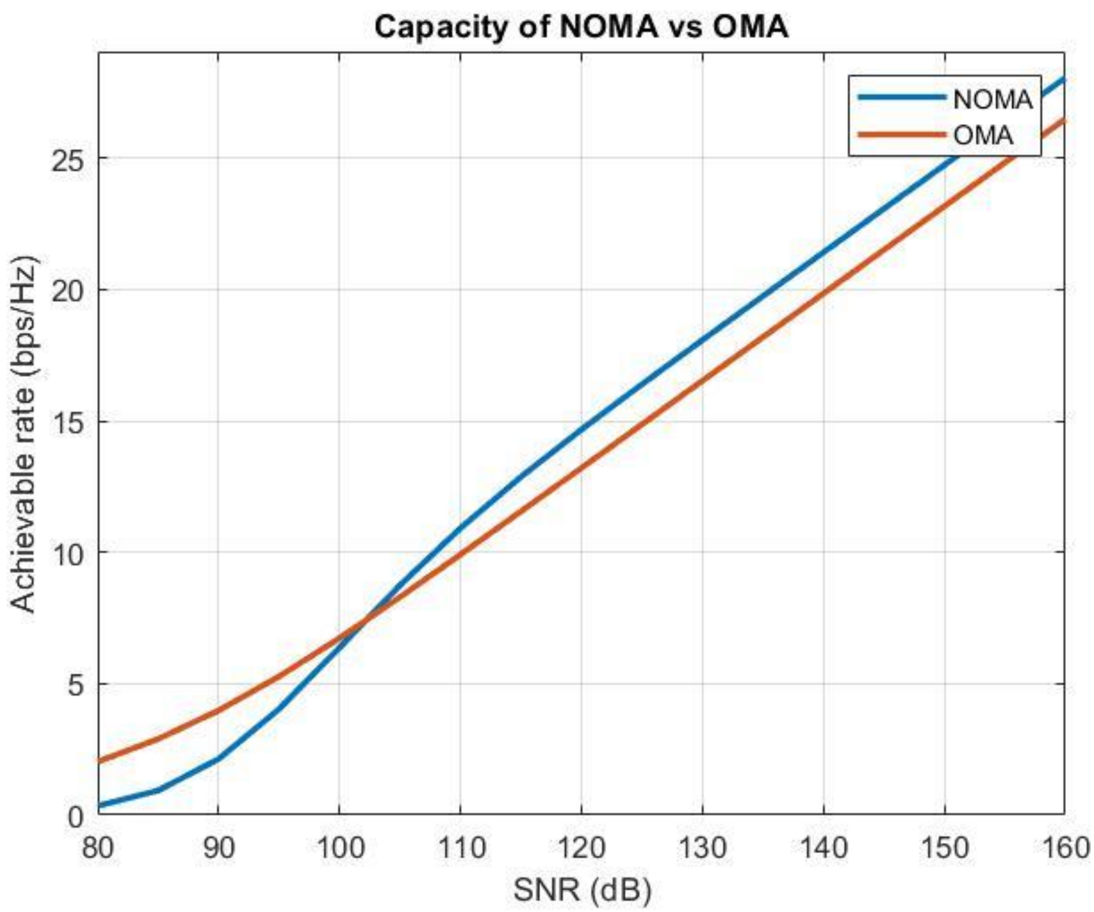

Figure 17: Comparing NOMA vs. OMA capacities

From the simulation results, it is clear that at low SNR, OMA outperforms NOMA due to the interference caused by simultaneous transmission in NOMA. However, at high SNR, NOMA offers higher capacity and outperforms OMA.

Furthermore, NOMA achieves this with minimal resource utilization. In this example, TDMA requires 3 time slots for the entire transmission, whereas NOMA completes the transmission in a single time slot, reducing the latency significantly. This highlights the potential benefits of NOMA in future communication technologies.

7.1.7 Performance analysis of NOMA for large users

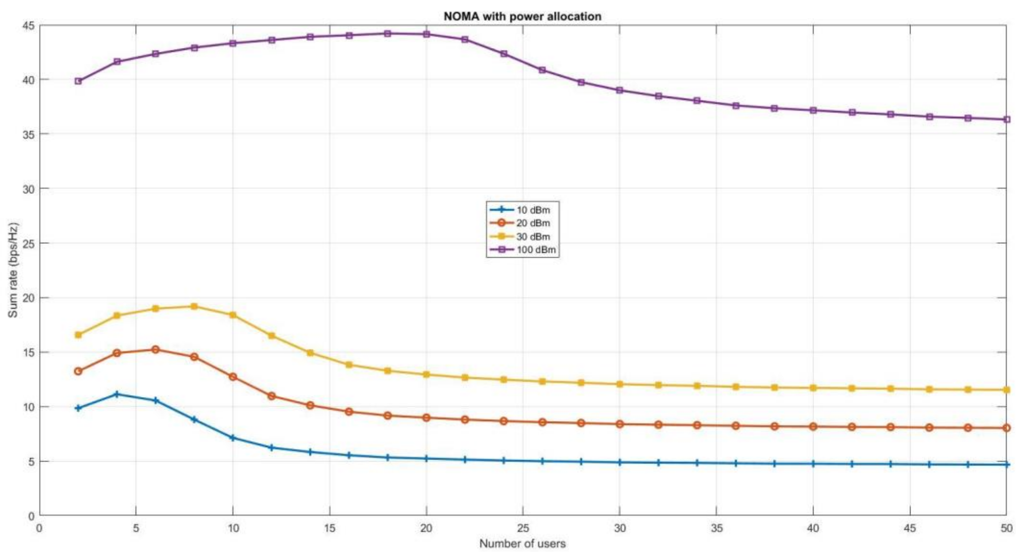

Figure 18: Performance analysis of NOMA for large users

In the simulation results, it was observed that as the number of users of SC-NOMA is increased, the sum capacity of the network initially increases and then drops and saturates. This initial increase is due to the same reasons that NOMA offers better capacity than OMA. The interference levels are manageable, and the strongest user, although allocated the least power, is given a respectable amount of power. However, a drop-off point is observed beyond which the capacity falls, and this can be considered as the maximum limit on the number of users that can be admitted into the network without performance degradation.

Moreover, it was observed that the drop-off point moves towards the right as the transmit power is increased. For instance, when 10 dBm transmit power was used, the sum rate started to decrease beyond 4 users, while when 100 dBm transmit power was used, the drop-off point was beyond 20 users. This behavior is mainly due to the power allocation strategy that was adopted, whereby the weakest user was assigned the least fraction of power, and a small fraction of 100 dBm is greater than a small fraction of 10 dBm. Therefore, to accommodate more users without performance degradation, it is necessary to increase the transmit power.

When the number of users in SC-NOMA increases, the network's sum capacity initially increases due to the better interference management and power allocation strategy. However, the sum capacity eventually saturates and drops off at a certain point, indicating the maximum number of users the network can handle without performance degradation. The drop-off point moves towards higher numbers of users as transmit power increases, since weaker users get a larger fraction of power. To accommodate more users without performance degradation, increasing the transmit power is necessary.

7.1.8 Performance analysis of hybrid NOMA

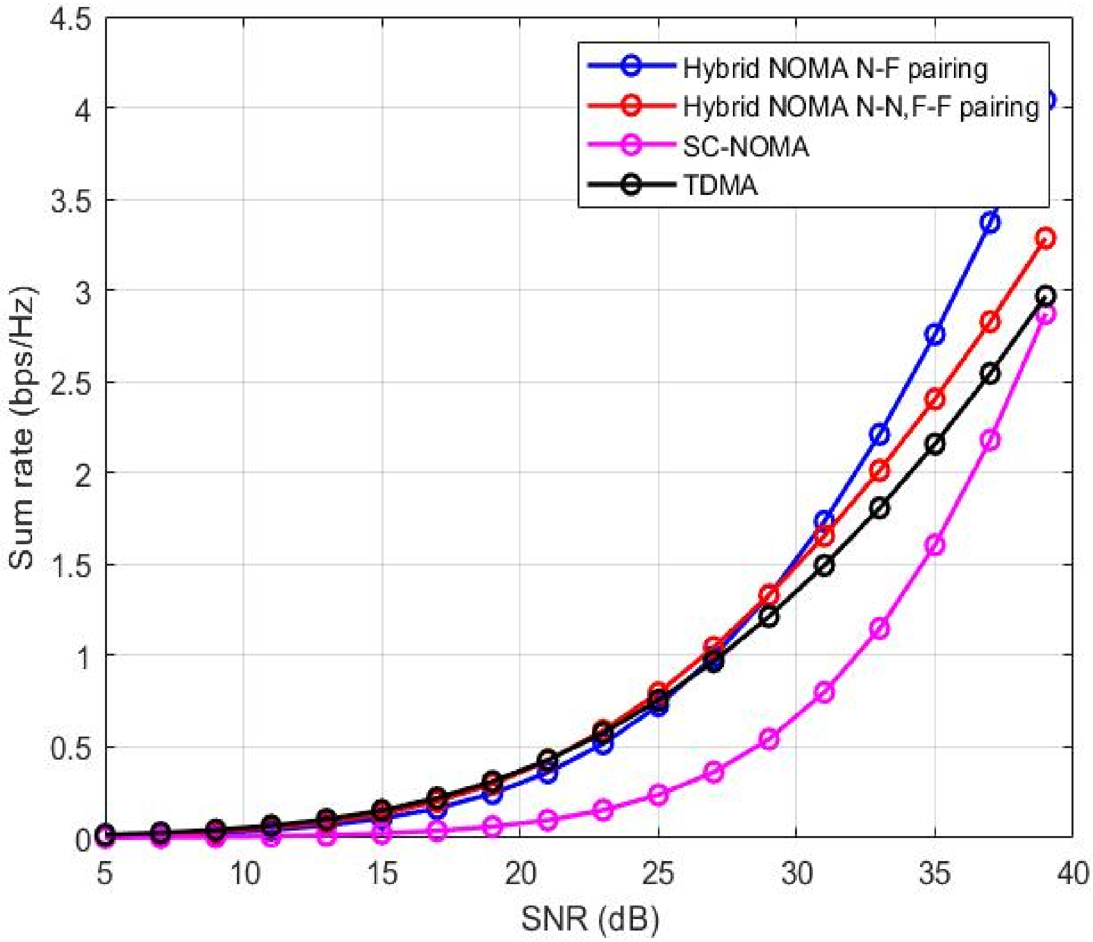

Figure 19: Performance analysis of hybrid NOMA

The following observations were made during the study of NOMA in comparison to TDMA:

When a near user is paired with a far user, the sum rate achieved is higher. This highlights the fact that NOMA performs better when there is a significant difference in channel conditions between users.

When near-near and far-far pairing is used, NOMA still outperforms TDMA in terms of sum rate, but the improvement is not as significant.

SC-NOMA performs poorly compared to TDMA because the overloading of all users onto the same carrier creates interference issues. This observation reinforces the idea that simply increasing the number of users sharing the same carrier without addressing interference issues will have a negative impact on performance.

CHAPTER 8: CONCLUSION AND RECOMMENDATIONS

Based on the simulations performed, it can be concluded that NOMA is an effective multiple access technique for wireless communication. In an ideal channel, the principle of NOMA was successfully demonstrated by superimposing data from two users and decoding them using SIC at the receiver. In noisy or AWGN channel, the BER performance of two users was compared, and it was observed that the user with higher power weight achieved a lower BER, indicating that NOMA can provide better performance for users with different channel conditions.

Furthermore, the performance of NOMA in a Rayleigh fading channel was evaluated, and it was found that the BER decreases as the transmit power increases. The simulation results were also compared with analytical expressions, which gave similar result.

In conclusion, the simulation results suggest that NOMA can provide significant benefits in terms of spectral efficiency and system capacity, especially in scenarios with limited resources. Therefore, it is recommended to further explore and develop NOMA-based systems for wireless communication applications, keeping in mind the specific requirements and challenges of different scenarios. Also, different limitation of NOMA can be overcome using technique like hybrid NOMA.

CHAPTER 9: REFERENCES

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