DESIGN AND PERFORMANCE ANALYSIS OF IRS AIDED DYNAMIC-NOMA SYSTEM

A Project Report Submitted

by

PRAJJWAL KUMAR

(1901EE77)

In Partial Fulfilment

of the Requirements for the award of the degree

BACHELOR OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY PATNA

May 2023

THESIS CERTIFICATE

This is to certify that the thesis titled **A Simple Design of IRS aided Dynamic-NOMA System** , submitted by **Prajjwal Kumar**, to the Indian Institute of Technology, Patna, for the award of the degree of **Bachelor of Technology**, is a bona fide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Prof. Preetam Kumar
Supervisor
Professor
Dept. of Electrical Engineering
IIT-Patna, 800 013

Place: Patna

Date: 9th May 2023

ACKNOWLEDGEMENTS

I would like to thank the project's supervisor, **Prof. Dr. Preetam Kumar**, for his unwavering assistance. A special thanks to my coworker **Ashish Kumar Pandey** who assisted me in brainstorming and idea sharing and enabled me to complete the assignment with accurate data.

I am grateful to my parents, my friends, juniors, and seniors for their encouragement and personal support. Without their support, I wouldn't have been able to reach this point.

A very special thanks to **Anjana P.** a person whom I met at the beginning of this project, and she never let me down during my project work. Her presence has been a constant source of strength and inspiration, and I am truly grateful for her love, encouragement, and belief in me.

At last, I would like to thank god for making this project possible.

ABSTRACT

KEYWORDS: OMA, NOMA, SDMA, FNOMA, DNOMA, Sum-Rate, Outage Probability

In order to fulfil the era of Modern 6G wireless Communication, the NOMA (Non-orthogonal Multiple Access) systems along with the IRS (Intelligent Reflecting Surface) are commonly used here in this project I have designed IRS-aided Dynamic NOMA system. The design of a straightforward IRS (Intelligent Reflecting Surface) assisted Non-Orthogonal Multiple Access (NOMA) downlink transmission is presented in this thesis. Conventional SDMA is specifically employed at the base station to produce orthogonal beams by utilizing the spatial directions of the nearby customers' channels. Then, by lining up the weak user's effective channel vectors with the preset spatial directions, IRS-assisted Dynamic NOMA is employed to make sure that a second weak user can also be serviced on these beams. To demonstrate the effectiveness of the suggested **IRS-DNOMA** scheme, analytical and simulation results are given. Additionally, a performance analysis of the system was completed in order to improve the sum-rate value by determining the best power coefficient and contrasting it with the ideal scenario.

TABLE OF CONTENTS

LIST OF FIGURES

ABBREVIATIONS

OMA	Orthogonal Multiple Access
NOMA	Non-Orthogonal Multiple Access
IRS	Intelligent Reflecting Surface
LAN	Local Area Network
SIC	Successive Interference cancellation
SINR	Signal to Interference Noise Ratio
SDMA	Space Division Multiple Access
KKT	Karush–Kuhn–Tucker
BPCU	Bits Per Channel Use
QoS	Quality of Service

NOTATION

α_i	power allocation coefficients
$R_(sum)$	Overall sum rate for the system
$\hat{R}_i$	Threshold rate for i_{th} user
$\mathbf{L}$	Lagrangian Function
D_{a_i}	Partial derivative w.r.t to a_i user
a_i^{opt}	optimal power coefficients for i_{th} user
$f(x)$	Probability density function
$F(x)$	Cumulative Density function

CHAPTER 1

INTRODUCTION

In order to maintain the demand and supply equilibrium in Wireless communication in terms of information and data exchange, we use **OMA** for 2G, 3G, 4G cellular networks,and Broadcast networks.OMA is a multiple access method used in wireless communication systems that permit numerous users to share a single communication channel. Each user is given a distinct sub-channel to send their data while using it, which divides the available communication channel into orthogonal sub-channels, such as time slots or frequency bands. Due to Orthogonality, Each user's data can be broadcast freely without interfering with that of other users.In the proposed system model **NOMA** is used instead of OMA, It is used in wireless communication systems to permit several users to use a single communication channel. Power domain multiplexing in NOMA enables several users to broadcast their data concurrently over the same frequency band and time slot. Different power levels are allotted to users in NOMA in order to transmit data over the same frequency band and time slot. The greatest power level is assigned to the user with the weakest channel condition, while the lowest power level is assigned to the user with the strongest channel condition. This makes it possible for numerous users to transmit data over the same channel at once without interfering with one another. NOMA is one of the best technique for enhancing the spectral efficiency and capacity of wireless communication systems, particularly in 5G and beyond networks. It is used for Wireless LANs, cellular networks, and satellite communications. There are two types of NOMA one is **FNOMA** and the other one is **DNOMA**. In this thesis, analysis of a system model involving DNOMA along with the IRS technology was done which includes the sum rate comparison, Outage Probability comparison with the fixed NOMA. The system model includes the **IRS** technology, IRS also known as reconfigurable intelligent surface, It is a new technology in wireless communication that uses numerous low-cost passive reflecting elements, such as antennas or metamaterials, to enhance the propagation of wireless signals between a transmitter and a receiver.

1.1 Limitations of OMA

OMA is a conventional Technique in which different users are given mutually exclusive time slots or frequency bands to broadcast their data. Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA) are the most widely used OMA techniques.
There are various Limitations of OMA:

- Limited capacity: OMA can support a limited number of users due to the division of the available spectrum into orthogonal sub-channels.
- Interference: OMA can still experience interference from other wireless signals that are not orthogonal to the sub-channels used by OMA.Due to Interference, the quality of signal is degraded.
- Limited Bandwidth: The limited bandwidth issue in OMA arises because the number of orthogonal sub-channels that can be allocated to users is limited by the available bandwidth of the communication channel. As the number of users increases, the available bandwidth must be divided into more sub-channels, resulting in a decrease in the amount of bandwidth available for each user. This can lead to a reduction in the data rate and capacity of the communication system.
- Limited number of users: OMA is not scalable to support many users, as the number of orthogonal sub-channels is limited by the available bandwidth. As the number of users increases, the performance of the system reduces.
- Fixed Allocation: Each user in OMA has a fixed amount of resources allotted to them, including bandwidth and power. When some users do not use the resources they are allotted while other users might need more resources, this might result in the underutilization of resources.

1.2 Advantages of NOMA over OMA

NOMA and OMA are both multiple access techniques used in wireless communication systems. However, NOMA has several advantages over OMA, including improved spectral efficiency, better user fairness, higher capacity, better coverage, and lower overhead. NOMA achieves these advantages by allowing multiple users to share the same resources in a non-orthogonal manner, whereas OMA divides the available bandwidth into orthogonal sub-channels. NOMA's power domain multiplexing enables it to support a larger number of users with varying traffic demands, resulting in a more balanced distribution of resources, higher capacity, and better coverage, especially in scenarios with low SNR or high interference. Furthermore, NOMA's resource allocation schemes and channel estimation techniques are simpler and require less overhead compared to OMA. Overall, NOMA is a promising multiple-access technique for future wireless communication systems.

Which can be better illustrated by the following figure, in which power and frequency both are optimally allocated for multiple users in NOMA.

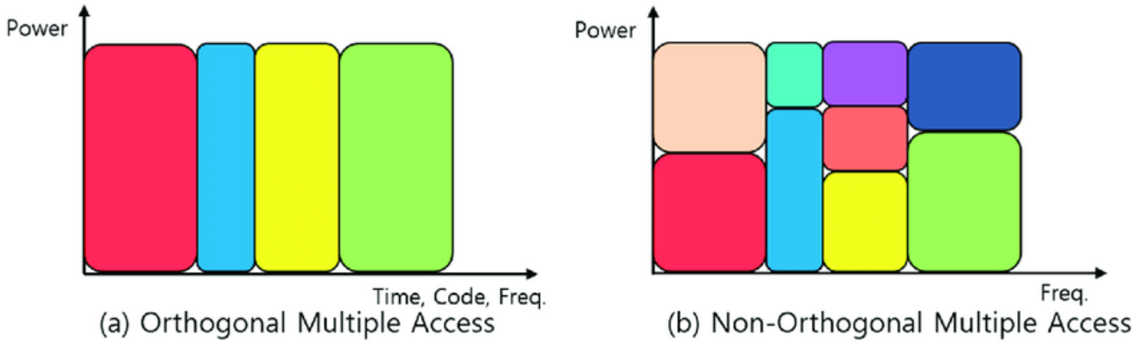

Figure 1.1: Power and Frequency spectral allocation in OMA and NOMA [1]

1.3 Challenges in NOMA

Despite the fact that NOMA is better than OMA, There are a lot of challenges in NOMA that we face, some of the major ones include:

- NOMA requires efficient power allocation schemes to ensure that users with poor channel conditions receive enough power to maintain good communication quality. Designing these power allocation schemes can be challenging, in case of large numbers of users.
- NOMA requires effective interference management to ensure that users sharing the same resources do not interfere with each other. This can be particularly challenging in dense wireless networks with many users. Which also results in an increase in Receiver complexity. To remove the interference, **SIC** process is used at the receiver side.
- Each user receives the combined signal using this method. The strength of each user's signal is arranged in declining order. The signal-to-interference-plus-noise ratio (SINR) is constantly monitored by the receiver. If the SINR at the receiver is greater than a certain level, a user can decode its signal. The signals of other users are treated as interference, and the user with the highest signal power is decoded first. The interference term is removed from the combined signal once the strongest signal has been decoded in order to decode the following stronger signal.

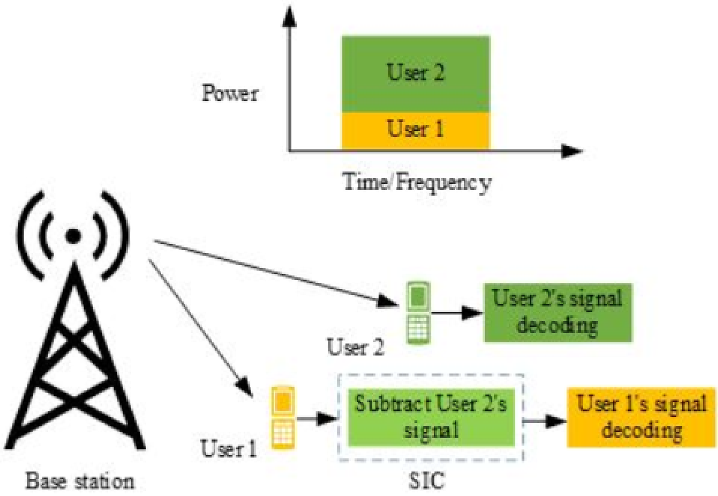

Figure 1.2: A Simple NOMA with two users and one Base station [2]

1.4 Intelligent Reflecting Surface

Intelligent Reflecting Surface (IRS), also known as reconfigurable intelligent surface, is a technology that has gained significant attention in the field of wireless communication systems, including 5G and 6G. An IRS is composed of numerous passive reflecting elements, such as antennas or metamaterials, that can manipulate the wireless signals impinging on them [4][3].

The primary purpose of an IRS is to enable dynamic control and manipulation of radio waves by reflecting them in a desirable manner. By adjusting the phase and amplitude of the reflected signals, an IRS can optimize the wireless propagation environment and enhance the overall performance of the communication system. Some of the key benefits and uses of IRS in 5G and 6G communication are as follows[4, 5, 3]:

1. **Improved Coverage and Signal Strength**: IRS can be strategically deployed in areas with poor coverage or signal quality. By reflecting and focusing the signals toward the desired areas, it can enhance the coverage and signal strength, leading to improved communication reliability and higher data rates.

2. **Increased Capacity**: IRS can mitigate interference and enhance spectral efficiency by optimizing signal propagation. It can selectively reflect signals to desired receivers while attenuating or nullifying signals to unintended receivers, thereby increasing the system capacity and improving overall network efficiency.

3. **Energy Efficiency**: By intelligently controlling the reflected signals, an IRS can reduce the transmit power required by the base station or user devices. This leads to energy savings and improved energy efficiency, making IRS an attractive technology for sustainable and green communication systems.

4. **Mobility Support**: IRS can adaptively reconfigure its reflecting elements based on the changing wireless environment and user mobility. It can track the positions of mobile users and dynamically adjust the signal reflection pattern, enabling seamless connectivity and smooth handovers.

5. **Cost-Effective Deployment**: Compared to traditional infrastructure deployment, IRS offers a more cost-effective solution. It consists of passive reflecting elements that can be easily integrated into buildings, walls, or other surfaces, requiring minimal additional hardware and infrastructure.

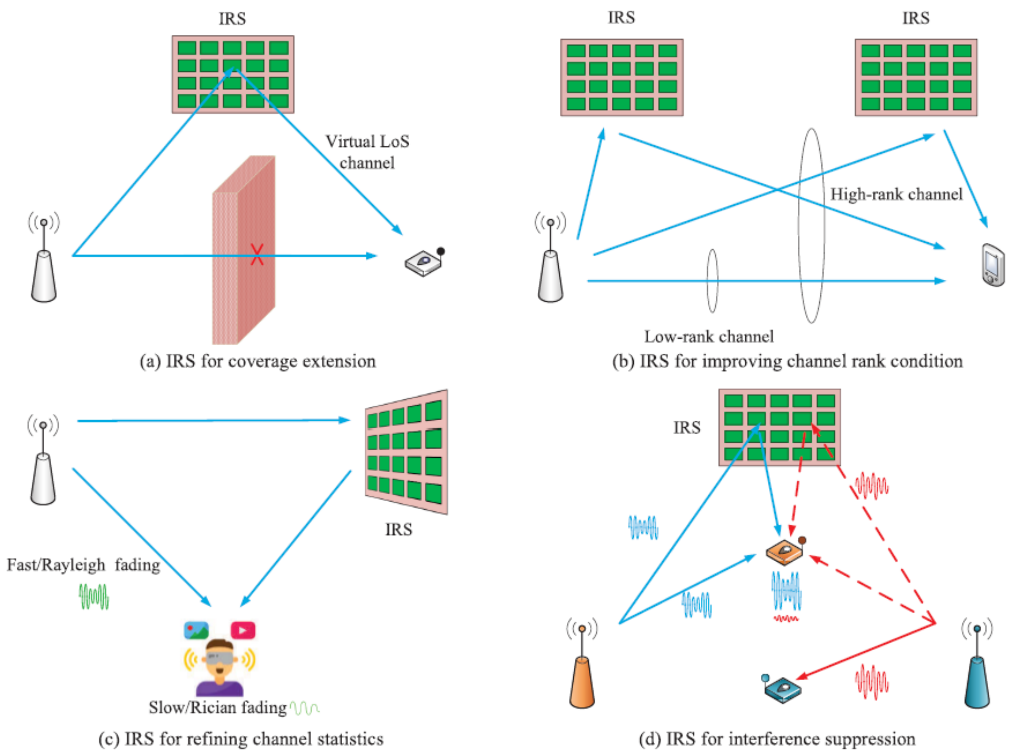

Figure 1.3: Use of Intelligent Reflecting Surface over wireless communication [3]

1.5 Dynamic NOMA

In Dynamic NOMA also called as ordered NOMA, the power allocation and modulation schemes are adjusted dynamically based on the instantaneous channel conditions of the users.

Power and modulation schemes can be adapted to the changing channel conditions, and different users can be assigned different power levels and modulation schemes depending on their channel conditions in each time instance.

The order of Decoding for the Dynamic NOMA system based on instantaneous channel gain and it is given as: $|\hat{h_1}|^2 < |\hat{h_2}|^2 < ...... < |\hat{h_k}|^2$

The weaker user is decoded first, who has channel gain

$$\left|\hat{h_1}\right|^2 = min(|h_1|^2, |h_2|^2, ...|h_k|^2) \tag{1.1}$$

The strongest user is decoded at the last, who has channel gain

$$\left|\hat{h_k}\right|^2 = max(|h_1|^2, |h_2|^2, ...|h_k|^2) \tag{1.2}$$

Considering two user cases, the received signal for Dynamic NOMA is given as:

$$y_i = \hat{h_i}(\sqrt{a_1\rho_s}x_1 + \sqrt{a_2\rho_s}x_2) + n_i \tag{1.3}$$

where $h_i \sim C(N, \sigma^2)$ is channel coefficient of Rayleigh fading channel. x_i is the message.
for decoding, the signal x_i SINR at i^{th} user is given by:

$$\psi_{u_i}^{x_i} = \frac{a_1\rho_s|\hat{h_i}|^2}{\sum_{k=2}^{K} a_k\rho_s|\hat{h_i}|^2 + 1} \tag{1.4}$$

Where $\psi_{u_i}^{x_i}$ is the SINR for decoding symbol x_i and user u_i, after that same technique of SIC is applied for the other user in order to decode the other signal.

CHAPTER 2

SYSTEM MODEL

Here we have considered a 2 user **downlink** scenario for Dynamic NOMA system along with Intelligent Reflecting Surface. where there are two types of users namely near user and far user, and it was assumed that there is no direct link between base station and distant user.

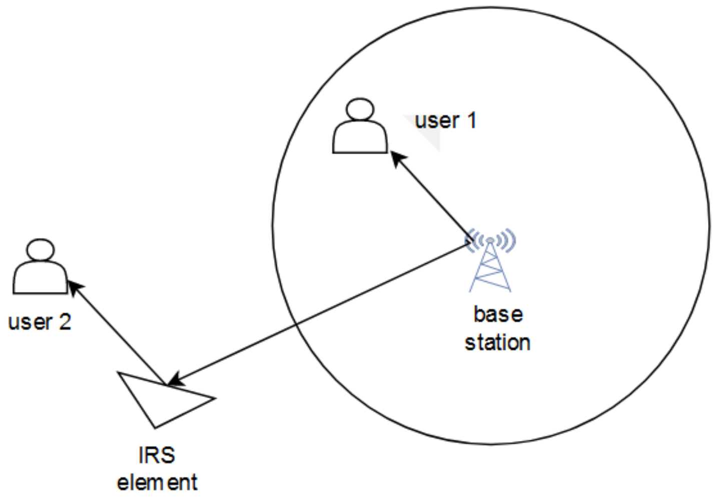

Figure 2.1: A simple design of IRS NOMA system with zero forcing beam forming with 2 users (user 1 is near user and user 2 is far user)

The base station, which is equipped with M antennas, first uses **SDMA** and generates K beam forming vectors, denoted by, w_k to serve K $(M <= K)$ nearby customers by using zero-forcing beam forming. In our case we have done analysis for 2 users so the near user is 1 i.e $K = 1$.The IRS is deployed close to user 2, and it is having N number of reflecting elements.

The Base station Broadcast is given by $w_1(\alpha_1 s_1 + \alpha_2 s_2)$, where s_1 denotes the signal to be sent to user 1 and α_i is the power allocation coefficient and $\alpha_1^2 + \alpha_2^2 = 1$.

The signal received by user 2 will be given as:

$$y_2 = \lambda_2(\alpha_1 s_1 + \alpha_2 s_2) + n_2 \tag{2.1}$$

$$\lambda_2 = min(|h_2^H \Theta_2 G_2 w_1|^2, |h_1|^2) \tag{2.2}$$

where n_2 is additive white Gaussian noise with 0 mean and variance equal to 1.
G_2 denotes the $N * M$ complex Gaussian channel matrix from base station to the IRS associated with user 2.
W_1 denotes the beam forming vector, h_2 denotes the complex Gaussian channel vector from the IRS to user 2.
Θ_2 is the diagonal matrix and each of its main diagonal and is denoted by $\beta_{k,i}e^{-j\theta_{k,i}}$, where $\theta_{k,i}$ denotes the reflection phase shift and $\beta_{k,i}$ denotes the amplitude reflection coefficient [3].
Each element of G_2 and h_2 are independent Gaussian distributed with zero mean and unit variance, and h_1 denotes the channel coefficient of user 1.

Where ρ denotes the Transmit SNR, $h_2 = G_2 w_2$, θ_2 is an $N * 1$ vector containing elements on the main diagonal of Θ_2^H , and D_2 is the diagonal matrix with diagonal elements obtained from h_2^H.

It was assumed that $\alpha_1 <= \alpha_2$ and hence the signal interference plus noise ratio (SINR) for user 2 to decode its message is given by :

$$SINR_2 = \frac{\lambda_2 \alpha_2^2}{\lambda_2 \alpha_1^2 + \frac{1}{\rho_s}} \tag{2.3}$$

Applying on-off control to IRS NOMA, where each diagonal element of Θ is either 0 (off) or 1 (on), is another low-cost implementation option and have better result from[6].

It was assumed that $N = P \times Q$, where P and Q are integers. It was defined $V = \frac{1}{\sqrt{Q}} I_P \bigoplus 1_Q$.
where I_p is a $P \times P$ identity matrix , 1_Q is a $Q \times 1$ all ones vector, and $\bigoplus$ denotes the Kronecker product it was assumed that v_p is the p^{th} column of V vector, $v_p^H v_l = 0$ for $p = l$, and $v_p^H v_p = 1$. [6]

Then from equation 2.2

$$\lambda_2 = min(|v_{p2}^H D_2 h_2|^2, |h_1|^2) \tag{2.4}$$

$$\lambda_1 = max(|v_{p2}^H D_2 h_2|^2, |h_1|^2) \tag{2.5}$$

2.1 Sum Rate

The sum rate, also known as the total achievable rate or system capacity, is a metric used to measure the overall capacity or data rate of a communication system. It quantifies the total amount of information that can be reliably transmitted through the system per unit of time. For the above system model with **FNOMA** the sum rate expression will be

$$R_{sum} = R_1 + R_2 \tag{2.6}$$

where R_1 is the achievable rate of user 1 and R_2 is the achievable rate for the user 2.

$$R_{sum} = \log_2(1 + \rho_s|h_1|^2\alpha_1^2) + \log_2(1 + \frac{|v_{p2}^H D_2 h_2|^2\alpha_2^2}{|v_{p2}^H D_2 h_2|^2\alpha_1^2 + 1/\rho_s}) \tag{2.7}$$

Here α_1^2 ,α_2^2 are power coefficients, respectively and $\alpha_1^2 + \alpha_2^2 = 1$.
For the above system model with **DNOMA** the sum rate expression will be

$$R_{sum} = \log_2(1 + \rho_s\lambda_1\alpha_1^2) + \log_2(1 + \frac{\lambda_2\alpha_2^2}{\lambda_2\alpha_1^2 + 1/\rho_s}) \tag{2.8}$$

λ_1 and λ_2 defined earlier.

CHAPTER 3

POWER OPTIMIZATION

Power optimization in (NOMA) refers to the process of efficiently allocating power resources among multiple users in order to maximize system performance. In NOMA, power allocation plays a crucial role in achieving a balance between the users' data rates and maintaining fairness among them.

The main objective of power optimization in NOMA is to allocate different power levels to different users in a way that maximizes the overall system capacity or sum rate while meeting the quality of service (QoS) requirements of each user. This optimization process takes into account various factors such as channel conditions, user requirements, and system constraints.

For the successful decoding of the signal of user 1 and user 2 rates must be greater than their threshold rate.

$$R_1 >= \hat{R}_1 \tag{3.1}$$

$$R_2 >= \hat{R}_2 \tag{3.2}$$

On solving the above equations, we get the following constraints for the power coefficients.

$$a_2 >= \frac{R_2(1+\rho_s\lambda_2)}{\rho_s\lambda_2(1+R_2)} \tag{3.3}$$

$$a_1 >= \frac{R_1}{\lambda_1\rho_s} \tag{3.4}$$

where $a_1 = \alpha_1^2$, and $a_2 = \alpha_2^2$.

The optimization problem is to maximize the sum rate of the system and it can be done as follows:

$$P_1 : max_{(a_1,a_2)} R_{sum}(a1, a2) = \log_2(1 + \rho_s\lambda_1 a_1) + \log_2(1 + \frac{\lambda_2 a_2}{\lambda_2 a_1 + 1/\rho_s}) \tag{3.5}$$

Subject to the condition : $a_2 >= \frac{R_2(1+\rho_s\lambda_2)}{\rho_s\lambda_2(1+R_2)}$, $a_1 >= \frac{R_1}{\lambda_1\rho_s}$, $\sum_{i=1}^{2} a_i <= 1$.

The above constraints result from the requirement that each user's capacity satisfy the necessary rate requirement in order to guarantee QoS. Using the objective function's Hessian matrix P_1 makes it easy to show that both the objective function and the constraints have a concave shape. Therefore, **KKT** criteria are both essential and adequate for the optimum solution to issue P1.

The following is the Lagrangian function for solving P1:

$$\mathbf{L}(\mathbf{a},\gamma,\beta) = \log_2(1+\rho_s\lambda_1 a_1) + \log_2(1+\frac{\lambda_2 a_2}{\lambda_2 a_1 + 1/\rho_s}) + \gamma_1(a_2 - \frac{R_2(1+\rho_s\lambda_2)}{\rho_s\lambda_2(1+R_2)}) + \gamma_2(a_1 - \frac{R_1}{\lambda_1\rho_s}) + \beta(\sum_{i=1}^{2} a_i - 1) \tag{3.6}$$

here γ and β are non-negative Lagrangian's multiplier.Applying the KKT conditions[7] as follows:

$$D_{a_1}(\mathbf{L}(\mathbf{a},\gamma,\beta)) = 0$$
$$D_{a_2}(\mathbf{L}(\mathbf{a},\gamma,\beta)) = 0$$
$$\gamma_1(a_2 - \frac{R_2(1+\rho_s\lambda_2)}{\rho_s\lambda_2(1+R_2)}) = 0$$
$$\gamma_2(a_1 - \frac{R_1}{\lambda_1\rho_s}) = 0$$
$$\beta(\sum_{i=1}^{2} a_i - 1) = 0$$
$$\gamma_1, \gamma_2, \beta >= 0$$

For $\gamma_2 > 0$, by applying the KKT condition, we get the value of $\mathbf{a_1^{opt}}$as:
$\mathbf{a_1^{opt}} = \frac{R_1}{\lambda_1\rho_s}$ and $\mathbf{a_2^{opt}} = 1 - a_1^{opt}$.

The ideal values of $\mathbf{a_2^{opt}}$ and $\mathbf{a_1^{opt}}$ can guarantee that distant customers with poor channel conditions receive the necessary power to comply with the threshold rate requirement. The remaining power is given to the nearby user with a good channel condition. Such an ideal method of power distribution can maximize the rate of nearby consumers with robust channels, while ensuring the lowest possible rate of distant users.

CHAPTER 4

PROBABILITY OF OUTAGE

The probability of outage in wireless communication refers to the likelihood or probability that the quality of the wireless communication link falls below a certain acceptable threshold or fails to meet the desired quality of service (QoS) requirements. It represents the probability that the received signal strength or quality is insufficient for the successful transmission and reception of data.

Outages can occur due to various factors, including distance-dependent path loss, fading, interference, noise, and environmental conditions. The probability of an outage is typically influenced by parameters such as signal-to-noise ratio (SNR), signal-to-interference-plus-noise ratio (SINR), and the specific QoS requirements of the communication system.

Mathematically, the probability of outage P_{out} can be expressed as :

$$P_{out} = Pr(Rx < Rmin) \tag{4.1}$$

where:

1. Pr denotes the probability,
2. Rx represents the received signal quality or received SNR/SINR,
3. R_{min} is the minimum required or desired signal quality threshold.

For the FNOMA case for the purposed system model, we have the probability of outage for user 2(far user) [6]:

$$P_{out_2} = \frac{\zeta^{N/2}}{(\Gamma(Q))^P}(\zeta^{\frac{-Q}{2}}\Gamma(Q) - 2K_Q(2\sqrt{(\zeta)}))^P \tag{4.2}$$

- N is the total number of IRS elements present in the system model.

- $N = P \times Q$
- $\zeta = \frac{Q\epsilon_2}{\rho(a_2^2 - a_1^2\epsilon_2)}$
- $\epsilon_2 = 2^{R_2} - 1$

Where R_2 denotes the target rate for user 2, $K_Q(.)$ denote the Bessel function and $\Gamma(.)$ denotes the gamma function.

For the **Dynamic NOMA** case, the rate of user which is decoded first is given as:

$$C_{u_2}^{x_2} = \log_2{(1 + \frac{\lambda_2\alpha_2^2}{\lambda_2\alpha_1^2 + 1/\rho_s})} \tag{4.3}$$

If this rate will be less than the desired rate then there will be an outage if,

$$C_{u_2}^{x_2} <= \hat{R}_2 \tag{4.4}$$

on solving the above inequality, we get

$$\lambda_2 < \frac{QR_2}{\rho_s a_2 - R_2\rho_s a_1} \tag{4.5}$$

let's assume that

$$\begin{aligned} \beta_1 &= |h_1|^2 \\ \beta_2 &= \left|V_{P2}^H D_2 h_2\right|^2 \end{aligned} \tag{4.6}$$

The PDF of user 1 by assuming the channel of user 1 as Rayleigh fading channel

$$f_{|h_1|^2}(\beta_1) = \frac{1}{\delta_1^2} e^{-\frac{\beta 1}{\delta_1{}^2}} \tag{4.7}$$

where

$$|h_1| = \sqrt{\delta/2}(x + jy)$$

Here δ is the expected channel gain. The PDF of user 2 is given as [6] [8]:

$$f_{\left|v_{P_2D_2h_2}\right|^2}(\beta_2) = \frac{2\beta_2{}^{\frac{Q-1}{2}} K_{Q-1}\left(2\sqrt{\beta_2}\right)}{\Gamma(Q)}$$

The CDF of user 2 is given as

$$
\begin{aligned}
&F_{\lambda_2}\left(\hat{\lambda}_2\right) = \Pr\left(\lambda_2 \leqslant \hat{\lambda}_2\right) \\
&= 1 - \Pr\left(\lambda_2 > \hat{\lambda}_2\right) \\
&= 1 - \Pr\left(\min\left(\beta_1, \beta_2\right) > \hat{\lambda}_2\right) \\
&= \frac{1 - \left(2\hat{\lambda}_1 K_Q\left(2\sqrt{\hat{\lambda}_1}\right)\right)}{\Gamma(Q)} \cdot e^{-\frac{\lambda_1}{\delta_1^2}}
\end{aligned}
$$

solving gives

$$
F_{\lambda_2}\left(\hat{\lambda}_2\right) = \frac{1 - \left(2\hat{\lambda}_1 K_Q\left(2\sqrt{\hat{\lambda}_1}\right)\right)}{\Gamma(Q)} \cdot e^{-\frac{\lambda_1}{\delta_1^2}} \tag{4.8}
$$

Now PDF of user 2 is calculated as:

$$
f_{\lambda_1}\left(\hat{\lambda}_1\right) = \frac{d}{d\lambda_1} F_{\lambda_1}\left(\hat{\lambda}_1\right)
$$

$$
\begin{aligned}
&= \frac{Q \cdot \hat{\lambda}_1^{(Q/2-1)} \cdot K_Q\left(2\sqrt{\hat{\lambda}_1}\right) \cdot e^{-\left(\frac{\hat{\lambda}_1}{\delta_1^2}\right)}}{\Gamma(Q)} - \frac{2}{\delta_1^2 \Gamma(Q)} \hat{\lambda}_1^{Q/2} K_Q\left(2\sqrt{\hat{\lambda}_1}\right) e^{-\frac{\hat{\lambda}_1}{\delta_1^2}} \\
&- \frac{\sqrt{2}\hat{\lambda}_2^{\frac{Q-1}{2}} e^{-\frac{\hat{\lambda}_2}{\delta_1^2}\left(I_{\frac{Q+1}{2}}\left(2\sqrt{\lambda_2}\right) + \frac{I_{Q-1}}{2}\left(2\sqrt{\lambda_2}\right)\right)}}{\Gamma(Q)}
\end{aligned} \tag{4.9}
$$

The outage probability for user 2 for the DNOMA system model is given as[9, 10, 11]:

$$
\begin{aligned}
&= \int_0^{\lambda_2} f_{\lambda_2}\left(\hat{\lambda}_2\right) d\hat{\lambda}_2 \\
&= \frac{Q}{\Gamma(Q)} \cdot \left(\frac{\delta_1^2}{2}\right)^{\left(\frac{Q}{2}-1\right)} \cdot \frac{1}{2}\left[\Gamma\left(\frac{Q}{2}, \frac{\lambda_2}{\delta_1 2}\right) - \Gamma\left(\frac{Q}{2}\right)\right] + \\
&\frac{\lambda_2^{Q/2+1}}{\Gamma(Q)} \cdot e^{-\frac{\lambda_2}{\delta_1^2}} \cdot \gamma\left(\frac{Q}{2}+1, \frac{4\lambda_2}{\delta_1^2}\right) + \frac{2^{Q-2}\lambda_2^Q \Gamma\left(\frac{Q+1}{2}, \frac{2\lambda_2^2}{\delta_1{}^2}\right)}{\Gamma(Q)}
\end{aligned} \tag{4.10}
$$

where $\gamma(\alpha, x) = \int_0^x t^{\alpha-1} e^{-t} dt$ is an incomplete gamma function.

$$P_{out} = \frac{Q}{\Gamma(Q)} \cdot \left(\frac{\delta_1^2}{2}\right)^{\left(\frac{Q}{2}-1\right)} \cdot \frac{1}{2}\left[\Gamma\left(\frac{Q}{2}, \frac{\lambda_2}{\delta_1 2}\right) - \Gamma\left(\frac{Q}{2}\right)\right] + \frac{\lambda_2^{Q/2+1}}{\Gamma(Q)} \cdot e^{-\frac{\lambda_2}{\delta_1^2}} \cdot \gamma\left(\frac{Q}{2}+1, \frac{4\lambda_2}{\delta_1^2}\right) + \frac{2^{Q-2}\lambda_2^Q \Gamma\left(\frac{Q+1}{2}, \frac{2\lambda_2^2}{\delta_1{}^2}\right)}{\Gamma(Q)} \tag{4.11}$$

Since $V = \frac{1}{\sqrt{Q}} I_P \bigoplus 1_Q$ for IRS-NOMA with on-off control, it is simple to confirm that $v_p^H D_2 h_2$ and $v_l^H D_2 h_2$ are independently and identically distributed (i.i.d.) for $p \neq l$.

Therefore, we need to take power P to 4.11 and calculate the final Outage Probability.

CHAPTER 5

RESULTS

The Results of the above analysis for optimal power allocation, Sum Rate comparison, and Outage Probability are plotted in the **MATLAB** and compared with the simulation of the above system model.

5.1 Sum-Rate comparison of DNOMA vs FNOMA

The value of power coefficients are taken as $a_1 = 0.1$ and $a_2 = 0.9$. The value of N that is the total number of IRS elements are 12.

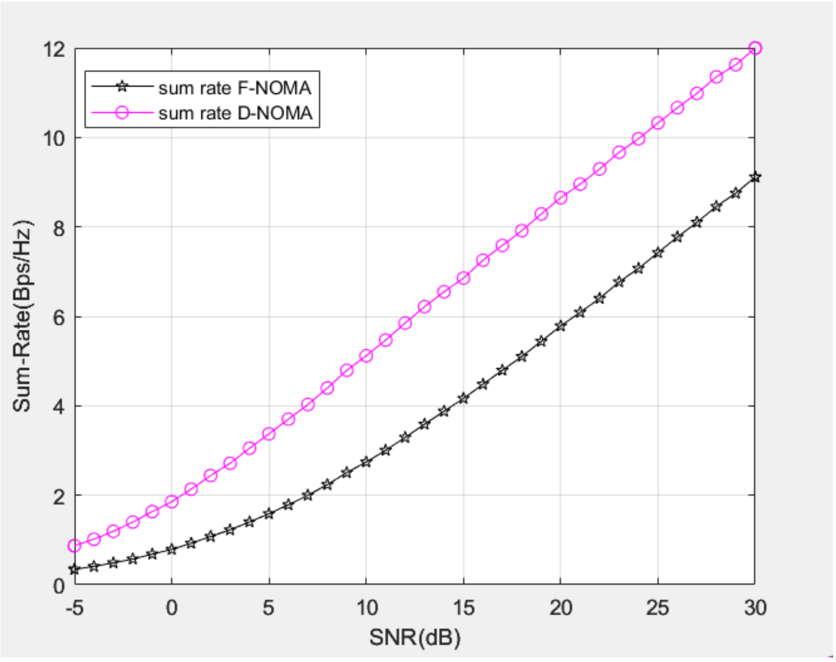

Figure 5.1: Plot between SUM-RATE and Transmit SNR in dB for comparison of SUM-RATE of FNOMA and DNOMA

It has been observed from the figure 5.1 that the system having Dynamic NOMA has better SUM-RATE as compared to Fixed NOMA case.

5.2 SUM-RATE after Optimal power Allocation for FNOMA vs DNOMA

The value of power coefficients $a_1 = 0.1$ and $a_2 = 0.9$ are taken for ideal case, for optimal power allocation case values taken are $\mathbf{a_1^{opt}} = \frac{R_1}{\lambda_1 \rho_s}$ and $\mathbf{a_2^{opt}} = 1 - a_1^{opt}$. The value for N(*number of IRS elements*) is taken as 12.

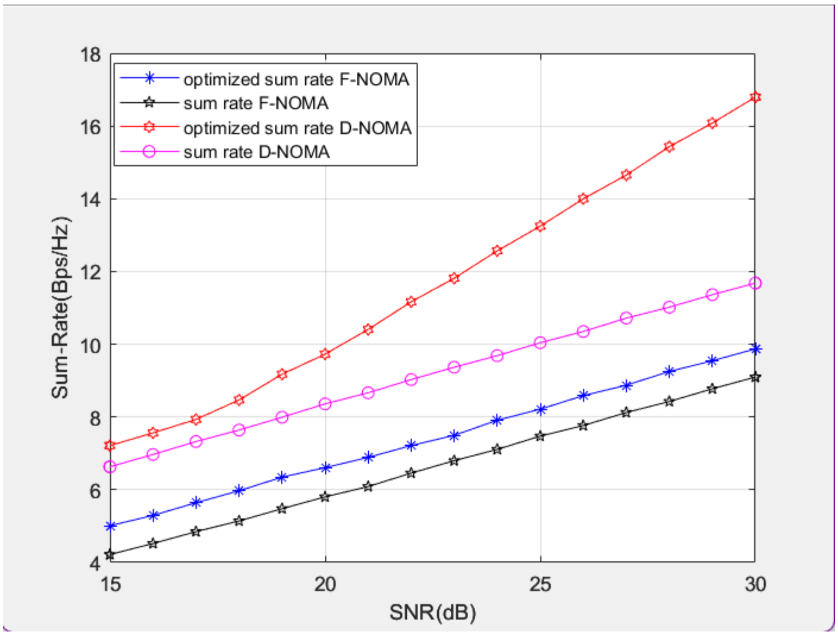

Figure 5.2: Plot between SUM-RATE and Transmit SNR in dB for comparison of SUM-RATE of FNOMA and DNOMA for the optimal power coefficient vs fixed power coefficient

It is evident from figure 5.2 that Sum-rate for the Dynamic NOMA system model is better than Fixed NOMA. Talking about optimal Power allocation, which is obtained analytically by applying KKT conditions, have better Sum-Rate performance for both system model using FNOMA and DNOMA.

5.3 Probability of Outage for DNOMA vs FNOMA

The value of power coefficients $a_1 = 0.1$ and $a_2 = 0.9$ are taken for ideal case. Total number of IRS elements taken are 12 and Threshold Rate for the user 2 is taken as $2(BPCU)$ and value of δ_1 that is expected value of the channel gain for user 1 is taken as 1.

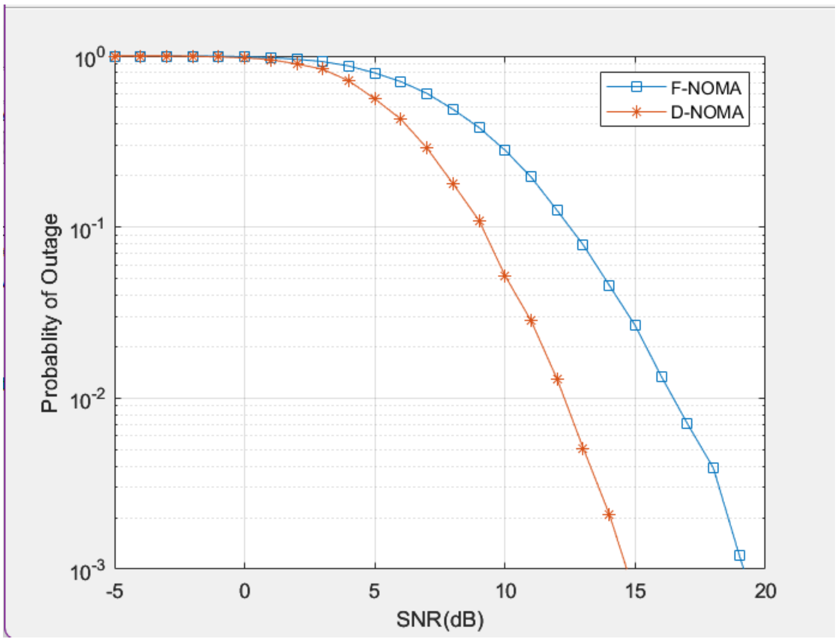

Figure 5.3: Plot between Probability of Outage and Transmit SNR(dB) for F-NOMA and D-NOMA system model

It can be seen from the simulation in the plot 5.3 that Probability of outage for the system having Dynamic NOMA performed better as compared to fixed NOMA.

From figure 5.4 it can be observed that the Probability of outage is better in the Dynamic NOMA system model as compared to the Fixed NOMA system model. It can be seen that the proposed DNOMA system model have better diversity gain as compared to FNOMA case. Both analytical and simulation Results have been plotted, and it can be seen that it is matching with the simulation.

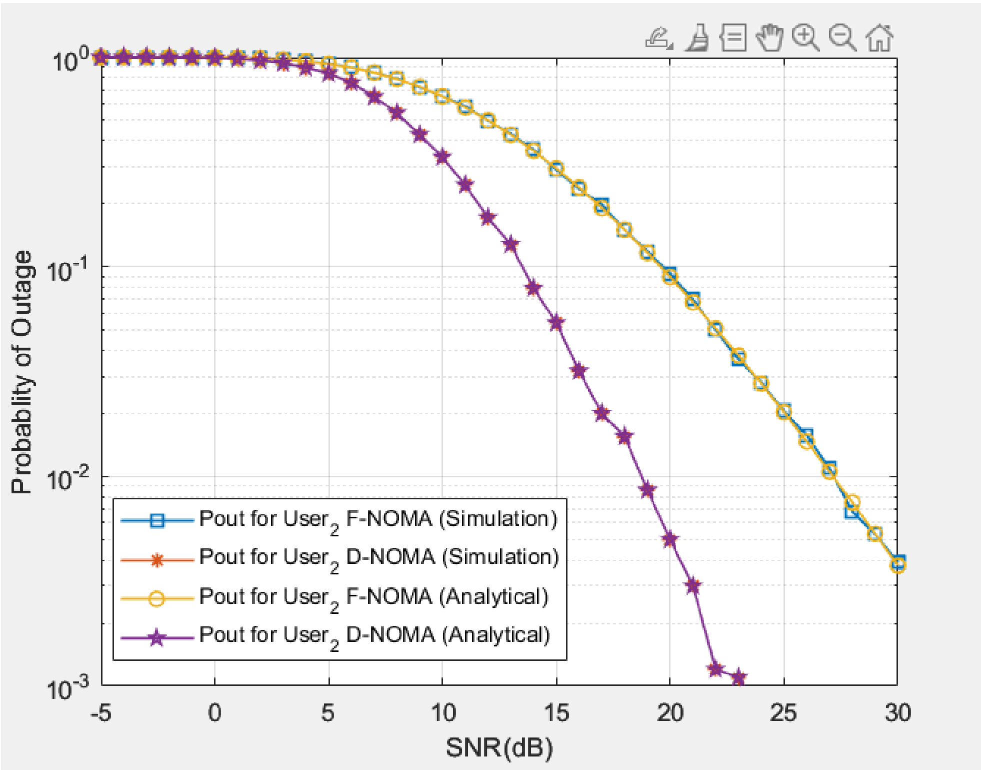

Figure 5.4: Plot for Probability of Outage for user 2 vs Transmit SNR(ρ_s) and comparison of Fixed NOMA vs Dynamic NOMA in terms of simulation and analytical results

CHAPTER 6

CONCLUSION

It was evident from both figures 5.2 and 5.4 that Dynamic NOMA works very well and have better performance than Fixed NOMA either talking about sum rate or Probability of outage.

Here in this proposed model, we have used finite resolution beam forming [6] for the IRS DNOMA system model. From figure 5.2 we can conclude that The optimal power coefficient has a better overall sum rate as compared to the ideal case. Talking about the Outage Probability from figure 5.4, the analytical results almost came out to be similar to our proposed model [12] having DNOMA. we conclude that by using DNOMA we will have a better sum rate and outage probability performances as compared to the conventional NOMA - IRS system model which can be fruitful for the 5G and beyond communication system. Future works can be done on Analysis of Outage performance for **Multiuser** system model, and Analysis of Outage performance for **Uplink** DNOMA system model.

REFERENCES

[1] J. Cheon and H.-S. Cho, "Power allocation scheme for non-orthogonal multiple access in underwater acoustic communications," *Sensors*, vol. 17, p. 2465, 10 2017.

[2] S. M. R. Islam, M. Zeng, and O. A. Dobre, "Noma in 5g systems: Exciting possibilities for enhancing spectral efficiency," 2017.

[3] Q. Wu, S. Zhang, B. Zheng, C. You, and R. Zhang, "Intelligent reflecting surface-aided wireless communications: A tutorial," *IEEE Transactions on Communications*, vol. 69, no. 5, pp. 3313–3351, 2021.

[4] Q. Wu and R. Zhang, "Towards smart and reconfigurable environment: Intelligent reflecting surface aided wireless network," *Comm. Mag.*, vol. 58, no. 1, p. 106–112, jan 2020. [Online]. Available: https://doi.org/10.1109/MCOM.001.1900107

[5] ——, "Towards smart and reconfigurable environment: Intelligent reflecting surface aided wireless network," *CoRR*, vol. abs/1905.00152, 2019. [Online]. Available: http://arxiv.org/abs/1905.00152

[6] Z. Ding and H. Vincent Poor, "A simple design of irs-noma transmission," *IEEE Communications Letters*, vol. 24, no. 5, pp. 1119–1123, 2020.

[7] C.-L. Wang, J.-Y. Chen, and Y.-J. Chen, "Power allocation for a downlink non-orthogonal multiple access system," *IEEE Wireless Communications Letters*, vol. 5, pp. 532–535, 10 2016.

[8] H. Liu, H. Ding, L. Xiang, J. Yuan, and L. Zheng, "Outage and ber performance analysis of cascade channel in relay networks," *Procedia Computer Science*, vol. 34, pp. 23–30, 2014, the 9th International Conference on Future Networks and Communications (FNC'14)/The 11th International Conference on Mobile Systems and Pervasive Computing (MobiSPC'14)/Affiliated Workshops. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1877050914008655

[9] M. Abramowitz and I. A. Stegun, *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables*. Dover Publications, 1972.

[10] A. Erdélyi *et al.*, *Higher Transcendental Functions*, ser. vols. I, II, and III. New York: McGraw Hill, 1953–1955.

[11] I. S. Gradshteyn and I. M. Ryzhik, *Table of Integrals, Series and Products*, 6th ed. New York, NY, USA: Academic, 2000.

[12] P. Kumar, A. K. Pandey, and P. Kumar, "Analysis of outage probability for DNOMA IRS system over rayleigh fading channel," *IEEE Communication Letters*, to be communicated.