Analysis of Non-Orthogonal Multiple Access (NOMA) for Wireless 5G Communication

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Electrical Engineering

by

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Spring Semester,2020-2021

May 2021

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Abstract

The non-orthogonal multiple access (NOMA) scheme is investigated as a possible radio access scheme for 5G wireless communication in this study. The demand for high-speed and efficient wireless communication systems has increased in recent years.

We first go through the basics of the methodology for both downlink and uplink networks, before moving on to discussing network capacity optimization under fairness constraints. We also look at how imperfect receivers affect NOMA network efficiency, as well as the SE of NOMA networks and how it relates to EE. Finally, the outage probability and the relationship between outage probability and SNR are discussed. I demonstrate how NOMA networks outperform other multiple access schemes in terms of EE,SE and sum capacity, as well as outage probability vs SNR for two users, three users, four users, and five users, and compare the results and show how half-duplex NOMA and full-duplex NOMA have different outage probabilities.

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Abbreviations

NOMA	**N**on **O**rthogonal **M**ultiple **A**ccess
OMA	**O**rthogonal **M**ultiple **A**ccess
SIC	**S**uccessive **I**nterfearence **C**ancellation
AWGN	**A**dditive **W**hite **G**aussian **N**oise
BS	**B**Base **S**taition
CDMA	**C**ode **D**ivision **M**ultiple**A**ccess
TDMA	**T**ime **D**ivision **M**ultiple**A**ccess
FDMA	**F**requency **D**ivision **M**ultiple**A**ccess
OFDMA	**O**rthogonal **F**requency **D**ivision **M**ultiple**A**ccess
CSI	**C**hannel **S**tate **I**nformation
SC	**S**uperposition **C**oding
SNR	**S**ignal to **N**oise**R**atio
EE	**E**nergy **E**fficiency
SE	**S**Spectral **E**fficiency
OP	**O**utage **P**robability
DF	**D**ecode and **F**arward
HD	**H**alf **D**uplex
FD	**F**ull **D**uplex
LI	**L**oop self **I**nterference

Chapter 1

Introduction

1.1 Overview

The definition of NOMA for the forthcoming 5G networks is explored in this chapter. NOMA is unique among multiple access schemes in that it provides users with orthogonal access in terms of time, frequency, code, and space.In order for the SIC receiver to differentiate between users in both the uplink and downlink networks, NOMA uses superposition coding at the transmitter. In order to implement real-time power allocation and SIC algorithms in cellular networks, high computational power is needed.

This thesis discusses the fundamentals and capability limitations of NOMA as a possible radio access technology. The SIC receiver's flaws and their effect on overall ability are also discussed. We also add to the literature by demonstrating how NOMA outperforms traditional OFDMA in terms of energy and spectral performance. Finally, I show how outage Probability varies with snr for two users, three users, four users and five users. NOMA is a relatively new technique that has the ability to solve the high complexity of current schemes and, as a result, has gotten a lot of attention from the research community in preparation for implementation in 5G networks.

In new radio (NR) utilization scenarios, the criteria for effectively utilizing the spectrum are of great importance due to the rapidly growing demand for wireless networks.NOMA has gotten a lot of coverage as a way to improve the SE of the fifth generation (5G) mobile communication network.There are two types of NOMA schemes: power-domain NOMA and code-domain NOMA. In this thesis I have studied the power domain NOMA. The most important aspect of NOMA is that it enables multiple users to share the same physical resource (such as time, frequency, or code) at various power levels. The SIC is performed on the receiver side.

For two users using Half Duplex (HD) and Full Duplex (FD) NOMA, I also show the OP versus received SNR curve.

1.2 Motivation

All modern cellular networks use OMA methods such as TDMA, FDMA, and CDMA. None of these methods, however, would be able to satisfy the high requirements of future radio access systems.

Some of the characteristics of OMA schemes are mentioned below. TDMA-based networks require precise timing synchronization, which can be difficult, particularly in the uplink, since each user's information is sent in non-overlapping time slots. In FDMA implementations like OFDMA, information for each user is allocated to a subset of subcarriers. CDMA uses codes to identify users on the same channel. Multiple access systems that provide users with orthogonal access in time, frequency, code, or space are radically different from NOMA. Each consumer in NOMA works in the same band and at the same time, with only the difference in their power levels separating them.

Multiple users can be served at the same frequency and time.
NOMA can handle a much larger number of users.
Higher SE (More data rate per Hz)
It is beneficial if users are distributed geographically.
Improve your coverage to mobile phone users on the outskirts of town (users far from the base station)

Chapter 2

Non-Orthogonal Multiple Access

2.1 Overview

The modulation scheme is orthogonal frequency division multiplexing (OFDM), and the multiple access scheme is NOMA.OFDMA is used in traditional 4G communication networks as a natural extension of OFDM, where each device's information is assigned to a subset of sub carriers.Each consumer in NOMA, on the other hand, has access to all sub carriers.

2.2 Difference between OMA and NOMA

The key multiple access strategy that has been in use in the emerging wireless networking environment is OMA. In OMA, orthogonal services are assigned to various users to reduce the ISI in the frequency or time domain. The spectral efficiency is severely harmed as a result of this allocation technique. The key differences between OMA and NOMA techniques are seen in Figures 2.2 and 2.3. A provided bandwidth is subdivided into three users in OMA, so each user can only use a portion of the bandwidth. If each of the three users has a poor channel, the overall SE of the OMA system would be harmed, while in NOMA, maximum bandwidth is provided to each users, regardless of their levels of power. User3 is the closest user, so it has less power, while user1 is the farthest away, so it has more power. Since both strong users and weak users are equally likely to use the available bandwidth, spectral performance improves. A broad frequency band is subdivided into several orthogonal subcarriers in traditional OMA techniques, such as OFDMA schemes which are the central technologies behind today's 4G communication networks. The primary goal of OFDMA system is to reduce inter-user interaction, so each sub-carrier is assigned to a single user. In the case of NOMA, multiple users may share the same orthogonal resources via power domain. In several areas, NOMA outperforms traditional techniques. It is one of the most important 5G innovations. There are numerous advantages to this, including improved spectral performance, a significant increase in the number of users, which is an important necessity of Internet of Things, reduced latency, improved user fairness, and numerous other advancements in the field of mobile communication.

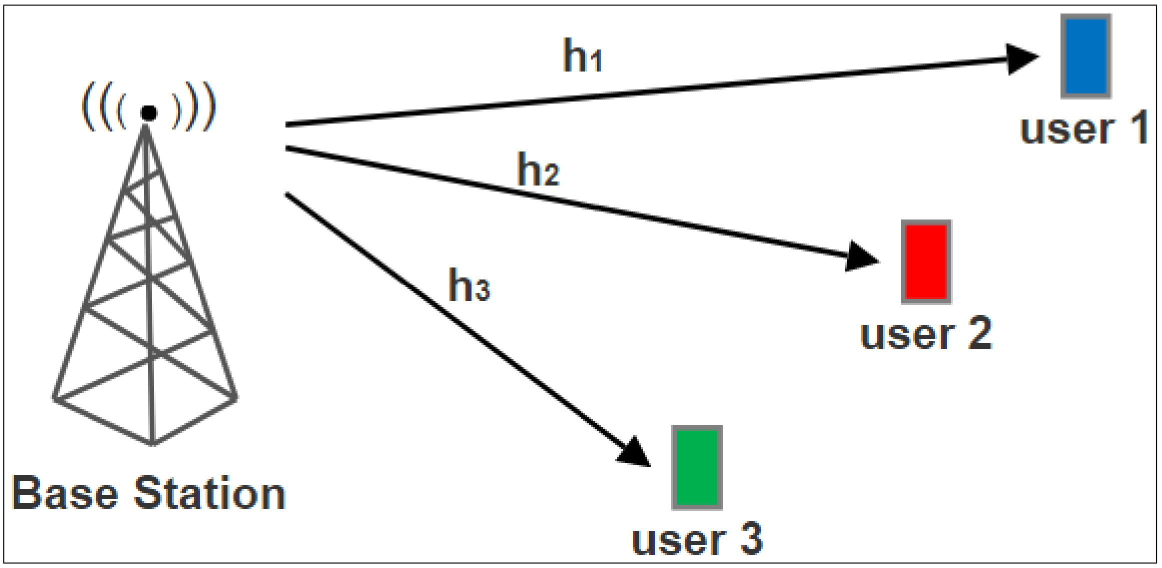

Figure 2.1: This is a System model of the NOMA communication system, which has three users

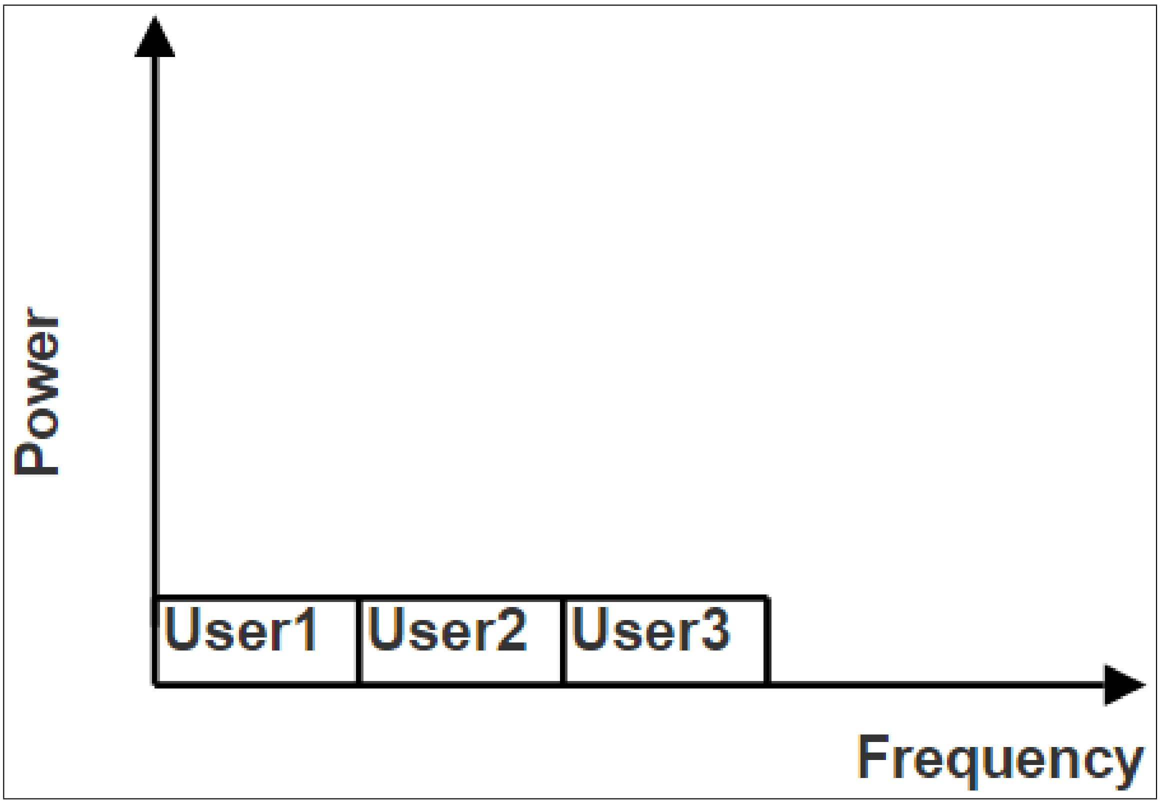

FIGURE 2.2: In this diagram of Orthogonal Multiple Access (OMA), frequency division is clearly visible.

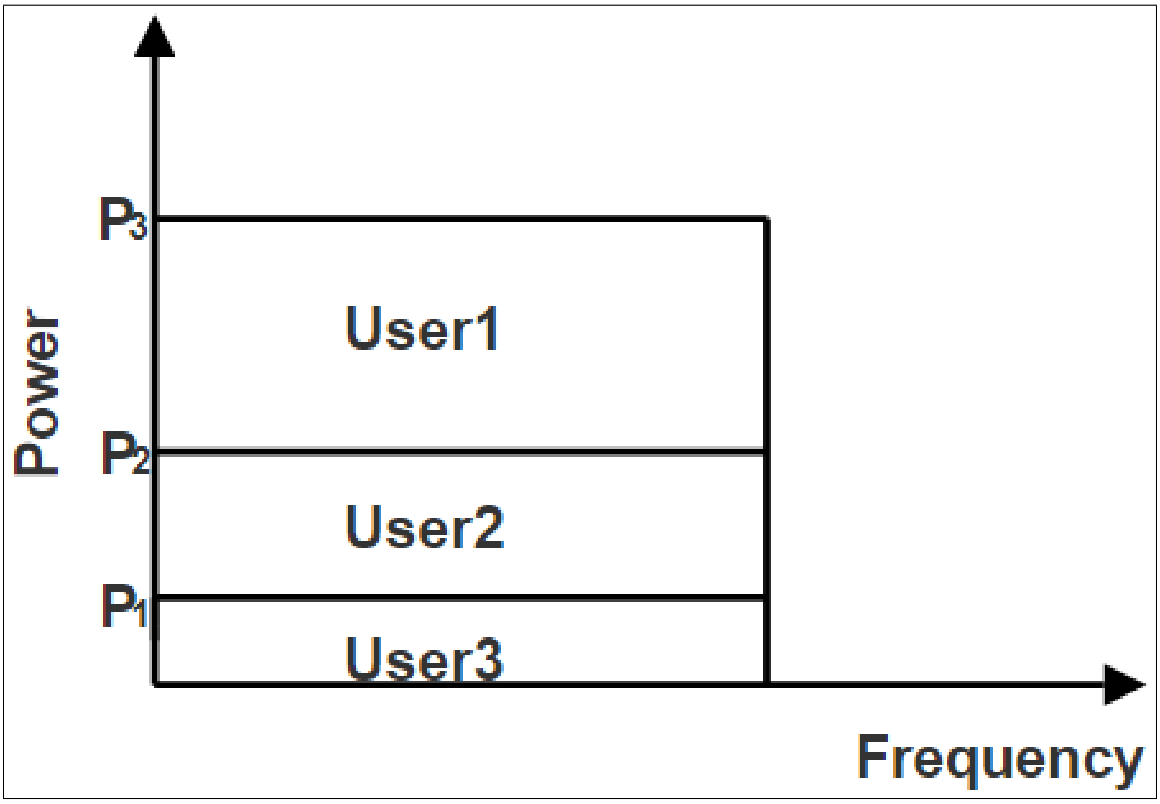

FIGURE 2.3: Non Orthogonal Multiple Access (NOMA), We can clearly see how power was divided in this diagram.

The poor users are not given much attention in traditional OMA techniques. Priority is provided to stronger users over weaker users. As a result, poor users must wait for services. NOMA, on the other hand, ensures that users are allocated resources fairly, which benefits a vulnerable user. Weak users with bad channel conditions are granted more power allocation in NOMA. Weak users are those that are located far away from the BS, where there is a higher risk of fading and multiple reflection, resulting in a signal week. As a result, if these users are given more power, the signal will be able to reach them and they will be able to decipher it.

2.3 Superposition coding and Successive interference cancellation (SIC)

The use of the same spectrum for all users is mainly owing to superposition coding at the transmitter and SIC at the receiver. At the transmitter site, all of the individual information signals are superimposed into a single waveform, and SIC decodes the signals one by one until it finds the desired signal at the receiver. Figure 2.4 illustrates the description.

In the illustration, the three separate colored information signals are superimposed at the transmitter. All three signals are included in the received signal at the SIC receiver. The 1^{st} signal decoded by SIC is the strogest, while the others are considered interference. The obtained signal is subtracted from the 1^{st} decoded signal, and if the perfect decoding is found, the waveform with the remaining signals is correctly obtained. SIC repeats the procedure until the required signal is found.

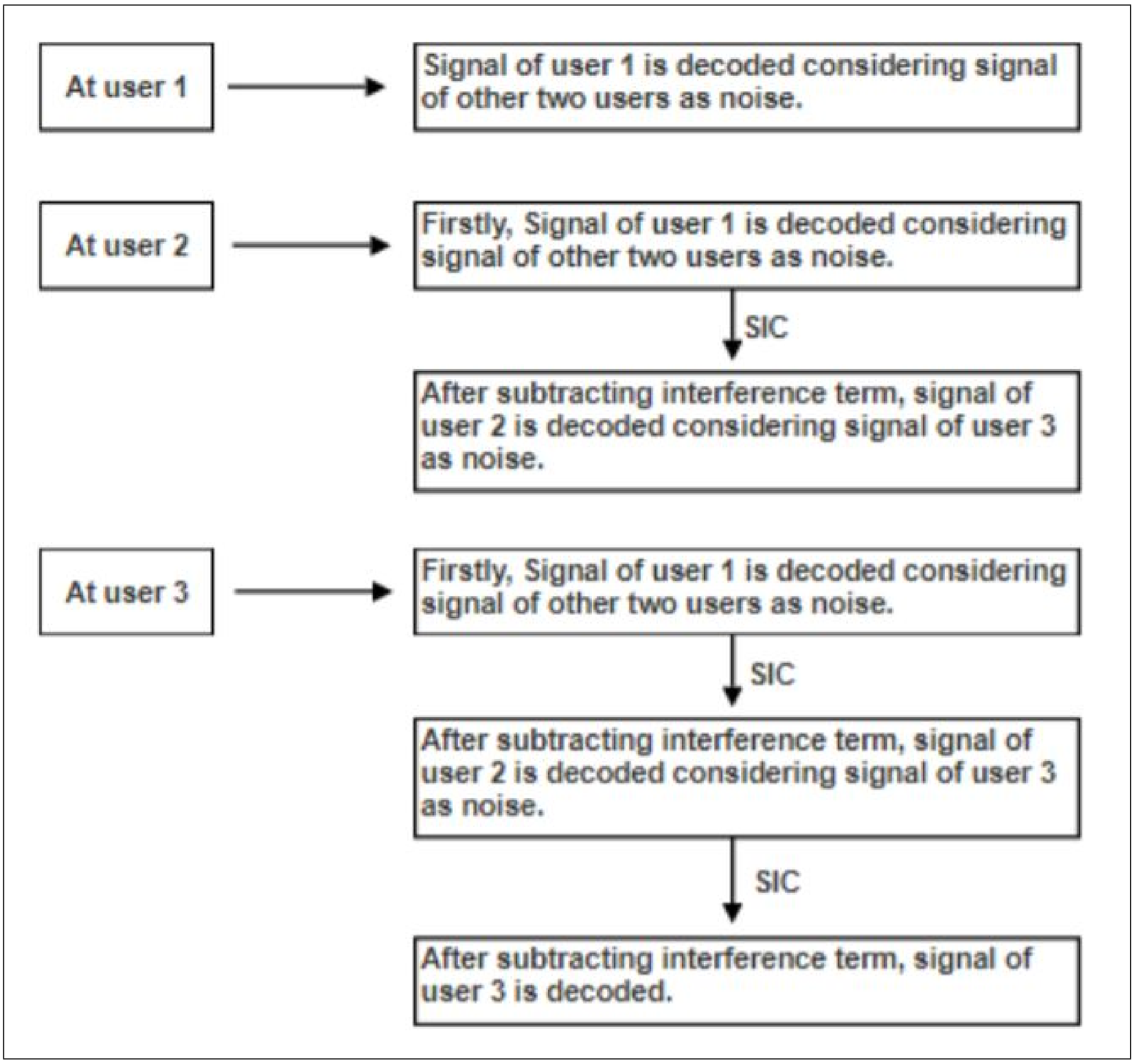

FIGURE 2.4: Block diagram of the SIC technique

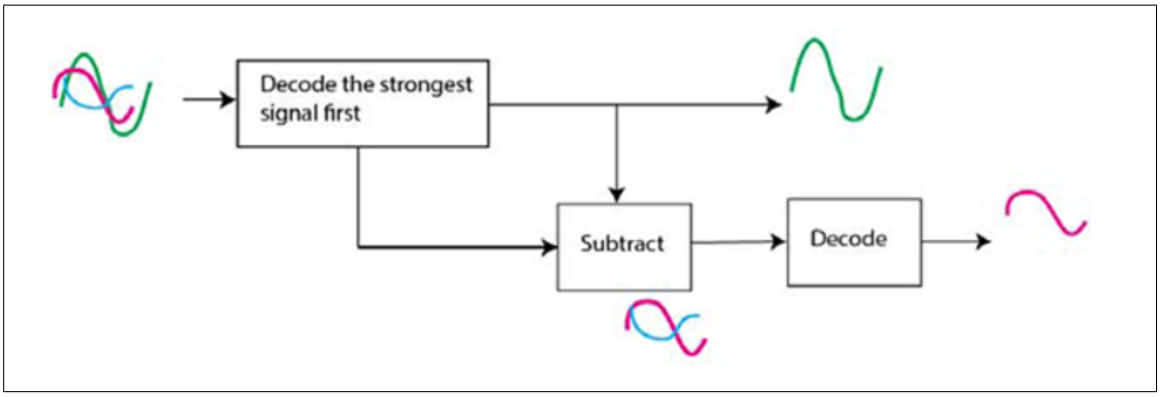

FIGURE 2.5: This is showing Successive Interference Cancellation

2.4 NOMA for Downlink

Downlink NOMA multiplexes users in the power domain, sharing the same time, code, and frequency resources. SIC is used to demultiplex these users at the receiver.

The BS superimposes the waveforms of information for its serviced users in NOMA downlink. SIC is used by each UE to detect its own signals. Figure 2.5 depicts a BS and three SIC receivers on UEs. The UE_3 is the nearest to the BS in the network, while the UE_1 is the farthest. In NOMA downlink, The UE that is farther away from the BS gets more Power, while the UE nearest to the BS receives the least power. Every UE in the network receives the same signal, which includes data for each users. Each UE begins by decoding the strongest signal and subtracting it from the signal received. Until the SIC receiver detects its own signal, the subtraction is repeated. Signals for UEs farther away will be cancelled by UEs close to the BS. Since the signal from the farthest UE makes the greatest contribution to the received signal, it will be decoded first.

The BS's transmitted signal can be written as follows:

$$x(t) = \sum_{k=1}^{K} \sqrt{P_T \alpha_k} x_k(t) \tag{2.1}$$

$$P_k = P_T \alpha_k \tag{2.2}$$

- x(t) is the OFDM waveform's individual information.
- α_k is the power allocation coefficient for the UE_k.
- The total power available at BS is P_T
- P_k is the power allocated to each UE_k

The signal got at the UE_k is

$$y_k(t) = g_k x(t) + w_k(t) \tag{2.3}$$

g_k is the channel attenuation factor for the link between the BS and the UE_K, and $w_k(t)$ is the AWGN at the UE_k with mean zero and density N_0(W/Hz).

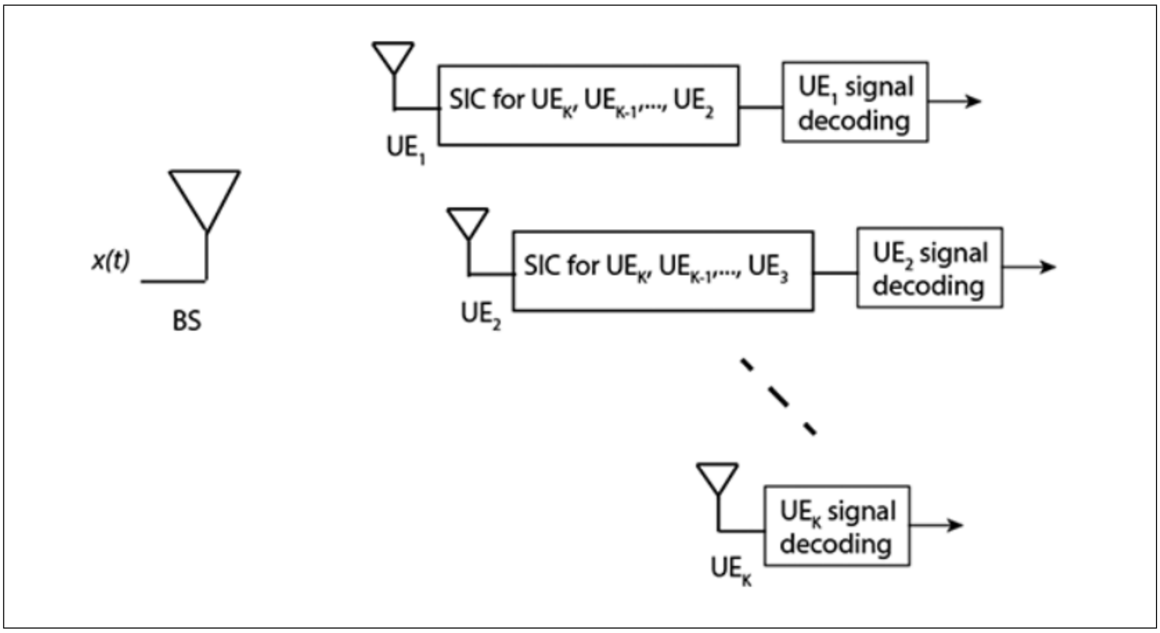

Figure 2.6: Downlink NOMA

The SNR for UE_K is written as

$$SNR_k = \frac{P_k g_k^2}{N_0 W + \sum_{i=1}^{k-1} P_i g_k^2} \tag{2.4}$$

W is the transmission bandwidth

If NOMA is used, the throughput (bps) for each UE_k is as fallows

$$R_k = W_k \log_2 \left(1 + \frac{P_k g_k^2}{\sum_{i=1}^{k-1} P_i g_k^2 + N_0 W} \right) \tag{2.5}$$

UEs in OFDMA are allocated to a subcarrier category that will receive their data. When the total power and bandwidth are evenly distributed among the UEs, the throughput of each UE for OFDMA can be written as:

$$R_k = W_k \log_2 \left(1 + \frac{g_k^2 P_k}{N_k} \right) \tag{2.6}$$

where $N = W_k N_0$ and $W_k = \frac{W}{K}$

The sum capacity of OFDMA and NOMA can be given as

$$R_T = \sum_{k=1}^{K} R_k \tag{2.7}$$

The fairness index can be written as

$$F = \frac{\left(\sum R_k\right)^2}{k \sum R_k^2} \tag{2.8}$$

2.5 NOMA for uplink

In uplink NOMA, multiple users send signals to a single BS in the same time slot and frequency band. Following that, the base station uses SIC to interpret the individual user signals from the superposed received signal, starting with the strongest and working down to the weakest users.

The implementation of NOMA on the uplink differs slightly from that on the downlink. Figure 2.6 illustrate a network that uses NOMA to multiplex K UEs in the uplink. This time, BS uses SIC to differentiate between the user signals.

The received signal by the BS in the uplink, which includes each user signals, is given as

$$y(t) = \sum_{k=1}^{K} g_k x_k(t) + w_t \tag{2.9}$$

The link between the BS and the UE_k has a channel attenuation gain of g_k, $x_k(t)$ is the information waveform for the k^{th} UE, and w(t) is the AWGN at the BS with mean zero and density N_0 (W/Hz).

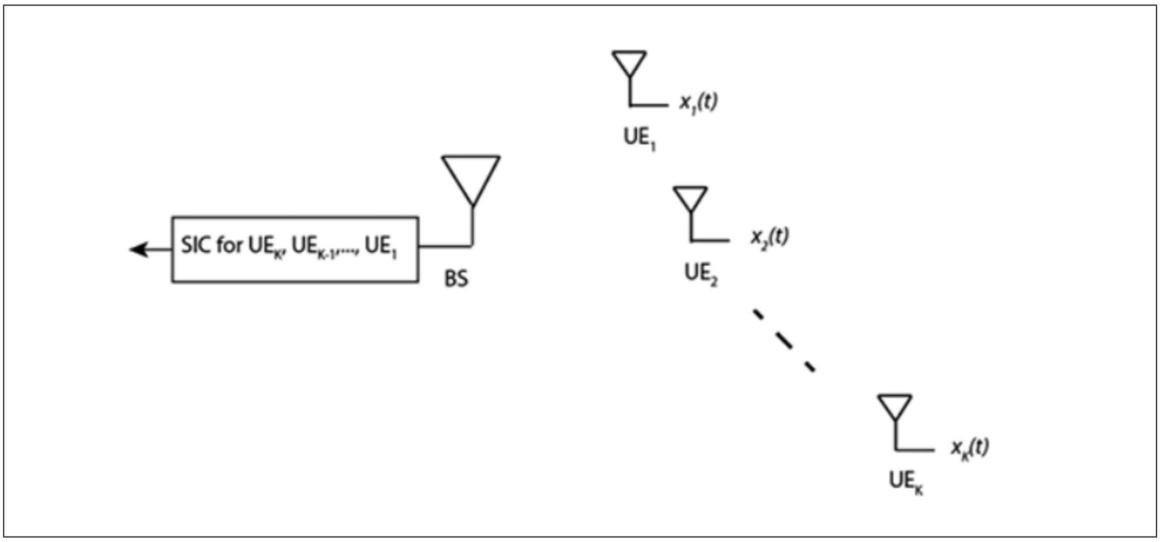

FIGURE 2.7: Uplink NOMA

As in the downlink, UEs can optimize their transmit powers based on their positions in the uplink. In this case, however, we assume that users are evenly distributed throughout the cell coverage and that the collected power levels from different users are already evenly distributed. This argument is more practical from a practical perspective, since power optimization necessitates a relationship with all UEs, which can be difficult to enforce.

Chapter 3

Imperfecteness in NOMA

In the previous pages, we've assumed that the SIC receiver has complete cancellation. In actual SIC, subtracting the decoded signal from the obtained signal without making an error is extremely difficult. The NOMA definition is applied to the SIC receiver's cancellation error in this segment.

We just look at the downlink here, but the topic can easily be expanded to include the uplink. Remember that the SIC receiver iteratively decodes the information signals to achieve the desired signal. The original individual waveform should be regenerated and subtracted from the obtained signal in SIC after decoding the signal. While it is theoretically possible to complete this method error-free, some cancellation error is expected in practice.

The SNR for the k^{th} consumer with cancellation error in downlink is written as

$$SNR_k = \frac{P_k g_k^2}{WN_0 + \epsilon \sum_{i=k+1}^{K} P_i g_k^2 + \sum_{i=1}^{k-1} P_i g_k^2} \tag{3.1}$$

The cancellation error word ϵ reflects the remainder of the signal that was cancelled. Since perfect cancellation is assumed, the 3^{rd} term in the denominator is not included in the previous section.

Chapter 4

Spectral Efficiency and Energy Efficiency

The network's throughput performance has been a focus of most previous analyses. We will look at the energy efficiency (EE) of NOMA systems as well as the spectral efficiency (SE) of NOMA systems in this section. In addition to the power consumed by the information waveform, we consider the network's static power consumption due to the power amplifiers. The information signal power and the circuit's used power (mainly by power amplifiers) can be used to calculate the total power usage at the transmitter. When the downlink is factored in, the total power absorbed by the BS becomes

$$P_{total} = P_{static} + P_T \tag{4.1}$$

where P_T denotes the total signal power and P_{static} denotes the power used by the circuitry.

The aggregate rate over the total consumed power of the base station is known as EE.

$$EE = \frac{R_T}{P_{total}} = SE\frac{W}{P_{total}}(bits/joule) \tag{4.2}$$

The (R_T/W) in bps/Hz is spectral efficiency SE. The EE and SE relationship (EE-SE) in Shannon theory ignores the circuit's power consumption and thus is monotonic, with a higher SE often resulting in a lower EE. The EE rises in the low SE region and falls in the high SE region while considering circuit power. The top of the curve represents the system's maximum EE.

For a fixed P_{total}, the relation of EE-SE is linear,with the positive slope of RT/P_{total},and an increase in SE leads to an increase in EE. NOMA is more energy efficient than OFDMA, as we'll see in the next chapter.

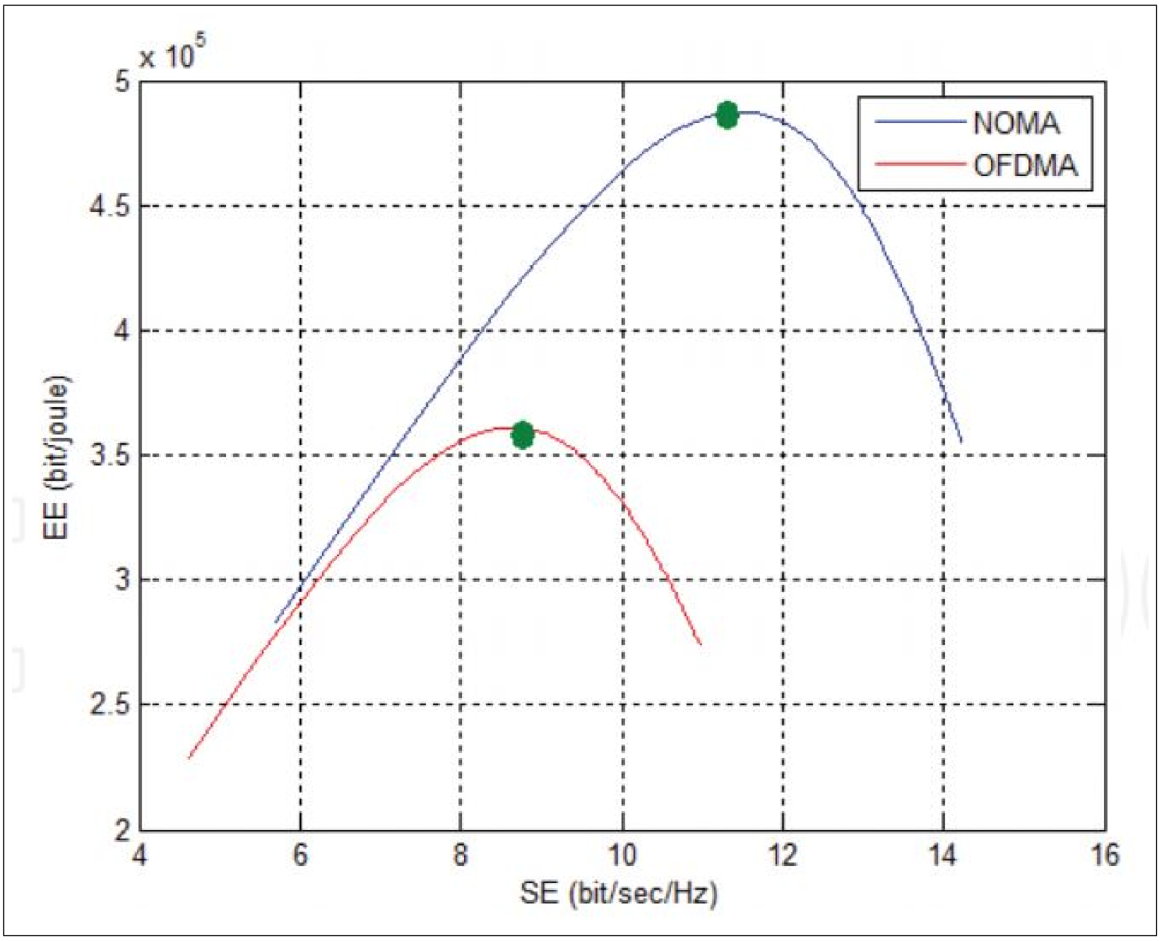

FIGURE 4.1: NOMA and OFDMA EE-SE trade-off curves

Chapter 5

Proposed System Analysis

5.1 System Model

Outage probability in cellular communications is defined as the point at which the receiver power value falls below the threshold, at which point the receiver is said to be out of the range of BS.

Consider the NOMA-based communication system depicted in Figure 5.1, in which two single antenna users U_1 and U_2 share data using a single antenna, half-duplex, DF relay r. The communication protocol is divided into two stages, as shown below.

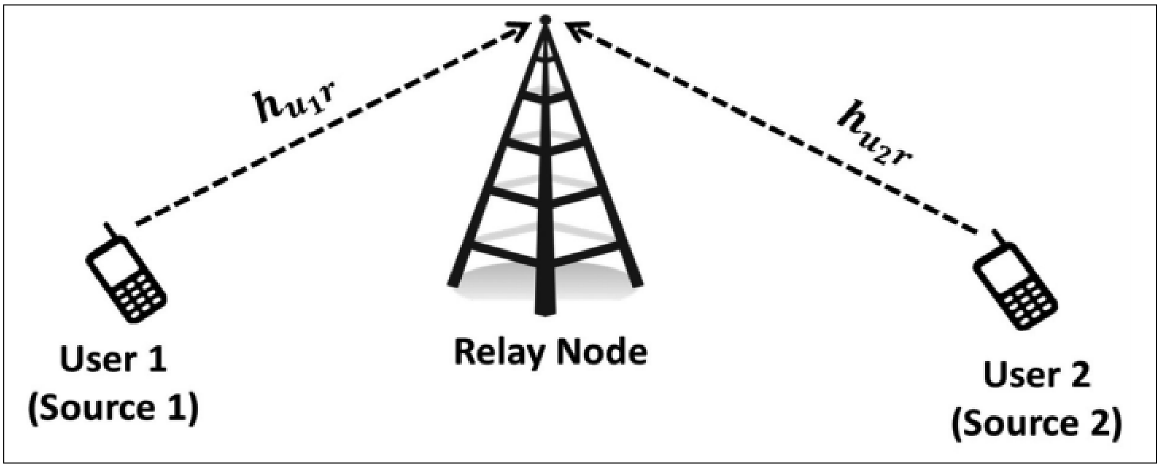

FIGURE 5.1: Phase 1: Noma Uplink Phase, the user 1 is nearer user

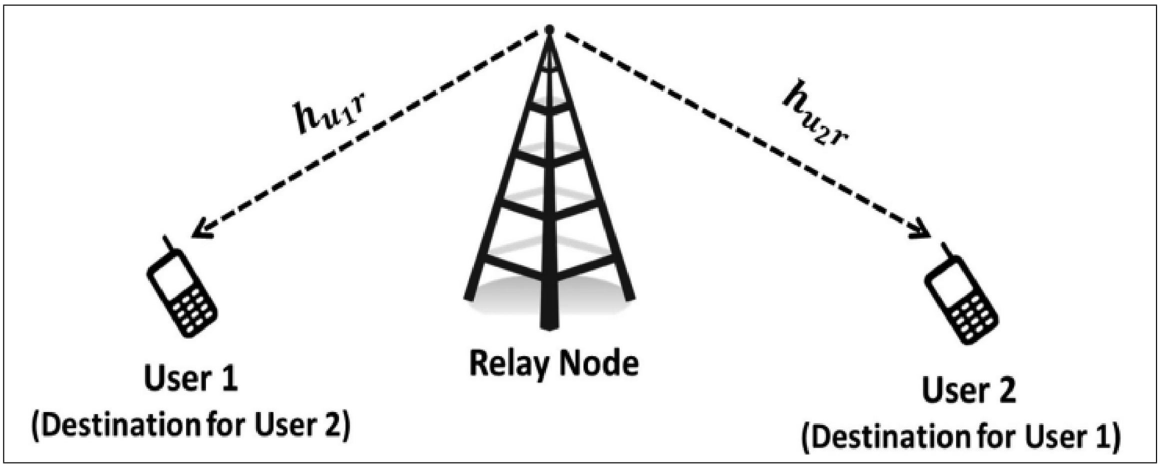

FIGURE 5.2: Phase 2: Relay broadcast phase, the user 1 is nearer user

Phase 1:

Users u_1 and u_2 send their respective symbols x_1 and x_2 to the relay at the same time, as shown in Figure 5.1. Provided that there is no direct path between u_1 and u_2, the received symbol y_r at the relay, which is a superposition of the signals transmitted by users, is given as

$$y_r = \sqrt{\alpha_1 P_s h_{u_1r}} x_1 + \sqrt{\alpha_2 P_s h_{u_2r}} x_2 + n_r \tag{5.1}$$

where $\alpha_1 P_s$ and $\alpha_2 P_s$ are the powers allocated to u_1 and u_2, with $0 < \alpha_1, \alpha_2 < 1$and $\alpha_1 + \alpha_2 = 1$

Total power is needed in a hybrid NOMA system to handle inter-cell interference while also limiting inter-pair interference.

The quantity $h_{u_ir} \sim \zeta N(0, \sigma^2_{u_ir})$ denotes the Rayleigh faded channel coefficient for the link $u_i - r$ i$\in$ {1, 2} . Without sacrificing generality, u_1 is a strong close user, and u_2 is a weak far user, according to our assumptions such that $\sigma^2_{u_1r} \geq \sigma^2_{u_2r}$. The relay decodes the symbol x_1 from the stronger consumer u_1 first, disregarding the signal from u_2. The intervention from u_1 is then cancelled to decode the symbol x_2 belonging to u_2. As a result, the SNRs for decoding x_1 and x_2 at the relay are

$$\gamma^r_{x_1} = \frac{\alpha_1 \rho_s \beta_{u_1r}}{\alpha_2 \rho_s \beta_{u_2r} + 1} \tag{5.2}$$

where $\rho = \frac{P_s}{\sigma^2}$, the channel gain coefficients are denoted by $\beta_{u_1r} =\mid h_{u_1r} \mid^2$, $\beta_{u_2r} =\mid h_{u_2r} \mid^2$ and distributed as

$$f_{\beta_{u_ir}}(x) = \frac{1}{\sigma^2_{u_ir}} \exp\left(-\frac{x}{\sigma^2_{u_ir}}\right), i \in \{1,2\} \tag{5.3}$$

It can be noted that if the transmission rates of users u_1, u_2 are restricted to be lower than $\log_2\left(1+\alpha_2\rho_s\beta_{u_2r}\right)$, $log_2\left(1+\frac{\alpha_1\rho_s\beta_{u_1r}}{\alpha_2\rho_s\beta_{u_2r}+1}\right)$
respectively, The relay is assumed to have successfully decoded the corresponding symbols.

Phase 2:

As shown in Figure 5.2, the relay linearly combines u_1 and u_2 decoded symbols and broadcasts the superimposed signal at total power P_r to u_1 and u_2. The obtained symbols at users u_1 and u_2 can be expressed as follows, assuming channel reciprocity.

$$y_{u_i} = h_{u_ir}\left(\sqrt{\alpha_3 P_r}x_1 + \sqrt{\alpha_4 P_r}x_2\right), i = 1,2 \tag{5.4}$$

The power factors for symbols x_1 and x_2, which correspond to transmission to users u_1 and u_2, respectively, are $\alpha_3, \alpha_4 > 0$ with $\alpha_3 + \alpha_4 = 1$. The interference corresponding to their transmitted symbols x_1 and x_2 in the first step is then cancelled by users u_1 and u_2 from their respective received signals y_{u_1} and y_{u_2}. As a result, the SNRs for decoding x_1 at u_2 and x_2 at u_1 are:

$$\gamma^{u_2}_{x_1} = \alpha_3\rho_r\beta_{u_2r}\gamma^{u_1}_{x_2} = \alpha_4\rho_r\beta_{u_1r} \tag{5.5}$$

Where $\rho_r = \frac{P_r}{\sigma^2}$. Thus the achievable rates for u_1 and u_2 are obtained as

$$C_{u_1} = \frac{1}{2}\log_2\left(1 + min\left(\alpha_2\rho_s\beta_{u_2r}, \alpha_4\rho_r\beta_{u_1r}\right)\right) \tag{5.6}$$

$$C_{u_2} = \frac{1}{2}\log_2\left(1 + min\left(\frac{\alpha_1\rho_s\beta_{u_1r}}{\alpha_2\rho_s\beta_{u_2r}+1}, \alpha_3\rho_r\beta_{u_2r}\right)\right) \tag{5.7}$$

5.2 Performance analysis

5.2.1 System outage probability

Let's call the appropriate data rates for users u_1 and u_2 are $\tilde{R}_1$ and $\tilde{R}_2$, respectively.

As a result, the system OP, which is defined as the likelihood that at least one of the users is down, can be calculated as follows:

$$P(\xi) = 1 - P\left(C_{u_1} \geq \tilde{R}_1, C_{u_2} \geq \tilde{R}_2\right) \tag{5.8}$$

where the quantities R_1, R_2 and q_1 are defined as

$$R_1 = 2^{2\tilde{R}_1} - 1, R_2 = 2^{2\tilde{R}_2} - 1, q_1 = max\left(\frac{R_2}{\alpha_3\rho_r}, \frac{R_1}{\alpha_2\rho_s}\right) \tag{5.9}$$

are constant and

$$\psi = \frac{\alpha_1\rho_s\beta_{u_1r} - R_2}{\alpha_2 R_2\rho_s} \tag{5.10}$$

is a function of β_{u_1r}. It's worth mentioning that the overall failure probability above represents the fact that a relay or uplink outage affects the downlink user's decoding accuracy. As a result, both uplink and downlink transmission are included in the full outage Probability study. The expression in (5.8) can be simplified as follows:

$$P(\xi) = P\left(\xi|\psi < q_1\right)P\left(\psi < q_1\right) + P\left(\xi|\psi \geq q_1\right)P\left(\psi \geq q_1\right)$$

$$P(\xi) = 1 - P\left(q_1 \leq \beta_{u_2r} \leq \psi, \beta_{u_1r} \geq q_2\right) \tag{5.11}$$

where the quantity q_2 is defind as

$$q_2 = max\left(\frac{\alpha_2 R_2^2}{\alpha_1\alpha_3\rho_r} + \frac{R_2}{\alpha\rho_s}, \frac{R_1R_2 + R_2}{\alpha\rho_s}, \frac{R_1}{\alpha_4\rho_r}\right) \tag{5.12}$$

which is contant. Since $\psi = \frac{\alpha_1\rho_s\beta_{u_1r} - R_2}{\alpha_2 R_2\rho_s}$ is a function of β_{u_1r} the OP in (5.12) is averaged with respect to β_{u_1r} to yield the expression for the average system OP as

$$\begin{aligned} P(\xi) &= 1 - \frac{1}{\sigma^2_{u_1r}} \int_{q_2}^{\infty} \left(\frac{1}{\sigma^2_{u_1r}} \int_{q_1}^{\psi} e^{\frac{-\beta_{u_2r}}{\sigma^2_{u_2r}}} d\beta_{u_2r} \right) e^{\frac{-\beta_{u_1r}}{\sigma_{u_1r}}} d\beta_{u_1r} \\ &= 1 - \frac{1}{\sigma^2_{u_1r}} \int_{q_2}^{\infty} \left(e^{\frac{-q_1}{\sigma^2_{u_2r}}} - e^{\frac{-\psi}{\sigma^2_{u_2r}}} \right) e^{\frac{-\beta_{u_1r}}{\sigma_{u_1r}}} d\beta_{u_1r} \\ &= 1 - e^{-\left(\frac{q_2}{\sigma^2_{u_1r}} + \frac{q_1}{\sigma^2_{u_2r}} \right)} + \frac{e^{-\left(\frac{q_2}{\sigma^2_{u_1r}} + \frac{\alpha_1 q_2}{\alpha_2 R_2 \sigma^2_{u_2r}} - \frac{1}{\alpha_2 \rho_s \sigma^2_{u_2r}} \right)}}{1 + \frac{alpha_1 \sigma_{u_1r}}{\alpha_2 R_2 \sigma^2_{u_2r}}} \end{aligned} \tag{5.13}$$

where the terms q_1 and q_2 are defined in (5.9) and (5.12), respectively.

The next result shows an intriguing behavior of the system's OP at high SNR.

$$\begin{aligned} P(\xi) &= 1 - \frac{1}{\sigma^2_{u_1r}} \int_{q_2}^{\infty} \left(\frac{1}{\sigma^2_{u_1r}} \int_{q_1}^{\psi} e^{\frac{-\beta_{u_2r}}{\sigma^2_{u_2r}}} d\beta_{u_2r} \right) e^{\frac{-\beta_{u_1r}}{\sigma_{u_1r}}} d\beta_{u_1r} \\ &= 1 - \frac{1}{\sigma^2_{u_1r}} \int_{q_2}^{\infty} \left(e^{\frac{-q_1}{\sigma^2_{u_2r}}} - e^{\frac{-\psi}{\sigma^2_{u_2r}}} \right) e^{\frac{-\beta_{u_1r}}{\sigma_{u_1r}}} d\beta_{u_1r} \\ &= 1 - e^{-\left(\frac{q_2}{\sigma^2_{u_1r}} + \frac{q_1}{\sigma^2_{u_2r}} \right)} + \frac{e^{-\left(\frac{q_2}{\sigma^2_{u_1r}} + \frac{\alpha_1 q_2}{\alpha_2 R_2 \sigma^2_{u_2r}} - \frac{1}{\alpha_2 \rho_s \sigma^2_{u_2r}} \right)}}{1 + \frac{\alpha_1 \sigma^2_{u_1r}}{\alpha_2 R_2 \sigma^2_{u_2r}}} \end{aligned} \tag{5.14}$$

Proposition: At high SNR, the system OP $P(\xi)$ is not affected by the SNR terms ρ_s andρ_r , the stronger user minimum QoS rate $\tilde{R}_1$ and relay power factors α_3 or α_4

Proof: In (5.14), q_1 and q_2 are functions the SNR terms ρ_s and ρ_r. Therefore, at high SNR, we can use the approximation $1 - e^{-x} = x, x << 1$. Now the expression (5.14) is written as

$$P(\xi) = \frac{q_2}{\sigma^2_{u_1r}} + \frac{q_1}{\sigma^2_{u_2r}} + \frac{1}{1 + \frac{\alpha_1 \sigma^2_{u_1r}}{\alpha_2 R_2 \sigma^2_{u_2r}}} + \frac{\frac{1}{\alpha_2 \rho_s \sigma^2_{u_2r}} - \frac{q_2}{\sigma^2_{u_1r}} - \frac{q_2 \alpha_1}{\alpha_2 R2 \sigma^2_{u_2r}}}{1 + \frac{\alpha_1 \sigma^2_{u_1r}}{\alpha_2 R_2 \sigma^2_{u_2r}}} \tag{5.15}$$

where $\frac{1}{1+\frac{\alpha_1 \sigma^2_{u_1r}}{\alpha_2 R_2 \sigma^2_{u_2r}}}$ is a constant and the denominator of all other terms in (5.15) is a function of the SNR terms ρ_s and ρ_r. As a result, except for $\frac{1}{1+\frac{\alpha_1 \sigma^2_{u_1r}}{\alpha_2 R_2 \sigma^2_{u_2r}}}$, all of the terms in (5.15) can be ignored at high SNR. The expression for the system's asymptotic outage probability is now written as

$$P(\xi) = \frac{\alpha_2 R_2 \sigma^2_{u_2r}}{\alpha_1 \sigma^2_{u_1r} + \alpha_2 R_2 \sigma^2_{u_2r}} \tag{5.16}$$

which is unaffected by SNR terminology, relay power variables, or a stronger user QoS constraint. The proof is now complete.

5.2.2 NOMA Relaying System (Full Duplex and Half Duplex)

Half duplex data flow is bidirectional, but only in one direction at a time. The data flow in Full Duplex is bidirectional and simultaneous. We may use FD/HD relaying for close users to increase the efficiency of far users. The FD NOMA converges to an error floor, yielding a diversity order of zero. The FD-NOMA outperforms the HD-NOMA in terms of OP in the low SNR region but in the high SNR region HD-NOMA is superior. Based on the OP we measured, we also look at the system throughput in delay-limited transmission.

We'll look at an FD cooperative NOMA system with one source, the BS, that wants to communicate with far user U_2 with the help of close user U_1, as shown in Figure 5.3. User relaying is defined as U_1 decoding and forwarding information to U_2 using the decode-and-forward (DF) protocol. The U_1 node has one transmit and one receive antenna to allow FD communication, while the BS and U_2 are single antenna nodes. It's worth noting that U_1 can switch between FD and HD mode.

Both wireless links in the network are assumed to be non-selective block Rayleigh fading with additive white Gaussian noise of mean power N_0..

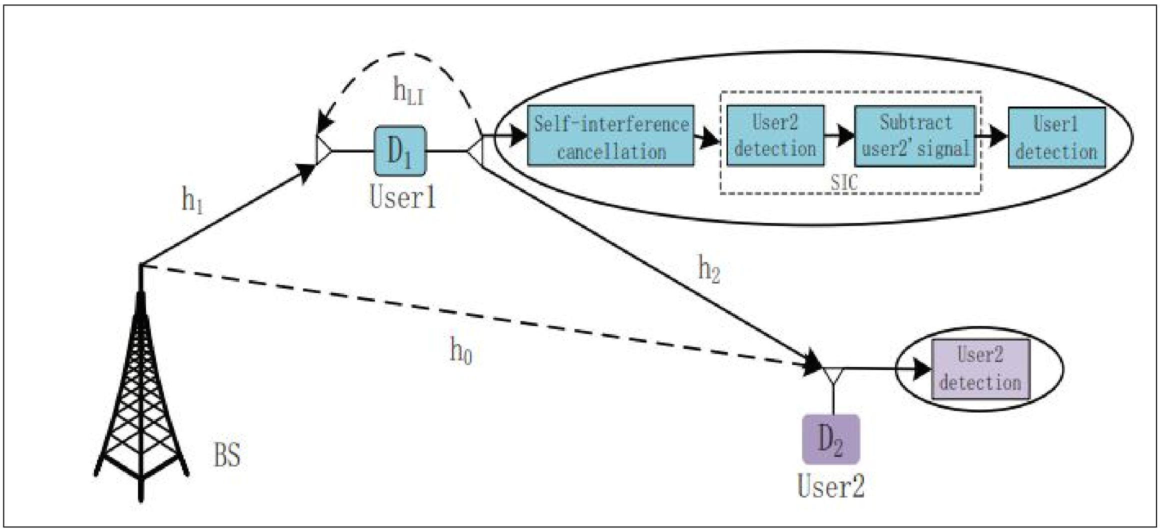

Figure 5.3: User1 is closer to BS in a downlink FD/HD cooperative NOMA system model.

Chapter 6

Simulation and Results

6.1 For downlink, rate pairs with OFDMA and NOMA

For the purposes of this discussion, we'll assume the two users in the network, and we'll look at the upper and lower bounds of the feasible rate regions for these two users. Both users are at the same distance from the base station in a symmetric downlink channel.

$SNR1 = SNR2 = 10dB$ The boundaries of the achievable rate regions R_1 and R_2 for NOMA and OFDMA are shown in Figure 6.1. Except at the corners stages(where the rates are equal to the single user capacities), as shown in Figures 6.1 and 6.2, NOMA achieves higher rate pairs than OFDMA . Both NOMA and OFDMA users experience 1.6 bps/Hz throughputs when the fairness is high. When the fairness is lower, however, NOMA's sum capacity and individual throughputs are higher.

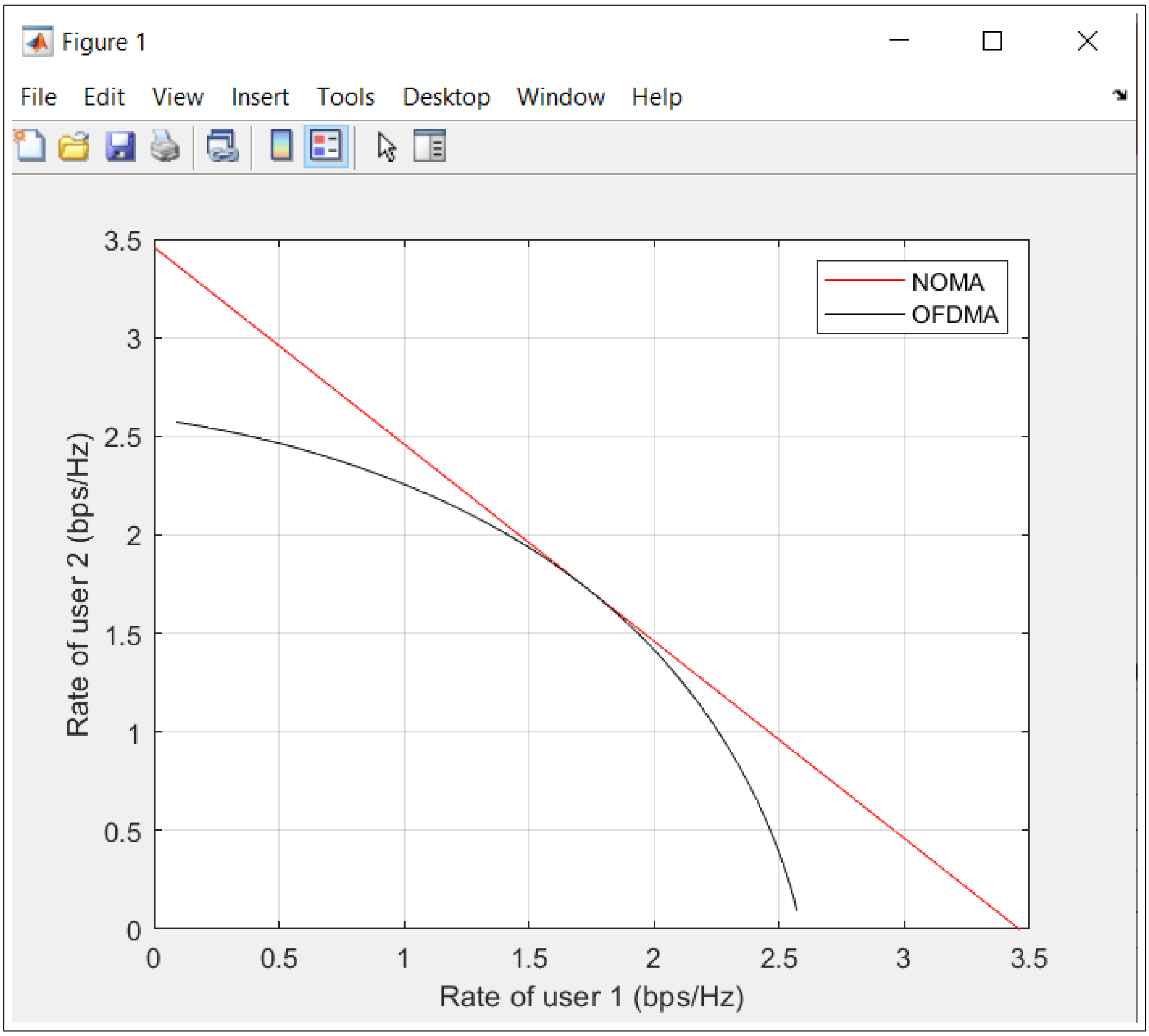

FIGURE 6.1: For downlink, rate pairs with NOMA and OFDMA $SNR_1 = 10dB$ and $SNR_2 = 10dB$

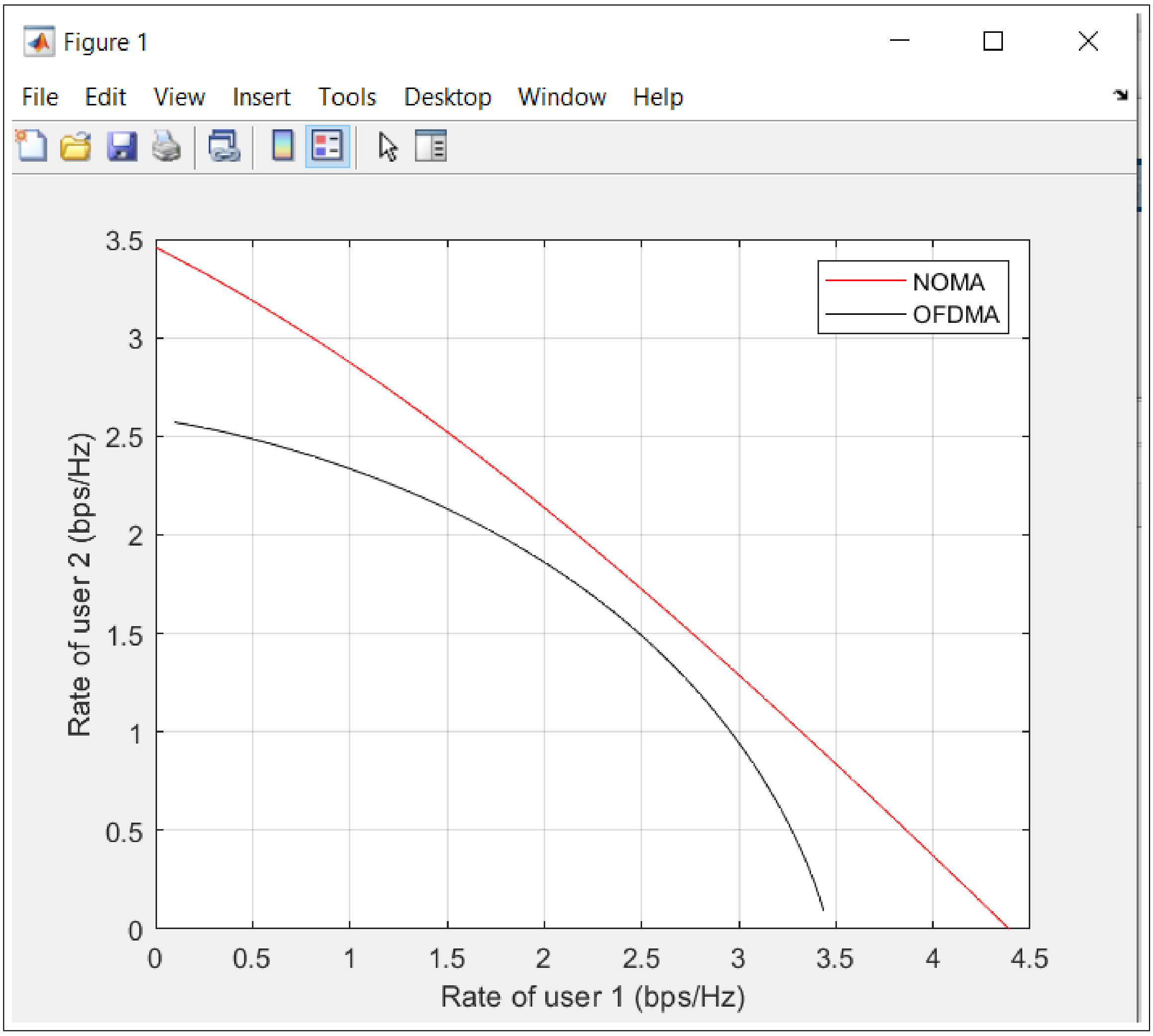

FIGURE 6.2: For downlink, rate pairs with NOMA and OFDMA $SNR_1 = 20dB$ and $SNR_2 = 10dB$

6.2 SE-EE trade-off with NOMA

The EE and SE of NOMA and OFDMA are compared here. We'll take a look at the downlink once more. The system bandwidth W = 5 MHz. The channel gain for UE_1 is taken as g_2^1 =-120dB and for UE_2 is taken as g_2^2 =-140dB, Noise density $N_0 = 150dBW/Hz$. The BS's static power consumption is assumed to be P_{static} = 100W. Figure 6.3 depicts the obtained EE-SE curves for this setup. The NOMA system has a higher EE and SE than the OFDMA system. When P_T is at 17 W and 18 W, respectively, NOMA and OFDMA reach their top-points. At this stage, both systems have reached their maximum EE. At Top point and beyond, NOMA clearly outperforms OFDMA in both EE and SE.

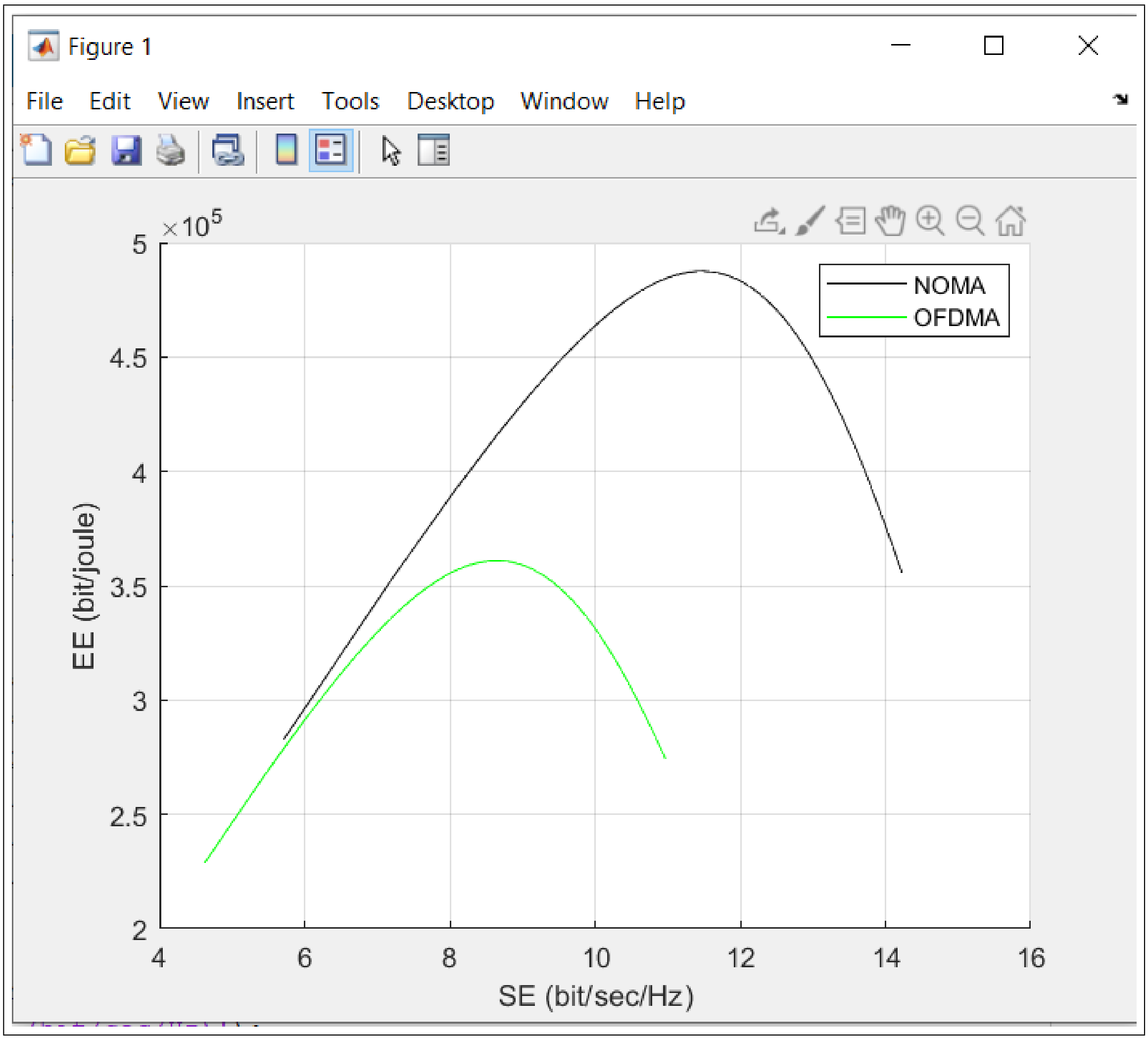

FIGURE 6.3: NOMA and OFDMA EE-SE trade-off curves

6.3 Outage Probability

6.3.1 Outage probability for two users

This section both confirms and demonstrates the system's success, as well as the various analytical results obtained in the previous sections. The parameters are taken as $\sigma^2_{u_2r} = 2, \alpha_1 = 0.2, \alpha_2 = 0.8, \rho_r = \rho_s, \tilde{R}_1 = 3$ and $\tilde{R}_2 = 0.5$ bps/Hz and $k^u = r^u = 60$, Figure 6.4 depicts the system's outage Probability versus SNR for two users. The user1 is the one who is closest to BS.

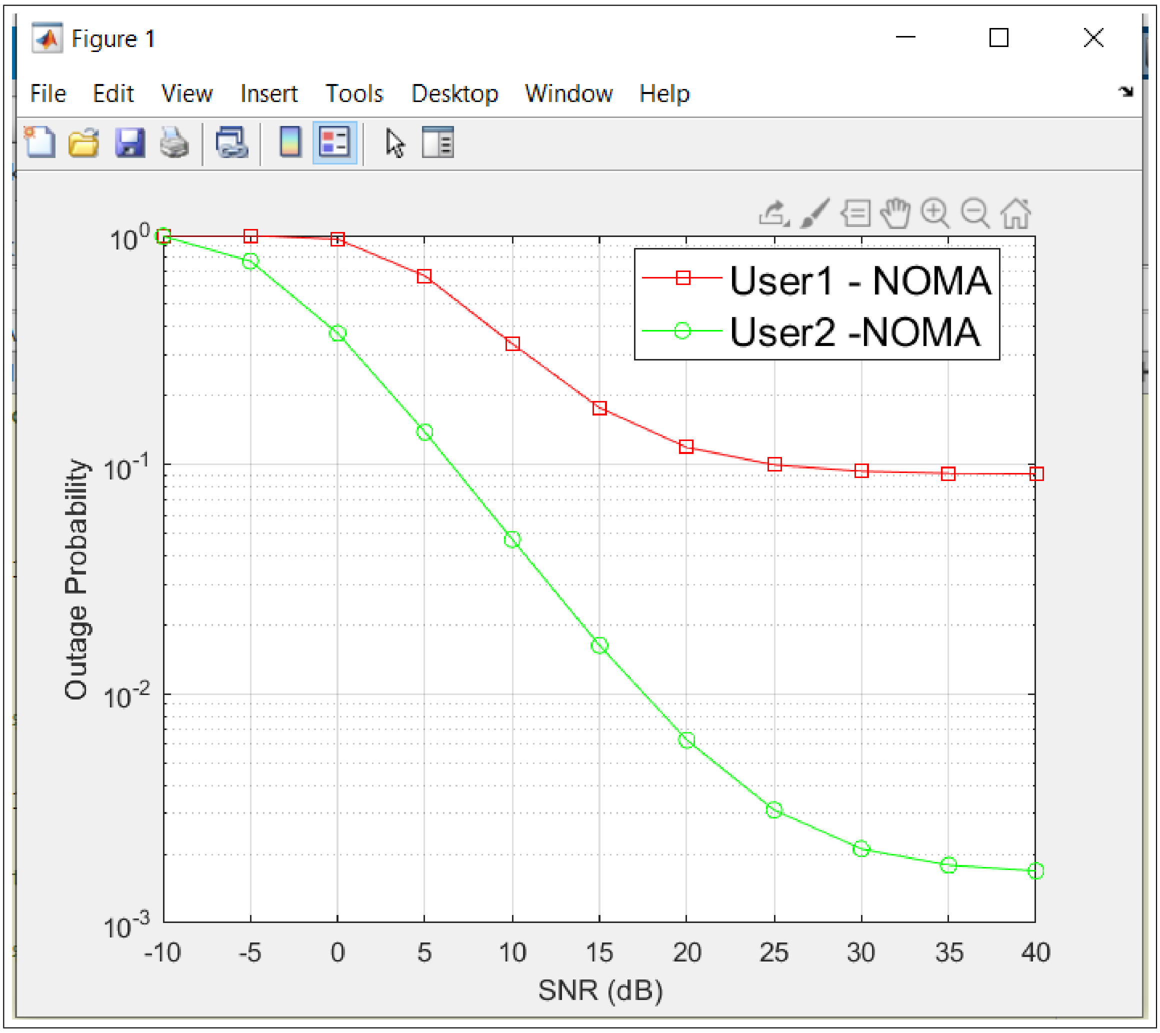

FIGURE 6.4: For two users, OP vs SNR results

6.3.2 Outage probability for three users

The various parameters for this plot are fixed as $\sigma^2_{u_2r} = 2, \alpha_1 = 0.1, \alpha_2 = 0.3, \alpha_3 = 0.6, \rho_r = \rho_s, \tilde{R}_1 = 1, \tilde{R}_2 = 0.5$ and $\tilde{R}_3 = 0.4$ bps/Hz and $k^u = r^u = 60$, Figure 6.5 depicts the system's OP versus SNR for three users. User1 is the closest user, while user3 is the furthest away.

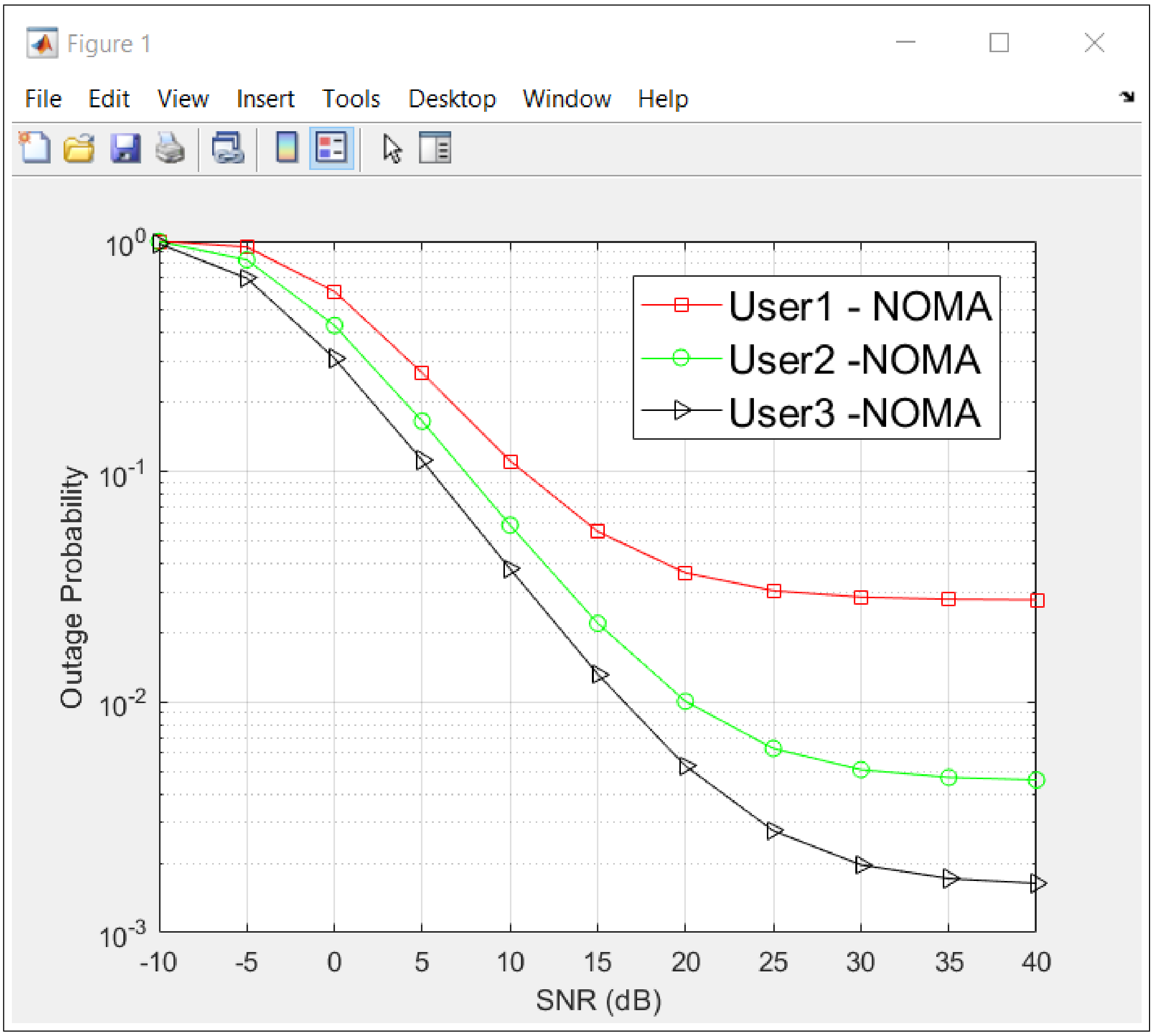

FIGURE 6.5: For three users, OP vs SNR results

6.3.3 Outage probability for four users

The various parameters are fixed as $\sigma^2_{u_2r} = 2, \alpha_1 = 0.1, \alpha_2 = 0.2, \alpha_3 = 0.3, \alpha_4 = 0.4, \rho_r = \rho_s, \tilde{R}_1 = 1, \tilde{R}_2 = 0.5, \tilde{R}_3 = 0.4$ and $\tilde{R}_4 = 0.3$ bps/Hz and $k^u = r^u = 60$, Figure 6.6 shows the OP of the system versus SNR for four users together. User1 is the closest user, followed by user2, user3, and finally user4.

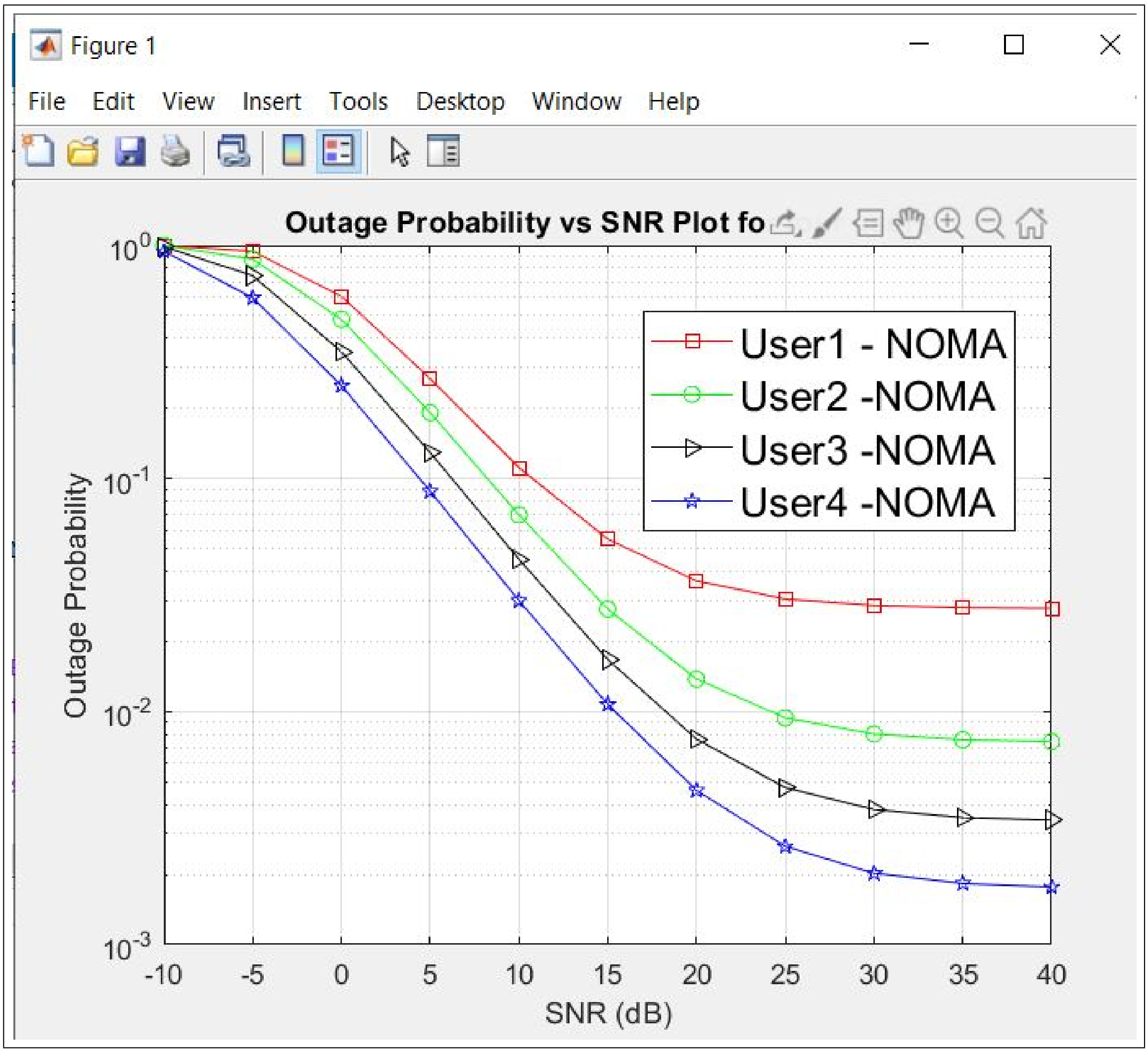

FIGURE 6.6: For four users, OP vs SNR results

6.3.4 Outage probability for five users

The various parameters for the plot are $\sigma^2_{u_2r} = 2, \alpha_1 = 0.1, \alpha_2 = 0.15, \alpha_3 = 0.2, \alpha_4 = 0.25, \alpha_5 = 0.3, \rho_r = \rho_s, \tilde{R}_1 = 1, \tilde{R}_2 = 0.5, \tilde{R}_3 = 0.4, \tilde{R}_4 = 0.35$ and $\tilde{R}_5 = 0.3$ bps/Hz and $k^u = r^u = 60$, Figure 6.7 depicts the system's OP versus SNR for a group of five users. User1 is the closest user, followed by user2, user3, user4, and user5.

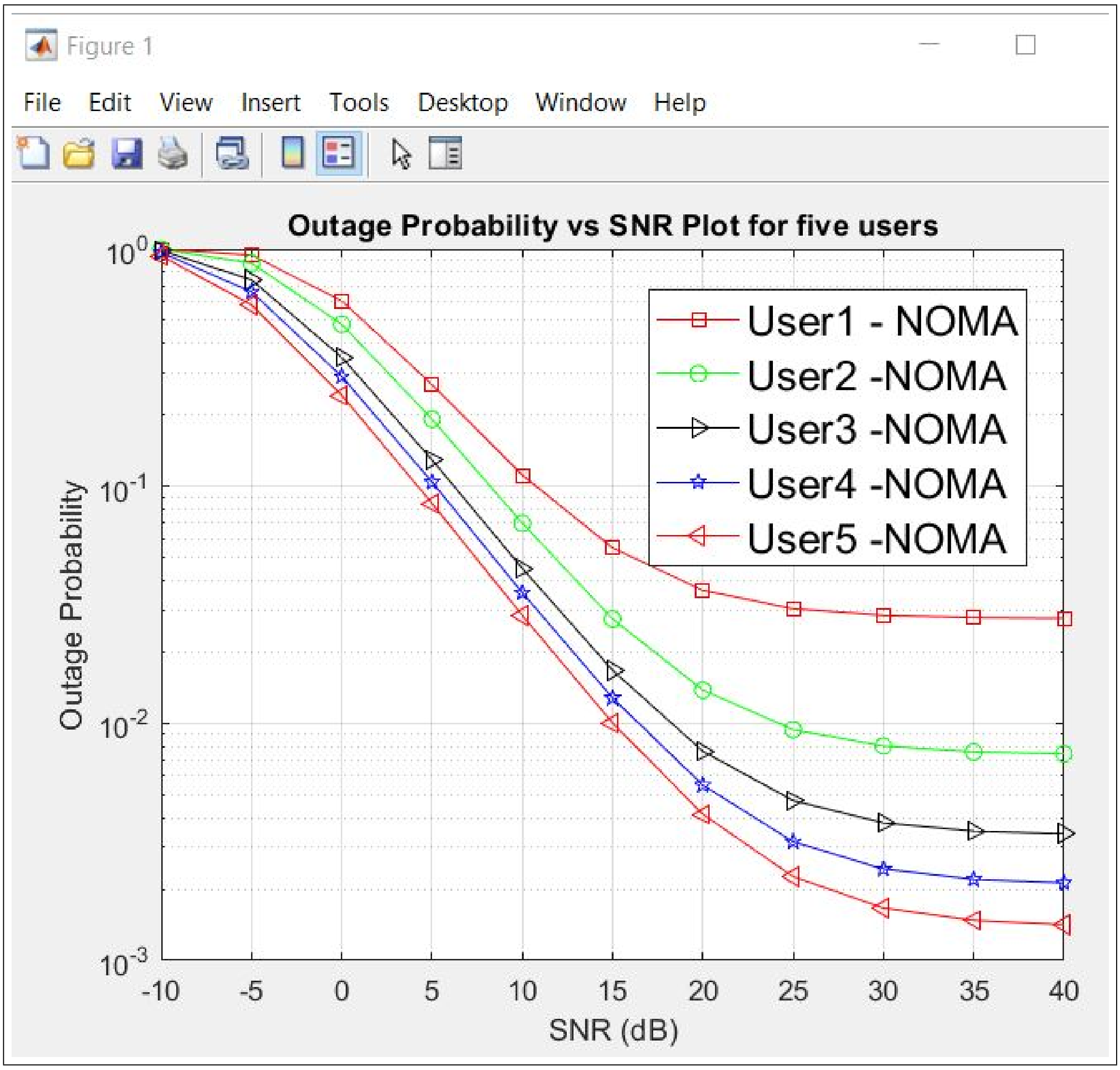

FIGURE 6.7: For four users, OP vs SNR results

6.3.5 OP for two users for HD/FD NOMA

This section validates the behaviour of outage probability vs SNR for the HD NOMA and FD NOMA. various parameters are $\sigma^2_{u_2r} = 2, \alpha_1 = 0.2, \alpha_2 = 0.8, \rho_r = \rho_s, \tilde{R}_1 = 3$ and $\tilde{R}_2 = 0.5$ bps/Hz and $k^u = r^u = 60$, Figure 6.8 shows the outage probability of the system versus SNR for two users.

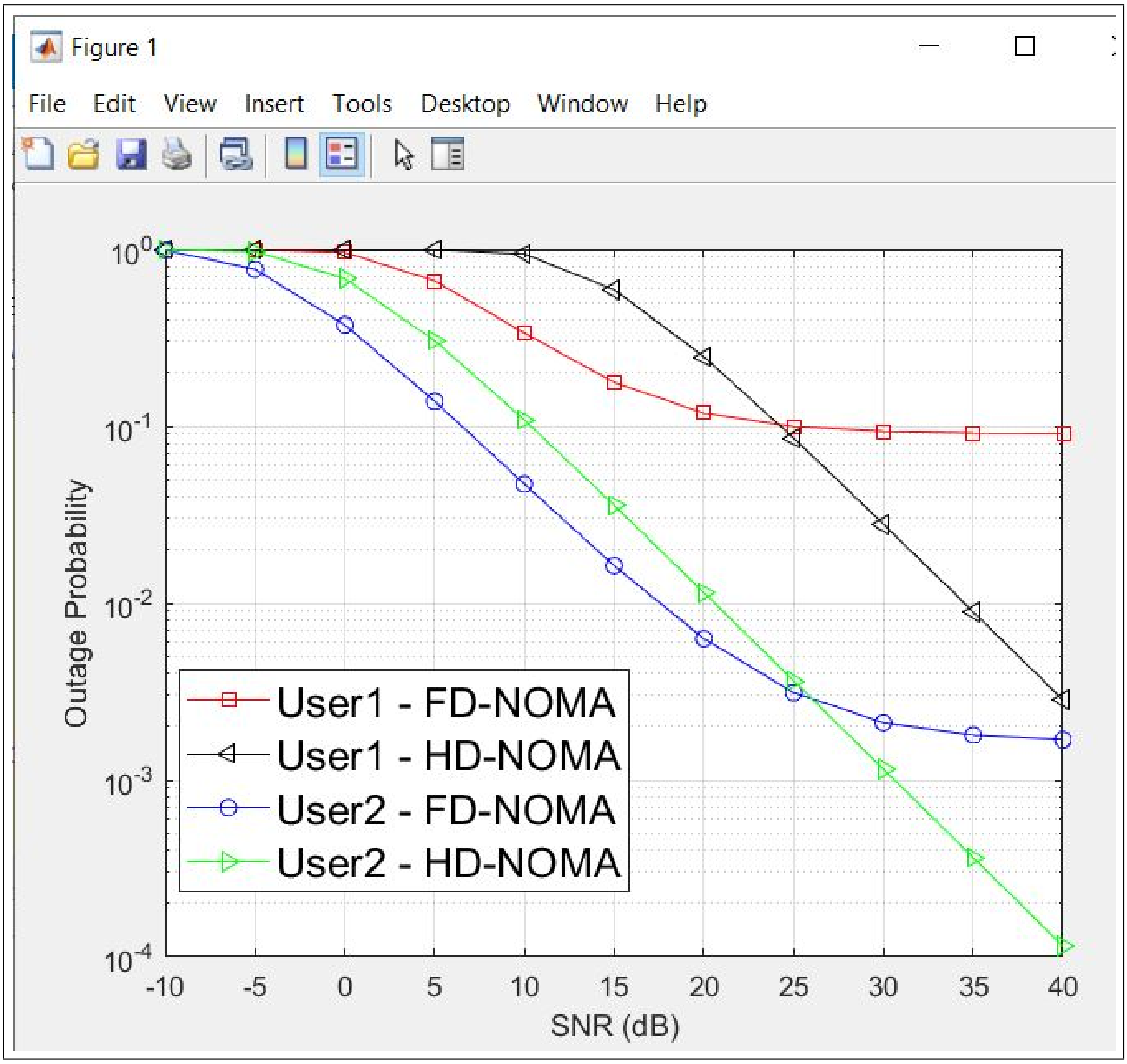

FIGURE 6.8: For HD NOMA and FD NOMA, OP vs SNR output for two users

Chapter 7

Conclusion and future research scope

7.1 Conclusion

We've gone through the basics of NOMA and seen how it outperforms traditional OFDMA in terms of Sum Capacity, Energy Efficiency, and Spectral Efficiency. We've also spoken about how imperfection at the SIC receiver affects device efficiency. NOMA remains the best choice for potential 5G networks due to its unique features. Figures 6.4 and 6.5 depict the system's outage probability vs SNR for two and three users, respectively. The simulated and empirical values derived from outage Probability expressions are nearly identical.It's also observed that at high SNR, the outage Probability curve reaches the asymptotic floor. It can also be shown that as the value of $\beta_{u_1 r}$ increases, the value of this asymptotic floor decreases monotonically.

The outage Probability of two users versus SNR for HD/FD NOMA is plotted in Figure 6.8. In the presence of low SNR, the outage output of FD NOMA outperforms that of HD NOMA. This is due to the fact that LI is not a significant impact factor for FD NOMA in the low SNR region. In the high SNR region, the asymptotic curves closely resemble the exact performance curves. It is demonstrated that error floors occur in FD NOMA and that zero diversity order can be obtained. This is due to the fact that in FD NOMA, there is loop interference. In the high SNR region, the HD NOMA outperforms the FD NOMA.

7.2 Future Scope

However, there are still some obstacles to overcome in order to successfully introduce NOMA. First of all, to running SIC algorithms, particularly for a large number of users at high data rates, necessitates a lot of computing power.

Second, power allocation optimization remains as a challenging problem, particularly when the UEs are moving fast in the networks

Will explore outage probability for more than five users.

Finally, cancellation errors, which are common in fading channels, are vulnerable to SIC receivers. It can be combined with other diversity techniques like multiple-input-multiple-output (MIMO) or coding schemes to increase reliability and reduce decoding errors. MIMO for NOMA has been implemented in recent works.

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