ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTING

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Performance Evaluation for Down link Nonorthogonal Multiple Access in 5G Network

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A Thesis Submitted to ASTU in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Electrical Communication Engineering

June 27, 2019

Adama, Ethiopia

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Approval by Board of Examiners

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Declaration

I declare that this thesis is my original work, it has not been previously submitted to this University or to any other University for a degree or other qualification, and all sources of materials used for the thesis have been fully referenced.

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ABSTRACT

Non-orthogonal multiple access (NOMA) as one of the upcoming and promising multiple access technologies has a significant impact on the development of the 5G wireless communication systems, which states in. Non-orthogonal multiple access (NOMA) is a promising technique for the fifth generation (5G) mobile communication due to its capability of achieving high spectral efficiency and high data rate, SE, EE, fairness, and throughput varies as user location varies in a silgle cell BS. NOMA has been much studied in the literature from an information-theoretic perspective in terms of data rate capacity. A systematic approach to analyze the differences between NOMA and OMA is provided as well. Non-orthogonal multiple access can support more connections than other systems and improve allocation of system capacity, SE, EE, throughput and fairness.

Basically, NOMA schemes consist of two parts: power-domain multiplexing and code-domain multiplexing. The basic idea of NOMA for multiple access is to introduce different power allocation and channel assignment, which the previous generation of mobile networks have been relying only on the same time/frequency/code domain. Totally, Optimum NOMA system capacity and efficiency acheived. Down link power domain adaptive non-orthogonal multiple access (NOMA) enables power-domain multiplexing using successive interference cancellation (SIC) algorithm to cancel the interference of another user and noise propagating through channel.

All of the above were used Okumura Hata model to model or estimate the channel between base station and random location in single cell down link power domain adaptive NOMA. The system will optimize channel assignment by assuming power allocation constant and vice versa. NOMA were optimized through data rate, SE, EE, throughput, and fairness efficient network. Then, energy of NOMA were 27.6 percent saved and the SE of NOMA were 92.88 percent spectral efficient and 48.9 percent optimum data rate achieved in NOMA than OMA than previous network generation all using different parameter in MAT LAB simulation. Therefore, the better performance power domain down link adaptive NOMA 5G network achieved in final result. The future work is included at the end of this thesis.

Index Terms—Non-orthogonal multiple access, power allocation and optimization, successive interference cancellation, , sum rate, fairness, spectral, and energy efficiency, and channel assignment.

Acknowledgement

I am deeply grateful to my supervisor Dr. Faysa Debo for his constant guidance, advice, encouragement and support for my masters study. He granted me a great edibility and freedom in my research work. He taught me academic knowledge, research skills and writing skills. I will continue to be deeply influenced by his work enthusiasm, and clarity in thinking and professional integrity. It is my honor to study and do research under his supervision. Also, I would like to express my thanks to Dr Eristu Yigzaw as my external examiner, Dr Satyasis Mishra as internal examiner, and finally thanks to PhD candidate Shanko Chura as Co-advisor. I really appreciate their valuable time.

Besides, I would like to give special thanks to Dr. krishna Murti, Dr.Engr Achim Ebenthall, Gamachu Kushule, Michael Legese and Mujahid Jemal for insightful discussions and valuable suggestions on my research work and for sharing their academic experiences and constructive viewpoints at Adama Science and Technology University of Ethiopia. I want to thank my love Wubalem Mangistu for his continuing encouragement and accompanying on my masters of Electrical Engineering adventure. I would also like to thank my dear landlord family (Gadesa Faye, Solomon Gaddisa, , Admasu and Belete Ababu, and other family) in adama, and arsi Zone, ethiopia for their continuing support and encouragement when I was working MSc in Electrical Communication Engineering.

I would like to thank all my dear friends who helped me a lot when I was in Adama Science and technology University, additionally on my Job and I miss the fun we had together. Finally, I would like to thank my parents and my younger sister for their patience, Acknowledgements understanding, unconditional love and support over all these years. All my achievements would not have been possible without their constant encouragement and support.

Contents

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List of Abbreviations

1G	First Generation of Mobile Networks.
2G	Second Generation of Mobile Networks.
3G	Third Generation of Mobile Networks.
3GPP	3rd Generation Partnership Project.
4G	Fourth Generation of Mobile Networks.
5G	Fifth Generation of Mobile Networks.
AMPS	Advanced Mobile Phone System
AWGN	Additive White Gaussian Noise
BPSK	Binary Phase-Shift Keying.
BS	BS Base Station
CCI	Co-Channel Interference.
CDMA	Code Division Multiple Access.
CRNN	Channel Response Normalized by Noise
CNR	Channel to Noise Ratio
CSI	Channel State Information
CSI-R	Channel State Information at the Receiver.
FDMA	Frequency Division Multiple Access.
EE	EE Energy Efficiency
GSM	Global System for Mobile Communications
HetNet	Heterogeneous Network
iid	independent and identically distributed
ICT	Information and Communication Technology (ICT)
IMT	International Mobile Telecommunications
IoT	Internet of Things
i.e.	"In other words."
IP	Internet Protocol

ITU	International Telecommunication Union
ITU-R	International Telecommunications Union-Radio
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
MA	Multiple Access
MIMO	Multiple-Input Multiple-Output
M2M	Machine-to-machine.
MIMO	Multiple-input Multiple-output.
MISO	Multiple Input Single Output.
MUST	Multiple-User Superposition Transmission
NOMA	Non Orthogonal Multiple Access
OMA	Orthogonal Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing.
OFDMA	Orthogonal Frequency Division Multiple Access
OMA	Orthogonal Multiple Access
PAM	Pulse Amplitude Modulation.
QAM	Quadrature Amplitude Modulation.
QoS	Quality of Service.
RAT	Radio Access Technology.
RF	Radio frequency.
SC	Superposition Coding.
SER	Symbol Error Rate.
SIC	Successive interference cancellation.
SIMO	Single-input Multiple-output.
SINR	Signal to Interference and Noise Ratio.
SISO	Single-input Single-output.
SNR	Signal-to-noise Ratio.
TDMA	Time Division Multiple Access.
UMTS	Universal Mobile Telecommunications System.
SSB	Single-Side-band
UE	User Equipment
UT	User Terminals

Chapter 1

Introduction

1.1 Background

From the last few decades wireless communication in [1] has undergone very rapid changes. One of the reason for this rapid increase is the way it has affected our lives. Cellular telephony in [2], wifi and other services offered by wireless communicating devices is the major driving force behind all this. The so-called 5th generation (5G) system will be designed to offer greater spectral efficiency [3] as compared to the conventional fourth generation (4G) systems. The work in this thesis deals with the novel concept of non-orthogonal multiple access (NOMA), witch is enabler towards the 5G of wireless networks.

Nowadays, fifth generation (5G) wireless networks have attracted wide research interest after the last drop has been wringed from fourth generation (4G). To meet these high demands, there are a number of solutions proposed to cope with this evolution. Hence, multiple access (MA) techniques can now be fundamentally categorized as orthogonal multiple access (OMA) and nonorthogonal multiple access (NOMA). One of these is the non-orthogonal multiple access (NOMA) as in [5, 6], which is proposed to enhance the efficiency of the air interface as well as making efficient use of available resources.

The 5G cellular system is expected to be standardized and deployed by the early 2020s. The standardization of the new air interfaces for 5G is expected to gain momentum after the International Telecommunication Union Radio communication Sector's (ITU-R) in [7] meeting at World Radio Communication Conference (WRC), hold in 2015. Although IMT requirements for 5G are not yet to be defined, the common consensus from academic researchers and industry is that in principle it should deliver a fibre-like mobile internet experience with peak rates of up to 10 Gbps in static/low mobility conditions, and 1 Gbps blanket coverage for highly mobile/cell edge users (with speeds of 300 km/h. The round-trip time latency of the state-of-the-art 4G system (Long-Term Evolution – Advanced; LTE-A) is around 20 ms, which is expected to diminish latency less than 1 ms for 5G network. The Table 1.1 in [7] summarizes the roll-out year as well as the International Mobile Telecommunications (IMT) requirements for the peak average data rates of different generations of the cellular system.

Table 1.1: Specification of different generation of cellular system.

IMT Requirement of Data Rate			
Generation	Rollout Year	Mobile Users	Stationary Users
1G	1981	non	non
2G	1992	non	non
3G	2001	384 Kbps	>2 Mbps
4G	2011	100 Kbps	1 Gbps
5G	2021	1 Gbps	10 Gbps

Evolution summary of LTE Technology to Beyond 4G in [8] (summary of IMT-advanced requirements for 4G is as follows):

- Peak data rate of 100 Mbps for high mobility (up to 360 km/h) and 1 Gbps for stationary or pedestrian users.
- User-plane latency of less than 10 ms for one way transmission, i.e., up or down link.
- Scalable bandwidth up to 40 MHz, extendable to 100 MHz.
- Downlink peak spectral efficiency (SE) of 15 bit/s/Hz.
- Uplink peak SE of 6.75 bit/s/Hz.

As in [10] the 5G network specification will be as follows:

Table 1.2: Fifth generation (5G) specifications.

Specification on 5G Wireless Performance	
Parameter	Performance
Network Capacity	10000 Times Capacity of Current Network
Peak Data Rate	10Gbps
Cell Edge Data Rate	100Mbps
Latency	<1ms
Bandwidth	Possibly 1-2 Ghz
Parameter	Performance

The cellular communication systems in [9],[10] have evolved from 1G to 5G and provided us with different services. For example, 1G focused on voice services, 2G improved voice services and supported text messaging services, 3G integrated voice services and affordable mobile internet services, 4G supports high capacity mobile multimedia service and 5G demands higher capacity, lower latency and more consistent experience. The following provides a road-map of the evolution towards 5G communications in [11].

Before 1G (<1983) : All the wireless communications were voice-centric and used analogue systems with single-side-band (SSB) modulation. Then FDMA for 1G. At 1983 (1G) all the wireless communications were voice-centric. In 1966, Bell Labs had made a decision to adopt analogue systems for a high-capacity mobile system, because at that time the digital radio systems were very expensive to manufacture. An analogue system with FM radios was chosen. In 1983, the US cellular system was named AMPS (Advanced Mobile Phone Service). AMPS were called 1G at the time.

2G (1990) : During this period, all the wireless communications were voice-centric. European GSM and North America IS-54 were digital systems using TDMA multiplexing. Then, GSM was named 2G at the time when 3G was defined by ITU in 1997. Thus, moving from 1G to 2G means migrating from the analogue to digital system. Then TDMA mostly for 2G. In 1995 (2.5G) all the wireless communications are mainly for high-capacity voice with limited data service. The CDMA (code division multiple access) system using 1.25 MHz bandwidth was adopted in the United States of America. At the same time, European countries enhanced GSM to GPRS and EDGE systems.

3G (1999) : In 3G wireless communications platform has voice and data capability. 3G is the first international standard system released from ITU in contrast to previous generation systems. 3G exploits WCDMA (Wideband Code Division Multiple Access) technology using 5 MHz bandwidth. It operates in both frequency division duplex (FDD) and time division duplex (TDD) modes. Thus, migrating from 2G to 3G systems we have evolved from voice-centric to data-centric system. Code-division multiple access (CDMA) also for 3G.

4G (2013) : In 2013 the 4G is a high-speed data rate plus voice system. There are two 4G systems. The bandwidth of both systems is 20 MHz's. The major cellular operators are favorable to LTE, and most countries around the world have already started issuing licenses for 4G using current developed LTE systems. The cost of licensing through auction is very high. Orthogonal frequency- division multiple access (OFDMA) for 4G are primarily orthogonal multiple access (OMA) schemes. The United States has developed the WiMAX (Worldwide Interoperability for Microwave Access) system using orthogonal frequency-division multiplexing (OFDM) evolving from WiFi. LTE system that was similar to WiMAX because, it was developed after WiMAX.

5G (2021) : In 2021 the 5G is still to be defined officially by standardization bodies. It will be a system of super high-capacity and ultra-high-speed data with new design requirements tailored towards energy elicited systems and reduced operational expenditure for operators. Thus, moving from 4G to 5G means a shift in design paradigm from a single-discipline to a multi-discipline system. Therefore, orthogonal and none-orthogonal multiple access schemes are proposed for 5G networks.

As a result, the growth of global mobile data traffic is expected to keep increasing aggressively. For this reason, efficient use of the limited available spectrum is a crucial and challenging task to meet the increasing number of connected devices in [11] and their demands.To meet these demand, a number of requirements need to be satisfied. First, the number of users that can be accommodated within a cell needs to be significantly increased without necessarily increasing the number of Base Stations (BS). Secondly, future generation data and multimedia traffic require a high data rate in order of hundreds of Mb/s for high mobility users and up to Gb/s for low mobility or fixed users with the end-to-end latencies not exceeding 5 ms. Thirdly, the expected increase in data traffic should not have a significant cost on battery life. Finally, the cost of delivering high quality services and high data rate should be kept affordable.

Therefore, fulfilling these requirements requires maximizing bandwidth efficiency by exploiting all available degrees of freedom (time/frequency/power/space), minimizing power consumption, and utilization of fading and interference which would lead to improved 5G network system performance.

One of these key technologies is multi-carrier Multiple Access Schemes (MAS) which are based on Orthogonal Frequency Division Multiplexing (OFDM) such as Orthogonal Frequency Division Multiple Access (OFDMA) and Single Carrier OFDMA (SC-OFDMA). These schemes enable efficient as well as robust performance against fading by converting the channel bandwidth into many parallel, overlapping and orthogonal at fading sub channels. To further improve the spectral efficiency, Non-Orthogonal Multiple Access (NOMA) has recently been proposed for the future 5th Generation (5G) mobile systems to complement the existing orthogonal MAS.

In [13],[14] NOMA utilizes the principles of superposition coding (SC) and successive interference cancellation (SIC) for power domain NOMA and message passing algorithm (MPA) for code domain NOMA to minimize undesired interference such that they share the same time/frequency/code resource block. The combined received signals are detected by employing successive interference cancellation (SIC), which inherently requires large power separation between users for successful detection. This increases the overall system capacity however, as the users transmit at different power levels then throughput and fairness is poor for the weaker power users.

The Figure 1.1 shows total global monthly data (Exabytes per month) and voice traffic as in [14], [15], [16]. It depicts a continued strong growth in data rate. This increment is driven by increased smart phone subscriptions and average data volume per subscription. To further meet the overwhelming requirement of data rates, various new technique have been proposed in recent years, and these techniques include massive multiple-input multiple output (MIMO), millimeter wave communications, and non-orthogonal multiple access (NOMA). Among them, NOMA takes advantage of spectrum efficiency by allowing multiple users to occupy the same sub-channel, which is different from the resource allocation in OFDM systems. Therefore, NOMA has been well considered as a promising candidate for the next generation mobile communication systems.

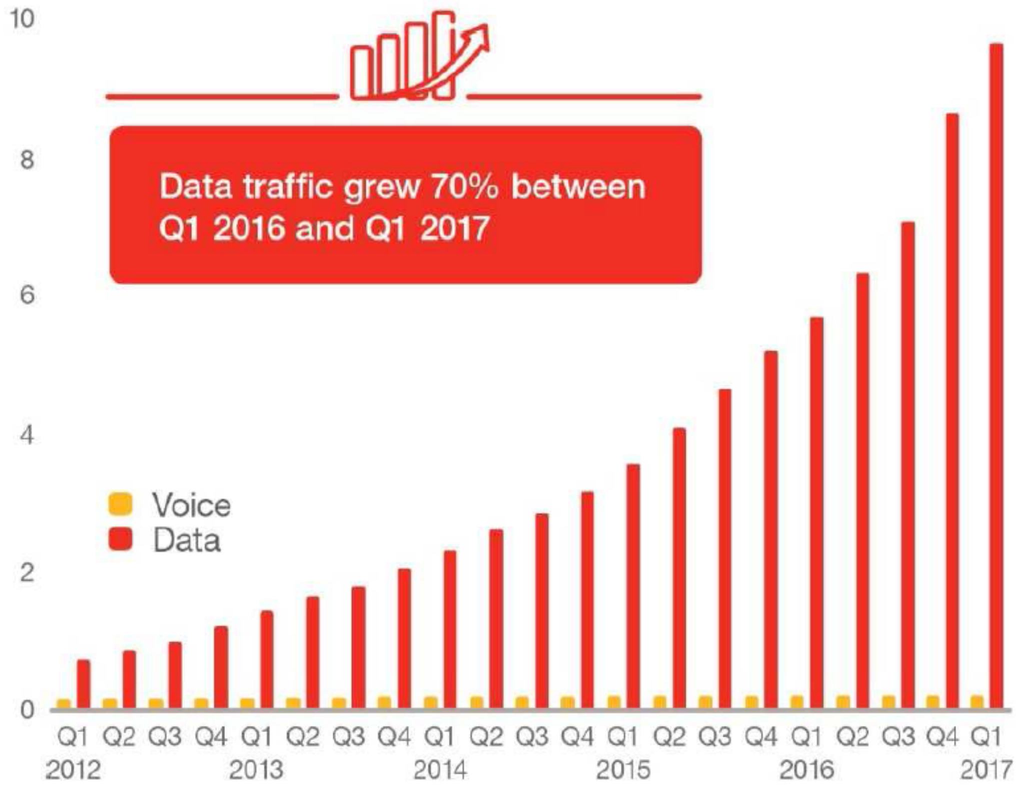

Figure 1.1: Mobile data traffic growth predicted by Erickson

1.2 Salient Features of 5G

The 5G technology in [17] is expected to provide a new (much wider than the previous one) frequency bands along with the wider spectral bandwidth per channel. The 5G is different from the previous networks by the following advanced terms.

- High increased peak bit rate up 1000 times higher mobile data volume per area.
- 10 to 100 times higher user data-rate (10 Gbps), 5G support speed up to 10 Gbps.
- High capacity to allow more devices connectivity concurrently and instantaneously.
- Lower cost of infrastructural development.
- Higher reliability of the communications.
- 10 to 100 high number of inter-connected devices.
- 10 times longer battery life means lower battery consumption.
- 5 times reduced end to end latency i.e. up-to 1ms.

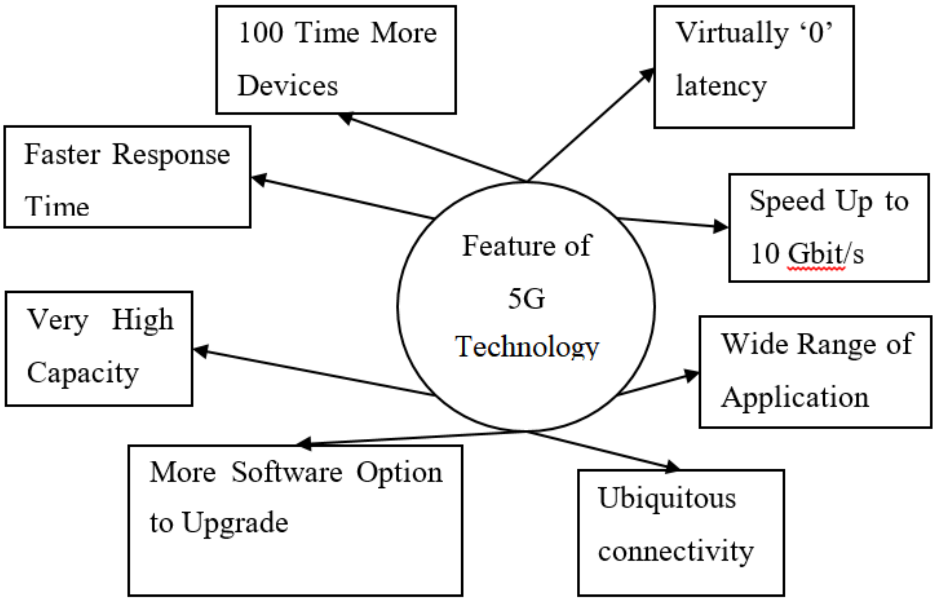

Figure 1.2: Feature of 5G network.

Therefore, the key features of power domain NOMA in 5G network also summarized as follows:

1. Improved SE: NOMA exhibits a high SE, which is attributed to the fact that it allows each resource block (e.g., time/frequency/code) to be exploited by multiple users.
2. Ultra-high connectivity: With the capability to support multiple users within one resource block, NOMA can potentially support massive connectivity for billions of smart devices. This feature is quite essential for IoT scenarios with users that only require very low data rates but with massive number of users.
3. Relaxed channel feedback: In NOMA, perfect uplink CSI is not required at the base station (BS). Instead, only the received signal strength needs to be included in the channel feedback.
4. Low transmission latency: In the up-link of NOMA, there is no need to schedule requests from users to the BS, which is normally required in OMA schemes. As a result, a grant-free up-link transmission can be established in NOMA, which reduces the transmission latency drastically.

1.3 Applications of 5G Network Service

According to the 3rd generation partnership project (3GPP), the International Telecommunication Union (ITU) in [18] has classified 5G networks in to three major families of applications.

- Enhanced Mobile Broadband (eMBB): Very high data rate communications across a wide coverage area.

- Ultra-reliable and Low-latency Communications (uRLLC): Strict requirements on latency and reliability for mission critical communications, such as remote surgery, autonomous vehicles or the Tactile Internet.
- Massive Machine Type Communications (mMTC): It need to support a very large number of connected devices in a small area, which may only send data sporadically, such as Internet of Things (IoT) use cases.

On top of this, Enhanced Vehicle-to-Everything (eV2X) in [19] communications are also considered as an important service that should be supported by 5G networks. These scenarios require massive connectivity with high system throughput and improved spectral efficiency (SE) and impose significant challenges to the design of general 5G networks. Hence, the spectral efficiency becomes one of the key challenges to handle such explosive data traffic.

Moreover, due to the rapid development of the Internet of Things (IoT) in [20], 5G needs to support massive connectivity of users and/or devices to meet the demand for low latency, low-cost devices, and diverse service types. To satisfy these requirements, enhanced technologies are necessary. Note that Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) Rel-13 is doing ongoing studies toward NOMA in the form of multi-user superposition transmission (MUST). So far, some potential candidates have been proposed to address NOMA challenges in 5G, such as:

- Massive MIMO.
- Millimeter Wave Communications.
- Ultra-Dense Network.
- Non-Orthogonal Multiple Access (NOMA).

Among those 5G NOMA requirements, achieving high spectral efficiency is the key requirement because it provides us with much lower cost per bit. In order to achieve high spectral efficiency 5G system, channel coding and modulation are the key part of the 5G network physical layer in [20],[21]. The channel coding and modulation of the 5G system requires to achieve better spectral efficiency, support multi-terminal encoding and decoding schemes in cooperative communications or heterogeneous networks and reduce transmission and computation power.

1.4 Network Service Technology in 5G Network

1.4.1 Signal Domain Segmentation Technology

Signal domain segmentation technology in [22] is based on the overall optimization of multiuser communication system. At the transmitting terminal, the user is differentiated based on the non-orthogonal features of multiple signal domains (e.g. power domain, generalized spatial domain, coding domain). At the receiving terminal, the multi-user detection receiver can be realized by using SIC method or other sub-optimal detection algorithm based on the feature structure of the users' pattern and the main concern of this thesis is based on power domain NOMA. Signal domain segmentation multiple access representative technology mainly as:

- Power domain NOMA.
- Bit division multiplexing (BDM) multiple access.
- Superposition modulation (SM).
- Pattern division multiple access (PDMA).
- Space coupled multiple access (SCMA).
- Low density signature multiple access (LDSMA).
- Inter-leave division multiple access (IDMA) etc.

1.4.2 Waveform Design Technology

On the other hand, waveform design techniques are primarily designed to optimize the multi-carrier modulation waveform and filter modes to achieve the non-orthogonal carriers which is not concerned in this thesis. Waveform technology for NOMA is mainly composed as follows:

- Faster-than-nyquist (FTN).
- Generalized multi-carrier (GMC).
- Filter band multi-carrier (FBMC).
- Generalized frequency division multiplexing (GFDM).
- Universal filtered multi-carrier (UFMC).
- Bi-orthogonal frequency division multiplexing (BFDM).
- Overlap time division multiplexing (OVTDM) etc.

1.5 Wireless Channel Communication

Wireless communication in [23] [23], [24], shows that the signals propagate from the transmitter to receiver passing through free space. During this propagation time, the signals have to go through reflection, diffraction and scattering due to the surrounding structures between transmitter and receiver. For these reasons, the signals received at the destination are not the same as transmitted signals. Generally, in cellular systems, due to the height of cellular antenna is smaller than the surrounding structures, the line-of-sight (LOS) communication between the transmitter and receiver is mostly not possible. Therefore, signals arrive at the receiver through different paths and delays, which give rise to multi-path communication. Due to this reason for transmission, the quality of signals may affect by different channel condition as in that introduce as follows.

1.5.1 Path-Loss

When the signal propagates through channel, the attenuation takes place based on the distance between the transmitter and receiver. This attenuation is called path-loss. As the distance between the transmitter and receiver increases, the strength of the signal becomes weaker. To this problem, the repeaters and amplifiers are used. The degradation of signal strength due to path-loss relative to distance is defined as the ratio of transmitted power P_t to the received power P_r, i.e., (Pt/Pr) or in decibel $P_L(dB) = 10\log_{10}(P_t/P_r)$ called path loss(P_L).

1.5.2 Noise

Noise is the unwanted signal in communication system superposed on a wanted signal, which tends to unclear the signal at receiver. There are various forms of noise in communication system these are thermal noise, inter-modulation, cross-talk, impulse noise and white noise etc.

1.5.3 Fading

Fading is defined as the distortion of signal over a certain propagation media. In wireless communication, the fading is occurred due to multipath propagation. A signal that propagates from the transmitter to the receiver through multiple paths is called multipath propagation. There are different factors that cause multipath propagation, these are atmospheric ducts, ionosphere reflection and refraction, and reflection from terrestrial objects, such as mountains and buildings. The effects of multipath propagation include the variations on signal amplitude, phase and angle. This distortion of signals caused by multipath is known as a multipath fading. The variations in transmitted signal in wireless communication are classified according to their fading scale.

1.6 Communication Channel Model

The performance of any communication system in [25] is eventually determined by the medium or channel between transmitter and receiver. To design communication system all factors that affect the propagation signals are must be considered. Some typical communication channels models are introduced as follows.

1.6.1 Additive White Gaussian Noise (AWGN) Model

In an ideal wireless communication channel, the receiver perfectly decoded input signal without any noise. This mean the bit error probability of such a channel is zero. However, in the real world receiver always add noise to the transmitted signal. AWGN is adding white Gaussian noise to the signal propagating through channel. Where, $r(t)$ is the output of the AWGN channel with input $s(t)$ and white Gaussian noise $n(t)$. The mathematically the received signal can be represented as follow:

$$r(t) = s(t) + n(t) \tag{1.1}$$

AWGN is present in any communication channel. The following sections explain about the fading channels considered in the system as in [26].

1.6.2 Rayleigh Fading Channel

Rayleigh fading is one of statistical models for estimating the effect of propagation environment on a radio signal. This channel model is usually used in case of multi-path propagation between the transmitter and receiver but no line of sight (LOS). It is the most useful model in case when there are many objects between the transmitter.

1.7 Modulation Schemes

Modulation is the process of varying one or more properties of a high-frequency periodic waveform called the carrier signal, with a modulating signal, which typically contains information to transmit in [27]. In general, it involves translating a baseband signal on to a modulated signal. The base band signal means source signal whereas modulated signal is a signal at a higher carrier frequency. At receiver, the original signal recovers through a process called demodulation. There are different digital modulation in [27], [28] techniques such as:

- Binary phase shift keying (BPSK).
- Quadrature phase shift keying (QPSK).
- Quadrate amplitude modulation (QAM).
- Frequency shift keying (FSK).
- Minimum shift keying (MSK).

The performance of NOMA using BPSK modulation over Rayleigh fading channels has been investigated in this thesis. That means lower order of modulation techniques is better to use in communication system for signal quality. Therefore, in this thesis, binary phase shift keying is assumed as modulation technique.

Binary phase shift keying is the simple modulation in PSKs scheme using two phases and the transmitted signal is a sinusoid of fixed amplitude. It has one fixed a phase when the data is at one level and when the data is at the other level which separated by phase of 180^0. In BPSK, the binary digits $'1'$ and $'0'$ may be represented as analog levels $+\sqrt{E_b}$ and $-\sqrt{E_b}$ respectively.

1.8 Problem Statement

Evaluate the performance gap between OMA and NOMA based on bandwidth, data rate, resource allocation, spectral, and energy efficiency. The bandwidth in OMA is not efficiently used or its not spectral efficient as well as due to the increment number of users from time to time, OMA lacks to fulfill the demand of large number of user. To analyze and quantify the effects of power allocation on the performance improvement of NOMA based on throughput, fairness, data rate , SE and EE. However, by adapting NOMA, a more complex transmitter and receiver are required to mitigate the spectral efficiency. Furthermore, power domain NOMA usually works well when only two or more users share the same resource block bandwidth with the same time, frequency, space and code.

Using BPSK modulation techniques to improve system performance of NOMA with signal to noise ratio increment. Maximizing the power and improving system EE and SE of adaptive power domain NOMA. In order to improve system capacity of orthogonal multiple accesses (OMA), a non-orthogonal multiple access (NOMA) scheme have been proposed. In this thesis to increase system capacity, improve system spectral efficiency and support more users by using limited resource block, the combination of OMA and NOMA or NOMA techniques in 5G network are proposed by using the SC at transmitter side and SIC algorithm at receiver side. These algorithms used to cancel the interference introduced by NOMA.

1.9 Objectives of the Thesis

1.9.1 General Objective

Improve system performance of 5G network using adaptive non orthogonal multiple access.

1.9.2 Specific Objectives

- User were randomly located in the cell, and to estimate channel model using Hata Okumura model and BPSK modulation.
- To investigate and analyze characteristic of NOMA with OMA depending on the data rate over variable distance at different power level without SIC algorithm.
- To investigate and analyze characteristic of NOMA with OMA depending on the data rate over variable distance at different power level with SIC algorithm.
- To evaluate energy optimization of SE and EE of NOMA and OMA.
- To evaluate proportionality of SE and EE of NOMA.
- To evaluate performance of adaptive NOMA and OMA in EE and SE over variable distance (using minimum enegry to serve high number of user).
- To evaluate performance of adaptive NOMA in EE and SE over variable distance.
- Power resource allocation to each user in adaptive NOMA at variable distance.

1.10 Literature Review

Since the basic concept of NOMA was introduced and the cell-edge user throughput performance improvement was demonstrated in [6, 7], NOMA has attracted much research attention considering fixed static.The NOMA system has also been envisioned as a key technology in the 5^{th} generation mobile communication systems [10]. More specifically, by utilizing the SIC technology, multiple users can be multiplexed on the same frequency band with different power levels [14, 15]. This is different from the conventional orthogonal multiple access (OMA) scheme. In the downlink NOMA system, the user who has the higher channel state information (CSI) can remove the interference signal from the other users who has less CSI [19, 20]. This protocol enables NOMA to achieve higher spectrum efficiency than the OMA scheme.

Besides the performance analysis, the power resource allocation was investigated in NOMA systems. By using fractional transmit power allocation (FTPA) among users and equal power allocation across subchannels, the authors in [39, 40] compared system-level performance of the NOMA system with the OMA system, and showed that the overall cell throughput, EE, cell-edge user throughput, and the degree of proportional fairness of NOMA are all superior to those of the OMA scheme. Though FTPA is simple to implement, it fails to optimally allocate power among multiplexed users on each sub-channel.

Thus, a new power allocation scheme based on water filling was proposed to achieve high spectral efficiency [45]. A cooperative relay system based on NOMA was proposed in [46], where the improvement of the spectral efficiency was presented by numerical results. All of the above were not used Hata Okumura model to model or estimate the channel between base station and random lacation of user in single cell down link power domain adaptive NOMA. Therefore, this the all above researches were based on fixed power allocation to user at fixed user location. But, in this thesis NOMA system performance evaluated at random user location in a single cell BS down link power domain adaptive non orthogonal multiple access.

1.11 Methodology

All above problem of statement and objectives of the thesis will be improved and performance will be analyzed by different techniques and the theses will be done based on down link power domain adaptive NOMA and OMA multiple access techniques for 5G networks. The following methods will use to achieve the methodology of thesis:

- Literature Review: Including Reading books, research papers and using internet, journals, and books.
- Modeling: Involves analysis of performance evaluation on adaptive NOMA by choosing Hata Okumura model to estimate channel and BPSK modulation schemes.
- Simulation: simulating the modeled system by using MATLAB software and document

written by LATEX software and beamer this PPT.

- Rayleigh fading channel model used in matlab simulation.
- One cell radius of 30 to 1.5 km average used in simulation for random location of users.
- Finally, throughput, fairness, data rate, SE, and EE over random distance location of user performance optimized using MATLAB simulation.

1.12 Outline of the Thesis

After the background of 5G network to down link power domain adaptive NOMA described in chapter one, the remaining chapters organized as follows. Chapter 2 discusses comparison of non-orthogonal multiple access and orthogonal multiple access techniques. Chapter 3 introduces performance evaluation and system models of adaptive down link power non-orthogonal multiple access as well as performance analysis and power optimization. Chapter 4 discusses about simulation results. Finally, in chapter 5, includes the thesis conclusion and recommendations for future works.

Chapter 2

Comparison of OMA and Non-Orthogonal Multiple Access

2.1 Orthogonal Multiple Access (OMA) Resources Allocation

In the fourth generation, OFDM has been widely adopted because it can effectively eliminate the interference between signal waveforms and highly increased the sum rate of the wireless system. OFDM is an advanced technology which has high transmitting rate, the concept of this advanced technology is to transform the serial data into parallel and multiplexed into relatively low speed and modulated by different carriers. The symbol bandwidth is dramatically enlarged by two parallel channel. The spectrum of each sub-carrier are not mutually overlapping by using multiplexing method in traditional frequency division.

The LTE systems, the minimum unit in the frequency domain is the sub-carrier with a bandwidth of 15 kHz. The minimum unit of the time domain is an OFDM symbol with 1/14ms. Each resource unit consists of one sub-carrier and OFDM symbol. LTE system adopt multi-antenna exploiting the degrees of freedom offered in spatial domain to carry user information. In particularly, each antenna utilizes the same frequency spectrum and time domain resources as other antennas. Since, OMA in [30] the frequency and time domain carry the same users information power. The OFDM technology in the LTE system does not adopt the power domain of the user information transmission. It is the two-dimensional plane of resource carrying system, but the transmission capability of wireless channel relatively weak.

Conventionally, NOMA can be integrated in existing and future wireless systems, because of its compatibility with other communication technologies. One of the two kinds of power domain NOMA will be introduced in this thesis, which are adaptive non-orthogonal multiple access (NOMA). Particularly, in this thesis the NOMA principle ensures that two to three users are simultaneously served on one sub channel n as in mat-lab simulation.

In [28],[29] the differences between OMA and NOMA technology in power domain as figure 2.1, and 2.2 shows resource allocation for user information carried in frequency and time domain of OFDM, and NOMA technology respectively. Then NOMA is better SE than OMA.

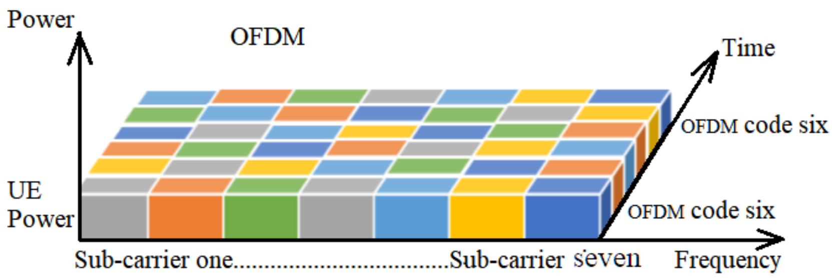

Figure 2.1: Resource allocation in an OMA-based system.

An enormous number of filters are required at transmitter and receiver side, this dramatically increases the construction cost of the system and its complexity in [31],[32]. Simultaneously, Sufficient frequency intervals must be maintained between the sub-carriers to deal with the inter carrier mutual crosstalk, which will reduce the spectrum efficiency of the system. All of the current cellular networks implement orthogonal multiple access (OMA) techniques such as TDMA, FDMA or CDMA together. However, none of these techniques can meet the high demands of future radio access systems. The characteristics of the OMA schemes can be summarized as follows:

- In TDMA, the information for each user is sent in non-overlapping time slots, so that TDMA-based networks require accurate timing synchronization, which can be challenging, particularly in the up-link.
- In FDMA implementations, such as orthogonal frequency division multiple accesses (OFDMA), information for each user is assigned to a subset of sub-carriers.
- The CDMA utilizes codes in order to separate code of users over the same channel.

Thus, in [34], [33] 4G wireless networks i.e OMA is mainly based on OFDMA. OFDMA assigns each tone to at most one user such that each user gets disjoint set of sub-carriers. Each user experiences a different channel gain on each sub- carrier. However, OMA can only support limited numbers of users due to limitations in the number of orthogonal resources blocks, which limits the SE and capacity of current networks. To deal with more strict and harsh situation using 5G network to manage more data, to pursuit higher sum rate and capacity, more spectrum and energy efficiency. OFDM is not enough to meet those deliverables. Therefore, NOMA is well considered to achieve higher system throughput and keep the low cost at the same time.

2.2 Non-Orthogonal Multiple Access (NOMA) Resources Allocation

In contrast to OMA, NOMA in [35] [37] [39] allows allocate the same frequency/time/-code/space for multiple users over one sub-channel within the same cell at different power level and offers a number of advantages, including improved energy and spectral efficiency (SE) as well as low transmission latency (no scheduling request from users to base station is required). At the transmitter side, signals from various users are superposed and the resulting signal is then transmitted over the same channels. At the receiver sides, multiuser detection (MUD) algorithms, such as successive interference cancellation (SIC), parallel interference cancellation (PIC) are utilized to detect the desired signals. But, SIC algorithms were considered through this thesis.

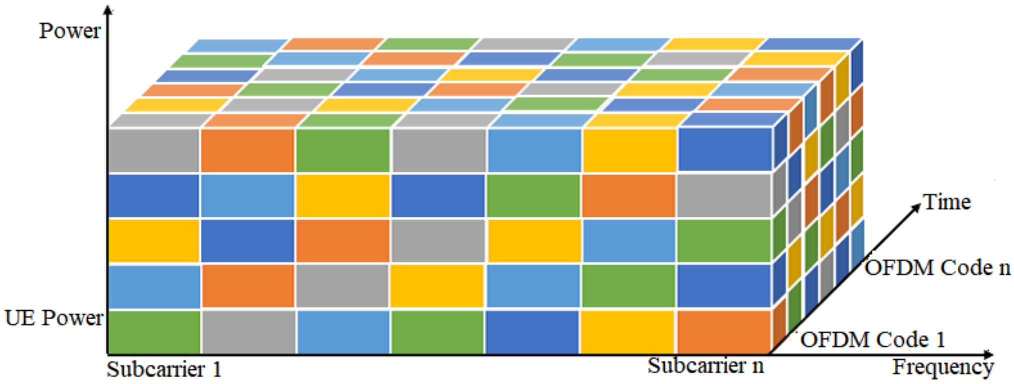

Figure 2.2: Resource allocation in NOMA-base system.

In [37] the Figure 2.2 shows power domain NOMA system resource allocation in the frequency, time, and code domain were considered. However, the difference between them is that each resource unit on the time and frequency domain plane can carry multiple users with different signal power level. Obviously, NOMA technology is a system allowing a three-dimensional resource allocation. Hence, NOMA provides a higher flexibility in resource allocation compared to traditional OMA systems. Although this thesis primarily surveys the down link power-domain adaptive NOMA using successive interference cancellation (SIC) algorithm. NOMA will not depend on the frequency domain to divide users, it will superpose multiple users in the power domain, although the signal waveform could be based on the OFDMA. Therefore, recently, several NOMA schemes have attracted lots of attention. While the majority of recent works see CDMA as an orthogonal multiple access (OMA) technique, there are three major categories of NOMA and group of other papers that categorize it as a NOMA technique.

1. Code domain non-orthogonal multiple access.
2. Non-orthogonal multiple access multiplexing in multiple domains.
3. Power domain non-orthogonal multiple access (the major content of this thesis).

Code domain NOMA uses user-specific sequences for sharing the entire radio resource. On the other hand, power domain NOMA exploits the channel gain differences between the users for multiplexing via power allocation.

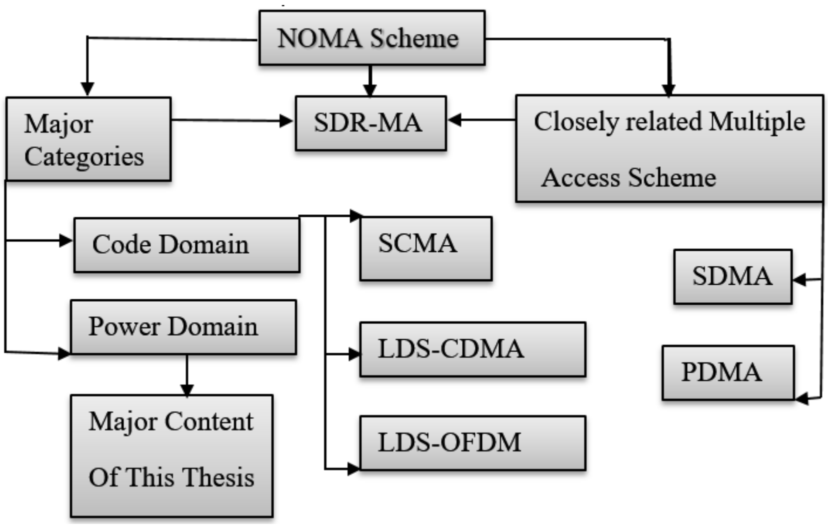

Figure 2.3: A simple classification of NOMA techniques.

2.2.1 Code-Domain NOMA

Unlike power-domain NOMA, which attains multiplexing in power domain, code-domain NOMA in [37],[39] achieves multiplexing in code domain. Like the basic code division multiple access (CDMA) systems in [39], code-domain NOMA shares the entire available resources (time/frequency). In contrast, code-domain NOMA utilizes user-specific spreading sequences, that were either sparse sequence or non-orthogonal cross-correlation of low correlation coefficient. Code-domain NOMA can be further divided into a few different classes.

- Low-density spreading CDMA (LDS-CDMA).
- Low-density spreading OFDM (LDS-OFDM).
- Sparse code multiple access (SCMA) etc.

The multiplexing is then performed either in the code domain or spatial domain, or a combination of them. For SDMA, the working principle is inspired by basic CDMA systems. The use of low-density spreading sequences helps LDS-CDMA to limit the impact of interference on each chip of basic CDMA systems. LDS-OFDM can be thought of as an amalgamation of LDS-CDMA and OFDM, where the information symbols are first spread across low-density spreading sequences and the resultant chips are then transmitted on a set of sub-carriers. SCMA is a recent code-domain NOMA technique based on LDS-CDMA. In contrast to LDS-CDMA, the information bits can be directly mapped to different sparse code-words, because both bit mapping and bit spreading were combined. When compared to LDS-CDMA, SCMA provides a low complexity reception technique and offers improved performance.

2.2.2 NOMA Multiplexing in Multiple Domains

There exist some other multiple access techniques, which are also closely-related to power domain NOMA and code domain NOMA, including pattern division multiple access (PDMA) and spatial division multiple access (SDMA). Instead of using user-specific spreading sequences, SDMA distinguishes different users by using user channel impulse responses (CIRs). This technique is particularly useful for the cases where number of up link users is considerably higher than that of corresponding receiving antennas in BS. Some other multiple access schemes such as multi-user shared access (MUSA), pattern division multiple accesses (PDMA), and bit division multiplexing (BDM) are also proposed. At the transmitter side, PDMA first maximizes the diversity and minimizes the overlaps among multiple users in order to design non-orthogonal patterns. Code domain NOMA and NOMA multiplexing in multiple domains were not major content this thesis, then adaptive power domain NOMA will be seen.

2.2.3 Down Link Power-Domain NOMA

The main advantage of this power domain NOMA is that, users have no longer need to share neither frequency or time (spectrum sharing), as well as NOMA technology has the characteristics of high spectrum utilization, high flexibility, and improved system capacity since they are superimposed in the different power level domain. In order to realize the power domain NOMA the thesis can adopt user scheduling algorithm at the transmitter side and perform the SIC detection at the receiver side to separate the user signals from each other.

Down-link power-domain NOMA in [40],[41],[42] was proposed as a candidate radio access technology for 5G cellular systems in order to support higher throughput massive and heterogeneous connectivity for 5G networks. The multi-user cellular communication systems, a proper power control can be performed at the transmitter, such that the interference to be effectively mitigated at the receiving terminal. The performance of SIC detector highly depends on the received signal quality. Therefore, the performance of SIC detector improves with the increasing disparities of the strength received signals.

When OFDMA is used, which is a typical example of OMA, each user is allocated one subcarrier. In this example, the spectral efficiency of OMA is poor since the IoT device in [43] is served with more bandwidth than what it actually needs, while the broadband user is not assigned enough bandwidth. Thus, Non-Orthogonal Multiple Access is a good examine to push Internet of Things which bands a lot of terminals and sensors. At the same time, there are several disadvantages about Non-Orthogonal Multiple Access system. As a result, the use of NOMA efficiently supports massive connectivity and meets the users' diverse QoS requirements.

Non-Orthogonal Multiple Access accept more terminals with different kinds of Quality of Service. Figure 2.3 were classification of NOMA scheme techniques. Non-Orthogonal

Multiple Access can utilize the spectrum more efficiently and it wouldn't influence a lot for their performance with appropriate power allocation and Successive Interference Cancellation techniques. Non-Orthogonal Multiple Access multiplexing by strong and weak channel condition users. By resting the orthogonal limitation of orthogonal multiple access, non-Orthogonal multiple access capacitate a more elastic regulation of the resources of radio, and it also supports an efficient method to increase consumer fairness through appropriate resource allocation. Assume that user one is an IoT device requiring only a low data rate, and user two is a user demanding a high data rate.

Non-orthogonal multiple access (NOMA), in contrast, allows multiple users to share the same resource elements, be it in the time, frequency, space, or code domain. NOMA is currently a hot research topic for 5G and beyond systems, both in academia and industry. Due to the different interpretations, there is not a consensus about applying this term to some well-known existing techniques such a CDMA.

The following multiple access lies at the heart of cellular communication systems in previous network generations. It refers to a technique that allows multiple users to share a communication channel. The first generation (1G) to the fourth-generation (4G) of cellular networks have adopted radically different multiple access schemes with one common theme in mind to have orthogonal signals for different users at the receiver side.

- Frequency division multiple access (FDMA).
- Time division multiple access (TDMA).
- Code division multiple access (CDMA).
- Orthogonal frequency division multiple access (OFDMA).
- Space division multiple access (SDMA).

Superposition Coding with Successive Interference Cancellation: A large body of papers consider NOMA to be equivalent to superposition coding and successive interference cancellation (SC-SIC), respectively, at the transmitter and receivers. In fact, the key term is SIC as it also appears in the up link transmission.With this in mind, SC-SIC is also applied to several different cases, such as multiple-input multiple-output (MIMO) networks and multi-cell networks (SISO or MIMO), in which SC-SIC is suboptimal.

2.2.3.1 Successive Interference Cancelation (SIC)

The successive interference canceler is a kind of non-linear multi-user receivers which estimates and cancels multiple access interference successively using feedback in [44] [45]. Successive interference cancellation (SIC) detects just one user per stage. The strongest received signal is detected first, then the next strong. Then this will cancel the interfering signal provided that the decision was correct. The process is repeated until the weakest user is decoded.

Superposition coding at the transmitter and successive interference cancellation (SIC) at the

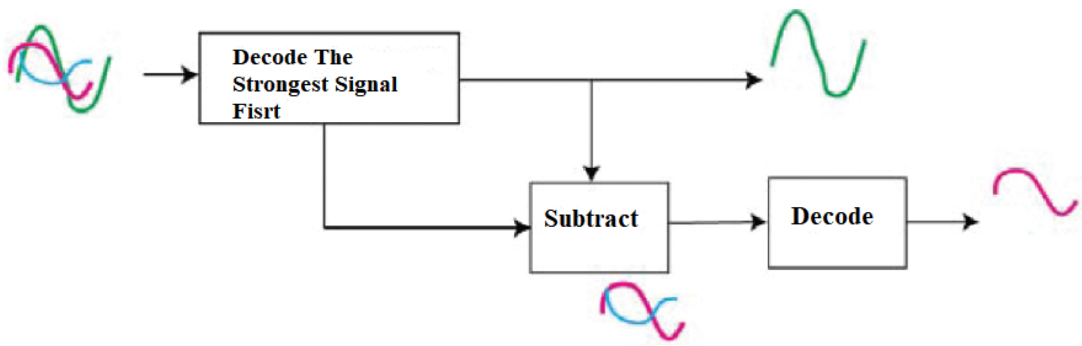

Figure 2.4: Block diagram of successive interference cancellation.

receiver makes it possible to utilize the same spectrum for all users. At the transmitter site, all the individual information signals are superimposed into a single waveform, while at the receiver, SIC decodes the signals one by one until it finds the desired signal. The first signal that SIC decodes is the strongest one while others as interference. The first decoded signal is then subtracted from the received signal if the decoding is perfect. Then waveform with the rest of signals is accurately obtained. SIC iterates the process until it finds the desired signal.

After each user's transmitted data is estimated that received signal for that user can be reconstructed or regenerated and subtracted from the received signal waveform by recreating the transmit signal and applying an estimate of the channel to it. This can be subtracted from the composite received signal, which then allows subsequent users to experience a cleaner signal. In the scheme, the received signal is first passed through a bank of matched filters. Then the user with the strongest correlation value (the correlations of each of the users' spreading sequence $S_k(t)$ with the received signal y(t) is selected for decoding.

$$y(t) = \sum_{m=1}^{M} A_m(t) S_m(t) b_m(t) + n(t), \qquad t \in [0, T] \tag{2.1}$$

The successive interference cancellation (SIC) detector takes a serial approach to cancel interference from the system. First operation in the SIC detector consists of sorting out the users' signals in a descending order according to theirs dedicated power level of each users depending on channel condition which are estimated from the output of conventional receiver. This regenerated signal provides an estimate of the MAI caused by the strongest user, $b_m(t)$, which is then subtracted from the total received signal Y(t), yielding a partially cleaned version of the received signal $y_1(t)$. If the user estimates is accurate, the remaining users see less MAI in the next stages. Thus, this new version of the received signal can be used to detect the next strongest user in the system.

The benefit of sorting signals out in a descending order of power is because the strongest users or weaker channel condition can give the most accurate estimate and consequently the removal of this signal will provide the most benefit to the remaining users. System made by precision of the power ordering depending on the channel condition. This process is repeated until all users are detected. The SIC detector takes a serial approach to canceling interferences as shown in Fig. 2.5.

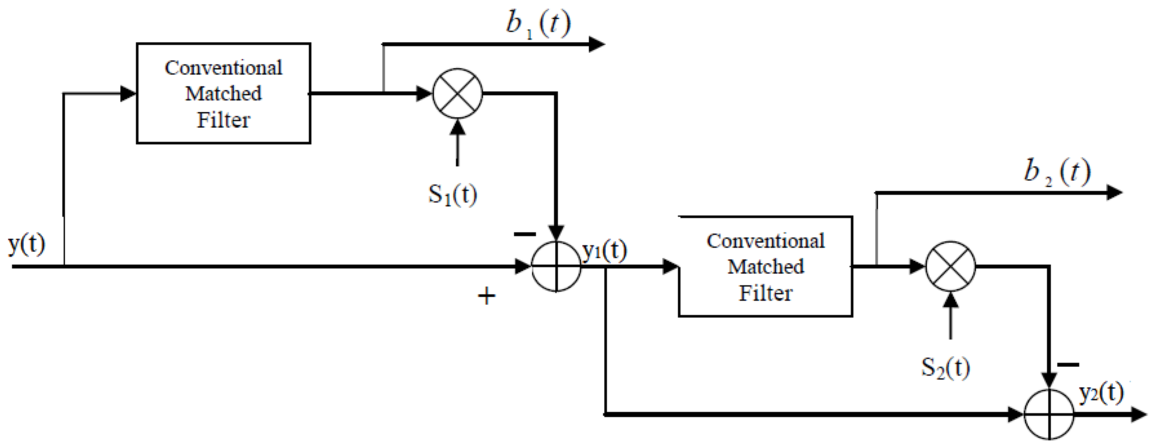

Figure 2.5: Successive interference cancellation.

The key idea of SIC technique is that users who have higher channel gains can decode the data that has been successfully decoded by the users who have less channel gains. In this case, since user 2 has a higher channel gain than user 1, then user 2 can decode the data that has been successfully decoded by user 1 as in Figure 2.5.

- The transmit signal is superposition coded signals of the two users.
- At the receiver, user 1 treats user 2's signal as noise and decodes its data from y1.
- user 2 with better channel performs SIC, i.e., it decodes the data of user 1 and subtracts user 1's signal from y2. After that, user 2 can decode its data.

Assume m^{th} user has the strongest correlation value, total received signal (y(t)), spreading code for the strongest power of user one ($S_1(t)$), estimated user symbol of the strongest user one ($B_m(t)$), and partially cleaned version of the received signal after detection of user one ($y_1(t)$).

$$Y(t) = y(t) - A_m(t)S_m(t)b_m(t) = \sum_{j=1, j\neq m}^{M} A_j b_j S_m(t) + A_m(b_m - B_m)S_m(t) + n(t) \qquad (2.2)$$

A potential problem with the SIC detector occurs if the initial data estimates are not reliable. In this case, even if the timing, amplitude, and phase estimates are perfect, but, the bit estimate is wrong, the interfering effect of that bit on the signal-to-noise ratio is quadrupled in power (the amplitude doubles, so the power quadruples). Thus, a certain minimum performance level of the conventional detector is required for the SIC detector to yield improvements. It is crucial that the data estimates of at least the strongest users that are canceled first be reliable. Note that, in each stage estimate of the users are obtained by making a decision at the output of detector.

The Imperfect channel state information estimation (CSI) : The interfering signal from the other users must be reconstructed before it is removed from the received signal. This contribution depends on the estimation of channel state information. The imperfect estimation of CSI will lead to residual cancellation errors. One concern is that if the difference of users' received powers is large, the residual error from canceling the stronger user can still swamp the weaker users signal.

The Limitations of the SIC Receiver or Complexity scaling in the down link every access scheme has to decode the signal from every user in the cell and normally each user only has to decode its own information. With SIC every user has to decode not only its own signal but also the data from every user with a higher channel gain. This means that the decoding complexity grows linearly with the number of users which may result in a significant delay. In our model this will be mitigated with the use of clusters users although no measure of the delay improvement or any other delay analysis will be done.

However, the far user treats signal of near user as interference. Now if the difference between channel gain of either users or their power allocation factors is less, then the SIC performance can face severe degradation. This SIC performance degradation increases the BER at receiver. This issue needs to be resolved for better NOMA performance witch need another mechanism not in this thesis.

In [46], [47] the SIC in NOMA system is main technology at receiver side. Considering a down link power NOMA transmission scenario where a single base station transmits superposition coded information to two users. The channel gains from the base station to these two users are H_1 and H_2, respectively. Assume that $|H_1| < |H_2|$, and both H_1 and H_2 are perfectly known to both the transmitter and receivers. The transmit signal or the sum of two signals, can be expressed as follows.

$$X = \sqrt{P_1}S_1+\sqrt{P_2}S_2 \tag{2.3}$$

The transmitting massage signal X_m is intended for user $m,\ m = 1,\ 2$. Therefore, the received signal at user m can be written as follows.

$$Y_m = H_m X_m+w_m=H_m\left(\sqrt{P_1}S_1+\sqrt{P_2}S_2\right)+w_m,\ \ for\ m= 1,2 \tag{2.4}$$

H$\in\mathbb{C}^{NXM}$, $Y\in\mathbb{C}^{NX1}$, X$\in\mathbb{C}^{MX1}$ and $w_m \sim CN\left(0,\sigma_n^2\right)\in\mathbb{C}^{NX1}$is independent and identically distributed complex additive white Gaussian noise (AWGN) with mean zero and variance σ_n^2. The signal transmit X_m has an average power constraint of P = P1 + P2, where P1 and P2 are the transmit powers for user 1 and 2, respectively. For all possible splits $P_T = \sum_{m=1}^{M} P_m$ of the total power at the base station. The optimal points are achieved by superposition coding at the transmitter and SIC at each of the receivers. The cancellation order at every receiver is always to decode the weak users before decoding its own data.

2.2.4 Channel and Signal to Interference plus Noise Ratio Model

Power factor α is allocated to user 1 for a large R1:

$$\alpha_1^2 = min\left(1, \frac{\left(|h_1|^2 + \frac{1}{SNR}\right)\left(2^{R_1} - 1\right)}{|h_1|^2 2^{R_1}}\right) \quad and \quad \alpha_1^2 + \alpha_2^2 = 1$$

The optimal solution to power factor in the n^{th} cluster using SNR ρ, (P/N_o) can also be obtained by using the Karush-Kuhn-Tucker (KKT) condition below where $\alpha_2^n = 1 - \alpha_1^n$ and also, w is the AWGN with zero mean and variance σ_n^2.

$$\alpha_i^n = \frac{1}{\sqrt{1 + |h_{2,n}|^2}} - \frac{\left(\sqrt{(1 + |h_{2,n}|^2\rho)} - 1\right)\left(\sum_{i=1,\ i \neg n}^{N} |h_{2,i}w_i|^2\rho + 1\right)}{\rho\left(|h_{2,i}w_i|^2\right)\sqrt{(1 + |h_{2,n}|^2\rho)}}$$

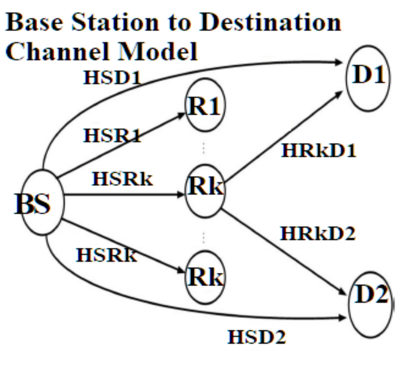

Figure 2.6: The NOMA down link channel model.

$$X_s = \sqrt{\alpha_1 P_s} x_1 + \sqrt{\alpha_2 P_s} x_2$$

$$Y_{R_k} = h_{SR_k} X_S + n_{R_k}$$

$$Y_{R_k} = h_{SR_k}(\sqrt{\alpha_1 P_s} x_1 + \sqrt{\alpha_2 P_s} x_2) + n_{R_k}$$

$$Y_{D_1} = h_{SD_1}(\sqrt{\alpha_1 P_s} x_1 + \sqrt{\alpha_2 P_s} x_2) + n_{D_1}$$

$$Y_{D_2} = h_{SD_2}(\sqrt{\alpha_1 P_s} x_1 + \sqrt{\alpha_2 P_s} x_2) + n_{D_2}$$

In the second phase, Rk transmits the signal $X_{R_k} = G_k Y_{R_k}$ to both D_1 and D_2, with G_k denoting the amplifying gain at the k-th relay, i.e.,

$$G_k^2 = \frac{P_{R_k}}{P_S |H_{SR_k}|^2 + N_o}$$

where P_{R_k} denotes the transmit power of the k-th relay. Without loss of generality, we assume that the transmit powers at all relays equal to the transmit power of the BS, i.e., $P_{R_1} = P_{R_2} = ... = P_{R_K} = P_S = P$. Therefore, the received signals at D1 and D2 (forwarded by Rk) are given by;

$$Y_{R_k D_1} = h_{R_k D_1} X_{R_k} + n_{R_k D_1}$$

$$Y_{R_k D_1} = G_k h_{SR_k} h_{R_k D_1} (\sqrt{\alpha_1 P_s} x_1 + \sqrt{\alpha_2 P_s} x_2) + G_k h_{R_k D_1} n_{R_k} + n_{R_k D_1}$$

$$Y_{R_k D_2} = G_k h_{SR_k} h_{R_k D_2} (\sqrt{\alpha_1 P_s} x_1 + \sqrt{\alpha_2 P_s} x_2) + G_k h_{R_k D_2} n_{R_k} + n_{R_k D_2}$$

To calculate the instantaneous signal-to-interference-plus-noise ratio (SINR) of the two phases, let us define the average transmit SNR, $\gamma_0 = P/N0$, and the random variables (RVs) $Qi = \gamma_0 |h_{SD_i}|^2$, $L_k = \gamma_0 |h_{SR_k}|^2$ and $Z_{ik} = \gamma_0 |h_{R_k D_i}|^2$ represent the instantaneous SNRs of the links $S \to D_i$ $S \to R_k$ $R_k \to D_i$ where $k = 1, 2, ..., K$ and $i = 1, 2$. In the first phase, treating Q_2 as interference in Y_{D_1}, the instantaneous SINR at D_1 can be given by

$$Y_{SD_1} = \frac{\alpha_1 \gamma_0 |h_{SD_1}|^2}{\alpha_2 \gamma_0 |h_{SD_1}|^2 + 1} = \frac{\alpha_1 Q_1}{\alpha_2 Q_1 + 1} \tag{2.5}$$

Similarly, the instantaneous SINR at D2 to detect x1 can be written as

$$Y_{SD_{12}} = \frac{\alpha_1 Q_2}{\alpha_2 Q_2 + 1}$$

Based on NOMA scheme, D_2 first decodes the message designated for D_1 and removes it using SIC, then it decodes its own message without interference. Therefore, the instantaneous SNR at D_2 can be expressed as;

$$Y_{SD_2} = \alpha_2 Q_2$$

In the second phase, the calculation of the instantaneous SINRs is similar to that in the first phase. Thus, the instantaneous SINR at D_1 related to link $R_k \to D_1$ can be written as

$$\gamma_{R_k D_1} = \frac{\alpha_1 L_k Z_{1k}}{\alpha_2 L_k Z_{1k} + L_k + Z_{1k} + 1}$$

Regarding the link $R_k \rightarrow D_2$, the instantaneous SINR at D_2 to detect X_1 and the instantaneous SNR at D_2 to detect its own data X_2 are, respectively, given by

$$\gamma_{R_k D_{12}} = \frac{\alpha_1 L_k Z_{2k}}{\alpha_2 L_k Z_{2k} + L_k + Z_{2k} + 1}$$

$$\gamma_{R_k D_2} = \frac{\alpha_2 L_k Z_{2k}}{L_k + Z_{2k} + 1} \tag{2.6}$$

Finally, from (2.5) to (2.5), the instantaneous SINRs at D1 and D2 based on selection combining, which has a lower complexity than maximal-ratio combining (MRC), can be written as

$$\gamma_{D_1} = max(\gamma_{SD_1}, \gamma_{R_1 D_1})$$

$$\gamma_{D_2} = max(\gamma_{SD_2}, \gamma_{R_1 D_2})$$

In this thesis only source to destination D channel estimation considered and the next chapter will be the performance of non orthogonal multiple access in down link power domain using SIC algorithm to evaluate performance of non-orthogonal multiple access by considering on the comparison of orthogonal and non-orthogonal multiple Access.

Chapter 3

Performance of Non-Orthogonal Multiple Access

3.1 Downlink Power Domain NOMA

In an orthogonal multiple access (OMA) system, such as TDMA FDMA and CDMA orthogonal resource allocation is used among users to avoid intra-cell (inter-user) interference. The number of users that can be supported is then limited by the number of orthogonal resources available. Non-orthogonal multiple access (NOMA) allows and utilizes intra-cell interference in the resource allocation of users. The Interference cancelation techniques, such as parallel interference cancelation (PIC), success interference cancelation (SIC) or multi-user detection (MUD) are used to mitigate this interference. NOMA is a technique being considered by 3GPP in Release 16.

The system model that is considered in this chapter allows to assess the performance of NOMA for typical configurations of multi-user SIMO systems without precoding at the base station, which is possible independently of the NOMA power allocation policy. Users are clustered into SIMO NOMA is used within one cluster as in Figure 3.1 in [48], where SIC is used at each terminal to separate the NOMA users signals. Inter-cluster interference is dealt with linear filtering at the terminals as in SIMO multi-user systems. The intra-cluster users are ordered according to their channel power. To the best of our knowledge, comprehensive simulation results are presented for the first time for multi-user NOMA systems with two or more than two users.

To address the various challenges of 5G networks, either develop novel modulation techniques to reduce multiple user interference for OMA or directly use NOMA. This thesis presents and analyses a down link NOMA-SIMO system with users grouped in one clusters and with SIMO processing removing the inter-user interference cancellation by SIC algorithm. Numerical results are presented for two to three users per one cluster with assumed BPSK modulation. With NOMA, the limited spectrum resources can be fully utilized to support more users, therefore the capacity of 5G networks can be improved significantly even though extra interference.

This wireless communication system in [47]-[50] consisting of a source, denoted by S, and two users which are associated with different channel conditions, witch denotes the user with good channel condition by UE_1, and the one with bad channel condition by UE_2. All nodes are equipped with a single-antenna. Let h_1, and h_2 denote the complex channel coefficient between S and UE_1, and UE_2 respectively. All channels are assumed to be independent and identically distributed Rayleigh block fading. From the assumption about channel quality,the H_1 greater than H_2 where H_n is equal to absolute value of h_n over two users noise power.

Down and up link NOMA can be viewed as special cases of multiple access channels (MACs) and broadcast channels (BCs). Therefore, the rate regions achieved by NOMA were bounded by the capacity regions of the corresponding MACs and BCs in [49]. Figure 3.1 shows a down link (DL) NOMA network. A BS transmits its signals to M user equipments (UEs) through N sub-channels, and SIC is employed at the receiver of UEs. Denote n as index for the n^{th} sub-channel where $n \in \{1,2,\ldots,N\}$ and m as index for the m^{th} mobile user where $m \in \{1,2,\ldots,M\}$. In the cell, M users are uniformly distributed in a circular region of radius R.

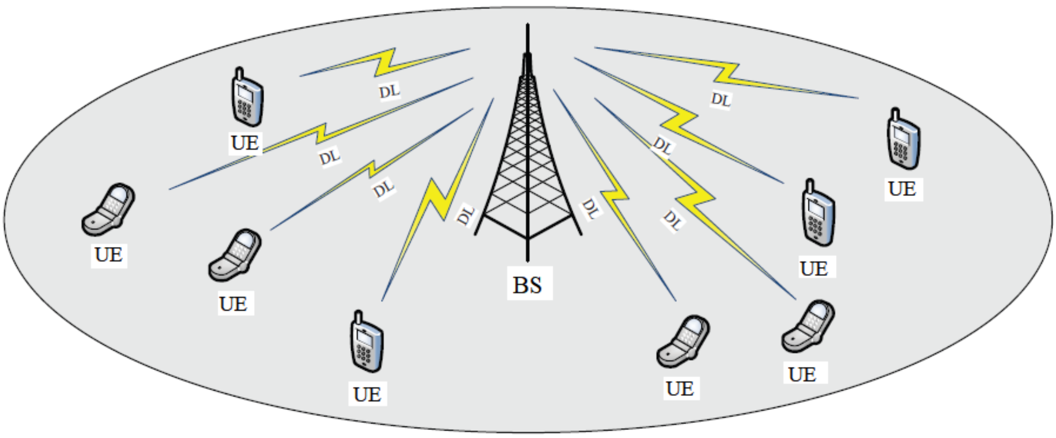

Figure 3.1: Down-link NOMA system model single-cell network.

As an alternative to OMA, NOMA in [48], [49] introduces a new dimension by performing multiplexing within one of the classic time/frequency/code domains. In other words, NOMA can be regarded as an ‘‘add-on”, which has the potential to be harmoniously integrated with existing MA techniques. The core of NOMA is to utilize power and/or code domains in multiplexing to support more users in the same resource block.

Power domain NOMA technology assigns different powers to different users according to the users' channel condition. In order to realize the power domain NOMA system, the user scheduling algorithm at the transmitter side by superimposed coding (SC) and perform the SIC detection at the receiver side to separate the user signals from each other. For multi-user cellular communication systems, a proper power control can be performed at the transmitter, such that the interference to be effectively mitigated at the receiving terminal. The performance of the SIC detector highly depends on the received signal quality. In general, the performance of the SIC detector improves with the increasing disparities of the strength received signals.

The user channels are fixed during the communication session and are known at the BS. The user with worse channel condition (weak user) decodes its message by treating the other user's interfering signal as noise, while the user with a relatively better channel condition (strong user) first decodes the weak user's message by treating its own signal as noise and then uses successive interference cancellation to decode its own message. There are two users on each sub-carrier since the increasing number of users multiplexed on the same sub-carrier cause the growth of hardware complexity and processing delay.Without loss of generality, it is assumed that user m and n are paired together for NOMA scheme.

The total bandwidth BW of the system is equally divided into N sub-channels where the bandwidth of each sub-channel is BWsc = Total BW/N. Let $M_n \in (M_1, M_2, \ldots, M_N)$ be the number of users allocated on the sub channel n (SC$_n$) and the power allocated to the M^{th} user on SC_n is denoted by $P_{m,n}$, i.e, user M on sub-channel n. Then, the sub channel and BS power constraints are given by:

$$P_T = \sum_{m=1}^{M_n} P_{m,n} = P_m \ \ \forall_{m,n}$$

$$P_S = \sum_{n=1}^{N} P_m$$

Where $P_{m,n}$ is allocated power on SC_n, P_m is sum of all users power in one sub-channel, and P_S is total transmitted power of the BS. In NOMA systems, assume that the BS has full knowledge of the channel state information.

According to the NOMA protocol multiple users can be allocated to the same sub channel with SIC technique. A block fading channel is considered in the system model and it is the same for each user per one sub-channel but it varies independently across different sub channels. Based on the parameters and constraints of the system, BS needs to assign multiple users in each sub channels with different power levels and allocate different powers across sub channel. Considering Mn users are allocated on SCn, the symbol transmitted by the BS on each sub channel SCn can be expressed as:

$$X_n = \sum_{m=1}^{M_n} \sqrt{P_{m,n}} S_m \tag{3.1}$$

$$Y_m = H_m x + n_m = H_m \left(\sqrt{P_{m_1,n}} S_1 + \sum_{m_1=1, m_1 \neq m_2}^{M_n} \sqrt{P_{m_2,n}} S_2 \right) + w_m, \ \ for\ m = 1,2 \tag{3.2}$$

The received signal at the m^{th} user on SC n is Y_m and H_m is absolute value of channel gain $h_{m,n}$ over noise power (variance σ_n^2). Where S_m is the modulated symbol of m^{th} user on SC_n, which is denoted by $UE_{m,n}$. Where $h_{m,n} = g_{m,n} * PL^{-1}(d)$ is the coefficient of SCn from the BS to $UE_{m,n}$, and where $g_{m,n}$ is assumed to have Rayleigh fading channel gain, and $PL^{-1}(d)$ is the path loss function between the BS and $UE_{m,n}$ at distance d. The performance gain of the NOMA over OFDMA will increase when the difference of channel gain of users become larger. Let $w_m \sim CN(0, \sigma_n^2)$ be the additive white Gaussian noise with mean zero and variance σ_n^2. In a down link NOMA network, each sub channel can be shared by multiple users.

3.2 Channel Estimation

In NOMA systems, the SIC process is implemented at UE receiver to reduce the interference from other users on the same sub-channel. The optimal decoding order for SIC is the increasing order of CRNNs in [50],[52] . Based on this order, any user can successfully and correctly decode the signals of the other users with smaller CRNN values. Thus, the interference from the users having poorer channel condition can be cancelled and removed by the user who has better channel condition. In order to maximize the sum rate of SCn, the NOMA protocol allocates higher power to the users with lower CRNN, i.e, for two users $UE_{m_i.n}$ and $UE_{m_j.n}$ sharing the same SCn with CRNN $|H_{m_i.n}| \geq |H_{m_j.n}|$ it always set $P_{m_i,n} \leq P_{m_j,n}$ to guarantee the weak user's communication quality. This assumption is widely used in the NOMA scheme. Consider that M_n users are allocated on SCn with CRNNs order as follows.

$$|H_{1.n}| \geq |H_{2.n}| \geq \cdots \geq |H_{m_k.n}| \geq |H_{m_k+1.n}| \geq \cdots \geq |H_{M_n,n}| \tag{3.3}$$

$$H_{N,M} \in \mathbb{C}^{N\ X\ M}$$

$$H_{1,1} = \begin{bmatrix} h_{1,1}, \ldots, h_{1,M} \\ \vdots \\ \alpha_{N,1}, \ldots, h_{N,M} \end{bmatrix} generalized$$

According to the optimal SIC decoding order, User m_k can successfully decode and remove the interference symbols from users $m_i > m_k$, for $k = 1, 2, 3 \ldots$, where $i \neq k$. However, the interference symbol from User m_i ($m_i < m_k$) cannot be removed and will be treated as noise by user m_k. Therefore, the SINR of user m_k with SIC at receiver can be written as:

$$SINR_{m_k,n} = \frac{P_{m_k,n} H_{m_k.n}}{1 + \sum_{i=1}^{k-1} P_{m_i,n} H_{m_k.n}} \tag{3.4}$$

Where $\sigma_n^2 = E\left[|w_{m_k,n}|^2\right]$ noise is power on SC_n and $H_{m_k.n} \triangleq |h_{m_k.n}|^2 / \sigma_n^2$ represents the channel response normalized by noise (CRNN) of the user m on SC_n. H represent the channel gain normalized by noise of user m on sub channel n. Without causing notational confusion, $h_{m_k.n}$ is the channel gain of $UE_{m_k.n}$, while $H_{m_k.n} \triangleq |h_{m_k.n}|^2/\sigma_n^2$ denotes the channel response normalized by noise (CRNN) of $UE_{m_k.n}$. Where means that "A is defined to be B".

The optimal power allocation with given channel assignment under various performance criteria for NOMA systems. Optimal power allocation with given channel assignment under various performance criteria of NOMA. Optimal power allocation of the users on each channel, which can be expressed as functions of the power budget of each channel. Then, the optimized power budgets of all channels and thus obtained the optimal multichannel power allocation, which can be characterized in a closed or semi-closed form.

To describe the dynamic matching between the users and channels, consider channel assignment as a two-sided matching problem between the set of M users and the set of N channels, where N=M/2 since each channel is shared by two users. Denote channel n by H_n. The UE_m and H_n are matched with each other if UE_m is assigned on Hn. Moreover, denote PF (UE_m) for m = 1, 2,..., M and for n = 1, 2,..., N to be the preference lists of the users and channels respectively. The UE_m prefers H_1 to H_2 if UE_m has a higher channel gain (h_n) on H_1 than H_2 as $h_{m_1,n} \geq h_{m_2,n}$, where H_n is channel response normalized by noise on the channel n.

In addition, if the users in set UE_{m_i} can provide better performance than the users in set UE_{m_k} on $H_{m,n}$, then $H_{m,n}$ prefers user set UE_{m_i} to user set UE_{m_k} (where UE_{m_i} and UE_{m_k} are the subsets of 1, 2,..., M). This preference is expressed as:

$$PM_m(UE_{m_i}) > PM_m(UE_{m_k}) \;\; for \;\; UE_{m_i}, UE_{m_k} \subset (UE_{m_i}, UE_{m_2}, ..., UE_{M,N})$$

Where $PM_m(UE_{m_i})$ denotes the performance measure of user set (UE_{m_i}) on channel n $H_{m_i,n}$, which could be the maximin fairness, sum rate, or energy efficiency will being introduced next. The following definition formally introduces a matching in the NOMA system and channel assignment optimization formulation as a two-side matches.

Definition 1. Consider the users and channels as two disjoint sets. A three-to-one matching is a mapping from all the subsets of users M into the one channels set N, which satisfies the following properties for $UE_m \in M_m$ and $H_n \in H_N$

1. $UE_m \in M_m$
2. $H_n \subseteq H_N$
3. $|UE_m| = 3, \quad |H_n| = 1$
4. $H_n \in UE_m \Longleftrightarrow (UEm) \in H_n$

Algorithm 1 Channel Assignment via user matching

1. Initialize:

(a) $S_{Match(m)}$ is the matched list to record users matched on $H_n, n = 1, 2, ..., N$.

(b) $S_{UnMatch(m_k)}$ is the set of unmatched users.

(c) Obtain preference lists $PF(UE_m), m = 1, 2, ..., M$ and $PF(Hn), n = 1, 2, ..., N$ according to CNRs.

2. while $S_{UnMatch}$ is not empty
3. for m = 1 to M do. Each user sends matching request to its most preferred channel n^* according to its preference list PF (UEm).
4. if $|S_{Match}(n^*)| < 3$ then Channel n^* adds UEm to $S_{match}(n^*)$ and removes UEm from $S_{UnMatch}$.

   end if
5. if $|S_{Match}(n^*)| = 3$ then

   (a) Identify the power allocation for every three users in $S_{UEm_i}, S_{UEm_{2i}}, \ and\ S_{UEm_{3i}} \subset S_{Match_{m,}}(n^*)$ according to the corresponding proposition with q_{n^*}.

   (b) Channel q_{n^*} selects a set of three users S_{UEm_i} satisfying the objective functions $O_{n^*}(UEm_i) > O_{n^*}(UEm_k)$, for $UEm_i, UEm_{2i}, and\ UEm_{3i} \subset S_{Match}m, (n^*)$ where $i = 1, 2 \ldots k-1$ for $k = 1, 2, \ldots K$, where they are integer numbers to identify users.

   (c) Channel n^* sets $S_{match}(n^*) = UEm_i$, and reject other users. Remove the allocated users from $S_{UnMatch}$, add the unallocated user to $S_{UnMatch}$.

   (d) The rejected user remove channel n^* from their preference lists.

   end if

   end for

   end while

The given a matching such that $UEm \notin (Hn)$ and $H_n \notin (UEm)$. If $O_n(S_{new}) > O_n(Hn))$ where $S_{new} \subseteq UEm \cup S$ and $S = (Hn)$, then S_{new} is the preferred user set for Hn and (UEm, SC_n) is a preferred pair on channel SC_n and O is user objective function on channel n (SC_n).

Meantime, $S_{Match}(n)$ and $S_{UnMatch}(n)$ for $n = 1, 2, ..., N$ are respectively initialized to record the allocated users on H_n and unallocated users. Then, the channel accepts user directly if the number of users on this channel is less than three, otherwise only the user that can improve the performance will be accepted. This matching process will terminate when there is no user left to be matched.

Algorithm 2 Joint Channel Assignment and Power Allocation Optimization.

1. Initialize: $q_n = \frac{P}{M}$ for $n = 1, ..., N$.
2. Repeat the first step.
3. Obtain channel assignment $\{S_{Match}(n)\}_{n=1}^{N}$ using Algorithm 1

4. Compute $P_1^*, P_2^*, P_3^*,\ and\ q^*$ according to the results this thesis mat-lab simulation.
5. Until the prescribed iteration number is reached.
6. Output: $\{S_{Match}(n)\}_{n=1}^{N}, P_1^*, P_2^*, and\ P_3^*$

Now, able to jointly optimize channel assignment and power allocation by using Algorithm 1 and the optimal power allocation obtained were described in Algorithm 2. In the initialization, the BS allocates power budgets to all channels depending on the user distance R (radius) in one cell base station. Furthermore, in Algorithm 2 the results can also reduce the complexity of exhaustive search in the joint continuous-discrete dimension of powers and channels. Next, the path loss over NOMA channel model and the optimization of SE, EE, and sum rate (data rate) for each user over multiple channel, where channel is assumed as fixed condition.

3.2.1 Path Loss Over NOMA Channel Model

3.2.1.1 Okumura Hata Model

Hata model is designed for large and small macro-cells, i.e. antenna heights above top roof levels adjacent to base station. Suburban path loss model the most widely used path loss model for signal strength prediction and simulation in macro cellular environments is the Hata-Okumura model in [53]. This model is valid for the 500-1500 MHz frequency range. Base station antenna height and receiver radius distances are greater than 30 meter and 1 km from the base station respectively. There exists an elaboration on the Hata-Okumura model that extends the frequency range up to 2000 MHz. It was found that these models are not suitable for lower base station antenna heights, and hilly or moderate-to-heavy wooded terrain. To correct these limitation a below model proposed.

Where A,B and C are variables factors that depend on frequency and antenna height as well as d is the distance in kilometers. The model is designed for large cells where there are no dominant obstacles between the base station and the mobile station and the terrain profile changes only slowly. The maximum path loss category is hilly terrain with moderate-to-heavy tree densities (Category A). The minimum path loss category is mostly flat terrain with light tree densities (Category C). Intermediate path loss condition is captured in Category B.

Table 3.1: Terrain catagoreis and constants.

Model parameter	Terrain Type A	Terrain Type B	Terrain Type C
A	4.6	4	3.6
B	0.0075	0.0065	0.005
C	12.6	17.1	20

Two forms of the Okumura-Hata model are available. In the first form, the path loss (in dB)

,witch is written as follows.

$$PL = PL_{freespace} + A_{exc} + H_{cd} + H_{cn} \tag{3.5}$$

Where $PL_{freespace}$ is the freespace path loss, A_{exc} is the excess path loss (as a function of distance and frequency) for a BS height h_b = 200 m, and a MS height h_m= 3 m. The correction factors over distance and chaneel n as h_{cd} *and* h_{cn} respectively. For a given reference distance d_0, the median path loss (PL in dB) is given below.

$$PL = A + 10B\log_{10}(d/d_0) + C \; for \; d > d_0$$

$$A = 20\log_{10}(\frac{4\pi d_0}{\lambda})$$

$$PL = 20\log_{10}(\frac{4\pi d_0}{\lambda}) + 10\gamma\log_{10}(d/d_0) + C \quad for \; d > d_0$$

The λ is being wavelength in meter, γ is the path-loss exponent with $\gamma = (a - b * h_b + c/h_b)$ for h_b between 10 m and 80 m, where h_b is the height of the base station in meter, $d_0 = 100m$ and a, b, and c are constants dependent on the terrain category witch are reproduced in Table 3.1. The γ is path-loss exponent given below.

Table 3.2: Path loss exponent constants.

Environment	Path Loss Exponent, n
Free Space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obsructed in building	4 to 6
Obsructed in factories	2 to 3

Therefore, the path loss is written as:

$$PL = A + B\log(d) + C$$

$$A = 69.55 + 26.16\log(f_c) - 13.82\log(h_b) - a(h_m)$$

$$B = 44.9 - 6.55\log(h_b)$$

The carrier frequency f_c is given in MHz and d is in kilometer. The function h_n and C are factors depend on the environment. For small and medium size cities:

$$a(h_n = (1.1)\log(f_c - 0.7)h_n - (1.56\log(f_c) - 0.8)$$

$$C = 0.$$

For metropolitan areas:

$$ah_n = \begin{cases} 8.29(\log(1.54h_n)^2 \ -1.1 \ \ for\, f \ \leq 200\, MHz) \\ 3.2(\log(11.7h_n)^2 \ -4.97 \ \ for\, f \ \geq 400\, MHz \end{cases}$$

$$C = 0.$$

For sub-urban areas:

$$C = -2[\log(f_c/28)]^2 - 5.4$$

For rural areas:

$$C = -4.78[\log(f_c/28)]^2 + 18.33\log(f_c) - 40.98$$

The function $a(h_n)$ in suburban and rural areas is the same as for urban (small and medium-sized cities) areas. Therefore, according to Hata model the path loss in an urban area at a distance d as follows.

$$PL_{urban}(d)dB = 69.55 + 26.16\log_1 o(f_c) - 13.82\log_1 o(h_t) - a(h_r) +$$

$$(44.9 - 6.55\log_1 o(h_t)\log_1 o(h_d))$$

Here, f_c is the carrier frequency, h_t is the height of the transmitting (base station) antenna, h_r is the height of the receiving (mobile) antenna, and ah_r is a correction factor for the mobile antenna height based on the size of the coverage area. Extension to Hata model is european cooperative for scientific and technical (COST) research extended the Hata model in GHz as follows.

$$PL_{urban}(d)dB = 46.3 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_t) - a(h_r)$$

$$+(44.9 - 6.55\log_{10}(h_t)\log_{10}(h_d)) + C_M$$

Here, C_M is $0dB$ for medium sized cities and suburbs and is $3dB$ for metropolitan areas. The remaining parameters are same as before. This model is restricted to the following range of parameters.

Let us focus on down link NOMA system considering that three users are multiplexed on the same sub-channel with the channel gains (channel coefficient) $|h_1|^2 \geq |h_2|^2 \geq |h_3|^2$ and

Table 3.3: This model is restricted to the following range of parameters:

Parameters Names	Ranges
Carrier Frequency	1.5 GHz to 2 GHz
Base Antenna Height	30 m to 300 m
Base Antenna Height	1 m to 10 m
Distance from BS (d)	1 km to 20 km

considering category B where $h_n = g_n \;\; PL^{-1}(d)$, assume g_n were on Rayleigh fading (follows Rayleigh distribution) channel gain or g_n is an N x M matrix (number of M transmit and N receive antennas), which denotes Rayleigh fading channel gains and $PL^{-1}(d)$ is the path loss function between the BS and user m at distance d.

$$PL = \left(\frac{\lambda}{4\pi d}\right)^{-\gamma} = \left(\frac{c}{4\pi df}\right)^{-\gamma} \tag{3.6}$$

$$c = 3x10^8 \frac{m}{s} \; and \; f \; is \; frequency \; per \; second$$

The γ is path loss exponent with is varied in different medium. Example, γ is two for free space.

$$h_n = g_n \;\; PL^{-1}(d) = g_n \left(\frac{\lambda}{4\pi d}\right)^{-\gamma}$$

$$h_n = g_n \;\; \left(\frac{4\pi df}{c}\right)^{\gamma} = g_n \;\; \left(\frac{4\pi df}{c}\right)^{2}$$

$$h_n = g_n \;\; \left(\frac{4\pi df}{c}\right)^{2}$$

Where $g_I \; and \; jg_Q$ represent the in-phase and the quadrature phase components, respectively. In this case, the channel gain coefficient denote $g = re^{j\emptyset}$ and it can be written as:

$$g_n = g = g_I + jg_Q$$

The PDF of the random variables r and $\emptyset$ obtained through the transformations. Based on the general transformation the PDF of r and $\emptyset$ random variables written as:

$$f\,(\mathrm{r},\emptyset) = \frac{r}{2\pi\sigma^2} \;\; exp\left(-\frac{\mathrm{r}^2}{2\sigma^2}\right), r \geq 0, \; 0 \leq \emptyset \leq \frac{\pi}{2} \tag{3.7}$$

$$f\,(r) = \int_0^{\frac{\pi}{2}} f(r,\emptyset\,)d\emptyset = \frac{r}{2\pi\sigma^2} \;\; exp\left(-\frac{\mathrm{r}^2}{2\sigma^2}\right), r \geq 0$$

$$f(\emptyset) = \int_0^{\infty} f(r,\emptyset)dr = \frac{1}{2\pi}\ ,\ 0 \leq \emptyset \leq \frac{\pi}{2}$$

This result shows that the magnitude of channel coefficients is a random variable with a Rayleigh distribution and the phase angle $\emptyset$ is uniformly distributed on $[0, \frac{\pi}{2}]$. Because the magnitude of channel coefficients follow a Rayleigh distribution model is commonly called a Rayleigh fading model.

3.2.2 Received Signal-to-Interference-plus Noise Ratio (SINR)

The received signal-to-interference-plus noise ratio (SINR) in [54] of the m^{th} user on the SCn is written by:

$$SINR_{m,n} = \frac{P_{m_k,n}|h_{m.n}|^2}{\sigma_n^2 + \sum_{m_i}^{M_{k-1}} P_{i,n}|h_{m.n}|^2} = \frac{P_{m_k,n}H_{m.n}}{1 + \sum_{m_i=1}^{M_{k-1}} P_{i,n}H_{m,n}} \tag{3.8}$$

Where, k=1,2,... K=3 users index for i=k-1 in other word, for three user the index will be 4 then i=k-l (4-1=3) is for third user index. The i=k-1 are user index that interfering m_k user, m_i were bad channel condition. Note that m=1, 2, ... M users, where M were three users considered in this thesis. Without causing notational confusion, $UE_{m,n}$ denotes the m^{th} user on SCn, while UE_m denotes the m^{th} user in the cell, where $m \in \{1, 2, \ldots, M\}$. Where $I_{m,n}$ is the interference that $UE_{m.n}$ receives from the other users on the SCn, or i is another users interfering user m in same sub channel n which can be expressed as follows.

$$I_{m,n} = \sum_{m_i}^{M_{k-1}} p_{i,n}H_{m.n} \tag{3.9}$$

3.2.2.1 Signal to Noise Ratio (SNR)

Signal to noise-Ratio (SNR) is defined as the ratio of the received signal power (P_r) to the noise power (P_{noise}). If SNR is more than one, then it shows that P_r is stronger than the noise power P_{noise}. The mathematical expression of SNR and it is normally expressed in decibel (dB) as follows.

$$\text{SNR}_{dB} = 10\log_{10}\left(\frac{\text{Signal Power}}{\text{noise power}} = \frac{P_r}{P_{noise}}\right) dB$$

$$\text{SNR} = \frac{\text{P}_\text{r}}{\text{P}_\text{noise}} \tag{3.10}$$

SNR is the average signal to noise ratio (SNR) given as: SNR = (E_b/N_o) where Eb is the bit energy. N_o and σ_w^2 are the noise energy and variance N_0=2σ_w^2 Where h_n is random channel attenuation factor capturing the joint effect of small-scale and large-scale fading link between user m and BS, and the power spectral density of additive white Gaussian Noise (AWGN) w_k

at the UE_m is N_{0_m}, which means that it follows the Gaussian distribution with zero mean and variance σ_m^2. Let us consider the farthest user signal decode first and other users data will be seen as interference. B or W denotes transmission bandwidth in this thesis. SNR1 for the closest UE1, the last signal it decodes will be its signal. Therefore, the signal-to-noise ratio (SNR) for UE_m can be written as follows.

$$SNR_1 = \frac{P_1 g_1^2}{N_0 B} \; For\ one\ user$$

$$SNR_m = \frac{P_{m_k} g_m^2}{N_0 B + \sum_{m_i}^{M_k} P_{m_i} g_M^2} \; \forall_{user}$$

The SC_n B of NOMA user m UE_m is $B_m = B_{total}/M$, data rate of OMA and NOMA will be:

$$R_{Toatal} = \sum_{m=1}^{M} R_M$$

$$F = \frac{(\sum R_M)^2}{M \sum R_M^2}$$

F which indicates how fair the system capacity is shared among the UE_m, that is, when F gets close to 1, and the capacity for each UE gets close to each other. F' is the target fairness index in the network. The objective of power allocation mechanism is as to maximize the sum capacity R_{total} under a fairness constraint for NOMA systems. The power allocation coefficients α_m for each UE_m can be seen before. The optimization problem is then formulated as:

$$Maximize\ B \log_2 \left[1 + \frac{P_m g_m^2}{N_o + \sum_{m=1}^{M-1} P_{m_i} g_m^2} \right]$$

$$Subjects\ to\ (s.t): \sum_{m=1}^{M} P_m \leq P_T$$

$$F = F' \ \ and \ \ P_M \geq 0, \forall_M$$

3.3 Power Allocation of NOMA System Model

In this thesis power domain adaptive NOMA down link the system model considered a single-cell wireless network in which the locations of M users are uniformly distributed in a disc with radius R, denoted by R, and the BS is located a the center of disc. It is assumed that all users are served by the same orthogonal channel use, which can be a time slot, a spreading code or a frequency channel. Furthermore, assume that all the users and the BS are equipped with a single antenna. The overall bandwidth B is divided into N sub-channels, each with bandwidth

B/N.We use M and N to denote the sets of users and subchannels, respectively, and $g_{m,n}$ to denote the channel gain between the BS and user m on subcarrier n. Let $P_{m,n}$ be the power allocated to user m on subcarrier n. A user m is said to be multiplexed on a subchannel n, if and only if $P_{m,n} \geq 0$. The power values are subject to optimization.

In cellular mobile communications, the system performance is usually limited by the low received signal-to-noise ratio (SNR) of the cell edge users. In the case of OMA transmission, if the objective of system design is to maximize the capacity, then those users located at the cell edge will rarely be scheduled in [54]. Therefore, it results in an unfair resource allocation and user starving. In particular, we examine the detection algorithm of the SIC receiver using the power domain in the channel and power allocation strategy in [54] taking into account user rate fairness requirement in the system.

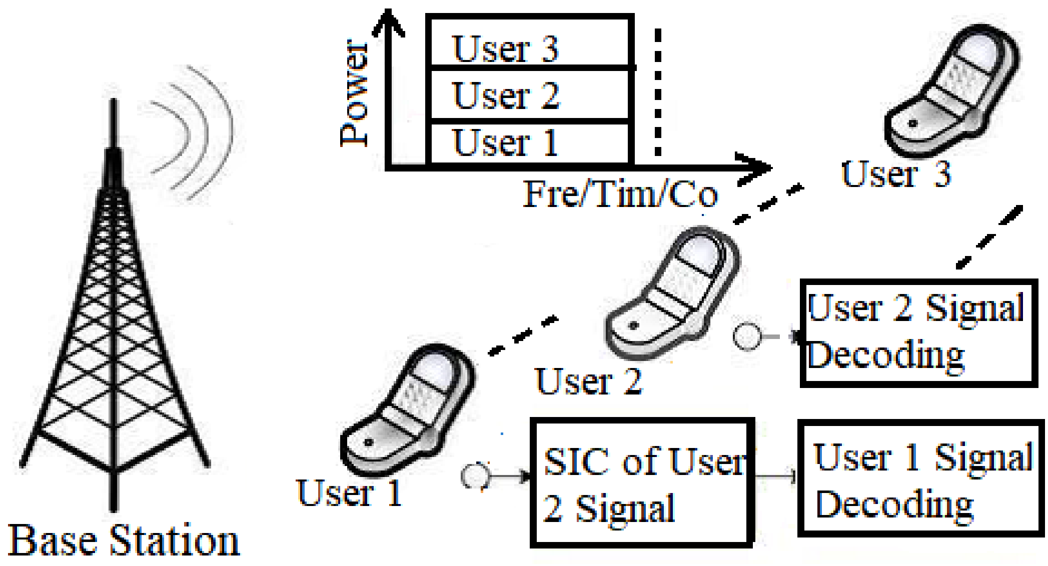

Figure 3.2: Down-link model of NOMA communication.

The closed form solution of the power allocation of NOMA system and the corresponding detection algorithm of the user power allocation are deduced. The figure 3.2 shows that there are three users that multiplexed into one sub-carrier or sub-channel etc. The user 1 is closer to the BS compared to user 2 and 3, which implies user 1 has a better channel condition comparing to user 2. The base station optimizes the transmit power for each user on sub-carrier. Instead of allocating all the power to one users, user 1 with stronger channel condition is allocated less transmitted power and more transmit power is allocate to user 3.

Compared to conventional OMA, user 2 is allocated with non-zero power which provides certain fairness in resource allocation. Assigning user 1 with less power leads a small decrease in its capacity but a significantly good effect on user 2's. Therefore, user pairing and power allocation are able to strike a balance between the system performance and resource allocation fairness. As shown in Figure 3.2, these three users, user 1, 2 and 3 as well as their data S_1, S_2, and S_3 transmitted on the same sub carrier with different transmit power P_1, P_2, and P_3 respectively by a BS. The corresponding transmitted information signal from BS is given by:

$$X_m = \sum_{m=1}^{M} \sqrt{\alpha_m P_T} S_m \quad for \sum_{m_i=1}^{M_u} {\alpha_m}^2 = 1$$

$$X_m = \sqrt{P_1} S_1 + \sqrt{P_2} S_2 + \sqrt{P_3} S_3 = PS$$

$$P_m = \alpha_m P_{Total} \tag{3.11}$$

$$Y_m = H_m X_m + w_m \tag{3.12}$$

$$Y_3 = H_1 X_1 + w_1 \;\; For \;\; user \;\; 1$$

$$Y_2 = H_2 X_2 + w_2 \;\; For \;\; user \;\; 2$$

$$Y_3 = H_3 X_3 + w_3 \;\; For \;\; user \;\; 3$$

Where S_1, S_2, and S_3 are information carrying signals for the strong and weak user respectively. P_{total} is the total BS's transmit power budget, $\alpha_1 \in$ [0, 1] or $\alpha = P_{user}/P_{total} * (distance)$ is the fraction of power allocated to the strong user to to power and $\alpha_2 = 1 - \alpha_1$. Simply, in system down link framework we illustrate basic NOMA concept and implement the case with single transmit and receive antenna. Where X_m is the individual information conveying OFDM waveform, α_m is the power allocation coefficient for the user equipment's. $P_m = \alpha_m P_{total}$ the power is allocated according to the distance of user equipment's to the BS.

It is also important to discuss how the users know their power allocation coefficients and thus their respective order in the decoding chain. When a user enters a cluster it is assigned an ID. Then, each user has to send pilots so that the base station is able to estimate each channel coefficient associated to each user. After that, the BS broadcasts a packet containing the power coefficients allocated to each user. By looking at the position associated to its ID, each user gets to know its own power coefficient and similarly gets to know the coefficients of all the other user being able to calculate his position in the decoding chain and comparing his coefficient with the others.

The idea is that each user information is independently modulated in a BPSK constellation and then the information is summed with appropriate power allocation coefficients that ensure the resulting signal forms a higher-order BPSK modulation. Where α_m is in the square root of the power allocation coefficient with the constraint M is the total number of users that share the same NOMA channel and X_m is the modulation symbol of user m.

Thus, the BS will allocate more power to user m_3 (weak user), which means $P_{m_3} \geq P_{m_2} \geq P_{m_1}$ due to the NOMA protocol. Let us now consider the down link case, with $|h_1| < |h_2| < |h_3|$ and both coefficients are constant (they are time invariant). In this case, since user 2 will have a better channel, it will perform SIC, decoding the data of user 1 and then subtracting that data from the linear superimposed signal ($y_2 = h_1x_1 + h_2x_2 + n_1$) etc. Finally, it decodes its own data. Since user 1 will have the worst channel, it will just treat user 2's signal as interference and decodes its own data from the superimposed signal of user 2 and 3.

For the down link NOMA network, SIC technique is well investigated. The implementation complexity of SIC at the receiver increases with the maximum number of the users allocated on the same sub-channel. In order to keep the receiver complexity comparatively low, considered a simple case where only one to three users are allocated on the same sub-channel n. This assumption is important because it also restricts the error propagation. The next section data sum rate of NOMA will be achieved.

3.4 Achievable Sum Rate (R) of NOMA

3.4.1 Capacity Region

When point to points case are analyzed, the capacity of channel is a performance limitation, namely, it can reliably communicate at rates R < C and cannot at rates R > C. In multi-user cases, this concept is extended to a capacity region C, namely a region where (e.g., for the 2 users case) user 1 and 2 can reliably communicate at R_1 and R_2. Since they are sharing the bandwidth, when one needs to communicate at a higher rate, the other may need to lower his rate. Some performance measures can be derived from this region C.

3.4.1.1 The Symmetric Capacity:

$$C_{sys} = \underbrace{max}_{(R,R)\in \mathtt{C}} R$$

Which is the maximum rate at which both users can simultaneously communicate.

3.4.1.2 The Sum Capacity:

$$C_{sum} = \underbrace{max}_{(R_1,R_2)\in \mathtt{C}} R_1 + R_2$$

Which is the maximum total throughput that can be achieved by the system. In the two user case, the capacity region needs to satisfy three constraints:

$$R_1 < \log_2\left(1+\frac{P_1}{N_o}\right) \quad and \quad R_2 < \log_2\left(1+\frac{P_2}{N_o}\right)$$

$$R_1 + R_1 < \log_2\left(1+\frac{P_1+P_2}{N_o}\right)$$

The first two constrains basically say that the rate of a user cannot be higher than the capacity of point-to-point link, where the other user is absent, which is obvious since the introduction of more users will degrade the individual rates and not improve them. The third constrain says that the total throughput of the system cannot exceed the capacity of point-to-point AWGN channel with the sum of two users received powers. This applies the two users signal sent are independent and therefore the power of aggregate received signal is the sum of individual power signals. Without this constrain the capacity region would be a rectangle, meaning that both users could simultaneously transmit at the point to point capacity, as if the other user did not exist, which would not make sense.

3.4.1.3 Shannon's Channel Capacity

Shannon derived the following capacity formula (1948) for an additive white Gaussian noise channel (AWGN) written as:

$$C = Wlog_2(1+S/N)[bits/second] \tag{3.13}$$

- W is the bandwidth of the channel in Hz.
- S is the signal power in watts.
- N is the total noise power of the channel watts.

Thus, the superposition coding scheme can be implemented by the following steps.

1. A given communication system has a maximum rate of information channel capacity C.
2. If the information rate R is less than C, then one can approach arbitrarily small error probabilities by using intelligent coding techniques.
3. Thus, if R $\leq$ C then transmission may be accomplished without error in the presence of noise.
4. To get lower error probabilities, the encoder has to work on longer blocks of signal data. This entails longer delays and higher computational requirements.

Unfortunately, Shannon's theorem is not a constructive proof it merely states that such a coding method exists in [50],[55]. The proof can therefore not be used to develop a coding method that reaches the channel capacity. The negation of this theorem is also true: if $R > C$, then errors cannot be avoided regardless of the coding technique used. According to the Shannon's capacity formula, the data rate for user 1 and 2 with band-width B can be achieved by:

$$R_1{=}B\log_2\left[1{+}\frac{P_1|h_1|^2}{P_2|h_1|^2+\sigma_n^2}\right] \tag{3.14}$$

$$R_2{=}B\log_2\left[1{+}\frac{P_2|h_2|^2}{\sigma_n^2}\right] bits/s \tag{3.15}$$

$$\sigma_n^2=\frac{No}{2}\ \ where\ No\ is\ noise\ power$$

M users are distributed in a down link network with SIC at the receivers and $|h_m|\geq|h_{m-1}|\geq\cdots\geq|h_1|$. The boundary of capacity region is given by:

$$R_m{=}B\log_2\left[1{+}\frac{P_m|h_m|^2}{\sigma_n^2+|h_m|^2\sum_{j=m+1}^{M}P_j}\right]\ for\ m=1,2,\ldots,M \tag{3.16}$$

Therefore, the overall sum rate of the NOMA system can be written as:

$$R=\sum_{n=1}^{N}\sum_{m=1}^{M_n}R_{m,n}(P_{m,n})=\sum_{n=1}^{N}R_n(P_n)$$

$$R_n(P_n)=B_{sc_n}\log_2\left(1+\alpha_nP_nH_{m,n}\right)+B_{sc_n}\log_2\left(1+\frac{(1-\alpha_n)P_nH_{2,n}}{1+\alpha_nP_nH_{2,n}}\right)$$

Where α_n is the power proportional factor for the two users on SCn. Generally, α_n is used for the user who performs SIC on SCn and $\alpha_n\in(0,1)$. The optimal power proportional factor can be decided within our proposed sub-channel assignment scheme. Denote the assigned power on $\mathrm{SC_n}$ by $\mathrm{P_n}$. The bandwidth of the sub-channel is B on $\mathrm{SC_n}$ and the power proportional factors for User 1 and 2 are α_1 and α_2, respectively. Instead power domain NOMA can support multiple users within the same resource block by distinguishing them with different power levels. The down link transmission of NOMA for the three user case is shown in below where the users are served at the same time/frequency/code resource block with a total power constraint. Specifically, the BS sends a superimposed signal containing the two signals for the two users. The data rates of user 1 and 2 in NOMA systems can be respectively represented as:

$$R_1{=}B_{sc_n}\log_2\left[1{+}\frac{|h_1|^2\alpha_1\ P_{1,n}}{\sigma_n^2}\right] \tag{3.17}$$

$$R_2 = B_{sc_n} \log_2 \left[1 + \frac{|h_2|^2 \alpha_2 \, P_{2,n}}{|h_2|^2 \alpha_2 \, P_{1,n} + \sigma_n^2} \right] \tag{3.18}$$

The sum rate can be written by:

$$R_{NOMA} = B_{sc_n} \log_2 \left[1 + \frac{|h_1|^2 \alpha_1 \, P_{1,n}}{\sigma_n^2} \right] + B_{sc_n} \log_2 \left[1 + \frac{|h_2|^2 \alpha_2 \, P_{2,n}}{|h_2|^2 \alpha_2 \, P_{1,n} + \sigma_n^2} \right] \tag{3.19}$$

In OFDMA systems, we assume OFDMA with orthogonal user multiplexing. The total bandwidth B_{sc_n} is occupied by these two users (assume that each user has half bandwidth). The data rates of user 1 and 2 in OFDMA systems can be respectively represented as:

$$R_1 = \frac{1}{2} B_{sc_n} \log_2 \left[1 + \frac{|h_1|^2 P_{1,n}}{\sigma_n^2} \right] \tag{3.20}$$

$$R_2 = \frac{1}{2} B_{sc_n} \log_2 \left[1 + \frac{|h_2|^2 \, P_{2,n}}{\sigma_n^2} \right] \tag{3.21}$$

Therefore, the sum rate of these two users in OFDM system can be expressed as:

$$R_{OFDMA} = \frac{1}{2} B_{sc_n} \log_2 \left[1 + \frac{|h_1|^2 P_{1,n}}{\sigma_n^2} \right] + \frac{1}{2} B_{sc_n} \log_2 \left[1 + \frac{|h_2|^2 \, P_{2,n}}{\sigma_n^2} \right] \tag{3.22}$$

Example in mathlab simulation the parameters values are: $\alpha_1 = 0.4 \quad \alpha_2 = 0.6 \; B_{sc_n} = 1$ Hz $\frac{|h_1|^2 \, P_{1,n}}{\sigma_n^2} = 20 \; dB \quad \frac{|h_2|^2 \, P_{2,n}}{\sigma_n^2} = 0 \; dB \quad \alpha_1 = \alpha$ were seen in power allocation coefficient first. Therefore, result as:

$$R_{OFDMA} = 4.11 + 0.650 = 4.76 \; bits/s$$

$$R_{NOMA} = 5.26 + 0.68 = 5.94 \; bits/s.$$

$\alpha_1 = 0.2 \quad \alpha_2 = 0.8 \; B_{sc_n} = 1$ Hz $\quad \frac{|h_1|^2 \, P_{1,n}}{\sigma_n^2} = 20 \; dB \quad \frac{|h_2|^2 \, P_{2,n}}{\sigma_n^2} = 0 \; dB \quad \alpha_1 = \alpha$ were seen in power allocation coefficient first. Therefore, result as:

$$R_{OFDMA} = 3.33 + 0.50 = 3.83 \; bits/s$$

$$R_{NOMA} = 4.39 + 0.74 = 4.53 \; bits/s.$$

The gain of the NOMA system is 34% more than that of the OFDMA scheme. Now consider better channel conditions to improve the channel gains as $\frac{|h_1|^2 \, P_{1,n}}{\sigma_n^2} = 30 \; dB \; \frac{|h_2|^2 \, P_{2,n}}{\sigma_n^2} = 10 \; dB$

Assume each user has the same weight band-width:

$$\alpha_1 = 0.2 \quad \alpha_2 = 0.8 \quad B_{sc_n} = 1\ Hz$$

$$R_{OFDMA} = 4.99 + 1.73 = 6.72\ bits/s$$

$$R_{NOMA} = 7.65 + 1.87 = 9.52\ bits/s.$$

The gain of the NOMA system is more than that of the OFDMA scheme. Based on the above numerical examples, it can be concluded that the sum data rate of the NOMA system will be improved when the channel gains increase, and the performance gain of NOMA over OFDMA increases when the channel conditions improved in [56]. The difference of two systems' sum rate in high signal-to-noise ratio (SNR) region can be calculated. Consider that two users are multiplexed on the same sub-channel with the channel gains $|h_1|^2 \geq |h_2|^2$. Therefore, the difference of sum rate can be written as:

$$R_{NOMA} - R_{OFDMA} = (\left(W_{sc_n} \log_2 \left[1 + \frac{|h_1|^2 \alpha_1\, P_n}{\sigma_n^2} \right] + W_{sc_n} \log_2 \left[1 + \frac{|h_2|^2 \alpha_2\, P_n}{|h_2|^2 \alpha_1\, P_n + \sigma_n^2} \right] \right) -$$

$$(\frac{1}{2} W_{sc_n} \log_2 \left[1 + \frac{|h_1|^2 P_n}{\sigma_n^2} \right] + \frac{1}{2} W_{sc_n} \log_2 \left[1 + \frac{|h_2|^2\, P_n}{\sigma_n^2} \right]))$$

$$\leftrightarrow_{\frac{P_n}{\sigma_n^2} \rightarrow \infty} \log_2 \left[\frac{P_n}{\sigma_n^2} |h_1|^2 \alpha_1 \right] + \log_2 \left[\frac{1}{\alpha_1} \right] - \log_2 \left[\frac{P_n}{\sigma_n^2} |h_1|\, |h_2| \right] \ldots$$

Therefore, the sum-rate difference result between OMA and NOMA will be:

$$= \log_2 [|h_1|] - \log_2 [|h_2|]$$

It can be concluded that the sum rate gap between NOMA and OFDMA will be increased when the channel gain difference of the two users is enlarged. Therefore, NOMA systems can out perform OFDMA systems only if the channel gain difference exists.

3.4.2 Spectral and Energy Efficiency of NOMA Systems

NOMA employs some controllable interference via non-orthogonal resource allocation and realizes overloading at the cost of slightly increased receiver complexity. Consequently, higher SE can be achieved by NOMA for 5G network. Although SE shows how efficiently a limited spectrum resource is utilized, it fails to provide any insight on how efficiently energy is utilized. With the rise in desire for green communications in recent years, reducing energy consumption has become of prime importance for researchers, and 5G has also targeted EE as one of the major parameters to be achieved. Nonetheless, Shannon's information capacity theorem illustrates that the two objectives of minimizing consumed energy and maximizing SE are not achievable simultaneously, and calls for a trade-off. It can be noted that with circuit power under consideration, there always exists an optimal point in the EE versus SE (EE-SE) curve. The degree of efficiency can be adjusted by varying total power using power-control schemes.

According to ITU requirements for IMT-2020, downlink peak spectral efficiency should be 30 bits/s/Hz. NOMA offers a higher spectral efficiency and a better user-fairness compared to OMA. NOMA is the theoretically optimal way of using the spectrum for both uplink and downlink communications in a single-cell network. Such better performance is achieved due to the fact that every NOMA user can enjoy the whole bandwidth, whereas OMA users are limited to a smaller fraction of the spectrum which is inversely proportional to the number of users. NOMA can also be combined with other emerging technologies, such as massive MIMO and millimeter wave (mmWave) technologies, to further improve spectral efficiency and support higher throughput.

In this regard, researchers all over the globe have started investigating NOMA as a promising multiple access scheme for future radio access in [52],[55]. NOMA achieves superior spectral efficiencies by SC at the transmitter with SIC at the receiver. On the top of that, the evolution of wireless networks to 5G poses new challenges for energy efficiency. With an extreme increase in the number of infrastructure nodes, total energy consumption may simply surpass an acceptable level. Although substantial energy is basically consumed by the hardware. NOMA has an inherent ability to adapt the transmission strategy according to the traffic and users' CSIs. Thus, it can achieve a good operating point, where both spectrum efficiency and EE become optimum.

NOMA is fundamentally different than these multiple access schemes which provide orthogonal to the users either in time, frequency, code or space. In NOMA, each user operates in the same band and at the same time where they are distinguished by their power levels. Orthogonal frequency division multiplexing (OFDM) is considered as the modulation scheme and NOMA as the multiple access schemes. In conventional 4G networks, as natural extension of OFDM, where OFDMA is used where information for each user is assigned to a subset of sub-carriers. In NOMA, on the other hand, all of the sub-carriers can be used by each user. Figure 3.3 illustrates the spectrum sharing for OFDMA and NOMA for two users.
NOMA technologies can still use the OFDM symbol as the smallest unit in the time domain, and insert the cycle prefix (CP) between the symbols to prevent inter-symbol interference (ISI). While, in the frequency domain, the smallest units can still be the sub-channels, and OFDM technologies are used in each sub-channels to keep the sub-channels are orthogonal

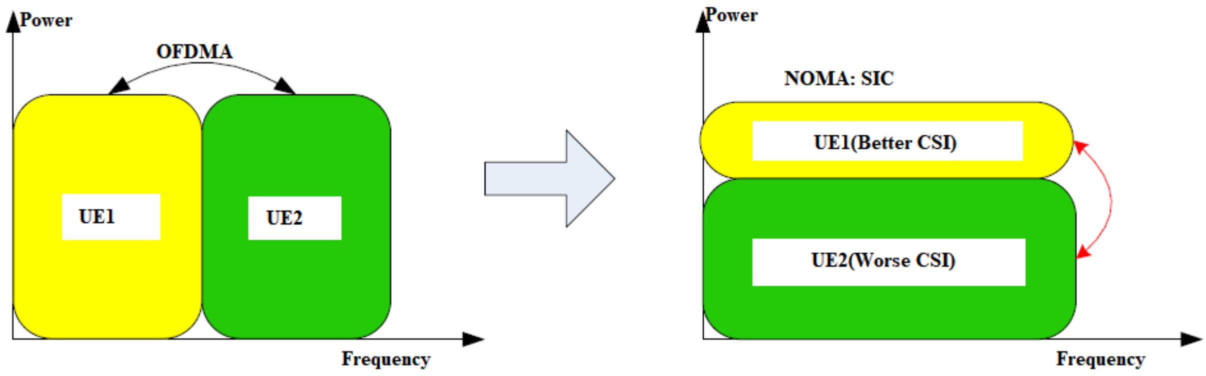

Figure 3.3: Spectram sharing of OMA and NOMA.

and non-interference with each other. However, the power of each sub-channel and the OFDM symbol is shared by multiple users instead of only for one user. In particular, the signal power of different users on the same sub-channel and OFDM symbol is non-orthogonal, which led to MAI for shared channels. In order to overcome the interference, NOMA at the receiver using a SIC technology for multi-user interference detection and deletion to ensure the normal communication of the systems. Thus, the receiver complexity of NOMA has improved compared with orthogonal transmission, but it can get higher spectral efficiency.

Energy efficiency is commonly defined as the ratio of data rate to the power consumption. Bits per Joule is commonly used to measure energy efficiency performance in wireless networks. For energy-efficient communication, it is desirable to send the maximum amount of data with a given amount of energy. To obtain an energy-efficient resource allocation scheme for this system, formulate the energy efficiency optimization problem as:

$$\underbrace{max}_{P_n>0} \sum_{n=1}^{N} \frac{R_n(P_n)}{P_c + P_n}$$

With bandwidth B_{sc_n}, R is achievable data rate, P is the transmit power, σ_n^2 is the AWGN power and $|h|^2$ is the channel power gain between transmitter and receiver.

$$R{=}B_{sc_n}\log_2\left[1+\frac{P\,|h|^2}{\sigma_n^2}\right]$$

The power consumption includes circuit and transmit power. The circuit power consumption (Pc) is the additional device power which includes signal processing and active circuit blocks such as analog-to-digital converter, synthesizer, and mixer during the transmission.Where B_{sc_n} is band-width and the circuit power consumption Pc is independent of the transmit power. The total power consumption at the transmitter can be represented as the sum of the information signal power and the power consumed by the circuits (mainly by power amplifiers). Where P_T the total signal power as is mentioned earlier and P_{static} is the power consumed by the circuitry. Considering the down link, the total power consumed by the BS can then be written as.

$$P_{total} = P_T + P_{static}$$

Energy efficiency needs to be redefined as data rate bits/s per unit energy, where an additional circuit power factor (Pc) needs to be taken into consideration. Energy efficiency (EE) is defined as the sum rate over the total consumed power of the base station. The given an amount of energy ΔE that is consumed in a duration ΔE, we have $\Delta E{=}P\Delta T$. Therefore, the energy efficiency is defined as:

$$EE = \frac{R\Delta T}{\Delta E} = SE\frac{B}{P_{total}} = \frac{R_T}{P + P_{circuit}} = \frac{R_T}{P_{total}}\ bits/Joule \tag{3.23}$$

Different resource allocation schemes are proposed to improve the system energy efficiency. The EE of a NOMA can be made higher than that of an OFDMA system. Most analysis so far included the throughput performance of the network, SE and EE of NOMA systems is also analyzed in this section. Spectral efficiency represents the information rate over a given bandwidth or “Total (average) number of delivered bits per unit bandwidth”.

$$SE = \frac{R}{B}[bits/s/hz] \tag{3.24}$$

The current radio access technology, orthogonal frequency multiple access (OFDMA), might not be the best option due to the issues of spectral efficiency and power utilization. Spectral-power efficiency is one of the fundamental topics of this thesis. The limits on spectral-power efficiency are usually expressed in two equivalent forms:

1. The maximum information rate per unit spectrum at a given power level.
2. The minimum power to support a given rate (or a set of rates for a multi-user system) per unit spectrum.
3. NOMA takes advantage of spectrum efficiency by allowing multiple users to occupy the same sub-channel.

When one coding scheme transmits R [bits/s] over an AWGN of bandwidth W [Hz], the spectral efficiency is increased depending on SNR. Basically, high spectral efficiency can be achieved when adopting a high order modulation and low code rate at a high SNR. Shannon theory in [50],[56] described the relationship between the spectral efficiency and signal to noise ratio

(SNR) for the reliable transmission as follows:

$$SE < \log_2(1+SNR) \tag{3.25}$$

NOMA spectrum sharing in a constructive way to further improve the spectrum utilization. Benefits resulted from the intelligent spectrum sharing of NOMA are listed below.

1. Improved spectrum efficiency: NOMA networks can make PUs primary user and SUs secondary user active.
2. Improved spectrum efficiency: NOMA networks can make PUs and SUs active simultaneously with acceptable reception quality. Thus, spectrum utilization efficiency is largely improved.
3. Massive connectivity: 5G wireless networks are envisioned to support a massive number of smart devices, such as augmented reality (AR), virtual reality (VR), on-line health care, and Internet of things (IoTs). This demand can be fulfilled by cognitive NOMA networks, where multiple PUs and/or SUs can be served simultaneously in one resource block with different power levels.
4. Low latency: Transmission delay of SUs can be reduced in NOMA networks, yielding low latency performance. For example, by leveraging NOMA to underlay CR networks, multiple SUs can be connected simultaneously, fundamentally differing from the OMA scenario in which only one SU can transmit when a resource block becomes available, thus potentially reducing the transmission delay for secondary access.
5. Better fairness: NOMA networks can guarantee improved user fairness. For instance, SUs in an underlay NOMA network have an equal chance to utilize the licensed spectrum, and a SU with a weak channel condition is allocated with more power to achieve a high data rate requirement. This yields a balanced tradeoff between fairness and throughput in the secondary network.

3.5 Efficiency Optimization of Non-Orthogonal Multiple Access

The brief description of energy efficient NOMA system in [53] and SIC is the main technology applied at the receiver in NOMA systems. The higher power is allocated to the user with a lower CNR of user equepment two on sub channel n $UE_{2,n}$, so that the decoding order of the SIC is not changed. However, in most existing works, the power order constraints were ignored. It is important to take such constraints into account explicitly in energy and data rate optimization for NOMA.

The joint optimization of power allocation and channel assignment in NOMA systems is, unfortunately, a mixed integer problem. Therefore, power allocation and channel assignment are often separately and alternatively optimized, i.e., fix one and optimize the other which may lead to, though possibly suboptimal, efficient resource allocation solutions. The most exciting thing is that, different from all existing works, were able to find the optimal power allocation for all users over multiple channels in [56].

3.5.1 Energy Optimization of NOMA Scheme

Consider a down link NOMA network where in a base station (BS) serves M users through N channels. The total bandwidth B_{sc_n} is equally divided to N sub-channel so the bandwidth of each channel is:

$$B_{sc_{each\ channel\ n}} = \frac{B_{sc_{total\ channel\ N}}}{M_{sub\ user\ group}}$$

. Let $M_n \in M1, M2, ..., M_M$ be the number of users using channel N for m = 1, 2,...,M and $\mathrm{UE_{m,n}}$ denotes user m on channel n for m = 1, 2,...,$\mathrm{M_m}$. Where $\mathrm{S_m}$ is the symbol of $\mathrm{UE_{m,n}}$ and $\mathrm{P_{m,n}}$ is the power allocated to $\mathrm{UE_{m,n}}$. Using SIC at each user's receiver causes additional complexity, which is proportional to the number of users on the same channel. Thus, in practice, each channel is often restricted to be assigned to two users which is also beneficial to reduce the error propagation of SIC. The signal transmitted by the BS on each channel n can be expressed as:

$$X_m = \sum_{m=1}^{M_n} \sqrt{P_{m,n}} S_m \tag{3.26}$$

The received signal at $\mathrm{UE_{m,n}}$ is:

$$Y_{m,n} = \sqrt{P_{m,n}} h_{m,n} S_n + \sum_{i=1 i \neq m}^{M_m} \sqrt{P_{m,n}} h_{m,n} S_m + W_{m,n} \tag{3.27}$$

In this thesis, number of user assumed is $M_n = 2-3$ for $m = 1, 2, ..., M$ and $N = 2M$. The CNRs of $\mathrm{UE_{1,n}}$ and $\mathrm{UE_{2,n}}$ are ordered as $H_{1,n} \geq H_{2,n}$. Then, the rates of $\mathrm{UE_{1,n}}$ and $\mathrm{UE_{2,n}}$ on channel n are given respectively by:

$$R_{1,n} = B_{sc_n} \log_2(1 + P_{1,n} H_{1,n}) \tag{3.28}$$

$$R_{2,n} = B_{sc_n} \log_2(1 + \frac{P_{2,n} H_{2,n}}{1 + P_{1,n} H_{2,n}}) \tag{3.29}$$

3.5.1.1 Performance Measurement of NOMA Systems

The performance of a NOMA scheme relies on resource allocation, including power allocation and channel assignment, for all users. In this thesis, optimization of resource allocation for NOMA system will be investigated. The following performance measures will be considered.

1. The system performance measurement is essential for any wireless network in order to estimate the quality of signal with reliability before implementation. The parameter for performance measurement of NOMA are distance from BS to UE, SNR, SINR, SE, EE and data rate. In this thesis, the measurement parameter that used to measures the performance of the NOMA system is distance versus above parameter by assuming different power level to each user.
2. Weighted sum-rate and fairness: In some application scenarios, instead of merely considering maximum throughput, UEs' priority and fairness in resource allocation need to be taken into account. A common criterion is the maximin fairness (MMF), which aims to provide fairness for all users. The corresponding resource allocation problem is given by maximum or minimum for $R_{1,n}$, $R_{2,n}$ for n=1,2,...,N. The corresponding utility function is expressed as $\sum_{m=1}^{M} W_m R_m$ by introducing a weight factor W_m for each UE_m to maintain fairness among UE_M. For example, the UE with poor channel condition could be allocated with higher weight than the UE with good channel condition, to avoid excessive imbalance in resource allocation among UE_M.
   In resource scheduling over a time duration, weights can be used to obtain fairness. For example, one can update $W_m = 1/R_{av_m}$ for each m, where R_{av_m} is the average rate of UE m. There are several measurements to quantify fairness. Jain's fairness index is one of the most common measures to represent fairness, defined as $F = \frac{\left(\sum_{m=1}^{M} R_{av_m}\right)^2}{M\sum_{m=1}^{M} R_{av_m}^2}$. A larger value of F, $0 \leq v \leq 1$, represents fairer rate distribution among UE_m from a system perspective.
3. Throughput maximization: Throughput, also referred to as sum-rate utility, represents the aggregate data rate of the UE_m in a cellular network. The utility function can be expressed by $\sum_{m=1}^{M} R_m$ if considered M UE_m in the system, where R_m is the instantaneous data rate of UE m, usually computed by Shannon's channel capacity equation in bits per second. Besides, spectrum efficiency, in bits per second per Hz, can also be used to quantify throughput in unit bandwidth.
4. Sum Rate: The most common objective is to maximize the sum rate (SR) of all users. To avoid that the resource on each channel is occupied by one user, the weights or QoS constraints are often introduced in to SR maximization. Where $W_{m,n}$ is the weight of $UE_{m,n}$, and the SR maximization with QoS constraints.

$$max \sum_{n=1}^{N} (W_{1,n}, R_{1,n} + W_{2,n}, R_{2,n})$$

$$max \sum_{n=1}^{N} (R_{1,n} + R_{2,n})$$

$$R_{m,n} \geq R_{m,n}^{min}, \quad m = 1,2......\forall n$$

Where $R_{m,n}^{min}$ is the QoS threshold of $UE_{m,n}$ and the optimal power allocation was only found for two users on one channel, while the joint resource optimization is either suboptimal, or needs exhaustive.

5. Power/energy minimization: Power/energy minimization is another category of objectives. It is an important performance metric especially for battery-limited transmitters in up-link transmission. A typical utility function is $\sum_{m=1}^{M} P_m$, where P_m is the transmit power for UE m. In addition, another performance metric is energy efficiency which is defined as transmitted bits per unit energy consumption. The function is expressed by $\frac{\sum_{m=1}^{M} R_m}{\sum_{m=1}^{M} P_m}$ in bit per Joule. optimal power allocation was only found for a few users on a single channel, but unknown for all users over multiple channels.
6. Energy Efficiency: Improve energy efficiency (EE) of the NOMA system, which is defined as the ratio between the sum rate and the power consumption of the whole system. Where P_T is the power consumption of the circuits and SIC on all channels. When weights or QoS constraints are introduced, the EE maximization problem can be formulated as:

$$max \frac{\sum_{n=1}^{N} (W_{1,n}, R_{1,n} + W_{2,n}, R_{2,n})}{P_T + \sum_{n=1}^{N} (P_{1,n} + P_{2,n})}$$

$$max \frac{\sum_{n=1}^{N} (R_{1,n} + R_{2,n})}{P_T + \sum_{n=1}^{N} (P_{1,n} + P_{2,n})} \tag{3.30}$$

$$R_{m,n} \geq R_{m,n}^{min}, m = 1,2......\forall n$$

7. Minimum number of allocated channels: Taking the scarcity of frequency resource into account, another type of utility metric amounts to minimizing the number of allocated sub-channels required to meet each UE's data demand. The benefits consist of two aspects. First, the inter-cell interference (ICI) is mitigated by minimizing the used channels in each cell. Second, it is relevant to make as much resource available as possible for elastic traffic, while guaranteeing the rates for real-time applications. The utility function is defined as $\sum_{m=1}^{M} |N_m|$ for OFDM-based systems due to exclusive channel access, and $U_{m=1}^{M} |N_m|$ for NOMA systems, where N_m is the set of allocated sub-channels of UE m.

3.5.1.2 Optimal Power Allocation for MaxiMin Fairness

Fairness: NOMA users experience unequal data rates, since this access method is based on SIC decoding order. Although the decoding order is formulated based on users' CSI, the NOMA service could be critical for some situations where strict fairness might be an issue. The power allocation problem from a fairness viewpoint can be investigated under two assumptions: i) the

BS has perfect CSI, and hence, users' data rates adapt to the channel conditions; and ii) users have fixed targeted data rates under an average CSI. If instantaneous CSI is available at the BS, fairness among users can be ensured by maximizing the minimum achievable data rate, i.e.,

$$OP_1^{MMF}[\max]_{(P_1,P_2)_{n=1,\dots,N}} min[R_{1,n}(P_{1,n},P_{2,n})],[R_{2,n}(P_{1,n},p_{2,n})]$$

The NOMA scheme enables a flexible management of the users' achievable rates and provides an efficient way to enhance user fairness. NOMA optimal power allocation system used to achieve the MaxiMin fairness (MMF). The NOMA scheme enables a flexible management of users' achievable rates and provides an efficient way to enhance user fairness. A widely used fairness metric is the maximin fairness (MMF), which is achieved by maximizing the worst (i.e.,minimum) user rate. The power allocation to achieve the MMF is given by the solution to the following optimization problem:

$$OP_1^{MMF}[\max]_{(P_1,P_2)_{n=1,\dots,N}} min[R_{1,n}(P_{1,n},P_{2,n})],[R_{2,n}(P_{1,n},p_{2,n})] \tag{3.31}$$

$$0 \le P_1 \le P_2, \quad \sum_{n=1}^{N}(P_{1,n}+P_{2,n}) \le P_T$$

$$\text{s.t.} \qquad P_1 = [P_{1,n}]_{n=1}^{N} \text{ and } P_2 = [P_{2,n}]_{n=1}^{N}.$$

Its optimal solution has only been found in the special case N = 1, i.e., a single channel, but unknown in the general case yet. The auxiliary variables $q = [q_n]_{n=1}^{N}$ where q_n represents the power budget for channel n with $P_{1,n}+P_{2,n} = q_n$. Suppose that the channel power budgets $[q_n]_{n=1}^{N}$ are given. The OP_1^{MMF} is decomposed into a group of subproblems for each channel n:

$$OP_{2,n}^{MMF}[\max,\min]_{(P_{1,n},P_{2,n})_{n=1,\dots,N}}[R_{1,n}(P_{1,n},P_{2,n})],[R_{2,n}(P_{1,n},P_{2,n})] \tag{3.32}$$

$$\text{s.t.} \qquad 0 \le P_{1,n} \le P_{2,n}, \quad P_{1,n}+P_{2,n} = q_n$$

Problem 1. First solve subproblem $OP_{2,n}^{MMF}$ and show that its optimal solution is given in a closed form. Suppose that $H_{1,n} \ge H_{2,n}$ where H is Channel to Noise Ratio (CNR). Then, the optimal solution to $OP_{2,n}^{MMF}$ for user l on channel n is given by:

$$P_{1,n}^{*} = A_n \quad and \quad P_{2,n}^{*} = q_n - P_{1,n}^{*} \quad where \quad H_{m,n} \triangleq \frac{|h_{l,n}|^2}{\sigma_n^2}$$

$$P_{1,n}^{*} = A_n \triangleq \frac{-(H_{1,n}+H_{2,n})^2+\sqrt{(H_{1,n}+H_{2,n})^2+4H_{1,n}H_{2,n}^2 q_n}}{2H_{1,n}H_{2,n}} \tag{3.33}$$

Deriving from the constraint $P_{1,n}+P_{2,n}=q_n$ we have $P_{2,n}=q_n-P_{1,n}$ so $P_{1,n}\leq P_{2,n}$ is equivalent to $P_{1,n}=\frac{q_n}{2}$. By substituting $P_{2,n}=q_n-P_{1,n}$ in to $R_{1,n}$ and $R_{2,n}$ the result will be:

$$R_{1,n}(P_{1,n})\triangleq W_{sc}\log_{10}(1+P_{1,n}H_{1,n})$$

$$R_{2,n}(P_{1,n})\triangleq W_{sc}\log_{10}(\frac{1+q_nH_{2,n}}{1+P_{1,n}H_{2,n}})$$

Where $P_{1,m}\geq A_n$ then $R_{1,n}(P_{1,n})\geq R_{2,n}(P_{1,n})$ and the objective of $OP_{2,n}^{MMF}$ is $R_{2,n}(P_{1,n})$ whitch is decreasing in $P_{1,n}$. So the maximizer is lower bound $P_{1,n}=A_n$. If $P_{1,n}\leq A_n$ the $R_{1,n}(P_{1,n})\leq R_{2,n}(P_{1,n})$ or $R_{1,n}(P_{1,n})\geq R_{2,n}(P_{1,n})$ and the objective of $OP_{2,n}^{MMF}$ is $R_{1,n}(P_{1,n})$ which is increasing in $P_{1,n}$. So the maximizer is upper bound $P_{1,n}=A_n$. Therefore, the optimal point is $P_{1,n}^*=A_n$. Finally, it can be verified that $P_{1,n}^*=A_n\leq\frac{q_n}{2}$. Note that from the above problem $R_{1,n}(P_{1,n}^*,P_{2,n}^*)=R_{2,n}(P_{1,n}^*,P_{2,n}^*)=f_{2,n}^{MMF*}$. Therefore, the optimum fairness will be:

$$f_m^{MMF*}\triangleq W_{sc}\log(\frac{H_{2,n}-H_{1,n}+\sqrt{(H_{1,n}+H_{2,n})^2+4H_{1,n}H_{2,n}^2q_n}}{2H_{2,n}}) \tag{3.34}$$

Where the $UE_{1,n}$ and $UE_{2,n}$ achieve the same rate at the optimal point. This indicates that, under the MMF criterion, the NOMA system will provide absolute fairness for two users on one channel. A NOMA system is called SIC-stable if the optimal power allocation satisfies $P_{1,n}\leq P_{2,n}$ on each channel n. In NOMA systems, SIC is performed according to the order of the CNRs of the users on one channel, which is guaranteed by imposing an inverse order of the powers allocated to the users, i.e., $P_{1,n}\leq P_{2,n}$ on channel n. Specifically, $UE_{1,n}$ (the strong user with a higher CNR) first decodes the signal of $UE_{2,n}$ (the weak user with a lower CNR) and then subtracts it from the superposed signal. Therefore, from the SIC perspective, a difference between the signal strengths of $UE_{2,n}$ and $UE_{1,n}$ is necessary.

However, even with the power order constraint, the power optimization may lead to $P_{1,n}=P_{2,n}$ i.e., $UE_{1,n}$ and $UE_{2,n}$ have the same signal strength, which is the worst situation for SIC. In this case SIC may fail or has a large error propagation makes system unstable. Indeed, the I pointed out that the power of weak user must be strictly larger than that of the strong user, otherwise the users' outage probabilities will always be one. Then in this thesis the outage probability is not considered.

Problem 2: The NOMA system is SIC-stable for $OP_{2,n}^{MMF}$ for $P_{1,n}^*<P_{2,n}^*$ in each channel n.

$$A_n=\frac{2H_{2,n}q_n}{(H_{1,n}+H_{2,n})+\sqrt{(H_{1,n}+H_{2,n})^2+4H_{1,n}H_{2,n}^2q_n}}<\frac{2H_{2,n}q_n}{H_{1,n}+H_{2,n}}\leq\frac{q_n}{2} \tag{3.35}$$

The NOMA system is always SIC-stable under the MMF criterion, as in this case the optimal power allocation always satisfies $P^*_{1,n} < P^*_{2,n}\ \forall_n$. On the other hand, NOMA system is not always SIC-stable under different criteria and constraints.

3.5.1.3 Optimal Power Allocation for Data SumRate

The optimal power allocation in [56],[57] for maximizing the weighted sum rate (SR) or maximizing the SR with QoS constraints.

3.5.1.4 A. Weighted SR Maximization (SR1)

According to, with given channel assignment, the problem of maximizing the weighted sum rate is equivalent to the following power allocation problem:

$$OP_1^{SR1}: \quad \overset{max}{P_1,P_2} \quad \sum_{n=1}^{N} g(P_{1,n},P_{2,n})$$

$$s.t. \quad 0 \leq p_1 \leq p_2, \quad \sum_{n=1}^{N} (P_{1,n}+P_{2,n}) \leq P_T$$

Where $g(P_{1,n},P_{2,n}) \triangleq W_{1,n}R_{1,n}(P_{1,n},P_{2,n}) + W_{2,n}R_{2,n}(P_{1,n},P_{2,n})$. The auxiliary variables $q = (q_n)_{n=1}^{N}$ that represent the power budgets on each channel n with $P_{1,n}+P_{2,n} = q_n$. Then, OP_1^{SR1} is decomposed into a group of subproblems for each channel n:

$$OP_{2,n}^{SR1}: \quad \overset{max}{P_{1,n},P_{2,n}} \quad g(P_{1,n},P_{2,n})$$

$$s.t. \quad 0 \leq P_{1,n} \leq P_{2,n}, \quad (P_{1,n}+P_{2,n}) = q_n$$

Propblem 3. First solve the subproblem $OP_{2,n}^{SR1}$ for each channel n. Suppose that $H_{1,n} \geq H_{2,n}$ $1 \leq \frac{W_{2,n}}{W_{1,n}} \leq \frac{H_{1,n}}{H_{2,n}}$ and $q_n > 2\Omega_n$

$$\Omega_n \triangleq \frac{W_{2,n}H_{2,n} - W_{1,n}H_{1,n}}{H_{1,n}H_{2,n}(W_{2,n}-W_{1,n})}$$

The optimal solution to OP_2^{SR1} is given by $q^*_{1,n} = \Omega_n$ and $q^*_{2,n} = q_n - q^*_{1,n}$. So, $P_{2,n} = q_n - P_{1,n}$ and $P_{1,n} \leq P_{2,n}$ is equal to $P_{1,n} \leq \frac{q_n}{2}$, and the objective becomes:

$$F(P_{1,n}) = W_{1,n}W_{sc}\log(\frac{q_nH_{2,n}+1}{P_{1,n}H_{2,n}+1})$$

By setting the derivative of F to zero for optimization withn $p_{1,m}$ function as follows.

$$\frac{\partial^2 F}{\partial P_{1,n}^2} = \frac{B_{sc}W_{2,n}}{(\frac{1}{H_{2,n}}+\Omega_n)^2} - \frac{B_{sc}W_{1,n}}{(\frac{1}{H_{1,n}}+\Omega_n)^2} = \frac{B_{sc}H_{1,n}^2 H_{2,n}^2 (W_{1,n}-W_{2,n})^2}{(H_{2,n}-H_{1,n})^2}(\frac{1}{W_{2,n}} - \frac{1}{W_{2,n}}) \leq 0$$

The Ω_m is a maximizer. The conditions $1 < W_{2,n}/W_{1,n} \leq \frac{H_{1,n}}{H_{2,n}}$ are both to avoid a failure of SIC. Indeed, if $\frac{W_{2,n}}{W_{1,n}} \leq 1$ or $\frac{W_{2,n}}{W_{1,n}} \leq \frac{H_{1,n}}{H_{2,n}}$ the solution to $OP_{2,n}^{SR1}$ is $P_{1,n}^* = P_{2,n}* = \frac{q_m}{2}$, i.e., the NOMA system is unstable. SIC may also fail on channel n if $q_n \leq 2$, which will lead to $P_{1,n}^* = P_{2,n}^* = \frac{q_m}{2}$ too. Therefore, the NOMA system is SIC-stable on channel n if and only if $1 < \frac{W2,n}{W1,n} < \frac{H1,n}{H2,n}$ and $q_n > 2$. For all channel n of N, OP_1^{SR1} the NOMA system is SIC-stable only if $P > 2\sum_{n=1}^{N}\Omega_n$ and $1 < \frac{W2,n}{W1,n} < \frac{H_{1,n}}{H_{2,n}}$ for n = 1, . . . ,N.

3.5.1.5 B. SR Maximization with QoS (SR2)

Consider by maximizing the SR with QoS constraints and the power allocation problem is given by:

$$op_1^{SR2} : \overset{max}{P_1, P_2} \sum_{n=1}^{N} (R_{1,n}(P_{1,n}, P_{2,n}) + R_{2,n}(P_{1,n}, P_{2,n}))$$

$$s.t. \qquad 0 \leq P_1 \leq P_2 \qquad \sum_{n=1}^{N} (P_{1,n} + P_{2,n}) \leq P_T$$

$$R_{m,n} \geq R_{m,n}^{min} \;\; form = 1,2 \;\; users \;\; and \;\; n = 1,...,N \;\; channels$$

As a special case of OP_1^{SR2}, first studied the power allocation for one channel. Thus, OP_1^{SR2} is still an open problem and its optimal solution is unknown yet. So, using similar method to address OP_1^{SR2} and by introducing the power budget q_m on each channel n, OP_1^{SR2} decomposes into the following subproblems for each channel n:

$$op_{2,n}^{SR2} : \overset{max}{P_{1,n}, P_{2,n}} \;\; and \;\; (R_{1,n}(P_{1,n}, P_{2,n}) + R_{2,n}(P_{1,n}, P_{2,n})$$

$$s.t. \qquad 0 \leq P_{1,n} \leq P_{2,n} \;\; P_{1,n} + P_{2,n} = q_n$$

$$R_{1,n} \geq R_{1,n}^{min} \;\; R_{2,n} \geq R_{2,n}^{min}$$

3.5.2 Optimal Power Allocation for Energy Efficiency

The optimal power allocation for maximizing the energy efficiency (EE) of the NOMA systems with weights or QoS constraints in [55],[57]. The problem of maximizing the EE with weights is equivalent to the following power allocation.

$$OP_1^{EE1}: \quad \overset{max}{P_1, P_2} \quad \frac{\sum_{n=1}^{N} g(P_{1,n}, P_{2,m})}{P_T + \sum_{n=1}^{N}(P_{1,n} + P_{2,n})}$$

$$s.t. \quad 0 \leq P_1 \leq P_2, \quad \sum_{n=1}^{N}(P_{1,n} + P_{2,n}) \leq P_T$$

Where $g(P_{1,n}, P_{2,n}) \triangleq W_{1,n}R_{1,n}(P_{1,n}, P_{2,n}) + W_{2,n}R_{2,n}(P_{1,n}, P_{2,n})$. Introducing the auxiliary variables $[q_n]_{n=1}^{N}$ with $P_{1,n} + P_{2,n} = q_n$ for each channel n. Then, OP_1^{EE} is decomposed into the following subproblems for each channel n:

$$OP_{2,n}^{EE1}: \quad \overset{max}{P_{1,n}, p_{2,n}} \quad \frac{g(P_{1,n}, P_{2,n})}{P_T + \sum_{n=1}^{N}(q_n)}$$

$$s.t. \quad 0 \leq P_{1,n} \leq P_{2,n}, \quad P_{1,n} + P_{2,n} = q_n$$

Suppose the optimal solution is $H_{1,n} \geq H_{2,n}, \quad 1 < \frac{W_{2,n}}{W_{1,n}} < \frac{H_{1,n}}{H_{2,n}} \; and \; q_n > 2\Omega_n$, with omega as follows.

$$\Omega_n \triangleq \frac{W_{2,n}H_{2,n} - W_{1,n}H_{1,n}}{H_{1,n}H_{2,n}(W_{1,n} - W_{2,n})}$$

Then the optimal solution to $OP_{2,n}^{EE}$ is same with $OP_{2,n}^{SR1}$, i.e.,$P_{1,n}^{*} = \Omega_n \; and \; P_{2,m}^{*} = q_n - P_{1,n}^{*}$. The power budgets $[q_n]_{n=1}^{N}$ of $OP_{2,n}^{EE}$ is actually equivalent to $OP_{2,n}^{SR1}$. So, they have the same optimal solution. Therefore, the same SIC-stability conditions is obtained for $OP_{2,n}^{EE1}$. NOMA system is SIC-stable on channel n if and only if $q_n > 2\Omega_n$ and $1 < \frac{W_{2,n}}{W_{1,n}} < \frac{H_{1,n}}{H_{2,n}}$ and NOMA is SIC-stable on all channels only if $P_T > 2\sum_{n=1}^{N}\Omega_n$ and $1 < \frac{W_{2,n}}{W_{1,n}} < \frac{H_{1,n}}{H_{2,n}}$ for $n = 1, ..., N$. Similarly, to guarantee the NOMA system is SIC-stable, it is assumed that $q_n \geq \Theta_n > 2\Omega_n$ and $P_T \geq \sum_{n=1}^{N}\Theta_n$ for some positive channel n.

3.5.2.1 B. EE Maximization with QoS (EE2)

For maximizing the EE with QoS constraints the power allocation problem is given by:

$$max \frac{\sum_{n=1}^{N}(R_{1,n} + R_{2,n})}{P_T + \sum_{n=1}^{N}(P_{1,n} + P_{2,n})}$$

$$OP_1^{EE2}; \overset{max}{P_1, P_2} \quad \frac{\sum_{n=1}^{N} R_{1,n}(P_{1,n}, P_{2,n}) + R_{2,n}(P_{1,n}, P_{2,n})}{P_T + \sum_{n=1}^{N}(P_{1,n} + P_{2,n})}$$

$$s.t. \quad 0 \leq P_1 \leq P_2 \quad \sum_{n=1}^{N}(P_{1,n} + P_{2,n}) \leq P_T$$

$$R_{m,n} \geq R_{m,n}^{min} \quad m = 1, 2 \quad n = 1, ..., N$$

The optimal solution was only found for one channel n, i.e., $M = 1$. To solve OP_1^{EE2}, adopt $[q_n]_{n=1}^N$ with $(P_{1,n} + P_{2,n}) = q_n$ and decompose OP_1^{EE2} into a group of sub-problems for each channel n.

$$OP_{2,n}^{EE2}; \quad \overset{max}{P_{1,n}, P_{2,n}} \quad \frac{\sum_{n=1}^N R_{1,n}(P_{1,n}, P_{2,n}) + R_{2,n}(P_{1,n}, P_{2,n})}{P_T + \sum_{n=1}^N (q_n)}$$

$$s.t. \quad 0 \leq P_{1,n} \leq P_{2,n} \quad (P_{1,n} + P_{2,n}) = q_n$$

$$R_{1,n} \geq R_{2,n}^{min}, \quad R_{2,n} \geq R_{2,n}^{min}$$

Problem 4. Suppose that $H_{1,n} \geq H_{2,n}, \quad A_{2,n} \geq 2$, and $q_n \geq \gamma_n$, with

$$A_{m,n} = 2^{\frac{R_{m,n}^{min}}{B_{sc}}} \quad \gamma_n \triangleq \frac{A_{2,n}(A_{1,n} - 1)}{H_{1,n}} + \frac{A_{2,n} - 1}{H_{2,n}}, \quad \Gamma_n \triangleq \frac{H_{2,n} q_n - A_{2,n} + 1}{A_{2,n} H_{2,n}}$$

Then, the optimal solution to $OP_{2,n}^{EE2}$ is $P_{1,n}^* = \Gamma_n$ and $P_{2,n}^* = q_n - P_{1,n}^*$. The solutions of $OP_{1,n}^{EE2}$ and $OP_{2,n}^{EE2}$ coincide, since $OP_{1,n}^{EE2}$ is equivalent to $OP_{2,n}^{EE2}$ with given $[q_n]_{n=1}^N$. Therefore, the same SIC-stability conditions hold for $OP_{2,n}^{EE2}$ and OP_1^{EE2}. The NOMA system is SIC-stable on channel n if and only if $q_n \geq \gamma_n$ and $A_{2,n} \geq 2$, and NOMA is SIC-stable on all channels only if $P_T \geq \sum_{n=1}^N \gamma_n$, $A_{2,n} \geq 2$ for $n = 1, \ldots, N$. This is all about NOMA optimization on EE and sum rate system and finally the next chapter will be simulation results and discussions at all.

Chapter 4

Simulation Results and Discussions

In this chapter, simulation results are presented to evaluate the performance of down link power domain adaptive non-orthogonal multiple access using two, three or more user pairing in one sub-channel and power allocation uses SIC algorithm at receiver side. In the simulation, by considering one base station, and user randomly distributed in the cell range of 30 m to 1.5 km locations. The minimum distance between a user and BS is 30 meters, the bandwidth and carrier frequency for the system are 0.2Mhz and 2.0Ghz respectively.

The small number of user is used in order to reduce the demodulating complexity of the SIC receiver, by setting 1 to n sub-channels in this simulation, each sub channel can be allocated by two or more matched user pair. OMA scheme as the comparative can only be allocated by one user in a sub-channel. For the sub channel power allocation the data rate, spectral and energy efficiency of power domain adaptive NOMA and OMA had been compared over random distance in a single cell using SIC algorithm. For further analysis the relationship between spectral and energy efficiency, by setting the circuit power consumption vary from 0.5W to 10W and 1.5W to see the different performance of the SIC algorithm.

Figure 4.1 presents the performance of energy versus spectral efficiency. The maximum transmit power of BS is from 10dBm to 30 dBm and there are two and more users assigned in one single cell. Then energy efficiency grows with the increasing of maximum BS power, and it stabilized when it gets the optimal point, which means that whatever how much power you add on the system, the redundant power cannot be utilized to increase the energy efficiency. When considering the system performance with different levels of circuit power consumption, it is noticeable that circuit consumption is small, the performance of energy efficiency will be better.

Moreover, as the circuit power increase, the optimal point will move a little bit to right hand side which means that the BS needs more power to get to the optimal energy efficiency point when increase the circuit power consumption. In order to further compare the energy efficiency performance of OMA and NOMA, the energy efficiency for OMA and NOMA under the same conditions with two and more users on one sub-channel in the in one single cell had been plotted below. The circuit power consumption is 1w. In figure below, as clearly seen by mat-lab simulation that for two and more users were pair in a one sub-carrier, then NOMA system is always energy efficient than OFDM.

The figure 4.1 shows the obtained EE versus SE curves shows NOMA achieves higher EE and SE than OMA system. The optimum peak-points occur for NOMA and OMA when is at 17 W and 18W, respectively. At these points, both systems achieve their maximum EE and SE. NOMA clearly outperforms OMA at optimum point and beyond for both EE and SE.

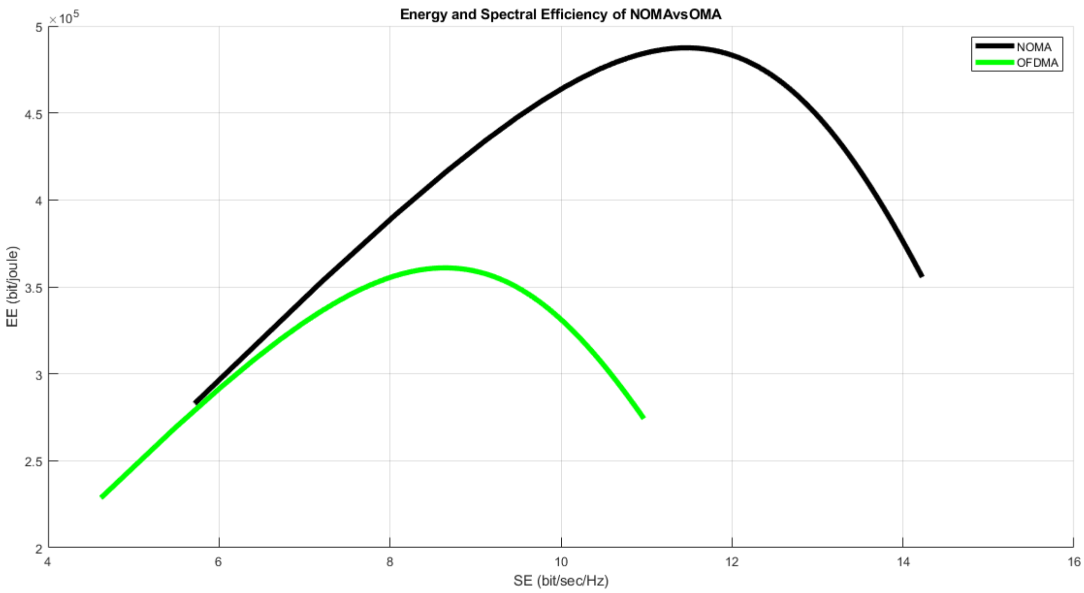

Figure 4.1: Energy and spectral efficiency of NOMA vs OMA.

$SNR_1 = SNR_2 = 10dB$. Here, comparing the EE and SE of NOMA with OFDMA. Again considering the down link NOMA the system bandwidth is taken as BW= 5 MHz. The channel gains for UE1 and UE2 are, respectively, taken as $g_1^2 = -120dB$ and $g_2^2 = -140dB$ Noise density N_0 is taken as -150 dBW/Hz.

The Energy Efficiency Ratio between system rate to the overall transmit power including circuit power which can be modelled as linear function. The energy efficiency and spectral efficiency relationship (EE-SE) in Shannon theory does not consider the power consumption of the circuit and consequently is monotonic where a higher SE always results in a lower EE. When the circuit power is considered, the EE increases in the low SE region and decreases in the high SE region. The peak of the curve (or the corresponding derivative of the EE-SE relationship) is where the system has the maximum energy efficiency. This point is called “optimum point”. For a fixed P_{total}, the EE-SE relationship is linear with a positive slope of R_T/P_{total} where an increase in SE simultaneously results in an increase in EE.Therefore, the power of the aggregate received signal is the sum of the powers of the individual received signals.

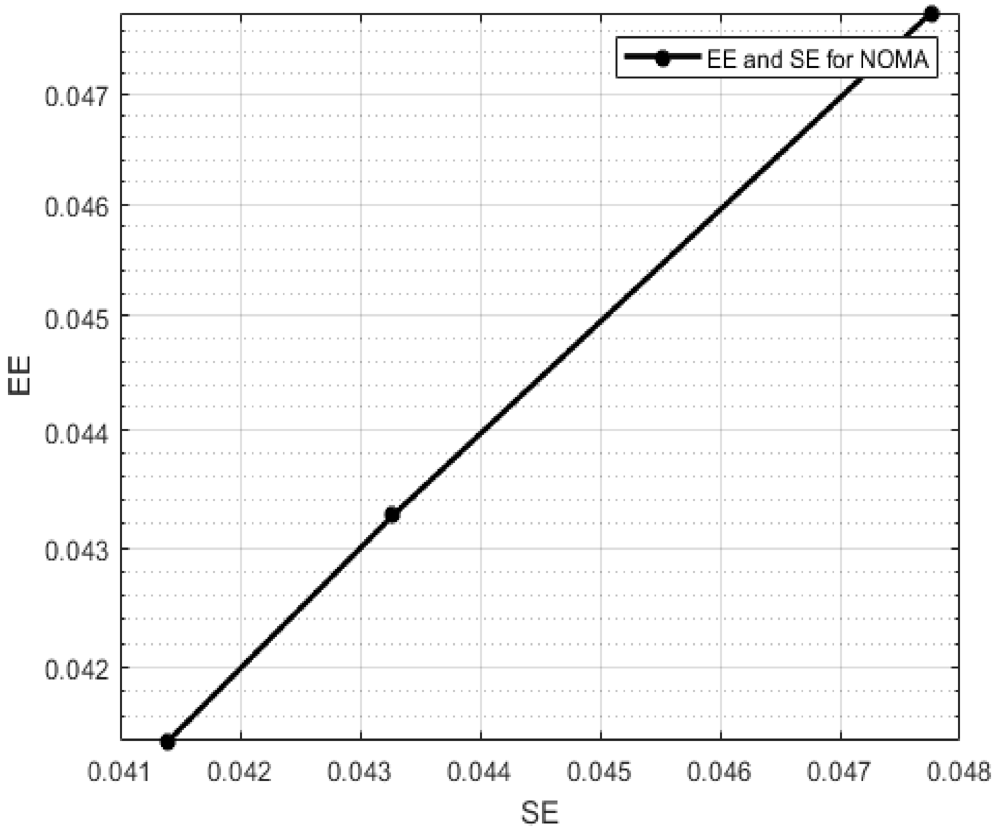

Figure 4.2: EE, and SE of NOMA on random location.

Figure 4.2 shows that NOMA EE increase results to increase in SE mean that direct proportional with limited number of user. SE and EE of NOMA improved or increase in stable maner as variable distance. NOMA EE of first user 0.1488 bit/s/J, NOMA EE of second user 0.1328 bit/s/J, and NOMA EE of third user 0.1303 bit/s/J results the SE of NOMA as first user to three user were first user SE 0.4327 bit/s/Hz, second user SE 0.4737 bit/s/Hz, and third user SE was 0.4798 bit/s Hz.

Figure 4.3 results that within minimum energy uses high number of user. The amplitude huge gap between SE and EE shows that energy efficiency of NOMA, but when the gap minimized efficiency minimized. Look the total rate of OMA was 2.9911 bit/s and total rate of NOMA 6.1579 bit/s using circuit power 10 watt tranmisin power of three user were 19.0726, 25.6650, and 26.8112 watt. The distance were varries from 30 meter to 1.8 km in radius. NOMA SE acheive than EE huge gap. Bandwidth efficeintly utilized for three user in adaptive NOMA and EE improved three user over random location.

Figure 4.4 shows that the SE of NOMA 0.4327 bit/s/Hz 0.4737 bit/s/Hz, and 0.4798 bit/s/Hz for three user much higher than that of OMA 0.1428 bit/s/Hz, 0.1563 bit/s/Hz, and 0.1583 bit/s/Hz for three users respectively. Again when seen that the EE of NOMA much better than that of OMA. 0.0491 bit/s/J, 0.0438 bit/s/J, and 0.0430 bit/s/J were of three user in OMA and 0.1488 bit/s/J, 0.1328 bit/s/J, and 0.1303 bit/s/J EE of three user in NOMA respectively. Therefore, energy of NOMA were 27.6 percent saved and the SE of NOMA were 92.88 percent spectral efficient than previous network generation all using different parameter in MAT LAB simulation. NOMA were SE as EE by power of three user optimized and fairness improved. In

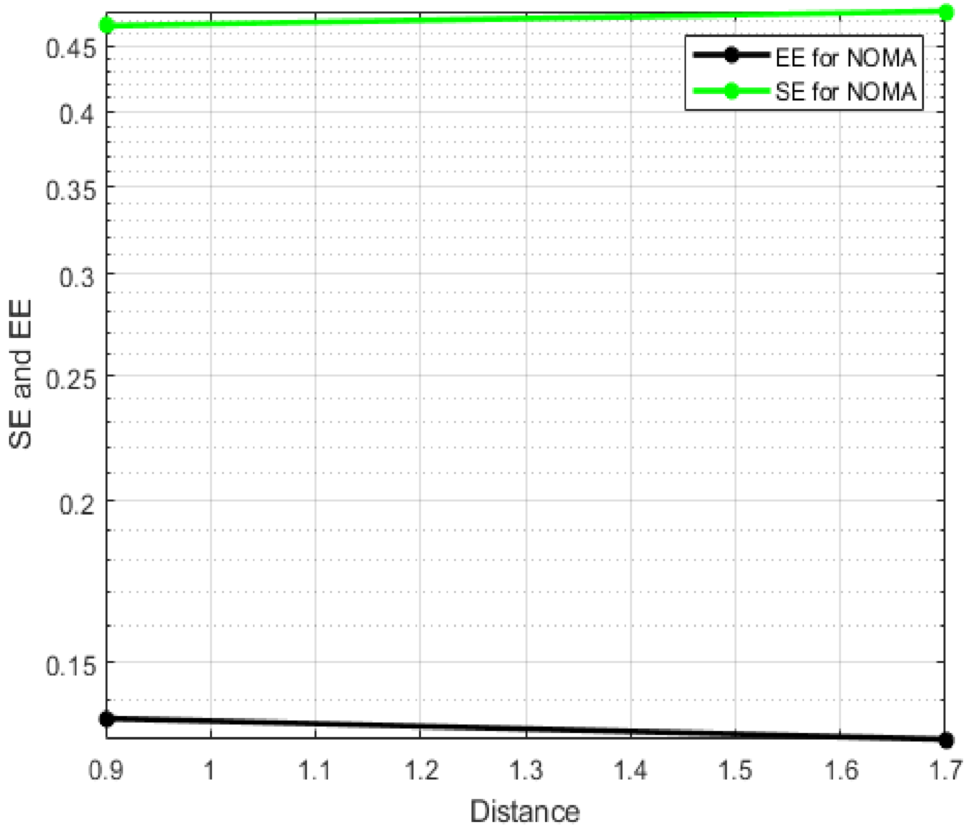

Figure 4.3: SE and EE comparison in NOMA over distance

user random location at cell radius varies from 30 m to 1.8 km without SIC algorithm OMA better than NOMA at first stage, because of interference from another users. Therefore, result shows performance degradation in NOMA of three user. After SIC applied NOMA have bettter performance than OMA because interference from another user canceled by SIC algorithm techniques. When allocated two or more user power became equalized SIC stability fail at three user power 24.3699, 24.3699, and 26.6099 watt respectively this needs another mechanism. When two or more users power became equal or user equal lacation from the BS OMA or PIC is the solution.

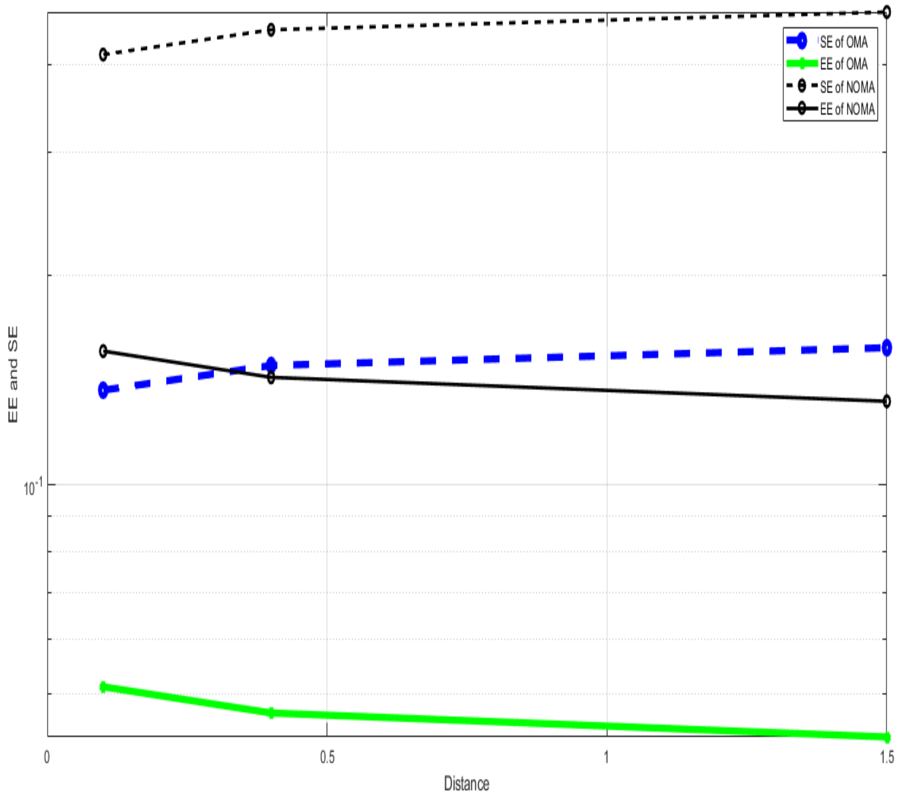

Figure 4.4: SE and EE comparison of OMA and NOMA over distance

4.1 Addaptive NOMA Data Rate Over Distance

Information theory indicates that orthogonal and non-orthogonal alternatives have the same fundamental limits in BC (broadcast channel) where the distortion is caused by additive white Gaussian noise (AWGN) and another user signal power. The Capacity boundary of NOMA depends on the differences in channel gains and power allocation. Power allocation for each user greatly affects the user throughput performance. Assume that there are three users in the network to analyze the boundaries of achievable rate region. Consider a symmetric down-link NOMA channel so that the users are at random distance to the BS as shown in figure 4.2.

In simulations, the base station is located in the cell center and the users are randomly distributed in a circular range with a radius of 1.5 km. The minimum distance between users is set to be 30 m, and the minimum distance between users and BS is 20 m. Each channel coefficient follows an $i.i.d.$ Gaussian distribution as $g_n\ CN(0,1)$ for $n = 1,...,N$ is sub channel and the path loss exponent is 2. The total power budget of the BS is $P = 41dBm$ and the maximum assumed circuit power consumption is $PT = 30dBm$.

As shown in figure 4.3 the data rate of user in NOMA with out SIC reduced over distance

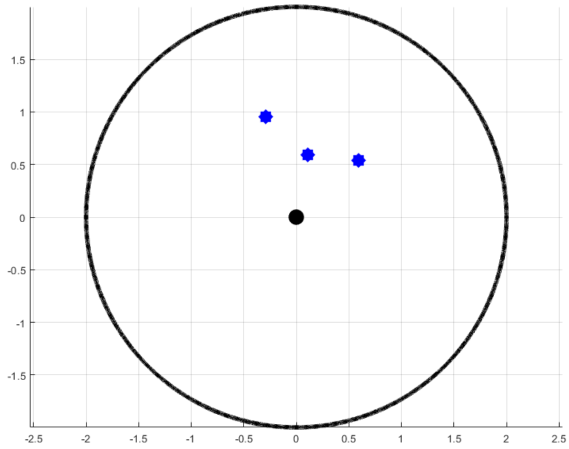

Figure 4.5: Random location of three user in single cell base station.

due to the interference power from another user in down link adaptive NOMA single cell. However, the first user had more data rate in NOMA than OMA, due to better channel condition have high power allocated with in reduced interference from another user. Therefore, in order to solve this problem down link power domain adaptive NOMA uses SIC algorithm at receiver side to cancel another user power interfering the rest users as shown in figure 4.4 below. In Figure 4.6 and 4.7 the data rate improved better when SIC algorithm applied for NOMA. Data rate improved better for OMA without SIC algorithm applied. NOMA EE in system process is adaptive not static system of solution. NOMA SE and Performance gain of NOMA over OMA increases when the channel conditions improved. Okumura Hata model at moderate terrain catagory to model channel. Resource allocation were different power allocation for each user depending on distance from BS and on better channel condition. User with worst channel condition with high power and for better channel condition lower power assigned. At equal power and user with equal distance from BS use OMA, PIC. The data rate of user in NOMA as in figure 4.4 increase due to SIC algorithm cancels the another users power signal interfering the with better channel condition. When SIC algorithm used in down link power domain adaptive NOMA, the data rate of user using NOMA is higher than OMA regardless of user distance from base station.

The optimal power allocation and matching algorithm, with OMA where each user occupies a bandwidth BW/M and the power is optimized in a water filling manner, where the power allocation was optimized via programming, the conventional user pairing (CUP) method used in where the same channel is assigned to the users with a significant channel gain.

Therefore, when the distance increased the data rate also increased as in NOMA than OMA system. However, the user throughput fairness is quite poor when the difference of the

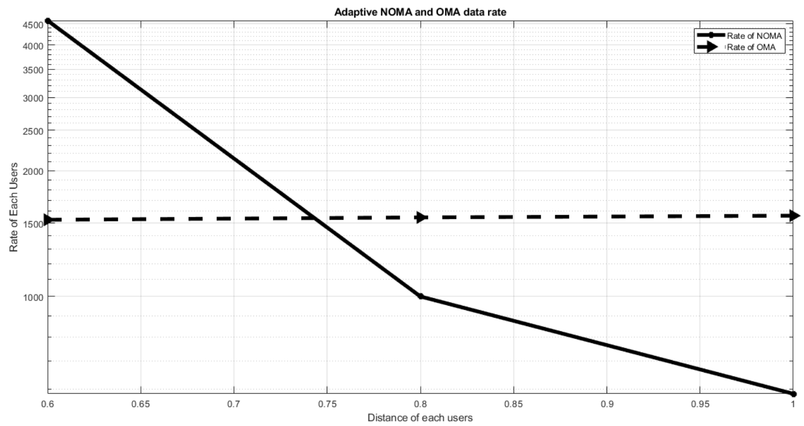

Figure 4.6: Comparison of data rate of OMA and NOMA without SIC

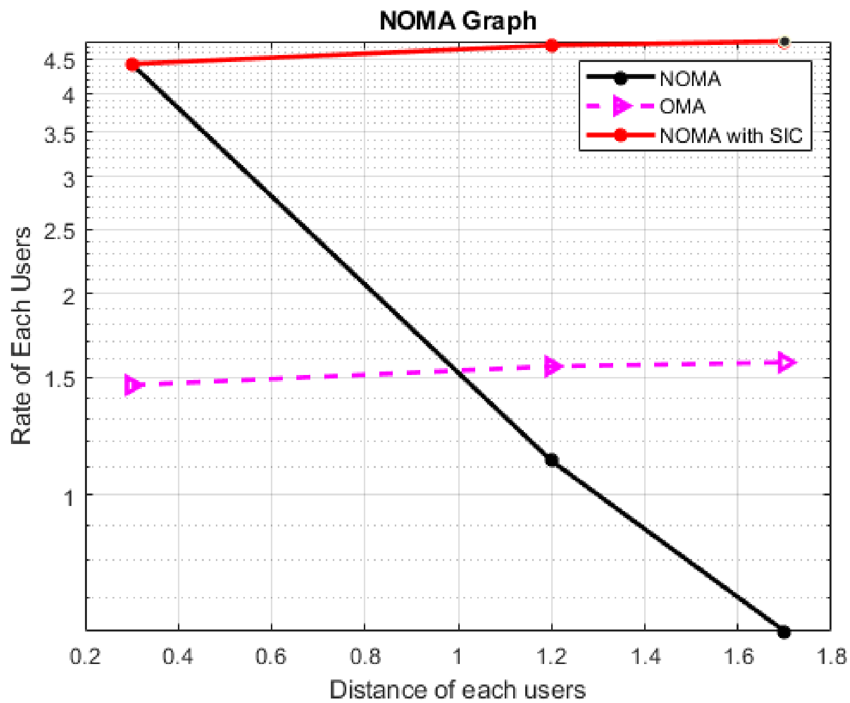

Figure 4.7: Comparison of data rate of OMA and NOMA with and without SIC.

received powers of the users is significant, as the rate of weak user is much lower than that of the strong user in NOMA with out SIC. In the down link power domain adaptive NOMA, as in figure 4.4 shown that the boundary of rate pairs of NOMA is outside of the OMA rate region in general. In multi-path fading channels with inter symbol interference (ISI), although OMA could achieve the sum capacity in the down link, NOMA is optimal while OMA is strictly suboptimal if channel state information (CSI) is only known at the mobile receiver. However, when the fairness is lower, both sum capacity and individual throughputs are higher with NOMA. Figure 4.4 shows rate pairs when the channel is asymmetric, that is, $SR1 = 20dB$ and $SNR2 = 0dB$. NOMA achieves much higher rate pairs than OMA, particularly for the farther user next user.

This upper bound on data rate R can be attained by using all the power and degrees of freedom to communicate to user m. Set the reference distance is 30 m for user one and 30m for user two. Secondly, also set the frequency of carrier to 2MHz, bandwidth to 200kHz, channel gain to 10dB, cell size to 1.500 km. Due to power allocation, each user will be allocated with 2.5 dB channel gain. path loss realization and channel realization are both set constant respectively. The reason is that the path loss would have more dominant impacts than the former. Clearly, if interference is zero, it means this model do not exist interference, which means it will become SNR.

Based on the above figure 4.6, that the x-axis denotes distance and the power allocation from 10dBm to 28dBm with divided to ten parts in every 2dBm. The y-axis denotes the system capacity rate in the unit of bps/Hz. The two lines illustrate the three user data rate in same pair based on different power allocation simultaneously. However, it can be seen that the system capacity rate of user-m' keeps relatively stable, although the rate is higher than user-m on previous power allocation site OMA. Correspondingly, the capacity rate of user-m has been increasing gradually, although user-m implement successive interference cancellation (SIC) to user-m' and remove its message with SINR. Thus, the user who implement SIC will have better capacity when the system allocate enough power.

According to the NOMA protocol multiple users can be allocated to the same sub channel with SIC algorithm technique. A block fading channel is considered in the system model and it is the same for each user per one sub-channel but it varies independently across different sub channels. Based on the parameters and constraints of the system, BS needs to assign multiple users in each sub channels with different power levels and allocate different powers across sub channel.

In Figure 4.2 to 4.8 the path loss of three users were 205.0061, 239.5509, and 268.1118 dB respectively. As shown in Figure 4.8 bar graph the data rate of NOMA is 6.1171 bit/s and total data rate of OMA were 2.9923 bit/s. Therefore, this shows that 48,9 percent optimum data

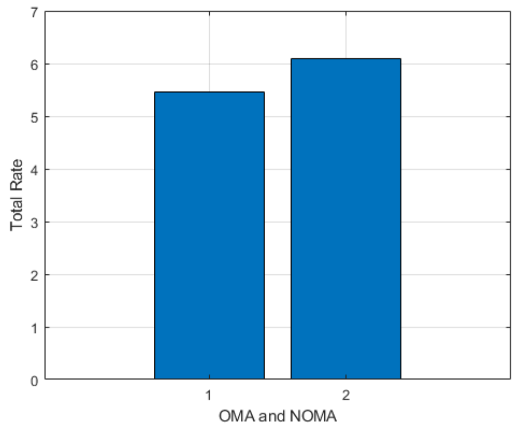

Figure 4.8: Data rate of NOMA and OMA in bar graph.

rate achieved in NOMA than OMA at three users power of 20.5006, 23.9551, and 26.8112 watt respectively at user locacation varies from 0.3 to 1.8000 km radius. Just as the position of three users in km from base station varies the data rate result vary and also power from BS also vary.

This all depends on the distance of user from the base station. For this reason, the power also vary as the date rate vary over a same channel. Then this will shows that NOMA is spectrally efficient than OMA at all. NOMA system also energy efficient than OMA. this means that the peak power ratio problem in OFDM or OMA solved in NOMA 5G network. Ingeneral, as shown in bar graph the NOMA system is total data rate is better than that of OMA.

At another position NOMA data rate increase depending on there distance from base sation. The position of three users 0.60141, 0.8497, and 1.2 km from BS. Similarly, the path loss of one to three users PL of users were is 205.0061, 239.5509, and 268.1118 respectively. Finally, the another users position from base station are 0.9551,and 0.8112 km, the data rate at another time for the first user is 4.4263, second user 1.0801, and third user 0.6107 kbps data. The average sum rate were 2.8857 kbps. Another rate after mobile 5.5022, 6.1171, 6.1171 using SIC algorithm etc. Total system rate 5.5022 and 6.117 kbps of OMA and NOMA respectevely. Finally, as shown in Figure 4.8 bar graph the NOMA system total data rate rate is better than that of OMA.

Generally, NOMA in 5G network were feature candidate multiple access techniques and it advanced optimized network signal domain segmentation system. Then NOMA were optimized data rate, SE, EE, throughput, and fairness efficient network as shown through this thesis at all. Therefore, energy of NOMA were 27.6 percent saved and the SE of NOMA were 92.88 percent spectral efficient and 48,9 percent optimum data rate achieved in NOMA than OMA than previous network generation all using different parameter in MAT LAB simulation. Then the next chapter of this thesis conclusions and recommendation for future works of performance evaluation of NOMA 5G network system.

Chapter 5

Conclusions and Recommendation for Future Works

5.1 Conclusions

In this thesis, the main goal is down link adaptive NOMA network system performance evaluation on wireless mobile network witch is focused on spectrum sharing, energy efficiency and data rate optimization over distance. There are three key technologies applied in NOMA system, SIC, power allocation and channel assignment. The better channel condition with lower power and poor channel condition allocated with higher power. This technologies are main contributors to the better performance of NOMA system in data rate optimization, spectral and energy efficiency. The system model for two or more user down-link power domain NOMA and an energy-efficient user scheduling scheme using power allocation algorithm.

The total result of this thesis shows that the data rate, spectral and energy efficiency comparisson of downlink power domain adaptive NOMA and OMA in a single cell one sub-channel. The randomly distributed users across the cell that uses NOMA with SIC algorithm techniques outperform OMA by data rate optimization, spectral and energy efficiency. But, NOMA with out SIC algorithm the user at better channel condition have good data rate than OMA with fading because of another users signal power interference. Therefore, the data rate, spectral, and energy efficiency in adaptive NOMA is better than OMA by down link transmission using one cell in one sub channel of two or more user who are located 30 m to 1.5 km radius from base station.

There are no systematic approaches for solving optimization problem efficiently. Therefore, in this thesis, the proposed energy-efficient resource allocation algorithms for three-user NOMA system and channel state sorting-pairing algorithm which is proposed to achieve maximum spectral, energy efficiency under the known sub-channel power. There are two parts of power allocation task, one is power assignment among multiplexed users in the same sub-carrier and the other one is power allocation among different sub-carriers.

The energy efficient resource allocation design for down link addaptive NOMA networks were investigated for mobile user, so the data rate NOMA is better than OMA. The data rate, spectral and energy efficient resource allocation or power for a single cell NOMA network with perfect CSI by making channel assignment constant. Generally, the addaptive NOMA power allocation for mobile user and another power alloaction, energy afficiency, spectral efficiency and data rate were seen at all using some considerations as follows.

1. The transmitted signal is narrow-band enough so that the channel can be considered power allocation for each user depend on there distance from BS or user location.
2. The channel is modelled as Rayleigh-fading, which means that in channel matrix H the better channel condition allocated with low power and poor condition with high power allocated.
3. Antenna elements are spaced sufficiently far apart such that the entries of matrix can be modelled as independent and identically distributed (i.i.d.) Gaussian random variables with zero-mean and unit variance ($W_k \sim CN(0,1)$), the denominated Rayleigh fading.
4. Perfect information of the channel matrix H, denoted as channel state information (CSI), is often considered to be known at the receiver (CSI-R). Due to the inherent complexity in estimating CSI at the transmitter side (CSI-T), unless otherwise stated, it is generally not considered to be available but, in this thesis random channel allocation is considered.
5. Transmitted symbols X or (Sm) uses BPSK modulation. To guarantee symmetry in the constellation, N is chosen as an even power of two, that is N = 2M ^{2n} for QAM, with n being an integer. This means that one channel service two or more users. The major modulation techniques used in this thesis is binary phase-shift keying (BPSK) uses $N = M^2$ for better performance evaluation of non-orthogonal multiple access (NOMA) in spectral efficiency than previous network called orthogonal multiple access (OMA) and achieve high data rate.

5.2 Recommendations for Future Works

In this chapter, the summary of this thesis present several potential future research topics that are related to the accomplished work. Furthermore, the entire system efficiency maximization problem was studied in NOMA and discussed the related future work. For multiple users pairing and power control problems, it is much more complex. For example, when applying SIC, user with good channel condition need to decode several other user signals and remove them from the original signal to achieve high data rate. While, it will consume more circuit on decoding, as the simulation result shows the circuit power consumption is a big influence against energy efficiency. Therefore, there is a trade off between reducing the circuit power consumption and maximizing data rate at the same time, which need to do further analysis. However, there are still many challenges and open issues in achieving energy-efficient 5G NOMA networks.

NOMA with MIMO: Not only user scheduling and power control, but also beam forming can be considered in the energy efficient resource allocation.

Throughout this thesis, any user in a NOMA system would be able to access the symbols being transmitted to any user in its cluster witch is security interruption. Users that were positioned later in the decoding chain would even decode the other user's symbols, in order to nullify that user interference on its own signal. Hence, the security topic has been disregarded in this thesis. In a future work, it is imperative to study some mechanisms that prevent this easy access to another user's information. Developing practical physical layer security techniques that address the security issues of NOMA in the down link is an important future research topic.

The order of the users is known at the BS and at each user, however, since this transmission of information is not error free, the effects of errors need to be studied or its better to see BER within power allocation control. If there is an error in the pilots that are sent to the BS, the users cannot be properly ordered and there will be problems regarding fairness, since users with better channels can be assigned with higher power allocation coefficients and thus accidentally end up in a water-filling situation. There is another problem that is if users were located at equal distance form bas station in NOMA techniques then SIC algorithm fail. Then, its better to develop another mechanisms to solve this algorithm problem.

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5.3 Appendix A

Channel state sorting-pairing algorithm [53-57]

To increase the system sum rate, decrease the interference between two users in the same subchannel and enhance the user fairness, the sorting- pairing algorithm are implemented in this thesis, which is pair the best channel-condition user with the worst channel-condition user for each subchannel. However, the last pair may have large interference between these two users because their channel conditions may have no much difference. But the other channels are performing very good, therefore, this pairing method can minimize the total system interference between two users in the same sub-channel.

Figure 5.1: Channel state flowchart algorithm

5.4 Appendix B

Partially Matlab code simulations

```
% Thesis: NOMA Simulation using MATLAB
% Student: Adere Ababu
% Professor: Dr. Feyisa Dibo
% Date: Novenber, 2011
% *************** MAIN PROGRAM FILE *************** %
% This is the NOMA simulation program's main file.
% NOMA_parameters.m, NOMA_base_convert.m, NOMA_modulate.m,
% NOMA_frame_detect.m, NOMA_demod.m
############################################################ %
% ************* NOMA SYSTEM INITIALIZATION: ************* %
% **** setting up parameters & obtaining source data **** %
% ############################################################ %
% Turn off exact-match warning to allow case-insensitive input files
warning('off','MATLAB:dispatcher:InexactMatch');
clear all; % clear all previous data in MATLAB workspace
close all; % close all previously opened figures and graphs
clc;
fprintf('\n\n##############################################\n')
fprintf('#*********** NOMA BER 5G Simulation ************#\n')
fprintf('##############################################\n\n')
% invoking NOMA_parameters.m script to set NOMA system parameters
%NOMA_parameters;
% save parameters for receiver
save('NOMA_parameters');
%Parameters
%%%% Matlab code of data rate vs distance over Rayleigh fading channel
clear all
clc
N=10∧6;% Number of bits
PsdB=0:5:25; % Transmitted power of source in dB
ps=10.∧(0.1.*PsdB);% Linear value of ps
alpha1=0.2;
alpha2=1-alpha1;
```

```
omega=1;%
m =1; % number fading parameter
b=rand(1,N)>0.5; % Generate 0s and 1s with equal probability
xs=2.*b-1;% BPSK modulation 0 -> -1; 1 -> 1
nErr=zeros(1,length(PsdB));
%% Channel gains i.e user n and user m
hstoun=[sqrt(gamrnd(m,omega./m,1,N))] ;% Channel coefficients for Soure-user n
Hstounav=sum((abs(hstoun)))/N;%Average channel gain for Soure-user n
hstoum=[ sqrt(gamrnd (m,omega./m,1,N ))] ;% Channel coefficients for Soure to user m
Hstoumav=sum((abs(hstoum)))/N;%Average channel gain for Soure to user m
%% AWGN
nstoun=(1/(sqrt(2))).*(randn(1,N)+1i.*randn(1,N)); %AWGN for at Desination for source-
Desination node
nstoum=(1/(sqrt(2))).*(randn(1,N)+1i.*randn(1,N));%AWGN for at Relay for Soure-Relay node
%% Matlab Code For SE Simulation of user n
for ii = 1:length(PsdB) ;
ystoun=(hstoun.*xs).*sqrt(alpha1*ps(ii))+nstoun;% the received signal in the direct path from
source to user n).
bHat = real(ystoun)>0;% receiver - hard decision decoding
nErr(ii) = size(find(b- bHat),2);% counting
end
semilogy(PsdB,'linewidth',2);
hold on
%% Matlab Code For SE Simulation of user m
for ii = 1:length(PsdB) ;
ystoum=(hstoum.*xs).*sqrt(ps(ii))+nstoum;% the received signal in the direct path from source
to user n).
bHat = real(ystoum)>0;% receiver - hard decision decoding
nErr(ii) = size(find(b- bHat),2);% counting energy end
semilogy(SE,EE,'k-','linewidth',2);
hold on
grid on
xlabel('Ps./No(dB)');
ylabel('SE');
title('SE vs EE over Rayleigh Fading Channel ')
```

```
legend('user n signal','user m signal')
% Thesis: NOMA Simulation using MATLAB
% Student: Adere Ababu
% Professor: Dr. Feyisa Dibo
% Date: Novenber, 2011

% *************** MAIN PROGRAM FILE *************** %
% This is the NOMA simulation program's main file.
% NOMA_parameters.m, NOMA_base_convert.m, NOMA_modulate.m,
% NOMA_frame_detect.m, NOMA_demod.m
% ########################################################## %
% ************* NOMA SYSTEM INITIALIZATION: ************* %
% **** setting up parameters & obtaining source data **** %
% ########################################################## %
% Turn off exact-match warning to allow case-insensitive input files
warning('off','MATLAB:dispatcher:InexactMatch');
clear all; % clear all previous data in MATLAB workspace
close all; % close all previously opened figures and graphs
fprintf('\n\n############################################\n')
fprintf('#*********** NOMA 5G Simulation ************#\n')
fprintf('############################################\n\n')
% invoking NOMA_parameters.m script to set NOMA system parameters
%NOMA_parameters;
% save parameters for receiver
save('NOMA_parameters');
%Parameters
SNR=[0:1:14]'; %column vector
snr=10.^(SNR/10);
SE=zeros(length(SNR),1);%we create initial zero vectors for SE
SE2=SE1;
SE3=SE1;
```