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Performance Analysis of Small Packets Transmission for Multiple-Input Multiple-Output Non-Orthogonal Multiple Access for 5G

تحليل اداء نقل الحزم الصغيره للوصول المتعدد الغير متعامد متعدد المدخلات متعددالمخرجات للجيل الخامس

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الإستهلال

بِسْمِ اَللَّهِ اَلْرَّحْمٰنِ اَلْرَّحِيمِ

وَيَسَـٔلونَكَ عَنِ اَلْرّوحِ قُلِ اَلْرّوحُ مِنْ أَمْرِ رَبّى وَما أوتيتُمْ مِنَ اَلْعِلْمِ إِلّا قَليلًا ﴿٨٥﴾

سورة اَلإِسْراءْ

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Abstract

The increasing demand of download data and the Internet of Things (IoT) poses challenging requirements for 5G mobile communication, such as high spectral and energy efficiency, massive connectivity and reliability. A promising technology, non-orthogonal multiple access (NOMA), is discussed, which can address some of these challenges for 5G. An advance of the Internet of Things is that some users in the system need to be served quickly for small packet transmission. However, supporting the IoT functionality in 5G networks is challenging since connecting billions of smart IoT devices with diversified quality of service (QoS) requirements is not a trivial task, given the constraint of scarce bandwidth. Non-orthogonal multiple access provides a promising solution to provide massive connectivity by efficiently using the available bandwidth resources. In this thesis, a new multiple-input multiple-output non-orthogonal multiple access (MIMO-NOMA) scheme is designed, where one user is served with its quality of service requirement strictly met, and the other user is served opportunistically by using the NOMA concept. The novelty of this new scheme is that, it confronts the challenge that the existing MIMO-NOMA schemes rely on the assumption that the users channel conditions are different, which is a strong assumption that may not be valid in practice. In this thesis, the developed precoding and detection strategies can effectively create a significant difference between the users' effective channel gains, and therefore, the potential of NOMA can be realized even if the users original channel conditions are similar. Throughout the thesis, analytical and numerical results are provided to demonstrate the performance of the proposed MIMO-NOMA scheme

المستخلص

ان الطلب المتزايد على تنزيل البيانات وإنترنت الأشياء يشكل متطلبات تعد تحديا لشبكات الاتصالات النقالة للجيل الخامس، مثل الكفاءة الطيفية وكفاءة الطاقة و قابلية الاتصال الهائل والاعتمادية. تمت مناقشة تقنية واعدة، وهي الوصول المتعدد الغير متعامد، و التي تتناول عدد من التحديات للجيل الخامس. من النواحي المتقدمة في انترنت الاشياء، وجود مستخدمين بحاجة للخدمة بسرعة لنقل الحزم الصغيرة لكن، عملية دعم مهام إنترنت الأشياء في شبكات الجيل الخامس تمثل تحديا حيث أن توصيل البلايين من أجهزة إنترنت الأشياء الذكية مع متطلبات جودة الخدمة ليست مهمة بسيطة ، نظرا لقلة عرض النطاق الترددي لنظام الوصول المتعدد غير المتعامد وتعد حل واعد لتوفير اتصال هائل عن طريق استخدام موارد النطاق الترددي المتاحة بكفاءة.في هذا البحث تم تصميم مخطط متعدد المدخلات متعدد المخرجات بالوصول المتعدد الغير متعامد، حيث تتم خدمة مستخدم واحد مع التقيد بمتطلبات جودة الخدمة بشكل صارم، اما المستخدم الثاني فتتم خدمته على حسب الفرصة المتاحة باستخدام مفهوم الصول المتعدد الغير متعامد. ان اوجه الحداثة في هذا المخطط، هو مواجهة التحديات في الفرضيات التقليدية للمخططات الموجودة متعددة المدخلات متعددة المخرجات بالوصول المتعدد الغير متعامد، و التي تعتمد على افتراض أن ظروف قناة المستخدمين مختلفة، وهو افتراض قوي قد لا يكون صالحا عمليا. ان استراتيجيات ما قبل الترميز والكشف و التي تم تطويرها في هذا البحث، قادرة على خلق فرق شاسع بين المكاسب الفعالة لقناة المستخدمين ، وبالتالي فإن المرجو من الوصول المتعدد الغير متعامد يمكن أن يتحقق حتى إذا كانت ظروف القناة الأصلية للمستخدمين متشابهة. خلال البحث، تم عرض النتائج التحليلية و الرقمية لعرض أداء المخطط المقترح متعدد المدخلات متعدد المخرجات بالوصول المتعدد الغير متعامد.

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List of Abbreviations

1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
i.i.d.	independent and identically distributed
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPCU	Bit Per Channel User
CDMA	Coding Division Multiple Access
CDI	Channel Direction Information
CP	Cyclic Prefix
CQI	Channel Quality Indicator
CSI	Channel State Information
FDMA	Frequency Division Multiple Access
FFT	Fast Fourier Transform
GOCA	Group Orthogonal Coded Access
IFFT	Inverse Fast Fourier Transform
IDMA	Interleave Division Multiple Access
IGMA	Interleave-Grid Multiple Access
IoT	Internet of Things
ISI	Inter Symbol Interference
LDS-SVE	Low Density Spreading With Signature Vector Extension
LTE	Long Term Evolution

MAS	Multiple Access Scheme
MAC	Multiple Access Channel
MIMO	Multiple Input Multiple Output
MISO	Multi-Input Single-Output
MUD	Multi-User Detection
MU-MIMO	Multiuser MIMO
MUSA	Multi-User Shared Access
NOCA	Non-orthogonal coded access
NCMA	Non-orthogonal coded multiple access
NOMA	Non-orthogonal multiple access
OFDM	Orthogonal Frequency division Multiple
OFDMA	Orthogonal Frequency Division Multiple Access
OMA	Orthogonal Multiple Access
PDF	Probability Density Function
PDMA	Pattern division multiple access
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quaternary Phase Shift keying
RDMA	Repetition division multiple access
RSMA	Resource spread multiple access
SC-FDMA	Single-Carrier Frequency Division Multiple Access
SCMA	Sparse code multiple access
SIC	Successive Interference Cancellation
SIMO	Single-Input Multi-Output
SISO	Single-Input Single-Output
SINR	Signal to Interference plus Noise Ratio
SM	Spatial Multiplexing
SNR	Signal to Noise Ratio
SU-MIMO	Single User MIMO
SVD	Singular Value Decomposition
TDMA	Time Division Multiple Access
TH	Tomlinson-Harashima

UE	User Equipment
V-BLAST	Vertical-Bell Labs Layered Space-Time
VP	Vector perturbation
ZF	Zero-forcing

List of Symbols

$\log$	natural logarithm
$\log_2$	logarithm to the base 2
$\lvert\cdot\rvert$	Magnitude operator
$\lVert\cdot\rVert$	Euclidean norm operator
$(\cdot)^T$	Transposition operator
$(\cdot)^{\mathrm{H}}$	Hermitian operator
$[\mathbf{A}]_{i,i}$	Element in the i^{th} row and the j^{th} column of a matrix $\mathbf{A}$
$\mathbb{C}$	The complex field
$\mathcal{N}(M,N)$	The complex Gaussian distribution with mean m and variance n
$\max(m,n)$	Maximum of m and n
$\min(m,n)$	Minimum of m and n
$\mathrm{argmax}\{\cdot\}$	arguments of the maxima
$\mathbf{0}_N$	Null matrix of size N
$\mathbf{I}_N$	Identity matrix of size N
$\mathbb{E}\{\cdot\}$	Expectation operator
$\mathrm{tr}\,[\cdot]$	Matrix trace operator
$\cup$	Union operator

Chapter one
Introduction

1.1 Overview

Non-orthogonal multiple access (NOMA) technique is widely considered as one promising technology to improve the system capacity of future wireless communication systems [1–3]. The basic principle of NOMA is to serve multiple users by power domain multiplexing at transmitter and successive interference cancellation (SIC) at receiver, which can achieve the capacity region of the downlink addictive white Gaussian noise channel and significantly outperform the orthogonal multiple access (OMA) schemes.

In short-packet communications, as pointed out by [4], the decoding error probability at a receiver is not negligible since the length of a code-word is finite (i.e., the block-length is finite). This is different from the Shannon capacity theorem, in which the decoding error probability is negligible as the block-length approaches infinity. Considering the effect of decoding errors, the channel coding rate in finite block-length regime was derived in [4]. This pioneering work serves as the foundation in examining the performance of short-packet communications. Triggered by [4], the impact of finite block-length on different communication systems has been widely studied.

For example, the achievable channel coding rate in quasi static multiple-input multiple-output (MIMO) fading channels was examined in [5]. In [6], the tradeoff between reliability, throughput, and latency in short-packet communications was investigated over Rayleigh fading channels. Furthermore, the information theoretic result in [4] was utilized for packet scheduling of a multi-user scenario, wherein the latency critical packets are transmitted in orthogonal channels [7]. Recently, non-orthogonal multiple access (NOMA) has attracted increasing research interests since it has been recognized as a promising technique that provides superior spectrum efficiency in 5G wireless networks [8]. NOMA is a multiuser multiplexing scheme that achieves multiple accesses in the power domain [3].

1.2 Problem Statement

One of the major problems with MIMO-NOMA is to achieve low latency of small packet transmission in 5G wireless networks,to achieve lower outage probability of small packet transmission with many QoS users in the same cell.

1.3 Proposed Solution

To improve the performance of MIMO-NOMA we consider a two-user NOMA system with finite block-length constraints, in which the transmission rates and power allocation are optimized. To this end, we investigate the trade-off among the transmission rate and decoding error probability, then a one-dimensional search algorithm is proposed to resolve the challenges mainly due to the achievable rate affected by the finite block-length and the guaranteed successive interference cancellation.

1.4 Objectives

The objectives of this study is to conduct a performance analysis of MIMO-NOMA by using the relevant performance measures. Namely, performance will be considered in terms of the transmit SNR, the outage probabilities at users are as functions of the transmit SNR with different power allocation policies and performance gap between the two MIMO-NOMA and MIMO-OMA.

1.5 Methodology

After conducting a through literature review, the considered MIMO-NOMA scenario system model will be implemented in MATLAB simulation environment and the results will be compared accordingly, the algorithm summed up to the following steps:

1. Analysis the MIMO-NOMA System Models and Consider a MIMO-NOMA downlink transmission scenario with one base station and two users.

2. Analysis power allocation policies with different users are depending on quality of service (QoS) for each user.
3. Evaluate the upper and lower Bounds on the outage probabilities for each user.

1.6 Thesis organization

The thesis will be organized as follows. Chapter two discusses a literature review MIMO-NOMA techniques. Chapter three discusses we formulate Performance for small packets transmission of Multiple Input Multiple Output Non-Orthogonal Multiple Access; Chapter four presents the implementation, simulation results and experimental results; finally, chapter five presents conclusions and recommendation.

Chapter Two
Background and Literature Review

2.1 Multiple Access Techniques

Radio resource is the medium in wireless communications to transmit data information from one device to another [9].The users transmit signals independently to a common receiver via specific channels. The transmissions must be within the total bandwidth with individual specific power user. Typically, the user transmissions are coordinated by the base stations, such that the received signals are received coherently. Multiple Access scheme (MAS) can be classified into two Orthogonal Multiple Access (OMA) and NOMA.

2.1.1 Orthogonal Multiple Access (OMA) Schemes

In OMA, multiple users transmit orthogonal signal waveforms (orthogonal channels) such that there is no interference in the users signal waveform [10]. Thus, the receiver detects the signal for each user without interference from other users with the error performances similar to that of a single user. Examples of OMA techniques include time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal division multiple access (OFDMA) and other MAC scheme which assign orthogonal signal waveforms.

2.1.1.1 Time Division Multiple Access (TDMA)

In wireless communication systems continuous transmission is not required because users do not use the bandwidth all the time. In this case TDMA is complementary Multiple access techniques to FDMA. In TDMA, the total bandwidth is available to the user but only for a finite period of time [9]. In most cases the available bandwidth is divided into fewer channels compared to FDMA and the users are allotted time slots during which they have the entire channel bandwidth at their disposal, as shown in Figure 2.1(a).

2.1.1.2 Frequency Division Multiple Access (FDMA)

In Frequency Division Multiple Access (FDMA) principle, different users would then be using different carriers or sub-carriers.The available bandwidth W is divided into M equal sub-band frequency channels serving M users simultaneously where each user is allocated its channel. Frequency spacing between the user channels is required to minimize inter channel interference caused by the non-linear effects of power amplifiers. In Figure 2.1(b), to access the system simultaneously having their data modulation around a different center frequency.

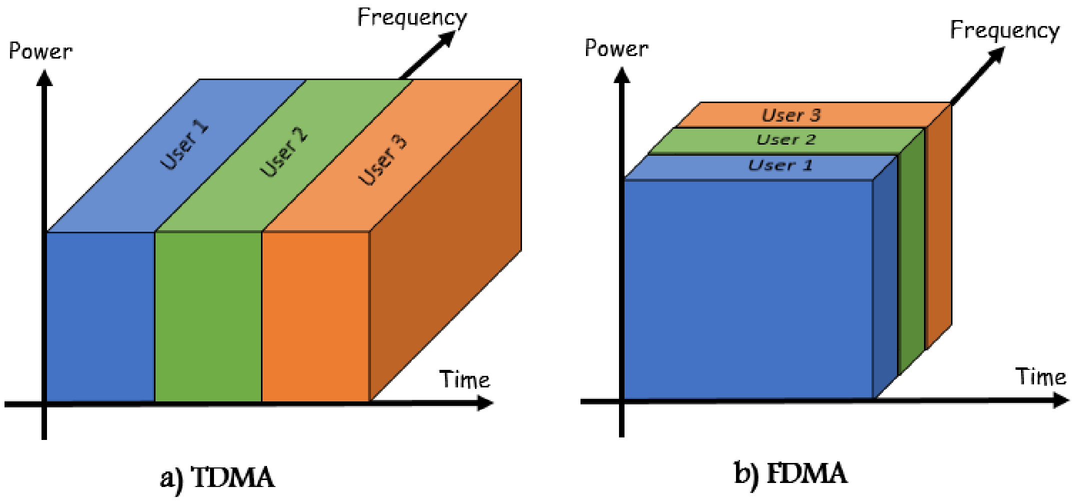

Figure 2.1: TDMA and FDMA Scheme

2.1.1.3 Orthogonal Frequency Division Multiplexing

In OFDM, the channel estimation techniques for OFDM systems based on pilot arrangement are investigated [11]. The objective is still to transmit a high-rate stream using multiple sub-carriers. OFDM overcomes the problem of the large transmission bandwidth available caused by guard bands. The implementations of OFDM is performed with a high efficient and Inverse Fast Fourier Transform (IFFT) is used in the transmitter for modulation, while fast Fourier transform (FFT) is used in the receiver for demodulation.

In OFDMA, instead of sequentially assigning OFDM symbols in time to different users, the OFDMA system directly assigns sub-carriers in frequency to different users. shows a simple OFDMA transmitter. The baseband data

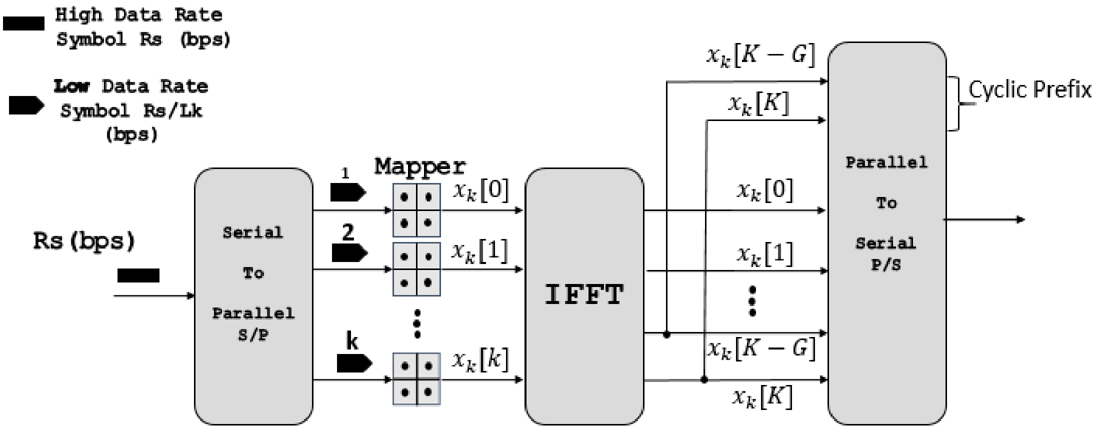

Figure 2.2: OFDMA Transmitter

symbols have high-rate stream of rate of Rs sps, and each data symbol lasts $1/Rs$ sec, then convert baseband data symbols of serial high-rate stream into k groups of data symbols by using Serial to parallel Conversion, each group contains L complex data symbols. The serial-to-parallel converter assigns the high-rate stream into kL separate low-rate sub-streams; each low-rate sub-stream has a rate of Rs/kL sps. This increases the symbol duration on each sub-carrier by a factor of approximately k, such that it becomes significantly longer than the channel delay spread.

The k parallel data streams are first independently modulated resulting by using different modulations in complex vector X_k , (eg. QPSK or 16 QAM) on each sub-carrier. The vector of data symbols X_k then passes through an Inverse FFT (IFFT) resulting in a set of N complex time-domain samples. The next features operation in the generation of an OFDM signal is the creation of a guard period at the beginning of each OFDM symbol, to eliminate the remaining impact of ISI caused by multipath propagation. The guard period is obtained by adding a Cyclic Prefix (CP) at the beginning of the symbol x_k to avoid ISI completely . The output of the IFFT is then Parallel-to-Serial (P/S) converted for transmission through the frequency-selective channel.

At the receiver, the reverse operations are performed to demodulate the OFDM signal.that only an ISI-free block of samples is passed to the DFT. If the number of k sub-carriers is designed to be a power of 2. a highly efficient FFT implementation may be used to transform the signal back to the frequency domain. Among the $k$parallel streams output from the FFT, the modulated subset of k sub-carriers are selected and further processed by

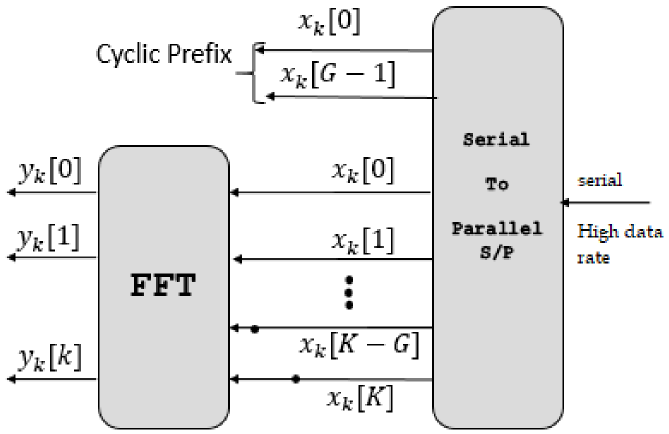

Figure 2.3: OFDMA Receiver

the receiver. In addition to possessing low-complexity modulation and better spectral efficiency, OFDMA affords two further advantages:

- It can take advantage of multiuser diversity through contiguous sub-carriers.
- It has low-complexity modulation that can be implemented using IDFT/DFT (and more efficiently using IFFT/FFT);
- It can adjust modulation and coding for each sub-carrier;
- It is effective at combating ISI and multipath fading;
- It has simple equalization;
- It has better spectral efficiency;

2.1.1.4 Single Carrier-Frequency Division Multiple Access(SC-FDMA)

Single-carrier FDMA scheme provides access to multiple users simultaneously accessing the system Different users can use different DFT- precoding sizes. The size of the DFT precoder for a user is proportional to the orthogonal subcarriers allocated to the user for uplink transmission Bandwidth In fig UE1 and UE2 use DFT sizes of M_1 and M_2 and separating by guard band to avoid co-channel Interference. A cyclic prefix CP is added after IDFT operation and the resulting sequence is up-converted to avoid ISI .

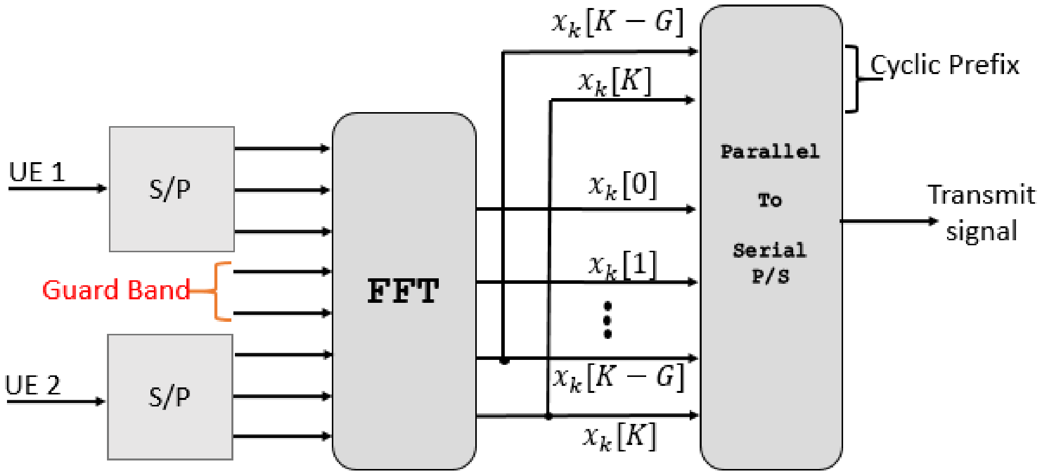

Figure 2.4: SCFDMA Transmitter

At the receiver side, the received signal is filtered, the cyclic prefix samples are removed and a size N DFT operation is performed on the received samples sequence. The symbols for each UE are separated by collecting data from the subcarriers allocated to a UE.

2.1.2 Non-Orthogonal Multiple Access (NOMA)

Non-orthogonal multiple access (NOMA) has become an important principle for the design of radio access techniques for the fifth generation (5G) wireless network NOMA is a multiple access technique presented in [12]. Unlike conventional multiple access scheme where different users are multiplexed in time or frequency domain, NOMA is a power domain multiplexing scheme [9]. Different users uses the same time and frequency resources but are multiplexed in power domain as shown in Figure 2.5.

A full list of types of NOMA schemes and the corresponding 3GPP contributions describing the schemes are given below.

- Non-orthogonal multiple access (NOMA)
- Group Orthogonal Coded Access (GOCA)
- Multi-user shared access (MUSA)
- Low density spreading with signature vector extension (LDS-SVE)

- Pattern division multiple access (PDMA)
- Frequency domain spreading
- Sparse code multiple access (SCMA)
- Non-orthogonal coded access (NOCA)
- Non-orthogonal coded multiple access (NCMA)
- Interleave Division Multiple Access (IDMA)
- Low code rate spreading
- Resource spread multiple access (RSMA)
- Interleave-Grid Multiple Access (IGMA)
- Low code rate and signature based shared access (LSSA)
- Repetition division multiple access (RDMA)

2.1.2.1 Power Domain- Non-Orthogonal Multiple Access (PD-NOMA)

In a PD-NOMA cellular system with one BS and a group of users, multiple users are multiplexed at the same bandwidth and same time. Specifically, in the downlink transmission, the BS broadcasts a superposition (SC) of multiple users' signals by properly choosing the transmit power coefficients for these users' signals subject to a total power constraint [13]. In NOMA UEs are multiplexed in the same time-frequency resources; this is possible by implementing superposition transmission schemes and adaptive power allocation in the transmitter [12]. The power ratio assigned to an allocated UE will depend on its channel conditions; the lower the channel gain, the higher the power ratio. Figure2.6 shows a resource allocation comparison between OMA and NOMA for two UEs. In the receiver, interference cancellation (IC) techniques are used.

2.1.2.2 Code Division Multiple Access Scheme

In CDMA, the same bandwidth is occupied by all the users, however they are all assigned separate codes, which differentiates them from each other (shown

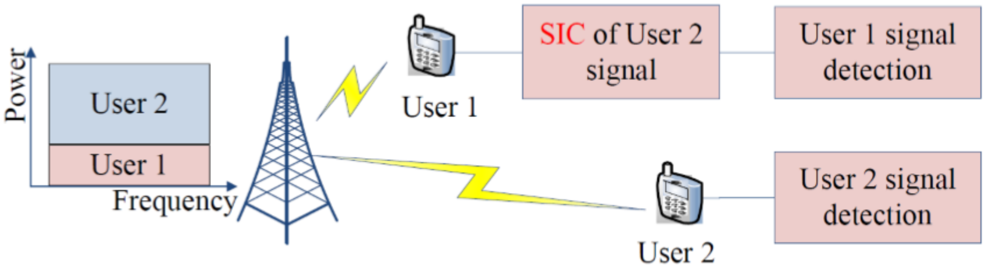

Figure 2.5: Basic NOMA scheme

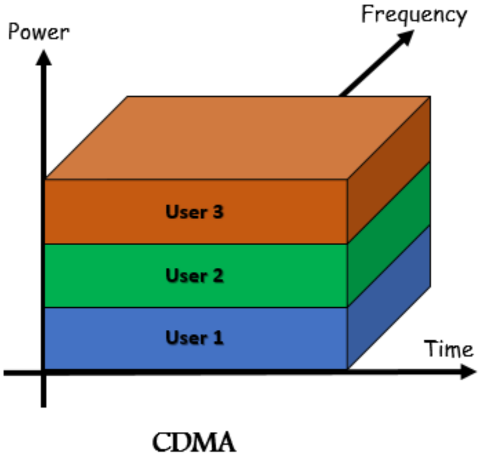

Figure 2.6: Basic CDMA Scheme

in Figure 2.6). CDMA utilize a spread spectrum technique in which a spreading signal (which is uncorrelated to the signal and has a large bandwidth) is used to spread the narrow band message signal.

2.2 Multiple Antenna Techniques

Multiple antennas technologies proposed for mobile communications systems have gained much attention in the last few years because of the huge gain they can introduce in the communication reliability and the channel capacity levels [14]. .When the antennas are sufficiently placed apart, independent signal paths can be created where the channel between different transmit and receive antenna pairs fade independently. An important characteristic of any multi-antenna configuration is the distance between the different antenna elements, largely due to the relation between the antenna distance and the mutual correlation between the radio-channel fading experienced by the signals at the different antennas. For mobile equipment surrounded by many scatters, the typical antenna separation is 0.5-1.0 of carrier wavelength λ_c. For BS antennas placed on high towers, larger antenna separation of around 10's of wavelengths may be required. Receive diversity is achieved by utilizing multiple receive antennas as in Single-Input Multi-Output (SIMO)scheme, while transmit diversity is achieved by utilizing multiple transmit antennas as in Multi-Input Single-Output (MISO) scheme Figure 2.7. When multiple transmit and receive antennas are employed such as MIMO, the capacity and diversity are increased significantly. This makes multi-antenna techniques an active are a of research in order to meet the capacity and throughput requirements out lined for 5G. For example, massive MIMO techniques have recently been proposed which sees the number of antenna elements significantly increased (10-100x).

The availability of multiple antennas at the transmitter and/or the receiver can be utilized in different ways to achieve different aims:

- Multiple antennas at the transmitter and/or the receiver can be used to provide additional diversity against fading on the radio channel.
- Multiple antennas at the transmitter and/or the receiver can be used to "shape" the overall antenna beam (transmit beam and receive beam respectively).
- The simultaneous availability of multiple antennas at the transmitter and the receiver can be used to create what can be seen as multiple parallel communication "channels" over the radio interface.

2.2.1 Multiple Input Multiple Output (MIMO) Communications

MIMO communications exploits the spatial dimension through the use of multiple antennas at both the transmitter and receiver [15]. This takes advantage of the rich scattering environment to allow for independent uncorrelated channels between any pair of receive Transmit antennas MIMO system capacity and diversity gain increases linearly on the order of transmit/receive antennas $M_{min} = \min(M_t, M_r)$ and $M_t \times M_r$, respectively, without any power or bandwidth penalty. Furthermore, MIMO enables the realization of spatial multiplexing (SM) where independent transmissions are transmitted over the same bandwidth. Another form of SM, known as Vertical-Bell Labs Layered Space-Time (V-BLAST), is also employed to increase the system capacity

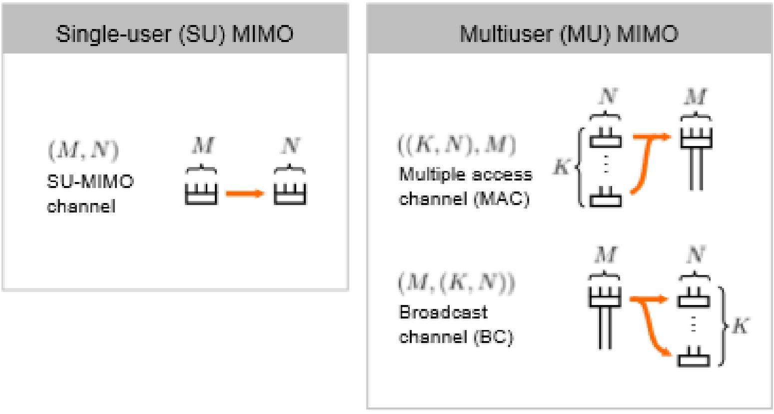

Figure 2.7: Single and Multiple user MIMO communication channel [16].

rather than diversity. In this section, we describe some simple models for these channels and give an overview of their theoretical performance limits.

2.2.1.1 Single-User MIMO (SU-MIMO)

The single-user channel models a point-to-point link between a base and a user. For the downlink, the base is the transmitter and the user is the receiver. For the uplink, the roles are reversed [17]. We define an (M, N) single-user (SU) MIMO channel as a communication link with $M \geq 1$ antennas at the transmitter and $N \geq 1$ antennas at the receiver. Special cases of the (M, N) MIMO channel are the $(M, 1)$ multiple-input, single-output (MISO) channel, the $(1, N)$ single-input, multiple-output (SIMO) channel, and the $(1, 1)$ single-input, single-output (SISO) channel. The baseband received signal at a given antenna is a linear combination of the $\mathbf{M}$ transmitted signals, each modulated by the channel's complex amplitude coefficient, and corrupted by noise. The baseband signal received over a SU-MIMO channel for the duration of a symbol period can be written using vector notation as

$$\mathbf{x} = \mathbf{H}\mathbf{s} + \mathbf{n} \tag{2.1}$$

where the notations are explained as follows.

- $\mathbf{x} \in \mathbb{C}^{(N \times 1)}$ is the received signal whose n-th element, $n = 1, \ldots, N$, is associated with antenna n.
- $\mathbf{H} \in \mathbb{C}^{(N \times M)}$ is the channel matrix whose $(n, m)^{\text{th}}$ entry, $n = 1, \ldots, N$, $m = 1, \ldots, M$, gives the complex amplitude between the m^{th} transmit antenna and the n^{th} receive antenna.

- $\mathbf{s} \in \mathbb{C}^{(M\times 1)}$ is the transmitted signal vector, having covariance $Q \triangleq \mathbb{E}\{\mathbf{s}\mathbf{s}^{\mathrm{H}}\}$, and subject to the power constraint $\mathrm{tr}\,[\mathbf{Q}] \leq P$.
- $\mathbf{n} \in \mathbb{C}^{(N\times 1)}$ is a circularly symmetric complex Gaussian vector representing additive receiver noise, with mean $\mathbb{E}\{\mathbf{n}\} = \mathbf{0}_N$ and covariance $\mathbb{E}\{\mathbf{n}\mathbf{n}^{\mathrm{H}}\} = \sigma^2\mathbf{I}_N$.

2.2.1.2 Multi-user MIMO (MU-MIMO)

We consider two types of multiuser channels: the multiple-access channel (MAC) and the broadcast channel (BC). The MAC is used to model a single base receiving signals from multiple users on the uplink of a cellular network. We will use the notation $((K, N), M)$ to denote a MAC with $K \geq 1$ users, each with $N \geq 1$ antennas, whose signals are received by a base with $M \geq 1$ antennas. We use the term MIMO MAC to denote a MAC with multiple $M > 1$ base antennas serving multiple $K > 1$ users, where each user has one or more antennas. The data signals sent by the users are independent, and the base receives the sum of K signals modulated by each user's MIMO channel and corrupted by noise. The baseband received signal can be written as:

$$\mathbf{x} = \sum^{K} \mathbf{H}_k \mathbf{s}_k + \mathbf{n} \tag{2.2}$$

where the notations are explained as follows.

- $\mathbf{x} \in \mathbb{C}^{(M\times 1)}$ is the received signal whose n-th element, $m = 1, \ldots, M$ is associated with antenna m.
- $\mathbf{H}_k \in \mathbb{C}^{(M\times N)}$ gives the complex amplitude between the n-th transmit antenna of user k and the m^{th} receive antenna. Each coefficient for the k^{th} user's channel $\mathbf{H}_k$ is assumed to be i.i.d. Rayleigh with unit variance, and the channels are mutually independent among the users
- $\mathbf{s}_k \in \mathbb{C}^{(M\times 1)}$ is the transmitted signal vector from user k, having covariance $\mathbf{Q} \triangleq \mathbb{E}\{\mathbf{s}\mathbf{s}^{\mathrm{H}}\}$, and subject to the power constraint $\mathrm{tr}[\mathbf{Q}] \leq P$.
- $\mathbf{n} \in \mathbb{C}^{(M\times 1)}$ is a circularly symmetric complex Gaussian vector representing additive receiver noise, with mean $\mathbb{E}\{\mathbf{n}\} = \mathbf{0}_N$ and covariance $\mathbb{E}\{\mathbf{n}\mathbf{n}^{\mathrm{H}}\} = \sigma^2\mathbf{I}_N$.

2.2.2 Precoding

When channel information is available at the transmitter, channel Precoding can be used to achieve higher sum rates. Precoding is classified into linear and non-linear Precoding.

2.2.2.1 Linear Precoding

In practice, the channel state information is limited at the transmitter due to estimation errors and quantization [18]. Inaccurate channel knowledge may result in significant loss of system throughput, as the interference between the multiplexed streams cannot be completely controlled. In closed-loop systems, the feedback capabilities decide which precoding strategies that are feasible. Each receiver can either feedback a quantized version of its complete channel knowledge or focus on certain critical performance indicators (e.g., the channel gain).

2.2.2.2 Non-linear Precoding

To improve the performance by alleviating above mentioned issues in linear precoding, nonlinear precoding schemes have been proposed [14, 22, 32, 33]. Two well known non-linear precoding schemes, namely, Tomlinson-Harashima (TH) and Vector perturbation (VP) precoding schemes [19].

2.3 Further Related Studies

For further extensive information, the study in [20] presented a comprehensive overview of the most promising modulation and mutliple access schemes for 5G systems. The survey Focused on multiplexing techniques, including modulation techniques in OMA and various NOMA techniques. The various modulation schemes are compared in terms of spectral efficiency, out-of-band leakage, and bit-error rate. Furthermore, the study in [21] introduced the basic concepts of MIMO-NOMA and summarize MIMO-NOMA technologies using to improving better Reliability and spectral efficiency to more users and he is point out an important of the stability of successive interference cancellation (SIC) that arises using achievable rates as performance metrics in practical MIMO-NOMA systems

The study in [22] proposed to utilize power allocation to mitigate the impact of imperfect SIC for a multiuser DL NOMA system, and solved the maximization of energy efficiency subject to a minimum data rate constraint for each user by using develop an iterative algorithm with a fast convergence speed .

The study in [23] considered the analysis of SIC in downlink NOMA rather than considering the perfect SIC conditions. Simulation results are provided at the end of the paper in terms of bit error rate (BER) at the receiver end using both perfect and imperfect SIC.

2.4 Future of 5G

The amount of global mobile data traffic is expected to increase over a 100-fold in the coming decade, from under 3 exabytes in 2010 to well over 500 exabytes by 2020 [24]. Combining cutting-edge network technology and the very latest research, 5G should offer connections that are multitudes faster than current connections, with average download speeds of around 1GBps expected to soon be the norm.

The networks will help power a huge rise in Internet of Things technology, providing the infrastructure needed to carry huge amounts of data, allowing for a smarter and more connected world.

2.4.1 Requirements

Although no formal definition for 5G exists yet,the academiain collaboration within dustry projects such as the Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS) [25], have proposed 5G technical requirements in table 2.1

2.4.2 Challenges

Challenges are the inherent part of the new development; so, like all technologies, 5G has also big challenges to deal with. As we see past i.e. development of radio technology, we find very fast growth [26]. The challenges of 5G are an summarized as follow:

1. *Inter-cell Interference* (ICI) management is one of the paramount issues that should be concerned in multi-tier Heterogeneous Networks (Het-

Table 2.1: 5G Technical Requirements

Capability	Description	5G Target
Peak data rate	Maximum achievable data rate	20 Gbit/s
User experienced data rate	Achievable data rate across coverage area	1 Gbit/s
Latency	Radio network contribution to packet travel time	1 ms
Mobility	Maximum speed for handoff and QoS requirements	500 km/h
Connection density	Total number of devices per unit area	106/km^2

Nets) [27],one of the major technological issues that need to be solved. There is variations in size of traditional macro cells and concurrent small cells that will lead to interference [28].

2. The issue of *efficient medium access control* in a situation, where dense deployment of access points and user terminals are required, the user throughput will be low.

3. The issue of *traffic management* in comparison to the traditional human to human traffic in cellular networks, a great number of Machine to Machine (M2M) devices in a cell may cause serious system challenges [29].

4. The issue of *multiple services*, where unlike other radio signal services, 5G would have a huge task to offer services to heterogeneous networks, technologies, and devices operating in different geographic regions [26].

5. Finally, the issue of *security and privacy*, which is one of the most important challenges that 5G needs to ensure the protection of personal data [30].

Chapter Three

System Model and Formulation Approach

3.1 Introduction

In this Chapter, we explain the system model of MIMO-NOMA Downlink transmission channel of this is the research , then evaluating the compression between the MIMO-NOMA and MIMO-OMA scheme, Evaluating the target data rate for each user at i^{th} layer in different power allocation coefficient. Finally we Analysis outage probability for each user.

3.2 System Model

Consider a MIMO-NOMA downlink DL broadcast channel scenario with one base station (BS) equipped with M antennas and two users each equipped with N antennas as shown in figure 3.1. The BS serves two users. The channel-matrices of the two users are denoted by $\mathbf{H}_1$ and $\mathbf{H}_2$, respectively. Two channel matrices are independent and identically complex Gaussian distributed with zero means and unit variances. In this research, we focus on the scenario without path loss, i.e., the two users have similar channel conditions.

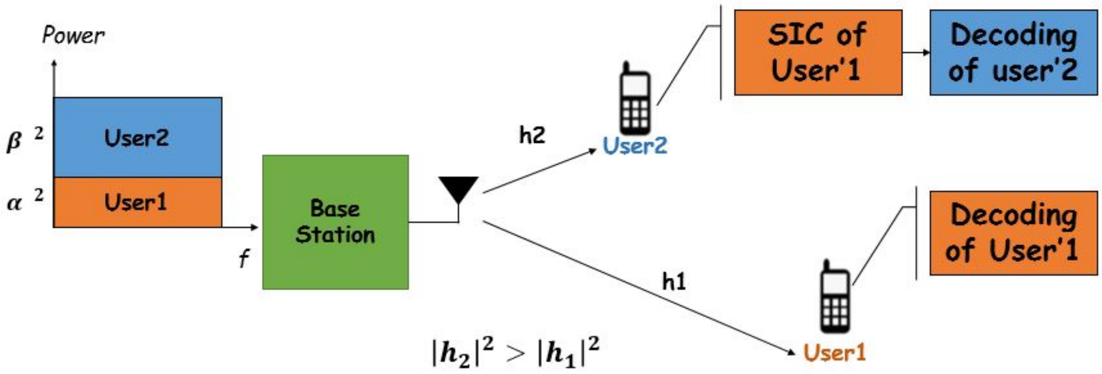

Figure 3.1: MIMO – NOMA Downlink Transmission Scenario.

Without loss of generality, we assume that user-1 needs to be connected quickly to transmit small packets. For example, this user can be an *IoT device* that needs to be served with a small-predefined data rate. The BS will transmit signals contains of per-coding and information signals as given by

$$\mathbf{x} = \mathbf{P}\mathbf{s} \tag{3.1}$$

where $\mathbf{P}$ is an $M \times N$ Precoding matrix, $\mathbf{s}$ is the information bearing vector. The information bearing vector, $\mathbf{s}$, is constructed by using the NOMA approach as

$$\mathbf{s} = \begin{bmatrix} \alpha_1 s_1 + \beta_1 w_1 & \dots & \alpha_N s_N + \beta_N w_N \end{bmatrix}^T \tag{3.2}$$

where s_i and w_i are the N^{th} stream transmitted to user-1 and user-2 respectively. Similarly, α_i and β_i is power allocation coefficient for s_i and w_i respectively and defined as ${\alpha_i}^2 + {\beta_i}^2 = 1$.

3.2.1 Successive Interference Cancellation (SIC)

At the receiver, To decode the superposed information at each User ,SIC is commonly used to equalize multi-user detection (MUD). Due to the near-far effect, the channel conditions may vary significantly among users. SIC is performed at users with relatively high signal-to-interference-plus-noise ratio (SINR), and should be carried out in descending order of SINR.

To work SIC at user-2 we can use QR Decompression at Channel Matrix $\mathbf{H}_2$ as

$$\mathbf{H}_2^{\mathrm{H}} = \mathbf{Q}_2\widehat{\mathbf{R}}_\mathbf{2} \tag{3.3}$$

where $\mathbf{Q_2}$ is the $M \times M$ unitary matrix obtained from $\mathbf{H_2}$ and $\widehat{\mathbf{R}}_\mathbf{2}$ is $M \times N$ upper triangle matrix obtained from $\mathbf{H}_2$. $\widehat{\mathbf{R}}_\mathbf{2}$ is $M \times N$ matrix obtained from the QR decomposition.

SIC can cancel inter-layer interference between w_i and w_j, $i \neq j$ and intra-layer interference (between s_i and w_i). Then user-2 can decode the message intended for user-1 at the i^{th} layer, s_i, then the SINR for user-2 at i^{th} layer as

$$\mathrm{SINR}_{2,\bar{i}} = \frac{\alpha_i^2 \left[\mathbf{R}_2^{\mathrm{H}}\right]_{i,i}^2}{\beta_i^2 \left[\mathbf{R}_2^{\mathrm{H}}\right]_{i,i}^2 + (1/\rho)} \tag{3.4}$$

where ρ is signal-to-noise ratio. $[\cdot]_{i,j}$ denotes the element in the i^{th} row and the j^{th} column of the matrix. $\mathbf{R}_2^{\mathrm{H}}$ is a lower triangular matrix. $R_{m,i}$ denote the target data rate of user m at the i^{th} layer. The receive signal at user-2 is given by

$$\mathbf{y}_2 = \mathbf{R}_2^{\mathrm{H}}\mathbf{s} + \mathbf{n}_2 \tag{3.5}$$

where $\mathbf{y}_2$ is the receive signal at user-2. $\mathbf{n}_2$ is complex Gaussian distributed with zero means and unit variances. $\mathbf{R}_2^{\mathrm{H}}$ is a lower triangular matrix. User 2 can successfully remove the user-1 (interference) one by using successive interference cancellation(SIC) and its own message can be decoded with the following SNR,

$$\mathrm{SNR}_{2,i} = \rho\beta_i^2\left[\mathbf{R}_2^{\mathrm{H}}\right]_{i,i}^2 \tag{3.6}$$

Similarly, estimating receive signal for user-1 is given by:

$$\mathbf{y}_1 = \mathbf{H_1Ps} + \mathbf{n}_1 \tag{3.7}$$

3.2.2 Zero Forcing Detection

We recall that the received signal $\mathbf{y}$ is filtered by a linear filter and each data symbol is detected separately. Applying the zero forcing at user-1, the system model at user-1 can be written as

$$(\mathbf{H}_1\mathbf{V}_2)^{\dagger}\mathbf{y}1 = \mathbf{s} + (\mathbf{H}_1\mathbf{V}_2)^{\dagger}\mathbf{n}_1 \tag{3.8}$$

User 1 can decode its message at the i^{th} layer with the following SINR

$$\mathrm{SINR}_{1,\bar{i}} = \frac{\alpha_i^2 z_i}{\beta_i^2 z_i + (1/\rho)} \tag{3.9}$$

where

$$z_i = \frac{1}{\left[\left(\mathbf{V}_2^{\mathrm{H}}\mathbf{h}_1^{\mathrm{H}}\mathbf{H}_1\mathbf{V}_2\right)^{-1}\right]_{i,i}} \tag{3.10}$$

3.3 Power Allocation Policies

In this section we formulate and evaluate the power allocation coefficient (α_i and β_i) because the design of power allocation coefficient helps us to insure that user-1 QoS can requirement can still *degraded* channel condition of user-1.In this system model there are two Power Allocation Policies.

3.3.1 Power Allocation Policy I

Recall that the power allocation coefficients are designed to realized its targeted data rate for each channel realization. we assume that the user-1 meet QoS requirements in the *long term service* then user-1 must be data rate of user-1 to detect s_i *less* than the target data rate for i^{th} layer. Then outage probability occurs when data rate of user-1 to detect s_i *greater* than the target data rate for i^{th} layer as

$$P^o_{1,i} = P\left(\log_2(1 + \mathrm{SINR}_{1,i}) < R_{1,i}\right) \tag{3.11}$$

where $P^o_{1,i}$ is the outage probability for user-1 at i^{th} layer, $R_{1,i}$ is the target data rate for user-1 at i^{th} layer.

3.3.2 Power Allocation Policy II

In this policy , we assume that meet user-1 QoS requirements *instantaneously*. Then the power allocation coefficient are defined to ensure that the targeted data rate of user-1 is met *instantaneously*, then user-1 must be data rate of user-1 to detect s_i *greater* than the target data rate for i^{th} layer. Then outage probability occurs when data rate of user-1 to detect s_i *less* than the target data rate for i^{th} layer as following

$$P^o_{1,i} = P\left(\log_2(1 + \mathrm{SINR}_{1,i}) \geq R_{1,i}\right) \tag{3.12}$$

From the previous equation, the threshold power allocation coefficient $\varepsilon_{k,i}$, at user-k at i^{th} layer, is given by

$$\varepsilon_{k,i} = 2^{R_{k,i}}-1 \tag{3.13}$$

By defining $\varepsilon_{k,i} = 2^{R_{k,i}}-1$, the above constraint yields the following power allocation policy. According to Eq(3.9) the SINR is $\mathrm{SINR}_{1,i} = \frac{\alpha_i^2[z_i]}{\beta_i^2 z_i + (1/\rho)}$ and

$$\varepsilon_{1,i} = \frac{\alpha_i^2[z_i]}{\beta_i^2 z_i + (1/\rho)} \tag{3.14}$$

$$= \frac{(1-\beta_i^2)z_i}{\beta_i^2 z_i + (1/\rho)} \tag{3.15}$$

since $\alpha_i^2 + \beta_i^2 = 1$. After analyzing this equation we can evaluate the power allocation coefficient policy as

$$\beta_i^2 = \max\left\{0, \frac{z_i - \frac{\varepsilon_{i,1}}{\rho}}{z_i(1+\varepsilon_{i,1})}\right\} \tag{3.16}$$

In Eq(3.16) when the power allocation coefficient is zero $\beta_i^2 = 0$, the user-1 only served which SIC at user-2 can be carried *Not Successfully.*

To ensure that SIC at user-2 can be *successfully*, we revise the power allocation strategy as

$$\beta_i^2 = \max\left\{\min\left(\frac{z_i - \frac{\varepsilon_{i,1}}{\rho}}{z_i(1+\varepsilon_{i,1})}\right), \min\left(\frac{x_i - \frac{\varepsilon_{i,1}}{\rho}}{x_i(1+\varepsilon_{i,1})}\right)\right\} \tag{3.17}$$

From the previous equation, note that it is also possible to reverse the decoding order when $z_i > x_i$. In this case, we need to ensure that the following two conditions are satisfied. One is to ensure that user-1 can decode the message intended for user-2, w_i,

$$\log_2\left(1 + \frac{\beta_i^2[z_i]}{\alpha_i^2 z_i + (1/\rho)}\right) \geq R_{2,i} \tag{3.18}$$

and the other is to ensure user-1 can decode its own message is given as

$$\log_2\left(1 + \rho\alpha_i^2 z_i\right) \geq R_{1,i} \tag{3.19}$$

3.4 Performance Analysis at User-1

In this section will performance analysis at user-1 as follows

1. user-1 outage performance with the two different power allocation policies.
2. Evaluate data rate for i^{th} layer will be studied with two different power allocation policies.

3.4.1 Achievable Data Rate at user-1 Policy I

The date rate of user-1 at i^{th} layers is considered in this subsection .we know that user-1 QoS requirements in the long term.then the data rate of user-1 to detect s_i Must be **Greater** than the Target data rate of user-1 at i^{th} layer ($R_{1,i} > R_{1,i,target}$) as

$$R_{1,i} > \log_2(1 + \mathrm{SINR}_{1,i}) \tag{3.20}$$

3.4.2 Outage performance at user-1 Policy I

When is policy-I is used, the power allocation coefficient of user-1 QoS requirement in long term then, the signal to interference noise ratio for user-1 at i_{th} layer is

$$\mathrm{SINR}_{1,i} > \frac{\alpha_i^2 x_i}{\beta_i^2 x_i + (1/\rho)}$$

Apply Eq(3.13) to the previous equation yields

$$\varepsilon_{i,1} < \frac{\alpha_i^2 x_i}{\beta_i^2 x_i + (1/\rho)} \tag{3.21}$$

$$\varepsilon_{i,1} \times (\beta_i^2 x_i + (1/\rho)) < \alpha_i^2 x_i \tag{3.22}$$

$$\frac{\varepsilon_{i,1}}{\rho} < (\alpha_i^2 - \beta_i^2 \varepsilon_{i,1}), \tag{3.23}$$

and then, the receive Signal must be

$$x_i > \frac{\frac{\varepsilon_{i,1}}{\rho}}{\alpha_i^2 - \beta_i^2 \varepsilon_{i,1}} \tag{3.24}$$

From the previous equation, the outage probability for user-1 to detect s_i can be expressed as

$$P_{1,i}^o = P\left(x_i < \frac{\frac{\varepsilon_{i,1}}{\rho}}{\alpha_i^2 - \beta_i^2 \varepsilon_{i,1}} \right) \tag{3.25}$$

by using the exponential Probability density function (PDF) the outage probability can be expressed as

$$P_{1,i}^o = 1 - e^{-\left(\frac{\frac{\varepsilon_{i,1}}{\rho}}{\alpha_i^2 - \beta_i^2 \varepsilon_{i,1}} \right)} \tag{3.26}$$

The outage probability range is

$$1 < P_{1,i,target} < 1 - e^{-\left(\frac{\varepsilon_{i,1}}{\rho}\right)} \tag{3.27}$$

Note that

- We ignore $P_{1,i,target} = 1$, since this choice does not consider user-1 QoS requirements (only user-2 serve).
- The right-hand side of the above equation is a lower bound on the targeted outage probability which is achieved by giving all the power to user-1.

3.4.3 Algorithm of performance Analysis at user-1 Policy I

Algorithm 1 (in next page) show that the steps of the algorithm uses to calculate the outage probability and data rate at user-1 Policy-I, to simplify the the algorithm we assume that the target data rate for each user is $R_{1,1} = 0.5$ BPCU , $R_{1,2} = 1$ BPCU , $R_{1,3} = 1.5$ BPCU and $R_{1,4} = 2$ BPCU. The number of layer $N = 4$. The number of transmit antennas $M = 6$.

Algorithm 1 Algorithm for outage performance and data rate at user-1 Policy I

```
procedure ($\{M, N, Time(T_{max}), \mathbf{H}_1, \mathbf{H}_2\}$)
    Initialize Maximum iteration times:= $T_{max}$.
    Enter Range Signal to noise ratio of user-1.
    Enter Data rate for user-1 at each layers $R_{1,i}$.
    Obtain the target data rate for each layer $R_{1,i,target}$.
    for $i \leftarrow 1, \text{length}(SNR)$ do
        Obtain the outage probabilities $P_{1,i,target}$ according to Eq(3.25);
        Initialize $t = 0$;
        for all $t \leq T_{max}$ do
            Obtain the channel Matrix $(\mathbf{H}_1, \mathbf{H}_2)$
            Decoding at user-1 according to Eq(3.8)
            if $x_i < \frac{\varepsilon_{1,i}/\rho}{\alpha_i^2 - \beta_i^2 \varepsilon_{1,i}}$ then
                Obtain the Outage probabilities for each layer $P_{1,i}$;
            else
                Obtain the data rate at each layer $R_{1,i}$
            end if
        end for
    end for
    return Output=$\{P_{1,i}, P_{1,i,target}\}$
end procedure
```

3.4.4 Outage performance at user-1 Policy II

When a user-1 QoS requirement in the instantaneously, the power allocation policy-II used, which the power allocation coefficients to ensure that $\log(1 + \mathrm{SINR}_{1,i}) \geq R_{1,i}$, but outage can still occur at small channel gain ($\beta_i = 0$) or occur at the receive signal . Next, let us rewrite the expression of β_i in Eq(3.17) as follows:

$$\beta_i^2 = \min\left\{\beta_{i,z}^2, \beta_{i,x}^2\right\} \tag{3.28}$$

where

$$\beta_{i,z}^2 = \max\left\{0, \frac{z_i - \frac{\varepsilon_{i,1}}{\rho}}{z_i(1+\varepsilon_{i,1})}\right\}, \tag{3.29}$$

$$\beta_{i,x}^2 = \max\left\{0, \frac{x_i - \frac{\varepsilon_{i,1}}{\rho}}{x_i(1+\varepsilon_{i,1})}\right\}. \tag{3.30}$$

When $x_i > z_i$, the outage probability of user-1 at i^{th} layer is $\beta_{i,x}^2 \geq \beta_{i,z}^2$, then

$$P_1^o(x_i > z_i) = P\left(\log_2\left(1 + \frac{\alpha_{i,z}^2 z_i}{\beta_{i,z}^2 z_i + (1/\rho)}\right) < R_{1,i}\right). \tag{3.31}$$

When $z_i > x_i$ the outage probability of user-1 at i^{th} layer is $\beta_{i,z}^2 \geq \beta_{i,x}^2$

$$P_2^o(z_i > x_i) = P\left(\log_2\left(1 + \frac{\alpha_{i,x}^2 z_i}{\beta_{i,x}^2 z_i + (1/\rho)}\right) < R_{1,i}\right) \tag{3.32}$$

Next, by adding Eq(3.31) and Eq(3.32), we obtain the total outage probability of user-1 to detect s_i as $P_{1,i}^o = P_1^o(x_i > z_i) + P_2^o(z_i > x_i)$, which yields

$$P_{1,i}^o = P\left(\frac{z_i\alpha_{i,z}^2}{z_i\beta_{i,z}^2 + (1/\rho)} < R_{1,i}\right) + P\left(\frac{z_i\alpha_{i,x}^2}{z_i\beta_{i,x}^2 + (1/\rho)} < R_{1,i}\right) \tag{3.33}$$

From Eq(3.31), we assume that $\beta_{i,z}^2 \neq 0$ this means that ***no outage occurs***. Therefore, the outage event when $x_i > z_i$ is due to $\beta_{i,z}^2 = 0$ then user-1 is only served, i.e.,

$$\alpha_{i,z}^2 = 1 \text{ when } \beta_{i,z}^2 = 0$$

From Eq(3.25) then $P_1^o(x_i > z_i)$ when ($\beta_{i,z}^2 = 0$) we have that

$$P_1^o(x_i > z_i) = P(z_i < \frac{\frac{\varepsilon_{i,1}}{\rho}}{\alpha_i^2 - \beta_{i,z}^2\varepsilon_{i,1}}) \tag{3.34a}$$

$$= P(z_i < \frac{\frac{\varepsilon_{i,1}}{\rho}}{1 - (0)\varepsilon_{i,1}}) \tag{3.34b}$$

$$= P(z_i < \frac{\varepsilon_{i,1}}{\rho}) \tag{3.34c}$$

Then, the outage probability from Eq(3.31) can be simplified as

$$P_1^o = P\left(z_i < \frac{\varepsilon_{i,1}}{\rho}\right) \tag{3.35}$$

From Eq(3.32), we assume that the ($\beta_{i,z}^2 = 0$), then we have that

$$P_2^o(z_i > x_i) = P\left(x_i < z_i < \frac{\frac{\varepsilon_i}{\rho}}{\alpha_{i,x}^2 - \beta_{i,x}^2\varepsilon_{i,1}}\right) \tag{3.36a}$$

$$= P\left(x_i < z_i < \frac{\varepsilon_{i,1}}{\rho}\right) \tag{3.36b}$$

Add Eq(3.35) and Eq(3.36b) we can be simplify as $P_{1,i}^o = P_1^o(x_i > z_i) + P_2^o(z_i > x_i)$. Hence we have that

$$P_{1,i}^o = P\left(z_i < \frac{\varepsilon_{i,1}}{\rho}\right) + P\left(x_i < z_i < \frac{\varepsilon_{i,1}}{\rho}\right) \tag{3.37}$$

Since the second probability in the above equation is zero,the overall outage probability can be calculated as

$$P_{1,i}^o = 1 - e^{-(\frac{\varepsilon_{i,1}}{\rho})} \tag{3.38}$$

3.4.5 Algorithm of performance Analysis at user-1 Policy II

Algorithm 2 (in next page) show the algorithm to calculate the outage probability and Data rate at user-1 Policy-II, we assume that the target data rate for user-1 at is $R_{1,1} = 0.5$ BPCU, $R_{1,2} = 1$ BPCU, $R_{1,3} = 1.5$ BPCU and $R_{1,4} = 2$ BPCU. The number of layer $N = 4$. The number of transmit antennas $M = 6$.

3.5 Outage Performance at user-2

3.5.1 Outage probabilities at user-2 Policy I

To decode the superposed information at each receiver, Cover [31], first proposed the SIC technique, where SIC is carried out at user-2 to remove both intra-layer and inter-layer interference. The outage event for user-2 to decode its own message at the i-th layer. Since there are two messages at two layer, the outage event $\breve{O}_{2,m}$ is given:

$$\breve{O}_{2,m} = \breve{E}_{m,1} \bigcup \breve{E}_{m,2} \tag{3.39}$$

where the two events are defined as follows:

Algorithm 2 Search algorithm used in computing Outage probability and Data Rate at user-1 Policy II

```
procedure ($\{M, N, Time(T_{max}), \mathbf{H}_1, \mathbf{H}_2\}$)
    Initialize Maximum iteration times:= $T_{max}$.
    Enter Range Signal to noise ratio of user-1.
    Enter Data rate for user-1 at each layers $R_{1,i}$.
    Obtain the target data rate for each layer $R_{1,i,target}$.
    for $i \leftarrow 1, \text{length}(SNR)$ do
        Obtain the outage probabilities $P_{1,i,target}$ according to Eq(3.25);
        Initialize $t = 0$;
        for all $t \leq T_{max}$ do
            Obtain the channel Matrix $(\mathbf{H}_1, \mathbf{H}_2)$
            Decoding at user-1 according to Eq(3.9)
            Obtain power allocation coefficient for each layers using Eq(3.17)
            if $x(i) < z(i)$ then
                if $x(i) < (\varepsilon_{1,i}/\rho)$ then
                    Obtain the Outage probabilities for each layer $P_{1,i}$
                end if
            else
                if $x(i) < (\varepsilon_{1,i}/\rho)$ then
                    Obtain the Outage probabilities for each layer $P_{1,i}$
                end if
                Obtain the Data Rate for each layer $R_{1,i}$
            end if
        end for
    end for
    return Output=$\{P_{1,i}, P_{1,i,target}\}$
end procedure
```

1. $\check{E}_{m,1}$: the event that user-2 cannot decode s_m, but can decode all the messages from the previous layers, s_n and w_n.
2. $\check{E}_{m,2}$: the event that user-2 cannot decode w_m, but can decode s_m, as well as s_n and w_n.

The outage probability for user-2 to decode its own message at the i^{th} layer can be expressed as

$$P^o_{2,i} = \sum_{m=1}^{i} P(\check{E}_{m,1}) + P(\check{E}_{m,2}) \tag{3.40}$$

The *first type* of outage probability $P(\check{E}_{m,1})$ can be given

$$\begin{aligned} P(\check{E}_{m,1}) = P\Big(&\log_2(1+\mathrm{SINR}_{2,\tilde{m}}) < R_{1,m}, \\ &\log_2(1+\mathrm{SINR}_{2,\tilde{n}}) > R_{1,n}, \\ &\log_2(1+\mathrm{SINR}_{2,m}) > R_{2,n}, ...(m-1)\Big) \end{aligned} \tag{3.41}$$

The *Second type* of outage probability $P(\check{E}_{m,2})$ can be given as

$$\begin{aligned} P(\check{E}_{m,1}) = P\Big(&\log_2(1+\mathrm{SINR}_{2,m}) < R_{1,m}, \\ &+\log_2(1+\mathrm{SINR}_{2,\tilde{m}}) > R_{1,m}, \\ &+\log_2(1+\mathrm{SINR}_{2,\tilde{n}}) > R_{1,n}, \\ &+\log_2(1+\mathrm{SINR}_{2,n}) > R_{2,n}, ...(m-1)\Big) \end{aligned} \tag{3.42}$$

by using SINR expression in Eq(3.5), the above Eq(3.37) can be expressed as follows

$$\begin{aligned} P(\check{E}_{m,1}) = P\Big(&\log_2\left(x_m < \frac{\alpha_m^2 x_m}{\beta_m^2 x_m + 1/\rho}\right) < R_{1,m}, \\ &\log_2(x_n < \frac{\alpha_n^2 x_n}{\beta_n^2 x_n + 1/\rho}) < R_{1,n}, \\ &\log_2(1+\rho\beta_n^2 x_n) > R_{2,n}, ...(m-1)\Big) \end{aligned} \tag{3.43}$$

Provided that power allocation policy I is used, the power coefficients are not functions of instantaneous channel gains, which yields the following:

$$P(\check{E}_{m,1}) = P\left(x_m < \frac{\varepsilon_{1,m}/\rho}{\alpha_m^2 - \beta_m^2\varepsilon_{1,m}}\right) \prod_{n=1}^{m-1} P\left(x_n < \frac{\varepsilon_{1,n}/\rho}{\alpha_n^2 - \beta_n^2\varepsilon_{1,n}}, x_n > \frac{\varepsilon_{2,n}}{\rho\beta_n^2}\right) \tag{3.44}$$

By applying the pdf of x_m, the above probability can be obtained as

$$P(\check{E}_{m,1}) = \frac{\gamma(M-m+1,\zeta_m)}{(M-m)!} \times \prod_{n=1}^{m-1}\left(1-\frac{\gamma(M-m+1,\max\{\zeta_n,\frac{\varepsilon_{2,n}}{\rho\beta_n^2}\})}{(M-m)!}\right) \tag{3.45}$$

where

$$\zeta_m = \frac{\varepsilon_{1,m}/\rho}{\alpha_m^2-\beta_m^2\varepsilon_{1,m}} \tag{3.46}$$

Similarly the probability of the second type of Eq(3.39) can be obtained as

$$P(\check{E}_{m,2}) = \sum_{m=1}^{i}\frac{\gamma(M-m+1,\max(\zeta_n,\frac{\varepsilon_{2,n}}{\rho\beta_n^2})}{(M-n)!} \times \prod_{n=1}^{m-1}\left(1-\frac{\gamma(M-m+1,\max(\zeta_n,\frac{\varepsilon_{2,n}}{\rho\beta_n^2})}{(M-n)!}\right) \tag{3.47}$$

3.5.2 Algorithm of Performance Analysis at user-2 Policy I

Algorithm 3 (in next page) show the algorithm to calculate the outage probability at user-2 Policy-I.which is the target data rate for each user is $R_{1,1} = 1$ BPCU, $R_{1,2} = 2$ The number of layer $k = 3$. The number of transmit antennas $M = 4$.

3.5.3 Outage probabilities at user-2 Policy II

With this type of power allocation,the power allocation coefficients become functions of the instantaneous channel gains, and this fact makes the evaluation of the outage probability very challenging, as explained in the following. First

$$y_{i,i} = \left(\mathbf{V_2^H H_1^H H_1 V_2}\right)^{-1} \tag{3.48}$$

then the power allocation coefficients at user-2 can be expressed as

$$\beta_i^2 = max\left\{0, min\left\{\frac{y_{i,i}(\frac{1}{y_{i,i}}-\frac{\varepsilon_{1,i}}{\rho})}{(1+\varepsilon_{1,i})}, \frac{x_i-\frac{\varepsilon_{1,i}}{\rho}}{x_i(1+\varepsilon_{1,i})}\right\}\right\}. \tag{3.49}$$

3.5.4 Algorithm of Performance Analysis at user-2 Policy II

Algorithm 4 show the algorithm to calculate the outage probability at user-2 Policy-II .which is the target data rate for each user is $R_{1,1} = 1$ BPCU, $R_{1,2} = 2$. The number of layer $k = 3$, and the number of transmit antennas $M = 4$.

Algorithm 3 Search algorithm used in computing Outage probability at user-2 Policy I

```
procedure EUCLID($\{M, N, Time(T_{max}), \mathbf{H}_1, \mathbf{H}_2\}$)
    Initialize Maximum iteration times:= $T_{max}$.
    Enter Range Signal to noise ratio of user-1.
    Enter Data rate for user-1 at each layers $R_{1,i}$.
    Obtain the target data rate for each layer $R_{1,i,target}$.
    for $i \leftarrow 1, \text{length}(SNR)$ do
        Obtain the outage probabilities $P_{1,i,target}$ according to Eq(3.25);
        Initialize $t = 0$;
        for all $t \leq T_{max}$ do
            Obtain the channel Matrix ($\mathbf{H}_1, \mathbf{H}_2$)
            Decoding at user-1 according to Eq(3.9)
            Obtain power allocation coefficient for each layers using Eq(3.16)
            if then
                Obtain the Outage probabilities at user-1 for each layer $P_{1,i}$;
            else
                Obtain the Outage probabilities at user-2 for each layer $P_{1,i}$
            end if
            Obtain approximation of the outage probability at $i^{th}$ layer according (3.47)
        end for
    end for
    return Output=$\{P_{1,i}, P_{1,i,target}\}$
end procedure
```

Algorithm 4 Search Algorithm Used in Computing Outage Probability at User-2 Policy II

```
procedure EUCLID($\{M, N, Time(T_{max}), \mathbf{H}_1, \mathbf{H}_2\}$)
    Initialize Maximum iteration times:= $T_{max}$.
    Enter Range Signal to noise ratio of user-1.
    Enter Data rate for user-1 at each layers $R_{1,i}$.
    Obtain the target data rate for each layer $R_{1,i,target}$.
    for $i \leftarrow 1, \text{length}(SNR)$ do
        Obtain the outage probabilities $P_{1,i,target}$ according to Eq(3.25);
        Initialize $t = 0$;
        for all $t \leq T_{max}$ do
            Obtain the channel Matrix $(\mathbf{H}_1, \mathbf{H}_2)$
            Decoding at user-2 according to Eq(3.9)
            Obtain power allocation coefficient for each layers using Eq(3.17)
            if then
                Obtain the Outage probabilities at user-1 for each layer $P_{1,i}$;
            else
                Obtain the Outage probabilities at user-2 for each layer $P_{2,i}$
            end if
        end for
    end for
    return Output=$\{P_{2,i}, P_{1,i,target}\}$
end procedure
```

Chapter Four
Results and Discussion

4.1 Introduction

In this chapter we discuss the performance Analysis of MIMO-NOMA Scheme is evaluated by MatLab simulation. First we discuss the result of the performance analysis for user-1 , user-2 in different policies and then discuss the result of MIMO-OMA compared to MIMO-NOMA schemes.

4.2 Performance Analysis at user-1

4.2.1 Performance analysis for user-1 at Policy-I

To simplify the simulation , we assume that the target data rate for user-1 at layer 1,2,3 and 4 $R_{1,1} = 0.5$ BPCU (Bit Per Channel User) , $R_{1,2} = 1BPCU$, $R_{1,3} = 1.5$ BPCU and $R_{1,4} = 2$ BPCU respectively for all $1 \leq i \geq 4$. with number of transmit antennas is 6 $(M = 6)$ and number of layers is 4 $(N = 4)$.

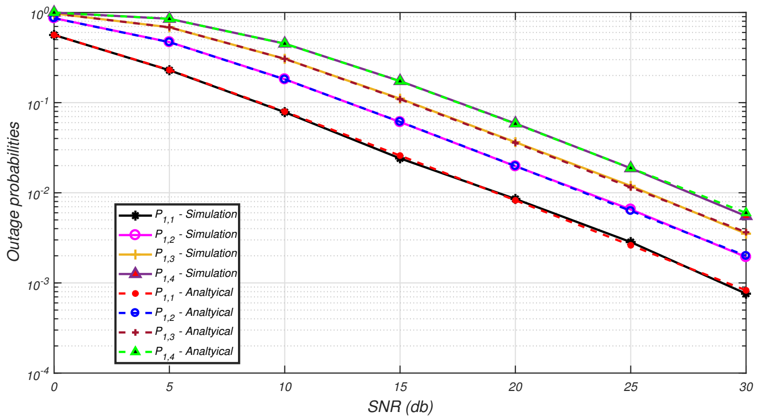

Figure 4.1: Outage performance at user 1 with power allocation policy-I

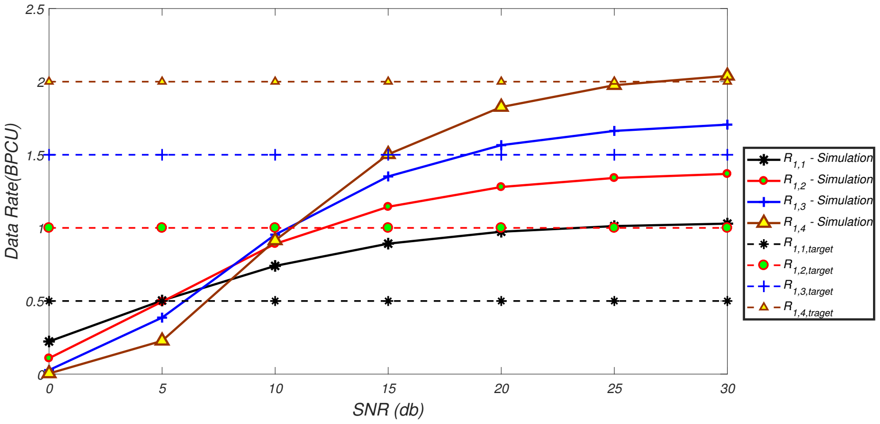

Figure 4.2: Data Rate at user 1 for each layers with power allocation policy-I

4.2.1.1 Outage Probabilities for User'1 at Policy-I

In figure 4.1 demonstrate the simulation result of the outage performance of user-1 at i^{th} layers is achieved by MIMO-NOMA scheme in different target data rate when the power allocation policy-I is used.The outage probability of i^{th} layers ($P_{1,i}$) is *"matched perfectly"* with *"analytical"* of outage probability of user-1 at i^{th} layers ($P_{1,i} - Analytical$). The outage probability for user-1 of layer'1 ($P_{1,1}$) has less outage probability of other layers because $R_{1,1_{target}}$ is greater than target data rate of other layers and so on other layers.

4.2.1.2 Data Rate for User'1 at Policy-I

In figure 4.2 show the result of simulation of Data rate user-1 at i^{th} layer. The data rate of user-1 at layer'1 ($R_{1,1}$) is begin at SNR $= 5$ dB (when $R_{1,1} \geq R_{1,1,target} = 0.5$ BPCU and when $P_{1,1} < 0.23$) when the $P_{1,1} > P_{1,1,target} = 0.23$ (See Figure 4.1), a $user_{1,1}$ *"outage"*, and so on at $R_{1,2}$ and $R_{1,3}$ .The data rate of user 1 at layer'4 the outage probability is very high which is the $User_{1,4}$ is begin forward data rate at SNR $= 27.5$ dB because the the target data rate is high.

4.2.2 Performance analysis for user-1 at Policy-II

In this subsection we discuss the simulation Result of user-1 at policy-II. We assume that the QoS's Requirement of user-1 is *instantaneously* the power allocation Policy-II is done. We assume that target data rate for user-1 at layer 1,2,3 and 4 $R_{1,1} = 1$ BPCU, $R_{1,2} = 3$ BPCU, $R_{1,3} = 5$ BPCU and $R_{1,4} = 6$

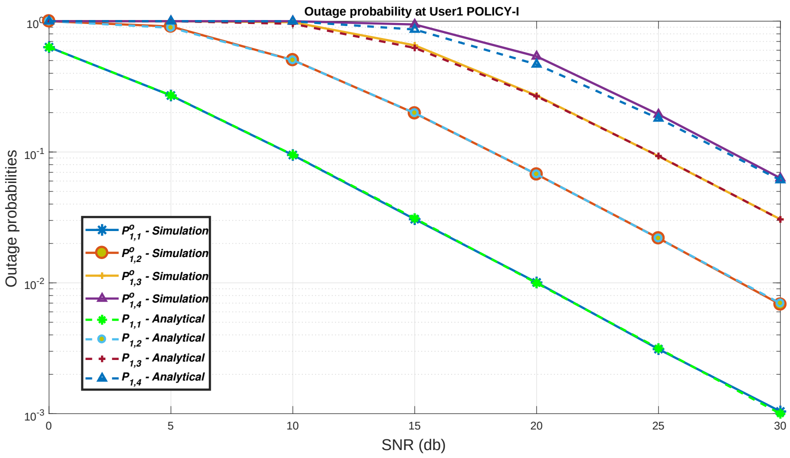

Figure 4.3: Outage probabilities at user 1 for each layers with power allocation policy-II

BPCU respectively for all $1 \leq i \geq 4$ with number of transmit antennas is 6 $(M = 6)$ and number of layers is 4 $(N = 4)$.

4.2.2.1 Outage probabilities for user-1 at Policy-II

In Figure 4.3, we demonstrate the simulation result of the outage performance of user-1 at i^{th} layers is achieved by MIMO-NOMA scheme in different target data rate when the power allocation policy-II is used.the outage probability of user-1 at i^{th} layer $(P_{1,i} - Simulation)$ is *"matched perfectly"* with the analytical results evaluated (3.20). Therefore, the use of power allocation policy-II guarantees that the outage probability at user 1 is $1 - e^{(\varepsilon_{1,i})/\rho}$ which is equivalent to the outage performance for the case in which all the power is allocated to user 1. The outage probability for user-1 of layer'1 $(P_{1,1})$ has less outage probability of other layers because $R_{1,1_{target}}$ is greater than target data rate of other layers and so on other layers.

4.2.2.2 Data Rate for User'1 at Policy-II

In figure 4.4 show the result of simulation of Data rate user-1 at i^{th} layer are shown as functions of the transmit SNR. The all data rate of user-1 at i^{th} layer is less than it target data rate at i^{th} layer $(R_{1,i} < R_{1,i,target})$. In this figure also observation that the data rate of user-1 at layer'4 have highest data rate of each other because the $R_{1,4,target}$ is higher. To improve the data rate of other layer must increase the the number of transmit antenna.

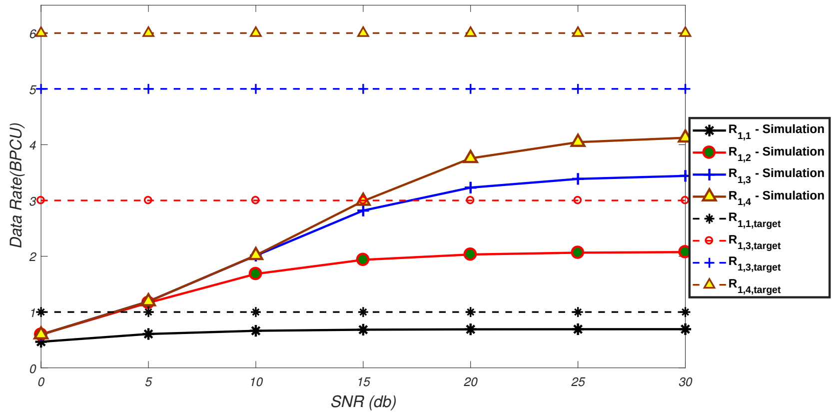

Figure 4.4: Data rate for user 1 for i^{th} layers with power allocation policy-II

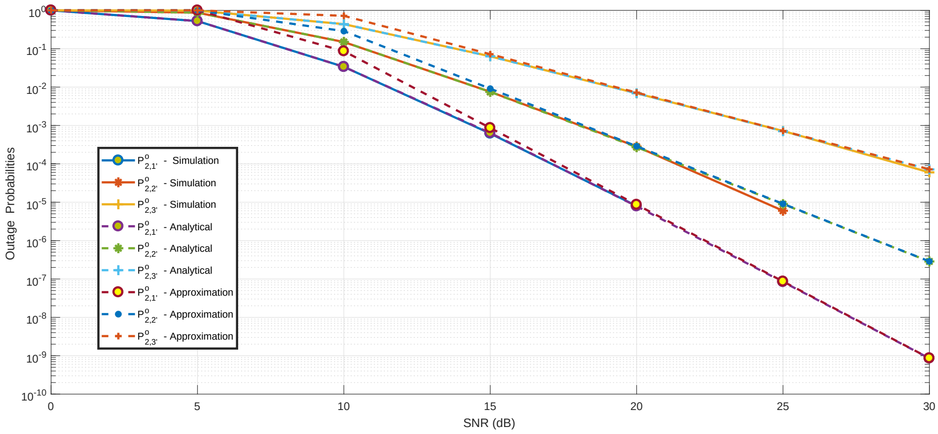

Figure 4.5: Outage probabilities at user 2 for each layers with power allocation policy-II

4.3 Performance Analysis at user-2

4.3.1 Performance Analysis at User-2 Policy I

The QoS Requirement of user-2 is *"Long term"* the power allocation Policy-I is done. We assume that target data rate for user-1 at layer 1,2 $R_{1,1} = 1$ BPCU, $R_{1,2} = 2BPCU$ respectively for all $1 \leq i \geq 3$ with number of transmit antennas is 4 $(M = 4)$ and number of layers is 3 $(N = 3)$.

4.3.1.1 Outage probabilities at user-2 Policy I

As show in figure 4.5 the outage probabilities at user 2 are shown as functions of the transmit SNR,when power allocation policy-I is used. As can be ob-

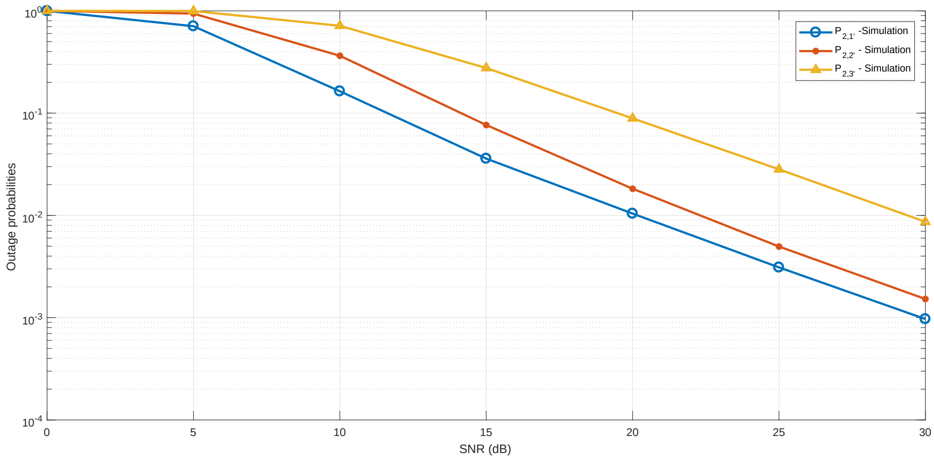

Figure 4.6: Outage probabilities at user 2 for each layers with power allocation policy-II

served from the figure, the curves for the simulation results match perfectly with the ones for the analytical result developed in (3.35), which demonstrates the accuracy of this exact expression for the outage probability. The curves for the approximation results developed in (3.36) match the simulation curves only at high SNR, which is due to the fact that this approximation is obtained with the high SNR assumption.

4.3.2 Outage probabilities at user-2 Policy II

In Figure 4.6 demonstrates the outage performance at user-2 when power allocation policy-II is used.As shown in the figure , the outage performance of user 2 can be improved by increasing the number of antennas at the base station or decreasing the targeted data rates.An important observation from this figure is that at high SNR, the slope of all the curves is the same, which means that the same diversity gain is achieved at all layers, regardless of the choice of the number of antennas at the base station.

Chapter Five
Conclusions and Recommendations

5.1 Conclusions

This thesis concentrates on the MIMO-NOMA Scheme in wireless communications systems, which is regarded as one promising technology in future 5G networks . We achieved the throughput gain of MIMO-NOMA with practical capacity-approaching techniques and reduced complexity at the receiver and to evaluate the performance gap between MIMO of OMA and NOMA., analyzed and quantified the effects of power allocation on the performance of MIMO-NOMA and to provide the closed-form expressions for the probability density function (PDF) of signal-to interference plus noise ratio (SINR) and calculated the outage for zero forcing (ZF) post-coded receivers.

In chapter 2 we introduced the literature Reviewer on the MIMO-NOMA scheme. The following two aspects are presented in this literature Review.

1. The basic principle of Multiple access Techniques is introduced and classified into two Orthogonal Multiple Access (OMA) and NOMA. In OMA, multiple users transmit orthogonal signal waveforms (orthogonal channels) such that there is no interference in the users signal waveform, OMA including the several types is TDMA, FDMA, OFDMA, SC-FDMA. In NOMA The base station (BS) transmits a signal superposition to all users. The users are paired so that in each pair there is one with a better channel condition and another with a poorer channel condition,also a NOMA including the several types is SCMA, MUSA, NCMA,...etc.

2. Reviewed Multiple Antenna scheme, Multiple antennas available at the transmitter-receiver can be improve the diversity and capacity of a mobile communication system and reviewed the MIMO system and including the two key technologies is single and multiple user systems.

In chapter 3 we concentrated the analyze system model of this thesis and we have considered a MIMO-NOMA DL transmission scenario,which new Precoding and power allocation strategy has been proposed to ensure that the potential of NOMA can be realized even if the participating users'channel conditions are similar.Particularly,the Precoding matrix has been designed to degrade user 1's effective channel gains while improving the signal strength at user 2 Two types of power allocation policies have been developed to meet user-1's QoS requirements in a long and short term, respectively. Analytical and numerical results have also been provided to demonstrate the advantages and disadvantages of the two power allocation policies. The outage performance of user 2 has been analyzed by using some bounding techniques.

In chapter'4 we discussed the discussed the performance Analysis of MIMO-NOMA Scheme is evaluated by MatLab simulation , The following two aspects are presented in this chapter.

1. We discussed the result Simulation performance analysis of user-1 ,which is he outage performance and Data rate of user-1 at i^{th} layers is achieved by MIMO-NOMA scheme in different target data rate when the power allocation policy-I and policy-II is used.The outage probability of i^{th} layers ($P_{1,i}$) is *"matched perfectly"* with *"analytical"* of outage probability of user-1 at i^{th} layers ($P_{1,i} - Analytical$) as proposed in policy-I and policy-II.

2. We discussed the performance analysis of user-2 at i^{th} layer is achieved by MIMO-NOMA scheme in different target data rate when the power allocation policy-I and policy-II is used which is the simulation results match perfectly with the ones for the analytical result developed analytical and approximation result.

3. We have proved that MIMO-NOMA is better than MIMO-OMA in terms of sum channel capacity .for any rate pair achieved by MIMO-OMA schemes there is a power split for which MIMO-NOMA schemes can achieve rate pairs that are strictly larger

5.2 Recommendations

The key drawbacks and future works are as follows.

1. New coding and modulation for NOMA: Fifth generation (5G) wireless networks face various challenges in order to support large-scale hetero-

geneous traffic and users [32], therefore new modulation and multiple access (MA) schemes are being developed to meet the changing demands.

2. hybrid MU-MIMO and NOMA: hybrid MU-MIMO and NOMA design scheme in wireless heterogeneous networks to improve the system throughput and also to increase multi-user diversity gains by exploiting the heterogeneous nature of the supporting wireless networks [33].

3. Imperfect CSI and limited channel feedback: The transmitter acquires the CSI through the limited feedback channel, is studied [34]. Making use of the imperfect CSI feedback, channel direction information (CDI) and channel quality indicator (CQI), we propose the user selection scheme to reduce the interference between the NOMA users.

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