ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

INSTITUTE OF TECHNOLOGY

ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

Performance Evaluation of Downlink Power Domain Non-orthogonal Multiple Access over Rayleigh Channel

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This thesis is submitted to the Department of Electrical and Computer Engineering at Addis Ababa University Institute of Technology in partial fulfillment of the requirements for the Degree of Masters of Science in Electrical Engineering (Specialized in Electronics & Communication Engineering).

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Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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Date of Submission: _____

This thesis has been submitted for examination with my approval as a university advisor.

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Abstract

In the future demand or number of mobile user for wireless service become very large, eventually the number of channels assigned to each cell will be insufficient to support the required number of users. And as its obvious spectrum is a very scares and limited resource, so that our country or any other countries can't use the resource as they want which direct the mobile communication unsustainable in system capacity/ efficiency and quality of user experience. In order to continue to guarantee the sustainability of mobile communication services over the following decade, new technology solutions that can answer to future challenges need to be recognized and developed. Non-orthogonal multiple access (NOMA) is one of radio access techniques for performance enhancement in next-generation cellular communications.

It's imperative to evaluate the performance of NOMA under Rayleigh fading channel. Multipath fading is a challenging channel for wireless communication and in the presence of Rayleigh fading channel it can cause drastic increase in either signal outage probability or average BER. Therefore this thesis uses outage probability and BER performance measurement matrix to evaluate downlink NOMA taking advantage of power domain user multiplexing scheme that utilizes superposition coding (SC) at the transmitter, successive interference cancellation (SIC) applied at the receiver and integrated with multiple-input multiple-output (MIMO) for future radio access.

Implementation of MIMO over NOMA and evaluate the impacts of Rayleigh fading channel on NOMA is done through simulation using Matlab simulation. From the simulation result the performance of NOMA is better than OFDMA in terms of BER reduction and for higher SNR value NOMA achieve acceptable performance based on both matrixes, therefore it's recommended to implement for future radio access.

***Key term*: Non-orthogonal multiple access (NOMA), Power domain NOMA, Superposition coding (SC), Successive interference cancellation (SIC), Multiple-input Multiple-output (MIMO), NOMA performance, Bit error rate (BER), Outage probability.**

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List of Abbreviations

3GPP - 3rd Generation Partnership Project

4G - Fourth Generation

5G - Fifth Generation

AMC - Adaptive Modulation and Coding

AWGN - Additive White Gaussian Noise

BER - Bit Error Rate

BPSK - Binary Phase Shift Key

BS - Base Station

CCU - Cell Center Users

CEU - Cell Edge Users

CDMA - Code Division Multiple Access

CQI - Channel Quality Indicator

CS - Compressive Sensing

CSI - Channel Stat Information

CWIC - codeword-level Interference Cancelation

DPC - Dirty Paper Coding

eMBB - Enhanced Mobile Broadband

EQPA - Equal Power allocation

FDMA - Frequency Division Multiple Access

FEC – Forward Error Correction

FRA - Future Radio Access

FSPA - Full Search Power Allocation

HARQ - Hybrid Automatic Repeat Request

HSPA - High Speed Packet Access

IRC – Interference rejection combining

LOS - Line of Sight

LTE - Long Term Evolution

METIS - Mobile and wireless communications Enablers for Twenty-twenty Information Society

MC - Monte Carlo

MCS - Modulation and Coding Scheme

MIMO - Multiple Input Multiple Output

MMSE - Minimum Mean Squared Error

MRC - Maximal Ratio Combining

MU - Multiuser

MUD - Multiuser Detection

NOMA - Non-orthogonal Multiple Access

OFDMA - Orthogonal Frequency Division Multiple Access

OLLA - Outer Loop Link Adaptation

OMA - Orthogonal Multiple Access

PDF - Probability Density Function

QOE - Quality of User Experience

QPSK - Quadrature Phase Shift Keying

SC FDMA - Single Carrier Frequency Division Multiple Access

SC - Superposes Coding

SE - Spectral Efficiency

SCMA - System Grant-free Multiple Access

SIC - Successive Interference Cancellation

SIMO - Single Input Multiple Output

SINR - Signal-to-Interference-plus-Noise Ratio

SISO - Single Input Single Output

SNR - Signal to Noise Power Ratio

SU - Single User

TDMA - Time Division Multiple Access

UE 1 - User One

UE 2 - User Two

ZF SIC - Zero Force Successive Interference Cancellation

Chapter 1: Introduction and general overview

1.1 Introduction

For the past and present cellular mobile communications generation different multiple access schemes has been introduced and from among those frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA) and orthogonal frequency division multiple access (OFDMA) are list and they categorized under orthogonal multiple access technologies based on their behaviors. In the 3.9 and 4th generation (4G) mobile communication systems such as Long-Term Evolution (LTE) and LTE-Advanced standardized by the 3rd Generation Partnership Project (3GPP) orthogonal multiple access based on OFDMA or single carrier (SC)- FDMA is adopted [1-3]. Orthogonal multiple access was a reasonable choice for achieving good system-level throughput performance in packet-domain services with simple single-user detection. However considering future radio access (FRA) in the 2020s further enhancement to achieve significant gains in capacity and system throughput performance is a high priority requirement in view of the recent exponential increase in the volume of mobile traffic e.g. beyond a 500 fold increase in the next decade and the need for enhanced delay-sensitive high-volume services such as video streaming and cloud computing [4]. Thus the 3GPP recently has initiated discussions on further evolution of LTE towards the future. In order to continue to ensure the sustainability of 3GPP radio access technologies over the coming decade new solutions must be identified and provided that can respond to future challenges [4, 5]. Also recent trends in research activity for the next generation of mobile and wireless communication systems for 2020 and beyond have emerged such as the Mobile and wireless communications Enablers for the 2020 Information Society (METIS) project [6].

To adapt such demands a combination of multiple approaches that is technologies for spectrum efficiency improvement spectrum extension with efficient use of higher frequency bands and network compression deploying small cells would be required. In this sense innovative radio access technologies to enhance significantly the spectrum efficiency and the small-cell enhancement now on-going in the 3GPP are very important. Although it may be very challenging

to achieve a further 3-fold enhancement in the spectrum efficiency compared to the LTE baseline for FRA toward the 2020s. Since LTE has already achieved a 3-4 fold enhancement in the spectrum efficiency compared to 3G High Speed Packet Access (HSPA). the target gain would be more than 10 fold compared to the 3G HSPA, for instance the gain in the total capacity such as beyond 500 fold can be achieved if other ways i.e. spectrum extension and network densification achieve a capacity gain of 50 fold [7].

To enhance the spectrum efficiency non-orthogonal multiple access (NOMA) scheme using interference cancellation is a promising new multiple access scheme for FRA [8-12]. NOMA allows allocating one frequency channel to multiple users at the same time within the same cell and offers a number of advantages. Including improved spectral efficiency (SE), higher cell-edge throughput, relaxed channel feedback and low transmission latency (no scheduling request from users to base-station is required). The available NOMA techniques can broadly be divided into two categories namely power-domain and code domain NOMA. This thesis focuses on the power-domain NOMA that superposes multiple users in power domain. At the transmitter side signals from various users are superposed and the resulting signal is then transmitted over statistical time varying flat fading channel. At the receiver sides multiuser detection (MUD) algorithms such as successive interference cancellation (SIC) are utilized to detect the desired signals.

1.2 Statement of the Problem

Multiple access is a very fundamental technique that let’s communication technology share the very limited spectrum resource in effective manners. As of today FDMA, TDMA, CDMA and OFDMA where mostly practiced techniques. However due to rapidly emerging number of user it required to find another technology with improved performance and capacity to support more number of user. NOMA is one of the multiple access which shows promising performance due to different studies.

Channel is the sensitive key part for wireless communication because of instability between transmitter and receiver due to rapidly changing the surrounding environment and mobility of the user. Since Rayleigh fading channel is a multipath component and drawback of wireless

communication and its potential to cause drastic increase in either average BER or signal outage probability, it is necessary to consider the effect of it while studying the performance of NOMA.

The problem considering in this thesis is to analyze the effect of Rayleigh fading channel on the performance of NOMA specifically the downlink communication with power domain multiplexing scheme using BER and outage probability performance measurement matrix.

1.3 Literature Review

On the area of NOMA there have been different studies made and from among those the following are reviewed to frame the scope of the thesis and the existing problem.

Research paper [13] addresses the power allocation issues in NOMA systems. First they proposed trade-offs based power allocation which was higher power needs to be allocated to the far user and vice versa to improve bit error rate (BER) performance, minimize the interference and perfect SIC at near user. But then it ultimately reduces the overall capacity gain of the pair. Secondly Conventional Power Allocation was proposed which is once the power is allocated to the far user such that its target rate is satisfied, the rest of the power is allocated to the near user. But it's explored at high signal to noise ratio (SNR) the difference between the powers of both users become negligible which increases the mutual interference extremely. In order to resolve these issues a threshold based power allocation scheme is proposed. The last proposal implicates that if the difference between power allocation factors of both users is less than around 0.35, then drastic effects start to occur on the performance of both users.

In [14], K. Higuchi and A. Benjebbour provided the channel capacity comparison of orthogonal multiple access (OMA) and NOMA, where a couple of users communicating with a base station (BS) over an additive white Gaussian noise (AWGN) channel. Their investigation showed that for the uplink, NOMA is competent of achieving the capacity region while OMA general acchive the capacity range less than NOMA except at one point. However at this optimal point rate-fairness is not maintained since the rate of the higher-power user is much greater than that of the low-power user when the difference of the received powers of the two users is high. In the downlink the

boundary of the capacity region is given by the rate tuples which is valid for all possible splits of total power at the BS. The optimal points can be achieved by NOMA with the aid of superposition coding at the transmitter and SIC at each of the receivers. More particularly the boundary of the rate pairs of Downlink NOMA is in general beyond that of OMA in asymmetric channels.

The work in [15] shows NOMA performance comparison with and without turbo. They proposed to implement turbo codes which error correcting codes that come very closer to achieving theoretical performance limits (Shannon's capacity) than any other error correction codes for NOMA in order to reduce BER. Its applied two encoders and one inter-leaver at the transmitter side and two decoders and one deinterleaver at the receiver side. As a result, they concluded that the performance of both; cell center users (CCU) and cell edge users (CEU) is better in terms of BER reduction with NOMA using the turbo codes than un-coded conventional NOMA.

On this paper [16] evaluated the system-level performance of NOMA considering more practical aspects of the cellular system and some of the key parameters and functionalities of the LTE radio interface such as frequency-domain scheduling, adaptive modulation and coding (AMC), hybrid automatic repeat request (HARQ) and outer loop link adaptation OLLA, in addition to NOMA specific functionalities such as dynamic multi-user power allocation. Because of NOMA has more degrees of freedom to co-schedule more users in the same sub-band, it is showed that the overall cell throughput, cell-edge user throughput and the degree of proportional fairness of NOMA are all superior to that for OMA using computer simulations. However the order of the gains depends on multiple factors such as the number of UEs per cell and the number of sub-bands for scheduling. In particular, wideband modulation and coding scheme (MCS) selection is seen as a limiting factor to harnessing the benefits of sub-band user multiplexing for NOMA. It was also found that OLLA also improves the overall cell throughput and CEU throughput of NOMA even when dynamic power allocation is applied.

Some of those literature reviewed in this thesis justify that NOMA is better than OMA on channel capacity and system level performance, and some of them shows how power should be allocate and the performance of NOMA with turbo coding. Other literature which is not included in this thesis also study the performance of NOMA using different performance measurement matrix.

However there is still open area to study the performance of NOMA using BER and outage probability performance measurement matrix under Rayleigh fading channel.

1.4 Objective

1.4.1 General Objective

The general objective of the thesis is to evaluate the performance of Downlink Non-orthogonal multiple access over poor channel condition like Rayleigh fading channel.

1.4.2 Specific Objective

The specific objective of this thesis is:

- To study and analysis the working principle of NOMA as it's a new multiple access scheme.
- To perform implementing MIMO on NOMA and study the performance improvement.
- To identify the impact of Rayleigh fading channel on NOMA using BER and outage probability performance measurement matrix.

1.5 Thesis Contribution

NOMA is one of the promising multiple access for future radio access technology, and before deploying for 5G it's helpful to evaluate the performance of NOMA. The specific contribution of this thesis are providing the working principal of Downlink NOMA by identifying the key power allocation requirements. System and signal model for downlink multiple input multiple output MIMO-NOMA is presented. Zero force (ZF) with SIC technique is applied in MIMO-NOMA in order to cancel out the multiuser interference. Finally the study of NOMA BER and outage probability under Rayleigh fading channel is presented.

1.6 Limitation of the Study

The thesis

- Considers only Downlink communication.
- Only focused on power allocation domain.
- Study the channel environment under Rayleigh fading channel.
- The performance investigation is based on Matlab simulation which is theoretical analysis.

1.7 Structure of the Thesis

This thesis contains totally six chapters. The first chapter presents introduction and general overview of NOMA, statement of the problem, objective of the thesis, contribution and limitation of the thesis. The rest of the thesis is organized as follows: Chapter 2 presents general concepts of Downlink NOMA with detail briefing of its technical working principal like Superposes coding, SIC, uplink and downlink power domain and advantage of NOMA compering with OMA. Chapter 3 analyze the application of NOMA in MIMO system in both uplink and downlink transmission. Single input multiple output (SIMO), singe user MIMO (SU-MIMO) and multiple user (MU-MIMO) also reviewed. Chapter 4 gives Simulation block and system model of Downlink NOMA at the transmitter and receiver side. Describes implementing of downlink MIMO-NOMA over Rayleigh channel. Chapter 5 provides the simulation results and discussion of Downlink NOMA over Rayleigh fading channel. And on the last chapter the conclusion and suggestion for future work are presented.

Chapter 2: Downlink NOMA Concept and Design

2.1 Introduction

The basic principle of NOMA is to simultaneously serve multiple users over same spectrum resources (i.e. time, frequency, code and space) but with different power levels at the expense of minimal inter-user interference [17-21]. On the other hand in the case of OMA, where every user is served on exclusively allocated spectrum resources. There are two method NOMA use to serve multiple user using the same resource and those are code domain and Power domain. This thesis study on the power-domain NOMA that superposes multiple users in power domain multiplexing scheme and exploits the channel gain difference between multiplexed users. At the transmitter side, various users signal will superposed and the combined signal is then transmitted over the same channels (i.e. the same time-frequency resources). At the receiver sides, SIC is applied to detect the desired information.

2.2 Superposes Coding (SC)

The SC is a technique of simultaneously communicating information to several receivers by a single source [22]. In other words it allows the transmitter to transmit multiple users' information at the same time. To make SC practical the transmitter must encode information applicable to each user. As an example for a two-user scenario, the transmitter will have to contain two point-to-point encoders that map their respective inputs to complex-valued sequences of the two-user signal. Figure 2.1 demonstrates schematic diagram how SC performed, where the quadrature phase-shift keying (QPSK) constellation of user 1 with higher transmitting power is superposed on that of user 2 with lower transmitting power. It can be mentioned that SC is a recognized non-orthogonal scheme that attains the capacity on a scalar Gaussian broadcast channel.

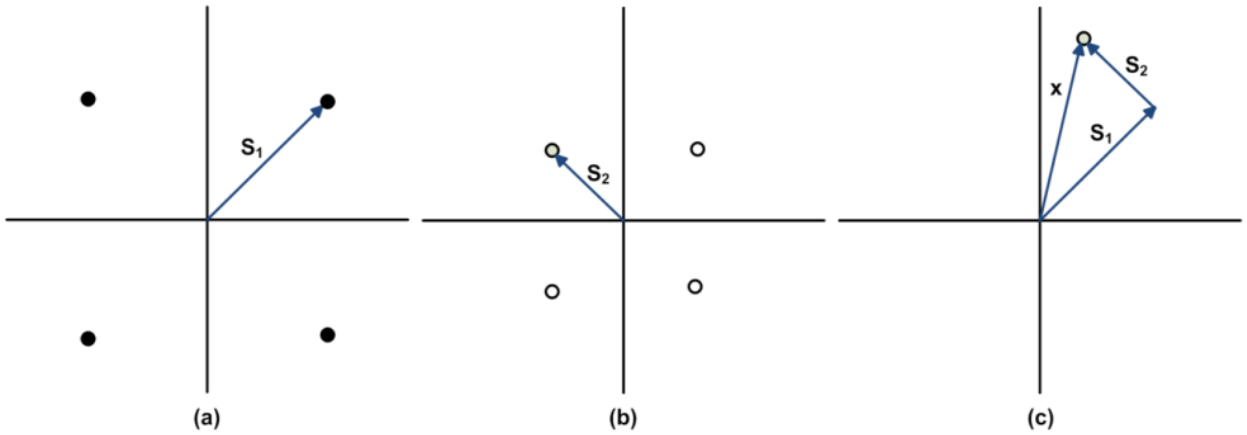

Figure 2. 1: An example of SC encoding (a) signal constellation of user 1 (b) signal constellation of user 2 (c) constellation of superposed signal [22].

2.3 Successive Interference Cancellation (SIC)

To decode the combined information which transmitted to each receiver NOMA uses SIC [22]. SIC is conceivable by exploiting specifications on the differences in signal strength among the signals of interest. The basic idea of SIC is that users information are successively decoded. The technique is after one user's signal is decoded, it is subtracted from the combined signal before the next user's signal is decoded. When SIC is applied one of the user signals is decoded treating the other user signal as an interferer but the latter is then decoded with the benefit of the signal of the former having already been removed. On the other hand to identify the prior to SIC, users are ordered according to their signal strengths so that the receiver can decode the stronger signal first then subtract it from the combined signal and isolate the weaker one from the residue. Note that each user is decoded treating the other interfering users as noise in signal reception. Figure 2.2 shows the technique for decoding the superposed signal at the receiving side. Here the constellation point of user 1 is decoded first from the received signal. Then the decoding of the constellation point of user 2 is performed with respect to decoded constellation point of user 1.

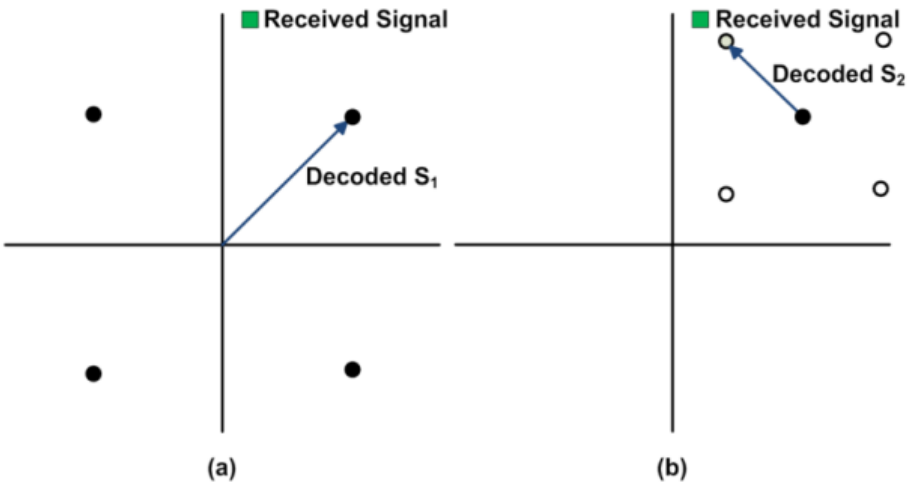

Figure 2. 2: An example of SIC decoding (a) decoding the signal of user 2 (b) decoding the signal of user 1 [22].

2.4 Power Domain NOMA

2.4.1 Downlink Power Domain NOMA

Considering a downlink NOMA transmission with a single antennas BS and single antenna L number of users with distinct channel gains. As shown in Figure 2.3 L-user downlink NOMA the BS transmitter non-orthogonally transmits L different signals by superposing them over the same spectrum resources whereas all L UE receivers receive their desired signals along with the interferences caused by the messages of other UEs. To find the final desired signal each SIC receiver first decodes the highest interferences signal and then subtracts them from the superposed signal. Since each UE receives all signals which means desired and interfering signals over the same channel, the superposing of different signals with different power levels is important to differentiate each signal and to perform SIC at a given UE receiver.

Similarly considering that the signals of NOMA users are superposed with a power level which is inversely proportional to the their channel gains, and that is low power allocated for the user with higher channel gain while high power allocated for the user with lower channel gain. As such the

user with highest channel gain (who receives strong interferences because of relatively high powers to the messages of low channel gain users) can suppress all interfering signals. In any case the user with lowest channel gain (who receives low interferences because of relatively low powers to the messages of high channel gain users) cannot suppress any interferences [23].

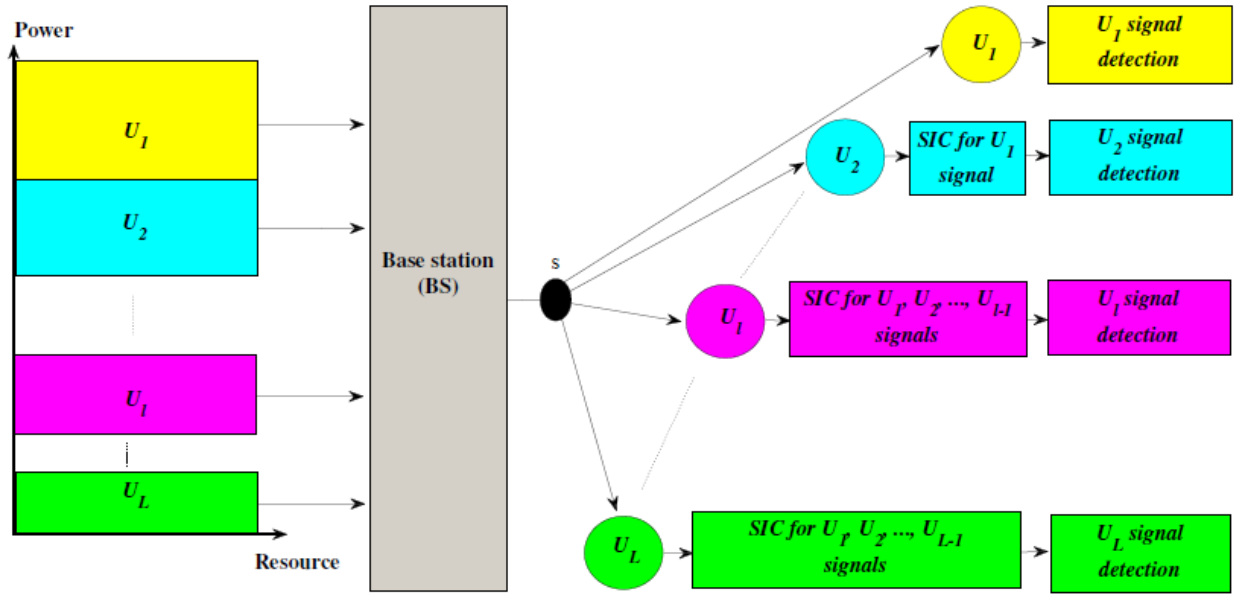

Figure 2. 3: Downlink NOMA network [24]

2.4.2 Uplink Power Domain NOMA

In uplink communication NOMA the working principle is somewhat different from the downlink communication NOMA. As shown in Figure 2.4 uplink NOMA multiple transmitters of different UEs non-orthogonally transmit to a single receiver at BS over same spectrum resources. Independently Each UE transmits its own signal at either controlled transmit power or maximum transmit power depending on the channel gain differences among the NOMA users. At the BS all received signals are the desired signals though they make interference to each other. Each received signal at SIC receiver (BS) experiences distinct channel gain because the transmitters are different. Note that to apply SIC and decode signals at BS it need to maintain the distinctness among various

message signals. As such conventional transmit power control (typically intended to equalize the received signal powers of all users) is not feasible in NOMA-based systems. In the figure below considering a general L-user uplink NOMA system in which L users transmit to a common BS over the same resources at either maximum transmit power or controlled transmit power. The BS applies SIC to decode each user that receives the superposed message signal of L different users. The received signal from the highest channel gain user is decoded first because it's likely the strongest at the BS. Consequently the highest channel gain user experiences interference from all other users in the NOMA cluster. After that the signal for second highest channel gain user is decoded and so on. As a result in uplink NOMA the achievable data rate of a user contains the interference from all users with relatively weaker channels. That is the highest channel gain user experiences interference from all users and the lowest channel gain user enjoys interference-free data rate [23].

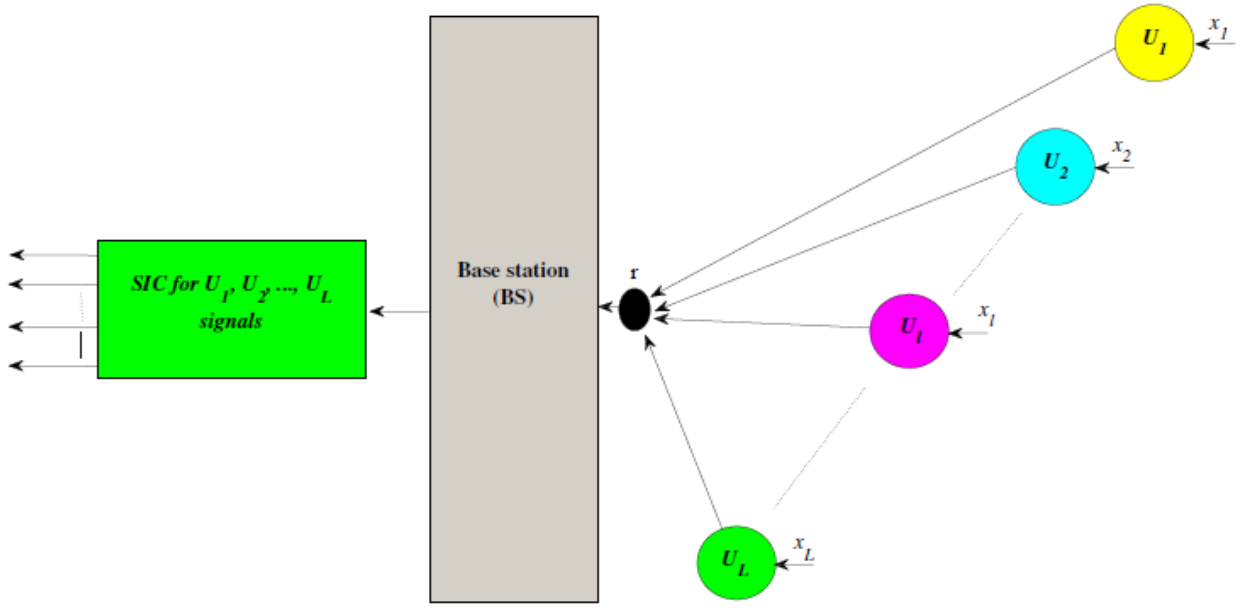

Figure 2. 4: Uplink NOMA network [24]

2.5 Advantages of NOMA

NOMA has been shown to be more spectral-efficient by 30% for downlink and 100% for uplink in enhanced mobile broadband (eMBB) when compared to OMA [25]. Therefore NOMA has been recognized as a strongly capable among all MA techniques since it has essential features to overcome challenges in counterpart OMA and achieve the requirements of next mobile communication systems [26-29]. The superiority of NOMA over OMA can be remarked as follows:

Spectral efficiency and throughput: In OMA such as in OFDMA a specific frequency resource is assigned to each user even it practices good or bad channel condition, thus the overall system suffers from low spectral efficiency and throughput. In opposite NOMA the same frequency resource is assigned to multiple mobile users with good and bad channel conditions at the same time. Hence the frequency resource assigned for the strong user is also used by the weak user and the interference can be detected through SIC processes at users' receivers. Therefore the probability of having improved spectral efficiency and a high throughput will be considerably increased as shown in Figure 2.5.

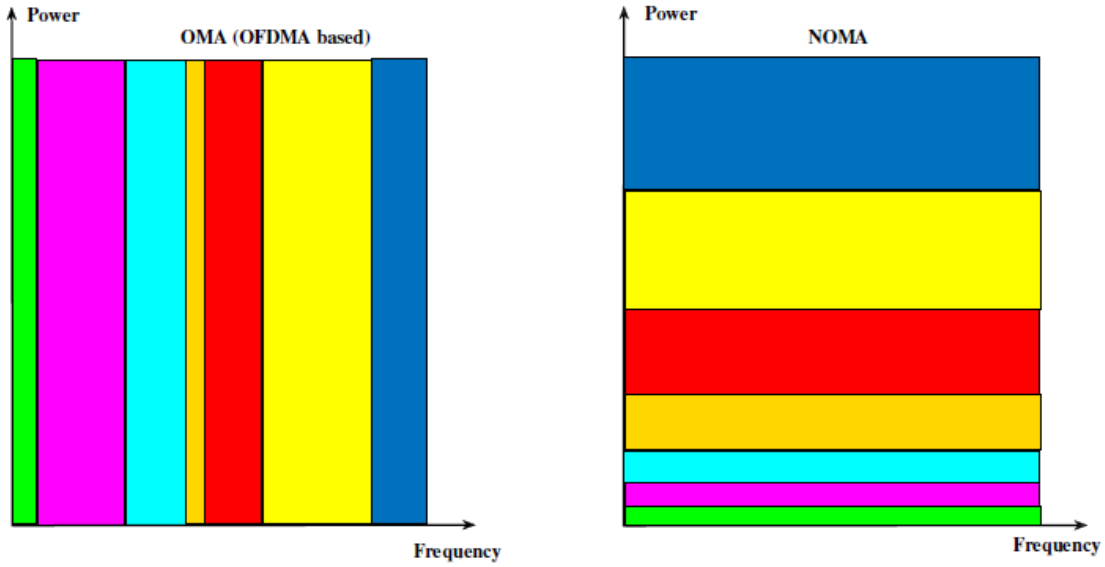

Figure 2. 5: A pictorial comparison of OMA and NOMA [25].

User fairness: In OMA for the case of OFDMA with scheduling the user with bad channel condition has to wait to access while the user with a good channel condition has a higher priority to be served which leads to a user fairness problem. This approach cannot support massive connectivity. In any case NOMA can serve multiple users with different channel conditions at the same time and in this manner it can provide improved user fairness [26].

Compatibility: NOMA is also compatible with the current and future communication frameworks since it does not require significant adjustments on the existing architecture. For example NOMA has been included in third generation partnership project long-term evolution advanced (3GPP LTE Release 13) [29-35].

Massive connectivity: In NOMA number of supportable users/devices isn't strictly limited by the number of orthogonal resources available because NOMA resource allocation is non-orthogonal. Therefore NOMA is capable of significantly increasing the number of simultaneous connections in rank-deficient scenarios, hence it has the potential to support massive connectivity. Even thou it should be noted that hardware imperfections and computational complexity can be observer while execution NOMA systems practically [36].

Low transmission latency and signaling cost: For OMA the communication between users and BS is depend on access-grant request. In order to start the communication the user need to send scheduling request to the BS. The BS receive the request and schedule the uplink transmission then respond to the user confirming the link is clear by sending clear-to-send signal. This causes high transmission latency and high signaling overhead. 5G can't be reliable on this much latency for massive connectivity. Specifically the access grant procedure in LTE takes about 15.5 ms before the data is transmitted. In this way the radical requirement of maintaining a user delay below 1 ms cannot be readily satisfied [37, 38]. For NOMA uplink communication, at the transmitter side system grant-free multiple access (SCMA) is used which pre-configure the resource defended in time and frequency domain like codebook and pilots. And at the receiver side blind detection and compressive sensing (SC) methods are user for performing joint activity and data detection.

Therefore dynamic scheduling is not needed for unlink NOMA schemes. In other word NOMA realized with significantly reduced transmission latency and signaling overhead. However applying SIC for increased number of user can be cause latency and this problem can be solve using advanced MIMO technique.

Relaxed channel feedback: channel feedback accuracy in case of power domain NOMA is not as critical as in case of OMA. Since NOMA is associated with channel stat information (CSI) feedback which uses power domain allocation. Perhaps it is not mandatory to have a very accurate CSI knowledge all the time. Generally for both fixed and mobile user limited accuracy related to maximum inaccuracy feedback channels as well as delay will not affect the attainable system performance significantly unless channel changes rapidly. The table below indicates the comparison of NOMA and OMA.

	Advantages	**Disadvantages**
OMA	▪ Sim-pler receiver detection	▪ Lower spectral efficiency ▪ Limited number of users ▪ Unfairness for users
NOMA	▪ Higher spectral efficiency ▪ Higher connection density ▪ Enhanced user fairness ▪ Lower latency ▪ Supporting diverse QoS	▪ Increased complexity of receivers ▪ Higher sensitivity to channel uncertainty

Table 2. 1: NOMA and OMA comparison [28]

Chapter 3: MIMO Framework for Downlink NOMA

3.1 Introduction

Recently in wireless communication the demand of high bit rate has increased. Multiple Input Multiple Output (MIMO) technology has the ability to improve the problem of traffic capacity in the wireless networks which proven by various studies. The systems uses multiple antennas at the transmitter and receiver ends of a wireless communication network defined as MIMO system. The systems take advantage of multipath transmission paths.

In many practical scenarios it is preferable to serve as many users as possible in order to reduce user latency and improve user fairness. MIMO technology delivers addition degrees of freedom for further performance improvement perhaps implementing MOMI technology to NOMA is importance.

The multiple input multiple output channel technology is aimed to increase the capacity in the wireless communication network. With the invention of MIMO the technology seems to gain popularity as it is being implemented in the current commercial wireless products and networks. Figure 3.1 shows a line of sight (LOS) antenna setup of a MIMO system.

The base technique of MIMO is that the sampled signals in spatial domain at both the transmitter and receiver end are combined to form effective multiple parallel spatial data streams that increase the data rate. The occurrence of diversity also improves the quality of the communication in terms of BER [41].

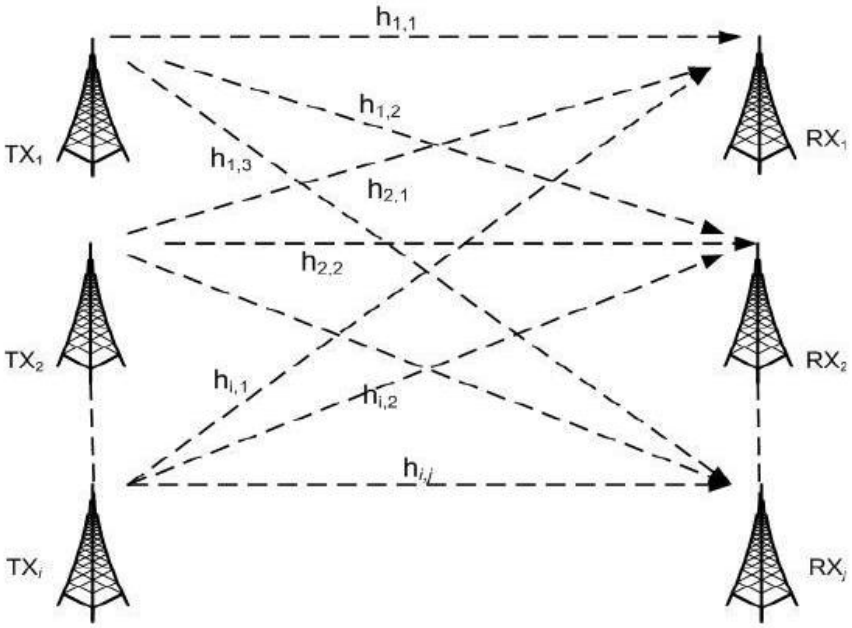

Figure 3. 1: MIMO wireless communication system [40]

The next section of this chapter presents detail description of SIMO and MIMO NOMA of downlink and uplink wireless transmission links.

3.2 Downlink MIMO-NOMA Transmission

3.2.1 NOMA Extension from SIMO to MIMO

MIMO technology is a main technologies which recognized to improve spectrum efficiency in LTE/LTE Advanced. Basically MIMO techniques can be categorized in to two direction those are single-user MIMO (SU-MIMO) where only one UE is served in data transmission and multi-user MIMO (MU-MIMO) where more than one UE is served in data transmission.

Because MIMO and NOMA technologies exploits the spatial domain and the power domain, the two technologies can be combined to further boost the system spectrum efficiency. In single-input single-output (SISO) and SIMO downlink the broadcast channel is degraded and superposition coding with SIC and dirty paper coding (DPC) are equivalent and both optimal from the viewpoint of the achievable capacity region. However for the downlink MIMO case the broadcast channel is

non-degraded and the superposition coding with a SIC receiver becomes non-optimal although DPC remains optimal [42-44].

Figure 3.2 shows combinations of downlink communication MIMO and NOMA considering SIMO and MIMO.

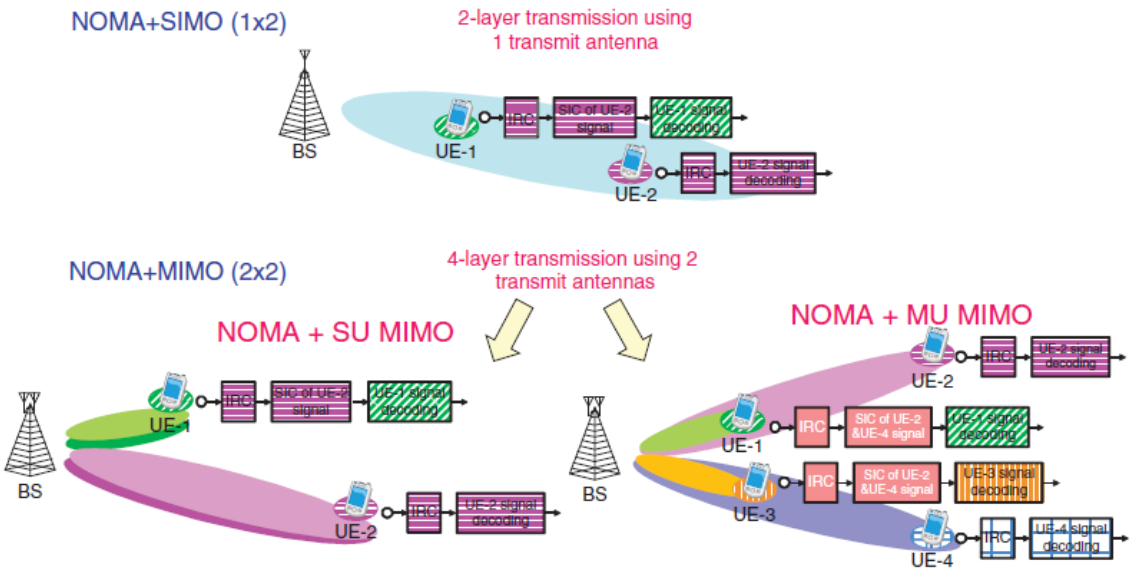

Figure 3. 2: NOMA extension from SIMO to MIMO (SU-MIMO and MU-MIMO) [45]

There are two major methods to combine MINO and NOMA technologies. One approach is to use the NOMA technique to create multiple power levels and apply the SU-MIMO and/or the MU-MIMO technique inside each power level. For example for NOMA with SU-MIMO (2×2) up to two-user multiplexing in the power domain non-orthogonal beam multiplexing enables up to four-beam multiplexing using only two transmit antennas. In addition the combination of NOMA with SU-MIMO can involve both open-loop MIMO for example space frequency block coding or large delay cyclic delay diversity and closed-loop MIMO based on CSI such as the pre-coder indicator, channel quality indicator (CQI) or rank indicator feedback by users. Open-loop MIMO schemes when combined with NOMA are expected to provide strong performance in high mobility scenarios.

The other approach is to convert the non-degraded 2×2 MIMO channel to two degraded 1×2 SIMO channels where NOMA is applied over each equivalent 1×2 SIMO channel separately as shown in Figure 3.3. For this scheme multiple transmit beams are created by opportunistic beam-forming and superposition coding of signals designated to multiple users is applied within each transmit beam (i.e. intra-beam superposition coding). At the user terminal the inter-beam interference is first suppressed by spatial filtering only by using multiple receive antennas then multi-signal separation such as SIC is applied within each beam. This scheme can be seen as a combination of NOMA with MU-MIMO where fixed rank 1 transmission is applied to each user. Thus SU-MIMO with rank adaptation is not supported and a large number of users would be required to obtain sufficient gains [46,47].

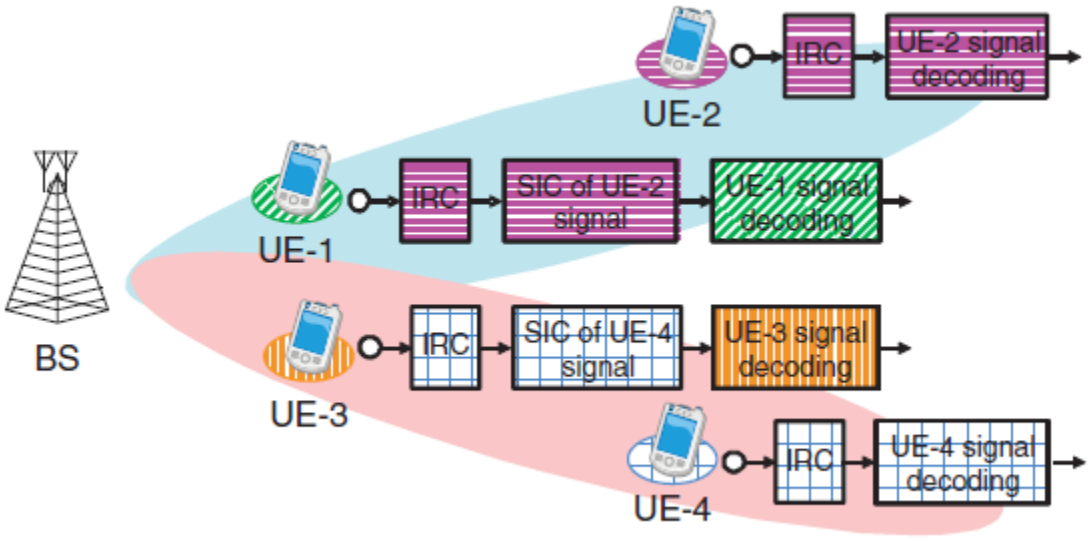

Figure 3. 3: NOMA combined with 2×2 MIMO using random beam-forming and applying IRC-SIC Receivers [46]

3.2.2 Applying SU-MIMO on NOMA

Here describe NOMA combined with SU-MIMO [48]. Figure 3.4(a) explains the case of 2×2 SU-MIMO while Figure 3.4(b) shows the proposed combination of NOMA with 2×2 SU-MIMO (Nt

= Nr = 2) where m = 2. UE-1 and UE-2 are NOMA paired cell-center and cell-edge users respectively.

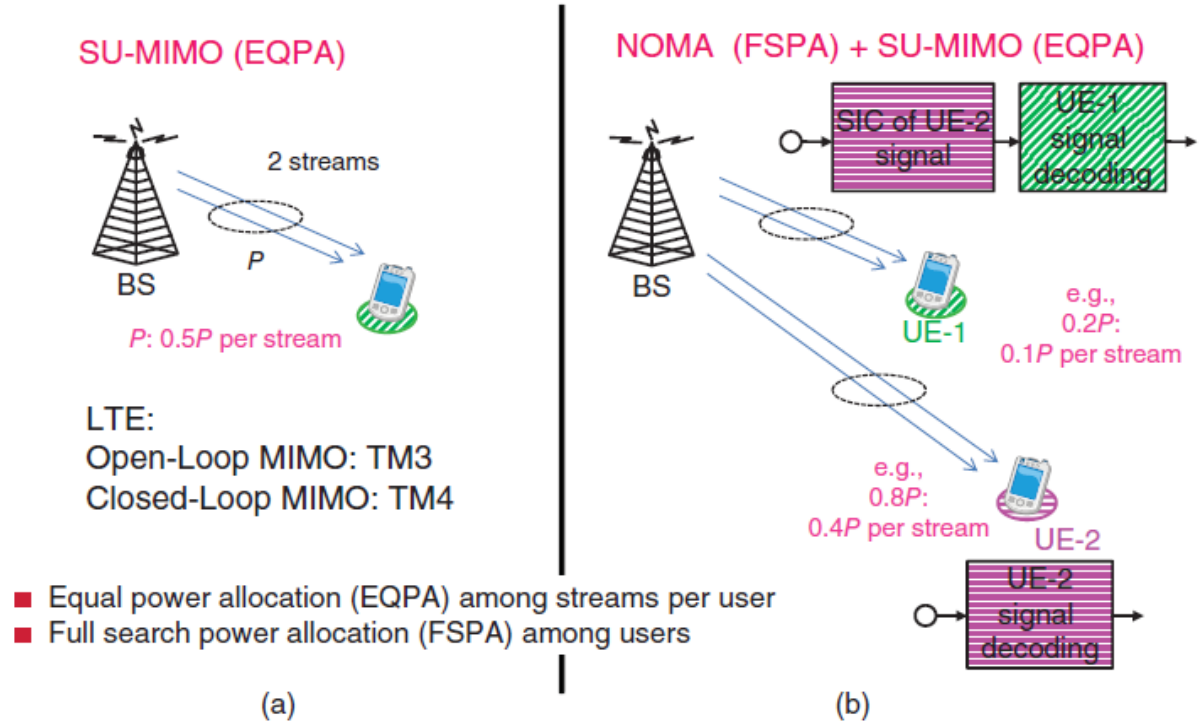

Figure 3. 4: Downlink NOMA with SIC combined with SU-MIMO (2×2 MIMO, 2 UE) [48]

By combining NOMA with SU-MIMO up to four-layer (four-beam) transmission is enabled using 2×2 MIMO. One example of multi-user/stream separation receiver is based on codeword-level SIC (CWIC) and is depicted in Figure 3.5.

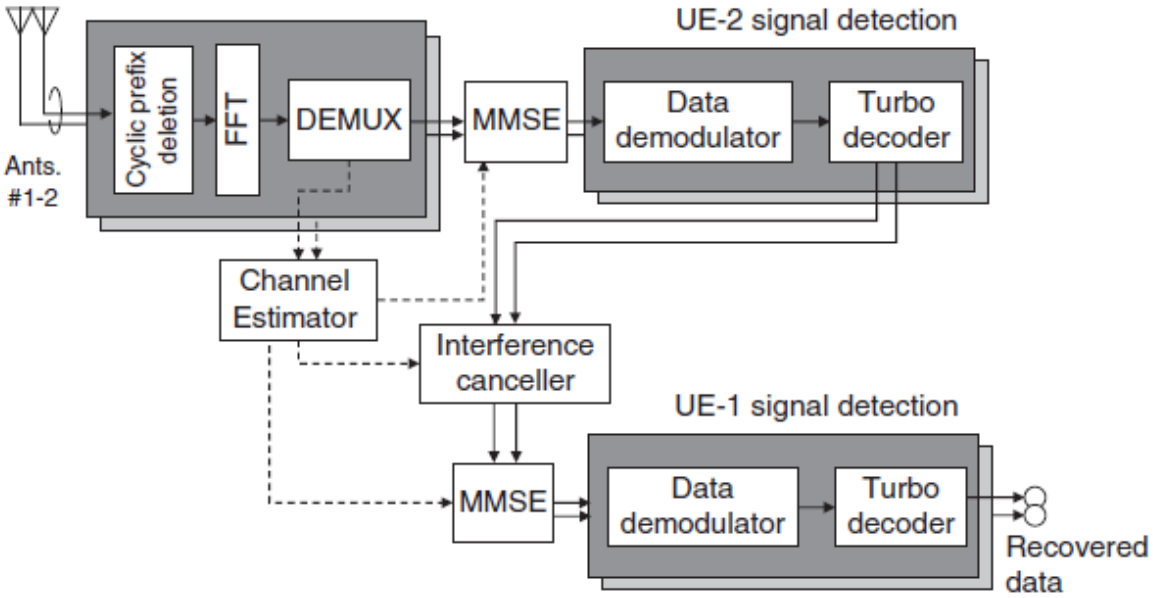

Figure 3. 5: Structure of CWIC receiver for cell-center UE [48]

3.3 MIMO-NOMA Uplink Transmission

NOMA can be readily combined with MIMO in the uplink. In the following discuss the combination of NOMA with MIMO for two cases.

3.3.1 Uplink SIMO

For a SIMO system in downlink only diversity gain can be achieved because the degree of freedom is 1. However for uplink not only diversity gain but also multiplexing gain can be achieved using so called virtual MIMO or collaborative MIMO technology. NOMA can be applied regardless of whether multiple antennas are used for diversity gain or multiplexing gain. Examples are shown in Figure 3.6 assuming a 1×2 antenna configuration. In Figure 3.6(a) UE-1 and UE-2 are separated in the power domain and multiple receive antennas are used for diversity gain by maximum ratio combining. In Figure 3.6(b) UE groups (UE-1, UE-3) and (UE-2, UE-4) are separated in the power domain and in each power layer UEs are separated in spatial domain by minimum mean-squared error (MMSE). In other words UE-1 and UE-3 in the first power layer and UE-2 and UE-4 in the second power layer. For a SC-FDMA and SIMO configuration only one or two data streams are

supported while up to two and four data streams are supported by the approaches in Figure 3.6(a) and (b) respectively. It can be seen that for the SIMO antenna configuration more data streams can be supported in uplink than downlink. For example for one receive antenna at the UE and two transmit antennas at the BS (1×2 uplink MIMO) up to two data streams are supported in downlink NOMA while up to four data streams are supported in uplink [49]. This is shown in Figure 3.6(b).

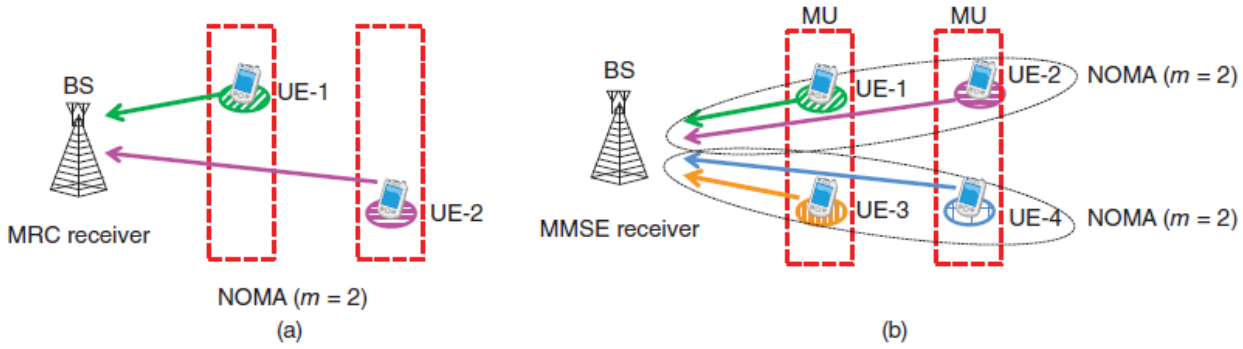

Figure 3. 6: Uplink NOMA with SC-FDMA and SIMO. (a) UE separation in power domain; (b) UE separation in power and spatial domain [49]

3.3.2 Uplink MIMO

When multiple antennas are also adopted at the UE the degree of freedom of each point to point link becomes more than 1. Thus multiple data streams can be transmitted by a UE to the BS. Examples of NOMA with MIMO assuming a 2×2 antenna configuration are shown in Figure 3.7. In Figure 3.7(a) UEs are separated in the power domain and the spatial domain is used to multiplex multiple data streams of a single UE. In Figure 3.7(b) UEs are separated in both power and spatial domain (UE-1) and (UE-2, UE-3) are separated in the power domain, and UE-2 and UE-3 are further separated in the spatial domain. For UE-1 SU-MIMO transmission is applied and for (UE-2, UE-3) MU-MIMO transmission is applied. It can be seen that for the MIMO antenna configuration the same number of data streams are supported in uplink and downlink. For example for a 2×2 system up to four data streams are supported in downlink and the same number for the uplink as shown by either Figure 3.7(a) or Figure 3.7(b).

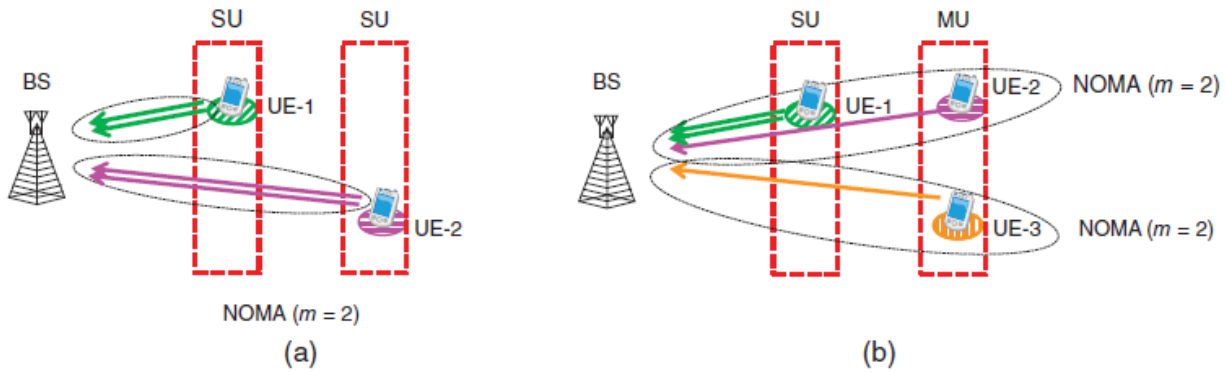

Figure 3. 7: Uplink NOMA with SC-FDMA and MIMO. (a) UE separation in power domain; (b) UE separation in power and spatial domain [45]

Chapter 4: Implementing Downlink MIMO-NOMA over Rayleigh Channel

4.1 Introduction

In this section, it will briefly discussed on system model of Downlink NOMA and gives Simulation block diagram at the transmitter and receiver side. Applying perfect SIC is delivered considering two scenario: the first is SIC on AWGN and Rayleigh fading channel in the case of SISO and the other is applying SIC on Rayleigh channel in the case implementing MIMO for the downlink NOMA.

4.2 Simulation Block Diagram of NOMA

In the below figure presents the simulation block diagram of NOMA which describe the detail flow of the user signal. Both user information randomly generated and to correct the error both signal encoded separately using turbo coding then both signal modulated using binary phase shift key (BPSK) modulation. To reduce the synchronization problem at the receiver, scrambling both signal is required and that is reduce the string of 0's and 1's at the transmitter side. Before superimpose those individual signal power allocate to each user based on their channel condition which is high power for CEU and low power for CCU. The antenna used for downlink communication is 2x2 MIMO antenna and the channel is Rayleigh fading channel.

At the receiver both user receive the same signal because superpose coding is done at the transmitter side. No need to apply SIC for the far user because high power assigned for that user. But for the near user perfect SIC is applied and that is decode the far user signal then subtracted it from the received signal then detect the near user signal.

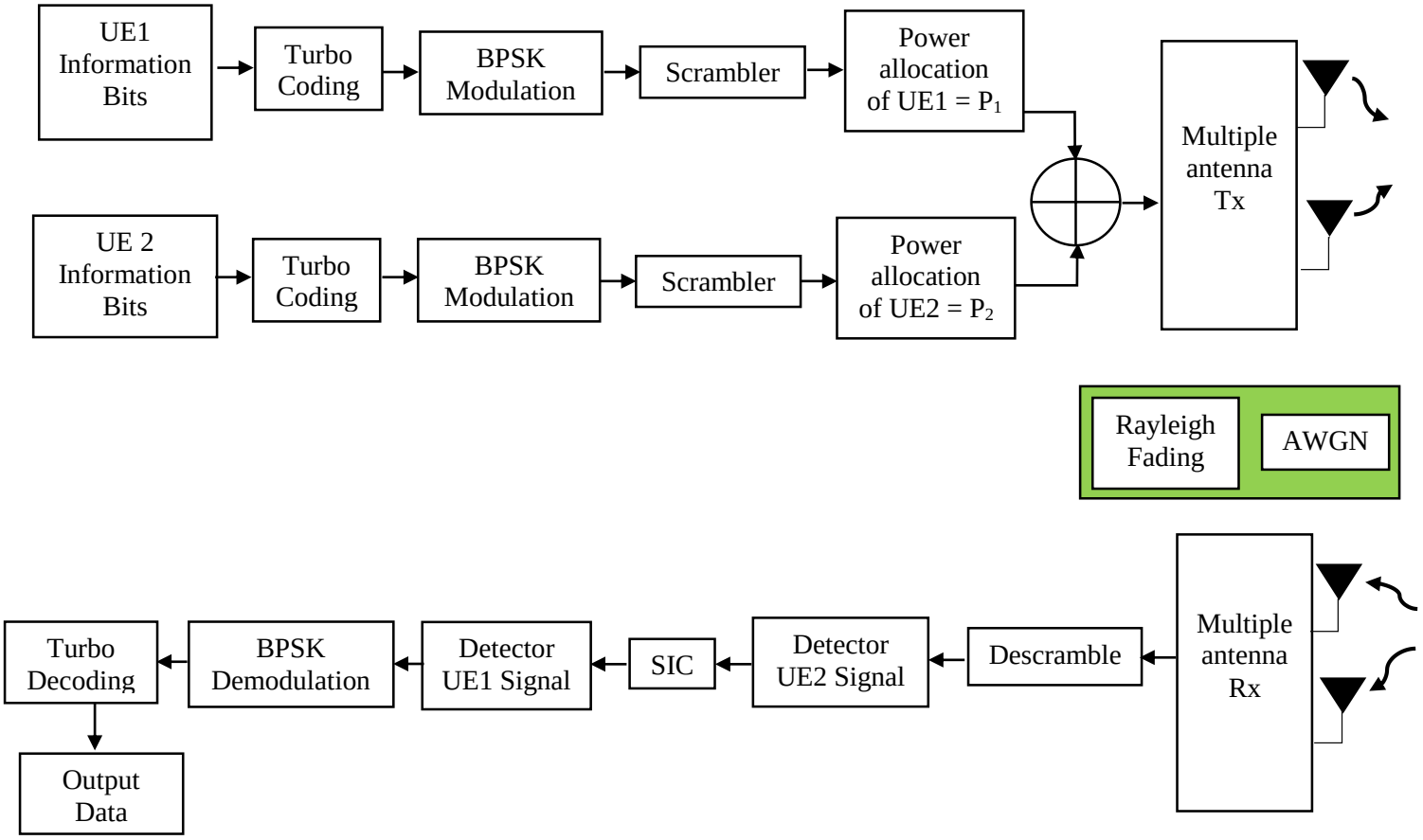

Figure 4. 1: Simulation design of transmit and receive downlink NOMA

4.3 Downlink NOMA Signal Model

The mathematical expression for implementing MIMO in NOMA over Rayleigh fading channel is delivered as follow. The transmit information of users UE_i (i = 1 , 2) at the BS is S_i. The transmit signal for UE_i is [50]

$$x_i = \sqrt{PS_i} \tag{4.1}$$

S_i – Message from UE_i

P – Transmission power

Before superposed the users signal need to allocate the power based on their channel condition. Let's say we have two users and the first user UE_1 is cell center (near user) with good channel condition and the second user UE_2 is cell edge (far user) with poor channel condition. The channel gains of UE_1 and UE_2 are $|h_1|^2$ and $|h_2|^2$ respectively where $|h_1|^2 > |h_2|^2$. The channel gain is inversely proportion to the power factor. These two users can be multiplexed over the same frequency band with different powers allocated to their message signals. The powers allocated to UE_1 and UE_2 are P_1 and P_2 respectively such that $P_1 < P_2$ and $P_1 + P_2 \leq P$, where P is the total transmit power. Therefore the transmit signal become

$$x_i = \sqrt{P_i S_i} \tag{4.2}$$

When the difference b/n power allocation of UE_1 and UE_2 is small, then UE_1 may not be able to successfully perform SIC [imperfect SIC] at the receiver. The interference due to UE_2 signal may not be cancelled perfectly through SIC.

The power difference between near and far users must be large to minimize the interference between them. As proposed in chapter one in order to improve BER performance the difference between power allocation factors of both users should be greater than around 0.35.

The transmit signals before transmitting using antenna are superposed as

$$x = \sum_{i=1}^{M} \sqrt{P_i S_i} = x_1 + x_2 = \sqrt{P_1 S_1} + \sqrt{P_2 S_2} \tag{4.3}$$

4.3.1 Channel Models and SIC

In this section two common channel models are presented; AWGN channel and Rayleigh fading channel. Detail description is given on SIC applying on the received signal which pass though this channels considering SISO.

4.3.1.1 AWGN Channel

The additive white Gaussian noise (AWGN) channel model is an ideal channel model as it merely adds the white Gaussian noise linearly into the signal [51]. Being the non-fading channel model

the phenomenon of fading is not taken into account for this channel type where the channel gain is always 1. It is a basic noise model used in Information theory to mimic the effect of many random processes that occur in nature. The modifiers denote specific characteristics: Additive because it is added to any noise that might be intrinsic to the information system. White refers to the idea that it has uniform power across the frequency band for the information system. It is an analogy to the color white which has uniform emissions at all frequencies in the visible spectrum. Gaussian because it has a normal distribution in the time domain with an average time domain value of zero.

Under the AWGN channel the received signal y for UE_i is represented as

$$y_i = x + n_i = \sum_{i=1}^{M} \sqrt{P_i S_i} + n_i \tag{4.4}$$

Where n_i is noise including inter-cell interference with power density of n_i is $N_{o,i}$. At user1 owing to the larger power of x_2 compared to x_1 and x_2 should be demodulated first. When demodulating x_2 at UE_1 x_1 becomes the interference component:

$$y_1 = x_2 + (x_1 + n_1) = x_2 + i_{1_AWGN} = \bar{y}_{x_2|UE_1} \tag{4.5}$$

Where i_{1_AWGN} is the interference for x_2 plus noise and we assume that the demodulated signal of x_2 at UE_1 is $\bar{x}_2|UE_1$. Then the noise enhancement ratio when demodulating x_2 at UE_1 is

$$e_{AWGN} = \frac{i_{1_AWGN}}{n_1} \tag{4.6}$$

After that $\bar{x}_2|UE_1$ is re-modulated in order to cancel this signal from y_1 and the received signal after SIC for x_2 is

$$\begin{aligned} y_1 &= y_1 - \bar{x}_2 \\ &= x_1 + (x_2 - \bar{x}_2) + n_1 \end{aligned} \tag{4.7}$$

where $\bar{x}_2$ is the re-modulated signal and the component $(x_2 - \bar{x}_2)$ is the remaining interference for x_1 after IC. The power of the remaining interference for x_1 is

$$P_{(x_2-\bar{x}_2)} = P_2\left(\frac{P_2}{i_{1_AWGN}}/\frac{P_2}{n_1}\right) = \frac{P_2}{e_{AWGN}} \quad (4.8)$$

where $\frac{P_2}{i_{1_AWGN}}$ is the signal-to-interference-plus-noise ratio (SINR) and $\frac{P_2}{n_1}$ is the SNR of x_2 from perfect SIC. Therefore the bound value for UE_1 after practical SIC of x_2 is

$$r_{1_SIC_AWGN} = \log_2(1 + \frac{P_1}{\frac{P_2}{e_{AWGN}}+n_1}) \quad (4.9)$$

4.3.1.2 Rayleigh Fading Channel

Rayleigh fading channel model is normally used to describe the time-varying nature of the received envelope of a flat fading channel. Or the received envelope of an individual multipath components. This model is based on assumptions that there are infinite arrival paths at the same time at all angles. All paths have zero mean and similar variance which means there is no dominant path and all path gains are statistically independent. By taking central limit theorem I (In-phase) and Q (Quadrature) components of the Rayleigh fading channel are Gaussian distributed.

Signal undergoes flat fading when coherence bandwidth over which the mobile radio channel has a constant gain and linear phase response is greater than the bandwidth of the signal and the delay spread is smaller than the symbol period. Flat fading can be summarized as.

$$B_S \ll B_c \quad (4.10)$$

and

$$T_S \gg \sigma T \quad (4.11)$$

Where Bs is the bandwidth of the signal, Bc is the coherence bandwidth, T_S is symbol period and σT is the rms delay spread of the channel.

In Rayleigh fading channel, the instantaneous SNR follows the probability density function (PDF) given by

$$f_\gamma(\gamma) = \begin{cases} \frac{1}{\gamma}\exp(-\frac{\gamma}{\bar{\gamma}}), & \gamma \geq 0 \\ 0 & , \ otherwise \end{cases} \quad (4.12)$$

Where γ and $\bar{\gamma}$ is respectively the instantaneous and average SNR [52].

Under the Rayleigh fading channel which is suitable for rich scattering scenarios without line of sight (LOS) while the received signal y for UE_i is represented as

$$y_i = h_i x + n_i = h_i \sum_{i=1}^{M} \sqrt{P_i S_i} + n_i \quad (4.13)$$

Where h_i is complex channel coefficient between user and base station, n_i is noise including inter-cell interference with power density of n_i is $N_{o,i}$. complex channel coefficient in the case of Rayleigh fading can be represented as

$$h_i = \frac{\bar{g}_i}{\sqrt{1+d_i^{\propto}}} \quad (4.14)$$

Where $\boldsymbol{g}_i$ is Rayleigh fading channel gain, α is path loss factor and d_i is distance. In the NOMA downlink decoding is in the order of the increasing channel gain normalized by the noise and inter-cell interference power $|h_i|^2/N_{0,i}$. For a two user case assume that $|h_1|^2/N_{0,1} > |h_2|^2/N_{0,2}$ so UE_1 first decodes x_2 and deletes its component from received signal y_1. And UE_2 decodes x_2 without interference cancellation because it has the first decoding order.

4.4 MIMO 2×2 Channel

In a 2×2 MIMO channel probable usage of the available two transmitting antennas can be as follows:

For example consider that (x_1, x_2, x_3 …. x_n) is transmission sequence. In normal transmission the sequence will be sending x_1 in the first time slot, x_2 in the second time slot, x_3 in third time slot and so on.

However as it now have two transmitting antennas it may group the symbols into groups of two. x_1 and x_2 send from the first and second antenna in the first time slot. x_3 and x_4 send from the first and second antenna In second time slot. x5 and x6 send for the first and second antenna in the third time slot and so on.

Reminding that only n/2 time slots is needed to complete the transmission if we grouping two symbols and sending them in one time slot. Hence the data rate is doubled.

This customs the simple explanation of a probable MIMO transmission scheme with two transmitting antennas and two receiving antennas. The two transmitted symbols interfered with each other and zero forcing equalizer is used to minimize the interference.

The channel is flat fading. In simple terms it means that the multipath channel has only one tap. So the convolution operation reduces to a simple multiplication [42]. The channel practiced by each transmitting antenna is independent from the channel practiced by other transmitting antennas.

For the i^{th} transmitting antenna to j^{th} receiving antenna each transmitted symbol gets multiplied by a randomly varying complex number $h_{j,i}$. As the channel under consideration is a Rayleigh channel the real and imaginary parts of $h_{j,i}$ are Gaussian n distributed having mean $\mu_{h_{j,i}} = 0$ and variance $\sigma^2_{h_{j,i}} = 1/2$.

The channel experienced between each transmitter to the receiving antenna is independent and randomly varying in time. On the receive antenna the noise has the Gaussian probability density function with

$$P(n) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(n-\mu)^2}{2\sigma^2}} \tag{4.15}$$

With $\mu = 0$ and $\sigma^2 = {N_o}/{2}$, the channel $h_{j,i}$ is known at the receiver.

4.4.1 SIC-ZF for 2×2 MIMO channel

At the receiver the two symbols interfere with each other, let's understand the math for extracting the symbols which interfered with each other. In the first time slot the received signal on the first receiver antenna is,

$$y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1 = [h_{1,1} \quad h_{1,2}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1 \tag{4.16}$$

The received signal on the second receive antenna is,

$$y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 = [h_{2,1} \quad h_{2,2}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2 \tag{4.17}$$

Where

y_1 is the received signal on the first receiver antenna and y_2 is the received signal on the second receiver antenna,

x_1, x_2 are user 1 and user 2 transmitted signal,

n_1, n_2 are the noise on the first and second receiver antennas,

$h_{1,1}$ is the channel from the first transmitter antenna to the first receiver antenna,

$h_{1,2}$ is the channel from the second transmitter antenna to the first receiver antenna,

$h_{2,1}$ is the channel from the first transmitter antenna to the second receiver antenna and

$h_{2,2}$ is the channel from the second transmitter antenna to the second receiver antenna.

For convenience the above equation can be expressed in matrix notation as follows [53]:

$$y = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + [n_1 \quad n_2] \tag{4.18}$$

Equivalent

$$y = \boldsymbol{H}x + n \tag{4.19}$$

Where $h_{1,2}\sqrt{P_2 S_2}$ is the interference for the first antenna and $h_{2,2}\sqrt{P_2 S_2}$ is the interference for the second antenna. We can get the weight factor of channel ZF criteria. To solve for x the SIC_ZF linear detector for meeting this constraint $\boldsymbol{WH} = \boldsymbol{I}$ is given by,

$$\boldsymbol{W} = (\boldsymbol{H^H H})^{-1}\boldsymbol{H^H} \tag{4.20}$$

Where the sign **H** in the superscript in the equation represents the Hermitian transpose. After the receiver perform SIC with ZF equalization approach, the receiver can obtain an estimate of the two transmitted symbolsx_1, x_2 .

$$\begin{bmatrix}\bar{x}_1\\ \bar{x}_2\end{bmatrix} = (\boldsymbol{H^H H})^{-1}\boldsymbol{H^H}\begin{bmatrix}y_1\\ y_2\end{bmatrix} \tag{4.21}$$

Take one of the estimated symbols (for example$\bar{x}_2$) and subtract its effete from the received vector y_1, y_2.

$$\begin{bmatrix}r_1\\ r_2\end{bmatrix} = \begin{bmatrix}y_1 - h_{2,1}\bar{x}_2\\ y_2 - h_{2,2}\bar{x}_2\end{bmatrix} = \begin{bmatrix}h_{1,1}x_1 + n_1\\ h_{2,1}x_1 + n_2\end{bmatrix} \tag{4.22}$$

Expressing in matrix notation,

$$\begin{bmatrix}r_1\\ r_2\end{bmatrix} = \begin{bmatrix}h_{1,1}\\ h_{2,1}\end{bmatrix}x_1 + \begin{bmatrix}n_1\\ n_2\end{bmatrix} \tag{4.23}$$

$$r = hx_1 + n \tag{4.24}$$

The above equation is same as equation obtained for receive diversity case. Optimal way of combining the information from multiple copies of the received symbols in receive diversity case is to apply Maximal Ratio Combining **(**MRC**)**.

The equalized symbol is,

$$\bar{x}_1 = \frac{h^H r}{h^H h} \tag{4.25}$$

This forms the simple explanation for Zero Forcing Equalizer with Successive Interference Cancellation **(**ZF-SIC**)** approach.

4.5 Signal to Noise Ratio

In an AWGN channel the modulated signal $s(t) = \Re\{u(t)e^{j2\pi f_c t}\}$ has noise n(t) added to it prior to reception. The noise n(t) is a white Gaussian random process with mean zero and power spectral density $N_0/2$.

We define the received signal-to-noise power ratio (SNR) as the ratio of the received signal power P_r to the power of the noise within the bandwidth of the transmitted signal s(t). The received power P_r is determined by the transmitted power, the path loss, shadowing and multipath fading. The noise power is determined by the bandwidth of the transmitted signal and the spectral properties of n(t). Specifically if the bandwidth of the complex envelope u(t) of s(t) is B then the bandwidth of the transmitted signal s(t) is 2B. Since the noise n(t) has uniform power spectral density $N_0/2$ the total noise power within the bandwidth 2B is $N = N_0/2 \times 2B = N_0B$. So the received SNR is given by [55]

$$SNR = \frac{P_r}{N_o B} \tag{4.26}$$

4.6 Outage Probability

Outage probability defined as the probability that the instantaneous signal-to-noise ratio fall below a given threshold. The outage probability relative to γ_o is defined as [54]

$$P_{out} = P(\gamma_s < \gamma_o) = \int_0^{\gamma_0} P_{\gamma_s}(\gamma) d\gamma \tag{4.27}$$

Where γ_s is SNR per symbol and γ_o typically specifies the minimum SNR required for acceptable performance. For example consider digitized voice $P_b = 10^{-3}$ is an acceptable error rate since it generally can't be detected by the human ear. Thus for a BPSK signal in Rayleigh fading SNR per bits γ_b < 7 dB would be declared an outage therefore $\gamma_o = 7dB$. In Rayleigh fading the outage probability becomes

$$P_{out} = \int_0^{\gamma_o} \frac{1}{\gamma_s} e^{-\gamma_o/\bar{\gamma}_s} d\gamma_s = 1 - e^{-\gamma_o/\bar{\gamma}_s} \quad (4.28)$$

Inverting this formula shows that for a given outage probability, the required average SNR $\bar{\gamma}_s$ is

$$\bar{\gamma}_s = \frac{\gamma_o}{-\ln(1-p_{out})} \quad (4.29)$$

In dB this means that 10 log γ_s must exceed the target 10 log γ_o by $F_d = -10\log[-\ln(1 - P_{out})]$ to maintain acceptable performance more than 100* (1 − P_{out}) percent of the time. The quantity F_d is typically called the dB fade margin.

Outage probability at mth user

$$P_m^{out} = 1 - P[E_{m,1}^c \cap \ldots \cap E_{m,m}^c] \quad (4.30)$$

Where $E_{m,j}$ is the event that the mth user cannot detect the jth user's message.

4.7 Bit Error Rate

Bit error rate is a key parameter that is used in assessing systems that transmit digital data from one location to another. BER is applicable to radio data links, Ethernet as well as fiber optic data systems. When data is transmitted over a data link there is a possibility of errors being introduced into the system. If this is so the integrity of the system may be compromised. As a result it is necessary to assess the performance of the system and BER provides an ideal way in which this can be achieved. BER assesses the full end to end performance of a system including the transmitter, receiver and the medium between the two.

In digital transmission the number of bit error is the number of received bits of a data stream over a communication channel that have been altered due to noise, interference, distortion or bit synchronization errors. BER is defined as the rate at which errors occur in a transmission system. In simple form [55],

$$BER = \frac{number\ of\ bits\ in\ error}{total\ number\ of\ bits\ sent} \quad (4.21)$$

Or it can be expressed as

$$BER = \int_0^{\infty} P_b(^{E}/_{r})P(r)dr \qquad (4.32)$$

Where $P_b(E/r)$ is the conditional error probability *P(r)* is the pdf of the SNR.

Chapter 5: Simulation Results and Discussion

5.1 Introduction

In this chapter presents simulation results using the MATLAB2017a which is interpret based on the concept of the previous chapters. The parameters used for simulation are listed in table 5.1.

Parameters	Type/Value
Number of bits	10^6
Channel	Rayleigh fading channel
Number of transmit antenna	2
Number of receive antenna	2
Power allocated for user 1 (CCU)	0.2
Power allocated for user 2 (CEU)	0.8
Modulation type	BPSK
SNR range	[0:30]dB
SNR threshold	17dB
BER threshold	$1e^{-4}$
Noise	AWGN
Iteration	2000
Performance matrix	BER and Outage probability
FFT size	64
Number of data subcarriers	52

Table 5. 1: Simulation parameters

Performance evaluation over Rayleigh fading channel is studied based on BER and Outage probability. Number of bits for transmit signal is 10^6 which is a suitable sample size for better observation on the BER.

Assuming that BS has total power of 1 and will allocate power for each user as proportional to their distance and the difference between power allocation factors should not be less than 0.35 to minimize the drastic effect on the performance of both user. Therefore 0.2 and 0.8 power allocated for CCU and CEU respectively.

On the other hand, simulations in this work are implemented using Monte Carlo (MC) method which is a stochastic techniques based on the use of random numbers.

5.2 Matlab Result

5.2.1 Transmitted Signal

The initial data is generated at the BS for downlink communication, and random binary number is generated for both user.

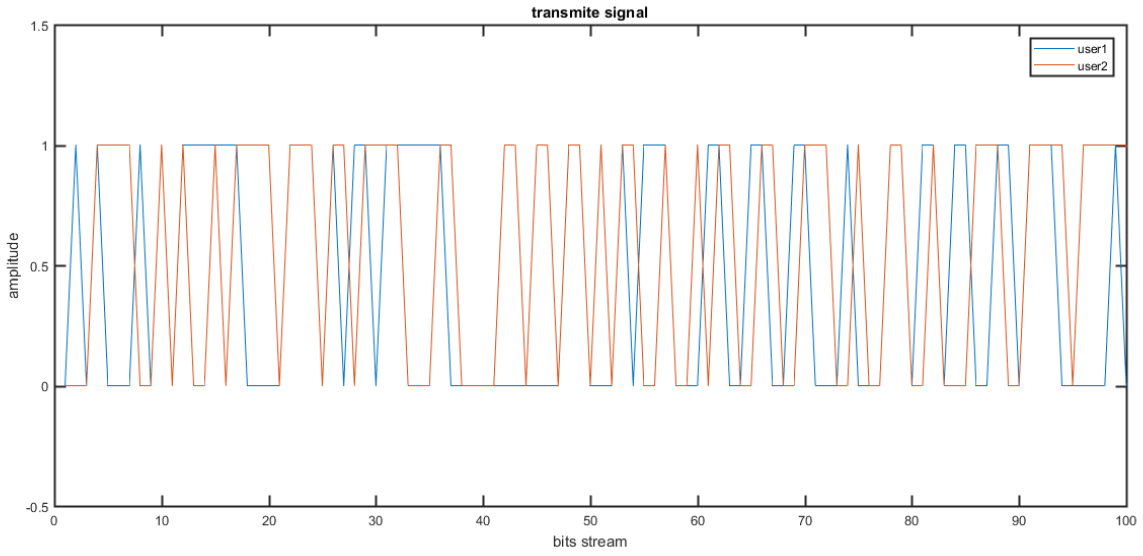

Figure 5. 1: User 1 and user 2 BPSK modulated signal

The result shown in the figure 5.1 represents randomly generated user one and user two data stream at the BS. Both signal carried using BPSK modulator therefore the amplitude is 0 and 1.

The Number of bits for transmit signal is 10^6 but the figure shows 100 number of bits which is zoomed to observe the bit stream clearly.

5.2.2 Power Allocation and Superposes Coding

The next figure 5.2 shows both user uses the same resource at the same time with the same BS. Different power is allocated to each user based on their channel condition, assuming the total power of the BS is 1. The far user channel vain is low and the near user channel gain is high and power allocation is inversely proportional to the channel gain. Therefore 0.8 for the far user (user 2) and 0.2 for the near user (user 2) is allocated.

The figure show superposes is done in order to transmit both user signal at the same time over the same resource. The user with higher transmit power which is user 2 superpose on that of user 1 with lower transmit power.

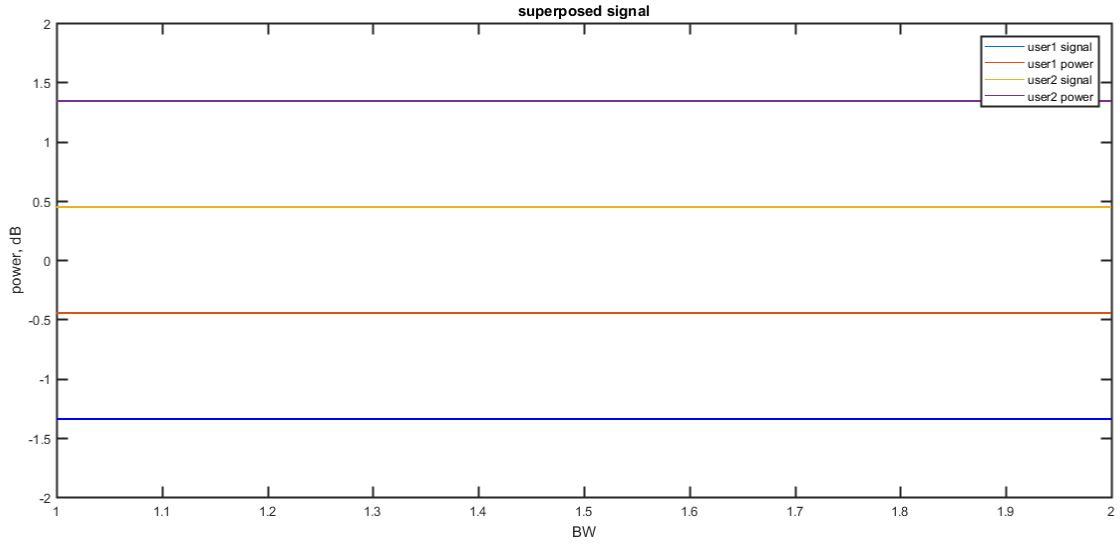

Figure 5. 2: Power allocation and superposes coding

5.2.3 Signal on the Receiver Antenna

The signal which is received by each user is similar signal because both user signals superposes to one another before it transmitted. The figure 5.3 presents the signal at the receiver antenna, it shows the effect of propagation environment which is pass through vary random or fading channel because of Rayleigh distribution. The signal undergoes this channel, there is no single path. The signal arrive at the receiver through different path and all path have no dominant path.

The figure explains many copies of the transmitted signal as each path can be arrive with different gain, phase and delays. But the signal bandwidth is less than the channel bandwidth.

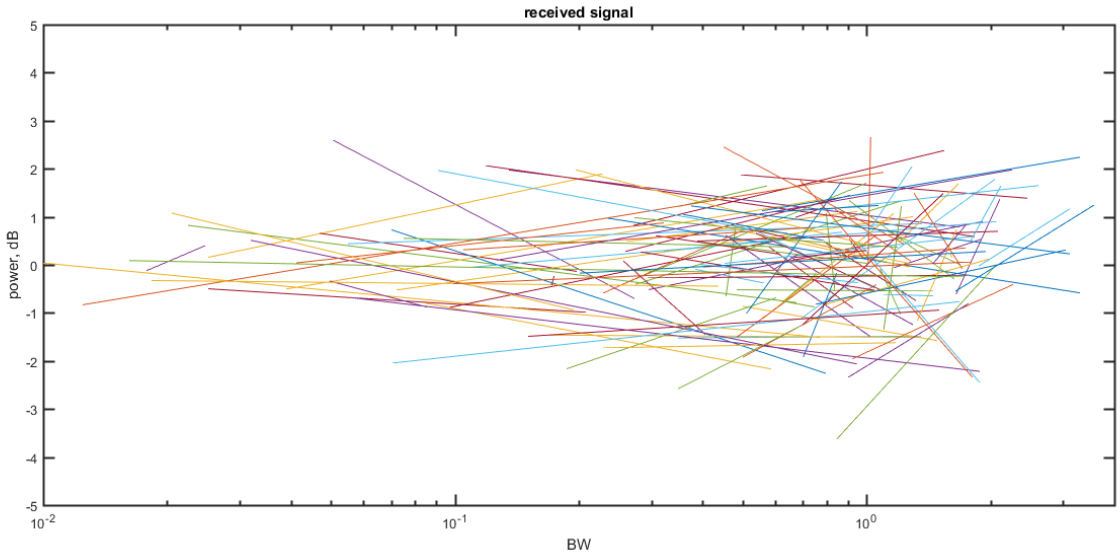

Figure 5. 3: Received signal pre decoding

5.2.4 Received Data after Perfect SIC

To detect the near user information with lower transmitted power perfect SIC is implemented. No need to implement SIC for the far user, it can be detect treating the near user signal as interference. Figure 5.4 in the above shows finally received user 1 data stream after removing the effect of the channel and interference signal by applying MUD algorithms such as ZF-SIC are utilized and detect the desired signals. There might be a small difference between the initial generated bit

stream and final received user 1 bit stream. The difference will be calculated using bit error rate in the next section using simulation.

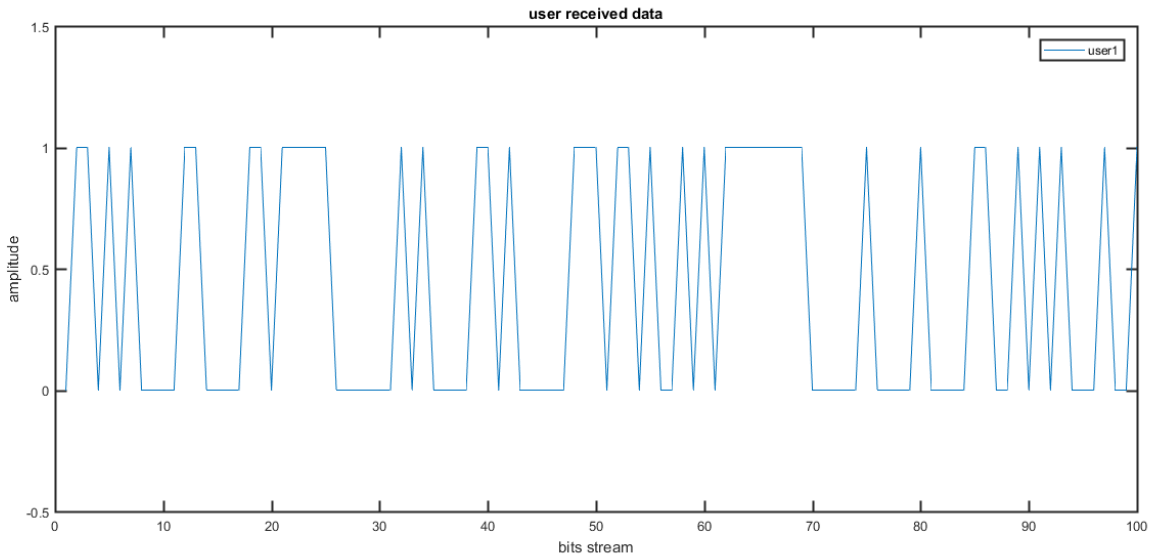

Figure 5. 4: Received data of user1 post decoding

5.2.5 Performance Evaluation of NOMA using BER Matric

In this section BER of user 1 is computed which pass through Rayleigh fading channel and AWGN, and the modulation scheme used for the simulation is BPSK modulation.

In the simulation the transmit SNR is varied between 0 to 30dB. Power allocation factors P_1 and P_2 are given as 0.2 and 0.8 for the far user and the near user respectively. MIMO 2x2 antenna is applied, two transmitter antenna at BS and two receiver antenna at user side is applied. Perfect SIC is implemented to detect the near user signal from the combined received signal.

The results presented in figure 5.5 shows the performance comparison of Downlink power domain NOMA user 1 (near user) with OFDMA BER simulated result over Rayleigh fading channel.

The performance of NOMA achieve less BER than OFDMA on every point of SNR, and NOMA achieve this error rate with user fairness and limited resource. As can be observed on both curve the error rate degrades as SNR increases. NOMA at 21dB SNR value the error rate for user1 is 10^{-3} which is acceptable error rate for audio and video transmission since it generally cannot be detected by the human ear. This error rate can be correct by using forward error correction (FEC).

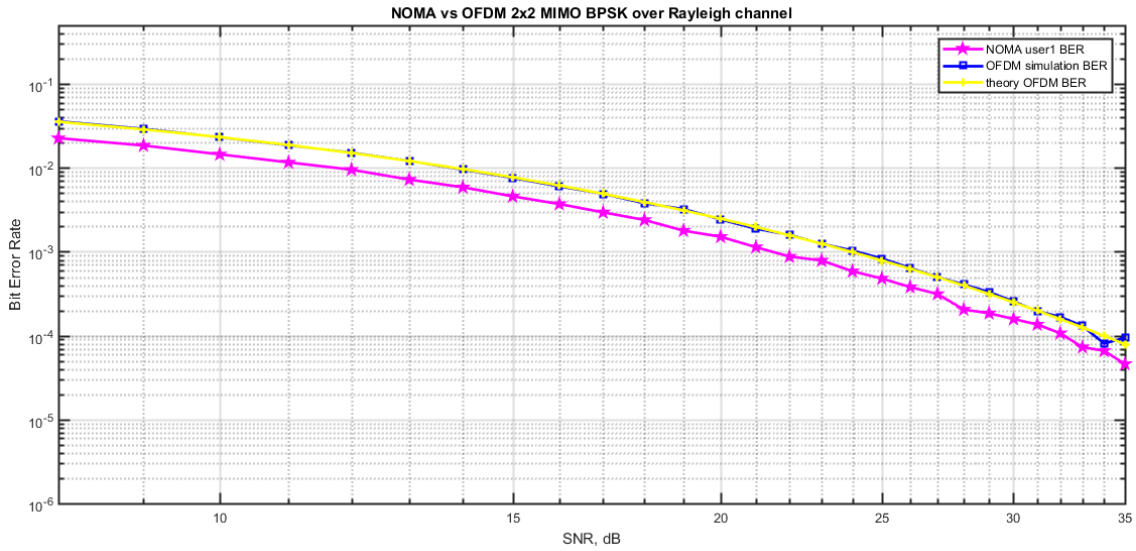

Figure 5. 5: BER performance of NOMA with 2x2 MIMO

5.2.6 Performance Evaluation of NOMA using Outage Probability Matric

The other performance measurement matrix to evaluate the performance of NOMA is Outage probability of user 1. Figure 5.6 describes the outage probability of NOMA in the presence of user 1 which is cell center (near user). The transmitted power to noise ratio of user is 0 to 30dB. The minimum SNR threshold given for this simulation is 17dB because for BPSK modulation and Rayleigh fading channel the minimum SNR required for acceptable performance should not be less than 10dB.

As can be seen from the figure it's the curve of outage probability vs. SNR. The SNR value below the threshold both curve shows that the information is declared as an outage. But for SNR value 14dB and above the outage probability of use 1 information start to decrease and become near to 0. For SNR value between 17dB and 30dB, the outage probability decreased from 0.9 to 0.1.

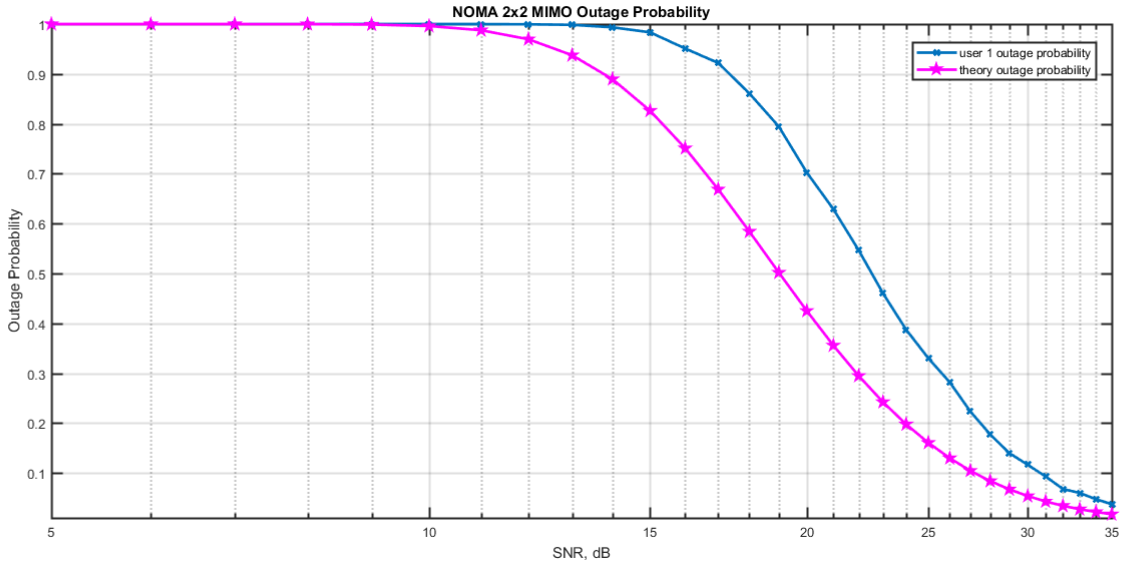

Figure 5. 6: Outage probability of NOMA with 2x2 MIMO

Chapter 6: Conclusions and Future Work

In this present thesis proposed to evaluate the performance of NOMA and it has been made a study on performance analysis of Downlink power domain user multiplexing scheme NOMA over Rayleigh fading channel. To enhance the spectrum efficiency NOMA is now a days a preferable techniques to multiplexing users at the same time with in the same cell. The performance evaluation of the simulator in an AWGN and Rayleigh fading channel in terms of BER and outage probability is presented in the current report.

The simulation results of NOMA BER shows that as the SNR increased the error rate degrades however for lower SNR value range up to 20dB the bit error rate value is high due to Rayleigh fading channel. For increased value of SNR above 21dB the bit error rate is less than 10^{-3} which is acceptable error rate for audio and video transmission because the human ear cannot detect such error.

From the BER simulation result NOMA performance is better than OFDMA in terms of BER reduction on every point of SNR even though NOMA serve 2 number of user and OFDMA serve single user. Those users in NOMA uses the total resource at the same time with different power allocation factor. 0.2 and 0.8 power allocated for the near user and the far user respectively this shows the fairness for the far user with poor channel condition. In case to add users in NOMA technology no need to split the BW but the power allocation factor. But in the case of OFDMA to add user the BW must split in to subset of subcarrier and eventually be out of resource.

The outage probability scenario for SNR value less than 14 dB the information of user 1 is declared as an outage and for SNR value 14dB and above the outage value is decreased and become nearly zero.

In conclusion, from the simulation result we notice that NOMA achieve enormous performance at higher SNR value based on both performance matrixes. However its faces difficulties to achieve small BER and outage probability for lower SNR. Therefore it would better to implement NOMA for higher SNR scenario. On this thesis and other previous literature shoes NOMA is better than

OMA one way or another. However at the receiver in order to decode the near user signal first decode the far user signal then subtract it from the received signal. But what if the number of user increased, the near user must decode all the rest of user signal first. This show the complexity at the receiver.

Future work

The performance evaluated in this thesis is under Rayleigh fading channel, there might be slightly change on the result if the channel environment changed therefore implementing NOMA on other different fading channels will be hold for future studies. Furthermore study the performance of NOMA compering with other multiple access technique and Implementing NOMA in real time platform in order to evaluate the performance over a practical medium is also future work.

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