Performance Evaluation of Cooperative Non-Orthogonal Multiple Access for Next Generation Wireless Communication

A project report submitted in partial fulfilment of the requirements for

the award of the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

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Under the guidance of

Mr R. Chandrasekhar

M.Tech, (Ph.D.)

PRAGNANAM BRAHMA

ANITS

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES

(UGC AUTONOMOUS)

(Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC with 'A' Grade)

Sangivalasa, Bheemili mandal, Visakhapatnam dist. (A.P)

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CERTIFICATE

This is to certify that the project report entitled **"Performance Evaluation of Cooperative Non-Orthogonal Multiple Access for Next Generation Wireless Communication"** submitted by **J. Jahnavi Sravya (317126512138), A. Satya Sai Praveen (317126512121), A. Nagendra (318126512L29), V. Pankaja Phani (317126512177)** in partial fulfilment of the requirements for the award of the degree of **Bachelor of Technology** in **Electronics & Communication Engineering** of Andhra University, Visakhapatnam is a record of bonafide work carried out under my guidance and supervision.

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ABSTRACT

Wireless Communication is the fastest growing and most vibrant technological areas in the communication field. For the communication to happen between the users and the base stations, we need to use the multiple access schemes. Basically we can divide these multiple access schemes into 2 types, they are Orthogonal multiple access technique and Non-Orthogonal multiple access technique. From first generation to fourth generation we used different types of OMA techniques, like in 1G-TDMA, 2G-FDMA, 3G-CDMA, 4G-OFDMA. In next generation wireless communication in order to increase the reliability and to provide access for multiple users, researchers are planning to bring NOMA technique to avoid the drawbacks from previous generation techniques and bring out the advantages of Non-Orthogonal Multiple Access technique in 5G and beyond generations. This NOMA technique is to serve multiple users using same resource in terms of time, frequency and space. Multiple users are multiplexed using super position coding technique on transmitter side and multiple users are separated using successive interference cancellation (SIC) on receiver side. Based on the strong and weak channel conditions between the users and the base station, there are strong user and weak user. In NOMA technique, after the data of user1 and user2 are multiplexed using super position coding technique on transmitter side then received for decoding. During decoding, near user decodes the data of the far user before decoding his data. The near user after decoding the data of far user transmits the data to the far user. The far user receives the two copies of same signal, one from the base station and the other from the near user. The data transmitted from the near user to the far user is relay. This concept is called as cooperative relay. Through this process, the outage probability of the far user decreases and we can increase the reliability and improve the quality of the signal. In this project the performance of communication system for 2-users in 3 phases i.e, NOMA with cooperation, NOMA without cooperation and OMA techniques is analysed and compared with respect to various parameters over a channel.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

NOMA- Non-Orthogonal Multiple Access

OMA- Orthogonal Multiple Access

FDMA- Frequency Division Multiple Access

CDMA- Code Division Multiple Access

SDMA- Space Division Multiple Access

TDMA- Time Division Multiple Access

OFDMA- Orthogonal Frequency Division Multiple Access

SIC- Successive Interference Cancellation

MUSA- Multi User Shared Access

SCMA- Sparse Code Multiple Access

LDS- Low-Density Spreading

PDMA- Pattern Division Multiple Access

BDM- Bit Division Multiplexing

IoT- Internet of Things

BS- Base Station

BER- Bit Error Rate

CSI- Channel State Information

SC- Superposition Coding

CHAPTER 1: INTRODUCTION

1.1 PROJECT OBJECTIVE

The objective of the project is to observe the performance of NOMA with the concept of Cooperative relay, NOMA without Cooperation and OMA with respect to various parameters like Outage probability, Channel capacity, Bit error rate and Sum rate.

1.2 PROJECT DESCRIPTION

Through this project, we will be able to improve the system performance, increase the reliability and quality of the signal and also achieve better sum rates and data rates than conventional NOMA technique.

1.3 INTRODUCTION

Non-orthogonal multiple access (NOMA), the main idea is to serve multiple users in terms of time, frequency and space. It is different from Orthogonal multiple access (OMA) techniques such as TDMA, CDMA, FDMA, and OFDMA. These conventional OMA techniques cannot meet the high demands of future radio access systems. In NOMA, each user operates in the same band and at the same time where they are distinguished by their power levels. NOMA is a combination of OFDMA with superposition coding on the transmitter side and successive interference cancellation (SIC) technique on the receiver side. In particular, multiple users' information signals are superimposed at the transmitter side. At the receiver side, successive interference cancellation (SIC) is applied for decoding the signals one by one until the desired user's signal is obtained, delivering a better trade-off among the throughputs of the system and user fairness. Normally, schemes of NOMA can be categorized into two types. One is power-domain multiplexing and the other one is code-domain multiplexing. In power-domain multiplexing, individual users are assigned distinct power coefficients according to their need and channel conditions so that high system performance can be achieved. Coming to code-domain multiplexing, different users are assigned distinct codes, and then those are multiplexed above the same time frequency resources, some of them are multiuser shared access (MUSA), sparse code multiple access (SCMA), and low-density spreading (LDS). In addition to power domain multiplexing and code-domain multiplexing, there are other NOMA schemes such as pattern division multiple access (PDMA) and bit division multiplexing (BDM). NOMA offers a set of desirable potential benefits such as enhanced spectrum efficiency, reduced latency with high reliability and massive connectivity. NOMA can be applied in 5G communications including machine to machine communications and Internet of Things (IoT). It is a versatile technology because it can be integrated with cooperative communications, Multiple Output and Multiple Input (MIMO), beamforming, etc. In NOMA, the important feature is that the user with better channel conditions has the information of the other user. The user with better channel conditions is called a strong user or near user and the user with weak channel conditions is called weak user or far user. In the case of 2 users, the near user decodes the information of the far user. As the far user has poor channel conditions with the base station (BS), the near user acts as a relay to the far user and transmits the signal to the far user. Now the far user will receive two different copies of the same message. One from the base station and one from the near user who is acting as a relay. From this, we can expect that the outage probability of the far user to decrease. This concept is called Cooperative communication or Cooperative relaying. Through this concept, we can reduce the outage probability and increase the reliability and quality of the signal, and achieve better sum rates and data rates. The remainder of this article presented in the following way: section 2 Elaborate system model performance, section 3 explains performance analysis of cooperative NOMA, section 4 gives analysis of simulation results in terms of, BER, channel capacity, and outage probability and section 5 gives conclusion remarks.

CHAPTER 2: WIRELESS COMMUNICATION

2.1 MULTIPLE ACCESS SCHEMES IN WIRELESS COMMUNICATION

In any cellular system or cellular technology, it is often desirable to have a scheme that enables several multiple users to gain access to it i.e, to allow the subscriber to send information simultaneously from the mobile station to the base station while receiving information from the base station to the mobile station and use it simultaneously. As cellular technology has progressed different multiple access schemes have been used. Multiple access schemes are used to allow many mobile users to share simultaneously a finite amount of radio spectrum.

2.2 REQUIREMENT OF MULTIPLE ACCESS SCHEMES

In any cellular system it is necessary for it to be able have a scheme whereby it can handle multiple users at any given time.

There are a number of requirements that any multiple access scheme must be able to meet:

- Ability to handle several users without mutual interference.
- Ability to be able to maximise the spectrum efficiency
- Must be robust, enabling ease of handover between cells.

2.3 TYPES OF MULTIPLE ACCESS SCHEMES

There are four main multiple access schemes that are used in cellular systems to allow access to the channel ranging from the very first analogue cellular technologies to those cellular technologies that are being developed for use in the future. The multiple access schemes are known as FDMA, TDMA, CDMA, SDMA and OFDMA.

2.3.1 FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)

FDMA is the most straightforward of the multiple access schemes that have been used. As a subscriber comes onto the system, or swaps from one cell to the next, the network allocates a channel or frequency to each one. In this way the different subscribers are allocated a different slot and access to the network. As different frequencies are used, the system is naturally termed Frequency Division Multiple Access. This scheme was used by all analogue systems.

FDMA is the basic technology for advanced mobile phone services. The features of FDMA are as follows.

- FDMA allots a different sub-band of frequency to each different user to access the network.
- If FDMA is not in use, the channel is left idle instead of allotting to the other users.
- FDMA is implemented in Narrowband systems and it is less complex than TDMA.
- Tight filtering is done here to reduce adjacent channel interference.
- The base station BS and mobile station MS, transmit and receive simultaneously and continuously in FDMA.

2.3.2 TIME DIVISION MULTIPLE ACCESS (TDMA)

The second system came about with the transition to digital schemes for cellular technology. Here digital data could be split up in time and sent as bursts when required. As speech was digitised it could be sent in short data bursts, any small delay caused by sending the data in bursts would be short and not noticed. In this way it became possible to organise the system so that a given number of slots were available on a given transmission. Each subscriber would then be allocated a different time slot in which they could transmit or receive data. As different time slots are used for each subscriber to gain access to the system, it is known as time division multiple access. Obviously this only allows a certain number of users access to the system. Beyond this another channel may be used, so systems that use TDMA may also have elements of FDMA operation as well.

In the cases where continuous transmission is not required, there TDMA is used instead of FDMA. The features of TDMA include the following.

- TDMA shares a single carrier frequency with several users where each users makes use of non-overlapping time slots.
- Data transmission in TDMA is not continuous, but occurs in bursts. Hence handoff process is simpler.
- TDMA uses different time slots for transmission and reception thus duplexers are not required.

- TDMA has an advantage that is possible to allocate different numbers of time slots per frame to different users.
- Bandwidth can be supplied on demand to different users by concatenating or reassigning time slot based on priority.

2.3.3 CODE DIVISION MULTIPLE ACCESS (CDMA)

CDMA uses one of the aspects associated with the use of direct sequence spread spectrum. When extracting the required data from a DSSS signal it was necessary to have the correct spreading or chip code, and all other data from sources using different orthogonal chip codes would be rejected. It is therefore possible to allocate different users different codes, and use this as the means by which different users are given access to the system.

The scheme has been likened to being in a room filled with people all speaking different languages. Even though the noise level is very high, it is still possible to understand someone speaking in your own language. With CDMA different spreading or chip codes are used. When generating a direct sequence spread spectrum, the data to be transmitted is multiplied with spreading or chip code. This widens the spectrum of the signal, but it can only be decided in the receiver if it is again multiplied with the same spreading code. All signals that use different spreading codes are not seen, and are discarded in the process. Thus in the presence of a variety of signals it is possible to receive only the required one.

In this way the base station allocates different codes to different users and when it receives the signal it will use one code to receive the signal from one mobile, and another spreading code to receive the signal from a second mobile. In this way the same frequency channel can be used to serve a number of different mobiles.

Code division multiple access technique is an example of multiple access where several transmitters use a single channel to send information simultaneously. Its features are as follows.

- In CDMA every user uses the full available spectrum instead of getting allotted by separate frequency.
- CDMA is much recommended for voice and data communications.
- While multiple codes occupy the same channel in CDMA, the users having same code can communicate with each other.

- CDMA offers more air-space capacity than TDMA.
- The hands-off between base stations is very well handled by CDMA.

2.3.4 SPACE DIVISION MULTIPLE ACCESS (SDMA)

Space division multiple access or spatial division multiple access is a technique which is MIMO (multiple-input multiple-output) architecture and used mostly in wireless and satellite communication. It has the following features.

- All users can communicate at the same time using the same channel.
- SDMA is completely free from interference.
- A single satellite can communicate with more satellites receivers of the same frequency.
- The directional spot-beam antennas are used and hence the base station in SDMA, can track a moving user.
- Controls the radiated energy for each user in space.

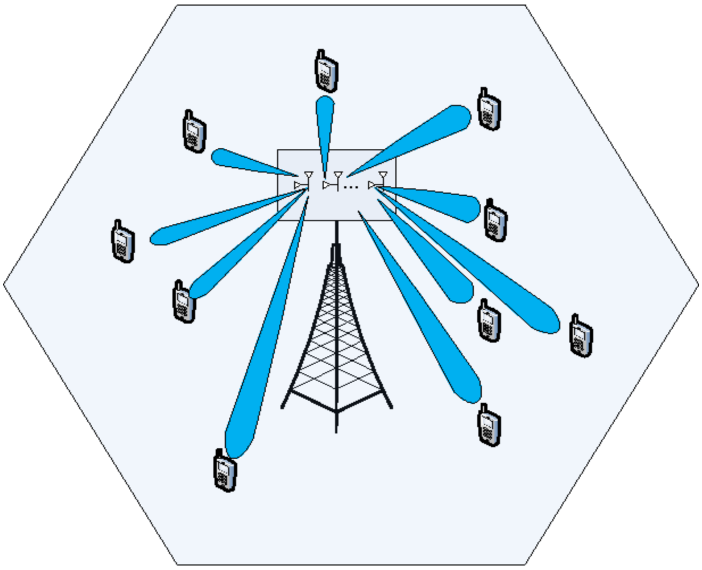


Fig.2.3.4. Space division multiple access in a cellular system (SDMA).

2.3.5 ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS (OFDMA)

OFDMA is the form of multiple access scheme that is being considered for the fourth generation cellular technologies along with the evolutions for the third generation cellular systems (LTE for UMTS / W-CDMA and UMB for CDMA2000).

- As the name implies, OFDMA is based around OFDM. This is a technology that utilises a large number of close spaced carriers.

- Orthogonal Frequency Division Multiplex, OFDM is a form of signal format that uses a large number of close spaced carriers that are each modulated with low rate data stream. The close spaced signals would normally be expected to interfere with each other, but by making the signals orthogonal to each other there is no mutual interference. The data to be transmitted is shared across all the carriers and this provides resilience against selective fading from multi-path effects.

- To utilise OFDM as a multiple access scheme for cellular technology, two different methods are used, one for the uplink and one for the downlink. In the downlink, the mobile receives the whole signal transmitted by the base station and extracts the data destined for the particular mobile. In the uplink, one or more carriers are allocated to each handset dependent upon the data to be transmitted, etc. In this way the cellular network is able to control how the data is to be sent and received.

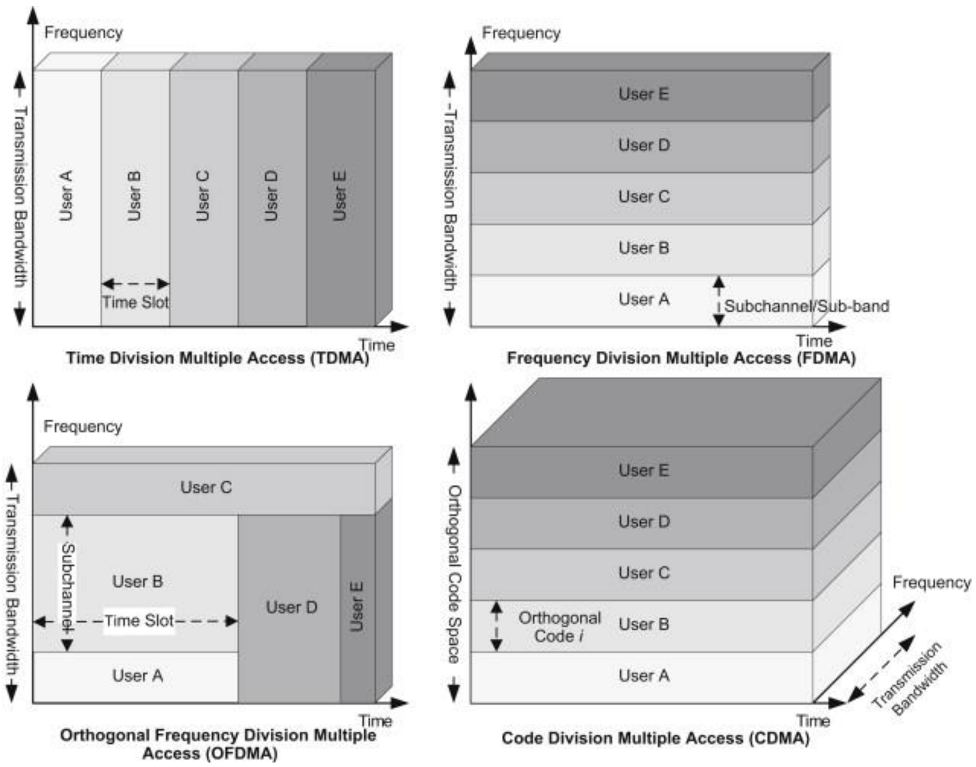


Fig.2.3. Comparison of multiple access schemes between multiple users (TDMA, FDMA, OFDMA and CDMA).

CHAPTER 3: NON-ORTHOGONAL MULTIPLE ACCESS

Multiple access (MA) techniques can be fundamentally categorized as orthogonal multiple access (OMA) and non-orthogonal multiple access (NOMA). In OMA, each user can exploit orthogonal communication resources within either a specific time slot, frequency band, or code in order to avoid multiple access interference. The previous generations of networks have employed OMA schemes, such as frequency division multiple access (FDMA) of first generation (1G), time division multiple access (TDMA) of 2G, code division multiple access (CDMA) of 3G, and orthogonal frequency division multiple access (OFDMA) of 4G. In NOMA, multiple users can utilize non-orthogonal resources concurrently by yielding a high spectral efficiency while allowing some degree of multiple access interference at receivers.

3.1 COMPARISION OF OMA AND NOMA

Although OMA techniques can achieve a good system performance even with simple receivers because of no mutual interference among users in an ideal setting, they still do not have the ability to address the emerging challenges due to the increasing demands in 5G networks and beyond

The superiority of NOMA over OMA can be remarked as follows:

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

(ii) User fairness, low latency, and massive connectivity: In OMA, for example in OFDMA with scheduling, the user with a good channel condition has a higher priority to be served while the user with a bad channel condition has to wait for access, which leads to a fairness problem and high latency. This approach cannot support massive connectivity. However, NOMA can serve multiple users with different channel conditions simultaneously; therefore, it can provide improved user fairness, lower latency, and higher massive connectivity.

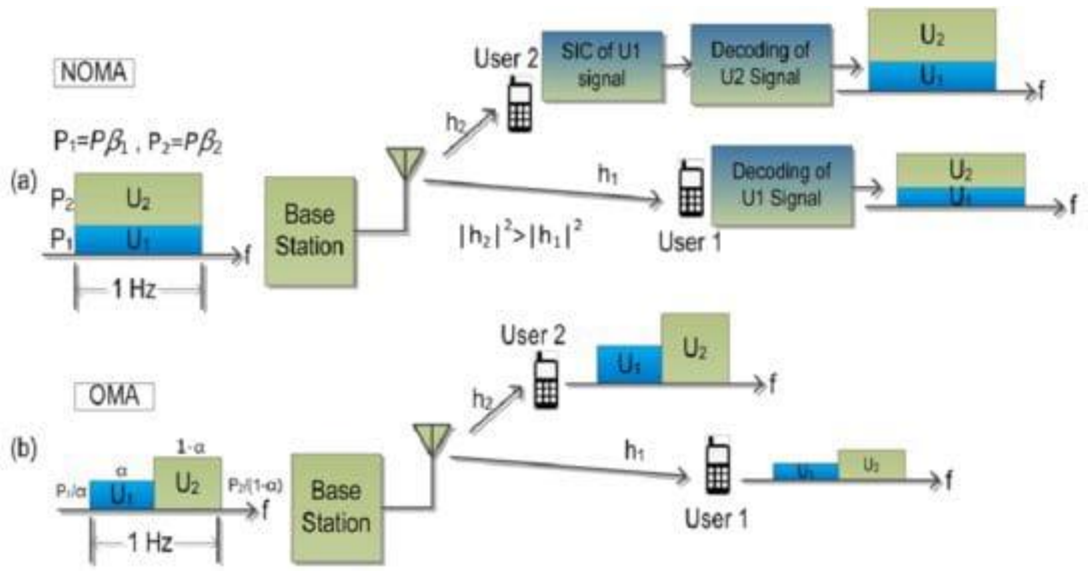


Fig.3.1 Difference between NOMA and OMA techniques in a cellular system.

Table 3.1. The comparison of non-orthogonal multiple access (NOMA) and conventional orthogonal multiple access (OMA).

Multiple Access Scheme	NOMA	Conventional OMA
Aim	Higher spectral efficiency, massive connectivity and user fairness.	Good system throughput, low cost of receiver.
Solution	Superposition coding scheme at the transmitter, successive interference cancellation at the receiver and more transmit power is allocated to users with worse channel conditions.	Multiple users are allocated with radio resources which are orthogonal in time, frequency, or code domain.
Pros	Multiple users can be served by sharing the same physical resource. The number of supported users or devices is not strictly limited by the amount of available resources and their scheduling granularity.	No interference exists among multiple users. Low complexity of receiver.

Cons	Interference exists among multiple users. High complexity of receiver.	A single radio resource can only be allocated to a user. The maximum number of supported users is limited by the total amount and the scheduling granularity of orthogonal resources.

In other words, the insufficient performance of OMA makes it inapplicable and unsuitable to provide the features needed to be met by the future generations of wireless communication systems. Consequently, researchers suggest NOMA as a strong candidate as an MA technique for next generations. Although NOMA has many features that may support next generations, it has some limitations that should be addressed in order to exploit its full advantage set. Those limitations can be pointed out as follows. In NOMA, since each user requires to decode the signals of some users before decoding its own signal, the receiver computational complexity will be increased when compared to OMA, leading to a longer delay. Moreover, information of channel gains of all users should be fed back to the base station (BS), but this results in a significant channel state information (CSI) feedback overhead. Furthermore, if any errors occur during SIC processes at any user, then the error probability of successive decoding will be increased. As a result, the number of users should be reduced to avoid such error propagation. Another reason for restricting the number of users is that considerable channel gain differences among users with different channel conditions are needed to have a better network performance.

3.2 NON-ORTHOGONAL MULTIPLE ACCESS

Non-orthogonal multiple access (NOMA), the main idea is to serve multiple users in terms of time, frequency and space. It is different from Orthogonal multiple access (OMA) techniques such as TDMA, CDMA, FDMA, and OFDMA. These conventional OMA techniques cannot meet the high demands of future radio access systems. In NOMA, each user operates in the same band and at the same time where they are distinguished by their power levels. NOMA is a combination of OFDMA with superposition coding on the transmitter side and successive interference cancellation (SIC) technique on the receiver side. In particular, multiple users' information signals are superimposed at the transmitter side. At the receiver side, successive interference cancellation (SIC) is applied for decoding the signals one by one until the desired user's signal is obtained, delivering a better tradeoff among the throughputs of the system and user fairness. Normally, schemes of NOMA can be categorized into two types. One is power-domain multiplexing and the other one is code-domain multiplexing. In power-domain multiplexing, individual users are assigned distinct power coefficients according to their need and channel conditions so that high system performance can be achieved. Coming to code-domain multiplexing, different users are assigned distinct codes, and then those are multiplexed above the same time-frequency resources, some of them are multiuser shared access (MUSA), sparse code multiple access (SCMA), and low-density spreading (LDS). In addition to power-domain multiplexing and code-domain multiplexing, there are other NOMA schemes such as pattern division multiple access (PDMA) and bit division multiplexing (BDM). NOMA offers a set of desirable potential benefits such as enhanced spectrum efficiency, reduced latency with high reliability and massive connectivity. NOMA can be applied in 5G communications including machine to machine communications and Internet of Things (IoT). It is a versatile technology because it can be integrated with cooperative communications, Multiple Output and Multiple Input (MIMO), beam forming, etc. In NOMA, the important feature is that the user with better channel conditions has the information of the other user. The user with better channel conditions is called a strong user or near user and the user with weak channel conditions is called weak user or far user.

3.3 TRANSMISSION IN NOMA

3.3.1 DOWNLINK NOMA TRANSMISSION

Downlink NOMA transmission employs the SC technique at the BS for sending a combination of the signals and the SIC technique may be invoked by the users for interference cancelation as shown in Fig.3.3. Numerous valuable contributions have investigated the performance of NOMA in terms of downlink transmission. A two-user NOMA downlink transmission relying on SIC receivers was proposed. Upon considering a range of further practical conditions in terms of the key link-adaptation functionalities of the LTE, the system-level performance.

For downlink transmission, the SIC is applied at the receiver, the superposition coding (SC) is used at the transmitter, and more power is allocated to a weaker user, namely $P_i \geq P_{i+1}$. First, each user decodes the signals from other weaker users, i.e., U_i can decode the signals of $\{U_n\}$ with $n < i$. Then, the signals of weaker users are subtracted from the received signal to decode the signal of user U_i, by treating the signals of $\{U_m\}$ with $m > i$ as interference.

Finally, for Un, it is just corrupted by the noise as the other users' signals have been successively decoded and cancelled out. Since a lower transmit power is assigned to a stronger user, the signal strength of a stronger user is not higher than that of a weaker user. Therefore, NOMA does not contradict the basic concept of SIC, in which decoding of the strongest signal should be performed first.

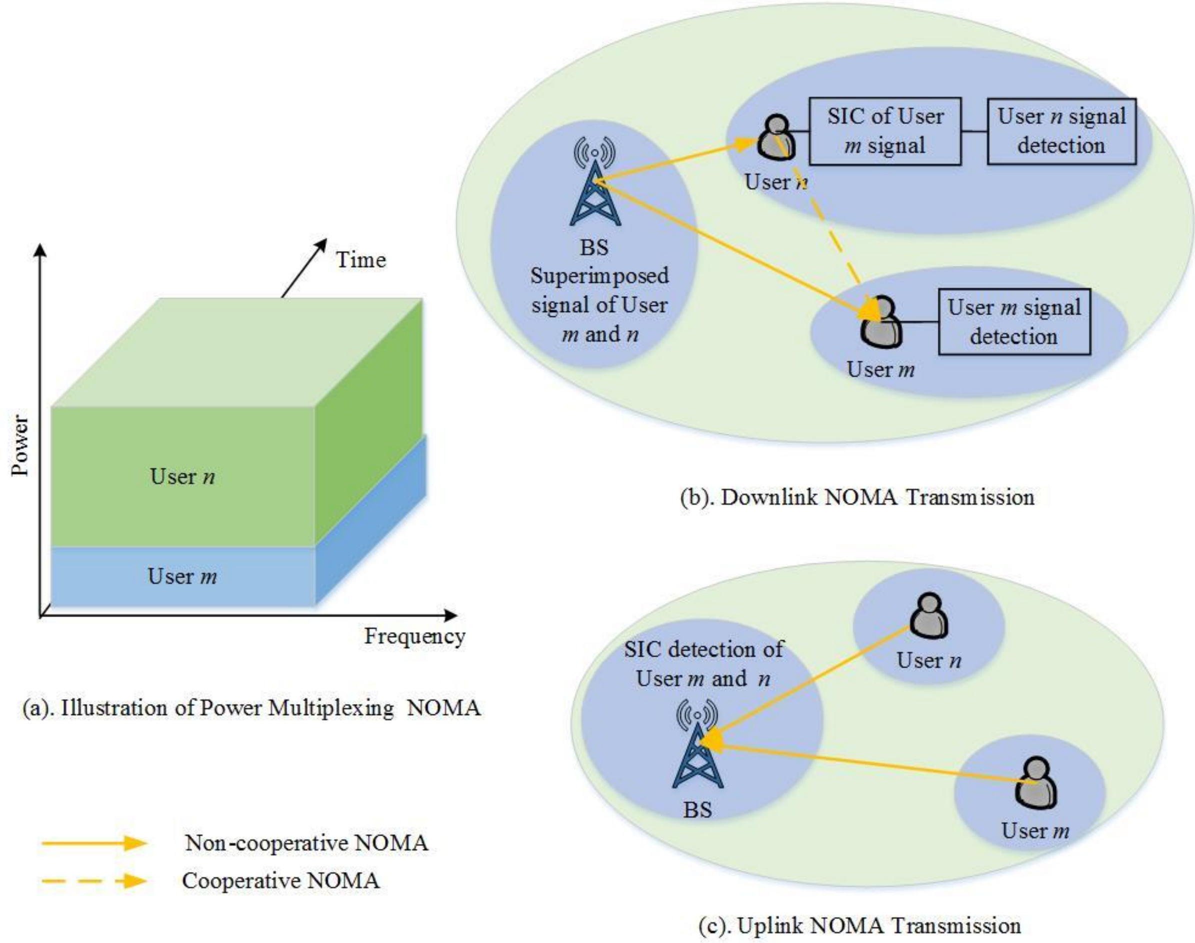


Fig. 3.3 Illustration of NOMA transmission. (a) Power multiplexing NOMA. (b) Downlink NOMA transmission. (c) Uplink NOMA transmission

A more general NOMA transmission scheme was proposed, which considered a BS communicating with *M* randomly deployed users. It was demonstrated that NOMA is capable of achieving superior performance compared to OMA in terms of both its outage probability and its ergodic rate. In Timotheou and Krikidis (2015), the fairness issues were addressed by adopting appropriate PA coefficients for the *M* users in a general NOMA downlink transmission scenario.

Motivated by reducing the signaling overhead required for CSI estimation, some researchers embarked on investigating the performance of downlink NOMA transmissions using partial CSI at the transmitter (Yang et al. 2016; Shi et al. 2016; Cui et al. 2016). More explicitly, Yang et al. (2016) studied the outage probability of NOMA by assuming either imperfect CSI or second order statistics-based CSI, respectively. By assuming the knowledge of statistical CSI, Shi et al. (2016) investigated the outage performance of NOMA by jointly considering both the decoding order selection and the PA of the users. By assuming that only the average CSI was obtained at the BS, Cui et al. (2016) studied both the optimal decoding order and the optimal PA of the users in downlink NOMA systems. Both the transmit power of the BS and rate-fairness of users were optimized. By considering only a single-bit feedback of the CSI from each user to the BS, the outage performance of a downlink transmission scenario was studied by Xu et al. (2016). Based on the analytical results derived, the associated dynamic PA optimization problem was solved by minimizing the outage probability. Zhang et al. (2017) investigated an energy efficiency optimization problem in downlink NOMA systems in conjunction with different data rate requirements of the users. It was shown that NOMA is also capable of outperforming OMA in terms of its energy efficiency.

Apart from wireless communication systems, the potential use of NOMA in other communication scenarios has also attracted interests. A pair of representative communication scenarios are visible light communication (VLC) (Komine and Nakagawa 2004; Marshoud et al. 2016; Yin et al. 2016; Zhang et al. 2016) and quantum-aided communication (Hanzo et al. 2012). To elaborate, Marshoud et al. (2016) applied the NOMA technique in the context of VLC downlink networks. By doing so, the achievable throughput was enhanced. It is worth pointing out that although the potential performance enhancement is brought by invoking NOMA into VLC networks, the hardware implementation complexity is also increased at transmitters and receivers as SC and SIC techniques are adopted. Botsinis et al. (2016) considered quantum-assisted multi-user downlink transmissions in NOMA systems, where a pair of bio-inspired algorithms were proposed.

3.4 UPLINK NOMA TRANSMISSION

In uplink NOMA transmission, multiple users transmit their own uplink signals to the BS in the same RB, as shown in Fig.3.3. The BS detects all the messages of the users with the aid of SIC. Note that there are several key differences between uplink NOMA and downlink

NOMA, which are listed as follows:

- **Transmit Power:** In contrast to downlink NOMA, the transmit power of the users in uplink NOMA does not have to be different, and it depends on the channel conditions of each user. If the users' channel conditions are significantly different, their received SINR can be rather different at the BS, regardless of their transmit power.
- **SIC Operations:** The SIC operations and interference experienced by the users in the uplink NOMA and downlink NOMA are also rather different. More specifically, as shown in Fig. 2.2b for downlink NOMA, the signal of User *n* is decontaminated from the interference imposed by User *m*, which is achieved by first detecting the stronger signal of User *m*, remodulating it, and then subtracting it from the composite signal. It means that SIC operation is carried out on strong user in downlink for canceling the weak user's interference. By contrast, in uplink NOMA, SIC is carried out at the BS to detect strong User *n* first by treating User *m* as interference, as shown in Fig. 2.2c. Then it remodulates the recovered signal and subtracts the interference imposed by User *n* to detect User *m*.
- **Performance Gain:** The performance gain of NOMA over OMA is different for downlink and uplink. Figure 1 of Shin et al. (2016) illustrates the capacity region of NOMA and OMA both for downlink and uplink. The capacity region of NOMA is outside OMA, which means that the use of NOMA in downlink has superior performance in terms of throughput. While in uplink systems, NOMA mainly has the advantages in terms of fairness, especially compared to that OMA with power control.

CHAPTER 4: COOPERATIVE NOMA

Cooperative communication, where the transmission between the source and destination is maintained by the help of one or multiple relays, has received significant attention of researchers since it extends the coverage area and increases system capacity while reducing the performance deteriorating effects of multipath fading.

The combination of cooperative communication and NOMA has been considered as a remarkable solution to further enhance the system efficiency of NOMA. Accordingly, a cooperative transmission scheme, where the users with stronger channel conditions are considered as relays due to their ability in the decoding information of other users in order to assist the users with poor channel conditions, has been proposed to be implemented in NOMA.

In NOMA, the important feature is that the user with better channel conditions has the information of the other user. The user with better channel conditions is called a strong user or near user and the user with weak channel conditions is called weak user or far user. In the case of 2 users, the near user decodes the information of the far user. As the far user has poor channel conditions with the base station (BS), the near user acts as a relay to the far user and transmits the signal to the far user. Now the far user will receive two different copies of the same message. One from the base station, and one from the near user who is acting as a relay. From this, we can expect that the outage probability of the far user to decrease. This concept is called Cooperative communication or Cooperative relaying. Through this concept, we can reduce the outage probability and increase the reliability and quality of the signal and achieve better sum rates and data rates.

However, aforementioned user cooperation schemes are more appropriate for short-range communications, such as ultra wideband and Bluetooth. Therefore, in order to further extend the coverage area and to exploit the advantages of cooperation techniques, the concept of cooperative communication, where dedicated relays are used, has also been investigated in NOMA.

4.1 ADVANTAGES OF COOPERATIVE COMMUNICATION

- The advantage of cooperative communication is that we have established two links to transmit the same message. Even if one link is in outage, chances are the other link is good. The probability that both links simultaneously go into outage is very less compared to the probability that any one link fails.

- We get reduced outage probability and hence diversity gain without the need of additional antennas (i.e., MIMO).
- Another advantage is that relaying can virtually extend the coverage area of the base station.

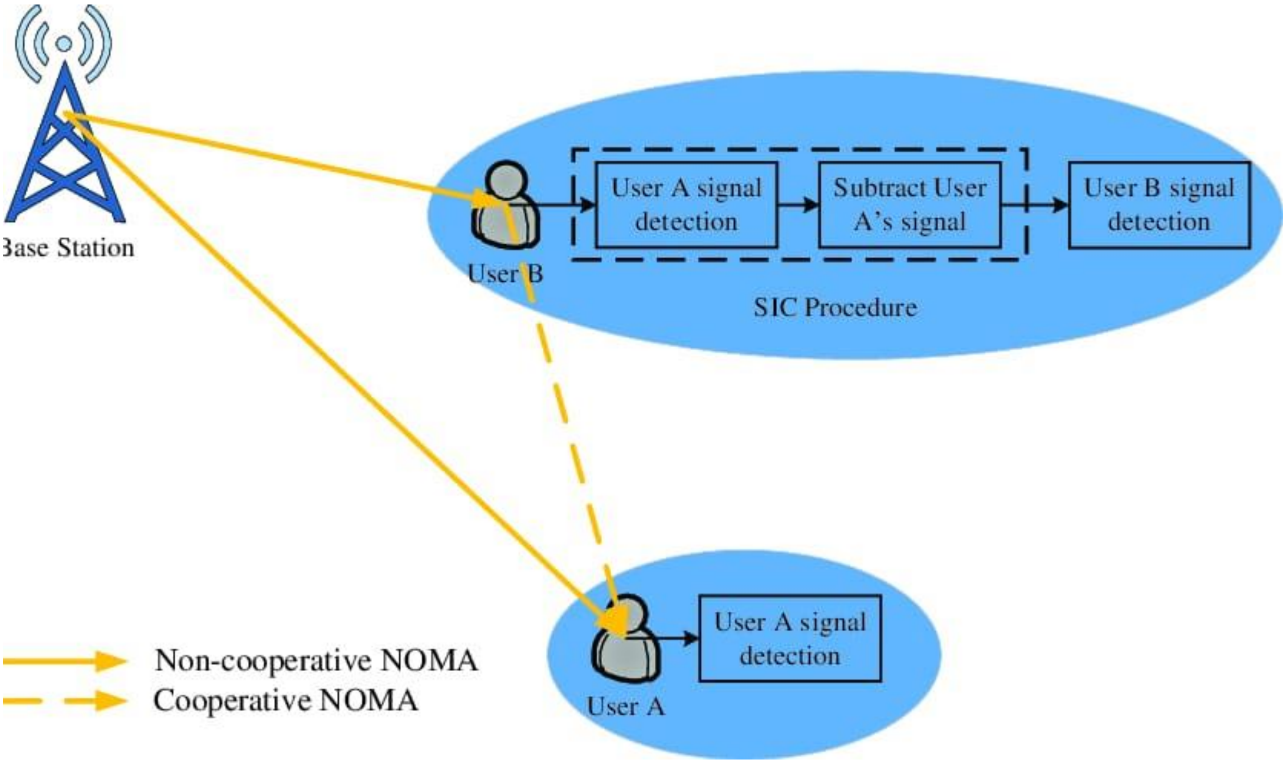


Fig.4.1 Comparison between NOMA and Cooperative NOMA.

4.2 SYSTEM MODEL

As we have seen the head of cooperative communication, let us design a cooperative system with NOMA. Here in this system, two users and a base station are taken into consideration where one user with weak channel conditions and another user with stronger channel conditions. There are two phases, one is the direct transmission phase from the base station to weak user and another stage is from strong user to weak user. Here we are concentrating on the weak user

Phase 1 :(Direct transmission)

In this phase, by the technique of NOMA, transmission of data from the base station to both strong user (near) and weak user (far). Near user using the technique of successive interference cancellation (SIC) decodes the far user's data. Later he decodes his own data.

Achievable rates at the near user and far user at the end of phase 1 are

$$R_n = \frac{1}{2} log_2(1 + \alpha_n \rho |h_n|^2) \qquad (1)$$

$$R_{f,1} = \frac{1}{2} log_2 \left(1 + \frac{\alpha_n \rho |h_n|^2}{\alpha_n \rho |h_n|^2 + 1}\right)$$

Where,

- α_n– Near user's power allocation coefficient
- α_f– Far user's power allocation coefficient
- h_n – Channel between BS and near user
- h_f– channel between BS and far user
- ρ– transmit SNR = P/v^2,where P is the transmit power and $\sigma^2$is the noise variance
- And, $\alpha_f + \alpha_n$=1

Phase 2: (Cooperative relay phase)

In this phase, the near user has the information of far user after performing SIC by the near user. So this information is transmitted to the far user to aid him. Now the achievable rate of far user at the end of cooperative stage is

$$R_{f,2} = \frac{1}{2} log_2(1 + \rho |h_n|^2) \qquad (3)$$

Here, $h_{nf}$is the channel between the near user and far user. We can already see that $R_{f,2} > R_{f,1}$.

At the end of these two phases the far user have two sets of same information. One is from the base station by the technique of NOMA and the one is from near user (by cooperative phase). Diversity combining technique can be used by far user. The copy with high SNR is chosen over the other one. After this the achievable rate of the far user will be

$$R_f = \frac{1}{2}\log_2 (1+\max (\frac{\alpha_f \rho |h_f|^2}{\alpha_n \rho |h_f|^2+1}, \rho |h_{nf}|^2)) \qquad (4)$$

If we did not use the concept of cooperative communication then the achievable rate of far user will be,

$$R_{f,noncoop}=\log_2 (1+\frac{\alpha_f \rho |h_f|^2}{\alpha_n \rho |h_f|^2+1}) \qquad (5)$$

For example if we use OMA, we will allocate half of the time slot for transmission of far user data. Then the achievable rate of far user would be

$$R_{f,OMA}=\frac{1}{2}\log_2(1+\rho|h_f|^2) \qquad (6)$$

By using these equations we will get the achievable rates of far user in three different techniques or scenarios.

4.3 RELAY AIDED NOMA

For ease of exposition, Rayleigh fading channels are considered and $N = 2$ in Fig. 2 isassumed in this section.

A. System Settings

1) **Relay with DF protocol**: For networks with DF protocol, where the SIC is utilized at relay and user ends, the decoding order for source to relay ($S \rightarrow R$) and relay to user ($R \rightarrow U$) transmissions must be organized in the same manner. Otherwise, the achievable sum rate will

decrease dramatically because of the min function, as shown in Fig. 3(a). Note that, for the composite architectures, such as Figs. 2(c) and (d), the decoding orders for $S \rightarrow R$ (uplink or

downlink) and $R \rightarrow U$ (downlink or uplink) transmissions are different. Consequently, the channel gains for the $S \rightarrow R$ link are configured as ascending (descending) while the one for the $R \rightarrow U$ link as descending (ascending). In fact, such settings for the composite architectures are reasonable

since it can reach a higher achievable sum rate and balance the throughput fairness among all multiplexed users.

2) **Relay with AF protocol**: For networks with AF protocol, where the SIC is only utilized at the user end, according to the decoding order at the user, the power allocations for $S \rightarrow R$ and

$R \rightarrow U$ transmissions must be performed in the same manner. Otherwise, the system performance,

e.g., the achievable sum rate and outage probability, will deteriorate significantly. A special case is that, for the uplink or downlink architecture, both $S \rightarrow R$ and $R \rightarrow U$ transmissions employ the same fixed power allocation scheme [7]. On the other hand, for the composite architecture, the channel gains for $S \rightarrow R$ and $R \rightarrow U$ links should be sorted in the same manner, namely both in ascending or descending orders. Unfortunately, such setting is impractical because it will result

in a poor throughput fairness among all users. Therefore, an uplink or downlink architecture for the AF relay network could be a better choice.

B. Power Allocation

An effective power allocation scheme designed for cooperative relay networks depends onthe symbols' decoding order. Generally, more power should be assigned to the earlier decoded symbols while less power is allocated to the later decoded ones. For networks with DF protocol,it is more complex to perform power allocation than the ones with AF protocol, especially with global instantaneous channel state information (CSI) [6]. Therefore, finding a simple and effective power allocation scheme for DF relay networks is demanding.

C. Performance Comparisons

1) **Uplink architectures***:* It has been shown that NOMA can be applied in the uplink transmission. However, since different users are located in different positions and experience different channel conditions, we have to face some ticklish problems. On one hand, it is difficult to realize signal synchronization at both transmitting and receiving ends, and on the other hand, realizing effective control on the transmit power among different users to avoid interference is very challenging in practice.

2) **Downlink architectures***:* One of the most famous downlink architectures is the classical three-node relay network [10], where a source, a half-duplex DF relay, and a user are considered,as shown in Fig. 2(e). However, most existing NOMA schemes only put emphasis on the Rayleighfading scenario [10]. For this reason, a NOMA scheme over Rician fading channel is proposed to handle this problem [11].

Fig. 2(b) shows another downlink architecture for cooperative relay systems [7], where a half-duplex AF or DF relay assists the communication between the source and users. Since the signal-to-interference-and-noise ratio (SINR) with DF relaying is always higher than that with AF relaying, the DF protocol is preferred over the AF one. As shown in Fig. 4, the outage probability and achievable sum rate can be significantly improved when the DF protocol is applied, especially in the low signal-to-noise ratio (SNR) region. This can be understood as follows. If more power is allocated to the weak user, the system's outage behavior will be improved, while the achievable sum rate of the NOMA system will decrease since less power is allocated to the stronger user, which has a full degree of freedom in the achievable rate. Therefore, there exists a tradeoff between the outage probability and achievable sum rate.

1) Composite architectures: Figs. 2(c) and (d) illustrate the composite architectures for DF relay systems. In general, such systems are asymmetric, where the channel gains for uplink transmission are sorted in ascending (descending) order while those for downlink transmissionin descending (ascending) order [5], [6]. Fig. 3(b) shows the gaps of achievable sum rate betweenNOMA and OMA [6] with different degrees of asymmetry.

Since the channel conditions for uplink and downlink transmissions are different in general,a power waste will be resulted if the transmit powers for the two links are both fixed as P_t. Without loss of generality, assume that the channel quality for the uplink is better than that forthe downlink. In this case, we do not need to allocate full power to all symbols for the uplink, whereas for the downlink, P_t must be fully allocated to all symbols. Therefore, if a central processing unit that can adjust the transmit power of the symbols according to the instantaneous CSI, the total power consumed by the system can be saved as less than $2P_t$ [6]. On the other hand, provided that the requirement of quality of service has been satisfied, the saved power can be allocated to the weak user so as to improve its data rate, outage probability, and fairness.

Assuming the knowledge of perfect CSIs, the achievable sum rate, energy efficiency, and normalized power utilization are chosen as performance metrics for comparison. We can see from Figs. 5(a-1) and (b-1) that NOMA shows significant superiority over OMA in terms of achievable sum rate. However, oppositely, as shown in Figs. 5(a-2) and (b-2), NOMA performs worse than OMA in terms of energy efficiency. This phenomenon can be explained by the fact that NOMA can fully utilize the pre-allocated power according to the channel conditions, which results in a boost in achievable sum rate, whereas for OMA, the pre-allocated power cannotbe used effectively since the near-far effect exists. As shown in Figs. 5(a-3) and (b-3), the real power utilization of NOMA is much larger than that of OMA, which can be up to 30%. AlthoughNOMA outperforms OMA in terms of achievable sum rate, the ratio between achievable sum rate and power consumption for NOMA is smaller than that of OMA, which means that the energy efficiency of the former is lower than that of the latter.

CHAPTER 5: PERFORMANCE ANALYSIS

The performance of NOMA with cooperation, NOMA without cooperation and OMA techniques is evaluated, analyzed and compared with each other with respect to calculating the parameters with the input transmit power over the Rayleigh fading channel.

Wireless channel is prone to multipath propagation and fading. Several channel models are available to capture the effects of fading. Each model deals with a particular scenario. One such model is Rayleigh fading model. Rayleigh fading model can be used when there is no line of sight (LOS) path between the transmitter and the receiver. In other words, all multipath components have undergone small scale fading effects like reflection, scattering, diffraction, shadowing etc.

5.1 PARAMETERS

5.1.1 OUTAGE PROBABILITY

In Wireless Communication, Outage probability is expressed as the probability that the information rate to the noise, interferences or any disturbances ratio is smaller than the threshold information rate to the noise ratio. The probability where the far user fails to receive the information from the base station is called as outage probability. We can express the outage probability as the CDF of SNR is given by

$P(C<r) = P\ (log_2(1 + h^2SNR) < r)$

Mathematically, the outage probability can be represented as the CDF of the SNR and is given by, Pout(R) = Pr [AR<R]

Where AR is considered as the achievable rate for the respective user and R is the target rate or the threshold value. If R is high blocking rate is more. To get output below a maximum value, the SNR threshold value should be kept low. If AR is less than the target rate, then the outage occurs. In case the target rate is high then the outage probability reaches the maximum value as noise dominates the original information. To calculate the outage probability for a user, set the target rate and count the number of times that the calculated achievable rates dropped below the target rate and plot them. In Cooperative NOMA outage probability decreases as directivity gain increases, because in Cooperative NOMA multiple antennas are used to increase directivity gain. As it is evident, that the outage probability should be less to get a significant result.

We know that the outage probability should be less for an effective communication system. When the outage probability vs. transmit power are simulated using matlab. We observed less outage probability in case of NOMA with cooperation then NOMA and more outage probability in case of OMA technique.

5.1.2 BIT ERROR RATE

As the data transmitted from source to destination, the rate of change of bits of information during transmission through a communication channel is called the bit error rate. This change of bits can be due to interference, noise, distortion. The formula for bit error rate is given by

BER=Errors received/ Total no. of bits

When the bit error rate vs. transmit power is simulated in matlab, the bit error rate in case of NOMA without cooperation is greater than NOMA with cooperation. As the bit error rate should be less, which is observed in NOMA with cooperation.

In a communication system, the receiver side BER may be affected by transmission channel noise, interference, distortion, bit synchronization problems, attenuation, wireless multipath fading, etc.

The BER may be improved by choosing a strong signal strength (unless this causes cross-talk and more bit errors), by choosing a slow and robust modulation scheme or line coding scheme, and by applying channel coding schemes such as redundant forward error correction codes.

The transmission *BER* is the number of detected bits that are incorrect before error correction, divided by the total number of transferred bits (including redundant error codes). The information BER, approximately equal to the decoding error probability, it is the number of decoded bits that remain incorrect after the error correction, divided by the total number of decoded bits (the useful information). Normally the transmission BER is larger than the information BER. The information BER is affected by the strength of the forward error correction code.

5.1.3 CHANNEL CAPACITY

The maximum achievable rate where there is effective transmission of information from source to destination through the communication medium. The data or a signal that can reliably transmit over a wireless communication channel at the highest rate is known as Channel capacity.

For the transmission of a signal from the transmitter to the receiver, the Rayleigh fading channel is used. The Channel capacity of Cooperative-NOMA is very high because the interference or noise added is very low.

Channel capacity of a system is the summation of individual achievable rates of a respective user. Channel capacity = Ar1 + AR2

Where,

AR1 is the total achievable rates of US1 and

AR2 is the total achievable rates of US2

When the channel capacity vs. transmit power are simulated in matlab, the achievable channel capacity is more in NOMA with cooperation, then OMA and less achievable rate in case of NOMA without cooperation.

5.1.4 SUM RATE

It is defined as the average sum of all the user rates in a network.

It is given by the formula

Sum rate=mean (R1+R2+R3+…..+Rn)

Where

Ri =user rate

i=1, 2, 3,….., n.

As we know that the achievable sum rate for an efficient communication system should be more, which is observed in NOMA with cooperation when compared with NOMA without cooperation and OMA techniques.

In this parameter of the achievable sum rate, NOMA with cooperation shown the better performance than other two techniques.

From the plot of achievable sum rate and transmit power, we observed that the achievable sum rate is more in NOMA with cooperation, then NOMA without cooperation and less achievable sum rate in case of OMA.

CHAPTER-6 MATLAB

6.1 MATLAB Introduction

MATLAB is a high performance language for technical computing. It integrates computation visualization and programming in an easy to use environment. MATLAB stands for matrix laboratory. It was written originally to provide easy access to matrix software developed by LINPACK (linear system package) and EISPACK (Eigen system package) projects. MATLAB is therefore built on a foundation of sophisticated matrix software in which the basic element is matrix that does not require pre dimensioning.

Typical uses of MATLAB

1. Math and computation
2. Algorithm development
3. Data acquisition
4. Data analysis, exploration and visualization
5. Scientific and engineering graphics

The main features of MATLAB

1. Advanced algorithm for high performance numerical computation, especially in the Field matrix algebra
2. A large collection of predefined mathematical functions and the ability to define one's own functions.
3. Two-and three dimensional graphics for plotting and displaying data
4. A complete online help system
5. Powerful matrix or vector oriented high level programming language for individual applications.
6. Toolboxes available for solving advanced problems in several application areas.

6.2 The MATLAB System

The MATLAB System consists of five main parts

- Development Environment:

  This is the set of tools and facilities that help you use MATLAB functions and files. Many of these tools are graphical user interfaces. It includes the MATLAB desktop and Command Window, command history an editor and debugger, and browsers for viewing help the workspace, files, and the search path.

- The MATLAB Mathematical Function Library:

This is a vast collection of computational algorithms ranging from elementary functions, like sum sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix Eigen values, Bessel functions, and fast Fourier transforms.

- The MATLAB Language:

  This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both programming in the small to rapidly create quickly programs, and "programming in the large" to create large and complex application programs.

- Graphics:

  MATLAB has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions for two-dimensional and three dimensional data visualization, video processing, animation, and presentation graphics. It also includes low-level functions that allow you to fully customize the appearance of graphics as well as to build complete graphical user interfaces on your **MATLAB applications**

- The MATLAB Application Program Interface (API):

  This is a library that allows you to write C and FORTRAN programs that interact with MATLAB. It includes facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files

6.3 Starting MATLAB:

On Windows platforms, start MATLAB by double-clicking the MATLAB shortcut icon on your Windows desktop. On UNIX platforms, start MATLAB by typing mat lab at the operating system prompt. You can customize MATLAB start-up. For example, you can change the directory in which MATLAB starts or automatically execute MATLAB statements in a script file named start-ups.

6.4 MATLAB Desktop:

When you start MATLAB, the MATLAB desktop appears, containing tools (graphical user interfaces) for managing files, variables, and applications associated with MATLAB. The following illustration shows the default desktop. You can customize the arrangement of tools and documents to suit your needs.

6.5 MATLAB Working Environment

- MATLAB Desktop:

  MATLAB Desktop is the main MATLAB application window. The desktop contains five sub windows the command window, the workspace browser the current directory window, the command history window, and one or more figure windows, which are shown only when the user displays a graphic.

  The command window is where the user types MATLAB commands and expressions at the prompt (>>) and where the output of those commands is displayed. MATLAB defines as the workspace as the set of variables that the user creates in a work session. The workspace browser shows these variables and some information about them. Double clicking on a variable in the workspace browser launches the Array Editor, which can be used to obtain information and income instances edit certain properties of the variable.

  The current Directory tab above the workspace tab shows the contents of the current directory, whose path is shown in the current directory window .For example, in the windows operating system the path might be as follows: C-MATLAB Work, indicating that directory "work" is a subdirectory of the main directory MATLAB WHICH IS INSTALLED IN DRIVE C. clicking on the arrow in the current directory window shows a list of recently used paths. Clicking on the button to the right of the window allows the user to change the current directory.

  MATLAB uses a search path to find M-files and other MATLAB related files, which are organize in directories in the computer file system. Any file run in MATLAB must reside in the current directory or in a directory that is on search path. By default, the files supplied with MATLAB and math works toolboxes are included in the search path. The easiest way to see which directories is on the search path. The easiest way to see which directories are soon the search paths, or to add or modify a search path, is to select set path from the File menu the desktop, and then use the set path dialog box. It is good practice to add any commonly used directories to the search path to avoid repeatedly having the change the current directory.

  The Command History Window contains a record of the command window, including both current and previous MATLAB sessions. Previously entered MATLAB commands can be selected and re-executed from the command History window by right clicking on a command or sequence of commands. This action launches a menu from which to select various options in addition to executing the commands. This is a use to select various options in addition to executing the commands. This is useful feature when experimenting with various commands in a work session.

- Using the MATLAB Editor to create M-Files:

  The MATLAB editor is both a text editor specialized for creating M-files and graphical MATLAB debugger. The editor can appear in a window by itself, or it can be a sub window in the desktop, M-files are denoted by the extension m The MATLAB editor window has numerous pull-down menus for tasks such as saving viewing, and debugging files. Because it performs some simple checks and also uses color to differentiate between various elements of code, this text editor is recommended as the tool of choice for writing and editing M functions. To open the editor, type edit at the prompt opens the M-file filenames in an editor window ready for editing. As noted earlier the file must be in the current directory, or in a directory in the search path

- Getting Help:

  The principle way to get help online is lo use the MATLAB help browser, opened as a separate window either by clicking on the question mark symbol (?) on the desktop toolbar, or by typing help browser at the prompt in the command window. The help Browser is a web browser integrated into the MATLAB desktop that displays a Hypertext Markup Language (HTML) documents. The Help Browser consists of two panes, the help navigator pane, used to find information, and the display pane, used to view the information. Self-explanatory tabs other navigator pane are used to perform a scratch.

  For example, help on a specific function is obtained by selecting the search tab, selecting Function Name as the Search Type, and then typing in the function name in the Search for field. It is good practice to open the Help Browser at the beginning of a MATLAB session to have help readily available during code development or other MATLAB task.

  Another way to obtain for a specific function is by typing doc followed by the function name at the command prompt. For example, typing doc format displays documentation for the function called format in the display pane of the Help

Browser. This command opens the browser if it is not already open.

M-functions have two types of information that can be displayed by the user. The first is called the HI line, which contains the function name and alone line description the second is a block of explanation called the Help text block. Typing help at the prompt followed by a function name displays both the HI line and the Help text for that function in there command window.

Typically look for followed by a keyword displays all the HI lines that contain that keyword. This function is useful when looking for a particular topic without knowing the names of applicable functions. For example, typing look for edge at the prompt displays the HI lines containing that keyword. Because the HI line contains the function name, it then becomes possible to look at specific functions using the other help methods. Typing look for edge-all at the prompt displays the HI line of all functions that contain the word edge in cither the HI line or the Help text block .Words that contain the characters edge also are detected. For example, the HI line of a function containing the word poly edge in the H1 line or Help text would also be displayed.

6.6 Saving and Retrieving a Work Session

There are several ways to save and load an entire work session or selected workspace variables in MATLAB. The simplest is as follows.

To save the entire workspace, simply right-click on any blank space in the workspace Browser window and select Save Workspace as from the menu that appears. This opens a directory window that allows naming the file and selecting any folder in the system in which to save it. Then simply click Save To save a selected variable from the workspace, select the variable with a left click and then right-click on the highlighted area. Then select Save Selection As from the menu that appears. This again opens a window from which a folder can be selected to save the variable.

To select multiple variables, use shift click or control click in the familiar manner, and then use the procedure just described for a single variable. All files are saved in the double-precision, binary format with the extension mat. These saved files commonly are referred to as MAT-files. For example, a session named, says mywork_2012-02-10, and would appear as the MAT-file mywork_2012_02_10.mat when saved. Similarly, a saved video called final video will appear when saved as final_ video mat.

To load saved workspaces and/or variables, left-click on the folder icon on the toolbar of the workspace Browser window. This causes a window to open from which a folder containing MAT-file or selecting open causes the contents of the file to be restored in the workspace Browser window. It is possible to achieve the same results described in the preceding paragraphs by typing save and load at the prompt with the appropriate file names and path information. This approach is not as convenient, but it is used when formats other than those available in the menu method are required.

- Graph Components:

  MATLAB displays graphs in a special window known as a figure. To create a graph, you need to define a coordinate system. Therefore every graph is placed within Axes, which are contained by the figure. The actual visual representation of the data is achieved with graphics objects like lines and surfaces. These objects are drawn within the coordinate system defined by the axes, which MATLAB automatically creates specifically to accommodate the range of the data. The actual data is stored as properties of the graphics objects.

- Plotting Tools

  Plotting tools are attached to figures and create an environment for creating Graphs. These tools enable you to do the following:

  1. Select from a wide variety of graph types
  2. Change the type of graph that represents a variable
  3. See and set the properties of graphics objects
  4. Annotate graphs with text, arrows, etc.
  5. Drag and drop data into graphs

Display the plotting tools from the View menu or by clicking the plotting tools icon in the figure toolbar, as shown in the following picture.

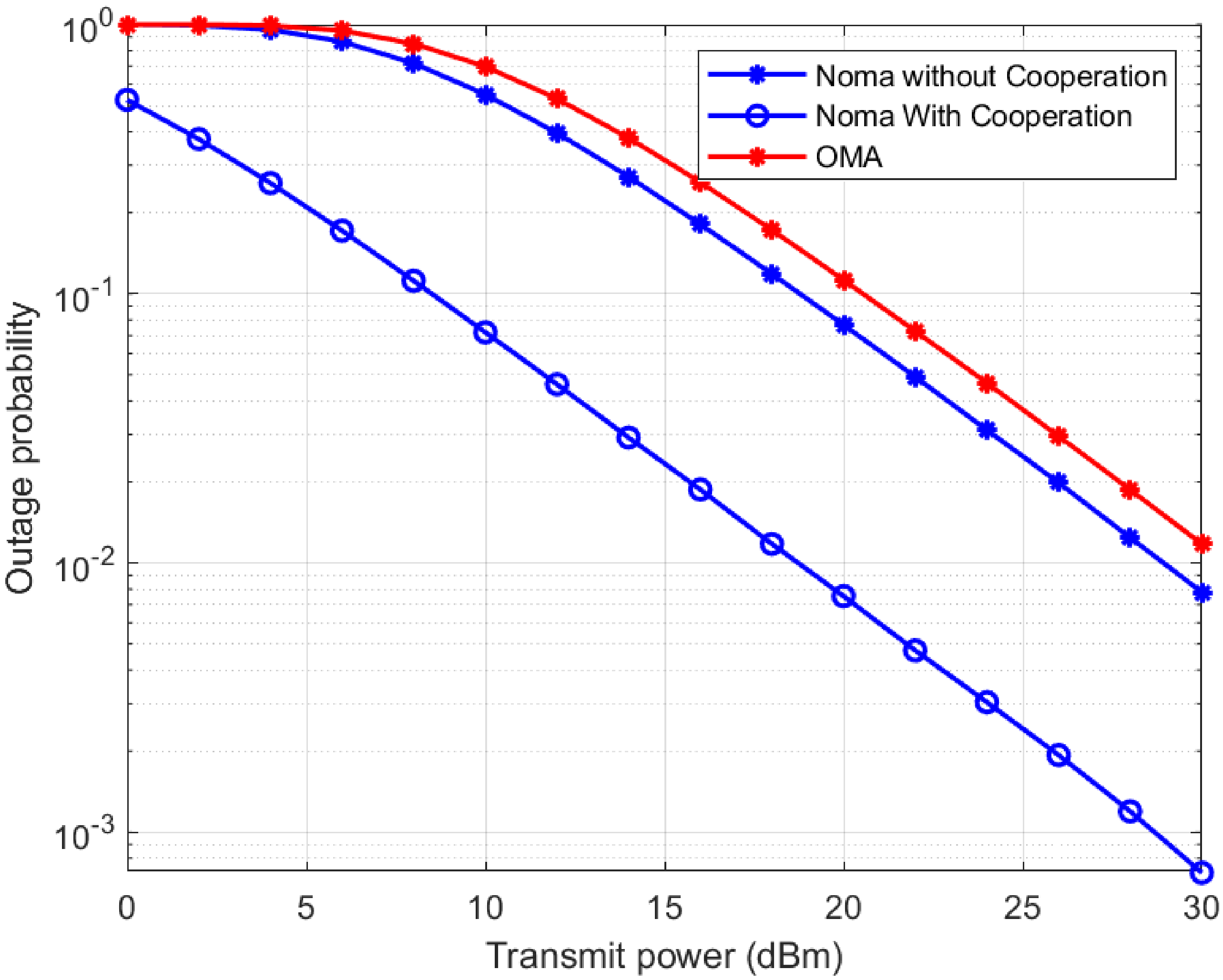
- Editor/Debugger Use the Editor/Debugger to create and debug M-files, which are programs you write to run MATLAB functions. The Editor/Debugger provides a graphical user interface for text editing, as well as for M-file debugging.

  To create or edit an M-file use File > New or File > Open, or use the edit function.

CHAPTER 7: SIMULATION RESULTS

Below are the simulation results for different parameters for the cooperative NOMA scenario.

I) <u>OUTAGE PROBABILITY vs TRANSMIT POWER</u>:

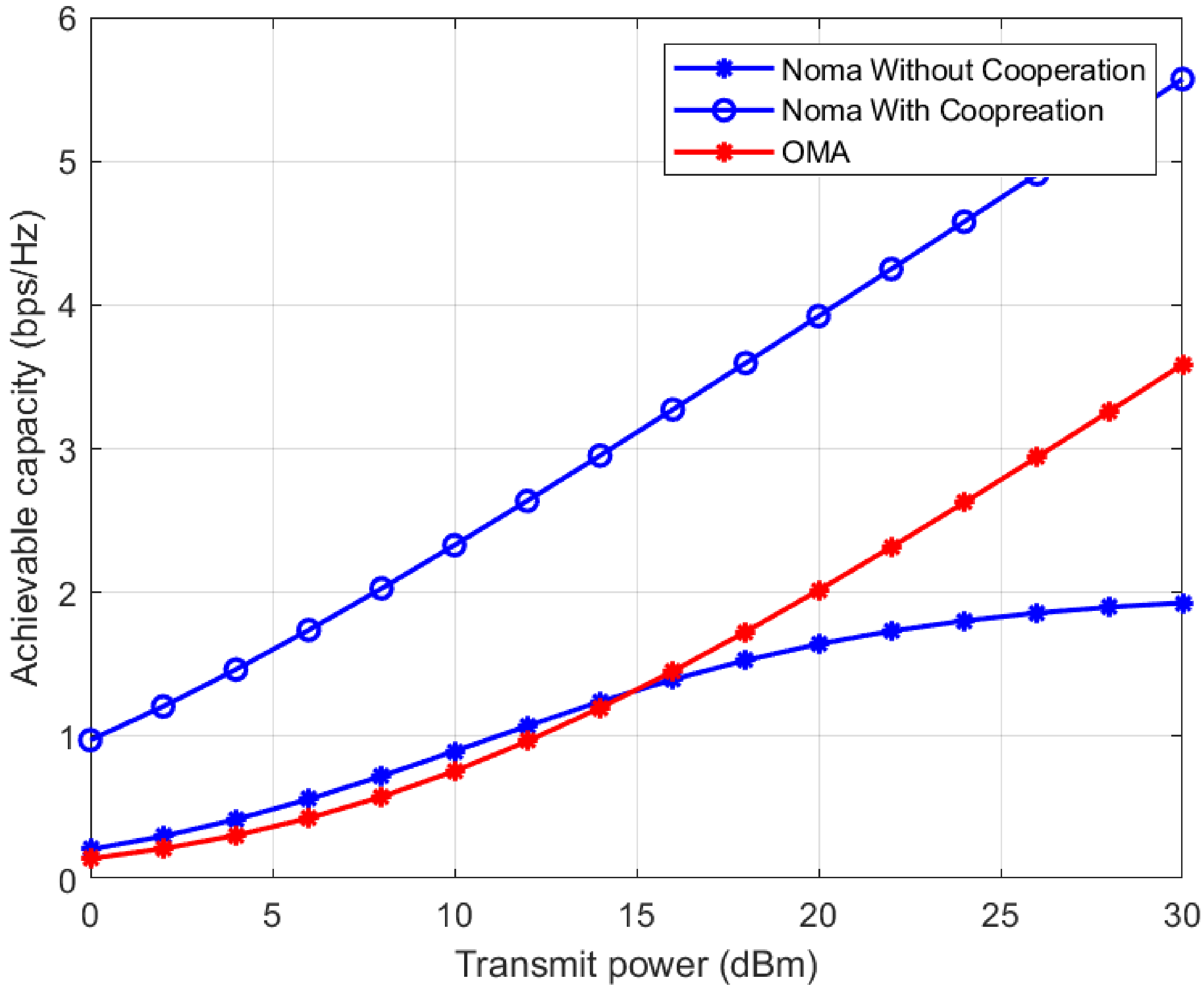


TRASNMIT POWER/OUTAGE PROBABILITY	NOMA WITHOUT COOPERATION	NOMA WITH COOPERATION	OMA
4 dBm	**0.9576**	**0.2568**	**0.9912**
8 dBm	**0.718**	**0.1114**	**0.8499**
12 dBm	**0.3958**	**0.04602**	**0.5304**
16 dBm	**0.1818**	**0.01854**	**0.2596**
20 dBm	**0.0771**	**0.007522**	**0.1134**
24 dBm	**0.03162**	**0.003002**	**0.04671**

In Fig. 7.1, the plot is obtained between Outage Probability vs. Transmit Power. From the equations of achievable rates of far user the outage probability is intended by pre defining a user rate. So if the user rate is less than that in any point that point is taken as an outage.

From the graph of outage probability vs. transmit power, at 4dBm of transmit power the outage probability is 0.9576 in case of NOMA without Cooperation, 0.2568 in case of NOMA with cooperation and 0.9912 in case of OMA technique. Similarly when compared at the transmit powers of 8 dBm, 12 dBm, 16dBm, at 20 dBm of transmit power the outage probability is 0.0075 in case of NOMA with cooperation, 0.077 in case of NOMA without cooperation and 0.1134 in case of OMA and at 24 dBm. As we know that the outage probability for an efficient communication system should be less, which is observed in NOMA with cooperation when compared with NOMA without cooperation and OMA techniques. In this parameter of Outage probability NOMA with cooperation shown the better performance than other two techniques.

II) <u>ACHIEVABLE CAPACITY vs TRANSMIT POWER</u>:

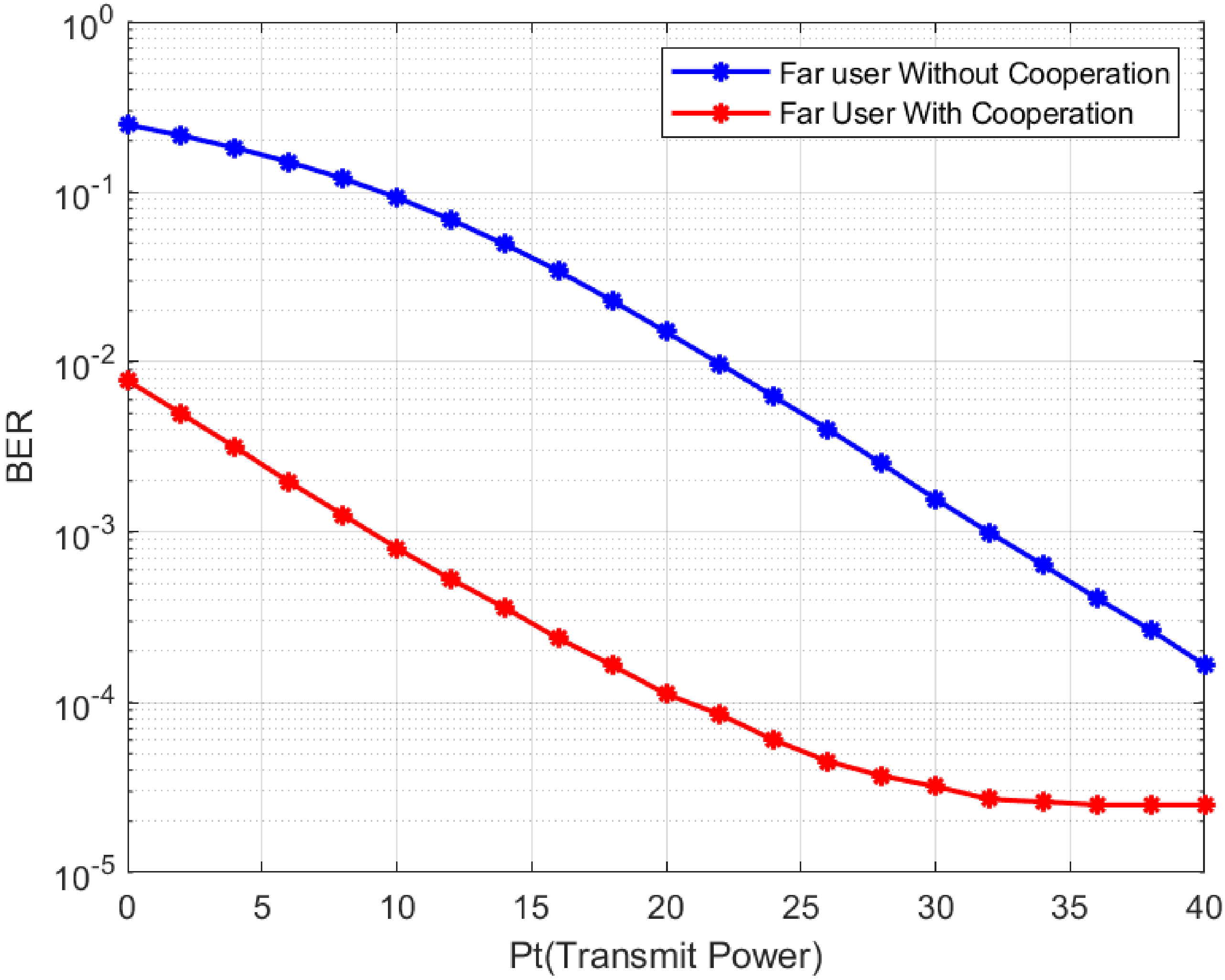


TRASNMIT POWER/ACHIEVABLE CAPACITY(bps/Hz)	NOMA WITHOUT COOPERATION	NOMA WITH COOPERATION	OMA
4 dBm	**0.4209**	**1.465**	**0.3101**
8 dBm	**0.7228**	**2.029**	**0.5784**
12 dBm	**1.0710**	**2.639**	**0.9639**
16 dBm	**1.3940**	**3.274**	**1.4520**
20 dBm	**1.6400**	**3.924**	**2.0141**
24 dBm	**1.8030**	**4.581**	**2.6240**

In Fig.7.2, the plot is between achievable capacity vs. transmit power. From the equations the achievable capacity is calculated for every point of transmit power and plotted against it.

In the plot of channel capacity and transmit power, at 4dBm of transmit power the achievable capacity is 04209 in case of NOMA without Cooperation, 1.465 in case of NOMA with cooperation and 0.3101 in case of OMA technique. Similarly when compared at the transmit powers of 8 dBm, 12 dBm, 16dBm, at 20 dBm of transmit power, the achievable capacity is 3.924 in case of NOMA with cooperation, 1.64 in case of NOMA without cooperation and 2.0141 in case of OMA and at 24 dBm. As we know that the achievable capacity for an efficient communication system should be more, which is observed in NOMA with cooperation when compared with NOMA without cooperation and OMA techniques. In this parameter of the achievable capacity, NOMA with cooperation shown the better performance than other two techniques.

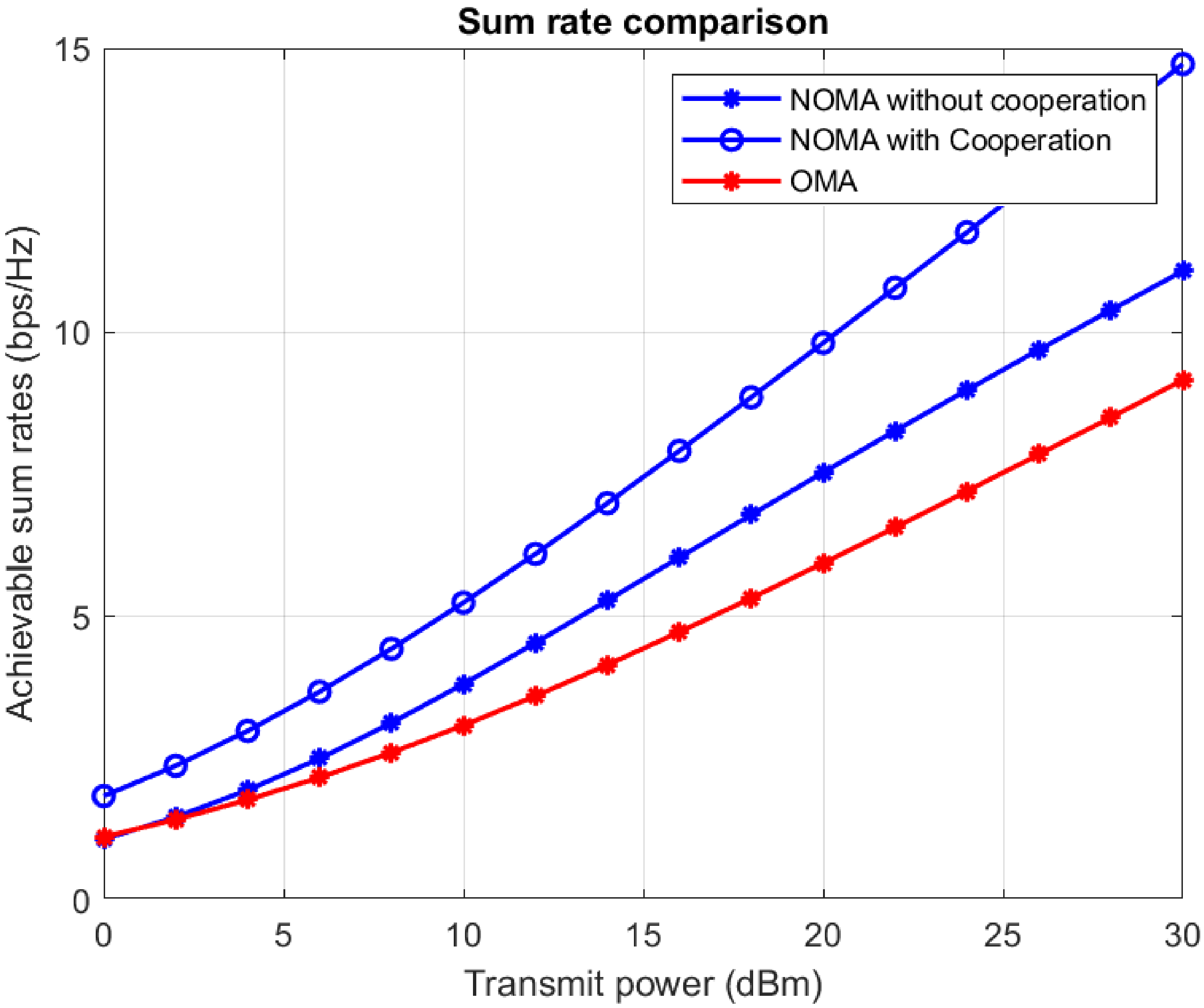
III) <u>BIT ERROR RATE vs TRASNMIT POWER</u> :



In Fig.7.3, the plot of Bit error rate (BER) vs. transmit power is obtained. For this calculation random data is generated for two users. Modulation is done followed by super position coding. At the receiver end of far user the transmitted data and decoded data is compared and the bit error rate is found by function in Matlab (ber (Tx Data, Rx Data)). And plotted against Transmit Power.

In the plot of bit error rate and transmit power, at 20 dBm of transmit power the bit error rate is approximately 0.0001 in case of NOMA with cooperation, 0.01 in case of NOMA without cooperation. As we know that the bit error rate for an efficient communication system should be less, which is observed in NOMA with cooperation when compared with NOMA without cooperation. In this parameter of bit error rate, NOMA with cooperation shown the better performance than other two techniques.

IV) <u>ACHIEVABLE SUM RATE vs TRANSMIT POWER</u>:



TRASNMIT POWER/ ACHIEVABLE SUM RATES	NOMA WITHOUT COOPERATION	NOMA WITH COOPERATION	OMA
4 dBm	**1.940**	**2.984**	**1.768**
8 dBm	**3.122**	**4.429**	**2.60**
12 dBm	**4.530**	**6.097**	**3.595**
16 dBm	**6.031**	**7.912**	**4.72**
20 dBm	**7.529**	**9.812**	**5.934**
24 dBm	**8.981**	**11.760**	**7.202**

In Fig.7.4, the plot is between achievable sum rate vs. transmit power. From the equations the achievable capacity is calculated for every point of transmit power and plotted against it.

In the plot of achievable sum rate and transmit power, at 4dBm of transmit power the achievable sum rate is 1.940 in case of NOMA without Cooperation, 2.984 in case of NOMA with cooperation and 1.768 in case of OMA technique. Similarly when compared at the transmit powers of 8 dBm, 12 dBm, 16dBm, at 20 dBm of transmit power, the achievable sum rate is 9.812 in case of NOMA with cooperation, 7.529 in case of NOMA without cooperation and 5.934 in case of OMA and at 24 dBm. As we know that the achievable sum rate for an efficient communication system should be more, which is observed in NOMA with cooperation when compared with NOMA without cooperation and OMA techniques.

In this parameter of the achievable sum rate, NOMA with cooperation shown the better performance than other two techniques.

CONCLUSION

NOMA can be integrated with other techniques like Cooperative Communication and MIMO technology. In order to increase reliability and improve the system performance, in this project NOMA is integrated with Cooperative communication concept and observed the performance and it is compared with NOMA without Cooperation and OMA techniques. When the performance of the communication system is evaluated with respect to parameters like outage probability, achievable channel capacity, bit error rate and sum rate, for an effective communication system the outage probability should be less, the achievable capacity should be more, bit error rate should be less and in case of sum rate it should be more and these outputs are observed from simulation results when these parameters are plotted against the transmit power in NOMA with cooperation than NOMA without cooperation and OMA techniques. Hence for effective communication between users in a network, NOMA can be integrated with the Cooperative communication concept.

FUTURE WORK

In this project, we mainly focused on observing the performance of Cooperative NOMA in a communication system. In future this work can be extended by combining this technology with MIMO (Multiple Input and Multi Output) for better performance of the system.

REFERENCES

[1] Dehuan Wan, Miaowen Wen, Fei Ji, Hua Yu, and Fangjiong Chen "Non-Orthogonal Multiple Access For Cooperative Communications: Challenges, Opportunities, And Trends" arxiv: 1801.04650v1 15 Jan 2018.

[2] Yua n w ei Liu, Zhijin Qin, Maged Elk a shla n, Zhiguo Ding, Arumugam Nalla nat h a n, and Lajos Ha nzo "Non-Orthogonal Multiple Access for 5G and Beyond"15 Mar 2017.

[3] S. M. R. Islam, N. Avazov, O. A. Dobre, and K. s. Kwak, "Power-domain non-orthogonal multiple access (NOMA) in 5G systems: Potentials and challenges," IEEE Communications Surveys Tutorials, vol. 19, no. 2, pp. 721–742, Secondquarter 2017.

[4] M. F. Kader, M. B. Shahab, and S. Y. Shin, "Exploiting non-orthogonal multiple access in cooperative relay sharing," IEEE Commun. Lett., vol. 21, no. 5, pp. 1159–1162, May 2017.

[5] Zhiguo Ding, Mugen Peng, and H. Vincent Poor "Cooperative non-orthogonal multiple access in 5G systems" IEEE COMMUNICATIONS LETTERS, VOL. 19, NO. 8, AUGUST 2015.

[6] L. Dai, B. Wang, Y. Yuan, S. Han, C.-L. I, and Z. Wang, "Non orthogonal multiple access for 5G: Solutions, challenges, opportunities, and future research trends," IEEE Commun. Mag., vol. 53, no. 9, pp. 74–81, Sept. 2015.

[7] J. B. Kim and I. H. Lee, “Non-orthogonal multiple access in coordinated direct and relay transmission,” IEEE Commun. Lett., vol. 19, no. 11, pp. 2037–2040, Nov. 2015.

[8] Z. Ding, Z. Yang, P. Fan, and H. V. Poor, “On the performance of non-orthogonal multiple access in 5G systems with randomly deployed users,” IEEE Signal Process. Lett., vol. 21, no. 12, pp. 1501–1505, Dec. 2014.