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Theme

Performance Analysis of Cooperative Non-Orthogonal Multiple Access System with Direct Links

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« Thanks»

First of all, we thank our Supervisor

Dr. Khelil Abdellatif

For his advice and assistance to us in order to finish this work in the best way.

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Thank you to everyone who help us.

Dedication

To our effort along this journey,

To our beloved ones, our families,

To those who believed in us, our true friends,

To all friends throughout the study trip,

we dedicate this work.

We hope that this work will be useful.

Abstract:

Recently, non-orthogonal multiple access (NOMA) is considered a promising technology for future networks. Furthermore, cooperative communication is integrated with NOMA to enhance the system performance and expand the coverage area. In this dissertation, we going through to show the basic concept of NOMA and compare it with conventional OMA. Also, cooperative NOMA consists of two possible scenarios as cooperative NOMA with direct or without links (in our study, we concentrate to the first scenario). Thus, we present the cooperative NOMA scenarios and protocols. We present the advantages of cooperative NOMA. In order to improve the system performance of NOMA, we consider cooperative NOMA with direct links when the users can hear their signal from two different sources i.e., directly from the source and indirectly with the help of the relay. We simulate the bit error rate (BER), outage probability and capacity of the cooperative NOMA with the direct links. The results indicate that the cooperative NOMA system enhances the BER, outage probability and capacity of NOMA.

Key Words: NOMA, Cooperative, BER, Capacity, Outage Probability.

Résumé:

Récemment, l'accès multiple non orthogonal (NOMA) est considéré comme une technologie prometteuse pour les futurs réseaux. De plus, la communication coopérative est intégrée à NOMA pour améliorer les performances du système et étendre la zone de couverture. Dans ce mémoire, nous allons montrer le concept de base du NOMA et le comparer avec l'OMA conventionnel. Aussi, le NOMA coopératif se compose de deux scénarios possibles en tant que NOMA coopératif avec ou sans liens directs (dans notre étude, nous nous concentrons sur le premier scénario). Ainsi, nous présentons les scénarios et protocoles NOMA coopératifs. Nous vous présentons les avantages du NOMA coopératif. Afin d'améliorer les performances du système de NOMA, nous considérons NOMA coopératif avec des liens directs lorsque les utilisateurs peuvent entendre leur signal à partir de deux sources différentes, c'est-à-dire directement à partir de la source et indirectement à l'aide du relais. Nous simulons le taux d'erreur binaire (BER), la probabilité d'interruption et la capacité du NOMA coopératif avec les liens directs. Les résultats indiquent que le système NOMA coopératif améliore le BER, la probabilité d'interruption et la capacité du NOMA.

Mots clés : NOMA, Coopérative, Capacité, BER et probabilité de panne.

ملخص :

في الآونة الأخيرة، يُنظر إلى الوصول المتعدد غير المتعامد (NOMA) على أنه تقنية واعدة للشبكات المستقبلية. بالإضافة إلى ذلك، تم دمج الاتصال التعاوني في NOMA لتحسين أداء النظام وتوسيع منطقة التغطية. في هذه الدراسة، سوف نعرض المفهوم الأساسي لـ NOMA ونقارنه مع OMA التقليدي. أيضًا، يتكون NOMA التعاوني من سيناريوهين محتملين مثل NOMA التعاوني مع أو بدون روابط مباشرة (في دراستنا ، نركز على السيناريو الأول). وبالتالي، نقدم سيناريوهات وبروتوكولات NOMA التعاونية. نقدم لكم مزايا نوما التعاونية. من أجل تحسين أداء نظام NOMA، فإننا نعتبر تعاونية NOMA بروابط مباشرة عندما يمكن للمستخدمين سماع إشاراتهم من مصدرين مختلفين، أي مباشرة من المصدر وبشكل غير مباشر من الترحيل. نقوم بمحاكاة معدل خطأ البتات (BER)، واحتمال الانقطاع وقدرة NOMA التعاونية مع الروابط المباشرة. تشير النتائج إلى أن نظام NOMA التعاوني يعمل على تحسين BER واحتمال الانقطاع وقدرة NOMA.

الكلمات المفتاحية:NOMA التعاونية، السعة، احتمال الانقطاع، معدل الخطأ.

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List of Abbreviations:

5G: Fifth Generation
6G: Sixth Generation
AF: Amplify-and-Forward
AWGN: Additive White Gaussian Noise
BER: Bit Error Rate
BS: Base Station
CDMA: Code Division Multiple Access
CSI: Channel State Information
D2D: Device-to-Device
DF: Decode-and-Forward
EE: Energy Efficiency
FDMA: Frequency Division Multiple Access
IEEE: Institute of Electrical and Electronics Engineers
IoT: Internet of Things
EGC: Equal-Gain Combining
MRC: Maximum Combining Ratio
NOMA: Non Orthogonal Multiple Access
OFDMA: Orthogonal Frequency Division Multiple Access
OMA: Orthogonal Multiple Access
QoS: Quality of Service
QPSK: Quadrature Phase-Shift Keying
SC: Superposition Coding
SE: Spectral Efficiency
SIC: Successive Interference Cancellation
SINR: Signal to Interference and Noise Ratio
SNR: Signal to Noise Ratio
TDMA: Time Division Multiple Access
VLC: Visible Light Communication
WSN: Wireless Sensor Networks

Contents

General Introduction

General introduction

In previous generations of communication networks, the reliance was entirely on orthogonal multiple access (OMA) technologies, which relies on dividing resources among the users available in the network, this is one of the main disadvantages of OMA charts is that the maximum the number of users is limited to the total amount available orthogonal resources, since when consuming the maximum of these resources, new users must wait until they are available again. Hence the search for new technologies to replace them, among the most important alternatives proposed for recent studies Non-orthogonal multiple access (NOMA) technologies.

In recent years, NOMA techniques have become one exciting area of research. NOMA is a new technology from multiple access technologies it is expected that this technology will be the basic technology for the efficient use of the spectrum in the future. This technology is a strong candidate to meet the requirements of future generations of communication networks. NOMA technology relies on sharing the same resources with users who are available in the network at the same time. Despite this, it is still the subject of research and has not yet been adopted, recent studies have shown that NOMA has the ability to be applied in future beyond 5G and 6G systems and several applications and technologies, such as cooperative NOMA networks.

Cooperative NOMA it is a composite technology that combines cooperative communication and NOMA technology, it is often applied for increasing energy efficiency of NOMA, combat the weakness of the channel and expanded coverage area, it also gives greater efficiency to the system. Cooperative NOMA is held in two major concepts: 1) cooperative-NOMA, where near users act as relays to help the far user and 2) relay-assisted/aided-NOMA where relays in the network help NOMA users to enhance coverage. Another concept of cooperative NOMA is to increase the capacity of the system in the case if the users have a direct link communication with the source and an indirect link with the relay. When using this technology, we will be faced with the challenge of whether it is effective enough to be used regardless of its cost, it is difficult to rely on a technology that costs a lot compared to its performance and effectiveness compared to previous technologies. Therefore, the ongoing studies on the cooperative NOMA is based on the effectiveness of the system compared to the regular NOMA.

In this thesis, we will learn about NOMA technology as we learn about the Noma cooperative composite technology, we also investigate and compare cooperative NOMA with a direct link with conventional NOMA (i.e., direct link), we will divide this work into three chapters:

The first chapter will introduce the concept general of downlink and uplink NOMA networks, with a simple comparison with OMA. We will know the techniques of superposition coding and successive interference cancellation of NOMA.

In the second chapter, we define cooperative NOMA communication. We introduce the role and types of the relay. Finally, we introduce a cooperative NOMA with a direct link (we focus on using a maximum ratio combining (MRC)).

Finally, in the third chapter, we simulate a cooperative NOMA system with a direct link in terms of outage probability, bit error rate and capacity of the system.

Chapter I

Non-Orthogonal Multiple Access (NOMA)

I.1. Introduction

Currently, all the cellular systems networks use OMA techniques, including TDMA, FDMA, CDMA and OFDMA. NOMA has been proposed as one of the candidate multiple access technologies in beyond 5G networks being introduced. In this chapter, we will explore the notion of NOMA technology. First, we will introduce the basic principle of NOMA in downlink and uplink. We also define the superposition coding (SC) and successive interference cancellation (SIC). Then, we compare NOMA and OMA. Also, we present the advantages and disadvantages of NOMA. Finally, we conclude the chapter with NOMA applications.

I.2. The basic principle of NOMA work

NOMA is currently a hot research topic for 5G and beyond systems [1]. NOMA technology is among the most promising technologies, which provide high system capacity, low latency, and massive connectivity, to meet many challenges in 5G wireless systems and beyond [2]. NOMA basically depends on serving multiple users at the same time taking advantage of differences in channel gain to allow users to share the same time and frequency resources to enhance their connection. This allows for a certain degree of interference at the receivers [3]. NOMA exploits SC at the transmitter and SIC at the receiver, thus multiplexing users in the power domain. As shown in Figure I.1, the base station (BS) sends the superposed signals to two users, where User 1 has higher channel gain than User 2. In NOMA, the user with higher channel gain and the user with lower channel gain are usually referred to as the strong user and the weak user, respectively. The strong user first subtracts the signal of the weak user through SIC, and then decodes its own signal; the weak user considers the signal of the strong user as noise and detects its own signal directly. With worse channel gain and more interference, the weak user is assigned more power in NOMA to ensure fairness.

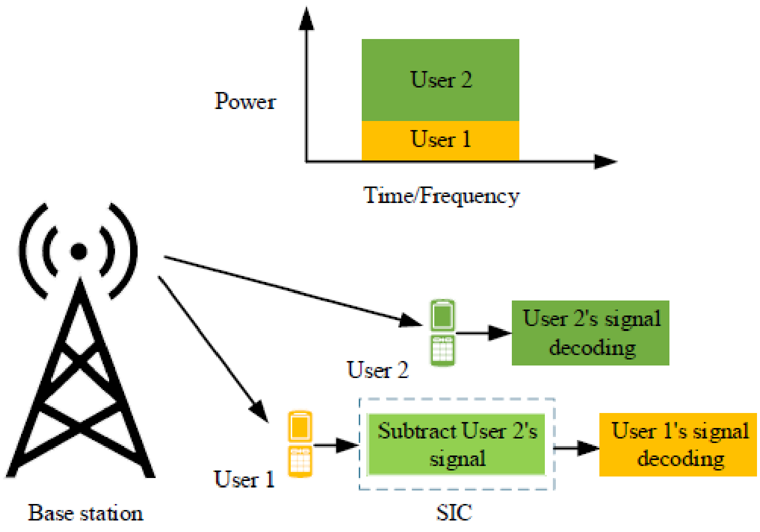


Figure I.1: A simplified scheme Explains mechanism of NOMA [4].

For example, we have a BS sends signals to two users in same resources, where the total energy is given by the following expression

$$P_t = P_1 + P_2 \quad (I.1)$$

where: P_t is total power, P_1 is the power of user-1 and P_2 is the power of user-2.

I.3. Superposition coding (SC)

Superposition coding is one of the fundamental building blocks of coding schemes in network information theory. This idea was first introduced by [5]. Subsequently, Bergmans adapted Cover's superposition coding scheme to the general degraded broadcast channel (this scheme is actually applicable to any non-degraded broadcast channel [6]. SC is a well-known non orthogonal scheme that achieves the capacity on a scalar Gaussian broadcast channel [7]. We present an illustration in Figure I.2. In this scenario with two users, the one BS will have two encoders in which the input source bits are mapped into output symbol sequences respectively. Consider a general case where each user sends 2 bits in 1 symbol. Therefore, the size of each user's constellation is 4, and composite constellation at the transmitter has 16 points. Figure I.2. (a) and Figure I.2. (b) show quadrature phase-shift keying (QPSK) constellations of UE-1and UE-2, respectively. As shown in Figure I.2, UE-2 will be allocated with more power than UE-1 because UE-1 has better channel conditions than UE-2. After a simple superposition of the two constellations, the composite constellation is then generated as shown in Figure I.2. (c)(d).

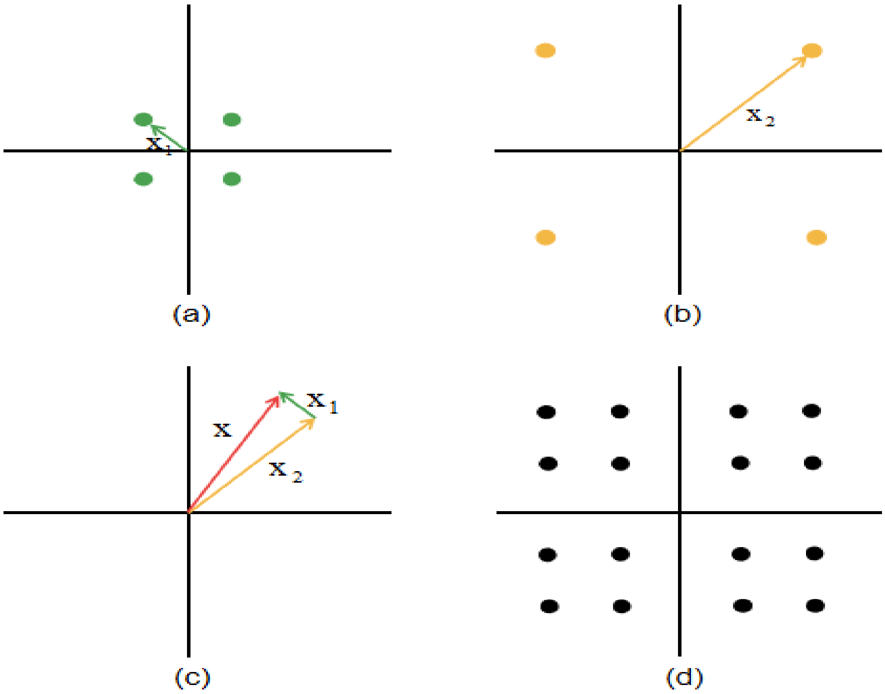
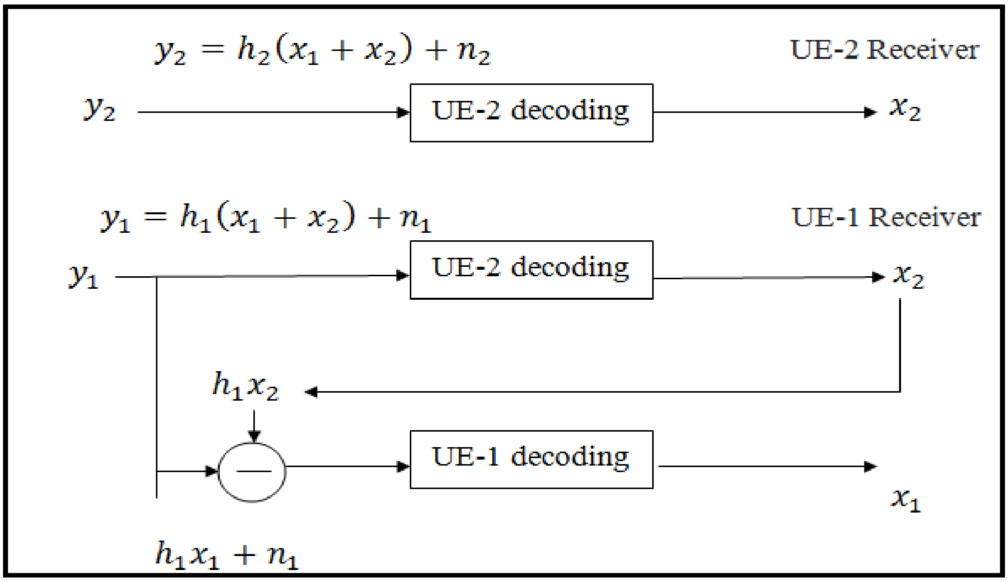


Figure I.2: Traditional superposition of two users' constellations (a) constellation of UE-1 (b) constellation of UE-2 (c) (d) constellation of the superimposed signal [8].

I.4. Successive interference cancellation (SIC)

NOMA has been recognized as a promising multiple access technique for the fifth-generation networks due to its superior spectral efficiency. In NOMA systems, the main technology is SIC technology. SIC is based mainly on the principle of decoding the signals received one by one consecutively [9], after decoding signal one of the users, it is subtracted from the collected signal before decoding the signal of the next user. When the SIC is applied, one of the user's signals is decoded normally, and the other user's signal is considered as an interference [10]. However, the latter is then decoded by taking advantage of the first user's signal, which has already been removed. By the SIC, the users are ranked according to their signal strength, so that the receiver can decode the strongest signal first. Subtract it from the combined signal, and isolate the weakest of the remaining signals. We note that each user is decrypted by the transaction of the other, it is noise in signal reception. The following figure shows how SIC works:



FigureI.3: Diagram showing how the SIC works in receivers between two users [11].

In this example we have two users, UE-1 is the near user, and has higher channel gain, and UE-2 is the far user it has lower channel gain. Therefore, UE-2 signal is decoded first. While the SIC is operated with a lower gain channel (UE-1), where it decodes the data of the other user first and then subtract it from the composite signal thus, it gets his own signal. In uplink NOMA transmission, we suppose that $|h_1|^2 / N_{0,1} > |h_2|^2 / N_{0,2}$. As a result, the BS receiver can detect the received signals in subsequent steps. At the first step, BS receiver detects the component $x_1$directly without employing SIC, and treats component x_2 as noise. Once the receiver correctly decodes component x_1, it reconstructs this signal component and subtracts it from the aggregate received signal y to decode x_2, asexplained in the Figure I.4 bellow .

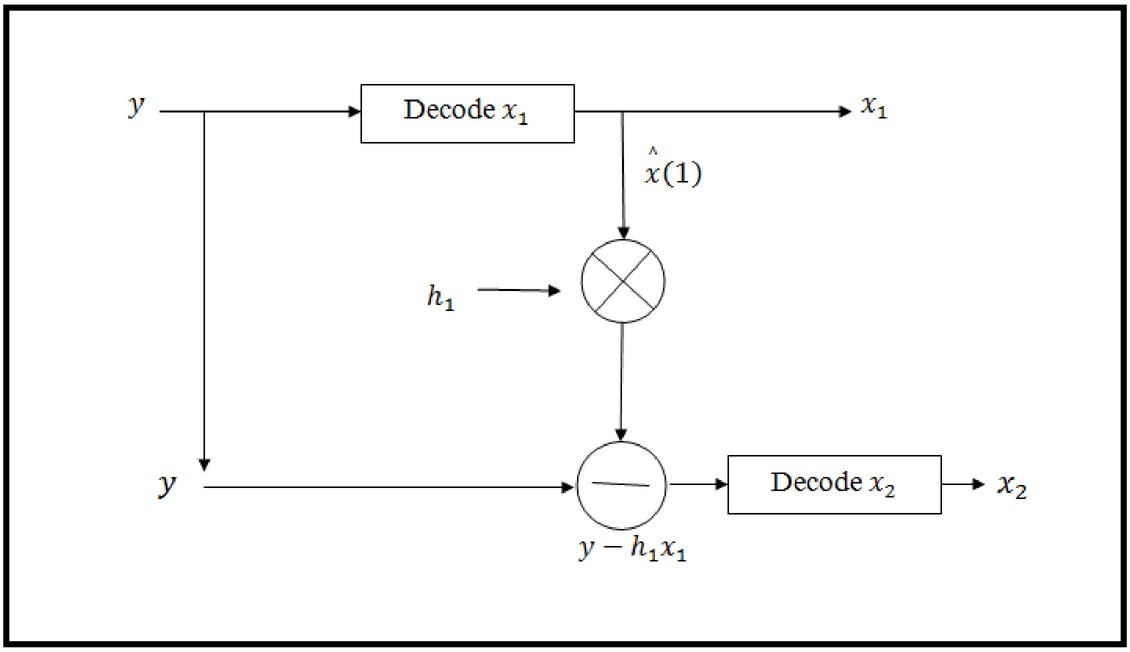


Figure I.4: Illustrating of the SIC process at the reception side of uplink NOMA transmission [12].

I.5. NOMA in downlink

In this section, we will see a downlink NOMA transmission with a single BS and two users with different channel gain. In NOMA scheme, the BS has a transmitter that sends various users signals in a superposition coding signal, this makes the receivers receive their desired signals with the presence of interference caused by the signals of the other user [13], for this, we need to have a SIC in one of the receivers. The Figure I.5 represents a scheme of NOMA in downlink case, we have BS sends signal to two users UE1 (near user) with SIC receiver and UE2 (far user) with a normal receiver. $h_1$is the channel user UE1, $h_2$is the of channel user UE2. We express the composite signal transmitted

$$X = \sqrt{P_1}x_1 + \sqrt{P_2}x_2 \tag{I.2}$$

Firstly, user 2 decodes its signal, and we express it with the following expression:

$$y_2 = \sqrt{P_t} h_2 x_2 + n_2 \tag{I.3}$$

Secondly, the first user uses the SIC to cancel the signal of the second user, we express the obtained signal by the following expression:

$$y_1 = \sqrt{P_t} h_1 x_1 + n_1 \tag{I.4}$$

where n_1, n_2 are the noise of UE1 and UE2.

P_1, P_2 are the transmit power for UE1 and UE2. P_t is the total transmit power. $P_1 + P_2 = 1$, $P_1 > P_2$

The achievable rates of UE1 and UE2 could be represented as follows:

$$R_1 = log_2\left(1 + \frac{P_t P_1 |h_1|^2}{N_{0,1}}\right) \tag{I.5}$$

$$R_2 = log_2\left(1 + \frac{P_t P_2 |h_2|^2}{P_t P_1 |h_1|^2 + N_{0,2}}\right) \tag{I.6}$$

where N_0 is the power spectral density.

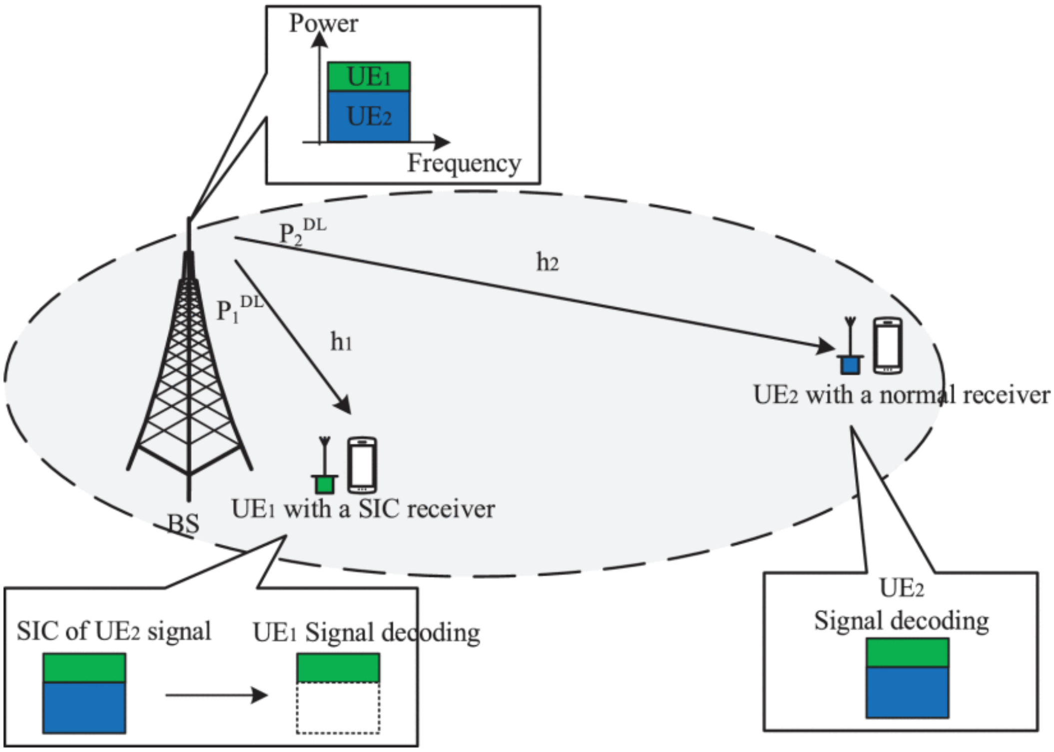


Figure I.5: Downlink NOMA with SIC applied at the receiver of the cell-center user [14].

I.6. NOMA in uplink

In uplink NOMA, signals are transmitted to the BS on the same channel. The transmission is non-orthogonal, and is done independently by each user with its maximum power or controlled transmit power. The role of the SIC and signal decoding is at the base station to distinguish the channel gain of the received signals. BS decodes the signal to the user with the highest channel gain first, as there is a high probability that this signal will be the strongest among the received signals. Then the base station decodes the signal for the next user with higher channel gain, and so on to the last user who has the lowest channel gain between users [3] [15]. For example, we have the Figure I.6 illustrates Uplink NOMA with SIC applied at the receiver of BS. We have two users sent to the base station, their channels are $h_1$for the user UE1 and h_2 for the user UE2, where $h_1 > h_2$. The base station apply SIC, the superposed received signals at BS is represented as:

$$y = \sqrt{P_t P_1} x_1 h_1 + \sqrt{P_t P_2} x_2 h_2 + n_0 \quad \text{(I.7)}$$

where P_1 and P_2 are the transmit power with : $P_1 + P_2 = 1, P_1 > P_2$.

n_0 denotes the AWGN observed at BS with the power spectral density N_0.

The achievable data rates per channel bandwidth in two user system expressed in bits per Hertz are given by the following expressions:

$$R_1 = log_2\left(1 + \frac{P_t P_1 |h_1|^2}{P_t P_2 |h_2|^2 + N_{0,1}}\right) \quad \text{(I.8)}$$

$$R_2 = log_2\left(1 + \frac{P_t P_2 |h_2|^2}{N_{0,2}}\right) \quad \text{(I.9)}$$

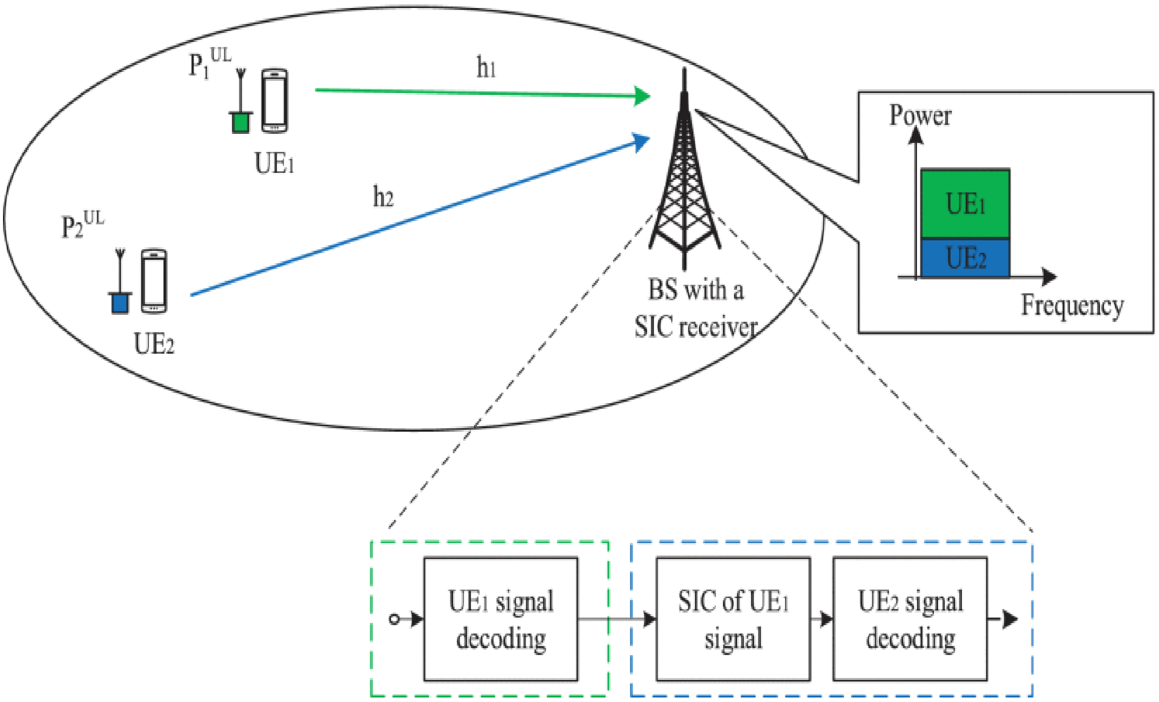


Figure I.6: Uplink NOMA with SIC applied at the receiver of BS [14].

I.7. Comparing NOMA with OMA

In this section, we will compare the difference between NOMA and OMA. In this comparison, we assume that we have one BS that is sent signal to two users in both cases

NOMA and OMA. In OMA, each user takes half bandwidth. Also, each user takes half the resources, but there is no interference between users. In NOMA, the signal is sent to both users using the same resource with the different power for each user, this causes interference to the signals in the reception. In comparing in terms of capacity, according to Shannon's capacity law, in NOMA the data rate of user 1 and user 2 is with Bandwidth W can be achieved by the following expressions:

$$R_1 = \mathrm{W}\, log_2\left(1 + \frac{P_t P_1 |h_1|^2}{N_{0,1}}\right) \quad \text{(I.10)}$$

$$R_2 = \mathrm{W}\, log_2\left(1 + \frac{P_t P_2 |h_2|^2}{P_t P_1 |h_1|^2 + N_{0,2}}\right) \quad \text{(I.11)}$$

In OMA the data rate of user 1 and user 2 is with Bandwidth W can be achieved by the following expressions:

$$R_1 = \frac{W}{2} log_2\left(\frac{P_1 |h_1|^2}{N_{0,1}}\right) \quad \text{(I.12)}$$

$$R_2 = \frac{W}{2} log_2\left(\frac{P_2 |h_2|^2}{N_{0,2}}\right) \quad \text{(I.13)}$$

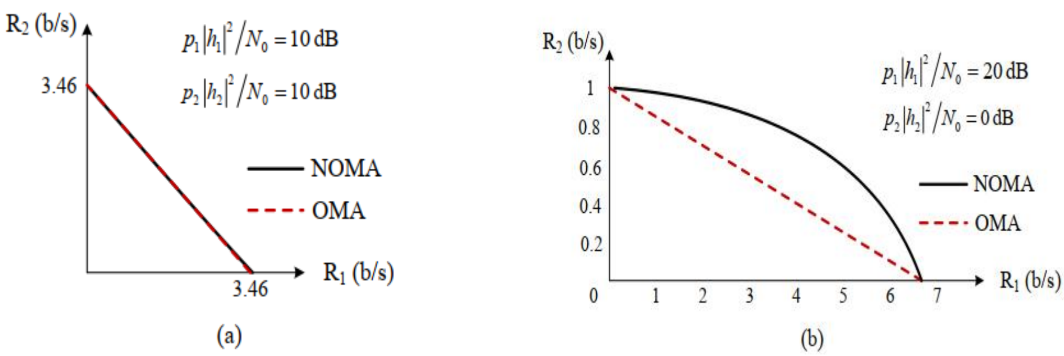


Figure I.7: Channel capacity comparison of OMA and NOMA in the downlink AWGN channel: (a) Symmetric channel; (b) Asymmetric channel [16].

where P_t=$P_1 = P_2$ for OMA users.

The Table I.1belowsummarizes the difference between NOMA and OMA

Specifications	NOMA	OMA
Full Form	Non-Orthogonal Multiple Access	Orthogonal Multiple Access
Receiver complexity	High	Low
Energy consumption	More	Less
Number of users/clusters	Lower	Higher
Number of user pairs	Less	More
System throughput (Assumption: User fairness is guaranteed)	Larger	Smaller

Table I.1: Difference between NOMA and OMA [17].

I.8. Spectral efficiency and energy efficiency

In this section, we analyze the energy efficiency (EE) and Spectral efficiency SE of NOMA systems; we incorporate the static power consumption of the network due to the power amplifiers in addition to the power consumed for the information waveform. The total power consumption at the transmitter can be represented as the sum of the information signal power and the power consumed by the circuits (mainly by power amplifiers). Considering the downlink, the total power consumed by the BS can then be written as

$$P_{total} = P_T + P_{static} \quad \text{(I.14)}$$

where P_T is the total signal power as mentioned earlier and P_{static} is the power consumed bythe circuit. Energy efficiency (EE) is defined as the sum rate over the total consumed power of the base station [18].

$$SE = \frac{R_T}{W} \tag{I.15}$$

$$EE = \frac{R_T}{P_{total}} = SE \frac{W}{P_{total}} \tag{I.16}$$

The energy efficiency and spectral efficiency relationship (EE-SE) in Shannon theory does not consider the power consumption of the circuit and consequently is monotonic where a higher SE always results in a lower EE. When the circuit power is considered, the EE increases in the low SE region and decreases in the high SE region. The peak of the curve (or the corresponding derivative of the EE-SE relationship) is where the system has the maximum energy efficiency. This point is called “green point” [6] [9]. For a fixed P_{total}, the EE-SE relationship is linear with a positive slope of R_T/P_{total} where an increase in SE simultaneously results in an increase in EE [19].

I.9. NOMA advantages

The main advantages offered by NOMA can be summarized in the following points:

- **High spectral efficiency:** Since a system can serve multiple users by using the same block of resources, it has high spectrum efficiency and thus improves system throughput [1].
- **Massive connectivity:** It is expected that NOMA is able to meet all the requirements of users despite their huge numbers [1].
- **Low latency:** Implementation of NOMA technology in communications will give a significant reduction in latency [1].

- **User fairness:** NOMA gives the largest possible fairness to the user by taking into account the status of each user's channel [20].
- **Compatibility:** NOMA is also compatible with current and future communication systems, therefore does not require major modifications to current architecture [20].

I.10. NOMA disadvantages

- In practical conditions during SIC processing, it leaves some residual interference; Successive Interference Cancellation is often incomplete [21].
- The current research working on NOMA assumes an ideal CSI to implement multi-user interlacing in a user's future or resource allocation in a BS. However, perfect CSI is impossible in practical scenarios [21].
- Compared with OMA, in NOMA, the SIC needs additional implementation complexity, because the SIC receiver has to detect and cancel other users' signals before its own signal is detected [21].
- Complexity in calculations, when there are many users, especially in an SNR, they all produce interference in each other's signals.
- Each of the users within the cluster need to decode information of all the other users even one having worst channel gains. This leads to complexity in the receiver. Moreover, energy consumption is higher [22].

I.11. Applications

Visible light communication: Similar performance gains if NOMA is implemented in VLC. As the channel generally does not change most of the time, the decoding becomes simpler [23].

Internet of things: The scenario in IoT is massive connectivity. Exploitation of non-Orthogonal resources as a means to enhance connectivity is subject to research [23] .

Device-to-device:D2D communications with non-orthogonal multiple access (NOMA) have been proved in enhancing the network capacity and reducing the burden of the traditional cellular network [24].

Wireless sensor networks: WSNs with NOMA can support higher data rate to the sink node, reduce the power consumption of sensor nodes and prolong the lifetime of the networks [25].

I.12. Conclusion

In this chapter, we have seen the concept of NOMA has been first illustrated NOMA in downlink and uplink by using a simple scenario with one BS and two users. Also, both SC and SIC, and we're comparing NOMA with OMA, and we have introduced some applications. From this chapter we can conclude that NOMA can serve more users in the same resources. Thus, NOMA can increase number of users and higher data rate. NOMA causes inter-user interference but can enhance the system capacity compared to OMA. In this regard, NOMA is proposed with various technologies such as cooperative communication to increase the system capacity and enhance energy efficiency. Therefore, in the following chapter, we study the cooperative NOMA.

Chapter II

Cooperative

NOMA

II.1.Introduction

Cooperative transmission is one of the most effective ways to mitigate the fading effect of wireless channels in a network. Currently, cooperative transmission is receiving great attention in wireless communication due to its ability to improve system performance and expand coverage [26]. Therefore, cooperative communication is integrated with NOMA to improve the NOMA's system performance. Cooperative NOMA transmission depends on relays/users/nodes, which work to help the users to receive their signals. There are two scenarios of cooperative NOMA: The first scenario is cooperative NOMA without a direct link, when the users receive their signals assisted only by the relay/users/nodes because the direct link with the users is not available due to long distance or obstacles. The second scenario is cooperative NOMA with a direct link, when the users receive their signal with direct and relay links. The most two cooperative relay techniques are used: Amplify and forward (AF) and decode and forward (DF). In this chapter, we define cooperative NOMA. Then, we introduce the cooperative NOMA techniques AF and DF. Then, we study a cooperative NOMA with direct links. Finally, we present the advantages of cooperative NOMA.

II.2.Definition of cooperative NOMA

As we have seen in the previous chapter, the NOMA network can serve multiple users at the same time and increase the system's capacity. Recently, several technologies have been suggested to improve the performance of NOMA such as cooperative communications. To increase the system capacity of NOMA and expand the coverage area, NOMA has been adopted with cooperative communications. The basic idea of cooperative communications is to help the far users to receive their signals if the connection between the BS and users does not exist, or to improve the performance of the far user when the direct and relay links exist at the user. Thus, two schemes are available for cooperative NOMA, cooperative assisted fixed relay and cooperative assisted user. We introduce each one in the following subsections [27]:

II.2.1. Cooperative NOMA assisted relay (or fixed relay)

Cooperative NOMA assisted relay it's based on a fixed relay as we shown in Figure II.1. In this type of network, the information is sent from the BS to the users through two phases, in the first phase, the BS transmits the SC signal to relay. The relay decodes the received signal and re-encodes it and forwards it to the users in the second phase [28-29].

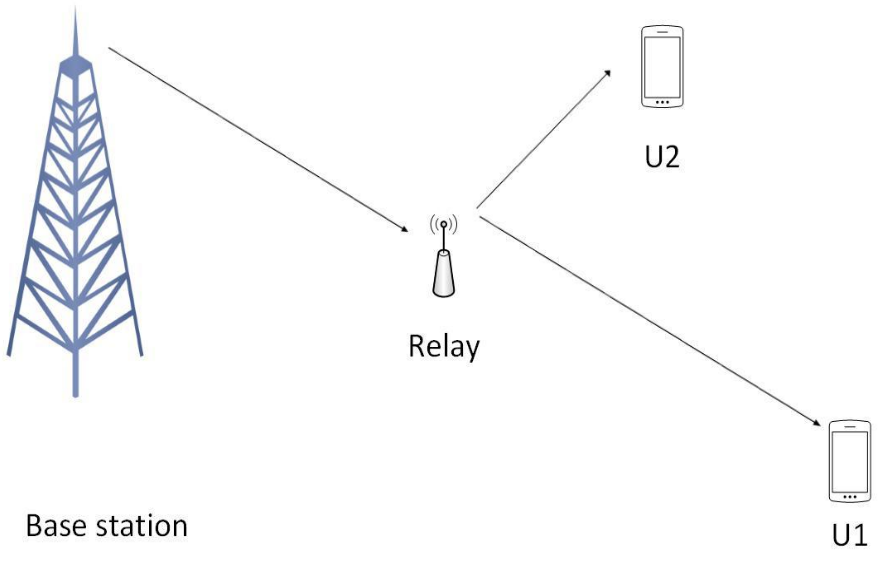


Figure II.1: Scheme Relay Cooperative.

II.2.2.Cooperative NOMA assisted use

In cooperative NOMA assisted user-relay when the near user works as an assistance user to help the far user when it can't receive the BS signal directly as presented in Figure II.2. The near user in NOMA receives two signals at the same time in NOMA i.e., its own signal and the far user signal. Thereafter, the near user decodes the received signal and separation its own signal and far user signal, then the near user (i.e., user-relay) re-encodes the far user signal and forwards it to the far user [30-31].

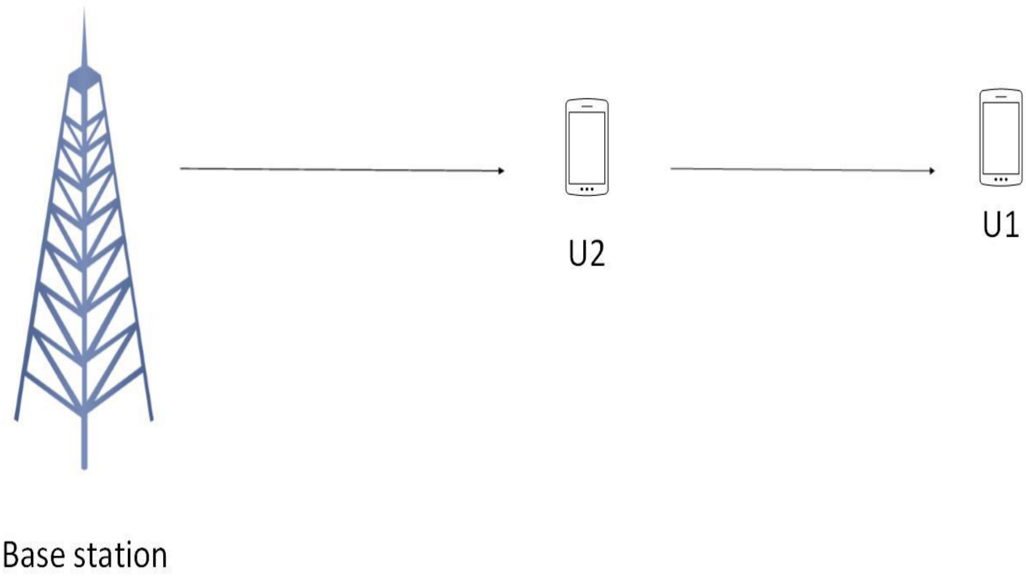


Figure II.2: Scheme User Cooperative.

II.3. Cooperative techniques

II.3.1. Amplify-and-forward (AF)

In the AF protocol, the BS transmits an SC signal to the relay and the relay amplifies the received signal without decoding to the users [32], [33]

We consider a downlink cooperative NOMA scheme that contains one base station BS, a single relay (R) and two users near user UE-2 and far user UE-1, as we see in Figure II.3. We assume that the relay works in the AF protocol. The wireless channel h,g_1 and g_2 following distribution channel fading of link BS-R, R-UE-1 and R-UE-2,respectively, this system is shown in figure II.3 below:

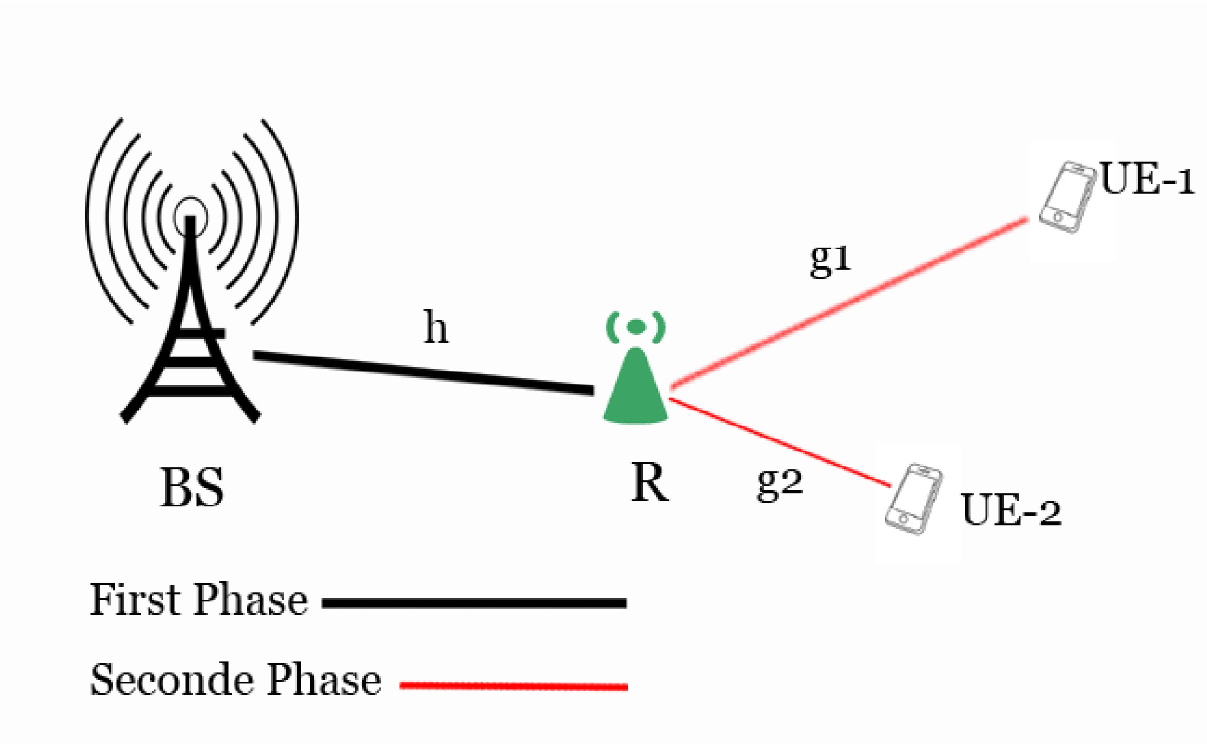


Figure II.3: Diagram illustrating a collaborative NOMA system.

In our system assume the BS in first time slot sends an SC signal to the R, the signal received at R it called y_R it can give as

$$y_R = h\left(\sqrt{a_1 P x_1} + \sqrt{a_2 P x_2}\right) + n_r \qquad \text{(II.1)}$$

where n_r are additive white Gaussian noise terms with variance σ^2andx_1 ,x_2 are the signals for UE-1, UE-2, respectively. We assumed that$\{x_1^2\} = E[x_2^2] = 1$. $a_1$and $a_2$are power allocation factors. To ensure fairness with the highest possible opportunity among users, we assume that $a_1 > a_2$, and $a_1 + a_2 = 1$.

The coefficient of amplification (the gain) β in AF protocol given by:

$$\beta = \frac{1}{\sqrt{P|h|^2 + \sigma^2}} \tag{II.2}$$

In the second time slot: the relay resends the signal y_R after amplifier it to users, we can write the received signal at user UE-1 by

$$y_{U1} = \beta\sqrt{P}g_1\left[h\left(\sqrt{a_1 P x_1} + \sqrt{a_2 P x_2}\right) + n_r\right] + n_{u1} \tag{II.3}$$

and we write the signal received at user UE-2 as:

$$y_{U2} = \beta\sqrt{P}g_2 h\left(\sqrt{a_1 P x_1} + \sqrt{a_2 P x_2}\right) + \beta\sqrt{P}g_2 n_r + n_{u2} \tag{II.4}$$

where n_{u1},$n_{u2}$are additive white Gaussian noise terms with variance σ^2.

In order to evaluate the performance of this system, we consider that the received signal interferes with the noise ratio (SINR) of UE-1 to detect x_1 is given by:

$$\gamma_{AF,1} = \frac{a_1\rho^2\beta^2|h|^2|g_1|^2}{\rho^2\beta^2|h|^2|g_1|^2 a_2 + \beta^2\rho|g_1|^2 + 1} \tag{II.5}$$

We denote the signal-to-noise ratio at the base station as $\rho = \frac{P}{\sigma^2}$, in UE-2 the SIC is implemented and the received SINR at UE-2 to detect $x_1$can be written by:

$$\gamma_{AF,2,x_1} = \frac{a_1\beta^2\rho^2|h|^2|g_2|^2}{\rho^2\beta^2|h|^2|g_2|^2 a_2 + \beta^2\rho|g_1|^2 + 1} \tag{II.6}$$

The received SINR at UE-2 to detect its own information is given by:

$$\gamma_{AF,2,x_2} = \frac{a_2\beta^2\rho^2|h|^2|g_2|^2}{\beta^2\rho|g_2|^2 + 1} \tag{II.7}$$

The Capacity of at UE-1 and at UE-2 can written by:

$$C_{AF,1} = \frac{1}{2}Log_2\left(1 + \gamma_{AF,1}\right) \tag{II.8}$$

$$C_{AF,2} = \frac{1}{2}Log_2\left(1 + \gamma_{AF,2,x_2}\right) \tag{II.9}$$

II.3.2. Decode-and-forward (DF)

In the DF protocol, the relay decodes the received signal from the BS. then, the relay re-encodes this signal to re-transmit it to users [32, 33]. In this scheme, we assume that we have two users, BS and relay as presented in Fig II.3. We assume that the relay works in DF protocol. We suppose that the communication between the BS and users does not exist, so the relay helps the users to receive their signals.

In the first phase, the BS transmits an SC signal to the relay. The relay decodes the far user signal then using the SIC decodes the near user signal. The signal at the relay can be given as:

$$y_R = h(x_1\sqrt{a_1 P} + x_2\sqrt{a_2 P}) + n_r \tag{II.11}$$

where $x_1,\ x_2$ are information of UE-1 and UE-2, respectively, $P$is the power of the BS, a_1, a_2 are power allocation coefficients of UE-1 and UE-2, respectively, where $a_1 > a_2$, and $n_r$is the noise at the relay.

Thus, the SINRs to detect $x_1$and x_2 at the relay node are written as [34]

$$\gamma_R^1 = \frac{a_1 P|h|^2}{a_2 P|h|^2 \sigma_r^2} \tag{II.12}$$

$$\gamma_R^2 = \frac{a_2 P|h|^2}{\sigma_r^2} \tag{II.13}$$

In the second time slot, the relay re-encodes signal decoding in the first phase and forwards it to the users. The far user decodes its own signal directly and the near user uses the SIC to decode its own signal.

The received signal at the users is given by

$$y_2 = g_2\left(x_1\sqrt{\alpha_1 P_r} + x_2\sqrt{\alpha_2 P_r}\right) + n_2 \tag{II.15}$$

$$y_1 = g_1\left(x_1\sqrt{\alpha_1 P_r} + x_2\sqrt{\alpha_2 P_r}\right) + n_1 \tag{II.16}$$

where $P_r$is the power total of relay. $g_1,\ g_2$ are the channel betwen relay and users and n_1, n_2 the noises at users, respectively.

UE-1 decode its signal directly without a SIC, so the SINR at UE-1 is given by:

$$\gamma_{DF,1} = \frac{\alpha_1 P_r |g_1|^2}{\alpha_2 P_r |g_1|^2 + \sigma_1^2} \tag{II.17}$$

The UE-2 decode UE-1 signal, then using the SIC decode its own signal [34]. The SINRs at UE-2 can be written as:

$$\gamma_{DF,2}^{2} = \frac{\alpha_1 P_r |g_2|^2}{\alpha_2 P_r |g_2|^2 + \sigma_2^2} \tag{II.18}$$

$$\gamma_{DF,2}^{1} = \frac{\alpha_2 P_r |g_2|^2}{\sigma_2^2} \tag{II.19}$$

We can write the Capacity of users as:

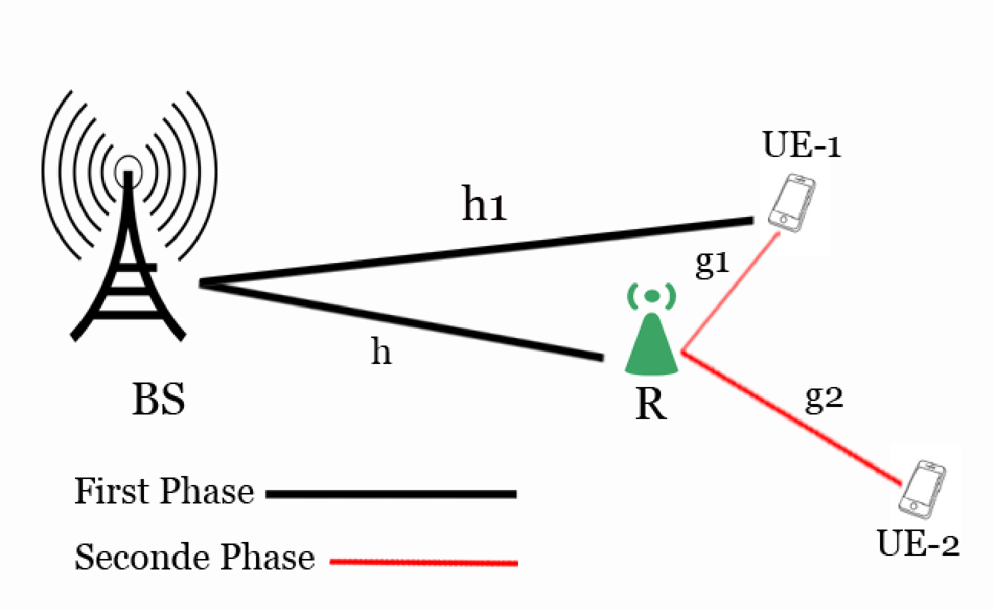
$$C_{DF,1} = \frac{1}{2} Log_2\left(1 + \gamma_{DF,1}\right) \tag{II.20}$$

$$C_{DF,2} = \frac{1}{2} Log_2\left(1 + \gamma_{DF,2}^{1}\right) \tag{II.21}$$

II.4. Cooperative NOMA Scenarios

In cooperative NOMA there are two scenarios, 1) cooperative NOMA without direct links and 2) cooperative NOMA with direct links.

1) Cooperative NOMA without direct links: In this scenario, the users can not hear the BS signal due to long distances or obstacles. In this case, the users receive their signal only with help of the relay node as presented in Figure II. 1 and Figure II. 2.
2) Cooperative NOMA with direct links: In this scenario, the users can hear the BS signal. Also, the users receive their signal with help of the relay. The users receive two signals from different sources as presented in Figure II.4. Thus, the users implement the diversity combining to receive signal at the users.



FigureII.4: Possible scenarios for cooperative NOMA, User 1 with a direct link, User 2 without a direct link.

II.4.1. Diversity combining techniques

II.4.1. Selection Combining

This technique is usually used in spatial diversity systems, it based on sampling of antenna signals, and then send the signal with the highest SNR value to the demodulator [35]. The system calculates the instantaneous SNR at each moment of the communication period we can write this SNR as:

$$\gamma_i = \frac{E}{N_0} |h_i|^2 \qquad \text{(II.22)}$$

Where:

h_i is the channel (complex) gain .

E is the energy.

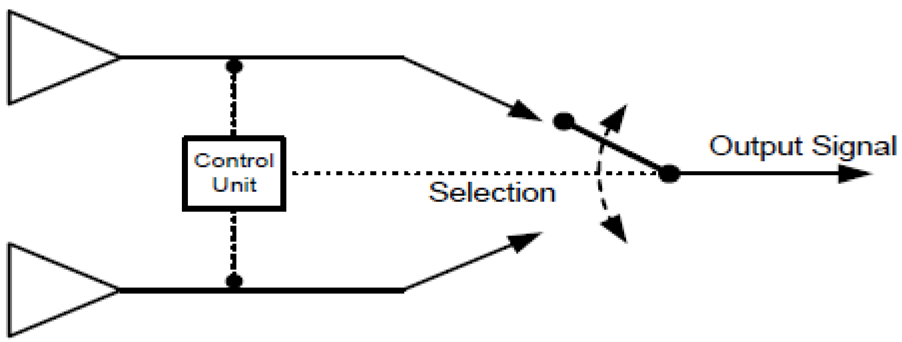
N_0 is the noise spectral power density.

The SNR total of SC technique were write as:

$$\gamma_{SC} = max\, \gamma_k \qquad \text{(II.23)}$$

Where k=1,…….,N. the number of antennas in the network .

The system will weigh the signal with the highest SNR and will also cancel the rest of the signals. the FigureII.5 below represents a simplified form of a system Selection Combining



FigureII.5: Selection Combining [36].

The output SNR (at the combiner output) is the maximum SNR of all the received signals.

Selection Combining is relatively easy to implement .But it is not an optimal system because it does not take advantage of all the received signals simultaneously. Therefore, several other diversity combining techniques have been proposed for study .

II.4.2. Equal-Gain Combining (EGC)

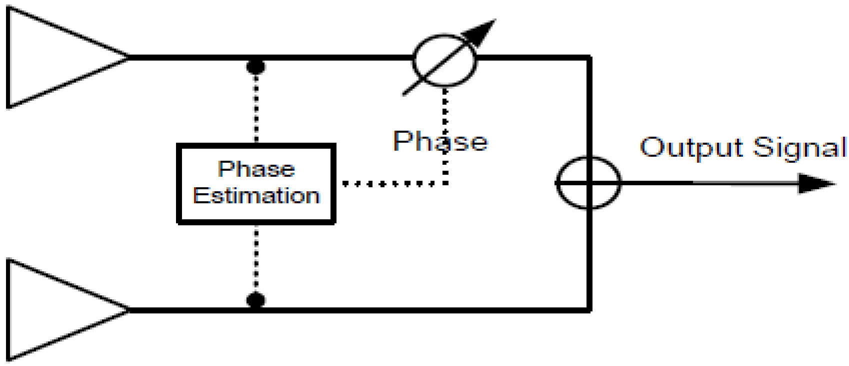
One technology that is often considered is the equal gain combining (EGC), where each signal received in an antenna is multiplied by a complex weight factor [37], all the diversity branches are coherently added with a same weighting factor [38], that is compensated from the rotational phase of each channel. We can write the complex weighting factor equation as follows:

$$a_k = \boldsymbol{e}^{-j\phi k} \quad \text{for } k = 1,2, \dots, N_r \tag{II.24}$$

The resulting SNR at the output of the equal-gain combiner can be given by:

$$\gamma_{EGC} = \frac{P\left(\sum_{k=1}^{N_r} |h_k|\right)^2}{\sum_{k=1}^{N_r} \sigma_k^2} \tag{II.25}$$

The figure.II.6 below explains how equal gain combining works, in this technique all signals are collected information received in the receiver, Then the signal amount is revealed to get estimates data sent, this technique despite its complexity, it is better than selection combining and marginally inferior to maximal ratio combining.



FigureII.6: Equal Gain Combining [36].

II.4.3. Maximum ratio combining (MRC)

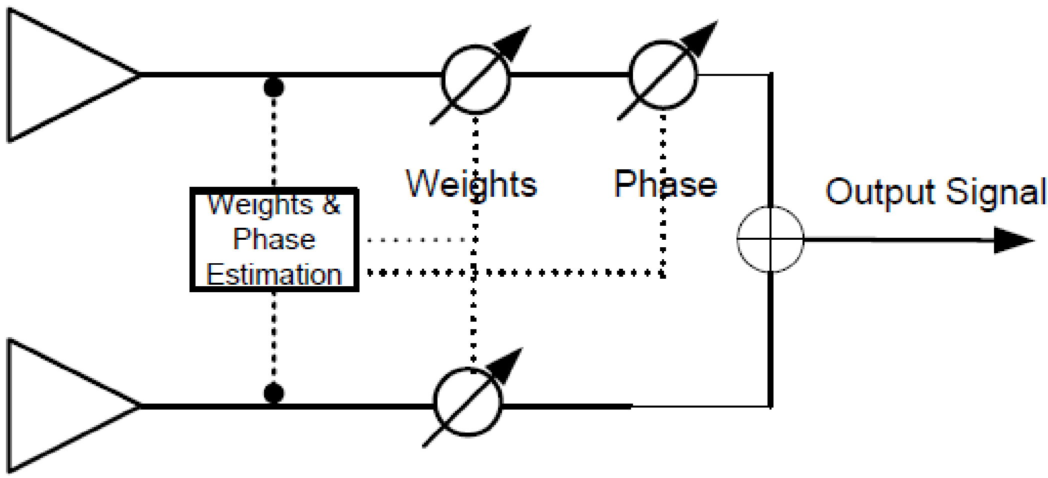
In this technique, the signals from all of the branches are weighted according to their individual SNRs, then they are summed up individually and then combined [39]. We can consider the MRC technique as the best combination technique, this is because all received signals are processed at the same time, moreover, each signal is multiplied by the parameter is associated with each channel's signal [36]. so that better fading reduction improves overall system performance, unlike EGC and SC using channel status information (CSI) to determine the weighting factor so that depending on the state of the channel may not always give us a good idea of the ideal weighting factor [37]. Therefore, the combination of maximum ratio (MRC) seeks to overcome this problem. Therefore, the combination of maximum ratio (MRC) seeks to overcome this problem where the weighting factors of the maximal-ratio combiner given by:

$$a_k = \frac{h_k^*}{\sigma_k^2} = \frac{|h_1|e - j\Phi k}{\sigma_k^2} \text{ for } k = 1, \dots, N_r \quad \text{(II.26)}$$

the SNR of MRC is summarized as follows :

$$\gamma_{MRC} = \sum_{k=1}^{N_r} \gamma_k \quad \text{(II.27)}$$

The igure.II.7 explains the mechanism of processing the received signals in the receiver, where, in the first stage, each signal is multiplied by the channel gain, then each result is multiplied by a weighting coefficient depending on the signal, its strength and its SNR this is in the second stage. In the third stage the results of all previous operations is combined to get the final result in the output.



FigureII.7: Maximum ratio combining [36].

Advantages of Maximal ratio combiner technique

- Maximal ratio combiner generates an acceptable SNR value.
- Accuracy is high.
- Produces the best reduction of fading

II.5. Advantages of cooperative NOMA

- NOMA's cooperative advantage is that we have created two links to transmit the same message. Even if one of the links is broken, the other one is probably fine [40].
- Relay can be an effective solution to expand the coverage area of the base station [40].
- Reduce outage probability and hence diversity gain without the need of additional antennas [40].
- Cooperative NOMA can achieve effective reuse of frequency, time, space, etc. resources in the wireless communication system, and greatly enhance the anti-fading performance [41].

- Cooperative communication allows radio stations to adapt seamlessly with channel and interference conditions [42].

II.6. Conclusion

In this chapter, we have given an overview of the NOMA cooperative based on relay. We first provided the fundamental structure for the Cooperative NOMA network, and we got to know the types of relays in terms of their role. Then we treated the most popular transmission protocols AF and DF. We also introduce diversity techniques of cooperative communications. Finally, we give some the advantages of the cooperative NOMA.

Chapter III

Simulation of Cooperative NOMA with Direct Links

III.1. Introduction

Through previous chapter, the advantage of cooperative communication is to extend the communication coverage area, improves the quality of service (QoS), and increases spectral efficiency. NOMA is integrated with cooperative communication to enhance network coverage, reliability, and transmission [43-45]. Also, based on the previous works, the DF outperformers AF protocol. In this chapter, we assume that the users can receive their signal from different sources (i.e., BS and relay), where the relay node works in DF protocol. We evaluate the bit error rate (BER) and outage probability and capacity of the system through simulation results.

III.2. System model

We consider a downlink of a cooperative NOMA system consisting of a base station (BS), a relay (R), and two users 1 (U1) and user 2 (U2). User 2 is far away and User 1 is close to the BS. We suppose that the relay node works in DF protocol and half duplex mode. Moreover, we assume that the users can receive the signal from the BS and from the relay node as presented in Figure 1. The system is working over the Rayleigh fading channel.

In the first phase, the BS transmits a superimposed coding (SC) signal with a different distribution of power parameters depending on the channel quality of each user. The users and relay receive a signal sent by the BS. The U1 detect its message x_1 directly. U2 and R detect x_1 firstly then subtract it from the total received signal to detect x_2.

The received signal at users and R is given by

$$y_i = \sqrt{P_S}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2)h_i + n \quad \text{, where i=1,2} \tag{III.1}$$

$$y_r = \sqrt{P_S}\left(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2\right)h_r + n \tag{III.2}$$

where $\alpha_1 + \alpha_2 = 1$. α_1 and α_2 are the power allocation coefficients of U1 and U2, respectively. $x_1$and x_2 are the messages of the U1 and U2, respectively. P_S is the BS transmit power. $n \sim CN(0, \sigma^2)$ is the AWGN.h_r and h_i are the Rayleigh fading channel between BS-R and BS-users, where$h_r \sim CN(0, \sigma_r^2), h_i \sim CN(0, \sigma_i^2)$,i=$\{1, 2\}$. $\sigma_r^2 = {d_r}^{-\alpha}$, and $\sigma_i^2 = {d_i}^{-\alpha}$ where d_r and d_i denote the distances between the BS-R and BS-users, respectively and α is the path loss exponent.

The SINR at relay is given by:

$$\sigma^2\gamma_R^1 = \frac{a_1 P_s|h_r|^2}{a_2 P_s|h_r|^2 + \sigma^2} \quad \text{(III.3)}$$

$$\gamma_R^2 = \frac{a_2 P_S|h_r|^2}{\sigma^2} \quad \text{(III.4)}$$

The SINR at U1 is given by:

$$\gamma_1 = \frac{a_1 P_S|h_1|^2}{a_2 P_S|h_1|^2 + \sigma^2} \quad \text{(III.5)}$$

The SINR at U2 is given by:

$$\gamma_2^1 = \frac{a_1 P_S|h_2|^2}{a_2 P_S|h_2|^2 + \sigma^2} \quad \text{(III.6)}$$

$$\gamma_2^2 = \frac{a_2 P_S|h_2|^2}{\sigma^2} \quad \text{(III.7)}$$

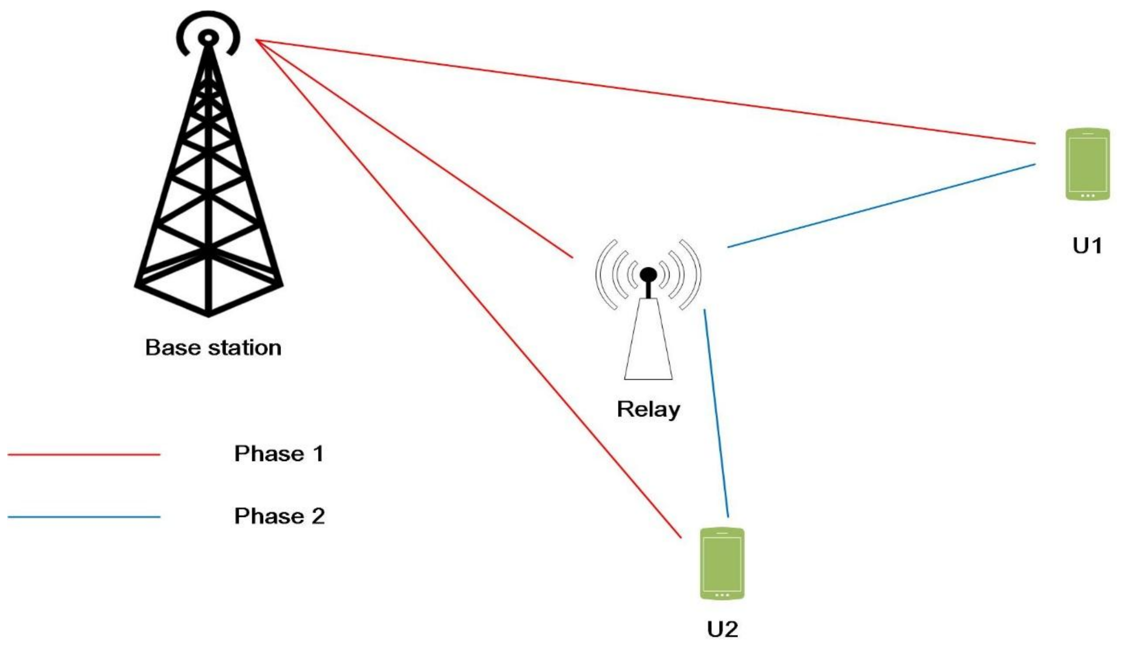


Figure III.1: Cooperative NOMA with direct links.

Based on the messages detected in the first phase, the relay implements an SC signal again and forwards it to users.
The received signal at users in the second phase is given by

$$y_{ri} = \sqrt{P_r}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2)h_{ri} + n \quad , \text{where } i = 1, 2 \tag{III.8}$$

Where P_r is the relay transmit power. h_{ri}isthe Rayleigh fading channel between R-users, where $h_{ri} \sim CN(0, \sigma_{ri}^2)$, i={1, 2}. $\sigma_{ri}^2 = {d_{ri}}^{-\alpha}$ where d_{ri} denote the distance between the R-users. The users receive two signals from different sources i.e., BS and relay. We assume that the users use MRC to improve their received signal. After MRC, the U1 detects its signal without SIC while U2 uses the SIC to detect its signal.
The SINR at U1 in the second phase is given by:

$$\gamma_{r1} = \frac{a_1 P_r |h_{r1}|^2}{a_2 P_r |h_{r1}|^2 + \sigma^2} \tag{III.9}$$

The SINR at U2 in the second phase is given by:

$$\gamma_{r2}^1 = \frac{a_1 P_r |h_{r2}|^2}{a_2 P_r |h_{r2}|^2 + \sigma^2} \tag{III.10}$$

$$\gamma_{r2}^2 = \frac{a_2 P_r |h_{r2}|^2}{\sigma^2} \tag{III.11}$$

III.3. Simulation and Results

In this section, we simulate the BER, outage probability and capacity of a cooperative NOMA system with a direct links.

III.3.1. Simulation parameters

In the simulations, we use the following parameters:

Parameters	**Values**
Distance between BS andU1	5 m

Distance between BS andU 2	3 m
Distance between BS andrelay	1 m
Distance between relayandU1	4 m
Distance between relayand U2	2 m
Path loss	4
SNR [dB]	0:5:40
Power allocation coeffiecent of U1	α_1=0.2
Power allocation coeffiecent of U2	α_2=0.8
Transmission rate	R = 0.1 bps/Hz
channel	Rayleigh

Table III.1: Simulation parameters.

III.3.2. Capacity of system

In this subsection, we perform the simulation capacity of cooperative NOMA with a direct links. We compare the capacity of a direct links and cooperative NOMA with the direct links.

The capacity of U1 and U2 in the first phase is given by

$$C_{U1} = log2(1 + \gamma_1) \quad \text{(III.12)}$$

$$C_{U2} = log2(1 + \gamma_2^2) \tag{III.13}$$

The capacity of U1 and U2 of MRC is given by

$$C_{U1,MRC} = \frac{1}{2} log2(1 + \gamma_{r1} + \gamma_1) \tag{III.14}$$

$$C_{U1,MRC} = \frac{1}{2} log2(1 + \gamma_{r2}^2 + \gamma_2^2) \tag{III.15}$$

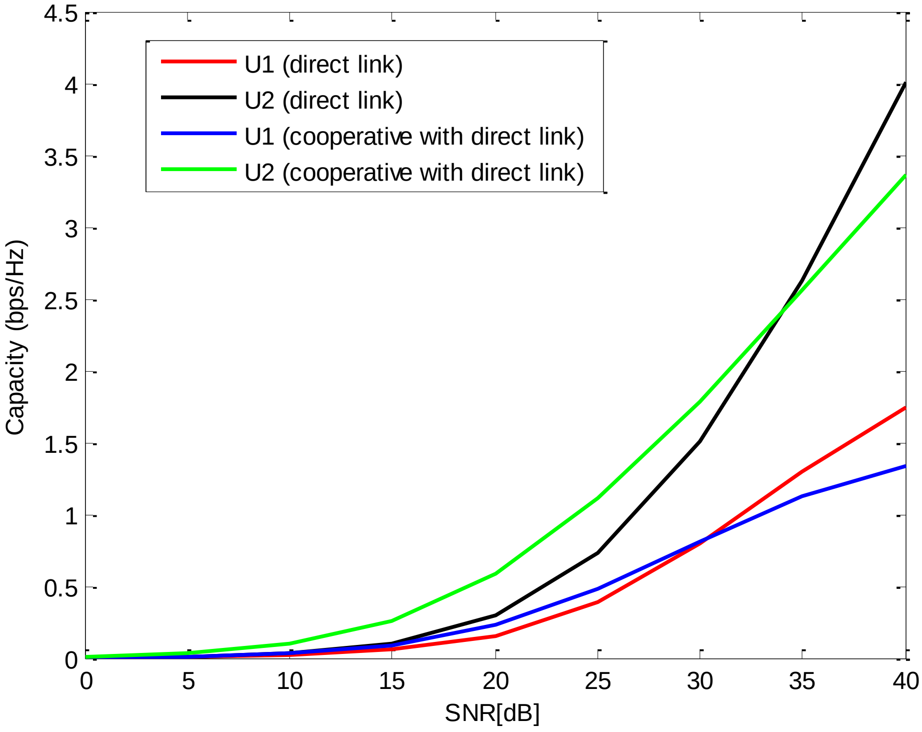


Figure III.2: Capacity of U1 and U2 of direct links and cooperative NOMA with direct links.

Figure III.2 presents the capacity of the two users of the direct links and the cooperative with the direct links. It is noted that the capacity of U2 is superior to U1 in the direct links and cooperative with the direct links. Also, the cooperative NOMA with a direct links improves the performance of the two users. We also notice that the capacity of users in the direct links is superior in the higher SNR it is due to the distance between each node.

III.3.3. Outage probability

In this subsection, we perform the simulation outage probability of cooperative NOMA with a direct links. We compare the outage probability of a direct links and cooperative NOMA with the direct links.

The outage probability of x_1 is defined as the capacity C_{U1}) of U1 is less than the rate R, i.e.,

$$P_{out,U1} = (C_{U1} < R) \tag{III.16}$$

The outage probability of x_2 is defined as the sum of: When x_1 is detected erroneously and correctly. Thus, the outage probability of x_2 at U2 in the first phase can be expressed by

$$P_{out,U2} = (C_{U2} < R) \tag{III.17}$$

When the MRC is implemented at U1, the outage probability of x_1 is defined as the capacity ($P_{out,U1,MRC}$) of U1 at output MRC is less than the rate R, i.e.,

$$P_{out,U1,MRC} = (C_{U1,\mathrm{MRC}} < R) \tag{III.18}$$

When the MRC is implemented at U2, the outage probability of x_2 is defined as the sum of: When x_1 is detected erroneously and correctly at output MRC. Thus, the outage probability of x_2 at U2 at output MRC can be expressed by

$$P_{out,U1,MRC} = (C_{U2,\mathrm{MRC}} < R) \tag{III.19}$$

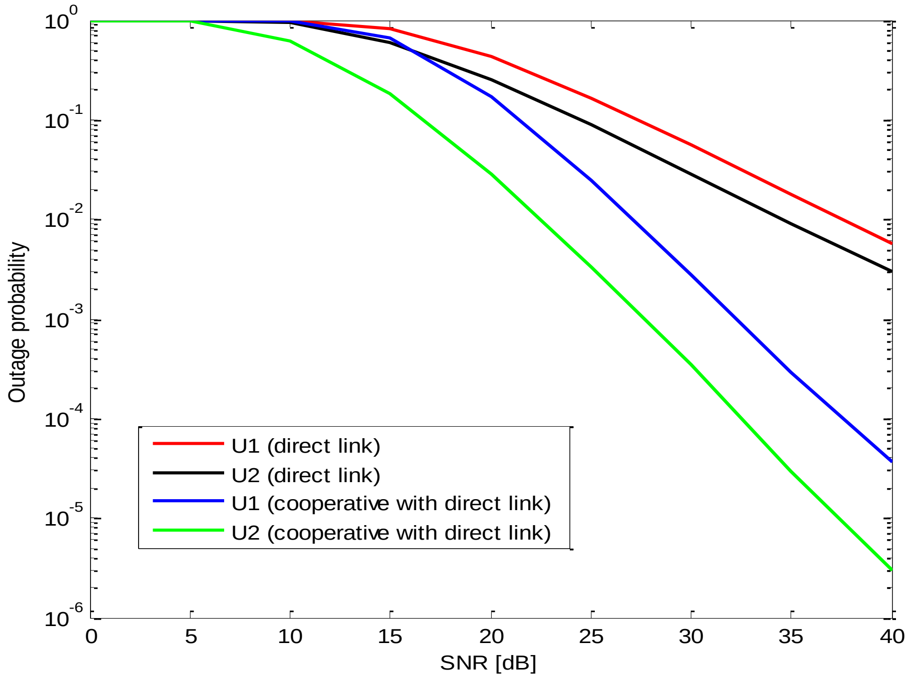


Figure III.3: Outage probability of U1 and U2 of direct links and cooperative NOMA with direct links.

Figure III.3 presents the outage probability of the two users of the direct links and the cooperative with the direct links. It is observed that the U2 achieves an outage probability better than U1 in the direct links and cooperative with the direct links. Also, the cooperative NOMA with a direct links decreased the outage probability performance of the two users.

Figure III.4 presents the outage probability versus different target rates (R) for the two users of the direct links and the cooperative with the direct links when the SNR=30dB. It is observed that the outage probability deteriorates with an increase in R. Again, the cooperative NOMA with a direct links achieves better performance for the two users in all values of R.

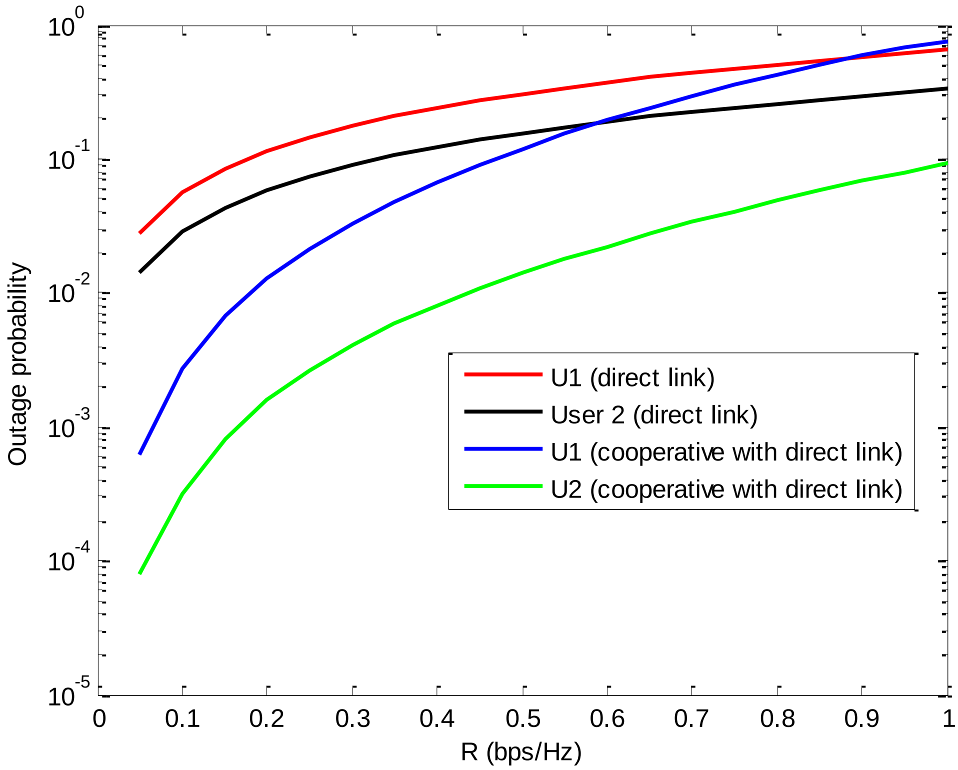


Figure III.4: Outage probability versus target rate (R) of U1 and U2 of direct links and cooperative NOMA with direct links.

III.3.4. BER

Figure III.5 presents the BER of the two users of the direct links and the cooperative with the direct links. It is observed that the U2 has better BER than U1 in the direct link and cooperative with the direct links. Furthermore, the BER performance of the cooperative NOMA with a direct links decreases the error performance of the two users.

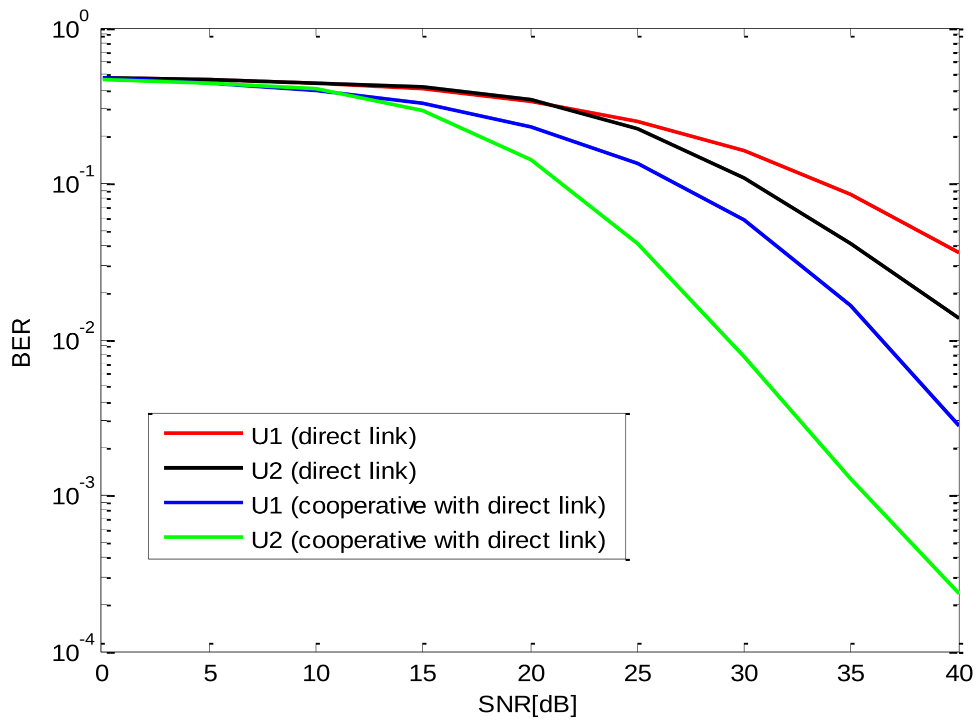


Figure III.5: BER of U1 and U2 of direct links and cooperative NOMA with direct links.

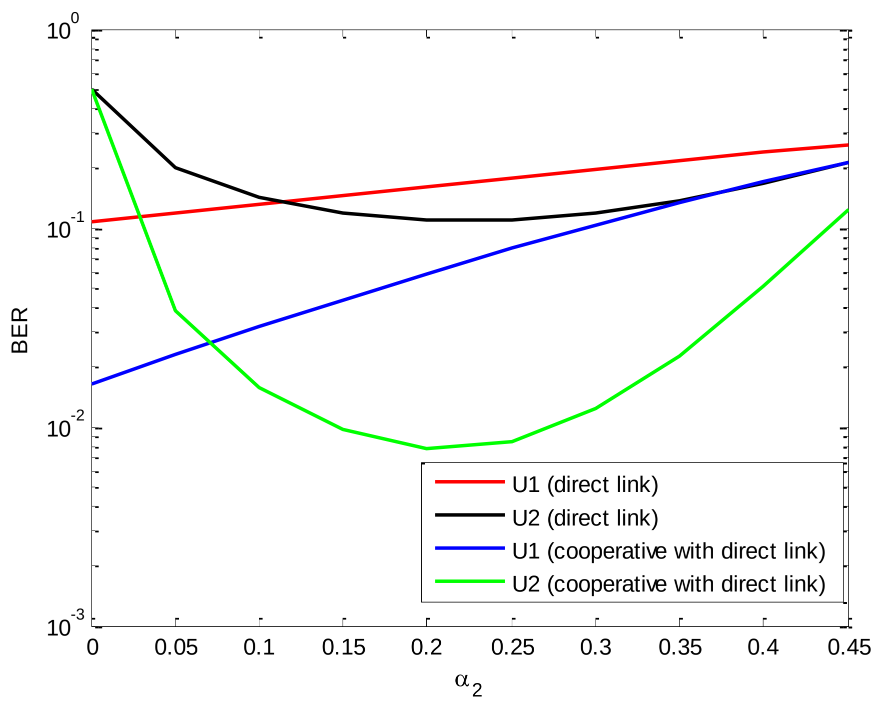


Figure III.6: BER versus power allocation (α_2) of U1 and U2 of direct link and cooperative NOMA with direct link.

Figure III.6 presents the BER versus $\alpha_2$of the two users of the direct links and the cooperative with the direct links. It can be seen that U2 has better BER than U1 in the direct links and cooperative with the direct links in all $\alpha_2$values. Also, the change of α_2 affects the performance of each user at the expense of the other. Thus, to achieve better performance $\alpha_2$should be between [0.1:0.25].

III.4. Conclusion

In this chapter, we simulate the cooperative NOMA with a direct links. We compare between direct links and cooperative NOMA with a direct link. The simulation results show that the BER, outage probability and capacity of cooperative NOMA achieve better performance than a direct links. Also, the increase in the target rate deteriorates the outage probability of the system. Moreover, the change in the power allocation coefficient affects the performance of each user at the expense of the other.

General Conclusion

General Conclusion

Recently, the study of access technologies has become one of the most important studies conducted in the field of communications, especially NOMA technology, which is considered a promising solution for the beyond of the fifth generation. The basic concept of NOMA is serving several users at the same time with different power allocation coefficients, using the same resource for all users. Thus, NOMA has a more effective and efficient system than OMA. NOMA needs two important techniques to work SC in emission and SIC in reception, herein lies NOMA's weak point, as it practically SIC cannot be always perfect, in some cases it is not possible to completely remove the interference.

Cooperation NOMA is a technology that combines regular NOMA networks and cooperative communications networks. Cooperative communication is based on the relays or assistance users. Also, there are several protocols of cooperative, the most famous of which are AF and DF. In the AF the coming signal to the relay is amplified and forwarded to the users without decoding at the relay while in the DF the received signal is decoded and re-encoded and forwarded to the users. The purpose of adopting this system is to increase the effectiveness of the communication network, in order to meet all the requirements of users, it also expands the coverage area.

In this thesis, we simulated a cooperative NOMA system with direct links to improve the NOMA system, which is containing one BS, one relay and two users. We simulate the outage probability, capacity and BER of our considered system. The simulation results indicate that the cooperative NOMA with the direct links increase the performance of the two users compared to NOMA in terms of capacity and it decreased the outage probability performance of the two users. In terms of the BER, we observe that the near user is better than the far user. We also noticed that the BER of the cooperative NOMA with the direct links improves more than the case of the direct links alone. Finally, we can conclude that the performance of cooperative NOMA with direct links is higher than that of non-cooperative NOMA networks.

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