Cooperative Relaying System

employing OFDM based NOMA System

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Moe Ma Ma Myo

(5118FG41-4)

Advisor: Prof. Shigeru Shimamoto

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Contents

List of Figures

List of Tables

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ABSTRACT

Non-Orthogonal Multiple Access (NOMA) becomes a promising candidate for future 5G due to its superior performances over orthogonal frequency division multiple access (OFDMA). Cooperative relaying system (CRS) is also defined as one technology that absolutely guarantees the enhancement of transmission rate of cell edge user and coverage extension. The technology combination of the NOMA and cooperative relay system has been considered as a promising architecture for the future wireless communication system. In the conventional NOMA, when users are growing within the same subcarrier, each user suffers more interference and achievable data rate loss. Therefore, we proposed the OFDM based NOMA cooperative relay system (CRS-NOMA) to improve the achievable rate of CRS. In the system implementation, the benefits of NOMA, multiple relay cooperative system, user pairing scheme, and low complexity power allocation method are utilized. Simulation results proved that our proposed system outperforms over that of orthogonal frequency division multiple access (CRS-OFDMA).

Keywords—OFDM based CRS-NOMA, CRS-OFDMA

CHAPTER 1

INTRODUCTION

1.1 Background

Today, modern businesses over the world use content delivery networks for serving contents to end-users. For example, YouTube, Alibaba, Netflix, and Amazon Prime Videos are mainly used media streaming services for downloading, watching, and sharing movies and media files. To approach the reality, the qualities of the contents are upgraded to super-resolution quality (e.g. 4K, 8K). Nowadays, the amount of mobile users is growing day by day. According to the CISCO, there will be 1.5 mobile devices per capita and mobile video will sharply increase up to 9-fold between 2017 and 2022, accounting for 79 percent of total mobile data traffic [1]. This means that huge data traffic and low access efficiency problem become big issues day by day. To this end, the wireless communication community is heading to the fifth generation 5G communication systems. Device-to-Device (D2D) communication, millimeter-wave communication (mmWave), multiple-input multiple-output (MIMO), and novel multiple access schemes are some exploring technologies for 5G.

Among them, cooperative relaying system is also a promising technology due to its enhancement of cell edge user throughput and coverage area extension. However, single relay assisted cellular network is not enough for huge file delivery. Hence, multiple relays assisted communications, in other words, diamond relay networks are investigated in recent studies to achieve a better transmission rate for cell-edge users. According to the previous works, most of the cooperative relay systems (CRS) are studied on the orthogonal frequency division multiple access scheme (OFDMA). This is because current LTE networks are mostly worked on OFDMA that enables multiple users to communicate simultaneously assigning orthogonal resources to avoid the interference. Consequently, high data congestion and low access efficiency can be occurred in the upcoming overcrowded 5G scenario [2].

To solve the issues, non-orthogonal multiple access scheme (NOMA) is considered as a solution because NOMA enables multiple users to communicate simultaneously by using power domain multiplexing at the transmitter side and successive interference cancellation (SIC) at the receiver side. However, when the number of users that share the same spectrum is growing, each user suffers higher interference and cannot achieve equal rate [3]. This motivates us to investigate the employment of the OFDM based CRS-NOMA system to enhance the achievable rate of the cooperative relay system.

1.2 Related Works

In order to utilize the system bandwidth, NOMA based dual-hop diamond relay network where a source transmits signals to a destination via two relays is proposed [4]. The achievable sum-rate is investigated under both statistical channel state information (S-CSI) and imperfect channel state information (I-CSI). The work confirmed that NOMA based diamond relay network achieves over OFDM based diamond relay network.

Since power allocation is important in the system rate maximization of CRS-NOMA, the author in [5] proposed a new optimal power allocation and hybrid relay selection method for NOMA multiple access relays assisted network as shown in figure 1. In the system, maximum assisted relays are limited to three due to computational complexity in power allocation.

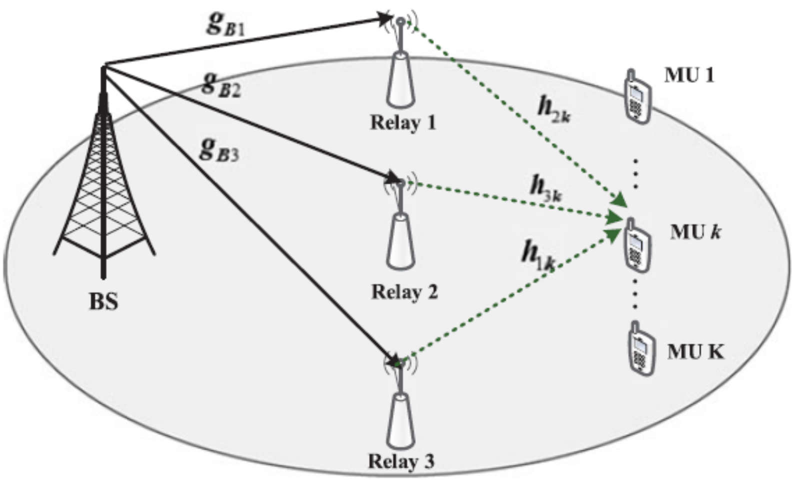

Figure.1. NOMA multiple access relay assisted network comprised of three relays, Received from [5].

Using massive multiple input multiple output MIMO and compatibility with the existing 5G technology, the author in [2] proposed two relays assisted NOMA scheme for 5G V2X communication. The achievable rate over SNR is studied and an efficient power allocation algorithm is also investigated to maximize the minimum achievable rate of the system.

In NOMA, when the number of cooperative relays that multiplexed on the same carrier are growing, each user are experienced more co-channel interference. As a result, system performance is degraded [6]. Moreover, broadcasting superimposed signals to all users on the same resource block is not impractical. Large decoding delay and serious propagation error can be occurred [7, 8]. Therefore, it is required to reduce the number of superimposed users on the same resource block through user pairing. Reasonable user pairing and power allocation algorithms can improve system capacity and reduce the inter-user interference. Therefore, OFDM based NOMA system is proposed with the ambitions of bit error rate (BER) reduction and sum-rate maximization while keeping fairness by the proportional bandwidth allocation according to various channel conditions of users [9]. The author in [10] also proposed OFDM based NOMA for uplink fixed scenario and analyzed the spectral efficiency improvement using water-filling power allocation.

According to the literature reviews, recent studies are focused on power allocation methods and relay selections to improve the sum-rate of the system. None of the works studies how to improve the performance of multiple relay cooperative system by employing the OFDM based NOMA. According to [9] and [10], improving system rate by reducing the co-channel interference is also one effective solution to enhance the system performance. Motivated by this idea, cooperative relay system is employed by OFDM based NOMA to achieve better performances.

1.3 Thesis Structure

In this work, a dual-hop OFDM based NOMA cooperative relay system (CRS-NOMA) is considered. In the scenario, relays are considered as mobile mode and selected multiple relays are assisted to transmit signals from source to destination that exists at the cell edge. The performances of the system are investigated under the power constraint. The main content is how to employ OFDM based CRS-NOMA to maximize the achievable data rate of the system and how to allocate power dynamically while reducing system complexity.

The purposes of the research work are as follow:

1. To improve the achievable rate of the system utilizing the benefits of OFDM based CRS-NOMA.

2. To study the effect of OFDM based CRS-NOMA under the various amount of system power.

3. To reduce the receiver complexity.

The structure of this article is as follows:

The first chapter introduces the background of the system and research purposes.

Chapter 2 introduces the basic principle of OFDMA, NOMA, and OFDM based NOMA. Besides, the brief introduction of cooperative relay system, relaying topologies and communication protocols are presented.

In Chapter 3, the communication system model of OFDM based CRS-NOMA and mathematical formulations are presented with the target of maximizing achievable data rate. And how power is allocated among users to achieve the system target is presented.

In Chapter 4, simulation results and discussions are expressed.

In Chapter 5, system conclusion and future work are presented.

CHAPTER 2

MULTIPLE ACCESS SCHEMES AND COOPERATIVE RELAY SYSTEM

In every communication network, multiple access schemes play a vital role because it is essential technology in assigning several users to the resources which is available in limitation.

2.1 Multiple Access Schemes

In this section, the characteristics of the multiple access schemes which are related to our work are explored. Generally, multiple access schemes have been classified into orthogonal and non-orthogonal. Orthogonal multiple access (OMA) has been widely used in the communication eras (e.g. 4G, 3G, 2G, etc.). Time division multiple access (TDMA), frequency division multiple access (FDMA), code division multiple access (CDMA), and orthogonal frequency division multiple access (OFDMA) are members of OMA [11]. In OMA schemes, users are assigned to orthogonal resources in either the frequency domain or time domain to avoid inter-user interference. In the current 4G communication system, OFDMA scheme is widely used.

2.1.1 Comparison of OFDMA and Conventional NOMA

In OFDMA, the available system bandwidth is divided into multiple smaller subcarriers and allows several users to communicate simultaneously by allocating the users to the different subcarriers with different power levels as shown in Figure. 2.

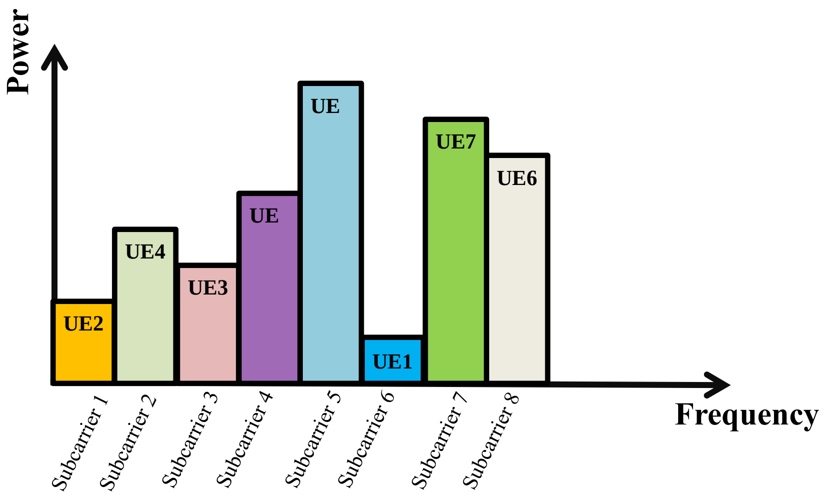

Figure.2: Orthogonal frequency division multiple access (OFDMA)

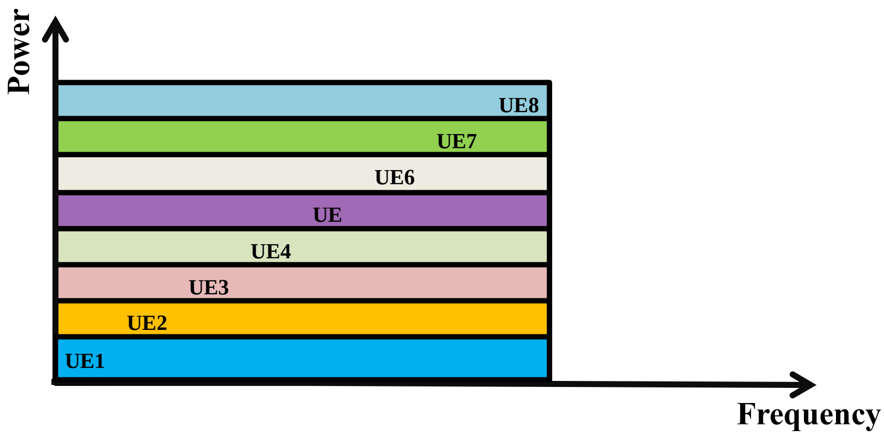

Figure. 3: Conventional Non-Orthogonal Multiple Access (NOMA)

However, the scarcity of the spectrum resources and growing users are the increasing burden of 4G. In order to meet the high demands of future radio access systems, NOMA becomes a widely focused access scheme for the fifth generation 5G era. In NOMA, there are two categories: power-domain NOMA and code-domain NOMA. In this work, power-domain NOMA is considered. In power domain NOMA, it allows several users to share the resources in both time and frequency domain by adjusting power levels as shown in Figure.3. For detail, the basic phenomenon of power domain NOMA is presented in the next section.

2.1.2 Performance of Power Domain NOMA

NOMA uses superposition coding (SC) at the transmitter side and the successive interference cancellation (SIC) at the receiver side to separate the users in both uplink and downlink channels. This SIC technology lets the limitations of OFDMA reduce.

Figure 4 shows the characteristics of conventional power domain NOMA technology under the consideration of 2 users downlink single cell scenario. When the source (BS) transmits data signals to user 1 and user 2, the available system power is distributed based on its channel conditions. In the figure, it is assumed that $h_1 > h_2$. Therefore, the distributed power of user 2 is greater than that of user 1, $p_1 < p_2$. According to NOMA principles [11], the broadcasted superimposed signal by the BS to the users can be given by

$$x_s = \sqrt{P_1}x_1 + \sqrt{P_2}x_2 \tag{1}$$

where P_i , $i \in \{1,2\}$ is the transmit power for user i and x_i is message signal of user i, $i \in \{1,2\}$. The total transmit power is P such that $P = P_1 + P_2$. The received signal at user i can be expressed as

$$y_i = h_i . x_s + n_i \tag{2}$$

In 2 users NOMA scenario, only one user performs SIC. Since SIC is performed at user 1 to decode the message signal x_2 and receive the message signalx_1, the received signal at user 1 can be expressed as

$$y_1 = \sqrt{P_1} x_1 h_1 + n_1 \tag{3}$$

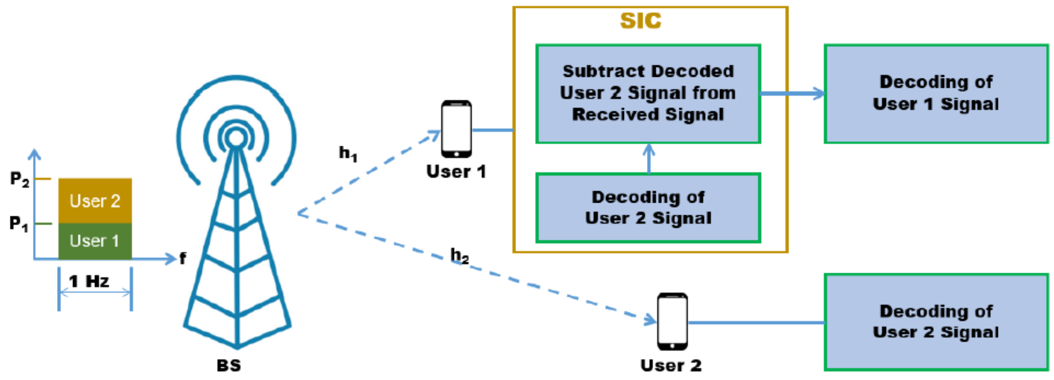

Figure.4: Conventional 2 Users Downlink NOMA, Taken from [11].

User 2 decodes the signals directly without SIC. Thus, the received signal at user 2 can be expressed as

$$y_2 = \sqrt{P_1} x_1 h_2 + \sqrt{P_2} x_2 h_2 + n_2 \tag{4}$$

where n_i denotes the AWGNs noise at the user i where $i \in \{1,2\}$ and $E\{|xi|^2\} = 1$ ($E\{x\}$ is denoted for the expectation process of x). Since the perfect SIC is assumed, the achievable data rate of the user 1 and 2 can be written as following using Shannon Formula, respectively. Here, the system bandwidth is assumed as 1 Hz.

$$C_1^{NOMA} = log_2\left(1 + \frac{P_1 h_1}{N_0}\right) \tag{5}$$

$$C_2^{NOMA} = log_2\left(1 + \frac{P_2 h_2}{P_1 h_2 + N_0}\right) \tag{6}$$

The achievable sum capacity of the system is

$$C_{total}^{NOMA} = C_1^{NOMA} + C_2^{NOMA} \tag{7}$$

2. 1. 2 OFDM based NOMA

Even though NOMA is emerged as a promising candidate for future 5G communication systems, how to control inter-user interference becomes a challenge when users are increasing within the same subcarrier. Therefore, OFDM based NOMA becomes an attracted technology that can reduce not only inter-user interferences but also power allocation complexity. Similarly with OFDMA, system bandwidth is divided into smaller orthogonal subcarriers and then allows limited users to share the specific subcarriers in OFDM based NOMA as shown in figure 5. By utilizing the benefits of both access schemes, better data rate and spectral efficiency can be achieved.

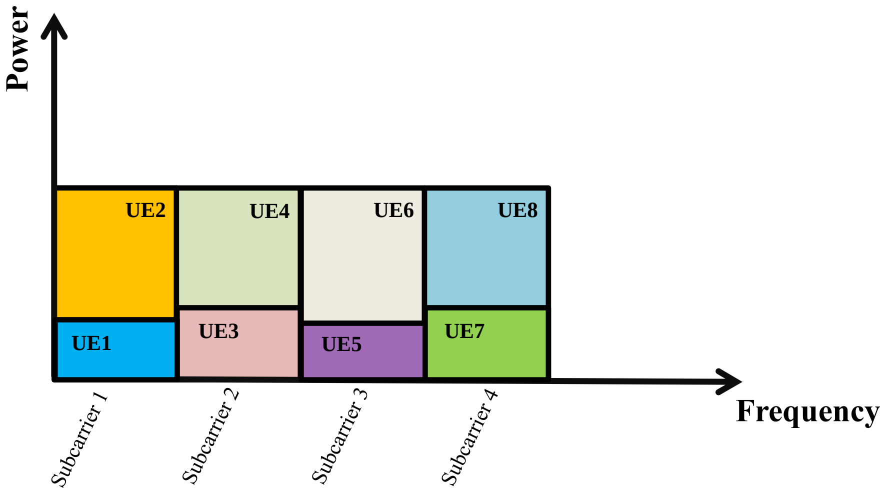

Figure. 5: OFDM based NOMA

2.2 Cooperative Relay System

As mentioned before, relay assisted cooperative transmission has been considered as a solution to improve the throughput of cell edge users and extend coverage range. To satisfy the high data rate, large scale cooperative relay system has been accepted a lot of attentions. In the cooperative relay system, the relay nodes having strong channel conditions assist to complete the communication between source and destination when the direct link is poor due to deep fading [12]. There are various relay topologies. Single relay assisted scenario, multiple relay assisted scenario, and multi-relay multi-hop scenario are some examples of cooperative relay systems as shown in figure 6. All schemes offer the advantages of the cooperative relaying system using cooperative communication protocols in both uplink and downlink.

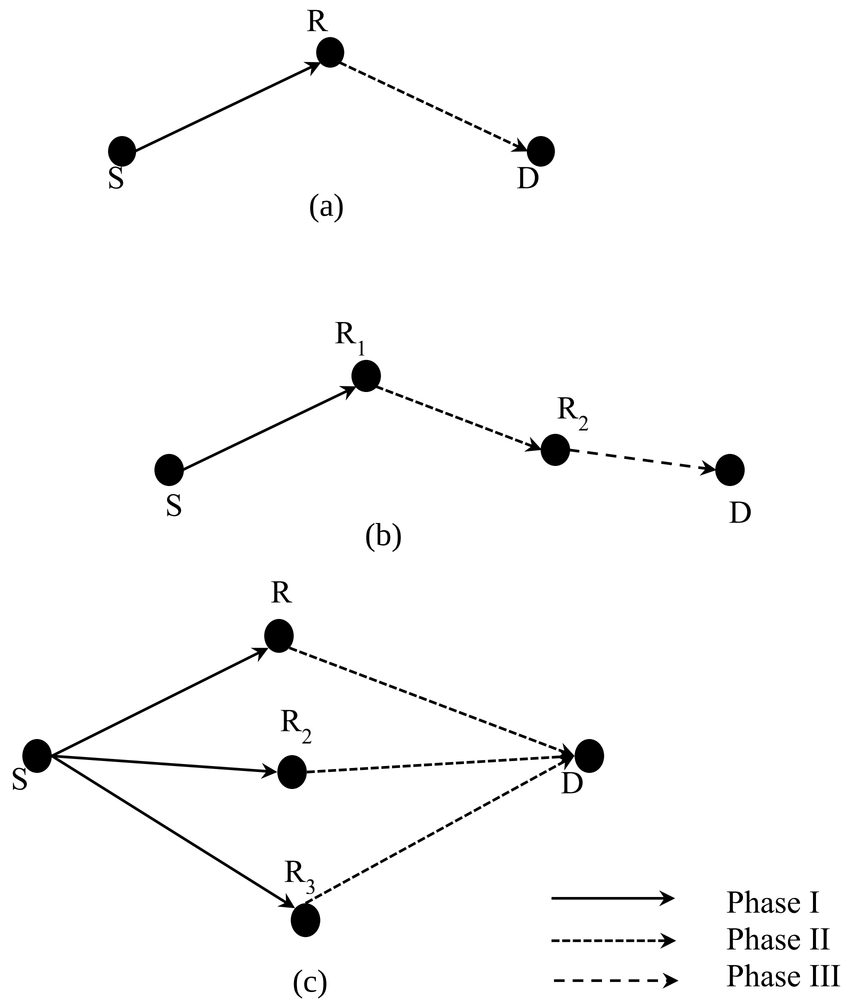

Figure. 6: Cooperative Topologies; (a) single relay assisted scenario, (b) multi-relays multi-hops scenario, and (c) multiple relays assisted scenario.

According to [13], cooperative protocols can be classified as:

1. Amplify and Forward (AF)
2. Decode and Forward (DF)
3. Coded Cooperation (CC)

Among them, commonly used AF and DF are illustrated in figure 7.

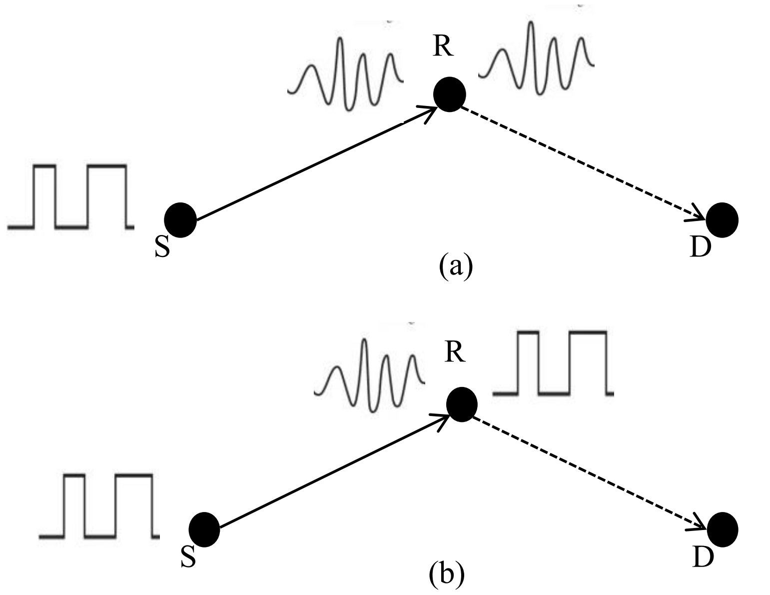

Figure. 7: Cooperative protocols: (a) Amplify and Forward (AF), (b) Decode and Forward (DF).

In AF method, the assisted relay is just analog repeater. When the relay receives the signal transmitted by the source node, in the first phase, the received signal is amplified and then forwarded to the destination in the second phase. One drawback of the AF method is that the relay amplifies the received signal including noise. Hence, two independently faded signals are received at the destination.

In DF method, the relay acts as digital regenerative raptors. When the relay receives the signal transmitted by the source node, in the first phase, it decodes the received signal and forwards it to the destination in the second phase. In DF method, much computing power is required if the relay node is applied by error correction techniques [14]. In this work, DF relaying protocol is considered for simplicity.

2.3 Section of This Chapter

In the first section of this chapter, the characteristics of OFDMA and conventional NOMA are introduced comparatively. The performance of power domain NOMA is presented in detail illustration with 2 users NOMA scenario. Then, OFDM based NOMA is introduced and explained how it utilizes resources. After that, the role of the cooperative relay system is introduced in the second section. Besides, various cooperative scenarios and commonly used forwarding strategies are presented.

CHAPTER 3

IMPROVING DATA RATE USING OFDM BASED CRS-NOMA

3.1 System Model

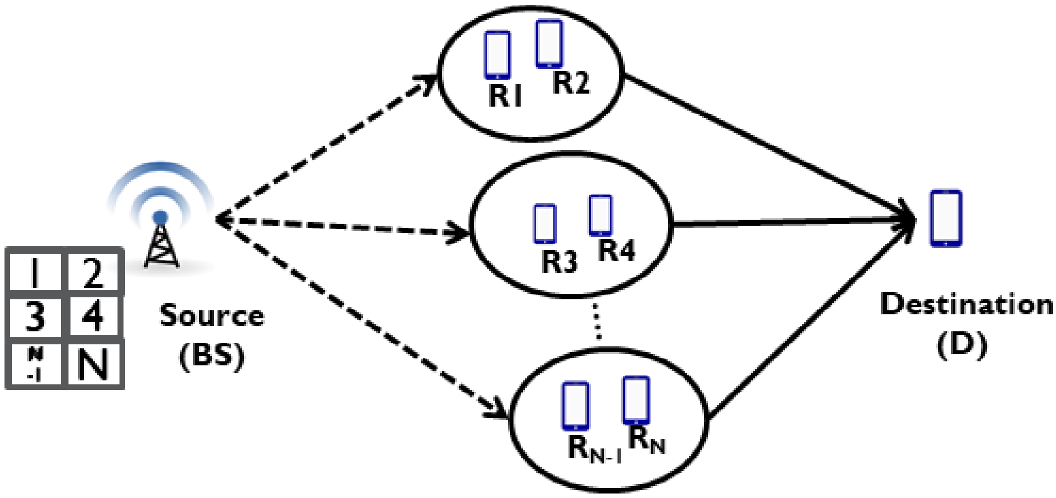

Figure.8. OFDM based CRS-NOMA system model

Consider a dual-hop cooperative relaying system as presented in figure 8, comprised of one source (BS) destination (D) pair and relay user equipment set $RUE_{set} = \{1,2,\ldots,\mathrm{N}\}$. It is assumed that the source and the destination are located at the center of the cell and the edge of the cell respectively. Besides, all relays are working in half duplex relaying mode and equipped with a single antenna. Hence, the transmission can be completed in two phases. There is no direct link between source and destination because of deep fading. Therefore, source to relay $S \rightarrow R_i$ and relay to destination $R_i \rightarrow D$ links are involved in this system, whose channel gains are represented by h_{SRi} and h_{RiD}, respectively. The channels are modeled as independent Rayleigh fading model and remain unchanged during each transmission slot.

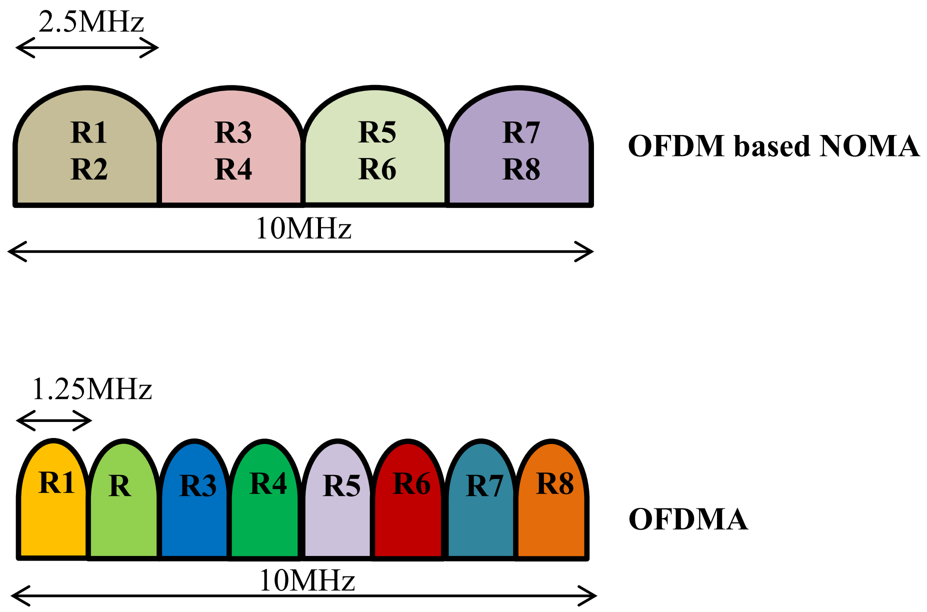

Fig. 9: Bandwidth Utilization of OFDM based NOMA Vs. OFDMA

In our work, we assume that the cellular network operates in OFDM based NOMA. Thus, there is no interference between different subcarrier users and only the interference of the same subcarrier superimposed users is considered. The maximum number of multiplexed user on each subcarrier is limited into two. Therefore, for *2N* relays, the overall system bandwidth *BW* is divided into *N* subcarriers. Hence, each subcarrier bandwidth is$BW_n = BW / N$. The bandwidth utilization of OFDM based NOMA and OFDMA schemes for 8 relays scenario is illustrated in figure 9. Similarly with the OFDMA, a subcarrier is assigned to only one relay pair in each hop which means there is no common channel between the user pairs. Let $\Omega_{i,j}$ denotes subcarrier set that is assigned to relay *i* over hop *j* and the maximum allowed transmission power of the system is P_{total}.

3.1.1 Relay Selection

In a cooperative relay system, relay selection also plays a critical role. In the state of the art, different algorithms and relay selection methods are investigated considering the quality of services QoS constraints, interference, buffer size, remaining power of the relay, and so on. In our work, the relay possible UEs are in mobility. Therefore, the set of cooperative relays are varying in each slot. Since the main idea of our work is to achieve the maximum data rate under limited system power and to fully utilize the advantages of the multi-relay cooperative system, BS performs the subcarrier based relay selection using conventional max-min relay selection [15], [16]. The relay selection criterion is

$$R_{set} = \cup_{n \in N} \left\{ \max_{i \in R_{set}} \left[min\left(h_{SR_{i,n}}, h_{R_{i,n}D} \right) \right] \right\} \quad (8)$$

where $R_{set} = \{1,2, \dots, R\}$ is set of selected relays from RUE_{set}, $h_{SR_{i,n}}$ is channel gain to noise ratio value of source to relay link over subcarrier n, and $h_{R_{i,n}D}$ is channel gain to noise ratio value of relay to destination link over subcarrier n.

3.1.2 User Pairing

In case two users are allowed to share the same channel with different power levels using NOMA, user pairing is sustainably performed at the transmitter side in order to assign that pair to a specific subcarrier [17]. In the OFDM based NOMA system, the achievable data rate is highly related to user pairing [18]. There are various channel condition based user pairing schemes such as random pairing [19], exhaustive pairing [20], and maximum and minimum gain pairing [21].

Each scheme has pros and cons depending on their scenarios. In this work, relays having adjacent channel conditions are paired using the index of relay set to assist the transmission. The mechanism of channel condition based user pairing is shown in Figure. 10. In order to perform SIC, the data reception at each receiver is necessary to order the channel gains from source to each relay link.

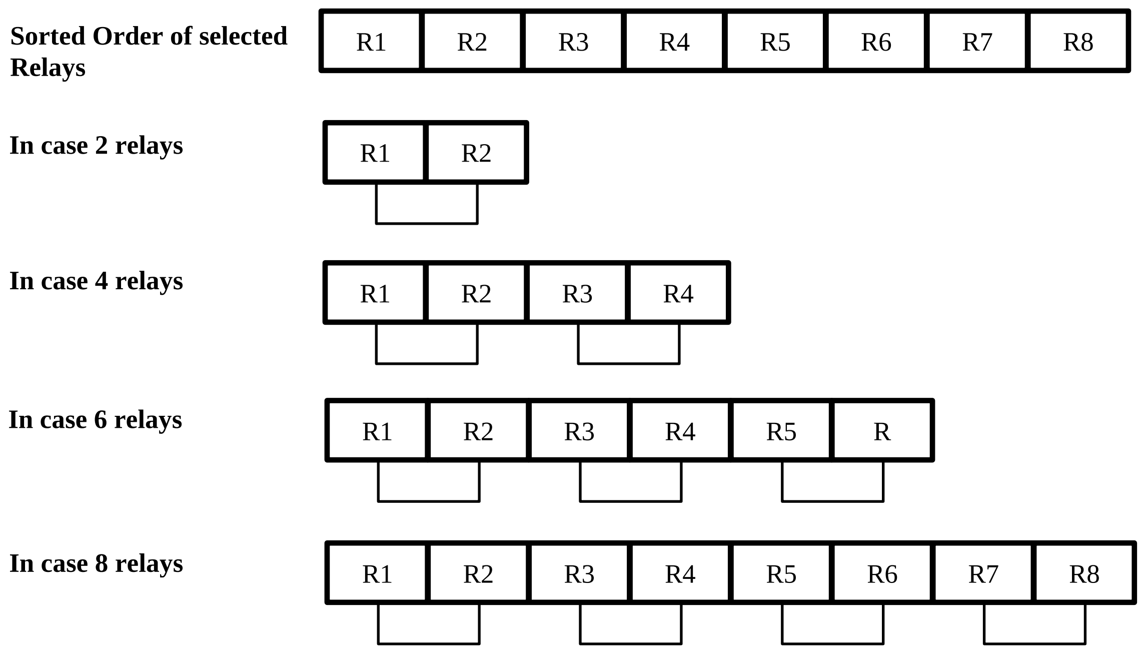

Figure. 10. Channel State based User Pairing

Therefore, channel gain to noise ratios of index relays within each pair are sorted as descending order such as

$$\frac{h_{SR_{1,n}}}{N_{SR_{1,n}}} > \frac{h_{SR_{2,n}}}{N_{SR_{2,n}}} > \ldots > \frac{h_{SR_{R,n}}}{N_{SR_{R,n}}} \quad (9)$$

and

$$\frac{h_{R_{1,n}D}}{N_{R_{1,n}D}} > \frac{h_{R_{2,n}D}}{N_{R_{2,n}D}} > \ldots > \frac{h_{R_{R,n}D}}{N_{R_{R,n}D}} \quad (10)$$

Later, we use $h_{SR_{i,n}}$ and $h_{R_{i,n}D}$ to denote the respective channel gain to noise ratios.

3.2 Problem Formulation

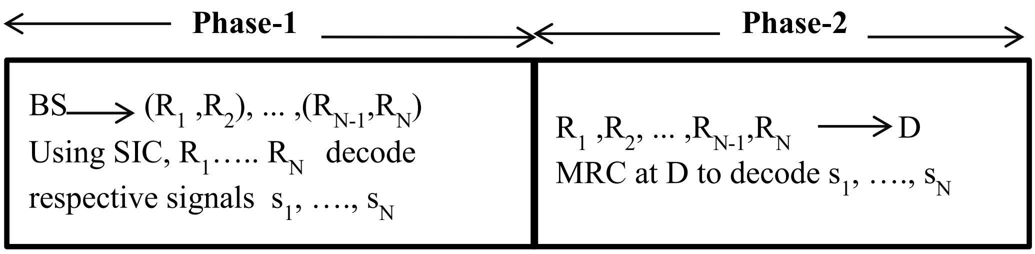

Figure. 11: Illustration of multiple relays assisted transmission within a time slot. Phase I: Transmission from BS to all relay pairs. Phase II: Transmission from all relays to the destination.

As illustrated in Figure 11, in the first phase, BS creates superimposed signals according to the number of available relay pair and then transmits to each pair over respectively assigned subcarriers with different powers according to NOMA principles. In this work, perfect SIC is considered. Therefore, according to [2][4][5], the received signal-to-interference-plus-noise ratio (SINR) at the ith relay node over subcarrier n is given by:

$$\gamma_{SR_{i,n}} = \frac{h_{SR_{i,n}} p_{SR_{i,n}}}{1+h_{SR_{i,n}} \sum_{j=1}^{i-1} p_{SR_{j,n}}}, \forall i \in \{1,2\}, \forall n \in N \tag{11}$$

where $p_{SR_{i,n}}$ denotes allocated power for *S*→*R_i* link over subcarrier *n*, and $h_{SR_{i,n}}$ denotes the channel gain between source and i[th] relay.

During the second phase, each relay decodes their respective signals using SIC and forwards it to the destination using assigned subcarrier and allocated power. Under the assumption of perfect SIC, the received signal-to-interference-plus-noise ratio (SINR) at the destination over subcarrier *n* is given by:

$$\gamma_{R_{i,n}D} = \frac{h_{R_{i,n}D} p_{R_{i,n}D}}{1+h_{R_{i,n}D} \sum_{j=1}^{i-1} p_{R_{i,n}D}}, \forall i \in \{1,2\}, \forall \in N \tag{12}$$

where $p_{R_{i,n}D}$ denotes allocated power for R_i→*D* link over subcarrier *n*, and $h_{R_{i,n}D}$ denotes the channel gain between i^{th} relay and destination. According to [2] [4] and [5], the achievable data rate of the R_i assisted link over two hops can be expressed as following using Shannon's capacity formula.

$$C_{SR_iD} = \frac{1}{2} BW_n . log_2 \left(1 + min\left(\gamma_{SR_{i,n}}, \gamma_{R_{i,n}D}\right)\right), \forall i \tag{13}$$

where $\frac{1}{2}$ is resulted from two transmission hops. Finally, the total achievable rate of the whole R_{set} assisted system can be written as

$$C^{NOMA} = \sum_{i=1}^{R} C_{SR_iD} \tag{14}$$

Our purpose is to maximize the achievable end-to-end transmission rate of the system under power constraint. Hence, the problem can be formulated as follow:

$$\max_{\{\Omega,p\}} \sum_{i=1}^{R} C_{SR_iD}$$

$$\text{s.t.} \qquad \sum_{n=1}^{N} \left[\sum_{i=1}^{2} p_{SR_{i,n}} + \sum_{i=1}^{2} p_{R_{i,n}D} \right] \le P_{total} \qquad C.1$$

$$p_{SR_{i,n}} > 0, \qquad p_{R_{i,n}D} > 0, \qquad \forall i \qquad C.2$$

$$\boldsymbol{\Omega}_{i,1} \cap \boldsymbol{\Omega}_{i,2} = 0, \forall i \in \{1,2,\dots,N/2\} \qquad C.3$$

where Ω and p denotes optimization variables.

3.3 Power Allocation Method

In power domain NOMA, power allocation strategy is the main factor to achieve not only the maximum transmission rate but also the fairness among users. The task of power allocation is to assign appropriate amount of power to the users to hit the maximum data rate of the system. In this work, relays are randomly moving and thus channel conditions are varying in every time slot. Therefore, a dynamic power allocation scheme is required.

In the study of power allocation methods, [22] analyzed the effects of three power allocation schemes: fixed power allocation (FPA), fractional transmit power allocation (FTPA), and full search power allocation (FSPA) under the consideration of 2 users NOMA downlink scenario. Among them, FTPA and FSPA are dynamic allocation schemes and reasonable with practical scenarios.

Hence, FTPA is applied in [23] such that BS distributes equal power to each subcarrier, and then the allocated power is distributed again to the same subcarrier superimposed users. Since the method neglects the channel conditions in first step power distribution, the authors in [25] and [26] proposed two layers power allocation scheme for OFDM based NOMA considering users' channel conditions.

Similarly, our power allocation procedure has two steps. Firstly, available system power is allocated to each users using the water-filling method according to the following equation.

$$P_{i,n} = \frac{\mu}{h_{i,n}} \tag{15}$$

where μ is a constant selected to satisfy the total transmit power constraint (C.1) and can be calculated as

$$\mu = \frac{P_{tot}}{\sum_{i=1}^{R} \sum_{j=1}^{2} \frac{1}{h_{i,n}}} \tag{16}$$

$$P_n = P_{i,n} + P_{i+1,n} \tag{17}$$

where P_{tot} is total transmit power of the system. And then, the total multiplexing power of each subcarrier can be obtained by summation of paired users' allocated power in the first step as shown in equation (7). Secondly, the fractional transmit power allocation (FTPA) method is iteratively used to fairly and dynamically allocate power to subcarrier super-imposed users according to the following equation,

$$P_{i,n} = \frac{P_n}{\sum_{j=1}^{N}[h_{j,n}]^{-\beta_j}} [h_{i,n}]^{-\beta_i} \quad (18)$$

where the parameter $\beta (0 \leq \beta \leq 1)$, is a decay factor and P_n is total multiplexing power of subcarrier n. The algorithm adjusts the decay factor iteratively to give the fair SINR values between two users.

Algorithm: Iterative FTPA algorithm

1. Input: $h_n = [h_1 \; h_2]$, P_n

2. Sort (h_n, 'descend').

3. Initialization: Set $\varepsilon = 0.0001$, $\beta = [0.1 \; 0.1]$ and SINR_diff=1.

4. While ($SINR\_diff \geq \varepsilon$) do

    Calculate $P_{i,n}$ using equation (18), $\forall i \in \{1, 2\}$

5. Calculate $SINR_i$, $\forall i \in \{1, 2\}$.

6. Calculate $SINR_{diff} = SINR_1 - SINR_2$.

7. if ($SINR\_diff \geq \varepsilon$)

8. $\beta_1 = \beta_1 + 0.00001$;

    Update β array.

9. else break;

10. end

11. end

3.4 Section of This Chapter

This chapter introduces the system model of OFDM based CRS-NOMA in the first section and then explains how relay selection is done. Furthermore, user pairing method is illustrated in the subsections. After that, well-known power allocation schemes and how the power allocation algorithm is utilized in our system are expressed.

CHAPTER 4

SIMULATION RESULTS AND DISCUSSIONS

4.1 Deployment and System Parameters

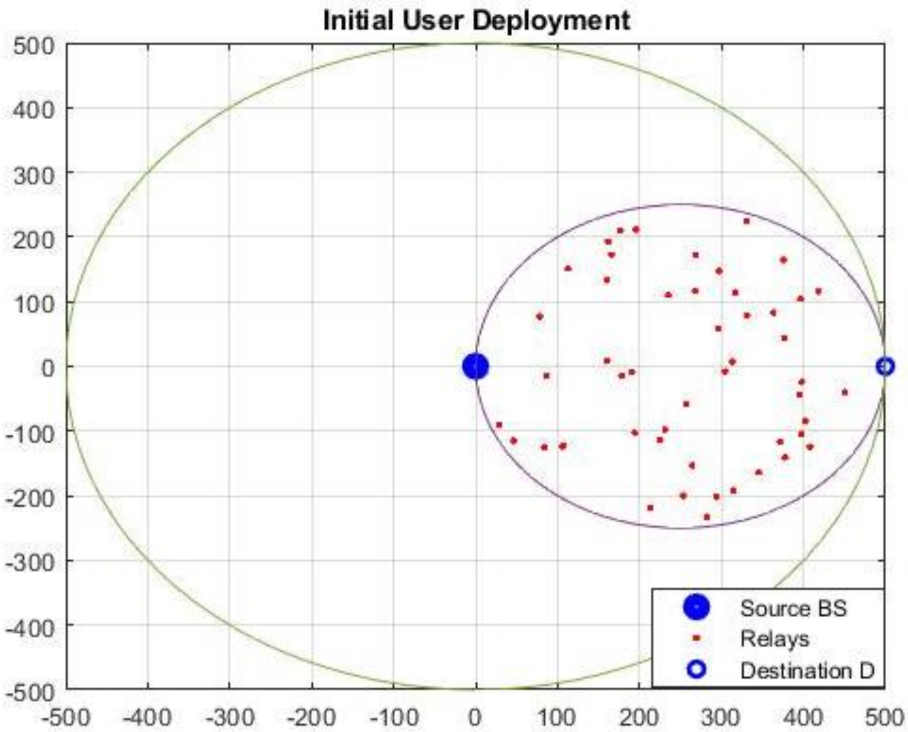

Figure.12: Initial User Distribution

Under the consideration of the dual-hop OFDM based CRS-NOMA system which consists of one source-destination pair and multiple relays. The distance between the source and destination is 500 meters. At the initial state, relays are randomly deployed within a 250-meter radius circle that is centered at the mid-point between source and destination and then moving with velocity $3ms^{-1}$ as shown in Figure 12. The main parameters of the system are given in Table.1.

System Parameters	Values
No: of RUEs	50
No: of Relays in R_{set}	8
Carrier frequency (f_c)	2GHz
Bandwidth BW	10MHz
No: of subcarriers in OFDM-NOMA	4
No: of subcarriers in OFDMA	8
Noise spectral density	-174dBm/Hz
Path loss model (BS-R and R-D link)	PL(dB)=128.1+37.6*log10($\boldsymbol{d}$ /1000);
Slow fading coefficient	Log-normal distribution with standard deviation of 8 dB
RUE Velocity range	3 ms^{-1}, random walk mobility model

Table 1: Simulation Parameters

In the system, OFDM based NOMA is utilized to reduce inter-user interference among the assisted relays. Since two users NOMA scenario is typical, only two users are allowed to share one subcarrier at most. Suppose that the number of maximum relay users is 8. Therefore, the overall system bandwidth is divided into 4 subcarriers in OFDM based NOMA and 8 subcarriers in pure OFDMA as depicted in figure 9.

Then, selected relays are paired based on channel conditions and then power is distributed using two layers power allocation scheme. To study the gap between our proposed scheme and pure OFDMA, simulations are implemented on MATLAB. The average results are evaluated through Monte Carlo simulation.

4.2 Results and Analysis

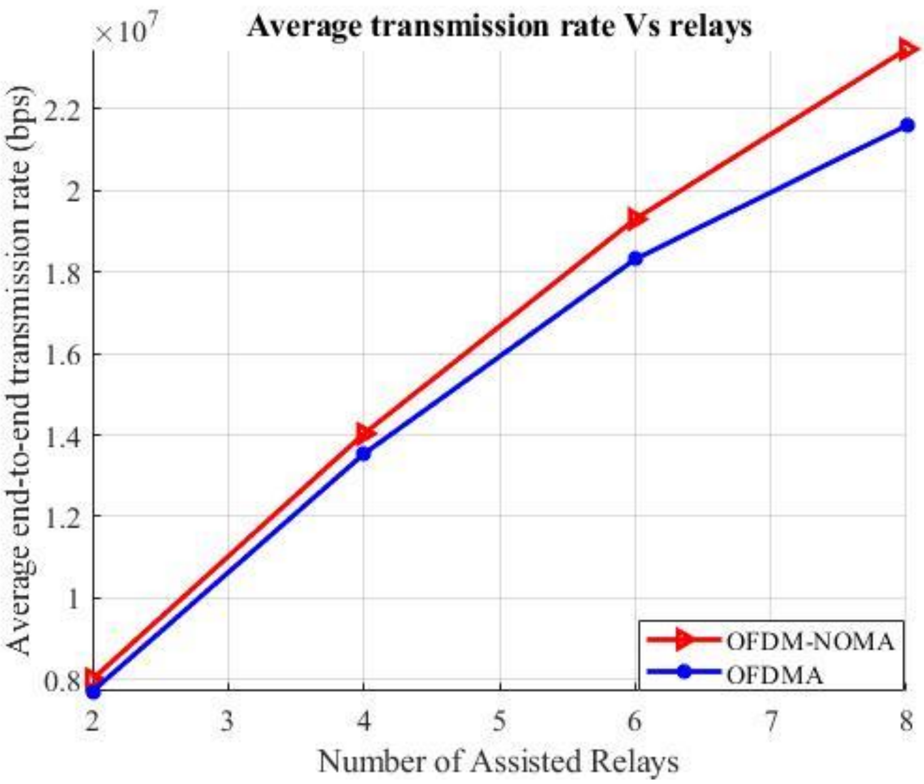

Figure.13: Average end to end transmission rate achieved by different number of assisted relays at transmit power 15dBm.

Figure 13 compares the achievable end-to-end transmission rate as a function of different relay numbers by using a fixed total transmit power 15dBm. Though the average rate of both OFDM-NOMA and OFDMA increase along with the increasing number of assisted relays, it can be easily seen that our proposed OFDM based NOMA outperforms OFDMA at every number of relays. That is because OFDMA limits bandwidth to each user while OFDM based

NOMA allows users higher bandwidth taking the benefits of subcarrier sharing and SIC. The numerical results are compared in Table.2

No. of Relays	2	4	6	8
OFDM-NOMA	8.0Mbps	14.0Mbps	19.3Mbps	23.5Mbps
OFDMA	7.7Mbps	13.5Mbps	18.3Mbps	21.6Mbps

Table 2: Achievable Rate Comparison

According to the table, OFDM based NOMA achieves 0.3Mbps, 0.5Mbps, 1Mbps, and 1.9Mbps in the case of two, four, six, and eight relays respectively. The achievable transmission rate gap is almost exponentially increasing along with the increasing number of relays. In terms of percentage, our proposed scheme is 5 % better than OFDMA on average. This is because the achievable rate is directly proportional to the available bandwidth at the users. Moreover, we observed that allocating the users into orthogonal subcarriers using OFDM based NOMA not only reduces the co-channel interference but also improves the system capacity because of bandwidth utilization.

Although BS and relays have separate power constraints in a practical scenario, the upper bound of system performance can be obtained with a total transmit power constraint [2]. Therefore, figure 14 is illustrated with the same simulation parameters by using a fixed number of 8 relays to provide a full picture showing how total transmit power affects the achievable end-to-end transmission rate. We can see that achievable rates of both schemes increase along with the increasing amount of total transmit power. Specifically, the performance of the proposed scheme gives a better data rate over that of OFDMA due to the allocation of perfect power pair to each user pair. In the case of each total transmit power amount, OFDM based NOMA has a 5% transmission rate gain compared to OFDMA. In other words, OFDM based NOMA can save 5% at power consumption compared to OFDMA. This is also proof that the system rate is strictly affected by the power allocation in NOMA and spectrum sharing architecture is vital in reducing inter-user interference.

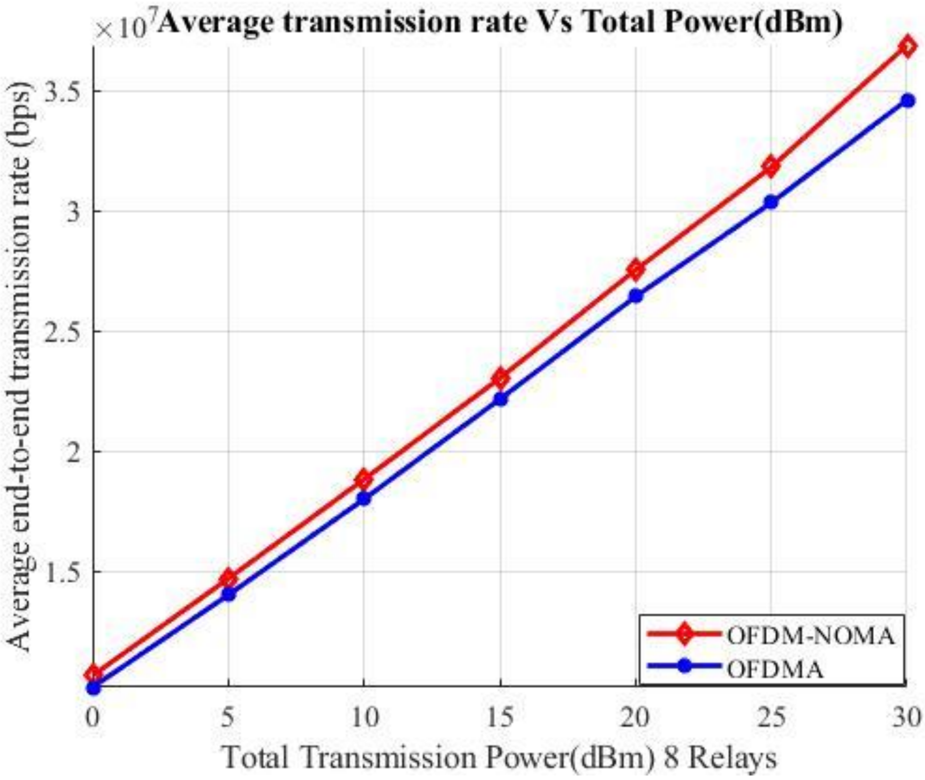

Figure.14: Average end to end transmission rate achieved by 8 relays under different transmit power (dBm)

4.3 Section of This Chapter

This chapter explores the utilization of OFDM based NOMA over the multiple relay cooperative system. Simulation results are compared in the subsections. The results show that the employment of OFDM based NOMA brings better achievable data rate and power consumption for multiple relay cooperative system compared to pure OFDMA.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

We have studied the effect of OFDM based CRS-NOMA as a function of the different number of assisted relays and different system power amount with the purpose of maximizing the achievable end-to-end transmission rate.

This research mainly includes three phases as follows.

1. The basic principles of promising multiple access schemes and large scale cooperative relaying system are introduced.

2. This paper utilizes the OFDM based NOMA to improve the achievable data rate of multiple relays assisted communication system.

3. In order to approach practical implementation, channel based relay selection, channel based user pairing, and two layer power allocation method that is the combination of water filling and fractal transmit power allocation is utilized.

Simulation results show that employing OFDM based CRS-NOMA has better performances under fair power allocation.

5.2 Future Work

NOMA opened very wide research issues due to its advantages in many aspects. Along with the bandwidth utilization of NOMA, power allocation becomes an important task. Though there are many power allocation algorithms in the literature, formulation complexity still remains. The two layer power allocation method is simple and easy to apply to OFMD based 2 user NOMA systems. However, the iteration cost is too high at the in charge of the system. Due to the limited ability of authors, there are still a lot of research questions in the power allocation part.

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