RELAY SELECTION IN SECONDARY UNDERLAY COOPERATIVE NOMA NETWORK WITH ENERGY HARVESTING

A project report submitted

in partial fulfilment of the requirement for the degree of

Bachelor of Technology

in

Electrical Engineering

by

Harsh Kumar Srivastava (2017UEE0071)

Under the Guidance of

Dr. Sudhakar Modem

DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY JAMMU

(JUNE 2021)

CERTIFICATE

This is to certify that the work contained in this report entitled **"Relay Selection in Cooperative NOMA with Energy Harvesting Nodes"** is a bonafide work of **Harsh Kumar Srivastava (2017UEE0071)**, carried out in the **Department of Electrical Engineering, Indian Institute of Technology Jammu** under my supervision and that it has not been submitted elsewhere for the award of any degree.

June, 2021

Jammu

Supervisor: Dr. Sudhakar Modem

Assistant Professor

Department of Electrical Engineering

Indian Institute of Technology Jammu

DECLARATION

I declare that this report presents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when required.

Harsh Kumar Srivastava (2017UEE0071)

ACKNOWLEDGEMENT

First and foremost, I would like to express my sincere gratitude towards my advisor Dr. Sudhakar Modem for his continuous support and guidance which made this project possible.

I would also like to thank Dr. Shashi Bhushan Kotwal for his active guidance throughout the completion of the project. He helped me to complete this project by providing suggestions and helped me plan this project in a better manner.

I am highly indebted to my institute IIT Jammu and its Electrical department for providing me with this wonderful opportunity. The learnings which I received through my faculty supervisor and everyone involved helped me achieve the completion of this project.

Last but not least, I would also like to extend my appreciation to those who could not be mentioned but have well played their role to inspire me behind the curtain.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

NOMA has emerged as a promising technique to combat spectral scarcity of wireless networks. Cooperative NOMA along with SWIPT (simultaneous wireless information and power transfer) provides communication networks with high spectral and energy efficiency. This project investigates a power constrained underlay secondary network with multiple relays and two users - near and far. The near user has energy harvesting capability and does cooperative transmission to the far user using harvested energy. A relay selection scheme is proposed with fixed power allocation at relay. Closed form expressions of outage probabilities at near and far-users, and system throughput are derived to evaluate the system performance. Simulation results corroborate the derived analytical expressions. The important insights of analytical results such as performance gain, optimal number of relays and effect of power constraints are discussed.

Chapter 1

Introduction

Due to massive connectivity demands of a wide variety of devices, spectral efficient radio access techniques are required for modern communication systems. In this regard, non-orthogonal multiple access (NOMA) has gained attention as a promising radio access technique for the future. Along with spectral efficiency, energy efficiency is also much needed. Energy efficient networks are enabled by RF-energy harvesting techniques in which energy is harvested from the radio signals. SWIPT enabled NOMA is used to form spectral and energy efficient networks. To further enhance performance, at the cost of little spectral resources and increased complexity, multiple relays are used. In this project, a relay selection scheme for a power constrained secondary cooperative NOMA network with multiple relays and energy harvesting at near-user is proposed.

1.1 Motivation

It is seen that relay selection has been frequently adapted for cooperative NOMA networks, and its effectiveness in terms of minimum outage probability and maximum diversity order has been shown. However, to the best of my knowledge the relay selection scheme has not been studied for power constrained secondary underlay cooperative NOMA network with energy harvesting at near-user. This is the primary motivator for this work.

1.2 Organization of the Report

The report is organized into seven chapters including this one. The second chapter provides a brief literature background about the project. After that the system model is thoroughly explained in chapter 3 followed by relay selection scheme and transmission protocol in fourth chapter. Chapter 5 presents performance analysis in terms of outage and throughput, closed-form expressions for which have been derived. Numerical results and discussions are done in chapter 6 followed by conclusion chapter 7.

Chapter 2

Literature Review

The next generation (5G and beyond) communication networks require immense evolution to support massive connectivity requirements of a wide variety of devices, high mobile data rates, better coverage, and low latency. Novel techniques are needed to support multiple new applications including cloud based applications, Internet of Things (IoT), and machine to machine communications [1]–[4].

2.1 NOMA

NOMA has emerged as a promising radio access technique to design spectrum efficient networks. Multiple users can be served simultaneously at a shared frequency channel using power allocation NOMA in which different power is allocated to messages of different users. To apply NOMA, superposition coding (SC) is used to superimpose messages of multiple users at the transmitter. Successive interference cancellation (SIC) is performed at each user to recover its message. A thorough investigation of NOMA is done in terms of performance analysis, resources allocations, user pairing, modulation schemes [5] and its integration with other 5G techniques [6], [7], [8].

Cooperative transmission can significantly improve performance and reliability of wireless networks and therefore it is widely adopted in wireless networks. Cooperation in NOMA users is motivated by the working principle of NOMA. As SIC is adopted at near-users, they have extra copies of far-users' information. Redundant information of far-users can be relayed by near-users to improve the performance of far-users [9], [10], [11].

2.2 Energy Harvesting

Beside spectral efficiency, self-sustainability and energy efficiency are other important design parameters of 5G wireless networks [4]. This becomes increasingly important where recharging/replacing of the batteries is highly expensive or not feasible, e.g., toxic chemical industries. To enable self-sustainable networks, RF-EH (Radio Frequency Energy Harvesting) has emerged as the key technology. Simultaneous wireless information and power transmission (SWIPT) is a way for RF-EH. In this, the same RF signal is used for both EH as well as information processing [12][13]. EH becomes particularly important in cooperative networks because any intermediate node may not be willing to cooperate at the expense of its own energy resources. Optimization of power allocation factors at source and power splitting ratio at relay were performed to maximize the rate of cooperative NOMA SWIPT network [14].

2.3 Relay selection

The performance of traditional cooperative relay networks is increased by deploying multiple relays at the expense of complexity and spectral resources [15], [16]. Relay selection is the prominent method to implement cooperative diversity. Through relay selection only one selected relay forwards the message, the spectral loss due to multiple relays does not exist. Various relay selection schemes have been investigated for cooperative NOMA multiple relay networks [17], [18], [19]. Briefly, the selection scheme has been thoroughly investigated for cooperative NOMA networks without considering both energy harvesting and ITL power constraints.

Chapter 3

System Model

This chapter aims to provide understanding of the system model used for this project. This chapter is divided into three sections describing the system model, channel characteristics and power constraints.

3.1 Model

We consider a NOMA based underlay secondary network with a source S, multiple relays R_k, where $k \in [1 . . . K]$ and two users, near-user denoted by NU and far-user denoted by FU, as shown in Fig 1.

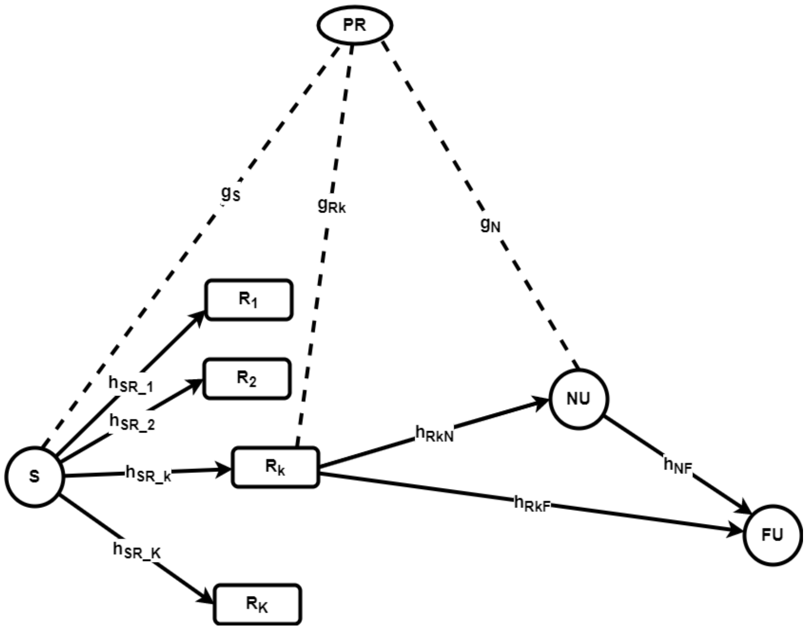

Fig 3.1 : System Model

The near-user is considered to be closer to the relay and thus, have stronger channel conditions than the far-user. The near-user is capable of harvesting energy from R_k and uses this harvested energy to relay information to the far-user.

3.2 Channel Characteristics

Communication channels between all nodes are taken to be half-duplex quasi-static path-loss Rayleigh fading type, and independent of each other. The channels between S-PR, R-PR and NU-PR are denoted by g_S ~ CN (0, d_S^{-m}), g_{Rk} ~ CN (0, d_{Rk}^{-m}) and g_N ~ CN (0, d_N^{-m}) respectively, where ‘d’ denotes the distance between the nodes and ‘m’ is path-loss constant , and PR stands for primary relay.

Similarly, the channels between S-R, R-NU, R-FU and NU-FU are denoted by h_{SRk} ~ CN (0, d_{SRk}^{-m}), h_{RkN} ~ CN (0, d_{RkN}^{-m}), h_{RkF} ~ CN (0, d_{RkF}^{-m}) and h_{NF} ~ CN (0, d_{NF}^{-m}) respectively.

3.3 Power Constraints

It is assumed that the underlay secondary network shares the spectrum of the primary network which imposes an interference temperature limit (ITL) and constrains the transmission power. The max power transmitted by source S, relay R_k and near user NU is P_S, P_{Rk} and P_{NU} respectively and is given as: $P_S = Ip/|g_S|^2$, $P_{Rk} = Ip/|g_{Rk}|^2$, PN = min(P_N^H, $Ip/|g_N|^2$)= P_N^H where Ip is the ITL, and P_N^H is the harvested power available at NU to transmit the FU’s message.

Chapter 4

Relay Selection And Transmission Protocol

This chapter provides understanding regarding the information transmission in the secondary network and the scheme used for relay selection.

4.1 Relay Selection Scheme

The relay selection scheme used is that the relay which has the highest SINR for decoding x_F or the highest SNR for decoding x_N is selected.

$\gamma_{Rsel,xF,1} = \max \{\gamma_{Rk,xF,1}\}_{k\in[1...K]}$ when selecting on the basis of SINR values for x_F

and

$\gamma_{Rsel,xN,1} = \max \{\gamma_{Rk,xN,1}\}_{k\in[1...K]}$ when selecting on the basis of SNR values for x_N.

Regardless of whether the relay selection is done based on the maximum value of SINR for decoding x_F or SNR for decoding x_N , the relay selected will be the same. This is because for any relay R_k both values depend on the same random variable $|h_{SRk}|^2$. Therefore, the proposed relay selection scheme maximizes $|h_{SRk}|^2$. This has been verified via extensive MATLAB simulations.

4.2 Transmission Protocol

For this project, downlink transmission in the secondary network is considered as shown in Fig. 2.

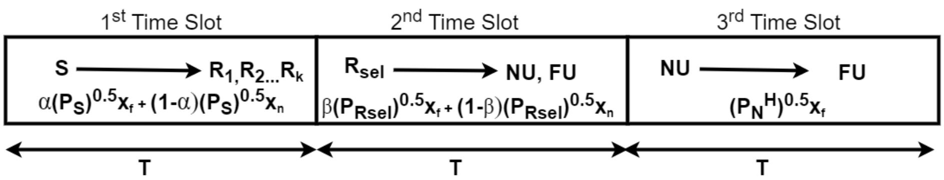

Fig 4.1: Transmission Protocol

The near and far user messages, x_N and x_F respectively, are transmitted from source to end users in three time slots each lasting for time T. In the first time slot, the secondary source transmits x_N and x_F to all the relays using NOMA. In the second time slot, the relay having maximum instantaneous SNR/SINR value for decoding x_N or x_F is selected which then transmits messages to NU and FU using NOMA. In the third time slot, NU forwards the message of FU using harvested energy from the relay

4.2.1 First time slot: source to relay transmission

The secondary source S transmits messages x_N and x_F to all the relays $[R_1, R_2, \ldots R_K]$ using NOMA. The secondary source transmits with power $I_p/|g_S|^2$ such that the received power at the PR is within the ITL. The received signal at the k^{th} relay R_k , $k \in [1 \ldots K]$ in the first time-slot is

$$y_{R_k,1} = \left(\sqrt{\alpha\,(I_p/|g_S|^2)}\,x_F + \sqrt{(1-\alpha)I_p/|g_S|^2}\,x_N\right)h_{SR_k} + n_{R_k} \quad (1)$$

where where $0 < \alpha < 1$ is the NOMA power-allocation parameter of the source, and $n_{Rk} \sim CN\,(0, \sigma^2)$ is the additive white Gaussian noise (AWGN) at the relay. Now, SINR for decoding x_F at the k th relay R_k can be written as

$$\gamma_{R_k,x_F,1} = \frac{\alpha\,(I_p/|g_S|^2)|h_{SR_k}|^2}{(1-\alpha)\,I_p/|g_S|^2\,|h_{SR_k}|^2 + \sigma^2} \quad (2)$$

And, SNR for decoding xN at the k th relay Rk can be written as

$$\gamma_{R_k,x_N,1} = \frac{(1-\alpha)\,I_p/|g_S|^2\,|h_{SR_k}|^2}{\sigma^2} \quad (3)$$

4.2.2 Second time slot: relay to NU, FU transmission

Assuming one or more relays successfully decode x_F and x_N after the first time slot. Now, the relay selection scheme is applied to select a relay R_{sel} . The selected relay R_{sel} then transmits signal to NU and FU using NOMA. The received signal at NU is

$$y_{N,2} = \left(\sqrt{\beta\,(I_p/|g_{R_{sel}}|^2)}\,x_F + \sqrt{(1-\beta)I_p/|g_{R_{sel}}|^2}\,x_N\right)h_{R_{sel}N} + n_N \quad (4)$$

where $0 < \beta < 1$ is the NOMA power-allocation parameter of the selected relay, and $n_N \sim CN\,(0, \sigma^2)$ is the additive white Gaussian noise (AWGN) at the NU.

The NU uses θ portion of the received signal power for energy harvesting and uses the rest for decoding messages as shown in Fig. 4. So, SINR for decoding x_F at NU can be written as

$$\gamma_{N,x_F,2} = \frac{(1-\theta)\beta\,(I_p/|g_{R_{sel}}|^2)|h_{R_{sel}N}|^2}{(1-\theta)(1-\beta)\,I_p/|g_{R_{sel}}|^2\,|h_{R_{sel}N}|^2 + \sigma^2} \quad (5)$$

and, SNR for decoding x_N at NU can be written as

$$\gamma_{N,x_N,2} = \frac{(1-\theta)(1-\beta) I_p/|g_{R_{sel}}|^2 |h_{R_{sel}N}|^2}{\sigma^2} \tag{6}$$

Similarly, the received signal at FU is

$$y_{F,2} = (\sqrt{\beta (I_p/|g_{R_{sel}}|^2)}\, x_F + \sqrt{(1-\beta) I_p/|g_{R_{sel}}|^2}\, x_N)\, h_{R_{sel}F} + n_F \tag{7}$$

where $n_F \sim CN(0, \sigma_2)$ is the additive white Gaussian noise (AWGN) at the FU.

The SINR for decoding xF at FU can be written as

$$\gamma_{F,x_F,2} = \frac{\beta (I_p/|g_{R_{sel}}|^2)|h_{R_{sel}F}|^2}{(1-\beta) I_p/|g_{R_{sel}}|^2 |h_{R_{sel}F}|^2 + \sigma^2} \tag{8}$$

4.2.3 Third time slot: NU to FU transmission

The NU uses harvested energy to transfer message x_F to FU. The power harvested at NU is $P_N^H = \theta\eta I_P/|g_{Rsel}|^2|h_{RselN}|^2$ where $0 < \eta < 1$ is the energy harvesting efficiency. For practical cases, harvested power P_N^H is very small [20] which ensures that $P_N^H << I_P/|g_N|^2$. So, the signal received at FU in the third time slot is

$$y_{F,3} = \sqrt{P_N^H}\, x_F h_{NF} = \sqrt{\theta\eta (I_p/|g_{R_{sel}}|^2)|h_{R_{sel}N}|^2}\, x_F h_{NF} + n_N \tag{9}$$

and, the SNR can be written as

$$\gamma_{F,x_F,3} = \frac{\theta\eta(I_p/|g_{R_{sel}}|^2)|h_{R_{sel}N}|^2 |h_{NF}|^2}{\sigma^2} \tag{10}$$

At the end of the third time slot, FU has two signals, one from the relay during the second time slot and the other from NU during the third time-slot. Now FU combines these messages using maximal ratio combining (MRC). The SNR after combining becomes $\gamma_{F,x_F} = \gamma_{F,x_F,2} + \gamma_{F,x_F,3}$ which can be written using (8) and (10) as

$$\gamma_{F,x_F} = \frac{\beta (I_p/|g_{R_{sel}}|^2)|h_{R_{sel}F}|^2}{(1-\beta) I_p/|g_{R_{sel}}|^2 |h_{R_{sel}F}|^2 + \sigma^2} + \frac{\theta\eta(I_p/|g_{R_{sel}}|^2)|h_{R_{sel}N}|^2 |h_{NF}|^2}{\sigma^2} \tag{11}$$

Chapter 5

Outage And Throughput Calculations

This chapter provides the analytical expressions for outages and throughput.

5.1 Outage at Relay

The k^{th} relay R_k where $k \in K$ is considered to be in outage when it is unable to successfully decode either x_F or x_N or both. We consider an outage at relay if all the relays are in outage due to which no relay is able to transmit information in the second time slot. This is equivalent to the selected relay being in outage. The outage probability can be written as

$$P_{out,rel} = Pr(\gamma_{R_{sel}, x_F, 1} < \tau_F) + Pr(\gamma_{R_{sel}, x_N, 1} < \tau_N, \gamma_{R_{sel}, x_F, 1} > \tau_F) \quad (12)$$

Let $P1_R = Pr(\gamma_{R_{sel}, x_F, 1} < \tau_F)$ and $P2_R = Pr(\gamma_{R_{sel}, x_N, 1} < \tau_N, \gamma_{R_{sel}, x_F, 1} > \tau_F)$.

We define a random variable Z such that $Z = (I_P/\sigma^2)|h_{SR}|^2|g_S|^2$ where, $|h_{SR}|^2 = \max\{|h_{SRk}|^2_{k\in K}\}$ and $F_{|h_{SR}|^2}(h) = (1 - e^{-\lambda_{SR}h})^K$. So, the CDF of Z can be written as

$$F_Z(z) = Pr(Z < z)$$

$$= Pr(\frac{(I_p/\sigma^2)|h_{SR}|^2}{|g_S|^2} < z)$$

$$= Pr(|h_{SR}|^2 < \frac{z|g_S|^2}{(I_p/\sigma^2)})$$

$$= \int_0^\infty \lambda_S (1 - e^{-\lambda_{SR}\frac{z|g_S|^2}{(I_p/\sigma^2)}})^K e^{-\lambda_S |g_S|^2} d|g_S|^2$$

$$= \prod_{k=1}^{K} \frac{\lambda_{SR}zk}{\lambda_{SR}zk+\lambda_S(I_p/\sigma^2)} \quad (13)$$

Now, $\gamma_{R_k, x_F, 1} = \frac{\alpha Z}{(1-\alpha)Z+1}$, so $P1_R = Pr(\gamma_{R_k, x_F, 1} < \tau_F)$

$$= Pr(\frac{\alpha Z}{(1-\alpha)Z+1} < \tau_F)$$

$$= Pr(Z < \frac{\tau_F}{\alpha - \tau_F(1-\alpha)})$$

$$= F_Z(\frac{\tau_F}{\alpha - \tau_F(1-\alpha)}) \qquad (14)$$

Similarly, $\gamma_{R_k, x_N, 1} = (1 - \alpha)Z$, so $P2_R = Pr(\gamma_{R_k, x_N, 1} < \tau_N, \gamma_{R_k, x_F, 1} > \tau_F)$

$$= Pr((1 - \alpha)Z < \tau_N, \frac{\alpha Z}{(1-\alpha)Z+1} > \tau_F)$$

$$= Pr(\frac{\tau_F}{\alpha - \tau_F(1-\alpha)} < Z < \frac{\tau_N}{1-\alpha})$$

$$= F_Z(\frac{\tau_N}{1-\alpha}) - F_Z(\frac{\tau_F}{\alpha - \tau_F(1-\alpha)}) \qquad (15)$$

So, $P_{out,rel}$ can be written as

$$P_{out,rel} = P1_R + P2_R$$

$$= F_Z(\frac{\tau_N}{1-\alpha})$$

$$= \prod_{k=1}^{K} \frac{\lambda_{SR}\tau_N k}{\lambda_{SR}\tau_N k + \lambda_S(I_p/\sigma^2)(1-\alpha)} \qquad (16)$$

5.2 Outage at Near-User

Outage occurs at NU if any one of the following conditions are met:

- All relays are in outage
- $\gamma_{F, x_F, 2} < \tau_F$ (i.e., NU fails to perform SIC to decode x_N), provided at least one relay is not in outage
- $\gamma_{F, x_F} < \tau_F$ (i.e., NU is able to perform SIC but fails to decode x_N), provided at least one relay is not in outage

The outage probability at NU given that at least one of the relays is not in outage, can be written as

$$P_{out,N} = Pr(\gamma_{N,x_F,2} < \tau_F) + Pr(\gamma_{N,x_N,2} < \tau_N, \gamma_{N,x_F,2} > \tau_F)$$

Let $P1_N = Pr(\gamma_{N,x_F,2} < \tau_F)$ and $P2_N = Pr(\gamma_{N,x_N,2} < \tau_N, \gamma_{N,x_F,2} > \tau_F)$.

We define a random variable X such that X = $(I_P/\sigma^2)|h_{RselN}|^2|g_{Rsel}|^2$ where, $F_{|h_{R_{sel}N}|^2}(h) = 1 - e^{-\lambda_{RN}h}$. So, the CDF of Z can be written as

$$F_X(x) = Pr(X < x)$$

$$= Pr(\frac{(I_p/\sigma^2)|h_{R_{sel}N}|^2}{|g_{R_{sel}}|^2} < x)$$

$$= Pr(|h_{R_{sel}N}|^2 < \frac{x|g_{R_{sel}}|^2}{(I_p/\sigma^2)})$$

$$= \int_0^\infty \lambda_R(1 - e^{-\lambda_{RN}\frac{x|g_{R_{sel}}|^2}{(I_p/\sigma^2)}})e^{-\lambda_R|g_{R_{sel}}|^2} d|g_{R_{sel}}|^2$$

$$= \frac{\lambda_{RN}x}{\lambda_{RN}x+\lambda_R(I_p/\sigma^2)} \qquad (17)$$

Now, $\gamma_{N,x_F,1} = \frac{(1-\theta)\beta X}{(1-\theta)(1-\beta)X+1}$, so $P1_N = Pr(\gamma_{N,x_F,1} < \tau_F)$

$$= Pr(\frac{(1-\theta)\beta X}{(1-\theta)(1-\beta)X+1} < \tau_F)$$

$$= Pr(X < \frac{\tau_F}{(1-\theta)(\beta-\tau_F(1-\beta)})$$

$$= F_X(\frac{\tau_F}{(1-\theta)(\beta-\tau_F(1-\beta)}) \qquad (18)$$

Similarly, $\gamma_{N,x_N,2} = (1-\theta)(1-\beta)X$, so $P2_N = Pr(\gamma_{N,x_N,2} < \tau_N, \gamma_{N,x_F,2} > \tau_F)$

$$= Pr((1-\theta)(1-\beta)X < \tau_N, \frac{(1-\theta)\beta X}{(1-\theta)(1-\beta)X+1} > \tau_F)$$

$$= Pr(\frac{\tau_F}{(1-\theta)(\beta-\tau_F(1-\beta)} < X < \frac{\tau_N}{(1-\theta)(1-\beta)})$$

$$= F_X(\frac{\tau_N}{(1-\theta)(1-\beta)}) - F_X(\frac{\tau_F}{(1-\theta)(\beta-\tau_F(1-\beta)}) \quad (19)$$

So, $P_{out,N}$ can be written as

$$P_{out,N} = P1_N + P2_N$$

$$= F_Z(\frac{\tau_N}{(1-\theta)(1-\beta)})$$

$$= \frac{\lambda_{RN}\tau_N}{\lambda_{RN}\tau_N+\lambda_R(I_p/\sigma^2)(1-\theta)(1-\beta)} \quad (20)$$

The total outage probability at NU is $P_{out,NU} = P_{out,rel} + P_{out,N}(1 - P_{out,rel})$.

5.3 Outage at Far-User

Outage occurs at FU if any one of the following conditions are met:

- All relays are in outage
- $\gamma_{F,x_F,2} < \tau_F$ provided that NU fails to decode x_F : $\gamma_{N,x_F,2} < \tau_F$, and at least one relay is not in outage
- $\gamma_{F,x_F} < \tau_F$ provided that NU is able to transmit to FU : $\gamma_{N,x_F,2} < \tau_F$, and at least one relay is not in outage

The outage probability at FU given that at least one of the relays is not in outage, can be written as

$$P_{out,F} = Pr(\gamma_{F,x_F,2} < \tau_F, \gamma_{N,x_F,2} < \tau_F) + Pr(\gamma_{F,x_F} < \tau_F, \gamma_{N,x_F,2} > \tau_F)$$

(21)

Let $P1_F = Pr(\gamma_{F,x_F,2} < \tau_F, \gamma_{N,x_F,2} < \tau_F)$ and $P2_F = Pr(\gamma_{F,x_F} < \tau_F, \gamma_{N,x_F,2} > \tau_F)$

then

$$P1_F = Pr(\gamma_{F,x_F,2} < \tau_F, \gamma_{N,x_F,2} < \tau_F)$$

$$= Pr\left(\frac{\beta(I_p/|g_{R_{sel}}|^2)|h_{R_{sel}F}|^2}{(1-\beta)I_p/|g_{R_{sel}}|^2|h_{R_{sel}F}|^2+\sigma^2} < \tau_F, \frac{(1-\theta)\beta(I_p/|g_{R_{sel}}|^2)|h_{R_{sel}N}|^2}{(1-\theta)(1-\beta)I_p/|g_{R_{sel}}|^2|h_{R_{sel}N}|^2+\sigma^2} < \tau_F\right)$$

$$= \int_0^\infty \left(\int_0^{\frac{u|g_{R_{sel}}|^2}{I_p/\sigma^2}} \lambda_{RF} e^{-\lambda_{RF}y} dy\right)\left(\int_0^{\frac{v|g_{R_{sel}}|^2}{I_p/\sigma^2}} \lambda_{RN} e^{-\lambda_{RN}x} dx\right)\lambda_R e^{-\lambda_R|g_{R_{sel}}|^2} d|g_{R_{sel}}|^2$$

(22)

where, $u = \frac{\tau_F}{\beta-\tau_F(1-\beta)}$ and $v = \frac{\tau_F}{(1-\theta)(\beta-\tau_F(1-\beta)}$

and,

$$P2_F = Pr(\gamma_{F,x_F} < \tau_F, \gamma_{N,x_F,2} > \tau_F)$$

Using the method in [20], we can write $P2_F$ as

$$P2_F = \int_0^\infty \int_0^{p(1-\theta)b} \int_0^{q/p} \lambda_R \lambda_{RF} \lambda_{NF} (e^{-\lambda_{RN}bp} - e^{-\lambda_{RN}bq/y}) e^{-\lambda_{RF}y - \lambda_{NF}x - \lambda_R b} dy\, dx\, db \qquad (23)$$

where, $q = \frac{1}{\eta\theta I_p/\sigma^2}\left(\tau_F - \frac{\beta(I_p/\sigma^2)y}{(1-\beta)(I_p/\sigma^2)y+b}\right)$ and $p = \frac{\tau_F}{(1-\theta)(\beta-\tau_F(1-\beta)}$

The total outage probability at FU is $P_{out,FU} = P_{out,rel} + (P1_F + P2_F)(1 - P_{out,rel})$

.

5.4 Throughput Performance

The system's throughput is based on evaluated outage probability at near and far users. The throughput of the system is expressed as the sum of near-user throughput and far user throughput. It can be written as

$$\Gamma = \Gamma_N + \Gamma_F$$

$$= r_N(1 - P_{out,NU}) + r_F(1 - P_{out,FU}) \quad (24)$$

where r_N and r_F are information transmission rates of near-user and far-user respectively. Also, the first and the second term indicate throughputs at near-user and far-user respectively.

Chapter 6

Numerical Results And Discussions

This chapter contains Monte-Carlo simulations of the proposed relay selection scheme and numerical analysis to validate the derived expressions. The simulations are performed using MATLAB.

For simulations, unless stated otherwise, the following parameters have been taken. The rate requirements for NU and F U are taken as rN = 2 and rF = 1 respectively. Distance between S and all relays is taken as dSR = 2. Distances between relays NU and relays F U are taken as dRN = 2 and dRF = 4 respectively. And, the distance between NU and F U is taken as dN F = 2. Also distance of source, relays and near-user of secondary network from primary transmitter are taken as dS = dR = dN = 6.

6.1 Outage at NU, FU

It is seen in Fig. 6.1 that the simulated outage probabilities match perfectly with the analytical expressions derived in Chapter 5. It is observed that the relay selection scheme proposed in this project does not only significantly reduce the far user outage compared to the single relay network but also the decline is steeper.

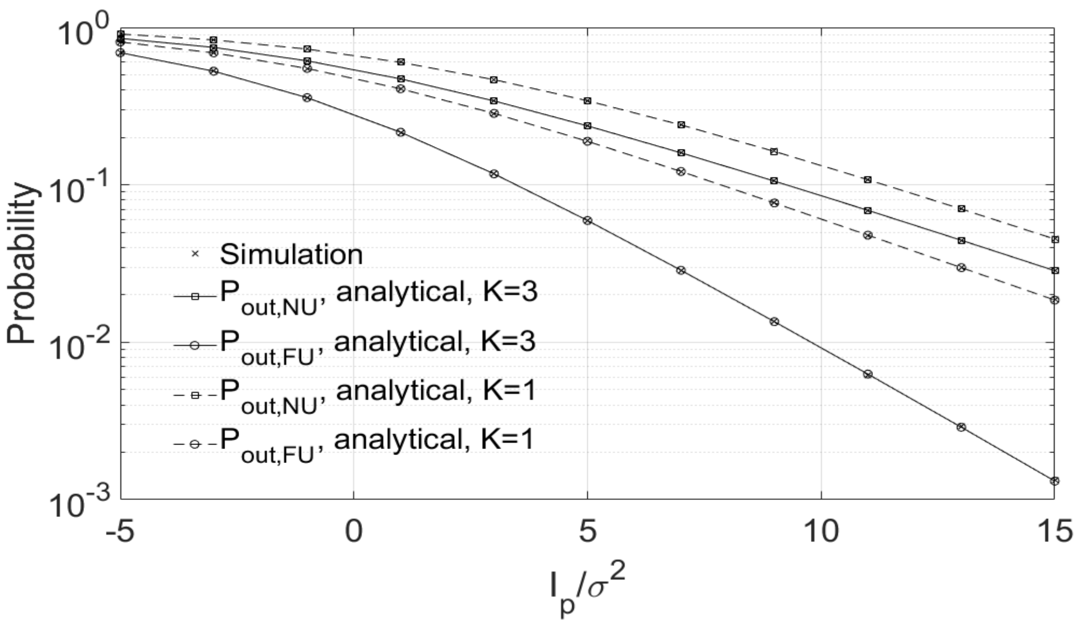

Fig 6.1: Outage probability of near-user and far-user vs I_p/σ^2

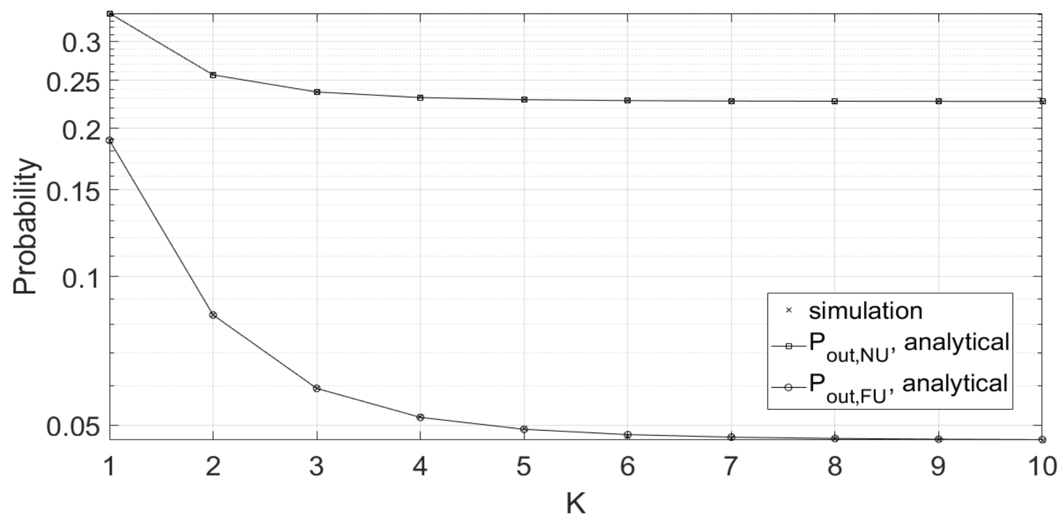

Fig 6.2: Outage probability of near-user and far-user vs K

6.2 Throughput vs K

Fig 6.3 shows the plot of the combined throughput of near and far users. This plot helps to determine the optimal number of relays to be used under various power constraints (ITL) to maximize system throughput.

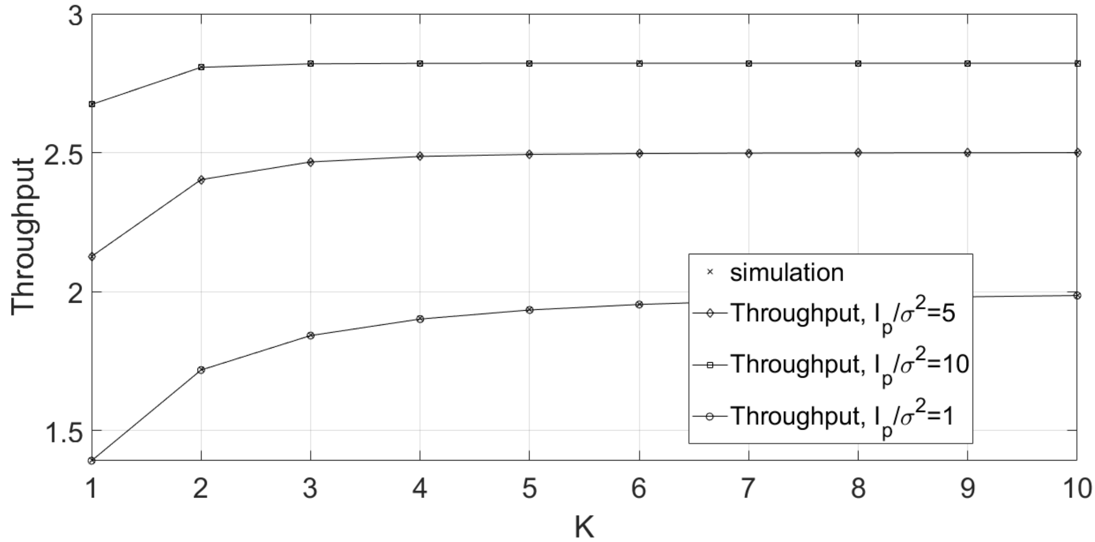

Fig 6.3: Throughput vs K

Chapter 7

Conclusion and Future Work

In this project, a secondary underlay cooperative NOMA network with multiple relays and energy harvesting near-user is investigated. To prevent inter-cell interference with the primary network, power constraints imposed due to ITL are taken into consideration at secondary nodes' transmission. A relay selection scheme is proposed to maximize system throughput. Performance of the network under proposed scheme is evaluated in terms of outage probabilities and combined throughput of near and far users. Analytical expressions for the same have been derived and verified by extensive MATLAB simulations. Outage and throughput as functions of ITL and K have been investigated and it is shown via numerical results that the performance (especially at FU) improves significantly. Further, the relation between the optimal number of relays for given power constraints, and system throughput is explored.

In future I would like to continue this research work and extend the scope of this project. Building upon this work, I plan to analyse the network taking into consideration parameters that are currently beyond the scope of this project. I also intend to work on an improvement of the selection scheme proposed in this project and also investigate the network for other performance metrics such as maximizing capacity, etc. At last, I plan to compile the research work in the form of an academic paper.

References

[1] E. Hossain and M. Hasan, “5G cellular: key enabling technologies and research challenges,” in IEEE Instrumentation & Measurement Magazine, vol. 18, no. 3, pp. 11-21, June 2015.

[2] T. O. Olwal, K. Djouani and A. M. Kurien, “A Survey of Resource Management Toward 5G Radio Access Networks,” in IEEE Communications Surveys & Tutorials, vol. 18, no. 3, pp. 1656-1686, third quarter 2016.

[3] M. Agiwal, A. Roy and N. Saxena, “Next Generation 5G Wireless Networks: A Comprehensive Survey,” in IEEE Communications Surveys & Tutorials, vol. 18, no. 3, pp. 1617-1655, thirdquarter 2016.

[4] D. Niyato, D. I. Kim, M. Maso and Z. Han, “Wireless Powered Communication Networks: Research Directions and Technological Approaches,” in IEEE Wireless Communications, vol. 24, no. 6, pp. 88-97, Dec. 2017.

[5] Khan R., et al. Modulation based non-orthogonal multiple access for 5G resilient networks 2018 IEEE Globecom Workshops (GC Wkshps), IEEE (2018)

[6] Islam S.M.R., et al.Power-domain non-orthogonal multiple access (NOMA) in 5G systems: Potentials and challenges IEEE Commun. Surv. Tutor. (2016), p. 1

[7] Basharat M., et al. A survey and taxonomy on non orthogonal multiple-access schemes for 5G networks Trans. Emerg. Telecommun. Technol., 29 (1) (2018), Article e3202

[8] Ding Z., et al. A survey on non-orthogonal multiple access for 5G networks: Research challenges and future trends IEEE J. Sel. Areas Commun. (2017)

[9] K. Janghel and S. Prakriya, “Performance of Adaptive OMA/Cooperative-NOMA Scheme With User Selection,” in IEEE Communications Letters, vol. 22, no. 10, pp. 2092-2095, Oct. 2018.

[10] M. Zeng, W. Hao, O. A. Dobre and Z. Ding, "Cooperative NOMA: State of the Art, Key Techniques, and Open Challenges," in IEEE Network, vol. 34, no. 5, pp. 205-211, September/October 2020, doi: 10.1109/MNET.011.1900601.

[11] Liaqat M., et al. Power-domain non orthogonal multiple access (PD-NOMA) in cooperative networks: an overview Wirel Netw. (2018), pp 1-23

[12] W. Liu, X. Zhou, S. Durrani and P. Popovski, "SWIPT with practical modulation and RF energy harvesting sensitivity," 2016 IEEE International Conference on Communications (ICC), 2016, pp. 1-7, doi: 10.1109/ICC.2016.7511404.

[13] Waqar O., Liaqat M. Throughput analysis of wireless energy-harvesting relaying protocols for nakagami-m fading channels. Arab. J. Sci. Eng., 44 (8) (2019), pp, 6851-6860

[14] B. Van Nguyen, Q.-D. Vu, K. Kim, Analysis and Optimization for Weighted Sum Rate in Energy Harvesting Cooperative NOMA Systems. arXiv preprint arXiv:1806.02064, 2018.

[15] Z. Ding, H. Dai and H. V. Poor, "Relay Selection for Cooperative NOMA," in IEEE Wireless Communications Letters, vol. 5, no. 4, pp. 416-419, Aug. 2016, doi: 10.1109/LWC.2016.2574709.

[16] Y. Li, Y. Li, X. Chu, Y. Ye and H. Zhang, "Performance Analysis of Relay Selection in Cooperative NOMA Networks," in IEEE Communications Letters, vol. 23, no. 4, pp. 760-763, April 2019, doi: 10.1109/LCOMM.2019.2898409.

[17] Hoang, T.M., Tan, N.T., Hoang, N.H. et al. Performance analysis of decode-and-forward partial relay selection in NOMA systems with RF energy harvesting. Wireless Netw 25, 4585–4595 (2019). https://doi.org/10.1007/s11276-018-1746-8

[18] A. V. and B. A. V., "Performance Analysis of NOMA-Based Underlay Cognitive Radio Networks With Partial Relay Selection," in IEEE Transactions on Vehicular Technology, vol. 70, no. 5, pp. 4615-4630, May 2021, doi: 10.1109/TVT.2021.3071338.

[19] Xu P., et al. Optimal relay selection schemes for cooperative NOMA IEEE Trans. Veh. Technol, (2018), p. 1

[20] Garima Singhal, Shashi Bhushan Kotwal, Sudhakar Modem, Shankar Prakriya., “Performance of Cooperative Relayed NOMA with Energy Harvesting Nodes in Underlay Networks”, 2020 International Conferences on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData) and IEEE Congress on Cybermatics (Cybermatics), 2020, pp. 385-391, doi: 10.1109/iThings-GreenCom-CPSCom-SmartData-Cybermatics50389.2020.00075.