EVALUATION OF RELAY SELECTION SCHEMES FOR COOPERATIVE NON-ORTHOGONAL MULTIPLE ACCESS (C-NOMA) WITH SIMULTANEOUS WIRELESS INFORMATION AND POWER TRANSFER (SWIPT)

MUHAMMAD SYAZWAN BIN ADI RUMI

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
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MUHAMMAD SYAZWAN BIN ADI RUMI

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Name of Candidate: MUHAMMAD SYAZWAN BIN ADI RUMI

I.C/Passport No: 990421-10-6985

Matric No: 17112597/2

Name of Degree: BACHELOR OF ELECTRICAL ENGINEERING

Title of Project Paper: EVALUATION OF RELAY SELECTION SCHEMES FOR COOPERATIVE NOMA (CNOMA) WITH SIMULTANEOUS WIRELESS INFORMATION AND POWER TRANSFER (SWIPT)

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ABSTRACT

In this project, the outage probability of cooperative relaying transmission in non-orthogonal multiple access (NOMA), where simultaneous wireless information and power transfer (SWIPT) is used as the energy harvesting (EH) method to power up the relaying operations is studied. Various relay selection schemes were evaluated and simulated using MATLAB version R2022a based on existing research papers that are conducted by other researchers. The basics of NOMA and basics of SWIPT were explained in words and simulated using MATLAB to further correlate the researched relay selection schemes with the basics. The main evaluation of performance for the relay selection scheme is the outage probability and achievable rate of the far user given that the system model is in C-NOMA with SWIPT. The researched relay selection scheme is through transmit antenna selection (TAS) where 3 schemes were proposed, and best-near best-far (BNBF) user selection schemes were proposed as user selection for relaying. The best method for selecting relay that is simulated in this project is when the far user is selected to have the maximised instantaneous achievable rate, and uses less complexity. An optional way to improve outage probability can also be by increasing the number of near users in the system to act as more route for relay selections, but that method is limited by the maximum transmit power that can be transmitted by the base station.

Keywords: Cooperative non-orthogonal multiple access(C-NOMA); simultaneous wireless information and power transfer (SWIPT); relay selection; outage performance;

PENILAIAN SKIM PEMILIHAN GEGANTI BAGI AKSES BERGANDA BUKAN ORTOGONAL SECARA KOPERASI (C-NOMA) DENGAN PEMINDAHAN MAKLUMAT DAN KUASA TANPA WAYAR(SWIPT) SERENTAK

ABSTRAK

Dalam projek ini, kebarangkalian gangguan telah dikaji untuk penghantaran penyampaian secara berkolaborasi dalam akses berganda bukan orthogonal (NOMA), di mana pemindahan maklumat dan kuasa tanpa wayar (SWIPT) yang telah digunakan sebagai penuaian tenaga (EH) untuk memberi kuasa kepada operasi penyampaian. Pelbagai skim pemilihan geganti telah dinilai dan disimulasi menggunakan aplikasi MATLAB versi R2022a berdasarkan kertas penyelidikan yang telah dijalankan oleh penyelidik-penyelidik lain. Asas-asas NOMA dan asas-asas SWIPT telah diterangkan dalam perkataan dan disimulasi menggunakan MATLAB untuk menghubungkait dengan lebih teliti antara skim pemilihan geganti yang telah dikaji dengan asas-asasnya. Penilaian utama dalam skim pemilihan geganti adalah dengan kebarangkalian gangguan dan kadar yang boleh dicapai oleh pengguna jauh dalam model sistem C-NOMA dan SWIPT. Skim pemilihan geganti yang dikaji adalah melalui pemilihan antena penghantar (TAS), di mana tiga skim telah dicadangkan, dan skim pemilihan pengguna dekat-terbaik jauh-terbaik (BNBF) telah dicadangkan sebagai pemilihan pengguna untuk penyampaian data. Kaedah terbaik untuk pemilihan geganti yang telah disimulasi dalam projek ini adalah apabila pengguna jauh dipilih dengan kadar boleh dicapai serta-merta yang maksimum, dan menggunakan kerumitan yang rendah. Kaedah alternatif untuk penambahbaikan kebarangkalian gangguan adalah dengan memperbanyakkan bilangan pengguna dalam sistem untuk bertindak sebagai laluan untuk pemilihan geganti, tetapi kaedah ini telah dihadkan oleh kuasa penghantaran maksimum yang boleh dihantar daripada stesen pengkalan.

Kata kunci: Akses berganda bukan ortogonal secara koperasi (C-NOMA); Pemindahan maklumat dan kuasa tanpa wayar (SWIPT); pemilihan geganti; kebarangkalian gangguan;

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LIST OF SYMBOLS AND ABBREVIATIONS

For examples:

NOMA	:	Non-orthogonal Multiple Access
SWIPT	:	Simultaneous wireless information and power transfer
BS	:	Base station
MA	:	Multiple access
SC	:	Superposition coding
EH	:	Energy harvesting
CSI	:	Channel state information
RF	:	Radio frequency
SIC	:	Successive interference cancelling
BER	:	Bit error rate
SNR	:	Signal to noise ratio
TAS	:	Transmit antenna selection
BNBF	:	Best-near best-far
BNWF	:	Best-near worst-far
WNBF	:	Worst-near best-far
RNRF	:	Random-near random-far
QoS	:	Quality of service
AWGN	:	Additive white gaussian noise

CHAPTER 1: INTRODUCTION

1.1 Background

The technology of mobile communication has had a significant impact on wireless networks. The number of mobile networks has continued to grow at an incredible rate, as expected. Kamal, M. A., et al. (2021) states that as the technology advances, society will have a much more mobility to be connected, characterized by significant gains in traffic volume, different depth of network usage, higher data consumption rate, and a lot more other situation. Network traffic will significantly grow. Nowadays, mobile devices are projected to be the most popular personal gadgets, other types of devices, such as wearables and smart devices, are expected to grow in popularity. As a result, 5G cellular communications system should be widely deployed to meet the ever-changing needs that previous generations of systems were unable to meet.

Despite advances in 4G wireless network technology, providing wireless network services that require high speed, quick response, high consumption, and energy efficiency is challenging. As a result, these features have emerged as important requirements for future 5G services. Current 4G/LTE networks are unable to deliver instant cloud services, interactive Internet, enhanced vehicle-to-everything (eV2X), Internet of Things (IoT), and communication with drones and robotics while retaining a high degree of user experience. As a result, the globe has experienced numerous technological advancements in the transmission arena.

This cutting-edge trend in technology change is how we live, work, and interact with one another. We've seen the birth of incredible services and applications, such as self-driving cars, artificial intelligence, smart homes, smart factories, smart cities, and drone-based delivery systems. The future wireless settings will be expanded by establishing the relationship between equipment and human-based guidance. Mobile phone communication capabilities will keep on expanding, and they will influence all parts of public life, creating a multidimensional, consumer-related ecosystem. Thus, it is crucial to tackle in aspect of cost-effective issues. With increased traffic, a considerably large number of implications, and an incredible amount of connectivity expansion are to be expected. Mobile networks will need to supply a thousand times the spectral efficiency of the present technology structure because of this huge increase in traffic. Furthermore, mobile networks of the fourth generation (4G) were linked to a 5 to 15-fold increase in spectrum efficiency (SE).

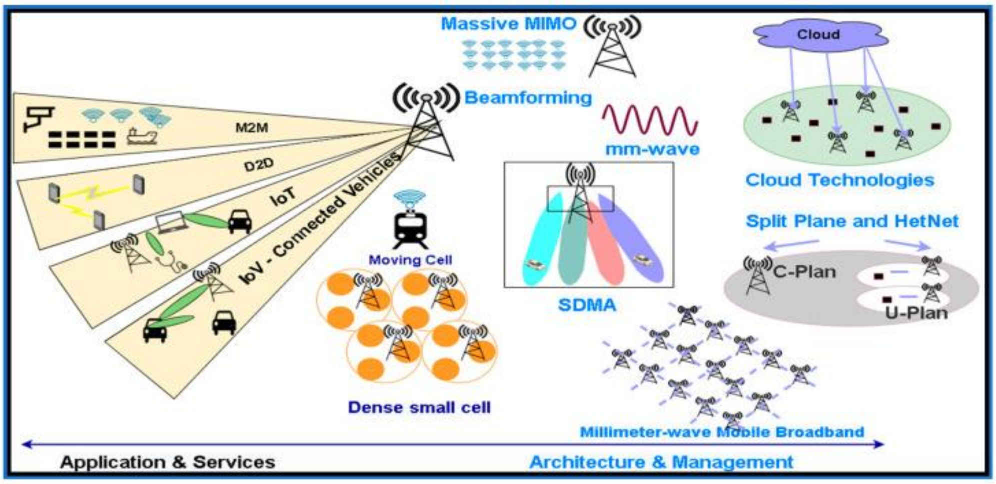

Figure 1.1: 5G designs and applications

The 5G network incorporates a variety of technologies, including the Internet of Things (IoT), device-to-device (D2D) communications, software-defined networking (SDN), mobile edge computing (MEC), cloud computing, and cloud radio access networks (CRANs). From research by Pi, Z., et al (2011) and Siddiqi M.A., et al. (2019), it is found out that maintaining the current rate of advancement toward addressing this critical need would necessitate the use of cutting-edge technology to boost the massive cellular capabilities envisaged in the celebrated 5G cellular architecture. The importance of wireless structures that offer improved spectral proficiency and broader bandwidth than current cellular networks via the placement of multiple antenna components and frequency reuse has been stressed in numerous academic and industrial related research studies to overcome the challenges.

Wireless networks of 5G network are intended to meet the increased needs for wireless communication. Rapid advancement of technology of the IoT, fifth generation networks must be able to accommodate massive amounts of device or consumer connectivity. According to Liaqat, M., et al. (2020), in comparison to current fourth generation (4G) cellular networks, 5G is expected to provide the following key benefits: 10–100 times faster data rates, up to 99.99 percent availability, reduced delays, 10–100 times more connected devices, guaranteed coverage, 10 times lower energy consumption, and efficient improvement of current wireless systems with new 5G techniques. To achieve these expectations, advanced technologies are necessary.

1.2 Multiple Access

Multiple access techniques have long been regarded as crucial in the design of wireless generation networks, as well as in evaluating the efficiency of any communication system. The basic physical connection in mobile network is defined by radio access technology. Radio access technology is implemented through the use of a radio access network, which connects wireless terminals to the core network via the channel access technique. Multiple access (MA) systems paves the way for multiple users to share the same resource. These methods may be classified into two categories: non-orthogonal multiple access (NOMA) and orthogonal multiple access (OMA). By allocating orthogonal resources to users, OMA methods avoid interfering signals. OMA techniques include time division multiple access (TDMA), frequency division multiple access (FDMA), and code division multiple access (CDMA). According to Liaqat, M., et al. (2020), existing OMA techniques, which distribute orthogonal resources like time, frequency, and codes to multiple users, lack the spectral efficiency necessary to handle 5G standards.

To design networks that has optimal spectral efficiency, NOMA has been demonstrated to be a good access mechanism for 5G networks. Multiple users can be handled at the same time, frequency, or spreading code using power domain NOMA, and multiplexing is implemented in the power domain at which, various power levels are allocated for different users. Power levels are allocated based on channel conditions or intended users' quality of service needs. To use NOMA, several users' messages are superimposed at the base station (BS) using superposition coding (SC). The messages of all weaker users are removed using successive interference cancellation (SIC) at each user, while the messages of strong users are treated as noise to detect their own information as mentioned in research by Ding, Z., et al. (2017). Massive connectivity, low latency, spectrum efficiency, and user fairness are all guaranteed by NOMA.

In a wireless network, every idle node can listen in on the communications of other network users. This idle node can assist in transmitting messages of its peer by utilizing the idea of cooperation. By transmitting several signals through relaying, this cooperation ensures increased consistency. Furthermore, when a direct contact between BS and a user cannot be formed due to poor channel conditions, relaying can assist in transferring the information of such users. In general, relay is chosen since it is closer to BS and requires less power at BS to send the signal to relay. According to Laneman, J. N., et al. (2004), relay networks are more reliable because of its vast advantages in terms of reliability, broader coverage area and power saving. Multiple cooperative relaying protocols have been developed to enable cooperation, the most notable of which are amplify and forward (AF) and decode and forward (DF). The intermediate relay node in AF relaying sends an amplified message to the destination, but in DF relaying, a re-encoded message is sent.

In cooperative networks, better performance comes at the expense of more spectral resources. NOMA can assist to decrease spectral loss due to collaboration since it can handle several users on the same frequency channels. Furthermore, according to Xu, Y., et al. (2015), as compared to cooperative OMA approaches, employing collaboration between relay with NOMA improves performance.

1.3 Energy Harvesting

Wei X., et al. (2017) states that self-sustainability and energy efficiency, in addition to spectral efficiency, are significant design characteristics for 5G wireless networks. Radio frequency energy harvesting (RF-EH) has emerged as a key approach for enabling self-sustaining networks in this area. Simultaneous wireless information and power transfer (SWIPT) is a method of RF-EH that uses the same RF signal for both EH and information processing. In other cases, recharging or changing batteries is either too expensive or impossible. Self-sustaining systems might be beneficial in sensor networks where fixed power lines cannot be established, or on the Internet of Things where replacing the batteries of a large number of nodes is technically infeasible.

In cooperative networks, any intermediate node may not be ready to participate because it will have to pay at the price of its own energy resources, or in case of dedicated relay, it may have a restricted power supply. In these cases, EH becomes particularly attractive as mentioned by Waqar, O., et al. (2019). The adoption of SWIPT encourages user participation by giving a solution for energy needs. As a result, combining SWIPT in cooperative NOMA networks, also known as cooperative NOMA (C-NOMA), results in spectral and energy efficient networks. Energy is collected from the transmitted source signal in these networks, but due to the random nature of the paths between source and relay, the harvested energy becomes random and unpredictable, making network analysis difficult and complicated.

1.4 Relay Selection

By forming a virtual antenna array with cooperative networks with many relays, it is possible to improve signal dependability. However, because network resources are limited, using all available nodes for relaying is not recommended. Relay selection is the most effective method for achieving cooperative diversity via multiple relaying. Only the best available relay is used for relaying information in a multi-relay cooperative network with relay selection. Because just one relay is active at any given time, all relays do not need to be in strict time or carrier synchronization. Due to the reduced complexity and costs, relay selection is taken into account.

The performance of a basic cooperative relay network can be improved by deploying several relays. Multiple relay networks, on the other hand, improve performance at the price of complexity and spectral resources. Relay selection (RS) is the most effective method for implementing cooperative diversity through multiple relaying. Only one selected relay passes the message across RS, hence there is no spectral loss due to many relays. Furthermore, unlike multiple relay networks, a single relay runs at a time, requiring no stringent time or carrier coordination across all relays, resulting in decreased complexity and costs. It is critical to clarify that, from a practical standpoint, RS is critical to the successful implementation of future networks.

1.5 Problem Statement

The problem statement for this project is ideally, any communication that involves transferring information should have the lowest value of outage probability as possible. In C-NOMA that is utilized by SWIPT energy harvesting method, the common problem is that to obtain low outage probability, it would come at the cost of high complexity. Having high complexity makes the production not viable and not effective to be mass produced. Thus, by selectively identifying the optimal method of relay selection in C-NOMA with SWIPT, it is possible to obtain the optimal outage probability using the least complexity as possible. Evaluating the performance of several relay selection schemes used in Cooperative NOMA (C-NOMA) with simultaneous wireless information and power transfer (SWIPT) is achievable by doing the analysis on the performance comparison of several relay selection schemes used in Cooperative NOMA (C-NOMA) based on the existing related works. The performance of cooperative NOMA is evaluated by observing the value of outage probability, achievable rate, and user SNR/SINR. At the end of this project, various relay selection schemes will be analyzed from various existing related works and some of the system models are simulated to further support the evidence of that is researched.

1.6 Objectives

The objective of this project is as listed below.

- To identify the best relay selection schemes that gives the optimal outage probability to all users in cooperative communication system with SWIPT using the least complexity as possible.
- To observe the system behavior in terms of achievable rate for all users when the transmit power from base station is increased

- To determine the variables that affects the outage probability of all users in C-NOMA with SWIPT when the transmit power from base station is increased

CHAPTER 2: LITERATURE REVIEW

Non-orthogonal multiple access (NOMA) was suggested for 3GPP LTE and is expected to be a key component of 5G mobile networks. The essential characteristic of NOMA is that it may serve numerous users at the same time, frequency, and code, but at different power levels, resulting in a considerable spectral efficiency increase over traditional orthogonal MA. Both academics and industry have suggested, examined, and investigated several NOMA systems. As a result, there are a variety of magazine articles and survey studies on the subject.

Research by Ding, Z., et al. (2017) covers the uses of NOMA in conjunction with MIMO technologies through cooperative NOMA and the interaction between NOMA and cognitive radio. It also examines the current state of standardization initiatives for NOMA deployment in LTE and 5G networks. NOMA introduces high co-channel interference among mobile users, posing significant design and resource management difficulties. The resource management problems in NOMA systems are further discussed in research by Song, L. et al. (2017) where the article covers about the primary NOMA taxonomy that is provided by focusing on the two major resource reuse categories: power-domain and code-domain NOMA. For the next-generation radio systems, NOMA has been highlighted as a promising technology to help achieve all of the system capacity, user connectivity, and service latency requirements, given its aim to connect everything and the much-improved hardware capability. In research conducted by Chen, Y., et al. (2018), they covered about a systematic overview of the modern and unique design of NOMA transmission based on a unified transceiver design framework, related standardization progress, and potentially usable technology in future cellular networks, allowing interested researchers to get a head start in this area.

As an effort to improve the self-sustainability and energy efficiency, the energy harvesting and information processing receivers operate at separate sensitivity levels, and they can't be done at the same time. In research conducted by Waqar, O., et al. (2019), two methods, power splitting (PS) and time switching (TS), have been suggested to address these practical restrictions, in which that the outage and ergodic throughputs of the TS and PS protocols considering the Nakagami-m fading channels are provided in the research using a novel analytical methodology. In research conducted by Yang, Z., et al. (2017), the effect of two forms of NOMA power allocation strategies, namely F-NOMA (fixed power allocation) and CR-NOMA (cognitive radio inspired NOMA), on SWIPT system is explored, where the energy harvesting relay connects a source to two consumers in a cooperative non-orthogonal multiple access (NOMA) network.

Rajaram, A., et al. (2019) conducted research that studies on SWIPT enabled modulation-based NOMA systems to improve energy harvesting efficiency and data rate. In various studies such as Kim, J.-B., & Lee, I.-H. (2015), Kim, J. B., et al. (2016), and Ashraf, M., et al. (2017), C-NOMA SWIPT networks with multiple antennas have been explored because the usage of multiple antennas can improve the energy efficiency and performance of systems. Alsaba, Y., et al. (2018) did research on a unique communication technique combining beamforming, energy harvesting, and a cooperative non-orthogonal multiple access (NOMA) system is presented where the NOMA is used with beamforming in a proposed approach to serve several users in each beamforming vector.

In further understanding about SWIPT, numerous information receivers and energy receivers were explored in a MISO downlink broadcast system, in which is explored by Xu, J., et al. (2014) for ideal CSI assumption and by Zhang, H., et al. (2013) for imperfect CSI assumption. For research conducted by Xu, J., et al. (2014), the two categories of information receivers—those that can cancel out interference and those that cannot—

were taken into consideration. The authors sought to simultaneously design beamforming and power allocation for each type of information receiver to maximize weighted sum harvest energy while maintaining the signal-to-interference-plus-noise ratio (SINR) requirements of each information receiver. For both types of information receivers, two solutions (based on the SDR and the uplink-downlink duality) were put out to overcome the non-convex issues. In research by Zhang, H., et al. (2013), to construct robust beamforming based on the SINR restriction and the total transmit power constraint, the worst harvested energy maximization issue was given. The problem was addressed, and a robust solution was obtained using an iterative technique based on the bisection method.

Various NOMA strategies have been researched especially in relay selection to enhance the NOMA's potential advantages in wireless networks, including 5G and beyond. Research by Tomida, S., et al. (2011), and Vanka, S., et al. (2012) explains about the fundamental concepts of NOMA, where NOMA is more preferable comparing to OMA due to its advantages for its different techniques. Benjebbour, A., et al. (2013) demonstrated multiple antennas techniques in NOMA. A two-stage relay selection technique was proposed Yang, Z., et al. (2017), where the outage probability of NOMA two-stage DF and AF schemes are calculated for NOMA networks with decode-and-forward (DF) and amplify-and-forward (AF) relaying protocols with differing quality of service requirements at the users. Research by Deyue, Z., et al. (2019) shows the effect of correlated fading channel on outage probability for decode-and-forward (DF) relaying non-orthogonal multiple access (NOMA) system is, where a source transmits messages to dual destinations with the help of multiple relays to obtain the best system outage performance.

Research by Guo, W., et al (2017) suggest a new relay selection strategy for a cooperative energy harvesting NOMA network. For cooperative NOMA transmission, the relays are considered to have no embedded energy supply and rely only on the energy gathered from the source's signals. Ding, Z., et al. (2014) made research on energy harvesting relay that can communicate with numerous source-destination pairs. Furthermore, this technique enables the energy harvesting relay to divide the energy among the various consumers in the most efficient manner possible. Chen, H.H., et al. (2014) proposed a game theory approach on SWIPT where three alternative network scenarios are modelled, with each link acting as a strategic player whose goal is to maximize the rate that may be accomplished by selecting the dedicated relay's power splitting ratio in order to achieve good network-wide performance.

To examine the effects of SWIPT on the multiple relays network, research conducted by Ding, Z., et al. (2014) suggested two distributed game theoretic algorithms for the multiple source's scenario and three relay selection strategies for the single source case. In a two-relay cooperative network with the separated information receiver and energy receiver, three additional relay selection schemes—time-sharing selection, threshold-checking selection, and weighted difference selection—were investigated by Michalopoulos, D, S., et al. (2015). In another research by Lu, X., et al. (2014), a Markov decision process-based optimal channel selection policy was presented to implement information transmission and the energy harvesting at the secondary user when the CSI is known. However, the size of the data queue and the energy queue affect how computationally complex the proposed channel selection policy is. The computational complexity increases dramatically with scale. Therefore, based on the imperfect CSI assumption for the secondary user, a suboptimal algorithm—namely, the online learning algorithm—was presented in research by Hoang, D. T., et al. (2014).

To further support the use of SWIPT in a cooperative network, a novel information and energy cooperation paradigm for CR networks was studied by Zheng, G., et al.

(2014), where the secondary transmitter helps the primary transmission based on the energy that the primary transmitter had harvested. At the secondary transmitter, namely, the PS scheme and the TS scheme were employed to simultaneously decode information and harvest energy. The findings from Zheng, G., et al. (2014) showed that the suggested information and energy collaboration model was superior comparing to a model that isn’t using the suggestion collaboration model.

CHAPTER 3: METHODOLOGY

3.1 Overview

The project was started by researching about the fundamentals of wireless communication. Various articles, research papers, videos, and resources from the internet have been studied to focus on understanding the concept that builds the foundation of relay selection schemes for Cooperative NOMA (C-NOMA) and simultaneous wireless information and power transfer (SWIPT). Then, further research was done by looking into algorithm or machine learning which seems to be utilized by most researchers as far as my research is concerned. The algorithmic model is used to strategically tackle the resource allocation and optimization for the network and find the best route for relay selection that satisfies every user. Some researchers also take deep learning method into consideration to get the best outage performance depending on the Channel State Information (CSI) of the users. This relationship may also be seen from game theory perspective where the system uses their information to compute power splitting ratios for all relays to achieve maximum achievable rates for each user.

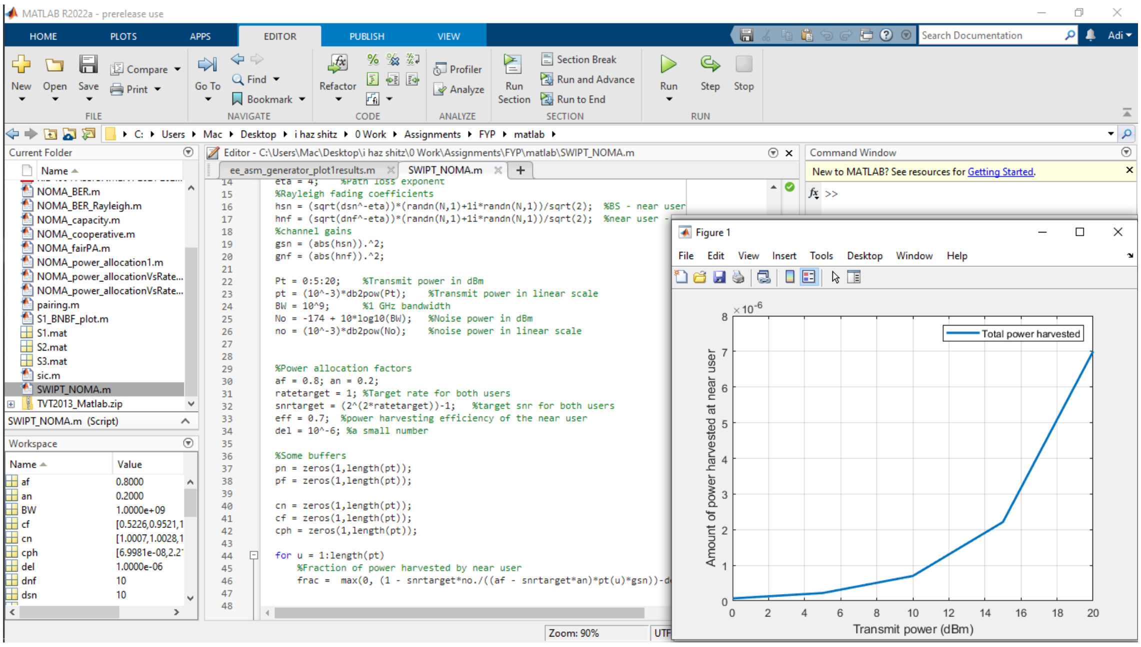

Figure 3.1: MATLAB R2022a software is used to run the simulation

The application used for simulating the system model is MATLAB R2022a. By taking the system model based on a research paper, the equations are identified, and the code for the simulation is constructed. The codes are usually mostly consists of equations which is based on theoretical value such as equations for signal message, selection algorithms, power allocation, target rate, and more. After doing multiple research of journals, four system models are successfully simulated. The results are plotted using MATLAB R2022a and is justified in this work.

3.2 Research materials

3.2.1 NOMA SIC

NOMA is a candidate multiple access scheme for 5G. It may appear surprising that NOMA permits several users to send and receive at the same time on the same frequency. We'll utilize NOMA downlink transmission with two users as an example to further illustrate the notion of NOMA. As shown in Fig. 1, the base station (BS) can service two users at the same time, code, and frequency, but at separate power levels. In particular, the BS will broadcast an overlaid mixture including two messages for each of the two users. Remember that traditional power allocation mechanisms, such as water filling, provide customers with strong channel conditions more power. Users with poor channel conditions gain more transmission power in NOMA than in traditional systems. Superposition coding on the transmitter side and successive interference cancellation (also known as SIC) on the reception side are the two main procedures that make NOMA possible. A graphical representation of superposition coding can be seen as shown in Figure 3.2 below

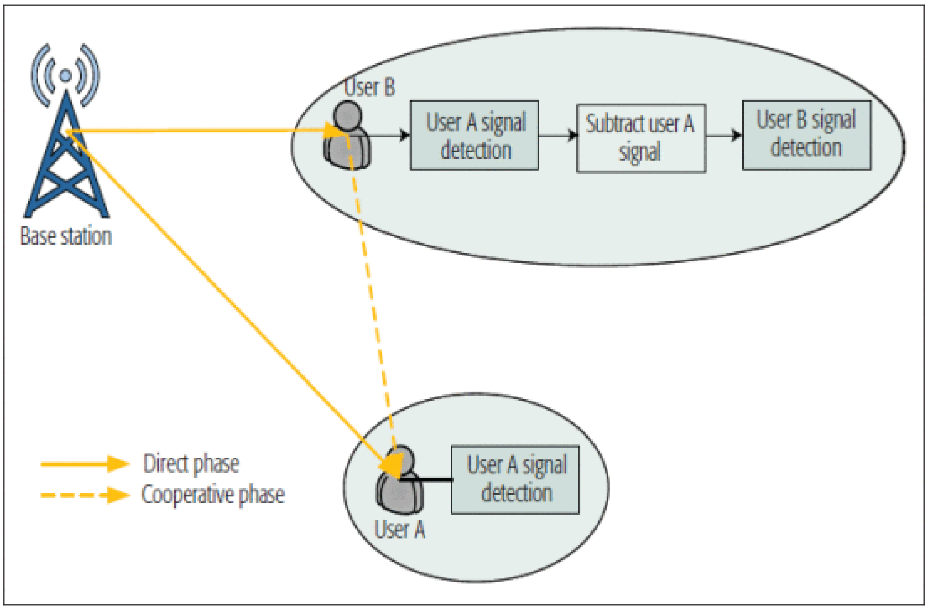

Figure 3.2: Non-cooperative NOMA transmission system model within the NOMA network of two-user

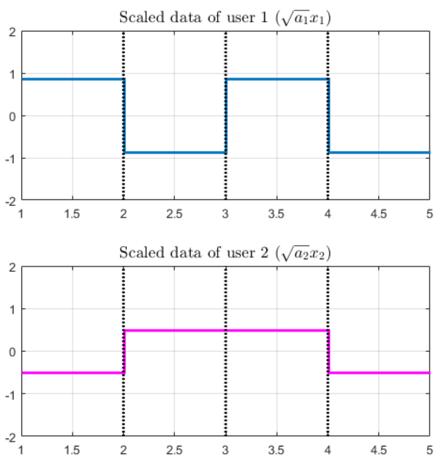

Figure 3.3: Data of user 1 and user 2

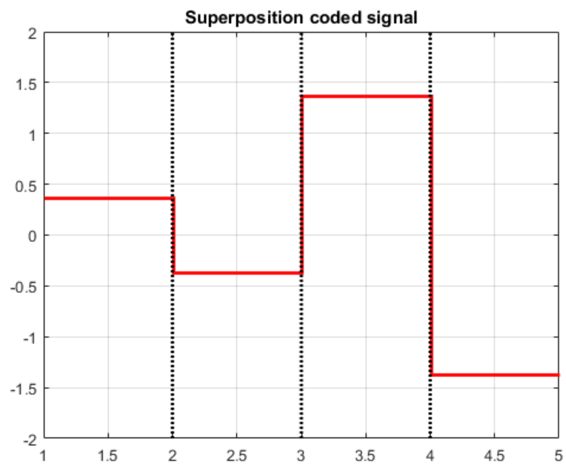

Figure 3.4: Superposition coded signal of user 1 and user 2 where x = √a1x1 + √a2x2

Successive Interference Cancellation (SIC) is a technique used by the receiver in a wireless data transmission to decode two or more packets that arrived simultaneously. SIC is an iterative method that decodes data in decreasing order of power levels. That is, the data pertaining to the user with the highest power is decoded first, followed by the data relating to the user with the next highest power. The message sent to the user with the weaker channel is given higher transmission power, ensuring that this user can detect its message directly by treating the information from other users as noise. The user with the weaker channel condition must first identify its partner's message, then deduct this message from its observation, and then decode its own data. The procedure is known as SIC. After applying SIC in the superposition coded signal above (subtracting the signal of user 1), it can be seen that in Figure 3.4, the graph is the same as of that user 2.

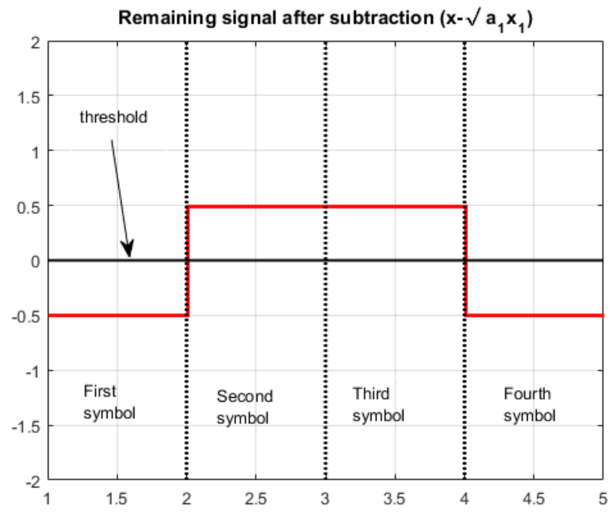

Figure 3.5: Applying SIC to the superposition coded signal

Multipath propagation and fading are common problems with wireless channels. To capture the effects of fading, there are several channel models available. Each model is focused on a specific circumstance. Rayleigh fading is an example of such a model. When there is no line of sight (LOS) between the transmitter and the receiver, it is now possible to employ the Rayleigh fading model. In other way, all multipath components have experienced small-scale fading effects like as reflection, scattering, diffraction, and shadowing.

3.2.2 Cooperative communication in NOMA

We know that NOMA uses successive interference cancellation (SIC), in which one user decodes the other user's message from the superposition coded incoming signal before decoding his own. Specifically, while conducting SIC, the near user decodes the information of the far user. This is a step that cannot be avoided. In every case, the data of the far user must be decoded by the near user. Now that the near user has access to the far user's data, he can use it to help the far user. Because the distant user's channel with the transmitting base station (BS) is poor, the close user's retransmission of his data will supply him with diversity. In other words, he'll get two copies of the same message. One is from the base station, while the other is from a nearby user functioning as a relay. As a result, we can anticipate a decrease in the likelihood of a far-user outage.

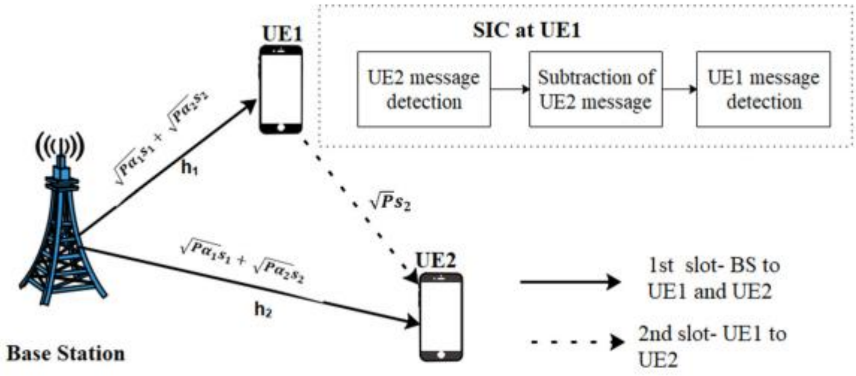

Figure 3.6: Two users cooperative communication in NOMA downlink

Cooperative communication/cooperative relaying is the term for this notion. We can see that NOMA naturally facilitates cooperative communication because the near user already has the data of the far user because it has to decode it. The advantage of cooperative communication is that there exists a constructed two lines to transmit the identical message. Even if one connection is down, chances are the other is up and running. When compared to the probability of any one link failing, the likelihood of both links failing at the same time is extremely low. Without the use of extra antennas, we may lower the likelihood of outages and thereby gain diversity (i.e., MIMO). Another benefit is that relaying allows the base station's coverage area to be practically extended.

The system model for a cooperative communication is at downlink transmission in a scenario with a base station (BS) and two NOMA users. With the BS, we have a near user with a stronger channel and a far user with weak channel conditions. The transmission is split into two parts. The first time slot will be referred to as direct transmission, while the second slot will be referred to as relaying.

The first slot is the direct transmission slot where the BS employs NOMA to transmit data destined for the near user and the far user. The near user uses SIC to decode the data of the distant user first, before moving on to decoding its own data. Direct decoding is all that the far user does. The next half of the time slot is called relaying slot. Because the near user decoded it in the previous time period, the near user already had the data of the distant user. The near user simply transmits this data to the far user during the relaying time window.

3.2.3 Simultaneous wireless information and power transfer (SWIPT)

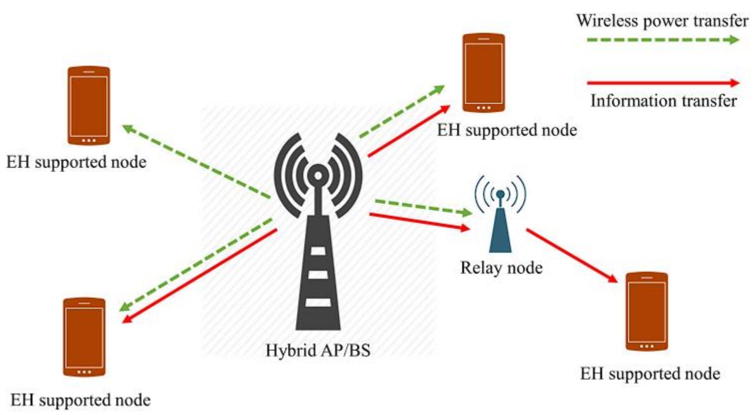

Figure 3.7: General system model of SWIPT

The power consumption of electronics is becoming increasingly essential as we move toward more complex communication networks. In a wireless network with hundreds of IoT sensors, for example, battery drain could cause the sensors to die. Green communication solutions, such as RF energy harvesting devices, are being pushed to address this issue. NOMA demands successive interference cancellation, which is a computationally costly process as we all know. This puts a strain on the battery's capacity. We used user cooperation to study the cooperative NOMA system, where the close user worked as a relay for the far user. Because the near user already had the data of the far user, this user cooperation was natural. Is the nearby user, however, capable of relaying that information? What if relaying depletes the battery of a nearby user? This is where RF energy harvesting may be of assistance.

Because of data transmissions, electromagnetic waves are always present all around us. Of course, we can't understand these signals unless they carry information that is meant for us. They also transport power, which we may harvest using basic RF circuits, in addition to transmitting information for someone else. Then we can use the power we've harvested to create our own communications. Our battery would never run out this way. There are two types of energy harvesting protocols, namely time switching and power splitting.

In the time switching protocol, the device works in a timed manner. The device captures electromagnetic energy from its surroundings during the first fraction of the time period. In the following fraction of the timeslot, the captured power is used for transmission. Next, in the power splitting protocol, the device splits the power of the received signal for energy collection and decoding. Unlike time switching, which requires different time slots for both processes, power splitting allows both energy harvesting and information decoding to be done at the same time. This approach is the one that is called SWIPT.

SWIPT is a potential technique for remotely powering up devices or nodes due to its inexpensive cost, wide operational range, and ability to use a small-sized receiver. Information can be delivered simultaneously with the wireless energy transfer using the same signal. Unlike traditional EH technologies, SWIPT is less reliant on the environment and can provide consistent energy supply in all types of weather. As a result, SWIPT has been suggested as a viable option for extending the life of energy-constrained systems.

CHAPTER 4: PROJECT RESULTS AND DISCUSSION

4.1 Simulation of Basic C-NOMA

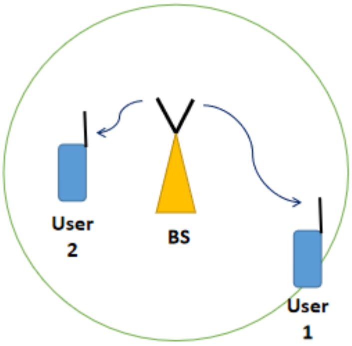

Figure 4.1: System model of NOMA downlink transmission

It is known that the superposition coded NOMA signal transmitted by the BS is,

Equation 4.1: Message signal

$$x = \sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2)$$

Where P is the transmit power. To obtain the signal to interference noise ratio and the achievable data rate, the equation are as shown below

Equation 4.2: Signal to interference noise ratio

$$\gamma_1 = \frac{|h_1|^2 P\alpha_1}{|h_1|^2 P\alpha_2 + \sigma^2}$$

$$\gamma_2 = \frac{|h_2|^2 P\alpha_2}{\sigma^2}$$

Equation 4.3: Achievable data rate

$$R_1 = log_2(1 + \gamma_1) = log_2\left(1 + \frac{|h_1|^2 P\alpha_1}{|h_1|^2 P\alpha_2 + \sigma^2}\right)$$

$$R_{1,2} = log_2\left(1 + \gamma_{1,2}\right) = log_2\left(1 + \frac{|h_2|^2 P\alpha_1}{|h_2|^2 P\alpha_2 + \sigma^2}\right)$$

$$R_2 = log_2(1+\gamma_2) = log_2\left(1+\frac{|h_2|^2 P\alpha_2}{\sigma^2}\right)$$

- α_1 - power allocation coefficient for far user
- α_2 - power allocation coefficient for near user
- h_1 - Rayleigh fading coefficient for far user
- h_2 - Rayleigh fading coefficient for near user
- P - Total transmit power
- σ^2 - Noise power
- $\alpha_1 + \alpha_2 = 1$
- $\alpha_2 > \alpha_1$

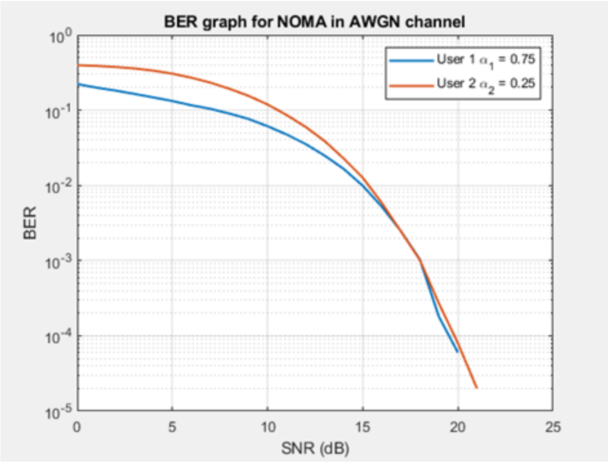

Figure 4.2: BER graph for NOMA in AWGN channel

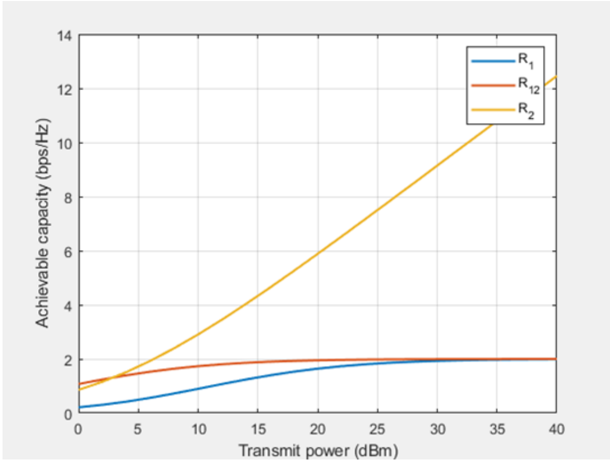

Figure 4.3: Achievable data rate for user 1 and user 2 for different power levels in dBm

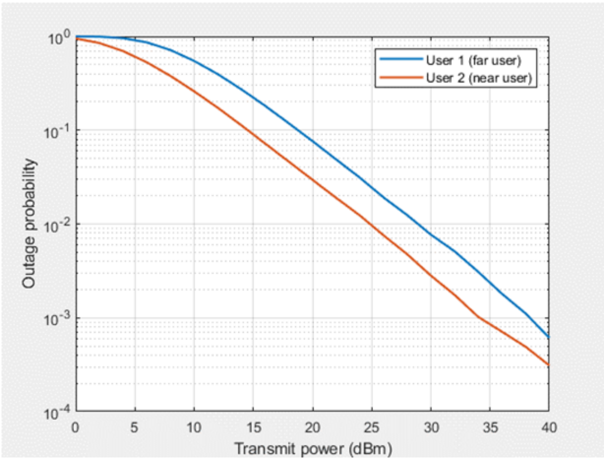

Figure 4.4: Outage probabilities when target rates are set for each user

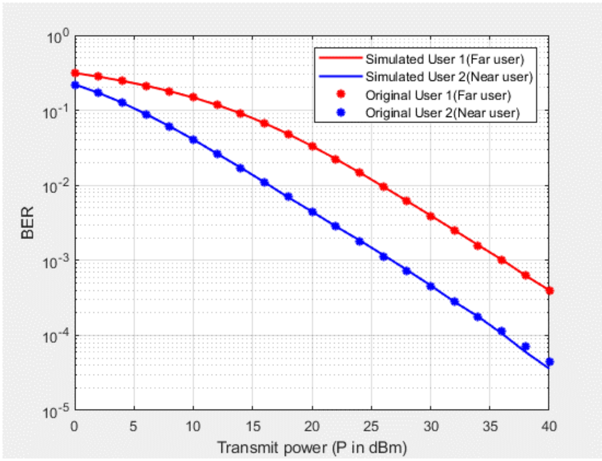

Figure 4.5: Comparison of BER graph of NOMA between original data and simulated data

From the BER graph for NOMA in AWGN in Figure 4.2, the waterfall trend can be seen. In addition, we noticed that user 2 has a slightly greater BER than user 1, particularly at low SNR. This is due to the fact that user 2 must perform SIC. User 2 must first estimate user 1's data from y before executing SIC. If this estimate is incorrect, it will show up in the decoding of its own data because the incorrect data will be deducted from y. In other words, user 2 must correctly decode both user 1's and its own data. Any errors in decoding user 1's or its own data will have an effect on its BER. As a result, user 2 has a higher BER than user 1.

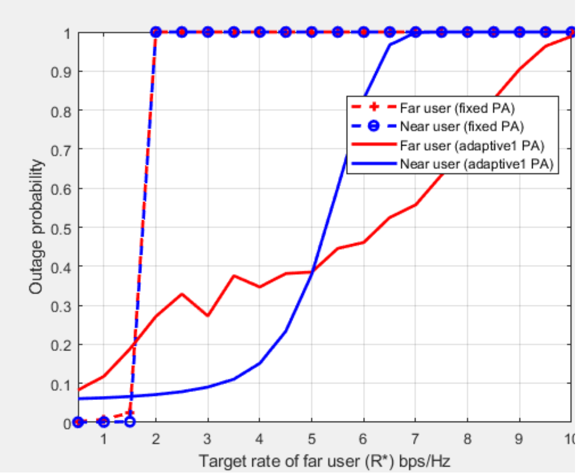

Figure 4.6: Outage probability when compared to the target rate for fixed power allocation and first version of adaptive PA

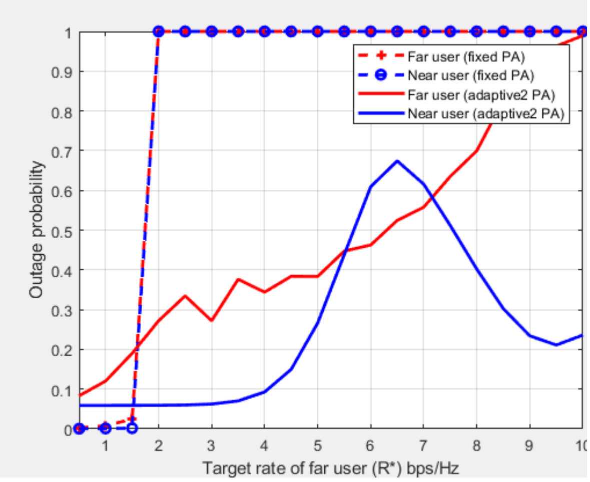

Figure 4.7: Outage probability when compared to target rate for fixed power allocation and second version of adaptive PA

From Figure 4.6 above, when target rate of far user, R* > 1.5 bps/Hz, we can observe that the fixed PA is underperforming, and its outage probability saturates to 1 all of the time. In other words, if we use fixed PA with R > 1.5 bps/Hz, the receiver is ALWAYS out of service. This is because fixed PA does not take into consideration the target rate requirements or exploit the immediate CSI. As a result, while fixed PA is straightforward to construct, it is not ideal. However, because near and far are dynamically modified based on goal rate requirements and CSI, our adaptive PA has a decreased outage probability. We can see in our adaptive PA that the outage probabilities of the far user grows as his target rate demand increases. This is to be expected, given the target rate rises.

For the next Figure 4.7, the adaptive power allocation is changed so that when the outage probability of far user is 1.0 (likely to be outage), the power allocation coefficient of far user is set to be 0, meaning no power is allocated to the far user and full power is allocated to near user. It was found out that the outage of a remote user follows the pattern shown in Figure 4.6. This means that when the power allocation of far user was tweaked, it had no effect on the far user's outage. The likelihood of an outage rises, peaks, and then begins to decline. When R* is between 0 and 6.5 bps/Hz, it appears that the graph is favoring the far user by giving more and more power to the user at the expense of the near user's performance. However, any value of α_1 above 6.5 bps/Hz may not entirely satisfy R. When this happens, we prioritize the person who is closest to us rather than squandering all of our strength on the user who is far away.

This shows that the wireless channel is a very dynamic environment. Fixed PA is unconcerned about the users' current channel conditions. Regardless of the channel condition, near and far coefficient remain constant. The adaptive PA, on the other hand, is a moving target. In other words, anytime the channel changes, the values of near and far coefficients are adjusted to match the specification. As a result, adaptive PA has a greater total rate and a lower outage than fixed PA.

When considering the effect of cooperation among the NOMA users, users with favorable channel conditions have previous knowledge of the messages of other users, which is a key component of PD-NOMA when employing SIC. This means that the messages from weak users are decoded first by the user with the better channel state. As a result, better users can take advantage of this duplicated data by acting as relays for other users who have a poor connection to BS. Therefore, the near user simply transmits this data to the far user during the relaying time window. The achievable rate of the far user at the end of the relaying slot is,

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

h_{nf} is the channel between the near user and far user. After selection combining, the achievable rate of the far user would be

$$R_{f,2} = \frac{1}{2} log_2 \left(1 + max(\frac{\alpha_f \rho |h_f|^2}{\alpha_n \rho |h_f|^2 + 1}, \rho |h_{nf}|^2) \right)$$

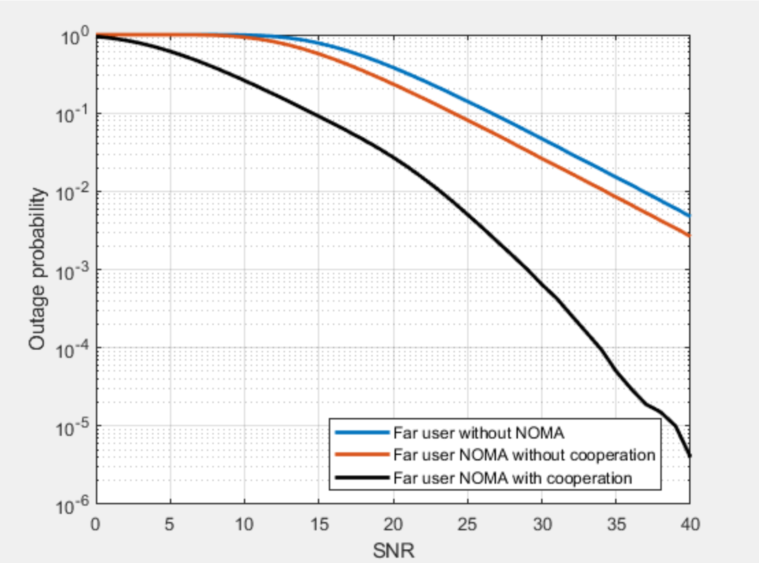

Figure 4.8: Outage probabilities of different variations on NOMA

From this graph of Figure 4.8, we order the performances of different schemes as: cooperative NOMA > non-cooperative NOMA > OMA. Thus, it can be concluded that the best performance and useful is the cooperative communication.

4.2 Simulation of basic SWIPT in C-NOMA

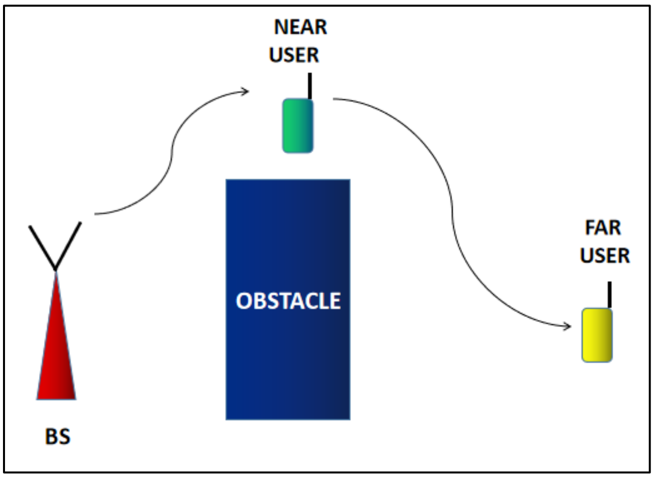

Figure 4.9: SWIPT C-NOMA system model

Based on Figure 4.9, the simulation model is about downlink transmission, where the base station (BS) utilizes NOMA to transmit information to both the near and far users at the same time. Unfortunately, there is a blockage in the path between the BS and the far user, leading to severe shadowing. As a result, the signal cannot be received by the far user. However, the near user has a strong connection to the BS channel. By applying the C-NOMA principles, the near user must first decode the data meant for the far user, then execute SIC to decode its own data. As a result, the near user has a copy of the far user's data and by functioning as a decode-and-forward relay, the near user can assist the far user in getting better quality of information.

However, the problem is that the near user lacks sufficient power to transfer both the information and power to the far user. To solve this, the near user can harvest enough power by using the power-splitting method of energy harvesting, also known as SWIPT (simultaneous wireless information and power transfer). We can observe the complete transmission in two different time slots. The data transmitted by the BS is received by the near user in the first time slot. The power splitting protocol harvests a portion of the incoming signal power and uses the remaining power for information decoding. The gathered power is used by the near user to relay data to the far user in the second time slot.

In time slot 1, the signal transmitted by the BS is given by

Equation 4.4: Message signal

$$x = \sqrt{P}(\sqrt{a_n}x_n + \sqrt{a_f}x_f)$$

- P – Transmit power
- a_n – Power allocated to the near user
- a_f – Power allocated to the far user
- x_n – Signal to near user
- x_f – Signal to far user

However, since the far user cannot receive this signal. The equation to calculate the signal received by the near user is as shown below.

Equation 4.5: Signal received by near user

$$y_n = \sqrt{P}\left(\sqrt{a_n}x_n + \sqrt{a_f}x_f\right)h_{sn} + w_n$$

- h_{sn} – Rayleigh fading coefficient between the BS and near user
- w_n – AWGN

From y_n , the near user is able to harvest a fraction of power denoted by the symbol ψ which can be called as the energy harvesting coefficient. The remaining fraction (1−ψ) is the fraction of power available for information decoding for the near user. Thus, the signal available for information decoding after energy harvesting, assuming the energy harvested from w_n is negligible, is now as below. w_{ch} is the thermal noise introduced by the energy harvesting circuitry.

Equation 4.6: Signal received by decoding

$$y_D = (\sqrt{1-\psi})\sqrt{P}\left(\sqrt{a_n}x_n + \sqrt{a_f}x_f\right) + w_{ch}$$

Then, the near user will execute its direct decoding for far user's signal. The achievable rate to decode the far user data by the near user is given by,

Equation 4.7: Achievable data rate for far user depending on near user's harvested power

$$R_{nf} = \frac{1}{2}\log_2(1 + \frac{P(1-\psi)a_f|h_{sn}|^2}{P(1-\psi)a_f|h_{sn}|^2 + \sigma^2})$$

The achievable rate for the near user to decode its own signal is given by,

Equation 4.8: Achievable data rate for near user

$$R_n = \frac{1}{2}\log_2(1 + \frac{P(1-\psi)a_f|h_{sn}|^2}{\sigma^2})$$

The total amount of power harvested by the near user can is given by,

Equation 4.9: Total power harvested by near user

$$P_H = P|h_{sn}|^2\zeta\psi$$

- ζ – Efficiency of the power harvesting component

In time slot 2, the near user will use the total harvested power in the previous slot to relay the signal that is intended for the far user. At far user, the equations for the received signal and the achievable data rate are given by,

Equation 4.10: Signal received by far user

$$y_f = \sqrt{P_H}\bar{x}_f h_{nf} + w_f$$

Equation 4.11: Achievable data rate for far user

$$R_f = \frac{1}{2}\log_2(1 + \frac{P_H|h_{sn}|^2}{\sigma^2})$$

- h_{nf} – Rayleigh fading channel between the near user and far user

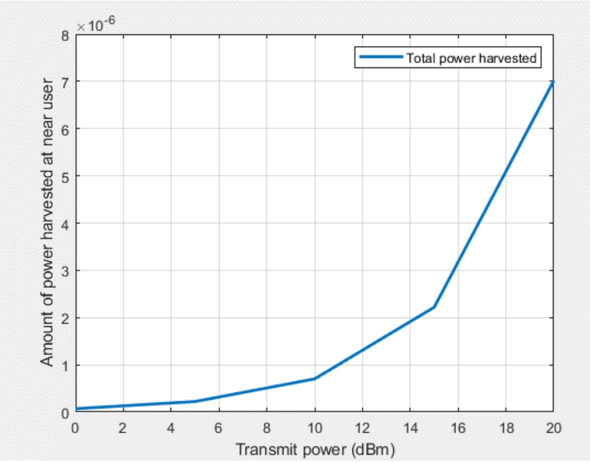

Figure 4.10: Power harvested at near user with increasing transmit power from BS

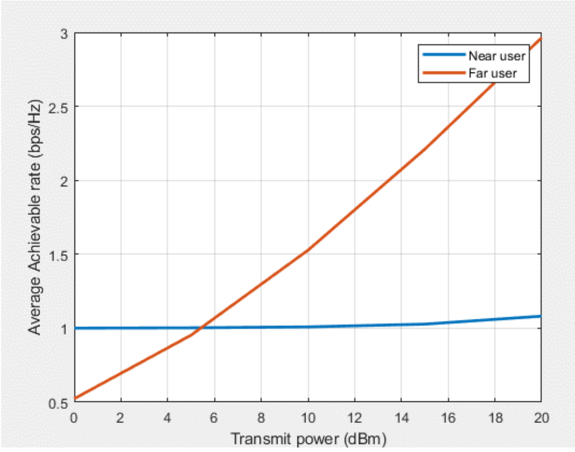

Figure 4.11: Average achievable rate using SWIFT in C-NOMA

The simulation target rate is set to be 1 bps/Hz for both near user and far user. For the first simulated Figure 4.10, it shows that as the base station transmits the information which also contains power, the near user receives both information & power and managed to harvest the energy. The higher the transmit power from BS, the more power is able to be harvested by the near user. This graph only shows near user because far user is not in reach by the BS, hence the absence of far user. This means that far user must somehow obtain energy and that energy is harvested by the near user as compensation.

In the next Figure 4.11, it shows the average achievable rate for both near user and far user. By this stage, the near user has decoded its message and transmitted the far user's message together with the harvested energy. We can observe that the near user's rate is saturated at around 1 bps/Hz wile the far user's rate also rises. This saturation is due to energy harvesting. All remaining power is harvested from the near user once the far user's data rate is fulfilled. However, the achievable rate at the near user is still limited due to the energy harvesting procedure, even if the transmit power is raised. This isn't really that much of a problem though because the near user's target rate of 1 bps/Hz is not ignored, which is a plus. As a result, this rate of saturation does not result in a significant outage for the near customer.

The amount of power harvested at near user grows as the transmit power from BS increases. As a result, the amount of power intended for the far user data is also increasing. This causes the rise in far user's achievable rate as seen in the Figure 4.11 above. Something to note is that this might make it seem that the far user must have been experiencing the lowest outage chance comparing to other users because it has higher achievable rate. However, when we plot and study the outage graphs, we are able to notice something completely contrary to the expectation.

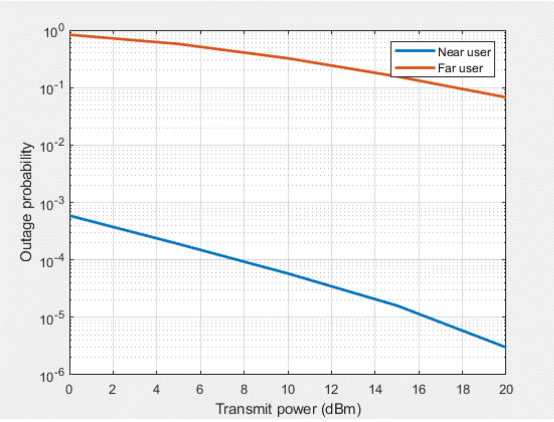

Figure 4.12: Outage probability of SWIPT in C-NOMA

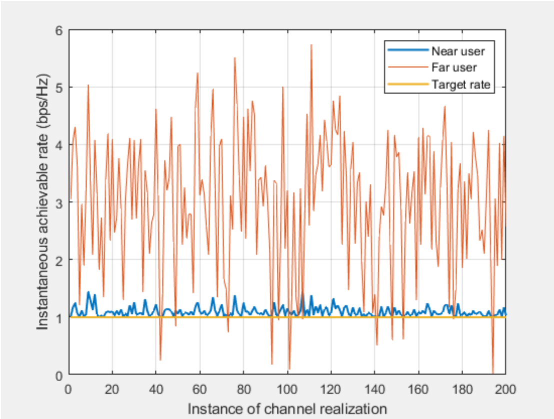

Figure 4.13: Instantaneous achievable rate of SWIPT in C-NOMA

Figure 4.12 shows that the far user has a substantially higher outage than the near user, although having a higher achievable rate on average. Since Figure 4.11 was plotted in terms of average value of performance, we can’t really see the real-time value of the performance. Thus, if we plot the users' instantaneous achievable rates, we get the graph as seen in Figure 4.13. Based on Figure 4.13, we can see why, while having a higher achievable rate, the far user has a higher outage. The far user's achievable rate is focused around 3 bps/Hz, but the overshoot of the wave makes the graph seems very unstable for far user. We notice that the far user's instantaneous achievable rate frequently falls below the target rate. This is not a good sign because we don't care how high the achievable rate is when it comes to outage calculations, but instead the number of times the target rate goes below the goal rate is what will determine the user experience of the network. For the far user, this type of fall is more common. As a result, the far user has a miserable outage performance.

To overcome this problem, researchers has come up with various ideas to get the best route in relaying to get the best performance in terms of QoS and outage probability. From my research of various research papers and journals, most of the target is to achieve in increasing the end-to-end sum rate and reduce the power consumption of wireless communications for NOMA wireless relay networks with as low computational complexity as possible. The next sections will explain more of the selected methods of relay evaluation by researchers.

4.3 Simulation of Transmit Antenna Selection (TAS)

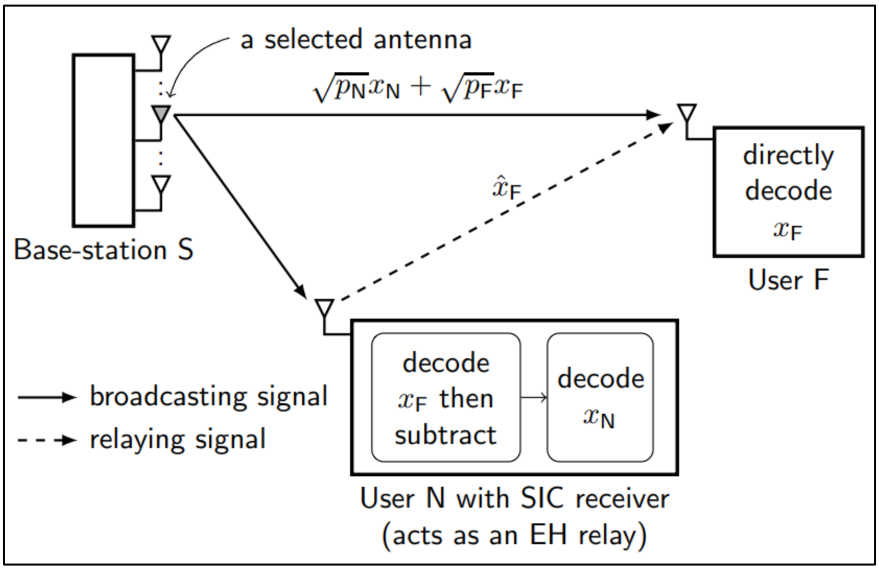

Figure 4.14: System model for hybrid time-switching/power-splitting (TS/PS) SWIPT-based cooperative relaying transmission with TAS for a two-user NOMA system

Much of the research into cellular network power control began in 1992-1993 with a set of findings that solved the basic challenge formulation, in which transmit power is the only variable, bound by a fixed target SIR, and optimised to reduce total power. Cooperative NOMA transmissions is no doubt that it could provide superior performance in terms of outage probability and it could be a long-term solution to the above-mentioned challenges in NOMA systems. However, it is still a challenge as to how should the selection of relays be done, given that the cell-center users allocate their power, and they must analyse their own data as well as transfer the data of the other far users. Thus, a TAS system for NOMA downlink energy harvesting (EH) multiple-antenna relaying networks was recently investigated by Do, T. N., et al. (2018).

Based on Figure 4.14, a two-user cooperative MISO-NOMA system is considered, in which a cell-center user works as a relay to improve communication from a BS to a cell-edge user. Using TAS can help to increase the performance of the cell-edge user and helps the cell-center user to save more power. Three different types of schemes were proposed for this algorithm, to which the signalling and channel state information (CSI) estimation/calculation system is used to run the suggested TAS schemes before data transmission. It is assumed that each scheme's required CSI is available and is known by the BS.

For Scheme I, the TAS criterion is to choose an antenna that maximises the far user's instantaneous transmission rate, which is given by the equation below,

Equation 4.12: Scheme I criterion equation for TAS

$$R_{iF} = \frac{1-a}{2}\log_2(1+\gamma_F^{e2e})$$

- γ_F^{e2e} = End-to-end SNR of the far user
- a = Fraction of block time for energy harvesting

The algorithm selection of Scheme I can be expressed as below,

Equation 4.13: Scheme I algorithm selection

$$i^* = \frac{1-a}{2}\log_2(1+\gamma_F^{e2e}) = \arg\max_{1\le i\le K} \min\{\gamma_{iF}^{xF}, \max\{\gamma_{iF}, \{\gamma_{NF}\}\}$$

- xF = Message of the far user

For Scheme II, the TAS criterion is to select an antenna that still maximizes the instantaneous transmission of the far user but offers relatively low computational complexity. This is because, Scheme I seem to need a very high complexity operation, whereby three kind of CSI channels are required, namely BS → Near user, Near user → Far user, and BS → Far user. In order to lower this complexity, Scheme II was done by focusing on the performance of the far user in the first phase/time slot. The instantaneous transmission rate for Scheme II is given by,

Equation 4.14: Scheme II criterion equation for TAS

$$R_{iF} = \min\{\frac{1-a}{2}\log_2(1+\gamma_{iN}^{xF}), \frac{1-a}{2}\log_2(1+\gamma_{iF})\}$$

The algorithm selection of Scheme II can be expressed as below,

Equation 4.15: Scheme II algorithm selection

$$i^* = \arg\max_{1\le i\le K} |h_{iF}|^2$$

- h_{iF} = Rayleigh fading of the far user with zero mean and variance of $\lambda_{BS\text{-}F}$

For Scheme III, the TAS criterion is to select an antenna that provides a maximum instantaneous harvested energy at the near user. Note that all the harvested energy at the near user will be used to transmit message to the far users. The algorithm selection of Scheme III can be expressed as below,

Equation 4.16: Scheme III algorithm selection

$$i^* = \arg\max_{1\le i\le K} |h_{iN}|^2$$

- h_{iN} = Rayleigh fading of the near user with zero mean and variance of $\lambda_{BS\text{-}N}$

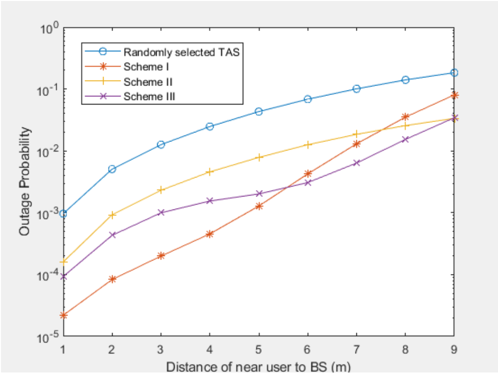

Figure 4.15: Outage probability of all Schemes when comparing the distance of near user to BS

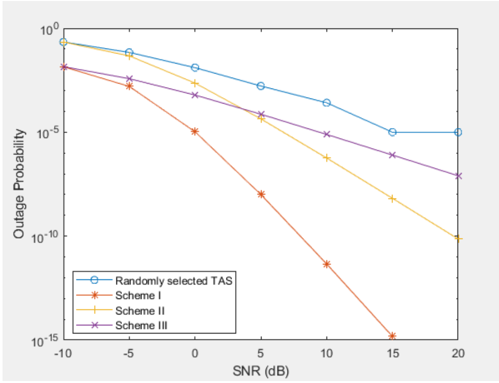

Figure 4.16: Outage probability of all schemes when comparing the SNR of the far user

Based on Figure 4.15, the effect of outage probability due to distance between BS and the near user was observed at the far user. All of the schemes have increasing outage probability when the distance is increased. There are several possible reasons for this, the first is when the near user is located further away from the BS, the total amount of energy harvested is decreasing, making it harder for the near user to transmit message to the far user using less power. Second is based on the principles of NOMA itself, where the system should make use of the difference of channel conditions of the channel to determines who will do the SIC to decode the message of both users and transmit the signal to the far user. However, when the near user is located closer to the far user, their channel condition becomes a lot more the same, which would lead to the decreasing performance of all the Schemes.

Figure 4.16 shows the performance comparison between all the proposed Schemes and randomly selected TAS. It can be seen that Scheme I provide the best performance of the outage probability, followed by Scheme II, and Scheme III. Scheme I beat all the other schemes in both lower SNR and higher SNR region. However, Scheme II performs better in the higher SNR region when comparing to Scheme III, while Scheme III performs better in the lower SNR region when comparing to Scheme II. The randomly selected

TAS is the most underperforming method because it doesn't really have any mathematical thoughts put into it, so it is the most random method.

It is important to note that given Scheme I beats all the other schemes, where Scheme I focuses on maximising the far user's instantaneous transmission rate, it actually uses a lot of mathematical equations and considers a lot of CSI, thus making it has the most complexity among all Schemes. For reduced complexity, Scheme II and Scheme III can be considered depending on the usage of the network either in the low SNR or high SNR regime.

4.4 Simulation of Best-Near Best-Far (BNBF) selection

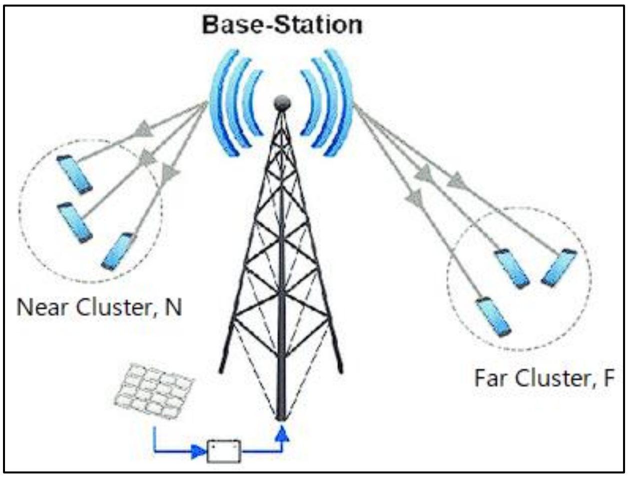

Figure 4.17: System model of the BNBF relay selection method

Figure 4.17 shows the system model of best-near best-far user selection scheme for relaying. Consider a cooperative network where there is a source of information which is the base station, BS, a cluster of F far users, and a cluster of N near users. The assumption is that single antenna is equipped to all of the nodes and the antenna is working in half-duplex mode. Every network is assumed to undergo and i.i.d. Rayleigh block flat fading.

It is also assumed that all terminals of all the users have the same AWGN mean power N_0, and that the BS knows all of the CSI for all near users and far users.

The Best-Near Best-Far (BNBF) User selection scheme here is proposed by implementing it before the data transmission happens by comparing their channel conditions using their CSI estimation in the system. In short, any near user or far user that have the best respective channel conditions will be chosen for relaying in the transmission slot. The BNBF selection scheme can be described as given below,

Equation 4.17: BNBF selection scheme for near user

$$N_s = \arg max_{i=1,\dots,N} |h_{SNi}|^2$$

Equation 4.18: BNBF selection scheme for far user

$$F_s = \arg max_{j=1,\dots,N} \left|h_{SFj}\right|^2$$

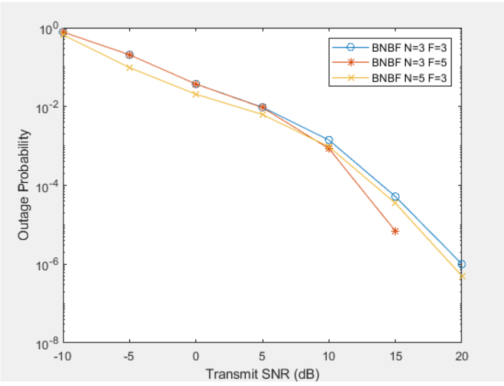

Figure 4.18: BNBF with number of near and far users' comparison

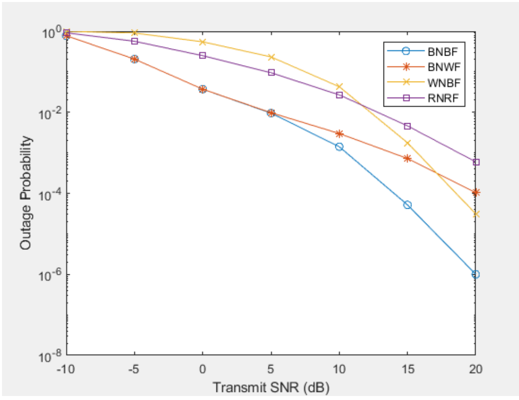

Figure 4.19: Best and Worst user selection comparison (BNBF = Best-Near Best-Far, BNWF = Best-near Worst-far, WNBF = Worst-near Best-far, RNRF = Random-near random-far)

After running the MATLAB simulation, two figures are taken for analysis. Figure 4.18 compares the effect of outage probability when different number of near users and far users are considered in the system. Based on Figure 4.18, it is found out that the system diversity order for this system model is depending on the number of far users. When the system is run using different number of near users, the outage probability is found to be overall better in both low and high transmit SNR regime. However, when the system is run using different number of far users, the outage probability is the same in the low transmit SNR regime and performs better in the higher transmit SNR regime. This shows that having more near users can help the system to get better performance of relaying for the C-NOMA with SWIPT. In the higher transmit SNR regime, far users can have a better performance when more energy is supplied by the near users. Thus, in theory more users in the system should be better to have the best outage performance, however when too many users are in the system, the problem would arise in the interference and SIC complexity. That problem is not covered in this section but is explained in Section 4.5. Something important to note from this is that more users in system will be better for outage performance, but too many users will also cause problem in the system.

For Figure 4.19, four different conditions are simulated, where the best users and the worst users are identified for both near users and far users. The performance of best-near best-far (BNBF), best-near worst-far (BNWF), worst-near best-far (WNBF), and random-near random-far (RNRF) were compared. It is found out that the outage performance for BNBF was the best in all SNR regime. It is also worth noting that when the best near users are prioritised, the outage performance starts with lower outage probability comparing to starting with worst near users. Thus, it can be concluded that the best near users should be prioritised when implementing this relay selection for cooperative-NOMA with SWIPT.

4.5 Simulation Comparison and Summary

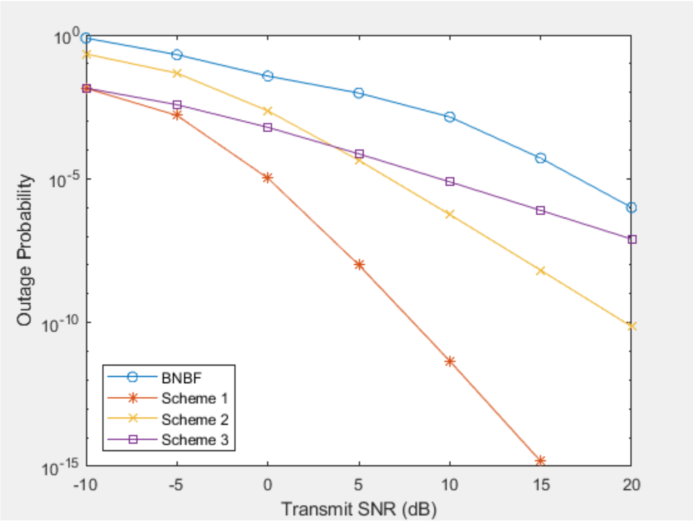

Figure 4.20: Outage probability of far user for different relay selection schemes

Figure 4.20 shows the outage probability comparison of the simulated relay selection schemes in previous sections. It is found out that the best relay selection scheme simulated in this paper is when Scheme 2 is used where the algorithm tries to achieve the maximized instantaneous transmission rate of the far user and uses less complexity. Scheme II is far superior to Scheme I because although Scheme I gives the lowest value of outage probability, that lowest value can be considered negligible if applied in real use case. The difference of outage probability may not even be noticed for Scheme I comparing to Scheme II. Scheme 2 and Scheme 3 differs in the mid-range of transmit SNR. The worst performance is the BNBF selection scheme, where number of users are mainly affecting the performance of the system.

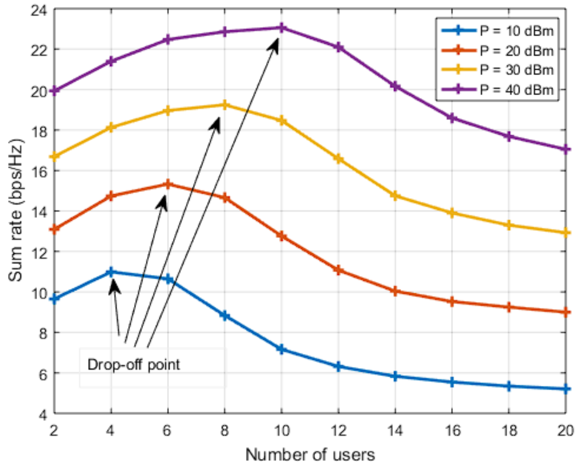

Figure 4.21: Effect of average achievable rate with increasing number of users

One of the problems that may arise is that when too many users are in the system. Section 4.4 explained that more users should have better outage probability, thus if infinite users are in the system, it should be the best outage probability. However, that statement is false because when simulated, the graph in Figure 4.21 shows that there is a drop-off point for every value of transmit power by the BS depending on the number of users in the system. By increasing the transmit power, the system can hold a greater number of users. The increase in value before the drop-off is due to the same reasons that NOMA offers better capacity than OMA. The interference levels are manageable and the strongest user, although he is allocated the least power, is given a respectable amount of power. The drop-off point can be seen as the maximum number of users that the system can hold. Thus, it can be concluded that if a system is limited by power, it is better to not add any more users when opting for better outage performance because number of users for a system can be increased when the power from BS is also increased.

CHAPTER 5: CONCLUSION AND FUTURE WORKS

5.1 Conclusion

To conclude, the system model for cooperative-NOMA, energy harvesting with SWIPT, and relay selection for the cooperative-NOMA with SWIPT were successfully constructed. SIC is a technique used by the receiver in a wireless data transmission to decode two or more packets that arrived simultaneously and is used by the near user to decode both its message and the far user message. This technique can be further utilized by the cooperative communication in NOMA where it is called as C-NOMA and is usually implemented with SWIPT to cover the power absence in the cell-edge far users. This project covers the basics of cooperative communication in NOMA, basics of energy harvesting with SWIPT, and several techniques that is utilized in such cooperation communication using dedicated relay selection to make sure that the system coordination and performance can be maximized in the data transmission.

Based on the simulations, it was proven that power and resource allocation is important for the user to have the lowest outage probability as possible. This can be further improved by applying the relay selection scheme for selecting the best route for data transmission depending on every user's channel state information, and energy harvesting for sustaining the power usage in cases that the cell-edge users are unable to receive it. The best method for selecting relay that is simulated in this project is when the far user is selected to have the maximized instantaneous achievable rate and uses less complexity which is described as Scheme II. Although Scheme I give the lowest value of outage probability, the value is too small that it can be considered as negligible as it will not be affecting the users when it is implemented in real use case. Thus Scheme II is the best method for relay selection because it offers low outage probability with less complexity. An optional way to improve outage probability can also be by increasing the number of near users in the system to act as more route for relay selections, but that method is limited by the maximum transmit power that can be transmitted by the base station.

5.2 Future Work

For future work, the outage performance part might even be solved without the need in taking the device complexity in consideration, but instead by using deep learning method. Research by Yin, Z., et al. (2022) shows that when considering a NOMA system with imperfect CSI, applying a deep learning and a special neural network to accurately identify CSI based on training can significantly improve the outage performance and recovers the diversity gain. The deep learning method could have more room of improvement and may even be applied in relay selection scheme, in which a classic example from one of the first algorithmic Distributed Power Control (DPC) using the Foschini and Miljanic algorithm which is described by Chiang, M., et al. (2008) to obtain the rate of convergence and robustness to stochastic dynamics.

Other than that, when considering a situation where low latency, high data rates, real time processing, reliability, storage are required, fog computing could solve the efficient energy utilization problems to further improve the performance metrics. Research by Hu, P, et al. (2017) shows that NOMA can be utilized further to address other issues such as resource optimization, poor processing power, and server placement using fog computing. As a result, more research on NOMA-based networks using energy-efficient fog computing designs could be looked into further to boost performance metrics even more.

5.3 Impact of Work to Environment and Society

Massive connection is projected with huge energy demands from network operators; hence in te future mobile wireless networks, trying to be efficient in using energy is a major challenge. Since non-orthogonal multiple access (NOMA) is the leading 5G multiple access scheme, there have been numerous research efforts aimed at improving the energy efficiency of wireless networks that are utilizing the NOMA technology while maintaining outstanding performance metrics such as high throughput, data rates, and capacity maximization. NOMA by nature itself has already outperforms the spectral efficiency of the conventional OMA because NOMA scheme can simultaneously handle multiple users via power domain division which makes it much more energy efficient comparing to OMA. According to Basnayake, V., et al. (2020), the goal of developing a low-cost, self-sustaining, environmentally friendly wireless network will need the use of energy-efficient NOMA or green NOMA in the next 5G mobile network design.

As mentioned in the project results before, if there are too many users in a system, there will be unavoidable interference, which is a major concern. In C-NOMA, SIC is applied here and this is actually one of the ways to overcome this interference problem in which when the interference is successfully minimized between individual cells using coordinated approach, the user throughput can be in better performance. This could help to in improving the spectral efficiency and energy efficiency of the system.

Other than that, one of the most apparent parts which contributes a lot in terms of energy consumption in this project is the SWIPT concept which is used in cooperative communication. Chen, H.H., et al. (2014) mentions that the power splitting mechanism that is used in simultaneous wireless information and power transfer (SWIPT) can be considered as a game theory approach by the system because the system will make use of all information that is known for all users and computes the power splitting ratios for all users to act as relays to achieve the highest, and maximum achievable rates for each user in the system. The energy is harvested at the relays selected from one of the near users and used to power the relay transmissions. Furthermore, the proposed algorithm, which combines energy delivery and information transfer into a single source, improves transmission reliability and energy efficiency. This solution is more energy efficient than the systems where the energy delivery and information transfer are decoupled and conducted by different sources. SWIPT could be used in various situations where the secondary devices are not in reach or is not suitable to be exposed by physical power source such as nanobots in human body for biomedical purposes. More applications are possible especially on the Internet-of-Things (IoT) applications where a lot of electronics are used to gather information but only uses minimal power to continue running. This could save a lot in terms of components cost which may rack up a lot when they are used in a massive adoption especially with the new technologies that are enabled with the emerging mobile networks.

When compared to a random user selection scheme, the advantage of opportunistic node location selection for user or relay selection is that it performs better in terms of high throughput and low outage probability. By meticulously selecting and adjusting the correct network parameters such as transmission rate and power splitting coefficient, it is possible that the anticipated energy efficiency may be reached, so that any other batteries will not be used to power up the relay transmission. One less battery in the world is always encouraged so that the environmental will not be polluted with more chemical substances needed to create even one cell of battery.

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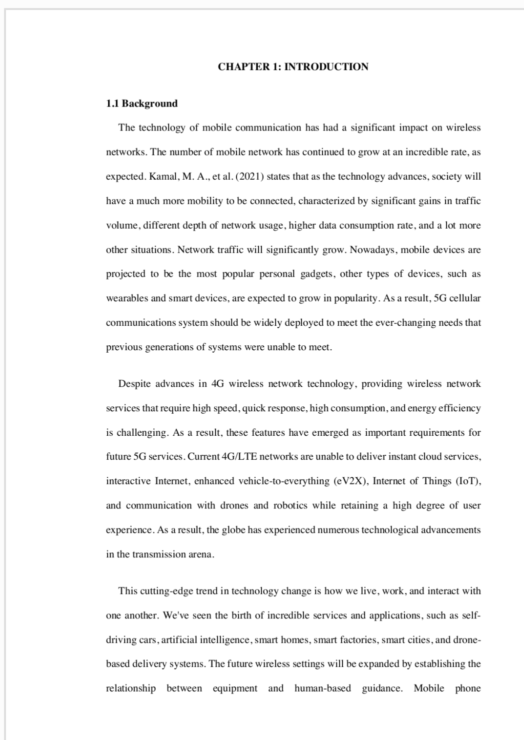

CHAPTER 1: INTRODUCTION

1.1 Background

The technology of mobile communication has had a significant impact on wireless networks. The number of mobile network has continued to grow at an incredible rate, as expected. Kamal, M. A., et al. (2021) states that as the technology advances, society will have a much more mobility to be connected, characterized by significant gains in traffic volume, different depth of network usage, higher data consumption rate, and a lot more other situations. Network traffic will significantly grow. Nowadays, mobile devices are projected to be the most popular personal gadgets, other types of devices, such as wearables and smart devices, are expected to grow in popularity. As a result, 5G cellular communications system should be widely deployed to meet the ever-changing needs that previous generations of systems were unable to meet.

Despite advances in 4G wireless network technology, providing wireless network services that require high speed, quick response, high consumption, and energy efficiency is challenging. As a result, these features have emerged as important requirements for future 5G services. Current 4G/LTE networks are unable to deliver instant cloud services, interactive Internet, enhanced vehicle-to-everything (eV2X), Internet of Things (IoT), and communication with drones and robotics while retaining a high degree of user experience. As a result, the globe has experienced numerous technological advancements in the transmission arena.

This cutting-edge trend in technology change is how we live, work, and interact with one another. We've seen the birth of incredible services and applications, such as self-driving cars, artificial intelligence, smart homes, smart factories, smart cities, and drone-based delivery systems. The future wireless settings will be expanded by establishing the relationship between equipment and human-based guidance. Mobile phone

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CHAPTER 1: INTRODUCTION 1.1 Background The technology of mobile communication has had a significant impact on wireless networks. The number of mobile network has continued to grow at an incredible rate, as expected. Kamal, M. A., et al. (2021) states that as the technology advances, society will have a much more mobility to be connected, characterized by significant gains in traffic volume, different depth of network usage, higher data consumption rate, and a lot more other situations. Network traffic will significantly grow. Nowadays, mobile devices are projected to be the most popular personal gadgets, other types of devices, such as wearables and smart devices, are expected to grow in popularity. As a result, 5G cellular communications system should be widely deployed to meet the ever-changing needs that previous generations of systems were unable to meet. Despite advances in 4G wireless network technology, providing wireless network services that require high speed, quick response, high consumption, and energy efficiency is challenging. As a result, these features have emerged as important requirements for future 5G services. Current 4G/LTE networks are unable to deliver instant cloud services, interactive Internet, enhanced vehicle-to-everything (eV2X), Internet of Things (IoT), and communication with drones and robotics while retaining a high degree of user experience. As a result, the globe has experienced numerous technological advancements in the transmission arena. This cutting-edge trend in technology change is how we live, work, and interact with one another. We've seen the birth of incredible services and applications, such as self- driving cars, artificial intelligence, smart homes, smart factories, smart cities, and drone- based delivery systems. The future wireless settings will be expanded by establishing the relationship between equipment and human-based guidance. Mobile phone communication capabilities will keep on expanding, and they will influence all parts of public life, creating a multidimensional, consumer-related ecosystem. Thus, it is crucial to tackle in aspect of cost-effective issues. With increased traffic, a considerably large number of implications, and an incredible amount of connectivity expansion are to be expected. Mobile networks will need to supply a thousand times the spectral efficiency of the present technology structure because of this huge increase in traffic. Furthermore, mobile networks of the fourth generation (4G) were linked to a 5 to 15-fold increase in spectrum efficiency (SE). Figure 1 5G designs and applications The 5G network incorporates a variety of technologies, including the Internet of Things (IoT), device-to-device (D2D) communications, software-defined networking (SDN), mobile edge computing (MEC), cloud computing, and cloud radio access networks (CRANs). From research by Pi, Z., et al (2011) and Siddiqi M.A., et al. (2019), it is found out that maintaining the current rate of advancement toward addressing this critical need would necessitate the use of cutting-edge technology to boost the massive cellular capabilities envisaged in the celebrated 5G cellular architecture. The importance of wireless structures that offer improved spectral proficiency and broader bandwidth than current cellular networks via the placement of multiple antenna components and 2 frequency reuse has been stressed in numerous academic and industrial related research studies to overcome the challenges. Wireless networks of 5G network are intended to meet the increased needs for wireless communication. Rapid advancement of technology of the IoT, fifth generation networks must be able to accommodate massive amounts of device or consumer connectivity. According to Liaqat, M., et al. (2020), in comparison to current fourth generation (4G) cellular networks, 5G is expected to provide the following key benefits: 10–100 times faster data rates, up to 99.99 percent availability, reduced delays, 10–100 times more connected devices, guaranteed coverage, 10 times lower energy consumption, and efficient improvement of current wireless systems with new 5G techniques . To achieve these expectations, advanced technologies are necessary. 1.2 Multiple Access Multiple access techniques have long been regarded as crucial in the design of wireless generation networks, as well as in evaluating the efficiency of any communication system. The basic physical connection in mobile network is defined by radio access technology. Radio access technology is implemented through the use of a radio access network, which connects wireless terminals to the core network via the channel access technique. Multiple access (MA) systems paves the way for multiple users to share the same resource. These methods may be classified into two categories: non-orthogonal multiple access (NOMA) and orthogonal multiple access (OMA). By allocating orthogonal resources to users, OMA methods avoid interfering signals. OMA techniques include time division multiple access (TDMA), frequency division multiple access (FDMA), and code division multiple access (CDMA). According to Liaqat, M., et al. (2020), existing OMA techniques, which distribute orthogonal resources like time, 3 frequency, and codes to multiple users, lack the spectral efficiency necessary to handle 5G standards. To design networks that has optimal spectral efficiency, NOMA has been demonstrated to be a good access mechanism for 5G networks. Multiple users can be handled at the same time, frequency, or spreading code using power domain NOMA, and multiplexing is implemented in the power domain at which, various power levels are allocated for different users. Power levels are allocated based on channel conditions or intended users' quality of service needs. To use NOMA, several users' messages are superimposed at the base station (BS) using superposition coding (SC). The messages of all weaker users are removed using successive interference cancellation (SIC) at each user, while the messages of strong users are treated as noise to detect their own information as mentioned in research by Ding, Z., et al. (2017). Massive connectivity, low latency, spectrum efficiency, and user fairness are all guaranteed by NOMA. In a wireless network, every idle node can listen in on the communications of other network users.

This idle node can assist in transmitting messages of its peer by utilizing the idea of cooperation. By transmitting several signals through relaying, this cooperation ensures increased consistency. Furthermore, when a direct contact between BS and a user cannot be formed due to poor channel conditions, relaying can assist in transferring the information of such users. In general, relay is chosen since it is closer to BS and requires less power at BS to send the signal to relay. According to Laneman, J. N., et al. (2004), relay networks are more reliable because of its vast advantages in terms of reliability, broader coverage area and power saving. Multiple cooperative relaying protocols have been developed to enable cooperation, the most notable of which are amplify and forward (AF) and decode and forward (DF). The intermediate relay node in AF relaying sends an amplified message to the destination, but in DF relaying, a re-encoded message is sent. 4 In cooperative networks, better performance comes at the expense of more spectral resources. NOMA can assist to decrease spectral loss due to collaboration since it can handle several users on the same frequency channels. Furthermore, according to Xu, Y., et al. (2015), as compared to cooperative OMA approaches, employing collaboration between relay with NOMA improves performance. 1.3 Energy Harvesting Wei X., et al. (2017) states that self-sustainability and energy efficiency, in addition to spectral efficiency, are significant design characteristics for 5G wireless networks. Radio frequency energy harvesting (RF-EH) has emerged as a key approach for enabling self- sustaining networks in this area. Simultaneous wireless information and power transfer (SWIPT) is a method of RF-EH that uses the same RF signal for both EH and information processing. In other cases, recharging or changing batteries is either too expensive or impossible. Self-sustaining systems might be beneficial in sensor networks where fixed power lines cannot be established, or on the Internet of Things where replacing the batteries of a large number of nodes is technically infeasible. In cooperative networks, any intermediate node may not be ready to participate because it will have to pay at the price of its own energy resources, or in case of dedicated relay, it may have a restricted power supply. In these cases, EH becomes particularly attractive as mentioned by Waqar, O., et al. (2019). The adoption of SWIPT encourages user participation by giving a solution for energy needs. As a result, combining SWIPT in cooperative NOMA networks, also known as cooperative NOMA (C-NOMA), results in spectral and energy efficient networks. Energy is collected from the transmitted source signal in these networks, but due to the random nature of the paths between source and relay, the harvested energy becomes random and unpredictable, making network analysis difficult and complicated. 1.4 Relay Selection By forming a virtual antenna array with cooperative networks with many relays, it is possible to improve signal dependability. However, because network resources are limited, using all available nodes for relaying is not recommended. Relay selection is the most effective method for achieving cooperative diversity via multiple relaying. Only the best available relay is used for relaying information in a multi-relay cooperative network with relay selection. Because just one relay is active at any given time, all relays do not need to be in strict time or carrier synchronization. Due to the reduced complexity and costs, relay selection is taken into account. The performance of a basic cooperative relay network can be improved by deploying several relays. Multiple relay networks, on the other hand, improve performance at the price of complexity and spectral resources. Relay selection (RS) is the most effective method for implementing cooperative diversity through multiple relaying. Only one selected relay passes the message across RS, hence there is no spectral loss due to many relays. Furthermore, unlike multiple relay networks, a single relay runs at a time, requiring no stringent time or carrier coordination across all relays, resulting in decreased complexity and costs. It is critical to clarify that, from a practical standpoint, RS is critical to the successful implementation of future networks. 1.5 Problem Statement The problem statement for this project is how to obtain the least outage probability by relay selection in C-NOMA that is utilized by the SWIPT energy harvesting method while still covering a broader coverage area. Evaluating the performance of several relay selection schemes used in Cooperative NOMA (C-NOMA) with simultaneous wireless information and power transfer (SWIPT) is achievable by doing the analysis on the performance comparison of several relay selection schemes used in Cooperative NOMA (C-NOMA) based on the existing related works. The performance of cooperative NOMA may be evaluated by observing the value of outage probability, achievable rate, and user SNR/SINR. At the end of this project, various relay selection schemes will be analyzed from various existing related works and some of the system models are simulated to further support the evidence of that is researched. 1.6 Objectives The objective of this project is as listed below. ? To identify the best relay selection schemes that gives the least outage probability to all users in cooperative communication system with SWIPT ? To observe the system behavior in terms of achievable rate for all users when the transmit power from base station is increased ? To determine the variables that affects the outage probability of all users in C- NOMA with SWIPT when the transmit power from base station is increased CHAPTER 2: LITERATURE REVIEW Non-orthogonal multiple access (NOMA) was suggested for 3GPP LTE and is expected to be a key component of 5G mobile networks. The essential characteristic of NOMA is that it may serve numerous users at the same time, frequency, and code, but at different power levels, resulting in a considerable spectral efficiency increase over traditional orthogonal MA. Both academics and industry have suggested, examined, and investigated several NOMA systems. As a result, there are a variety of magazine articles and survey studies on the subject. Research by Ding, Z., et al. (2017) covers the uses of NOMA in conjunction with MIMO technologies through cooperative NOMA and the interaction between NOMA and cognitive radio. It also examines the current state of standardization initiatives for NOMA deployment in LTE and 5G networks. NOMA introduces high co-channel interference among mobile users, posing significant design and resource management difficulties. The resource management problems in NOMA systems are further discussed in research by Song, L. et al. (2017) where the article covers about the primary NOMA taxonomy that is provided by focusing on the two major resource reuse categories: power-domain and code-domain NOMA. For the next-generation radio systems, NOMA has been highlighted as a promising technology to help achieve all of the system capacity, user connectivity, and service latency requirements, given its aim to connect everything and the much-improved hardware capability. In research conducted by Chen, Y., et al. (2018), they covered about a systematic overview of the modern and unique design of NOMA transmission based on a unified transceiver design framework, related standardization progress, and potentially usable technology in future cellular networks, allowing interested researchers to get a head start in this area. As an effort to improve the self-sustainability and energy efficiency, the energy harvesting and information processing receivers operate at separate sensitivity levels, and they can't be done at the same time. In research conducted by Waqar, O., et al. (2019), two methods, power splitting (PS) and time switching (TS), have been suggested to address these practical restrictions, in which that the outage and ergodic throughputs of the TS and PS protocols considering the Nakagami-m fading channels are provided in the research using a novel analytical methodology. In research conducted by Yang, Z., et al. (2017), the effect of two forms of NOMA power allocation strategies, namely F-NOMA (fixed power allocation) and CR-NOMA (cognitive radio inspired NOMA), on SWIPT system is explored, where the energy harvesting relay connects a source to two consumers in a cooperative non-orthogonal multiple access (NOMA) network. Rajaram, A., et al. (2019) conducted research that studies on SWIPT enabled modulation-based NOMA systems to improve energy harvesting efficiency and data rate. In various studies such as Kim, J.-B., & Lee, I.-H. (2015), Kim, J. B., et al. (2016), and Ashraf, M., et al. (2017), C-NOMA SWIPT networks with multiple antennas have been explored because the usage of multiple antennas can improve the energy efficiency and performance of systems. Alsaba, Y., et al. (2018) did research on a unique communication technique combining beamforming, energy harvesting, and a cooperative non-orthogonal multiple access (NOMA) system is presented where the NOMA is used with beamforming in a proposed approach to serve several users in each beamforming vector. For relay selection schemes, a two-stage relay selection technique was proposed Yang, Z., et al. (2017), where the outage probability of NOMA two-stage DF and AF schemes are calculated for NOMA networks with decode-and-forward (DF) and amplify-and- forward (AF) relaying protocols with differing quality of service requirements at the users. Research by Deyue, Z., et al. (2019) shows the effect of correlated fading channel 9 on outage probability for decode-and-forward (DF) relaying non-orthogonal multiple access (NOMA) system is, where a source transmits messages to dual destinations with the help of multiple relays to obtain the best system outage performance. Research by Guo, W., et al (2017) suggest a new relay selection strategy for a cooperative energy harvesting NOMA network. For cooperative NOMA transmission, the relays are considered to have no embedded energy supply and rely only on the energy gathered from the source's signals. Ding, Z., et al. (2014) made research on energy harvesting relay that can communicate with numerous source-destination pairs. Furthermore, this technique enables the energy harvesting relay to divide the energy among the various consumers in the most efficient manner possible. Chen, H.H., et al. (2014) proposed a game theory approach on SWIPT where three alternative network scenarios are modelled, with each link acting as a strategic player whose goal is to maximize the rate that may be accomplished by selecting the dedicated relay's power splitting ratio in order to achieve good network-wide performance. CHAPTER 3: CHAPTER 3: METHODOLOGY 3.1 Overview The project was started by researching about the fundamentals of wireless communication. Various articles, research papers, videos, and resources from the internet have been studied to focus on understanding the concept that builds the foundation of relay selection schemes for Cooperative NOMA (C-NOMA) and simultaneous wireless information and power transfer (SWIPT). Then, further research was done by looking into algorithm or machine learning which seems to be utilized by most researchers as far as my research is concerned. The algorithmic model is used to strategically tackle the resource allocation and optimization for the network and find the best route for relay selection that satisfies every user. Some researchers also take deep learning method into consideration to get the best outage performance depending on the Channel State Information (CSI) of the users. This relationship may also be seen from game theory perspective where the system uses their information to compute power splitting ratios for all relays to achieve maximum achievable rates for each user. 3.2 Research materials 3.2.1 NOMA SIC NOMA is a candidate multiple access scheme for 5G. It may appear surprising that NOMA permits several users to send and receive at the same time on the same frequency. We'll utilize NOMA downlink transmission with two users as an example to further illustrate the notion of NOMA. As shown in Fig. 1, the base station (BS) can service two users at the same time, code, and frequency, but at separate power levels. In particular, the BS will broadcast an overlaid mixture including two messages for each of the two users. Remember that traditional power allocation mechanisms, such as water filling, 11 provide customers with strong channel conditions more power. Users with poor channel conditions gain more transmission power in NOMA than in traditional systems. Superposition coding on the transmitter side and successive interference cancellation (also known as SIC) on the reception side are the two main procedures that make NOMA possible. A graphical representation of superposition coding can be seen as shown in Figure 2 below Figure 2 Non-cooperative NOMA transmission system model within the NOMA network of two-user Figure 3 Data of user 1 and user 2 Figure 4 Superposition coded signal of user 1 and user 2 where $x = \sqrt{a1}x1 + \sqrt{a2}x2$ Successive Interference Cancellation (SIC) is a technique used by the receiver in a wireless data transmission to decode two or more packets that arrived simultaneously. SIC is an iterative method that decodes data in decreasing order of power levels. That is, the data pertaining to the user with the highest power is decoded first, followed by the data relating to the user with the next highest power. The message sent to the user with the weaker channel is given higher transmission power, ensuring that this user can detect its message directly by treating the information from other users as noise. The user with the weaker channel condition must first identify its partner's message, then deduct this message from its observation, and then decode its own data. The procedure is known as SIC. After applying SIC in the superposition coded signal above (subtracting the signal of user 1), it can be seen that in Figure 5, the graph is the same as of that user 2. Figure 5 Applying SIC to the superposition coded signal Multipath propagation and fading are common problems with wireless channels. To capture the effects of fading, there are several channel models available. Each model is focused on a specific circumstance. Rayleigh fading is an example of such a model. When there is no line of sight (LOS) between the transmitter and the receiver, it is now possible to employ the Rayleigh fading model . In other way, all multipath components have experienced small-scale fading effects like as reflection, scattering, diffraction, and shadowing. 3.2.2 Cooperative communication We know that NOMA uses successive interference cancellation (SIC), in which one user decodes the other user's message from the superposition coded incoming signal before decoding his own. Specifically, while conducting SIC, the near user decodes the information of the far user. This is a step that cannot be avoided. In every case, the data of the far user must be decoded by the near user. Now that the near user has access to the far user's data, he can use it to help the far user. Because the distant user's channel with the transmitting base station (BS) is poor, the close user's retransmission of his data will supply him with diversity. In other words, he'll get two copies of the same message. One 14 is from the base station, while the other is from a nearby user functioning as a relay. As a result, we can anticipate a decrease in the likelihood of a far-user outage. Figure 6 Two users cooperative communication in NOMA downlink Cooperative communication/cooperative relaying is the term for this notion. We can see that NOMA naturally facilitates cooperative communication because the near user already has the data of the far user because it has to decode it. The advantage of cooperative communication is that there exists a constructed two lines to transmit the identical message. Even if one connection is down, chances are the other is up and running. When compared to the probability of any one link failing, the likelihood of both links failing at the same time is extremely low. Without the use of extra antennas, we may lower the likelihood of outages and thereby gain diversity (i.e., MIMO). Another benefit is that relaying allows the base station's coverage area to be practically extended. The system model for a cooperative communication is at downlink transmission in a scenario with a base station (BS) and two NOMA users. With the BS, we have a near user with a stronger channel and a far user with weak channel conditions. The transmission is split into two parts. The first time slot will be referred to as direct transmission, while the second slot will be referred to as relaying. The first slot is the direct transmission slot where the BS employs NOMA to transmit data destined for the near user and the far user. The near user uses SIC to decode the data of the distant user first, before moving on to decoding its own data. Direct decoding is all that the far user does. The next half of the time slot is called relaying slot. Because the near user decoded it in the previous time period, the near user already had the data of the distant user. The near user simply transmits this data to the far user during the relaying time window. 3.2.3 Simultaneous wireless information and power transfer (SWIPT) Figure 7 General system model of SWIPT The power consumption of electronics is becoming increasingly essential as we move toward more complex communication networks. In a wireless network with hundreds of IoT sensors, for example, battery drain could cause the sensors to die. Green communication solutions, such as RF energy harvesting devices, are being pushed to address this issue. NOMA demands successive interference cancellation, which is a computationally costly process as we all know. This puts a strain on the battery's capacity. We used user cooperation to study the cooperative NOMA system, where the close user worked as a relay for the far user. Because the near user already had the data of the far user, this user cooperation was natural. Is the nearby user, however, capable of relaying 16 that information? What if relaying depletes the battery of a nearby user? This is where RF energy harvesting may be of assistance. Because of data transmissions, electromagnetic waves are always present all around us. Of course, we can't understand these signals unless they carry information that is meant for us. They also transport power, which we may harvest using basic RF circuits, in addition to transmitting information for someone else. Then we can use the power we've harvested to create our own communications. Our battery would never run out this way. There are two types of energy harvesting protocols, namely time switching and power splitting. In the time switching protocol, the device works in a timed manner. The device captures electromagnetic energy from its surroundings during the first fraction of the time period. In the following fraction of the timeslot, the captured power is used for transmission. Next, in the power splitting protocol, the device splits the power of the received signal for energy collection and decoding. Unlike time switching, which requires different time slots for both processes, power splitting allows both energy harvesting and information decoding to be done at the same time. This approach is the one that is called SWIPT. SWIPT is a potential technique for remotely powering up devices or nodes due to its inexpensive cost, wide operational range, and ability to use a small-sized receiver. Information can be delivered simultaneously with the wireless energy transfer using the same signal. Unlike traditional EH technologies, SWIPT is less reliant on the environment and can provide consistent energy supply in all types of weather. As a result, SWIPT has been suggested as a viable option for extending the life of energy-constrained systems. CHAPTER 4: PROJECT RESULTS AND DISCUSSION 4.1 Simulation of Basic C-NOMA Figure 8 System model of NOMA downlink transmission It is known that the superposition coded NOMA signal transmitted by the BS is, $w = \sqrt{P}(\sqrt{\alpha 1}w1 + \sqrt{\alpha 2}w2)$ Where P is the transmit power. To obtain the signal to interference noise ratio and the achievable data rate, the equation are as shown below Signal to interference noise ratio, $|h1|^2 P\alpha 1$ $\gamma 1 = |h1|2P\alpha 2 + \sigma 2$ $|h2|^2 P\alpha 2$ $\gamma 2 = \sigma 2$ Achievable data rate, $|h1|^2 P\alpha 1$ $R1 = log2(1 + \gamma 1) = log2\ (1 + |h1|2P\alpha 2 + \sigma 2\ )$ $|h2|^2 P\alpha 1$ $R1,2 = log2(1 + \gamma 1,2) = log2\ (1 + |h2|2P\alpha 2 + \sigma 2\ )$ $R2 = log2(1 + \gamma 2) = log2\ (1 + |h2|^2 P\alpha 2\ \sigma 2\ )$? α1 - power allocation coefficient for far user ? α2 - power allocation coefficient for near user ? h1 - Rayleigh fading coefficient for far user ? h2 - Rayleigh fading coefficient for near user ? P - Total transmit power ? σ² - Noise power ? α1 + α2 =1 ? α2 > α1 Figure 9 BER graph for NOMA in AWGN channel Figure 10 Achievable data rate for user 1 and user 2 for different power levels in dBm Figure 11 Outage probabilities when target rates are set for each user Figure 12 Comparison of BER graph of NOMA between original data and simulated data From the BER graph for NOMA in AWGN in Figure 9, the waterfall trend can be seen. In addition, we noticed that user 2 has a slightly greater BER than user 1, particularly at low SNR. This is due to the fact that user 2 must perform SIC. User 2 must first estimate user 1's data from y before executing SIC. If this estimate is incorrect, it will show up in the decoding of its own data because the incorrect data will be deducted from y. In other 20 words, user 2 must correctly decode both user 1's and its own data. Any errors in decoding user 1's or its own data will have an effect on its BER. As a result, user 2 has a higher BER than user 1. Figure 13 Outage probability when compared to the target rate for fixed power allocation and first version of adaptive PA Figure 14 Outage probability when compared to target rate for fixed power allocation and second version of adaptive PA From Figure 13 above, when target rate of far user, R* > 1.5 bps/Hz, we can observe that the fixed PA is underperforming, and its outage probability saturates to 1 all of the time. In other words, if we use fixed PA with R > 1.5 bps/Hz, the receiver is ALWAYS out of service. This is because fixed PA does not take into consideration the target rate requirements or exploit the immediate CSI. As a result, while fixed PA is straightforward to construct, it is not ideal. However, because near and far are dynamically modified based on goal rate requirements and CSI, our adaptive PA has a decreased outage probability. We can see in our adaptive PA that the outage probabilities of the far user grows as his target rate demand increases. This is to be expected, given the target rate rises. For the next Figure 14, the adaptive power allocation is changed so that when the outage probability of far user is 1.0 (likely to be outage), the power allocation coefficient of far user is set to be 0, meaning no power is allocated to the far user and full power is allocated to near user. It was found out that the outage of a remote user follows the pattern shown in Figure 13. This means that when the power allocation of far user was tweaked, it had no effect on the far user's outage. The likelihood of an outage rises, peaks, and then begins to decline. When R* is between 0 and 6.5 bps/Hz, it appears that the graph is favoring the far user by giving more and more power to the user at the expense of the near user's performance. However, any value of ɑ1 above 6.5 bps/Hz may not entirely satisfy R. When this happens, we prioritize the person who is closest to us rather than squandering all of our strength on the user who is far away. This shows that the wireless channel is a very dynamic environment. Fixed PA is unconcerned about the users' current channel conditions. Regardless of the channel condition, near and far coefficient remain constant. The adaptive PA, on the other hand, is a moving target. In other words, anytime the channel changes, the values of near and far coefficients are adjusted to match the specification. As a result, adaptive PA has a greater total rate and a lower outage than fixed PA. When considering the effect of cooperation among the NOMA users, users with favorable channel conditions have previous knowledge of the messages of other users, which is a key component of PD-NOMA when employing SIC. This means that the messages from weak users are decoded first by the user with the better channel state. As a result, better users can take advantage of this duplicated data by acting as relays for other users who have a poor connection to BS. Therefore, the near user simply transmits this data to the far user during the relaying time window. The achievable rate of the far user at the end of the relaying slot is, 22 $Re,2 = 2\ log2(1 + \rho|hne|^2)$ 1 hnf is the channel between the near user and far user. After selection combining, the achievable rate of the far user would be 1 $\alpha e\ \rho|he$ | 2 2 $Re,2 = log2\ (1 + law(\ 2\ ,\ \rho|hne|\ ))$ $\alpha n\rho|he|$ + 1 2 Figure 15 Outage probabilities of different variations on NOMA From this graph of Figure 15, we order the performances of different schemes as: cooperative NOMA > non-cooperative NOMA > OMA. Thus, it can be concluded that the best performance and useful is the cooperative communication. 4.2 Simulation of basic SWIPT in C-NOMA Figure 16 SWIPT C-NOMA system model Based on Figure 16, the simulation model is about downlink transmission, where the base station (BS) utilizes NOMA to transmit information to both the near and far users at the same time. Unfortunately, there is a blockage in the path between the BS and the far user, leading to severe shadowing. As a result, the signal cannot be received by the far user. However, the near user has a strong connection to the BS channel. By applying the C-NOMA principles, the near user must first decode the data meant for the far user, then execute SIC to decode its own data. As a result, the near user has a copy of the far user's data and by functioning as a decode-and-forward relay, the near user can assist the far user in getting better quality of information. However, the problem is that the near user lacks sufficient power to transfer both the information and power to the far user. To solve this, the near user can harvest enough power by using the power-splitting method of energy harvesting, also known as SWIPT (simultaneous wireless information and power transfer). We can observe the complete transmission in two different time slots. The data transmitted by the BS is received by the 24 near user in the first time slot. The power splitting protocol harvests a portion of the incoming signal power and uses the remaining power for information decoding. The gathered power is used by the near user to relay data to the far user in the second time slot. In time slot 1, the signal transmitted by the BS is given by $w = \sqrt{P}(\sqrt{an}wn + \sqrt{ae}we)$? P − Transmit power ? an − Power allocated to the near user ? ae − Power allocated to the far user ? wn − Signal to near user ? we − Signal to far user However, since the far user cannot receive this signal. The equation to calculate the signal received by the near user is as shown below. $wn = \sqrt{P}(\sqrt{an}wn + \sqrt{ae}we)hsn + wn$? hsn − Rayleigh fading coefficient between the BS and near user ? wn − AWGN From wn , the near user is able to harvest a fraction of power denoted by the symbol ψ which can be called as the energy harvesting coefficient. The remaining fraction (1−ψ) is the fraction of power available for information decoding for the near user. Thus, the signal available for information decoding after energy harvesting, assuming the energy harvested from wn is negligible, is now as below. wch is the thermal noise introduced by the energy harvesting circuitry. 25 $wD = (\sqrt{1} - \psi)\sqrt{P}(\sqrt{an}wn + \sqrt{ae}we) + wch$ Then, the near user will execute its direct decoding for far user's signal. The achievable rate to decode the far user data by the near user is given by, 1 $P(1 - \psi)ae|hsn|2$ $Rne = \log2(1 + P(1 - \psi)ae|hsn|2 + \sigma2\ 2\ )$ The achievable rate for the near user to decode its own signal is given by, 1 $P(1 - \psi)ae|hsn|2$ $Rn = 2\log2(1 + \sigma2\ )$ The total amount of power harvested by the near user can is given by, $PH = P|hsn|2\zeta\psi$? ζ – Efficiency of the power harvesting component In time slot 2, the near user will use the total harvested power in the previous slot to relay the signal that is intended for the far user. At far user, the equations for the received signal and the achievable data rate are given by, $we = \sqrt{PH}w\bar{e}hne + we$ 1 $PH|hsn|2$ $Re = \log2(1 + 2\ \sigma2\ )$? hne – Rayleigh fading channel between the near user and far user Figure 17 Power harvested at near user with increasing transmit power from BS Figure 18 Average achievable rate using SWIFT in C-NOMA The simulation target rate is set to be 1 bps/Hz for both near user and far user. For the first simulated Figure 17, it shows that as the base station transmits the information which also contains power, the near user receives both information & power and managed to harvest the energy. The higher the transmit power from BS, the more power is able to be harvested by the near user. This graph only shows near user because far user is not in reach by the BS, hence the absence of far user. This means that far user must somehow obtain energy and that energy is harvested by the near user as compensation. In the next Figure 18, it shows the average achievable rate for both near user and far user. By this stage, the near user has decoded its message and transmitted the far user's message together with the harvested energy. We can observe that the near user's rate is saturated at around 1 bps/Hz wile the far user's rate also rises. This saturation is due to energy harvesting. All remaining power is harvested from the near user once the far user's data rate is fulfilled. However, the achievable rate at the near user is still limited due to the energy harvesting procedure, even if the transmit power is raised. This isn't really that much of a problem though because the near user's target rate of 1 bps/Hz is not ignored, 27 which is a plus. As a result, this rate of saturation does not result in a significant outage for the near customer. The amount of power harvested at near user grows as the transmit power from BS increases. As a result, the amount of power intended for the far user data is also increasing. This causes the rise in far user's achievable rate as seen in the Figure 18 above. Something to note is that this might make it seem that the far user must have been experiencing the lowest outage chance comparing to other users because it has higher achievable rate. However, when we plot and study the outage graphs, we are able to notice something completely contrary to the expectation. Figure 19 Outage probability of SWIPT Figure 20 Instantaneous achievable rate of in C-NOMA SWIPT in C-NOMA Figure 19 shows that the far user has a substantially higher outage than the near user, although having a higher achievable rate on average. Since Figure 18 was plotted in terms of average value of performance, we can't really see the real-time value of the performance. Thus, if we plot the users' instantaneous achievable rates, we get the graph as seen in Figure 20. Based on Figure 20, we can see why, while having a higher achievable rate, the far user has a higher outage. The far user's achievable rate is focused around 3 bps/Hz, but the overshoot of the wave makes the graph seems very unstable for 28 far user. We notice that the far user's instantaneous achievable rate frequently falls below the target rate. This is not a good sign because we don't care how high the achievable rate is when it comes to outage calculations, but instead the number of times the target rate goes below the goal rate is what will determine the user experience of the network. For the far user, this type of fall is more common. As a result, the far user has a miserable outage performance. To overcome this problem, researchers has come up with various ideas to get the best route in relaying to get the best performance in terms of QoS and outage probability. From my research of various research papers and journals, most of the target is to achieve in increasing the end-to-end sum rate and reduce the power consumption of wireless communications for NOMA wireless relay networks with as low computational complexity as possible. The next sections will explain more of the selected methods of relay evaluation by researchers. 4.3 Simulation of Transmit Antenna Selection (TAS) Figure 21 System model for hybrid time-switching/power-splitting (TS/PS) SWIPT-based cooperative relaying transmission with TAS for a two-user NOMA system Much of the research into cellular network power control began in 1992-1993 with a set of findings that solved the basic challenge formulation, in which transmit power is the only variable, bound by a fixed target SIR, and optimised to reduce total power. Cooperative NOMA transmissions is no doubt that it could provide superior performance in terms of outage probability and it could be a long-term solution to the above-mentioned challenges in NOMA systems. However, it is still a challenge as to how should the selection of relays be done, given that the cell-center users allocate their power, and they must analyse their own data as well as transfer the data of the other far users. Thus, a TAS system for NOMA downlink energy harvesting (EH) multiple-antenna relaying networks was recently investigated by Do, T. N., et al. (2018). Based on Figure 21, a two-user cooperative MISO-NOMA system is considered, in which a cell-center user works as a relay to improve communication from a BS to a cell- 30 edge user. Using TAS can help to increase the performance of the cell-edge user and helps the cell-center user to save more power. Three different types of schemes were proposed for this algorithm, to which the signalling and channel state information (CSI) estimation/calculation system is used to run the suggested TAS schemes before data transmission. It is assumed that each scheme's required CSI is available and is known by the BS. For Scheme I, the TAS criterion is to choose an antenna that maximises the far user's instantaneous transmission rate, which is given by the equation below, $1 - \alpha\ RiF = 2\ \log2(1 + \gamma Fe2e)$? $\gamma Fe2e$ = End-to-end SNR of the far user ? α = Fraction of block time for energy harvesting The algorithm selection of Scheme I can be expressed as below, $i* = 1 - \alpha\ 2\ \log2(1 + \gamma Fe2e) = \arg\ 1m{\leq}ia{\leq}xK\ \min\{\gamma ixFF, \max\{\gamma iF, \{\gamma NF\}\}$? wF = Message of the far user For Scheme II, the TAS criterion is to select an antenna that still maximizes the instantaneous transmission of the far user but offers relatively low computational complexity. This is because, Scheme I seem to need a very high complexity operation, whereby three kind of CSI channels are required, namely BS → Near user, Near user → Far user, and BS → Far user. In order to lower this complexity, Scheme II was done by focusing on the performance of the far user in the first phase/time slot. The instantaneous transmission rate for Scheme II is given by, $1{-}\alpha\ 1{-}\alpha\ RiF = \min\{\ 2\ \log2(1 + \gamma ixNF)\ ,\ 2\ \log2(1 + \gamma iF)\}$ The algorithm selection of Scheme II can be expressed as below, $i* = \arg\ \max|hiF|2\ 1{\leq}i{\leq}K$? hiF = Rayleigh fading of the far user with zero mean and variance of λBS-F For Scheme III, the TAS criterion is to select an antenna that provides a maximum instantaneous harvested energy at the near user. Note that all the harvested energy at the near user will be used to transmit message to the far users. The algorithm selection of Scheme II can be expressed as below, $i* = \arg\ \max|hiN|2\ 1{\leq}i{\leq}K$? hiN = Rayleigh fading of the near user with zero mean and variance of λBS-N Figure 22 Outage probability of all Figure 23 Outage probability of all Schemes when comparing the distance schemes when comparing the SNR of of near user to BS the far user Based on Figure 22, the effect of outage probability due to distance between BS and the near user was observed at the far user. All of the schemes have increasing outage probability when the distance is increased. There are several possible reasons for this, the first is when the near user is located further away from the BS, the total amount of energy harvested is decreasing, making it harder for the near user to transmit message to the far user using less power. Second is based on the principles of NOMA itself, where the system should make use of the difference of channel conditions of the channel to determines who will do the SIC to decode the message of both users and transmit the signal to the far user. However, when the near user is located closer to the far user, their channel condition becomes a lot more the same, which would lead to the decreasing performance of all the Schemes. Figure 23 shows the performance comparison between all the proposed Schemes and randomly selected TAS. It can be seen that Scheme I provide the best performance of the outage probability, followed by Scheme II, and Scheme III. Scheme I beat all the other schemes in both lower SNR and higher SNR region. However, Scheme II performs better in the higher SNR region when comparing to Scheme III, while Scheme III performs better in the lower SNR region when comparing to Scheme II. The randomly selected TAS is the most underperforming method because it doesn't really have any mathematical thoughts put into it, so it is the most random method. It is important to note that given Scheme I beats all the other schemes, where Scheme I focuses on maximising the far user's instantaneous transmission rate, it actually uses a lot of mathematical equations and considers a lot of CSI, thus making it has the most complexity among all Schemes. For reduced complexity, Scheme II and Scheme III can be considered depending on the usage of the network either in the low SNR or high SNR regime. 4.4 Simulation of Best-Near Best-Far (BNBF) selection Figure 24 System model of the BNBF relay selection method Figure 24 shows the system model of best-near best-far user selection scheme for relaying. Consider a cooperative network where there is a source of information which is the base station, BS, a cluster of F far users, and a cluster of N near users. The assumption is that single antenna is equipped to all of the nodes and the antenna is working in half- duplex mode. Every network is assumed to undergo and i.i.d. Rayleigh block flat fading. It is also assumed that all terminals of all the users have the same AWGN mean power N0, and that the BS knows all of the CSI for all near users and far users. The Best-Near Best-Far (BNBF) User selection scheme here is proposed by implementing it before the data transmission happens by comparing their channel conditions using their CSI estimation in the system. In short, any near user or far user that have the best respective channel conditions will be chosen for relaying in the transmission slot. The BNBF selection scheme can be described as given below, $Ns = \arg\ lawi{=}1,\ldots,N|hSNi|2\ Fs = \arg lawi{=}1,\ldots,N|hSFi|\ 2$ Figure 25 BNBF with number of near and far users comparison Figure 26 Best and Worst user selection comparison (BNBF = Best- Near Best-Far, BNWF = Best-near

Worst-far, WNBF = Worst-near Best- far, RNRF = Random-neam random- far) After running the MATLAB simulation, two figures are taken for analysis. Figure 25 compares the effect of outage probability when different number of near users and far users are considered in the system. Based on Figure 25, it is found out that the system diversity order for this system model is depending on the number of far users. When the system is run using different number of near users, the outage probability is found to be overall better in both low and high transmit SNR regime. However, when the system is run using different number of far users, the outage probability is the same in the low transmit SNR regime and performs better in the higher transmit SNR regime. This shows that having more near users can help the system to get better performance of relaying for the C-NOMA with SWIPT. In the higher transmit SNR regime, far users can have a better performance when more energy is supplied by the near users. Thus, in theory more users in the system should be better to have the best outage performance, however when too 36 many users are in the system, the problem would arise in the interference and SIC complexity. That problem is not covered in this section but is explained in Section 4.5. Something important to note from this is that more users in system will be better for outage performance, but too many users will also cause problem in the system. For Figure 26, four different conditions are simulated, where the best users and the worst users are identified for both near users and far users. The performance of best-near best-far (BNBF), best-near worst-far (BNWF), worst-near best-far (WNBF), and random- near random-far (RNRF) were compared. It is found out that the outage performance for BNBF was the best in all SNR regime. It is also worth noting that when the best near users are prioritised, the outage performance starts with lower outage probability comparing to starting with worst near users. Thus, it can be concluded that the best near users should be prioritised when implementing this relay selection for cooperative- NOMA with SWIPT. 4.5 Simulation Comparison and Summary Figure 27 Outage probability of far user for different relay selection schemes Figure 27 shows the outage probability comparison of the simulated relay selection schemes in previous sections. It is found out that the best relay selection scheme simulated in this paper is when Scheme 1 is used where the algorithm tries to achieve the maximized instantaneous transmission rate of the far user but at the cost of high complexity. The next is followed by Scheme 2 and Scheme 3 where it differs in the mid-range of transmit SNR. The worst performance is the BNBF selection scheme, where number of users are mainly affecting the performance of the system. Figure 28 Effect of average achievable rate with increasing number of users One of the problems that may arise is that when too many users are in the system. Section 4.4 explained that more users should have better outage probability, thus if infinite users are in the system, it should be the best outage probability. However, that statement is false because when simulated, the graph in Figure 28 shows that there is a drop-off point for every value of transmit power by the BS depending on the number of users in the system. By increasing the transmit power, the system can hold a greater number of users. The increase in value before the drop-off is due to the same reasons that NOMA offers better capacity than OMA. The interference levels are manageable and the strongest user, although he is allocated the least power, is given a respectable amount of power. The drop-off point can be seen as the maximum number of users that the system 38 can hold. Thus, it can be concluded that if a system is limited by power, it is better to not add any more users when opting for better outage performance because number of users for a system can be increased when the power from BS is also increased. CHAPTER 5: CONCLUSION AND FUTURE WORKS 5.1 Conclusion To conclude, the system model for cooperative-NOMA, energy harvesting with SWIPT, and relay selection for the cooperative-NOMA with SWIPT were successfully constructed. SIC is a technique used by the receiver in a wireless data transmission to decode two or more packets that arrived simultaneously and is used by the near user to decode both its message and the far user message. This technique can be further utilized by the cooperative communication in NOMA where it is called as C-NOMA and is usually implemented with SWIPT to cover the power absence in the cell-edge far users. This project covers the basics of cooperative communication in NOMA, basics of energy harvesting with SWIPT, and several techniques that is utilized in such cooperation communication using dedicated relay selection to make sure that the system coordination and performance can be maximized in the data transmission. Based on the simulations, it was proven that power and resource allocation is important for the user to have the lowest outage probability as possible. This can be further improved by applying the relay selection scheme for selecting the best route for data transmission depending on every user’s channel state information, and energy harvesting for sustaining the power usage in cases that the cell-edge users are unable to receive it. The best method for selecting relay that is simulated in this project is when the far user is selected to have the maximized instantaneous achievable rate, however this comes at the cost of high complexity. An optional way to improve outage probability can also be by increasing the number of near users in the system to act as more route for relay selections, but that method is limited by the maximum transmit power that can be transmitted by the base station. This shows that a lot more work must be done to get the ideal relay selection that is suitable for C-NOMA with SWIPT. 5.2 Future Work For future work, the outage performance part might even be solved without the need in taking the device complexity in consideration, but instead by using deep learning method. Research by Yin, Z., et al. (2022) shows that when considering a NOMA system with imperfect CSI, applying a deep learning and a special neural network to accurately identify CSI based on training can significantly improve the outage performance and recovers the diversity gain. The deep learning method could have more room of improvement and may even be applied in relay selection scheme, in which a classic example from one of the first algorithmic Distributed Power Control (DPC) using the Foschini and Miljanic algorithm which is described by Chiang, M., et al. (2008) to obtain the rate of convergence and robustness to stochastic dynamics. Other than that, when considering a situation where low latency, high data rates, real time processing, reliability, storage are required, fog computing could solve the efficient energy utilization problems to further improve the performance metrics. Research by Hu, P, et al. (2017) shows that NOMA can be utilized further to address other issues such as resource optimization, poor processing power, and server placement using fog computing. As a result, more research on NOMA-based networks using energy-efficient fog computing designs could be looked into further to boost performance metrics even more. 5.3 Impact of Work to Environment and Society Massive connection is projected with huge energy demands from network operators; hence in te future mobile wireless networks, trying to be efficient in using energy is a major challenge. Since non-orthogonal multiple access (NOMA) is the leading 5G multiple access scheme, there have been numerous research efforts aimed at improving the energy efficiency of wireless networks that are utilizing the NOMA technology while maintaining outstanding performance metrics such as high throughput, data rates, and capacity maximization. NOMA by nature itself has already outperforms the spectral efficiency of the conventional OMA because NOMA scheme can simultaneously handle multiple users via power domain division which makes it much more energy efficient comparing to OMA. According to Basnayake, V., et al. (2020), the goal of developing a low-cost, self-sustaining, environmentally friendly wireless network will need the use of energy-efficient NOMA or green NOMA in the next 5G mobile network design. As mentioned in the project results before, if there are too many users in a system, there will be unavoidable interference, which is a major concern. In C-NOMA, SIC is applied here and this is actually one of the ways to overcome this interference problem in which when the interference is successfully minimized between individual cells using coordinated approach, the user throughput can be in better performance. This could help to in improving the spectral efficiency and energy efficiency of the system. Other than that, one of the most apparent parts which contributes a lot in terms of energy consumption in this project is the SWIPT concept which is used in cooperative communication. Chen, H.H., et al. (2014) mentions that the power splitting mechanism that is used in simultaneous wireless information and power transfer (SWIPT) can be considered as a game theory approach by the system because the system will make use of all information that is known for all users and computes the power splitting ratios for all 42 users to act as relays to achieve the highest, and maximum achievable rates for each user in the system. The energy is harvested at the relays selected from one of the near users and used to power the relay transmissions. Furthermore, the proposed algorithm, which combines energy delivery and information transfer into a single source, improves transmission reliability and energy efficiency. This solution is more energy efficient than the systems where the energy delivery and information transfer are decoupled and conducted by different sources. SWIPT could be used in various situations where the secondary devices are not in reach or is not suitable to be exposed by physical power source such as nanobots in human body for biomedical purposes. More applications are possible especially on the Internet-of-Things (IoT) applications where a lot of electronics are used to gather information but only uses minimal power to continue running. This could save a lot in terms of components cost which may rack up a lot when they are used in a massive adoption especially with the new technologies that are enabled with the emerging mobile networks. When compared to a random user selection scheme, the advantage of opportunistic node location selection for user or relay selection is that it performs better in terms of high throughput and low outage probability. By meticulously selecting and adjusting the correct network parameters such as transmission rate and power splitting coefficient, it is possible that the anticipated energy efficiency may be reached, so that any other batteries will not be used to power up the relay transmission. One less battery in the world is always encouraged so that the environmental will not be polluted with more chemical substances needed to create even one cell of battery. 5 6 7 8 10 12 13 15 17 18 19 21 23 26 29 31 32 33 34 35 37 39 40 41 43