Jimma University
Jimma Institute Technology
Faculty of Electrical and Computer Engineering
Communication Engineering

Title: Performance Analysis of Cooperative SWIPT mm-Wave NOMA for Cell Edge Users

A Thesis Submitted to Jimma University Institute of Technology, School of Graduate Studies in Partial Fulfillment of the Requirements for Masters Degree In Communication Engineering.

By.
Geremu Tilahun

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Main advisor : Dr.Kinde Anlay(PhD)
Co-advisor: Mr.Getachew Alemu (M.Sc)

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DECLARATION

This Research Paper is my original work and has not been presented for a Degree in any other Universities.

Research paper submitted by

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Abstract

In a cellular network, a cell-edge user usually suffers from poor quality of service (QoS) and low signal-to-interference and noise ratio (SINR), This is due to low received signal power as the propagation distance increase and high fading effects, which leads to a considerable outage probability and low achievable data rate.

The performance of the cell-edge users is an essential issue in non-orthogonal multiple access (NOMA) systems. In this paper, we investigate the performance of the Simultaneous Wireless Information and Power Transfer (SWIPT) cooperative non-orthogonal multiple access (C-NOMA) system in half-duplex, decode and forward (DF), energy harvesting (EH), and power splitting relay networks over different scenarios which are characterized by Rayleigh fading channels and capacity advantage of maximum-ratio combining (MRC) over selection combining (SC) technique analyzed. The system performance of such networks is analyzed in terms of outage probability (OP), achievable capacity, and sum throughput, in comparison to the non-cooperative non-orthogonal multiple access and conventional orthogonal multiple access (OMA) system

In this paper, published research that focuses on the improvement of cell edge performance is reviewed. We consider a two-user non-orthogonal multiple access system in which the cell-center user act as an energy harvester and information relaying for the cell-edge user. We analyze the capacity advantage transmit antenna selection (TAS) policy at BS. To evaluate the performance of considered systems, we used a closed-form expression for the OP of both cell-center and cell-edge users, in addition to that we use Rayleigh fading channel, selection combining (SC), and maximum-ratio combining (MRC) at the cell-edge user, and also use a gradient decent algorithm that finds The optimal value of Power splitting(PS) coefficient, which maximize throughput for the cell-edge user.

Matlab simulation of numerical results has shown a cooperative SWIPT-NOMA using MRC has decreased in OP 40% compared to non-cooperative NOMA, 25.98% compared to cooperative NOMA without a direct link, and 9.02% compared to cooperative SWIPT-NOMA with SC techniques. The optimal value of the β is between 0.1 to 0.3 from the simulation result. Cooperative SWIPT-NOMA with MRC also provides an increase in achievable capacity, 66.12% compared to the conventional OMA system, 12.88% compared to the non-cooperative NOMA system, and a 2.18% improvement over SC techniques. Cooperative SWIPT-NOMA with MRC has a sum throughput improvement of 7.64% over the SC technique, 11.68% over the non-cooperative NOMA system, and 15.58% over the conventional OMA systems at low SNR.

key words: SWIPT, C-NOMA, TAS, PD-NOMA, SIC, OMA, NOMA, MRC

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Acronyms

GSM	Global System for Mobile Communications
GSMA	GSM Association
AF	Amplify and Forward
AWGN	Additive White Gaussian Noise
BS	Base Station
CDF	Cumulative Distributive Function
CDMA	Code Division Multiple Access
C-NOMA	Cooperative - Non-orthogonal Multiple access
CD-NOMA	Code Domain Non-orthogonal Multiple Access
DF	Decode and Forward
EH	Energy Harvesting
LDS-OFDM	Low Density Spreading Orthogonal Frequency Division Multiple Access
LDS-CDMA	Low density Spreading Code Division Multiple Access
MIMO	Multiple Input Multiple Output
NOMA	Non-orthogonal Multiple Access
OMA	Orthogonal Multiple Access
PDF	Probability Distribution Function
OP	Outage Probability
PS	Power Splitting
PD-NOMA	Power Domain Non-Orthogonal Multiple Access
SIC	Successive Interference Cancellation
SNR	Signal to Noise Ratio
SINR	Signal to Interference Noise Ratio
SWIPT	Simultaneous Wireless Information and Power Transfer
TAS	Transmit Antenna Selection
TDMA	Time Division Multiple Access

WPT	Wireless Power Transfer
WIT	Wireless Information Transmission
M2M	Machine to Machine
IoT	Internet of Things
EE	Energy Efficiency
SE	Spectral Efficiency
RF	Radio Frequency
QoS	Quality of Service
SC	Selection Combining
MRC	Maximum Ratio Combining
ID	Information Decoding
FDMA	Frequency Division Multiple Access
ISI	Inter Symbol Interference
SCMA	Sparse Coding Multiple Access
BNBF	Best Near Best Far
HD	Half Duplex
FD	Full-Duplex
MISO	Multiple Input Single Output
SCA	Successive Convex Approximation
CSI	Channel State Information
SDR	Semi Definite Relaxation
TWR	Two Way Relaxation
TS	Time Switching

Chapter One

1 Introduction

1.1 Background

According to the GSMA, 5G connections will surpass 1 billion in 2022 and 2 billion by 2025. By the end of 2025, 5G will account for over a 5th of total mobile connections, and more than two in five people globally will live within reach of a 5G network, in line with the Mobile economy report 2022 from the GSMA [1]. The 5G wireless technology promises more than just a faster network. A 5G network builds a bridge to future networks and also can build in different ways from multiple bands of the wavelength spectrum, low-band, mid-band, and High-band. High-band millimeter-wave frequencies have greater bandwidth available to carry more data in dense urban areas but require cell sites to be in close proximity and have limited penetration in buildings. Mid-band balances speed and range, providing broader coverage than high-band, and it's less penetration impact by buildings. Low-band, like the effective 600MHz spectrum, travels farther than other bands over hundreds of square miles and might skip through more limitations, providing better coverage and a stronger signal for both indoor and outdoor [3].

The 5G wireless systems are anticipated to meet unprecedented capacity and latency requirements. To resolve these challenges in 5G, non-orthogonal multiple-access (NOMA) is considered a promising technique due to its stability to enhance spectrum efficiency and multiple-user access. NOMA has the potential to support a higher number of users by multiplexing different users in the same resource [2]. For downlink NOMA, the underlying concept is to utilize the power domain for user multiplexing, which is different from conventional orthogonal multiple access (OMA) techniques (e.g Time/frequency/code division multiple access).

The concept of green communication has given rise to many new methods of power transmission one of which is wireless power transmission (WPT). In radiative WPT, power is transferred from source to destination with the help of electromagnetic (EM) radiation. The radiative WPT technique is also called energy beamforming and involves microwave transmission or laser beam [40]. Since EM waves can be used to transfer power and information, the technique which merges radiative wireless information transfer (WIT) with WPT, is commonly termed simultaneous wireless information and power transfer (SWIPT). The emergency of SWIPT has opened a new door to solve the problem of energy shortage in the wireless network.

Recent studies demonstrate that NOMA has the potential to be applied in various 5G communication scenarios, including Machine-to-Machine (M2M) communication and the Internet-of-Things(IoT). Moreover, there is some existing evidence of performance improvement when NOMA is integrated with various effective wireless communication techniques, such as Cooperative Communications,multiple-input-multiple-output (MIMO), beamforming, space-time coding, network coding, full-duplex, simultaneous Wireless Information, and Power Transfer (SWIPT).

Among these pillars of the 5G wireless network, we tried to study cooperative non-orthogonal multiple access (C-NOMA) by incorporating the SWIPT system with TAS and diversity combining techniques.

5G communication system incorporates NOMA technology for the cooperative communication system (C-NOMA) to achieve higher diversity and extended coverage. The technique to exploit the prior knowledge of strong users to improve the performance of weak users is known as cooperative NOMA. Massive Multiple-input Multiple-output (MIMO) has a number of antennas at the base station (BS) to serve hundreds of mobile users simultaneously. Via spatial multiplexing and directing power intently, massive MIMO can greatly outperform the state-of-the-art cellular standards jointly in terms of spectral efficiency (SE) and energy efficiency (EE)[4].

However, by using the cooperative relaying operation the cell-center user assists the cell-edge user information, which drains the cell-center user's battery. Assisting the cell-edge user information without draining its own battery is one of the limitations of relaying technique. Thus by integrating the new emerging technology SWIPT and C-NOMA, the cell center users can scavenge energy from a BS signal and use this harvested energy to power their relaying operation. SWIPT is an emerging technology to utilize RF signals to transmit information and energy concurrently and offers a promising solution to the above problems.

1.2 Statement of Problem

In a cellular network, a cell-edge user usually suffers from poor quality of service (QoS) and low signal-to-interference and noise ratio (SINR), This is due to low received signal power as the propagation distance increase and high fading effects where the cell-edge user is far away from the base station (BS), which leads to a considerable outage probability and low achievable data rate.

Improving the performance of the cell-center and cell-edge users is an essential issue in the wireless communication system, to improve the coverage, reception reliability, outage performance, and fairness data rate of users. Cooperative NOMA is a promising technology to overcome those issues in a future wireless mobile communication network, which improves the OP, and fairness and enhances the reliability of NOMA users. The traditional cooperative NOMA deploys an information relaying system, as a result, the construction of the power grid is hard, and hence the wireless-powered relay needs to be designed. Cooperative NOMA in which the cell-center user act as a relay to assist to forward cell-edge NOMA user analyzed with simultaneous wireless information and power transfer (SWIPT) to harvest energy at the cell-center for information relaying.

In the current aspect, the cell-center NOMA user with better channel condition is used as relaying to assist the information to the cell-edge NOMA user. Most of the existing works, about the cooperative NOMA, have been investigating its performance and capacity advantage using the SC technique from the diversity combining technique, in this paper, we also analyze the performance of cooperative SWIPT NOMA using the MRC technique with different metrics.

1.3 Objectives

1.3.1 General Objective

The main objective of this thesis is to analyze the performance of cell edge users by integrating NOMA and SWIPT for cooperative-based relaying transmission

1.3.2 Specific Objective

The specific objectives of this research are:

- To analyze the performance of cell-edge users with the integration of the SWIPT Cooperative-NOMA system.
- To investigate the performance of cooperative SWIPT-NOMA users in terms of outage probability, achievable capacity, and sum throughput.
- To analyze the capacity advantage of combining the SWIPT Cooperative-NOMA system with different diversity combining techniques.
- To compare the capacity advantage of combining cooperative SWIPT-NOMA with non-cooperative NOMA and conventional-OMA systems.

1.4 Methodology

In this thesis, the author investigates the performance analysis of cell edge users in terms of outage probability and sum throughput by combining cooperative SWIPT NOMA and TAS system. This can be achieved certainly, where the cell center users act as a relay by harvesting energy from the BS to assist the cell edge information. The method used to achieve the desired objective of this thesis is as follows.

Firstly, different publications are reviewed concerning NOMA, C-NOMA, SWIPT, and different Relaying mechanism, by analyzing the capacity advantages and requirements of combining those schemes. Secondly, to improve the outage performance of the cell-edge user, we consider the cell-center user as a relay that harvests energy from the BS through power splitting protocol, where the cell-center user can be employed to assist the direct NOMA transmission from BS to the cell-edge user with the relaying mechanism.

Finally, providing the validated result that shows the outage performance of the cell-edge user in terms of outage probability and Sum-throughput can be greatly outperformed by combining the SWIPT cooperative-NOMA system than the Non-cooperative NOMA and conventional-OMA. The result was validated by using MATLAB software Simulation tools.

1.5 Scope of The Thesis

The basic things that are going to be accomplished in this thesis are the first analyzing the simultaneous wireless information and power transfer (SWIPT) system in which the base station can transmit both information and power at the same time by the same RF signal and the received signal at the receiver are splitting into by energy harvesting and information decoding system by using the Power splitting (PS) protocol.

The second task we addressed in this thesis is considering the integration of cooperative relaying transmission with the energy harvesting SWIPT system and NOMA system, in which the cell-center user takes the process of operation of its own data and cell-edge user. The cell-center user first harvest energy from the received RF signal and decode the information of its own and far users with poor channel condition, then the cell-center user acts as a relay to assist the cell-edge user by powering their relay operation by harvested energy, which means without draining its own battery, to improve the energy efficiency of cell-center user and performance of the cell-edge user in terms of outage probability and reception reliability.

The third concept we addressed in this thesis is analyzing the performance of integration of simultaneous wireless information and power transfer (SWIPT) and cooperative relay NOMA system to compare the performance improvement over the conventional OMA and non-cooperative NOMA system.

1.6 significance of The Thesis

In the next generation of the wireless mobile communication system the need to improve the high data rate, scaleability, high network capacity, high spectral efficiency, high energy efficiency, low latency, and performance improvement of the cell-edge user will be accomplished by the key technology integration of non-orthogonal multiple access, cooperative relaying transmission and simultaneous wireless information and power transfer (SWIPT).

In the SWIPT system, dual-use of RF signals is exploited to simultaneously transmit information and energy transfer. Therefore, the receiver of SWIPT has to be split into an energy harvesting (EH) receiver and an information decoding (ID) receiver to deal with energy and information respectively to improve the energy efficiency of the cell-center user and outage probability of cell-edge user.

In a cooperative NOMA system, the near NOMA user acts as a relay to help transmit information to the far NOMA users, which shortens the lifetime of the energy-constrained near NOMA user. As a result cooperative-NOMA with SWIPT provide that the near user can harvest energy from received signals and the near user uses the harvested energy for relaying operation rather than its own energy to assist the information of far NOMA users.

1.7 Organization of the Thesis

This thesis work contains six chapters. Chapter one, includes an introduction, background, statement of problem, objectives, methodology, scope, and significance of the study. Chapter two deals with the technical background containing, including a literature review, and the background of multiple access techniques illustrated in terms of Non-orthogonal and cooperative Non-orthogonal, and simultaneous wireless information and power transfer (SWIPT). Chapter three generally discusses the SWIPT with NOMA Systems. Chapter four discusses the general concept and mathematical calculation of SWIPT with the integration of the cooperative-NOMA system. Chapter five illustrates the simulation result of mathematical expression and discussion of the MatLab results, while the last chapter contains the conclusion and recommendation for future works.

Chapter Two

2 Technical Background

2.1 Introduction

In wireless communication systems, multiple access techniques play a great role in allowing several users to access the available resource efficiently. Resources in a wireless communication system are very limited and shared among multiple users by using efficient multiple-access schemes [5][7]. There are different multiple access schemes in a wireless communication system that evolves from first-generation (1G) to the fourth generation (4G) with advancements in the capacity of handling a large number of users at a time [35].

NOMA is considered a breakthrough technology for 5G systems because of its superior spectral efficiency. Compared with the previous orthogonal multiple access technologies (OMA), i.e time division multiple access (TDMA), frequency division multiple access (FDMA), and code division multiple access (CDMA), the key characteristic of NOMA is that multi-user signals are multiplexed in the same time/frequency/code resources with different power factor [36]. Superposition coding and successive interference cancellation (SIC) have been used at the transmitter and receiver respectively.

Generally, this technique utilizes the power domain and code domain to achieve multiple access strategies which are unlike the conventional orthogonal multiple access (OMA) structures that have been proved to achieve higher spectral efficiency and system throughput in large-scale heterogeneous data traffic.

NOMA has been extended to a cooperative NOMA communication system, In cooperative NOMA near users with stronger channel conditions to the base station (BS) decode information for others and act as relays for far users with poor channels to the BS who is at the cell edge to improve reception reliability for them.

Inspired by this, SWIPT has been applied to cooperative NOMA from the perspective of enhancing spectrum efficiency and energy efficiency, the main feature is that the cell-center user acts as a relay that harvests energy from the base station (BS). We analyze the performance of the cooperative NOMA system with decode and forward (DF) relay.

2.2 Non-Orthogonal Multiple Access(NOMA)

As the number of users increases, OMA-based approaches may not meet the stringent emerging requirements including very high spectral efficiency, very low latency, and massive device connectivity. In NOMA, each user operates in the same band and at the same time where they are distinguished by their power levels to achieve spectral efficiency allowing some degree of multiple access [5]. NOMA allows multiple users to share time and frequency resources in the same spatial layer via simple linear superposition at BS and successive interference cancellation (SIC) at the user terminals. In NOMA the superposition coding at the transmitter and successive interference cancellation (SIC) at the receiver makes it possible to utilize the same spectrum for all users [36]. There exist two main NOMA techniques, power-domain, and code-domain NOMA.

2.2.1 Power Domain NOMA (PD-NOMA)

Power domain NOMA is based on the principles of superposition coding where the transmitted data stream is independently encoded and modulated, and the modulated signals are scaled and added together in the power domain as shown in the figure below. Due to different channel gains different power has been allocated among users. Hence large power is allocated for users with low channel gain and less power for users with high channel gain.

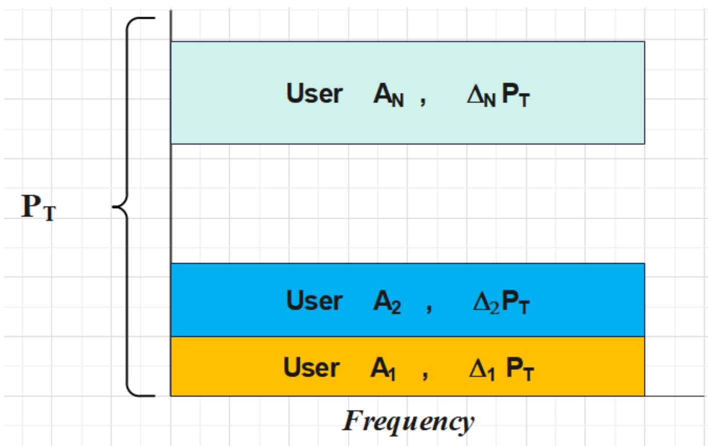

Figure 2.1: Power domain NOMA resource allocation[6]

Let UE_1 locating near the base station has been allocated with the power coefficient of θ_1 and UE_2 locating farther from the BS was allocated a power coefficient of θ_2. Since UE_1 has better channel condition as compared to UE_2 which result high power is allocated to UE_2, in which $\theta_2 > \theta_1$, and $\theta_1 + \theta_2 = 1$

The superimposed signal at the base station and the received signal information at downlink users are given below.

$$M_s = \sqrt{\theta_1 P} x_1 + \sqrt{\theta_2 P} x_2 \tag{1}$$

Where, M_s is the superposed message signal from BS, x_1 and x_2 are the message signals of each near and far users respectively .

$$r_{DL}^{nc} = h_{DL}\sqrt{P}(\sqrt{\theta_1} x_1 + \sqrt{\theta_2} x_2) + N_n \tag{2}$$

Where "nc" stands for non-cooperative, N_n is the additive White Gaussian Noise (AWGN) with zero mean and variance σ_n^2, P is transmit power of BS. In the above example of downlink PD-NOMA, the same supper-imposed transmitted signal from the BS is received at both UE_1 & UE_2. Then the multi-user signal separation technique called successive interference cancellation (SIC) is implemented at each user terminal to eliminate inter-user interference. For SIC, the optimal order for decoding is in order of the decreasing channel gain among near and far users from the BS, $|h_1|^2 > |h_2|^2$. SIC is deployed at the receiver to decode the superposed information, SIC is conceived by exploiting specifications on the differences in signal strength among the signal of interest. After one user's signals are decoded, it is subtracted from the combined signals before the next user's signals are decoded. When SIC is applied, one of the user signals is decoded, treating the other user signal as interference, but the latter is then decoded with the benefit of the signal of the former having already been removed.

2.2.2 Code Domain NOMA(CD-NOMA)

In conventional CDMA, users can share a common channel simultaneously. User separation is done by assigning codes, or spreading signatures, to each user uniquely. However, as a result of this channel sharing, ISI in CDMA-based systems is unavoidable. CD-NOMA mitigates this limitation by utilizing spreading codes with low-density signatures(LDS) and inter-leave sequences. In CD-NOMA, signals are spread using LDS(LDS-CDMA) which are comprised of sparse spreading codes each containing a small number of non-zero elements. The sparsity of the code allows for the generation of more unique codewords for signal transmission which, in turn, allows for more users to be non-orthogonally superimposed on a chip unlike PD-NOMA [7]. The chosen schemes for CD-NOMA are Low-Density Spreading CDMA (LDS-CDMA), Low-Density Spreading OFDM (LDS-OFDM), and Sparse Coding Multiple Access (SCMA).

2.2.3 Low-Density Spreading CDMA (LDS-CDMA)

Sparse spreading sequences are used in place of the previous conventional dense spreading sequence in the case of Low-Density Spreading. LDS is an improved version of CDMA where the number of non-zero spreading sequences are much less than that of CDMA which leads to less cross-sequence interference. Another advantage of LDS-CDMA is its ability to achieve overloading, that is when the number of users in a system exceeds the processing gain and LDS-CDMA can directly be converted to LDS-OFDM, where the chips are replaced by sub-carriers in OFDMA.

2.2.4 Low-Density Spreading OFDMA (LDS-OFDMA)

The LDS-OFDM system can be understood as a system that utilizes LDS for multiple access and OFDM for multi-carrier modulation mapping. Due to its orthogonal mapping and sparse spreading, LDS-OFDM benefits from frequency diversity as well as being able to achieve overloading. This allows a system's user capacity to rise as well as reduce the ISI that would usually accompany it [7]. However, this convenience comes at the price of high, sometimes unaffordable, receiver complexity.

2.2.5 Sparce-Code Multiple access (SCMA)

Sparse-Code Multiple Access (SCMA) has a similar analogy to that of Low-Density Spreading, where the bit streams are directly mapped to different sparse codewords in SCMA which makes it a different and enhanced version of LDS spreads. SCMA further optimizes the sparse spreading in LDS-CDMA by combining the LDS spreader with QAM mapping to directly map a set of bits to a complex sparse vector to generate codewords. SCMA codewords are sparse and allow for overloading much like LDS. Codebooks containing multi-dimensionally mapped codewords replace modulation mapping and spreading, allowing SCMA to benefit from multi-dimensional and shaping gains as opposed to code repetition in LDS [7]. However, SCMA enjoys a moderate receiver complexity since the codebooks are transparent between the transmitter and receiver.

Multiple access based on SCMA is the scheme in which multiple symbols of different users are superimposed for transmission, in sparse spreading the number of users' symbol collisions is minimized, and the use of multi-dimensional multiplexing makes it different from the CDMA technique which uses linear spreading.

2.3 Wireless Power Transfer (WPT)

WPT is an innovative concept that was originally devised by Nicola Tesla in the 1890s. WPT refers to the transmission of electrical energy from a power source through electromagnetic fields, to an electrical component or a portion of a circuit that consumes electrical power without the aid of wired interconnections [8]. The WPT system contains a transmitter connected to the main power source, which transforms the main power into a time-fluctuating electromagnetic field and one or more receiver devices to receive and harvest energy from the electromagnetic field as shown in the figure below.

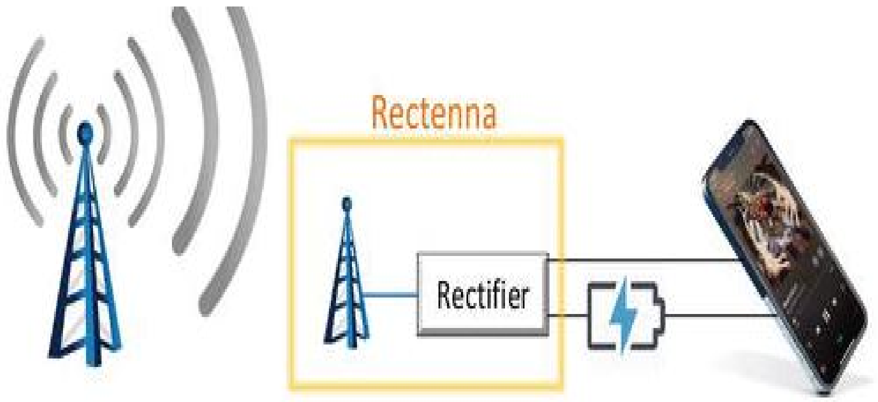

Figure 2.2: RF wireless Power Transfer(WPT) [41]

2.4 Simultaneous Wireless Information and Power Transfer (SWIPT)

Limited device battery life was always been a key consideration in the energy constraint wireless network and largely confines the performance of the network. To prolong the battery life a sustainable power supply has to be considered. As a promising solution to alleviate the energy bottleneck in wireless devices with limited battery capacity, the SWIPT technique has been widely researched in the cellular network [10]. SWIPT is a recently developed technique out of various WPT technologies and it enables the simultaneous transfer of information and power wirelessly.

SWIPT is an emerging technology that exploits the same emitted electromagnetic wave field to transmit information and energy concurrently to decode information and recharge batteries using the same wireless signals. In SWIPT systems, dual-use of RF signals are exploited to simultaneously transmit information and energy. Therefore the receiver of SWIPT has to be split into an energy harvesting (EH) receiver and an

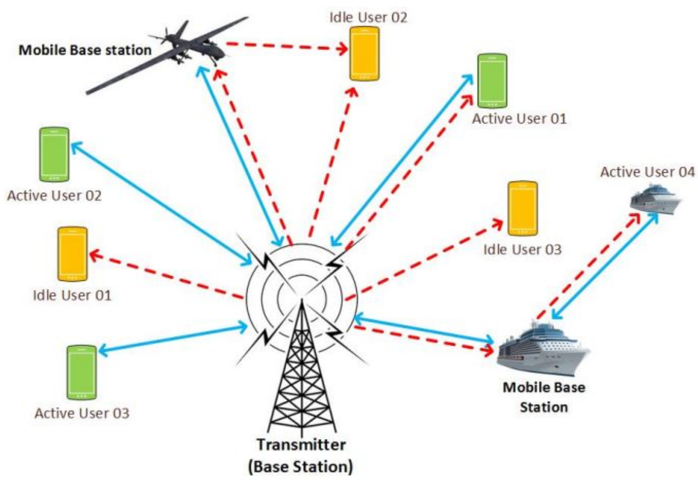

Figure 2.3: RF wireless Information and power Transfer(SWIPT)[8]

information decoding (ID) receiver to deal with the energy and information respectively. As the same signal is used for both power and information transfer there is no additional signal or spectrum is needed for energy transfer or information transfer, therefore SWIPT provides spectral efficiency to the network [9]. To further improve the spectral and energy efficiency of wireless information and power transfer, the combination of SWIPT and new techniques in the cellular network has drawn much attention recently.

2.5 Cooperative NOMA (C-NOMA)

Recently, non-orthogonal multiple access has gained extensive attention in 5G mobile networks since it can improve spectrum utilization efficiency. The basic principle of NOMA is to make multiple users work in the same frequency band simultaneously with different power levels [9]. A prominent feature of NOMA is its use of Successive Interference Cancellation (SIC) to decode user information when multiple users are permitted to transmit it at the same time/frequency/code domain. In this paper, we aim to exploit one aspect of the SIC, namely the availability of other users' data to realize. A key feature of the non-orthogonal multiple access (NOMA) technique is that users with better channel conditions have prior information about the messages of other users. The technique to exploit the prior knowledge of strong users to improve the performance of weak users is known as cooperative NOMA (C-NOMA). To overcome the deep fading of wireless propagation and reduce the outage probability, cooperative NOMA (C-NOMA) was used, where in the near NOMA users with strong channel conditions serve as relays to assist the far NOMA users with poor channel conditions [24].

2.6 Literature Review

One emerging technology and solution in which the SWIPT technique is applied on a cell center user in which power splitting is deployed and act as a relay to support a cell-edge user, form a new technique called SWIPT-CNOMA. In [11], the authors analyzed the capacity of a two-user NOMA system, where a relay is a cell-center user. Considering best user selection among multiple available users. The author in [12], considers the performance of the downlink SWIPT-NOMA system has been evaluated and SINR is derived for near and far users with outage probability for each user, where the near user acts as an energy harvesting (EH) node.

In [13], the authors consider nakagami-m fading channels over NOMA-based relaying networks. In this paper, the base station(BS) communicates with multiple mobile users simultaneously through Amplify and forward (AF) relay. The authors also investigate the system outage behavior, and closed-form expression for the exact outage probability and simply bound of outage probability. However, all of the aforementioned works only considered the cooperative transmission with half-duplex (HD) operation, the NOMA transmission is just performed in half the time block, and the left half of the time block is used for cooperative relaying in half-duplex (HD) cooperative NOMA system. The authors in [14], analyze the performance of cooperative NOMA systems under the assumption of imperfect channel state information is studied over the nakagami-m fading channel, and downlink cooperative non-orthogonal multiple access (NOMA) networks with decode and forward (DF) relaying, with two scenarios, user relaying with direct link and user relaying without a direct link are investigated. In [15], the authors take the advantage of NOMA in the study of relaying cooperative systems operating in half-duplex fixed decode and forward (DF), relaying scheme, and study EH with PS protocol, in this paper also approximates and an exact closed-form expression for OP performance analysis.

In [16], the authors investigate the outage performance of cooperative relaying transmission in two-user NOMA systems, where SWIPT is employed at the near users to power their relaying operations, and the authors also propose the best-near best-far(BNBF) user selection in which the three relaying protocol is considered, i.e, DF, amplify and forward (AF) and hybrid DF/AF protocols. The authors in [17], investigate the cell center and cell edge users in downlink scenarios of cooperative SWIPT NOMA system in terms of sum throughput, also closed-form expressions for the OP of both users are considered to evaluate the performance. the authors also use the gradient descent method to propose the algorithm that finds the optimal value for the power splitting coefficient.

In [18], outage probability and ergodic rate and energy efficiency using novel cooperative NOMA, where one near the user is employed as DF relay switching between full-duplex(FD) and half-duplex(HD) mode to help cell-edge user, also the authors consider two cooperative relaying scenarios which is no a direct link between the base station and far user and direct link exist between the base station and far user. However, in these past works, the self-interference (SI) channel introduced by the full-duplex relay(FDR) was not well characterized and investigated. The authors in [19], analyze two transmission scenarios for the base station (BS) in the cellular network to serve far users. In the first scenario, only a relay link by a cell center user is deployed to forward signals to far or cell-edge NOMA users, while in the second scenario both direct link and relay links are generally enabled to serve far NOMA users. The outage performance is analyzed and compared to provide insights into the design of a real multiple antenna NOMA network, also authors employ transmit antenna selection policy to formulate a closed-form expression of outage probability.

In [20], the authors study a downlink NOMA system with cooperative full-duplex relaying, where the cell-center user in terms of BS enabled to act as a full-duplex relay for the cell-edge user, and closed-form expressions are derived to evaluate the performance of the user in terms of outage probability and ergodic sum rate. The authors in [21], investigate the performance improvement for the cell-edge user, the system considers two user downlink NOMA. On/Off full-duplex and On/Off half-duplex cooperative relaying schemes are proposed to enhance the performance of users in terms of outage probability and sum throughput.

In [21], the authors in this paper investigated the cooperative NOMA SWIPT system, a cooperative MISO SWIPT NOMA protocol proposed. Users with strong channel conditions by adopting a power splitting system act as an energy harvesting relay. In this paper joint optimizing the power splitting ratio and beam-forming vectors, to resolve the formulated non-convex problem the semi-definite relaxation (SDR) technique is applied to reformulate the original problem by the rank one optimality. The iterative algorithm based on successive convex approximation (SCA) is proposed for complexity reduction. In [23], the authors in this paper study imperfect channel state information in an EH cooperative Non-orthogonal multiple access networks. To numerically evaluate the effectiveness of imperfect CSI in this paper a closed-form expression for the outage probability Monte-Carlo simulation is used.

In [24], the author investigates NOMA with fixed power allocation (F-NOMA) and cognitive radio-inspired NOMA (CR-NOMA) on the considered cooperative SWIPT system, a closed-form expression for the outage probability and their high SNR approximation are derived in this paper to characterize the performance of SWIPT -F-NOMA and SWIPT-CR-NOMA. Compared to the conventional system the proposed system in this paper effectively reduces the outage probability and although all of them realize

Table 1: Summary of the Literature

Ref	System Model	Transmission Protocol	Objectives
11	- Indoor - Downlink NOMA	- NOMA with dedicated relay	- Achievable rate
12	- Indoor - Rayleigh fading	- Near user DF relaying - Energy harvesting	- Outage probability - Energy efficiency
13	- Outdoor - Nakagami-m fading	- Dedicated AF relaying	- Outage probability - Ergodic sum rate
14	- IpCSI - SISO, Nakagami-m - Indoor	- Near user DF relay	- Outage Probability
15	- SISO - Rayleigh fading	- Dedicated DF relaying - Energy Harvesting	- Throughput - Bit error probability - Outage probability
16	- BNBF user selection - Outdoor - Rayleigh fading	- Near user NOMA - DF, AF, DF/AF - Energy harvesting	- Outage probability
17	- MISO - Indoor - Rayleigh fading	- Near user DF relay - Energy Harvesting	- Outage probability - Throughput
18	- Relay switching between HD/FD - SISO - Rayleigh fading	- Near user DF relay - Energy Harvesting	- Outage probability - Ergodic rate - Energy efficiency
19	- TAS - MIMO - Rayleigh fading - indoor	- Near user DF relay - Energy Harvesting	- Outage probability - Throughput
20	- Full duplex - SISO	- Near user DF relay	- Outage probability - Ergodic sum rate
21	- On/Off HDR/FDR - Rayleigh fading except SI channel - SISO	- Near user DF relay	- Outage probability - Sum Throughput

the same diversity gain. In [25], the authors study a joint power control and beamforming design for SWIPT in an AF-based two-way relaying (TWR) network. The proposed system consists of a two-source node and a relay node, the main objective of this paper is to maximize the weighted sum energy at the two source nodes subjected to quality of service constraint and transmit power constraint.

In this paper, the simultaneous SWIPT-based relaying is combined with C-NOMA and TAS system. The outage probability, achievable capacity, and sum - throughput advantage of cooperative NOMA with the integration of SWIPT-based relaying information by TAS and diversity combining techniques over Non-cooperative NOMA and conventional OMA are analyzed and validated by simulation. To obtain the optimal power allocation coefficient the gradient descent algorithm introduced in this paper and the optimal sum-throughput of the system is achieved. By using this optimal power allocation and relaying operation system the optimal sum throughput, achievable capacity, and outage probability of users were analyzed mathematically and validated using MATLAB software.

Chapter Three

3 SWIPT with Non-Orthogonal Multiple Access (SWIPT-NOMA) Systems

3.1 Introduction

In this section, we consider MIMO-NOMA downlink transmission where the base station (BS), denoted by S, simultaneously communicates with two NOMA, users, namely the cell-center user, A_1, and a cell-edge user, called A_2. To overcome the deep fading of wireless propagation and reduce the outage probability, cooperative NOMA was proposed where the near NOMA users with strong channel conditions serve as a relay to assist the far NOMA users with poor channel conditions. SWIPT allows energy-constrained users to extract energy and information from the transmitted RF signal using time switching (TS) or power splitting (PS) receiver architecture. This system allows the relay to split the received RF signal into two streams for EH and ID. The main advantage of the cooperative SWIPT-NOMA system is to avoid shortening the lifetime of the energy-constrained NOMA user that acts as a relay.

3.2 Down-link Non-Orthogonal Multiple Access MIMO(NOMA-MIMO) System

NOMA breaks the orthogonality of traditional multiple access to allow multiple users to share the same radio resource simultaneously. In this paper, NOMA should be considered for downlink communication. NOMA is expected to achieve high spectral efficiency over OMA by combining super positioning coding at the transmitter with SIC at the receivers. The design of NOMA is related tightly to the operation of deciding the pair of users to be multiplexed over an individual sub-channel and allocating the power levels corresponding to their channel conditions [27]. Paired users in a single sub-channels are widely suggested to have destructive channel conditions such that the user with bad channel conditions preferred to pair with the user with good channel conditions.

Figure 3.1 below illustrates a down-link NOMA system where two users are multiplexed where user 1 (A_1) represents a strong user, i.e, the user with good channel condition, while user 2 (A_2) represents the weak user, i.e, a user with poor channel condition.

A single cell consists of one BS and M-users, there are B frequency blocks, and the bandwidth of the frequency block is W. The BS groups m_B user per frequency block so that A_i is used to refer to the i-th user $(1 \leq i \leq m_B)$.

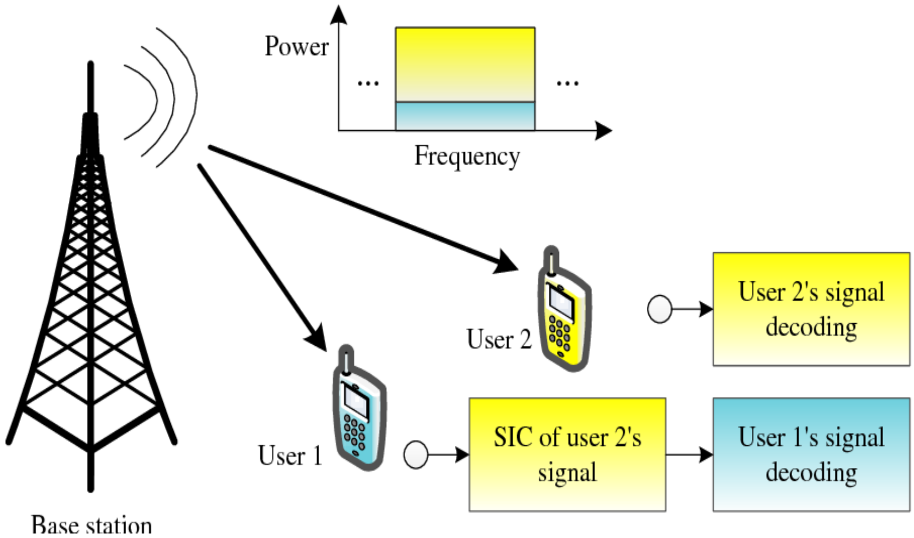

Figure 3.1: Two user Downlink NOMA with one Base station model[37]

Let us define the modulated signals per user per frequency block to be x_i, while the received signal per user is y_i, the BS transmits the user's data using superposition coding, the base station, cell center user and cell edge users has contain multiple antenna, in which the observed signal at user A_i is given by

$$y_i = h_{A_i} \sum_{k=1}^{m_B} \sqrt{p_k}\, x_k + N_{A_i} \tag{3}$$

where $\mathbf{P}$ is total available transmit power, the assigned power share per A_i is p_k, h_{A_i} fading coefficient of BS $\rightarrow A_i$ and N_{A_i} is represent AWGN. for the user sharing the same frequency block the all sum of assigned power shares for all users sharing the same frequency shall not exceed $\mathbf{P}$

$$\sum_{i=1}^{m_B} p_k = \mathbf{P} \tag{4}$$

In NOMA, successive interference cancellation (SIC) decodes the signals iteratively, where strong users de-multiplex other signals to retrieve their signal in the end where users suffer from bad channel quality decodes their signal directly treating other users' signals as interference. The instantaneous downlink signal to interference plus noise ratio (SINR) γ_i per A_i is given by [27],

$$\gamma_i = \frac{|h_{A_i}|^2 \; p_i}{|h_{A_i}|^2 \sum_{k=i+1}^{m_B} p_k + N_{A_i}} \tag{5}$$

where $|h_{A_i}|^2 \sum_{k=i+1}^{m_B} p_k + n_i$, represents other users interference and $i = 1, ..., m_B$, this implies for A_i decode the signal of other users sharing the same sub-channel as the weakest user allocated in this sub-channel. The achievable NOMA downlink throughput per user is given by [27],

$$R_i^{noma} = W \log_2^{(1+\gamma_i)} \tag{6}$$

SIC is influenced by power allocation performed by the BS, therefore assigned power for users allocated to sub-channels is given as, $|p_1| \leq |p_2| \leq ... \leq |p_m|$, that means users with poor channel gain given high power level than users with good channel gain that enhance the fairness of the system. In orthogonal multiple access (OMA), on the other hand, users are allocated orthogonal frequency or time slots to receive their information, where their total bandwidth and power are shared by the users equally, the throughput for each user for OMA becomes,

$$R_i^{oma} = \frac{W}{m} \log_2^{\left(1 + \frac{|h_{A_i}|^2 \; p_i}{N_{A_i}}\right)} \tag{7}$$

In addition to this the sum capacity for both OMA and NOMA system can be expressed as,

$$R_T = \sum_{i=1}^{m} R_i \tag{8}$$

The fairness index ”F” further defined as ,

$$F = \frac{(\sum R_i)^2}{m \sum R_i^2} \tag{9}$$

which indicates how fair the system capacity is shared among the users, i.e when F gets close to 1, the capacity for each user gets close to each other.

3.3 Radio Frequency Energy Harvesting(RF-EH)

The receiver radio frequency (RF) energy harvesting circuit can only harvest energy when the received signal power is greater than a certain sensitivity level. practical SWIPT receivers for energy harvesting (EH) and information decoding (ID) have been proposed using PS and TS. At the receiver, during a symbol period, T_s assuming the power received at the RF-EH circuit is P_{rx}, the amount of harvested energy can be represented as

$$P_R \ = \ \eta \, T_s \ (\ P_{rx} - P_{th} \ ) \tag{10}$$

where,0 $< \eta \leq 1$ is RF-EH efficiency, Assuming that the harvested energy at the receiver is stored in an ideal battery. The RF-EH circuit can only harvest energy when its receive signal power, P_{rx} is greater than the Radio Frequency-EH sensitivity level P_{th}, and harvested energy is proportional to P_{rx} - P_{th}. Different SWIPT radio frequency energy harvesting (RF-EH) operations are described below.

3.3.1 Time Switching Schemes(TS)

In a TS scheme, there are two orthogonal time slots, the transmitter divides the transmission block into two-time slots, one for transferring power and the other time slot, transmitter transfer modulated data signal to the receiver, and the receiver acquires information from the signal.

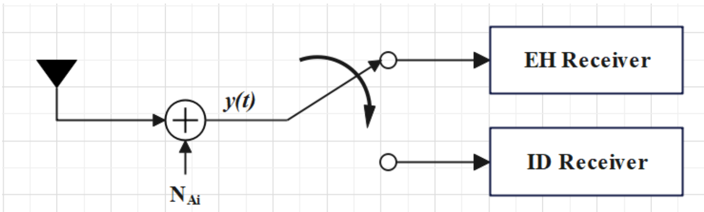

Figure 3.2: Time Switching(TS) receiver

In a time block of the PT phase, the transmitter transmits a pre-designed energy signal with average power $P_{s,1}$, thus the received RF signal at the RF-EH circuit is given by,

$$y(t) = h(t) \sqrt{\frac{P_s}{d^{\epsilon}}} \, x(t) + N(t) \tag{11}$$

Where x(t) is the pre-designed energy signal, d is the source to relay distance and ϵ is the path loss exponent. In the other time block of, the IT phase the baseband receiver signal given by,

$$y = h_{A_i} \sqrt{\frac{P_{s,1}}{d^{\epsilon}}} \, x + N_{A_i} \tag{12}$$

The transmitter transmits a modulated signal with average transmit power $P_{s,2}$ during the IT phase. The SNR at the ID circuit of the receiver is given by,

$$\gamma = \frac{P_{s,2} \mid h_{A_i} \mid^2}{d^{\epsilon} \ \sigma^2} \tag{13}$$

3.3.2 Power Splitting Scheme(PS)

In the power splitting scheme the transmitter transfer modulated data signal to a receiver with average transmitted power P_s then the receiver splits the received signal into two separate streams. One to draw energy and one to acquire information. In particular PS, the block time T is divided into two equal sub-blocks, in the first sub-block with T/2 duration time user A_1, utilize β for harvesting energy from its received signal.

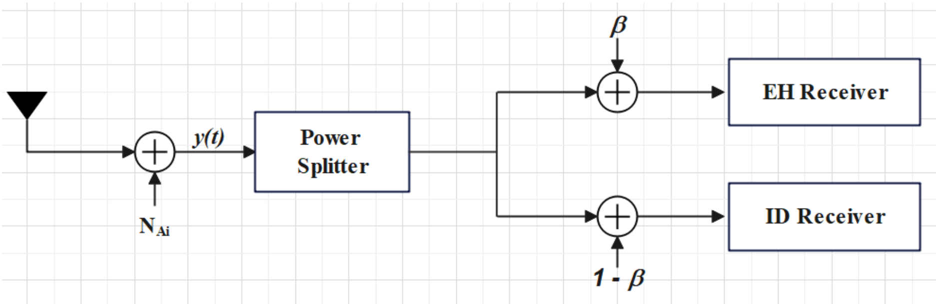

Figure 3.3: Power splitting(PS) receiver

In the second sub-block with T/2 duration time, user A_1 utilize the remaining $(1-\beta)$ for information decoding, where $0 \leq \beta < 1$ denotes the power splitting ratio. After power splitting(PS),the received RF signal at the RF-EH circuit is,

$$y(t) = h(t)\ \sqrt{\frac{\beta\ P_s}{d^{\epsilon}}}\ x(t) + N(t) \tag{14}$$

where, h(t) is a channel fading gain, x(t) represent the modulated information signal sent from the transmitters and $\tilde{n}(t)$ is a circuit noise. For Information decoding(ID), the RF signal is down converted to base band signal,the received signal is given by,

$$y = h_{A_i}\ \sqrt{\frac{(1-\beta)\ P_s}{d^{\epsilon}}}\ x + N_{A_i} \tag{15}$$

The signal-to-noise ratio(SNR) at the information decoding (ID) circuit of the receiver is given by,

$$\gamma = \frac{(1-\beta)\ \mid h_{A_i} \mid^2\ P_s}{d^{\epsilon}\ \sigma^2} \tag{16}$$

where n is the AWGN at the ID circuit with variance of σ^2, and $|h|^2$ is the fading power gain of the channel. In this paper, the proposed PS protocols first confirm the detection of the transmitted information of the far NOMA user, then harvests the rest of the energy. Since different constellation symbols may vary from symbol to symbol, it is possible that some symbols can activate the RF-EH circuit but others can not.

Chapter Four

4 SWIPT Cooperative Non-Orthogonal Multiple Access (SWIPT-CNOMA) system

In this section, a base station is equipped with a number of antenna N_s, and a cell-center and the cell-edge user is equipped with N_D antennas. Two transmission modes are introduced the direct and relay mode. One BS intends to transmit information to two NOMA users with the help of DF by employing relay mode operation to forward information of cell-edge NOMA user A_2. But A_2 also receives a signal in a direct mode directly from the BS without the assistance of a relay. In this system, the cell-center user not only processes its own data but also acts as a relay to assist the direct transmission from a BS to a cell-edge user, in addition to that the cell-center user also harvests the energy from the transmitted RF signal, all the harvested energy used for assisting the far user information during the relay operations.

4.1 System Model

In this study, a cooperative cellular scenario developing NOMA is considered with respect to evaluation for downlink performance as in figure 4.1. Two transmission schemes are introduced which are direct and relay modes. In particular, the system model includes one base station (BS), which intends to transmit information to two NOMA mobile users with the help of a DF relay A_1 in relay mode to distant node A_2, but in a direct mode A_2 can receive the transmit signal directly from the BS without assistance the relay node A_1. Relay is only provided by using the harvested energy from the BS. In practice, the relay is often installed at the intermediate position (outdoor). As a result, the construction of the power grid is hard, and hence the wireless-powered relay needs to be designed. In particular, the relay can perform signal processing and harvest energy, and such an energy signal can be extracted from the same received signal. In the context of energy harvesting, such a signal is transferred from the BS via an RF signal transmission environment. It noted that all the nodes operate in a half-duplex mode due to simple deployment. All the wireless links are assumed to exhibit frequency non-selective Rayleigh block fading, additive white gaussian noise (AWGN), and a TAS topology, in which such antenna selection criteria are required to enhance system performance with low cost of computations.

In this paper, we consider a cooperative NOMA downlink transmission where BS denoted by S, simultaneously communicates with the cell center user A_1 and cell-edge user A_2, by employing a two-user NOMA scheme as shown in Fig.4.1 Below. A base station equipped with N_s antennas, the cell center, and cell-edge mobile users.

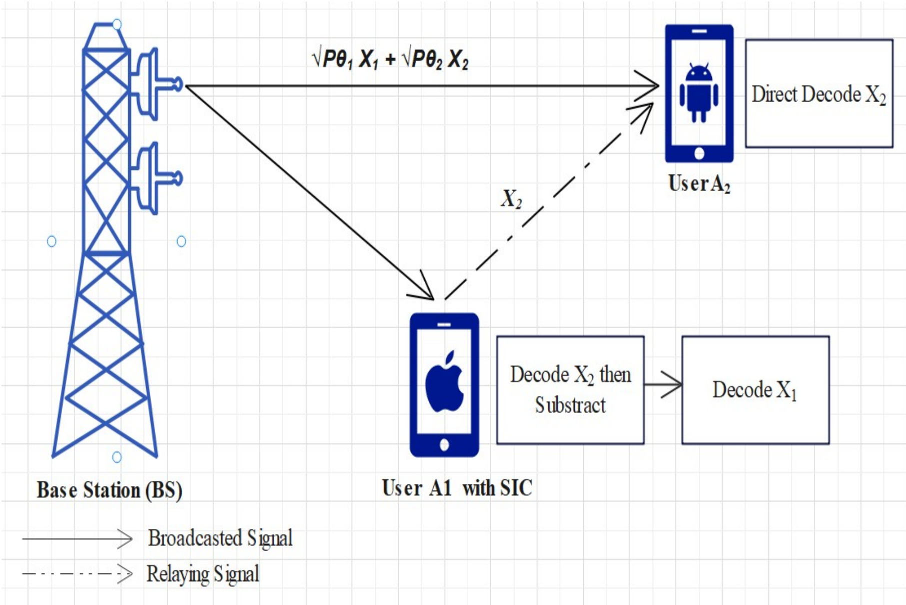

Figure 4.1: Power splitting Cooperative SWIPT-NOMA with TAS

Let h_{iD} denotes the fading coefficient of a channel from antenna i, i = 1...N_s to a user 'D' where D $\in \{A_1,A_2\}$. Assuming the wireless channels is in the network exhibits Rayleigh block flat fading, consider a channel from X to Y where X $\in$ {i,A_1} , Y $\in$ $\{A_1,A_2\}$ is exponential random variable. Let $\tilde{h}_{XY}$ and G_{XY} characterize the small-scale fading and large-scale path loss effect of the X $\longrightarrow$ Y channel. Since a small scale fading magnitude $|\tilde{h}_{XY}|$ follows Rayleigh distribution, the corresponding gain $|\tilde{h}_{XY}|^2$ follows the exponential distribution, whose CDF $F_{|\tilde{h}_{XY}|^2}$, and PDF $f_{|\tilde{h}_{XY}|^2}$ can be expressed respectively as:

$$F_{|\tilde{h}_{XY}|^2}\,(z) = 1 - e^{\dfrac{-z}{\tilde{\lambda}_{XY}}} \tag{17}$$

$$f_{|\tilde{h}_{XY}|^2}\,(z) = \frac{1}{\tilde{\lambda}_{XY}} e^{\dfrac{-z}{\tilde{\lambda}_{XY}}} \tag{18}$$

$\forall z \geq 0$ otherwise, i.e, $z < 0$, $f_{|\tilde{h}_{XY}|^2}(z) = 0$, where $\tilde{\lambda}_{XY}$ denotes the mean of $|\tilde{h}_{XY}|^2$. On the other hand, the large scale path-loss can be modeled as $G_{XY} = (d_{XY}/d_0)^{-\epsilon}\pounds$, where d_{XY} represents distance between the two nodes in meter(m), d_0 represents the reference distance, $\pounds$ is the average signal power attenuation at d_0, and ϵ represents the path-loss exponent. In this paper, a received signal at Y which is transmitted from X, $y_Y(t)$, can be expressed as

$$y_Y(t) = \sqrt{P_X\ G_{XY}}\ \tilde{h}_{XY}\ x(t) + n_Y(t) \tag{19}$$

Where P_X denotes the transmitted power of X, x(t) represents the transmitted signal, and $n_Y(t)$ is an additive white Gaussian noise at Y. In addition for the sake of exposition let $h_{XY} \triangleq G_{XY}\tilde{h}_{XY}$, consequently the CDF, $F_{|h_{XY}|^2}(z)$ and PDF, $f_{|h_{XY}|^2}(z)$ of $|h_{XY}|^2$ can be written as, $F_{|h_{XY}|^2}(z) = 1 - e^{\frac{-z}{\lambda_{XY}}}$, $f_{|h_{XY}|^2}(z) = \frac{1}{\lambda_{XY}}e^{\frac{-z}{\lambda_{XY}}}$, respectively, where $\lambda_{XY} \triangleq G_{XY}\tilde{\lambda}_{XY} = \frac{\pounds}{(d_{XY}/d_0)^{\epsilon}}\tilde{\lambda}_{XY}$ represents the mean of $|h_{XY}|^2$. In addition, the average channel gain can be written as

$$\mathbb{E}\left[|h_{XY}|^2\right] = \frac{\pounds}{(d_{XY}/d_0)^{\epsilon}} \tag{20}$$

We further assume $|\tilde{h}_{XY}|^2$ follows an exponential distribution with a unit mean.

In the concerned system, two scenarios are generally examined in this paper.

- The BS intends to communicate with the cell-edge user A_2 under the assistance of the cell-center user A_1. In this scenario, A_1 is regarded as the relaying user and the DF protocol is employed to decode and forward information to A_2. In this scheme, a direct link does not exist between BS and A_2.
- The direct link between BS and A_2 exists in addition to a relay link that is still employed to support A_2. As a result, a more complex process can be seen at the cell-edge NOMA user, as two signal streams are received and different diversity combining techniques like SC and MRC are employed.

4.2 Two User Cooperative-NOMA System

4.2.1 Direct Information Transmission and Energy Harvesting.

Suppose that antenna 'i' from N_s on the BS has been selected for information broadcasting to cell-center and cell-edge users. At the first time block, BS broadcasts a superposed or mixed-signal M_s of A_1 and A_2, where BS employs a single antenna selected from given base station N_s antennas. For such a cooperative NOMA system, the employed TAS is used to select a single antenna at BS for transmission, that maximizes the instantaneous SNR of cell-center user A_2.

At BS, the transmit antenna, that maximizes the instantaneous SNR at A_2, is selected for such cooperative NOMA transmission.

$$M_s = \sqrt{\theta_1\ P_s}\ X_1 + \sqrt{\theta_2\ P_s}\ X_2 \tag{21}$$

where X_1 and X_2 denotes the normalized signal transmitted to user A_1 and A_2 respectively, i.e, $\mathbb{E}[|X_1|^2] = \mathbb{E}[|X_2|^2] = 1$, and θ_1 and θ_2 denote the power allocation coefficient for users A_1 and A_2 respectively, following the principle of NOMA we assume that, $|h_{iA_1}|^2 > |h_{iA_2}|^2$, $\theta_1 + \theta_2 = 1$ and $\theta_2 > \theta_1$. P_s represents the transmitted power at the BS. We assume that a Rayleigh fading channels are deployed in such model, i.e, h_{iA_1} are selected at BS to perform signal transmission to A_1 and h_{iA_2} are selected for signal transmission to A_2, where $i \in [1, N_s]$.

Following the principle of wireless power transfer to a relay node A_1 in such NOMA system. In this paper, depending on the considered system, let user A_1 play a role in the RF-EH relay, in particular a block time T is divided into two sub-block. In the first sub-block with $T/2$ duration time, user A_1, simultaneously utilize a fraction β of the received power for energy harvesting and remaining fraction $(1-\beta)$ for information decoding, where $0 < \beta < 1$ denotes the power splitting ratio.

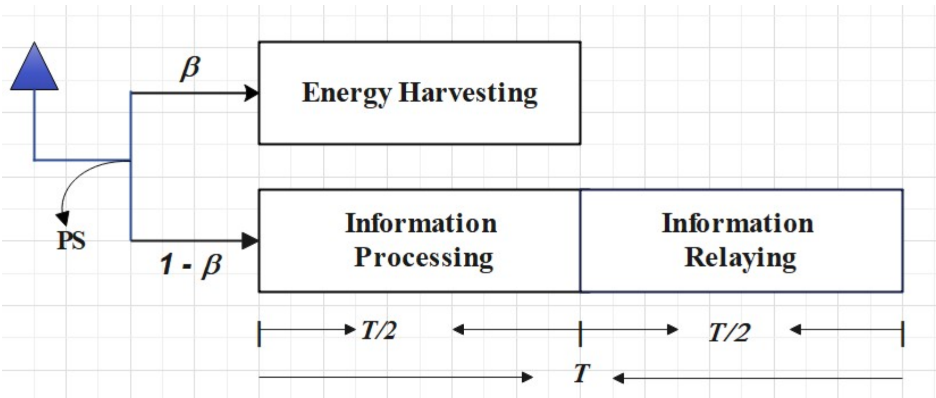

Figure 4.2: Illustration of PS SWIPT - based relaying Transmission

In the second sub-block with $T/2$ duration time, user A_1 employs all harvested energy to power the cell-center user for user A_2 information relaying operation. The cell-center users that assist the cell-edge NOMA users can harvest the amount of energy from the RF signal broadcasted by BS and the amount of energy that will be harvested by the cell-center user, A_1 can be calculated by,

$$E_{A_1} = \beta\,\eta\,P_s\,|h_{iA_1}|^2\,T/2 \tag{22}$$

Where, β, η are the power splitting ratio and energy efficiency factor respectively in which $0 < \eta < 1$, and $|h_{iA_1}|^2$ is a channel gain from base station N_s antenna to the cell center user A_1.

A) Successive Interference Cancellation(SIC) at User A_1

As BS antenna broadcast a superposed signal to users, a received base-band signal at user A_1 for information decoding can be expressed as,

$$Y_{iA_1}^{ID} = \sqrt{1-\beta}\; h_{iA_1} \left(\sqrt{(\theta_1\; P_s)}X_1 + \sqrt{(\theta_2\; P_s)}X_2\right) + N_{A_1} \tag{23}$$

Where N_{A_1} is denoted as AWGN noise with a variance, $N_{A_1} \sim \mathcal{CN}(0, \sigma_{A_1}^2)$

According to the principles of NOMA, the successive interference cancellation(SIC), the receiver user A_1 first decodes X_2 and subtracts this component from the received signal by considering it as noise to detect its own message X_1. Thus, the received signal-to-interference-plus-noise ratio (SINR) at user A_1 to decode X_2 can be expressed as

$$\gamma_{iA_1}^{X_2} = \frac{(1-\beta)\; P_s\; |h_{iA_1}|^2\; \theta_2}{(1-\beta)\; P_s\; |h_{iA_1}|^2\; \theta_1 + \sigma_{A_1}^2} \tag{24}$$

However, the instantaneous SNR between the i-th antenna at BS and A_1 can be derived to evaluate outage performance. The corresponding achievable data rate of user A_2 signal decoded at user A_1 using SIC is given by

$$\begin{aligned} R_{iA_1}^{X_2} &= \frac{1}{2} log_2\left(1+\gamma_{iA_1}^{X_2}\right) \\ &= \frac{1}{2} log_2\left(1+\frac{(1-\beta)\; P_s\; |h_{iA_1}|^2\; \theta_2}{(1-\beta)\; P_s\; |h_{iA_1}|^2\; \theta_1 + \sigma_{A_1}^2}\right) \end{aligned} \tag{25}$$

After SIC, the received signal to noise ratio(SNR) at A_1 to detect its own message X_1 can be expressed as

$$\gamma_{iA_1}^{X_1} = \frac{(1-\beta)P_s|h_{iA_1}|^2\theta_1}{\sigma_{A_1}^2} \tag{26}$$

The corresponding achievable data rate of user A_1 to decode its own message signal is

$$\begin{aligned} R_{iA_1}^{X_1} &= \frac{1}{2} log_2\left(1+\gamma_{iA_1}^{X_1}\right) \\ &= \frac{1}{2} log_2\left(1+\frac{(1-\beta)P_s|h_{iA_1}|^2\theta_1}{\sigma_{A_1}^2}\right) \end{aligned} \tag{27}$$

B) Information Decoding at User A_2

In this phase, the BS intends to serve directly A_2 based on the selected antenna following the index. In particular, the observation of the received signal at A_2 for a direct link from BS can be written as

$$Y_{iA_2}^{X_2} = h_{iA_2}\ (\sqrt{\theta_1 P_s}X_1 + \sqrt{\theta_2 P_s}X_2) + N_{A_2} \tag{28}$$

Where $N_{A_2} \sim \mathcal{CN}(0, \sigma_{A_2}^2)$ is a noise matrix at A_2 following AWGN. However, in contrast with the cell center A_1, cell-edge user A_2 can directly decode its information-bearing signal since higher transmitted power is allocated to user A_2 and thus the interference introduced by the user A_1 information signal can be considered as noise. Similarly, the instantaneous SINR between the transmitter on the i-th antennas at BS and A_2 during the first phase can be expressed as below.

The received SNR at A_2 to detect its own normalized information X_2 is given by

$$\gamma_{iA_2}^{X_2} = \frac{\theta_2 P_s |h_{iA_2}|^2}{\theta_1 P_s |h_{iA_2}|^2\ +\ \sigma_{A_2}^2} \tag{29}$$

where, σ_{A_2} is a variance of cell-edge user A_2. The achievable data rate of user A_2 in a direct link communication with a BS is given as

$$\begin{aligned} R_{iA_2}^{X_2} &= \frac{1}{2} log_2 \left(1 + \gamma_{iA_2}^{X_2}\right) \\ &= \frac{1}{2}\ log_2 \left(1 + \frac{\theta_2 P_s |h_{iA_2}|^2}{\theta_1 P_s |h_{iA_2}|^2\ +\ \sigma_{A_2}^2}\right) \end{aligned} \tag{30}$$

4.2.2 Cooperative Relaying Transmission

A cooperative transmission is carried out in two equal time phases, namely broadcasting and relaying phases. In the broadcasting phase, BS broadcasts the superposed signal using a non-cooperative two-user NOMA system to both user A_1 and A_2. In this case, the signal-to-noise ratio (SNR) and signal-to-interference-noise-ratio (SINR) at user A_1 and A_2, namely $\gamma_{iA_1}^{X_2}, \gamma_{iA_1}^{X_1}$,and $\gamma_{iA_2}^{X_2}$, can be expressed as in (24), (26), and (29) respectively. Assuming that all the energy harvested during the first phase is employed to power the relaying operation, the transmit power of user A_1 in the second phase can be expressed as

$$\begin{aligned} P_{A_1} &= \frac{E_{A_1}}{T/2} \\ &= \frac{\beta\eta P_s |h_{iA_1}|^2 T/2}{T/2} \\ &= \beta\eta P_s |h_{iA_1}|^2 \end{aligned} \tag{31}$$

In the second phase, A_1 first decodes the received source signal and then forwards the detected symbol by using the harvested energy. In the relaying phase, since user A_1 priorly knows X_2 during its SIC process, then user A_1 forwards the re-encoded version $\hat{X}_2$. Considering the DF relaying protocol, the baseband form of the received signal at user A_2 can be expressed as

$$Y_{A_1A_2} = \sqrt{P_{A_1}}\ h_{A_2}\hat{X}_2 + N_{A_2} \tag{32}$$

where, $\hat{X}_2$ denotes the re-encoded version of normalized signal X_2. We then compute SNR for the second hop A_1 - A_2 transmission during the second phase from (31) and (32), and it's given by

$$\gamma_{A_1A_2}^{X_2} = \frac{P_{A_1}|h_{A_2}|^2}{\sigma_{A_2}^2} \tag{33}$$

By inserting equation (31), to the given equation (33),

$$\gamma_{A_1A_2}^{X_2} = \frac{\beta\ \eta P_s|h_{iA_1}|^2|h_{A_2}|^2}{\sigma_{A_2}^2} \tag{34}$$

where, $|h_{A_2}|^2$ is a channel gain from cell-center user A_1 to cell-edge user A_2. In the principle of NOMA, the cell-center user has the information of the cell-edge user after performing SIC by the cell-center user. So this information is assisted to the cell-edge user. The achievable data rate achieved by the cell-edge user from the relayed information is given by

$$\begin{aligned} R_{A_1A_2}^{X_2} &= \frac{1}{2}log_2\left(1+\gamma_{A_1A_2}^{X_2}\right) \\ &= \frac{1}{2}log_2\left(1+\frac{\beta\ \eta P_s|h_{iA_1}|^2|h_{A_2}|^2}{\sigma_{A_2}^2}\right) \end{aligned} \tag{35}$$

Finally, cell-edge user A_2 combines the two signals, arriving in a different phase, i.e, the direct signal from BS and the relaying signal from cell-center user A_1 by employing selection combining(SC) and MRC techniques.

Selection Combining (SC)

In selection combining the direct transmission and relay link received signal from the antenna that experiences the highest SNR is selected for processing information at the cell-edge user A_2.

$$\gamma_{A_2}^{SC} = \max\ \{\gamma_{iA_2}^{X_2}, \gamma_{A_1A_2}^{X_2}\} \tag{36}$$

Therefore, the selection combiner output SNR is the maximum SNR of all the received signals from different paths. The achievable data rate of cell-edge user after SC can be expressed as

$$\begin{aligned} R_{A_2}^{SC} &= \frac{1}{2}log_2\left(1+\gamma_{A_2}^{SC}\right) \\ &= \frac{1}{2}log_2\left(1+\max\left\{\gamma_{iA_2}^{X_2},\gamma_{A_1A_2}^{X_2}\right\}\right) \end{aligned} \tag{37}$$

Thus, the achievable end-to-end SNR using SC at user A_2 can be expressed as

$$\gamma_{A_{2,SC}}^{e2e} = \min\left\{\gamma_{iA_1}^{X_2},,\gamma_{A_2}^{SC}\right\} \tag{38}$$

Maximum Ratio Combining (MRC)

In the selection combining technique, the strongest signal from all received signals from the different paths is chosen for processing at the receiver, The other received signal throws away in SC, whereas, in MRC all the received signals are used for processing at the receiver terminal. The MRC technique uses all the received signal elements from all paths, weighs them, and combines the weighted signals so that the output SNR is maximized. Therefore, the output of SNR after the MRC is given as

$$\gamma_{A_2}^{MRC} = \gamma_{iA_2}^{X_2} + \gamma_{A_1A_2}^{X_2} \tag{39}$$

MRC technique results in the weighted average of signals and hence the overall output SNR is equal to the sum of all SNR received at the receiver terminal. The achievable data rate of the cell-edge user after MRC can be expressed as

$$\begin{aligned} R_{A_2}^{MRC} &= \frac{1}{2}log_2\left(1+\gamma_{A_2}^{MRC}\right) \\ &= \frac{1}{2}log_2\left(1+\left(\gamma_{iA_2}^{X_2}+\gamma_{A_1A_2}^{X_2}\right)\right) \end{aligned} \tag{40}$$

Thus, the achievable end-to-end SNR using MRC at user A_2 can be expressed as

$$\gamma_{A_{2,MRC}}^{e2e} = \min\left\{\gamma_{iA_1}^{X_2},\gamma_{A_2}^{MRC}\right\} \tag{41}$$

4.3 Transmit Antenna Selection(TAS).

In particular, the optimal transmit antenna selection is employed at the BS. The proposed TAS are conducted before data transmission through the signaling and channel state information(CSI) estimation or calculation system. in this paper we assume that the required CSI of each user is available. It can be observed that the cooperative relaying operation depends on whether X_2 can be decoded at cell-center user A_1 or not. Let i^* denotes the selected antenna from the BS, $[1, N_s]$ antennas.

The end-to-end SNR at user A_2 can be written as equations (38) and (41), and the instantaneous transmission rate achieved by user A_2 associating with antenna i^* employing SC or MRC at the receiver terminal can be expressed as

$$R^j_{A_2} = \frac{1}{2}\log_2^{(1+\gamma^{e2e}_{A_{2,j}})} \tag{42}$$

Where, j $\in$ { SC, MRC}, the transmit antenna selection was selected based on the combining techniques used at the receiver terminal. The transmit antenna selection(TAS) criterion adopted aims to select an antenna that maximizes the instantaneous transmission rate of cell-edge user A_2. Mathematically, the selection of an antenna expressed as

$$i^*_j = \frac{1}{2}\log_2^{(1+\gamma^{e2e}_{A_{2,j}})} \tag{43}$$

$$i^*_j = arg \max_{1\leq i\leq N_s} \gamma^{e2e}_{A_{2,j}} \tag{44}$$

However, this scheme requires a high complexity operation, due to the channel-state-information(CSI) of three kinds of channel, namely BS - A_1, BS - A_2, and A_1 - A_2 channel are needed.

4.4 Achievable Rate Analysis

The achievable rate is a key performance metric for wireless mobile communication. The achievable data rate of an individual user with different techniques is given in equations (25), (27), (30), (35), (37), and (40). The sum rate is defined as the average sum of all user's achievable rates in a given system, the sum achievable rate of the cooperative NOMA system with different combining techniques such as SC and MRC is given below.

$$R^j_{sum} = R^{x_1}_{iA_1} + R^j_{A_2} \tag{45}$$

4.5 Outage Performance Analysis

The outage probability of the user can be defined as the probability that the instantaneous data rate of the user falls below a predefined target data rate [28]. Recall that R_1 and R_2 (bps/Hz) denote the target data rates of user A_1 and A_2,respectively.

$$Let, \begin{cases} \bar{\gamma_s} \triangleq \dfrac{P_s}{\sigma_s^2} & and \\ \bar{\gamma}_{A_1} \triangleq \dfrac{P_{A_1}}{\sigma_{A_1}^2} \end{cases} \tag{46}$$

Denotes the transmit SNR at BS and cell center user A_1, respectively [18][29]. In order to facilitate the performance analysis and for the sake of notational convenience, let $X \triangleq |h_{iA_1}|^2$, $Y \triangleq |h_{A_2}|^2$, and $Z \triangleq |h_{iA_2}|^2$, also, defined constant introduced and following self-defined functions [30] [31], are going to be used along the developed analysis. The 'γ_{th1}' and 'γ_{th2}' denotes the SNR threshold of user A_1 and A_2 respectively, when a half-time block is used, '$\bar{\gamma}_{th1}$' and '$\bar{\gamma}_{th2}$' also, the SNR threshold of user, when full-time block is used.

$$Constants: \begin{cases} a_1 \triangleq \dfrac{(1-\beta)\theta_2 P_s}{\sigma_{A_1}^2} \\ a_2 \triangleq \dfrac{(1-\beta)\theta_1 P_s}{\sigma_{A_1}^2} \\ b_1 \triangleq \dfrac{\theta_2 P_s}{\sigma_{A_2}^2} \\ b_2 \triangleq \dfrac{\theta_1 P_s}{\sigma_{A_2}^2} \\ c \triangleq \dfrac{\eta\beta P_s}{\sigma_{A_2}^2} \\ \mu_a \triangleq \dfrac{\gamma_{th2}}{a_1 - a_2\gamma_{th2}} \\ \mu_b \triangleq \dfrac{\gamma_{th2}}{b_1 - b_2\gamma_{th2}} \\ \bar{\mu}_a \triangleq \dfrac{\bar{\gamma}_{th2}}{a_1 - a_2\bar{\gamma}_{th2}} \\ \mu_1 = \dfrac{\gamma_{th1}}{a_2} \\ \bar{\mu}_1 = \dfrac{\bar{\gamma}_{th1}}{a_2} \\ \theta \triangleq \dfrac{\theta_2}{\theta_1} \end{cases} \tag{47}$$

4.5.1 Outage Analysis of Non-Cooperative NOMA

The outage probability(OP) of the communication channel can be defined as the probability of users that when the SNR of the channel falls below a pre-defined target data rate.

A). OP of User A_1 In Non-Cooperative: The OP of user A_1 can be expressed as

$$
\begin{aligned}
P^{nc}_{out,A_1} &= Pr(R^{nc}_{iA_1,x_2} < R_2) + Pr(R^{nc}_{iA_1,x_2} \geq R_2, R^{nc}_{iA_1,x_1} < R_1) && (48a)\\
&= Pr(\gamma^{nc}_{iA_1,x_2} < \bar{\gamma}_{th2}) + Pr(\gamma^{nc}_{iA_1,x_2} \geq \bar{\gamma}_{th2}, \gamma^{nc}_{iA_1,x_1} < \bar{\gamma}_{th1}) && (48b)
\end{aligned}
$$

The system used in this non-cooperative NOMA to analyze OP is a full-time slot. Where, $R^{nc}_{iA_1,x_2} = \log_2^{(1+\gamma^{nc}_{iA_1,x_2})}$, $R^{nc}_{iA_1,x_1} = \log_2^{(1+\gamma^{nc}_{iA_1,x_1})}$, $\bar{\gamma}_{th1} = 2^{R_1}-1$, and $\bar{\gamma}_{th2} = 2^{R_2}-1$.

A closed form expression for P^{nc}_{out,A_1} can be written as[17].

$$
P^{nc}_{out,A_1} = \begin{cases} 1 - e^{-\dfrac{\bar{\mu}_a}{\lambda_{iA_1}}}, & if, \ \ \bar{\gamma}_{th2} < \theta, \ \forall\bar{\gamma}_{th1}, \ \bar{\mu}_a \geq \bar{\mu}_1 \\ 1 - e^{-\dfrac{\bar{\gamma}_{th1}}{\lambda_{iA_1} a_2}}, & if, \ \ \bar{\gamma}_{th2} < \theta, \ \forall\bar{\gamma}_{th1}, \ \bar{\mu}_a < \bar{\mu}_1 \\ \quad 1, & if, \ \ \bar{\gamma}_{th2} \geq \theta, \ \forall\bar{\gamma}_{th1} \end{cases} \tag{49}
$$

from (24) & (26), the OP of user A_1, P^{nc}_{out,A_1}, in (48b) can be re-expressed as

$$
P^{nc}_{out,A_1} = Pr(\frac{a_1 X}{a_1 X + 1} < \bar{\gamma}_{th2}) + Pr(\frac{a_1 X}{a_1 X + 1} \geq \bar{\gamma}_{th2}, a_2 X < \bar{\gamma}_{th1}) \tag{50}
$$

The performance expressed in equation(50), above the right side equation can be written as $Pr(\frac{a_1 X}{a_1 X + 1} < \bar{\gamma}_{th2}) = Pr((a_1 - a_2\bar{\gamma}_{th2})X < \bar{\gamma}_{th2})$, its noted that this probability is always equal to 1 if , $(a_1 - a_2\bar{\gamma}_{th2}) < 0$, Relaying on this fact, and after some manipulation, the result in equation (49) can be attained [21].

B). OP of User A_2 Non-Cooperative:

The outage event of a cell-edge user A_2 only in the direct link will occur if X_2 cannot be decoded at user A_2, from the direct link broadcasted superposed message. The OP of user A_2 in Non-Cooperative can be expressed as

$$
\begin{aligned}
P^{nc}_{out,A_2} &= Pr(R^{nc}_{iA_2} < R_2) \\
&= Pr(\gamma^{nc}_{iA_2} < \bar{\gamma}_{th2})
\end{aligned} \tag{51}
$$

A closed form expression for P^{nc}_{out,A_2} can be expressed as

$$P^{nc}_{out,A_2} = \begin{cases} 1 - e^{-\dfrac{\bar{\mu}_a}{\lambda_{iA_2}}}, & if, \quad \bar{\gamma}_{th2} < \theta \\ 1, & if, \quad else \end{cases} \tag{52}$$

4.5.2 Outage Analysis of Cooperative NOMA

A). OP of user A_1 in CNOMA:

At user A_1, the outage event occurs, when the normalized message signal broadcasted from BS X_2 cannot be decoded during the SIC process or when user A_1 is not decoded its own message X_1, but X_2 successfully decoded at SIC process.

Thus, the OP of cell center user A_1 that acts as energy harvest and relay can be expressed as

$$\begin{aligned} P^{A_1}_{out} &= Pr\ (R^{x_2}_{iA_1} < R_2) \ + \ Pr\ (R^{x_2}_{iA_1} \geq R_2,\ R^{x_1}_{iA_1} < R_1) \\ &= Pr\ (\gamma^{x_2}_{iA_1} < \gamma_{th2}) \ + \ Pr\ (\gamma^{x_2}_{iA_1} \geq \gamma_{th2},\ \gamma^{x_1}_{iA_1} < \gamma_{th1}) \end{aligned} \tag{53}$$

During the cooperative NOMA, the operation could be divided equally into two-time slots which lead to operating in the half-time block, one for broadcasting and the other for relaying operation.

where, $R^{x_2}_{iA_1} = \dfrac{1}{2}\log_2^{(1+\gamma^{x_2}_{iA_1})}$, $R^{x_1}_{iA_1} = \dfrac{1}{2}\log_2^{(1+\gamma^{x_1}_{iA_1})}$ and the SNR threshold for successfully decoding the broadcasted normalized message signal of X_1 & X_2 from BS are given as $\gamma_{th1} = 2^{\ 2R_1} - 1$ and $\gamma_{th2} = 2^{\ 2R_2} - 1$ respectively.

A closed from expressed for the OP of User A_1 can be written as ,

$$P^{A_1}_{out} = \begin{cases} 1 - e^{-\dfrac{\mu_a}{\lambda_{iA_1}}}, & if, \quad \gamma_{th2} < \theta,\ \forall\gamma_{th1},\ \mu_a \geq \mu_1 \\ 1 - e^{-\dfrac{\gamma_{th1}}{\lambda_{iA_1} a_2}}, & if, \quad \gamma_{th2} < \theta,\ \forall\gamma_{th1},\ \mu_a < \mu_1 \\ 1, & if, \quad \gamma_{th2} \geq \theta,\ \forall\gamma_{th1} \end{cases} \tag{54}$$

from the equation (24) & (26) the OP of user A_1, $P^{A_1}_{out}$, in equation (53) can be re-expressed as

$$\begin{aligned} P^{A_1}_{out} = \ & Pr(\frac{a_1 X}{a_2 X + 1} < \gamma_{th2}) \ + \\ & Pr(\frac{a_1 X}{a_2 X + 1} \geq \gamma_{th2}, a_2 X < \gamma_1) \end{aligned} \tag{55}$$

from the expression above, if $\gamma_{th2} \geq \theta$ it can be observed that $Pr(\frac{a_1 X}{a_2 X+1} < \gamma_{th2}) = Pr((a_1 - a_2\gamma_{th2})X < \gamma_{th2})$ is equal to 1 where, $\theta = \dfrac{a_1}{a_2} = \dfrac{\theta_2}{\theta_1}$. Thus, by considering the relative relationships between γ_{th1}, γ_{th2}, & θ, with some algebraic manipulations the closed form expression for the OP of user A_1 can be attained as presented in equation (54).

B).OP of User A_2 in Cooperative NOMA:

As already seen in the section above the normalized message signal X_2 is not only decoded at cell-edge user A_2 but also decoded at near user A_1 in the SIC process. Note that the end-to-end SNR of the cell-edge user, $\gamma^{e2e}_{A_2,j}$ expression in equations (38), and (41), already takes place into account the SIC process associated with message signal X_2. At user A_2 SC, and MRC was applied and results $\gamma^{e2e}_{A_2,j}$. Thus, the OP of cell-edge user A_2 that will apply an SC can be expressed as

$$\begin{aligned} P^{A_2}_{out} &= Pr\ (R^{SC}_{A_2} \ < \ R_2) \\ &= Pr\ (\gamma^{e2e}_{A_{2,SC}} \ < \ \gamma_{th2}) \\ &= Pr\ (\max_{1\leq i\leq N_s} \min\{\gamma^{X_2}_{iA_1}, \max\{\gamma^{X_2}_{iA_2}, \gamma^{X_2}_{A_1A_2}\}\} \ < \ \gamma_{th2}) \end{aligned} \tag{56}$$

Thus, the OP of cell-edge user A_2 that will apply a MRC can be expressed as

$$\begin{aligned} P^{A_2}_{out} &= Pr\ (R^{MRC}_{A_2} \ < \ R_2) \\ &= Pr\ (\gamma^{e2e}_{A_{2,MRC}} \ < \ \gamma_{th2}) \\ &= Pr\ (\max_{1\leq i\leq N_s} \min\{\gamma^{X_2}_{iA_1}, (\gamma^{X_2}_{iA_2} + \gamma^{X_2}_{A_1A_2})\} \ < \ \gamma_{th2}) \end{aligned} \tag{57}$$

The closed form approximate expression for the OP of cell-edge user A_2 can be expressed as

$$\begin{aligned} P^{A_2}_{out} = &\sum_{i,j,k}^{N_s=i+j+k} \begin{pmatrix} N_s \\ i,j,k \end{pmatrix} \left(1 - e^{-\dfrac{\mu_a}{\lambda_{iA_1}} - \dfrac{\mu_b}{\lambda_{iA_2}}}\right)^i \ (-1)^j \\ &\times \ \exp^{\dfrac{k\mu_b}{\lambda_{iA_2}}} \ \frac{1}{\lambda_{A_2}} \ \left[\sqrt{\frac{4(j+k)\lambda_{A_2}\gamma_{th2}}{c\lambda_{iA_1}}}\ K_1 \left(\sqrt{\frac{4(j+k)\gamma_{th2}}{c\lambda_{iA_1}\lambda_{A_2}}}\right) - \Omega\left(\frac{\gamma_{th2}}{c\mu_a}, \frac{1}{\lambda_{A_2}}, \frac{(j+k)\gamma_{th2}}{c\lambda_{iA_1}}\right)\right] \\ &+ \left(1 \ - \ e^{-\dfrac{\mu_a}{\lambda_{iA_1}}}\right)^k e^{\dfrac{\gamma_{th2}}{c\ \mu_a\ \lambda_{A_2}}} \end{aligned} \tag{58}$$

From the equation above, the proof of $\Omega(\mu, \chi, \xi)$, is defined in[32], where,

$$\begin{aligned}\Omega\ (\mu, \chi, \xi) \ &= \frac{e^{-\mu\chi}}{\chi} - \xi\Gamma(0, \mu\chi) + \sum_{u=2}^{\infty} \frac{(-1)^u \xi^u}{u!} \\ &\times \left[\ e^{-\mu\chi} \sum_{u=1}^{u-1} \frac{(\upsilon - 1)\ !\ (-\chi)^{u-\upsilon-1}}{(u-1)\ !\ \mu^{\upsilon}} \ - \ \frac{(-\chi)^{u-1}}{(u-1)\ !}\ \mathbb{E}i(-\mu\chi)\ \right]\end{aligned} \tag{59}$$

Where, $\Gamma(:,:)$ is the upper incomplete Gamma function and $\mathbb{E}i$, is the exponential integral function defined in [33]. see the proof in the appendix

4.6 Sum-Throughput Analysis

In this section, we carry out the optimal analysis of the sum-throughput denoted by ' τ ', of the considered downlink scenario NOMA system. For the delay-limited transmission mode, the source BS transmits at a constant rate R_{A_1} *and* R_{A_2} corresponding requirement of each signal X_1 *and* X_2, respectively which may be subjected to outage due to fading. According to the system model and time division resource allocation rule summarized, users throughput in direct link mode (NOMA) and cooperative mode (CNOMA) could be derived under channel state information (CSI) constraints. Hence, the average throughput of each user generally can be expressed as

$$\tau_{A_l} \ = \ (\ 1 \ - \ P_{out}^{A_l})\ R_{iA_l} \tag{60}$$

Where, $l = \{1, 2\}$, R_{iA_1} and R_{iA_2} are the instantaneous achievable data rate of users.

4.6.1 Throughput of NOMA System

User A_1 **:** as mentioned before in a NOMA system the near user receives the superposed signal from the BS, to decode its own signal X_1 first must decode the far user or poor channel user signal X_2 and consider as the noise the decode information by canceling the noise using SIC it gets its own information X_1, Thus the throughput of the user A_1 is given as

$$\tau_{A_1}^{nc} \ = \ (\ 1 - P_{out,A_1}^{nc}\ )\ R_{iA_1,x_1}^{nc} \tag{61}$$

where, $R_{iA_1,x_1}^{nc} = \log_2^{(1+\gamma_{iA_1,x_1}^{nc})}$ and P_{out,A_1}^{nc}, the achievable data rate to decode x_2 , R_{iA_1,x_2}^{nc} also considered and expressed in equation (48) above.

User A_2 **:** As a far user, A_2 in the NOMA system only needs to decode their own information of X_2 in a direct link mode, thus the throughput of the far user is given by

$$\tau^{nc}_{A_2} \; = \; (\; 1 - P^{nc}_{out,A_2} \;) \; R^{nc}_{iA_2} \tag{62}$$

where, $R^{nc}_{iA_2} = \log_2^{(1+\gamma^{nc}_{iA_2})}$ and P^{nc}_{out,A_2} also expressed in equation (51) above .

The **sum-throughput** of the system can be expressed as the summation throughput of both two NOMA users and given as

$$\begin{aligned} \tau^{nc} &= \tau^{nc}_{A_1} + \tau^{nc}_{A_2} \\ &= \; (\; 1 - P^{nc}_{out,A_1} \;) \; R^{nc}_{iA_1,x_1} + \; (\; 1 - P^{nc}_{out,A_2} \;) \; R^{nc}_{iA_2} \end{aligned} \tag{63}$$

4.6.2 Sum-throughput of C-NOMA System

In a cooperative NOMA mode, the third communication link, i.e the link between $A_1 - A_2$ is built. A_1 will re-encode X_2 instead of discarding it, different from the direct link, the power splitter, in A_1 will be utilized. This leads to the power splitting(PS) factor being considered in the formula.

User A_1: C-NOMA throughput can be expressed as

$$\tau_{A_1} = (1 - P^{A_1}_{out}) R^{x_1}_{iA_1} \tag{64}$$

where, $R^{x_1}_{iA_1} = \dfrac{1}{2} \log_2^{(1+\gamma^{x_1}_{iA_1})}$ is a target data rate used to decode the message signal X_1
At User A_2 : The change in A_1 function will not affects the throughput for A_2 to decode X_2 under BS - A_2 link in the first time slot. Moreover, A_2 also receives the re-encoded signal forwarded from A_1 in the second time slot.

The throughput of user A_2 is given as

$$\tau_{A_2} = (1 - P^{A_2}_{out}) R^{j}_{A_2} \tag{65}$$

where, $R^{j}_{A_2}$ are the problem expressed in equation(42).

In this paper, the optimal analysis of the sum throughput is studied by introducing the gradient descent algorithm that will find optimal values of the power splitting (PS) coefficient. The optimal sum-throughput of the considered downlink scenario NOMA system denoted by τ, the algorithm used to find the optimal value of β, denoted by $\beta^{(*)}$, that results in the maximum value of the Sum-Throughput of the system.

The Sum-Throughput of cooperative-NOMA system can be expressed as

$$\begin{aligned} \tau &= \tau_{A_1} + \tau_{A_2} \\ &= (1 - P^{A_1}_{out}) R^{x_1}_{iA_1} + (1 - P^{A_2}_{out}) R^{j}_{A_2} \end{aligned} \tag{66}$$

Where, $P_{out}^{A_1}$ equation are described in (53) and $P_{out}^{A_2}$ equation are described in (56), and (57) by inserting the problem into the above equation the system can described as

$$\tau = R_{iA_1}^{x_1} e^{-\frac{\phi}{\lambda_{iA_1}}} + R_{A_2} \left[e^{-\frac{\mu_a}{\lambda_{iA_1}} - \frac{\mu_b}{\lambda_{iA_2}}} + (1 - e^{-\frac{\mu_b}{\lambda_{iA_2}}}) * \left[e^{\frac{\mu_a}{\lambda_i A_1}} - \frac{\gamma_{th2}}{c\lambda_{iA_1}\lambda_{A_2}} \Gamma(0, \frac{\mu_a}{\lambda_{iA_1}}) \right]\right] \tag{67}$$

Where, $\phi = \mu_a$ if $\mu_a \geq \frac{\gamma_{th1}}{a_2}$,otherwise $\phi = \frac{\gamma_{th1}}{a_2}$. Please note that $P_{out}^{A_1}$ and $P_{out}^{A_2}$ already take into account the effect of the factor 1/2, which appears due to the cooperative NOMA transmission is employed in a half time block. The considered problem is formulated as an unconstrained optimization problem, which can be expressed as

$$\max_{\beta} \ \tau \ = \ f(\beta) \tag{68}$$

where, $f(\beta)$: (0,1) $\rightarrow \mathbf{R}^+$, in which $\mathbf{R}^+$ denotes the set of position real numbers. The equation (68) above is also expressed as

$$\max_{\beta} \ g(\beta) \ = \ - \ f(\beta) \tag{69}$$

where, $g(\beta) : (0, 1) \rightarrow \mathbf{R}^+$. In order to facilitate the optimal analysis of τ , we make a further relaxation of $g(\beta)$ by assuming that $(1 - \beta)N_{A_1} \approx N_{A_1}$, since the noise power introduced by antenna is significantly small. Thus $g(\beta)$ can be also written as

$$\begin{aligned} g_j(\beta) \ &= \ - \ R_{iA_1}^{x_1} \ e^{\frac{\upsilon_j}{1-\beta}} \ - \ R_{A_2} \ e^{-\frac{\gamma_{th2}N_{A_1}}{(1-\beta)P_s(\theta_2 - \theta_1\gamma_{th2})\lambda_{iA_1}} - \frac{\mu_a}{\lambda_{iA_2}}} \\ &- \ R_{iA_2} \ (1 - e^{-\frac{\mu_b}{\lambda_{iA_2}}})e^{-\frac{\gamma_{th2}N_{A_1}}{(1-\beta)P_s(\theta_2 - \theta_1\gamma_{th2})\lambda_{iA_1}}} \\ &+ \ R_{iA_2}(1 - e^{\frac{\mu_b}{\lambda_{iA_2}}})\frac{\gamma_{th2}N_{A_2}}{\eta\beta P_s\lambda_{iA_1}\lambda_{iA_2}}\Gamma\left(0, \frac{\gamma_{th2}N_{A_1}}{(1-\beta)P_s(\theta_2 - \theta_1\gamma_{th2})\lambda_{iA_1}}\right) \end{aligned} \tag{70}$$

In the equation formulated above to get the optimized PS coefficient, where, j = 1 if $\frac{\gamma_{th2}}{(\theta_2 - \theta_1\gamma_{th2})} \geq \frac{\gamma_{th1}}{\theta_1}$ otherwise , j = 2, which indicates we have two values of υ_j which are $\upsilon_1 = \frac{\gamma_{th2}N_{A_1}}{P_s(\theta_2 - \theta_1\gamma_{th2})\lambda_{iA_1}}$ and $\upsilon_2 = \frac{\gamma_{th1}N_{A_1}}{\theta_1 P_s\lambda_{iA_1}}$ For some simplification let $\kappa_a = - \frac{\gamma_{th2}N_{A_1}}{(\theta_2 - \theta_1\gamma_{th2})P_s\lambda_{iA_1}}$, $\kappa_b = -\frac{\mu_b}{\lambda_{iA_2}}$, $\kappa_c = - \frac{\gamma_{th2}N_{A_2}}{\eta P_s\lambda_{iA_1}\lambda_{iA_2}}$ and $\phi = 1 - e^{-\kappa_b}$, then the equation formulated in (60) can be simple written as

$$\begin{aligned} g_\jmath(\beta) \;=\; & -R_{iA_1}^{x_1}\, e^{\dfrac{\upsilon_\jmath}{1-\beta}} - R_{iA_2} e^{\dfrac{\kappa_a}{1-\beta}+\kappa_b} - \\ & R_{iA_2}\phi e^{\dfrac{\kappa_a}{1-\beta}} - \frac{R_{iA_2\phi\kappa_c}}{\beta}\Gamma\left(0, -\frac{\kappa_a}{1-\beta}\right) \end{aligned} \tag{71}$$

The complicated expression of $g_\jmath(\beta)$ makes the optimal analysis of the power splitting coefficient (PS) of the function not trivial. Moreover, the gradient descent algorithm [34], is used in this paper to resolve the formulated problem. In general, the gradient descent algorithm is a simple yet efficient algorithm introduced to find the optimal power splitting coefficient as follows.

The optimal value of PS coefficient is denoted as $\beta^{(*)}$. We want to produce a minimizing sequence : $\beta^{(0)}, \beta^{(1)}, \cdots \beta^{(\kappa)}, \cdots \in$ **dom** g with $g(\beta^{(\kappa)}) \rightarrow g(\beta^{(*)})$ as $\kappa \rightarrow \infty$, where

$$\beta^{(\kappa+1)} = \beta^{(\kappa)} + t^{(\kappa)}\Delta\beta^{(\kappa)}$$

Where **dom** g indicates the domain of g and κ indicates the iteration number to find the optimal PS coefficient, $t^{(\kappa)}$ is called the step size or step length, and $\Delta\beta^{(\kappa)}$ represents the step to search direction. Considering the gradient decent algorithm introduced the search direction chosen in a negative gradient of the objective function. i.e $\Delta\beta^{(\kappa)} := -\bigtriangledown g(\beta)$ which results in

$$g(\beta^{(\kappa+1)}) < g(\beta^{(\kappa)})$$

The gradient decent algorithm will run until the stopping criterion is satisfied, i.e $||\bigtriangledown g(\beta^{(\kappa+1)})||_2 \leq \mathcal{S}_{th}$, where $\mathcal{S}_{th}$ represent a stopping threshold for the iteration, and $||\ .\ ||_2$ represent l_2- norm

The gradient of the objective function in equation (59) can be given as

$$\begin{aligned} \bigtriangledown g_\jmath(\beta) = & -\frac{R_{iA_1}^{x_1}\upsilon_\jmath e^{\dfrac{\upsilon_\jmath}{1-\beta}}}{(1-\beta)^2} - \frac{R_{iA_2}\kappa_a e^{\dfrac{\kappa_a}{1-\beta}+\kappa_b}}{(1-\beta)^2} - \frac{R_{iA_2}\kappa_a\phi e^{\dfrac{\kappa_a}{1-\beta}}}{(1-\beta)^2} + \\ & \frac{R_{iA_2}\ \kappa_c\ \phi\ e^{\dfrac{\kappa_a}{1-\beta}}}{(1-\beta)\beta} + \frac{R_{iA_2}\kappa_c\phi}{\beta^2}\ \Gamma\left(0, -\frac{\kappa_a}{1-\beta}\right) \end{aligned} \tag{72}$$

Note that, Based on the system parameters acquired through the channel state information (CSI) estimation process and before the data transmission process the optimization process can be done offline with the gradient descent algorithm.

Chapter Five

5 Results and Discussions

In this section, the simulation results are presented to validate the developed analysis and illustrate the achievable performance of the cooperative SWIPT-NOMA system in comparison with the conventional orthogonal multiple access (OMA) and non-cooperative NOMA system. For the parameter value the range of coverage and other values specifications [42][43] and the outdoor radio communication obstructed in building 3 upto 4 path loss exponent is preferably used. The provided simulation result is based on a typical down-link cooperative SWIPT-NOMA system .

Table 2: Simulation Parameters and Value

Parameters	Value
Power allocation coefficient of user A_1, θ_1	0.2
Power allocation coefficient of user A_2, θ_2	1 - θ_1
Antenna noise power, $N_{A_1} = N_{A_2}$	100dBm/Hz
Target data rate , $R_1 = R_2$	1bps/Hz
Distance between BS and user A_2, D_2	1Km
Distance between BS and user A_1, D_1	500m
Distance between user A_1 and A_2, D_3	$D_2 - D_1$
Referance distance,d_0	100m
Path loss at referance distance, $\pounds$	30dBm
Path loss exponent, ϵ	4
Time fraction for energy harvesting, β	0.2
Energy conversion eficiency of the EH, η	0.7

5.1 Outage probability Analysis

The simulation result is presented below for downlink transmission, investigating the performance of the scheme used for conventional OMA, non-cooperative NOMA, and cooperative SWIPT-NOMA systems. In the cooperative NOMA system, the near user act as a relay to assist the far user information, and at the far user different combining scheme such as MRC and SC are deployed to combine the information-bearing signal of direct and relaying transmission. The performance of the combining techniques was also analyzed by outage probability and achievable capacity of NOMA users.

In figure 5.1, we plot the OP of cell-center user A_1 and cell-edge user A_2 on the same plot for the cooperative SWIPT-NOMA and non-cooperative NOMA scheme as a function of the transmit signal-to-noise ratio (SNR). We can see from the simulation result from figure 5.1, that using the cooperative SWIPT-NOMA system with different combining techniques outperforms the non-cooperative NOMA system.

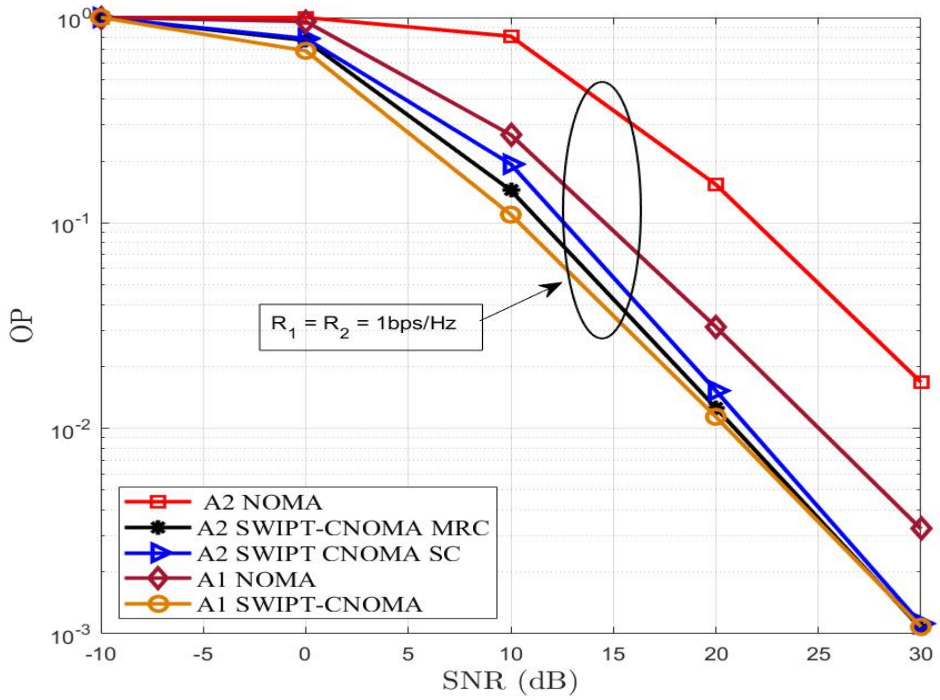

Figure 5.1: Comparison of the OP of cooperative SWIPT-NOMA and conventional-NOMA users as a function of SNR with $\beta = 0.2$, $\theta_1 = 0.2$ & $\theta_2 = 0.8$

The probability of an outage is higher at a low SNR value and decreases gradually as the SNR value increases. In addition to that the OP of cell-edge user A_2 with the MRC technique outperforms that of the cell-edge user A_2 with the SC technique. For efficient communication, the OP of the system should be less, which is observed in cooperative SWIPT-NOMA systems with MRC and SC techniques when compared with non-cooperative NOMA systems. The simulation result approves the purpose of the cooperative SWIPT-NOMA and also exactly matches the analytic result too. We consider the cell-center user A_1, as seen in figure 5.1 above its OP close to cell-edge A_2 in the cooperative SWIPT-NOMA system due to the relaying and RF energy harvesting operation employed.

In figure 5.2 we compare the OP of users with different target data rates for a given SNR. i.e $R_1 = 2bps/Hz$ & $R_2 = 1bps/Hz$. In this situation the OP of NOMA user A_1

increases than that of NOMA user A_2, due to the target data rate of user A_1 being greater than NOMA user A_2 and A_1 suffering performance loss compared to the user with less target data rates. It is noticed that if we increase the target data rate of NOMA users the outage probability also increases.

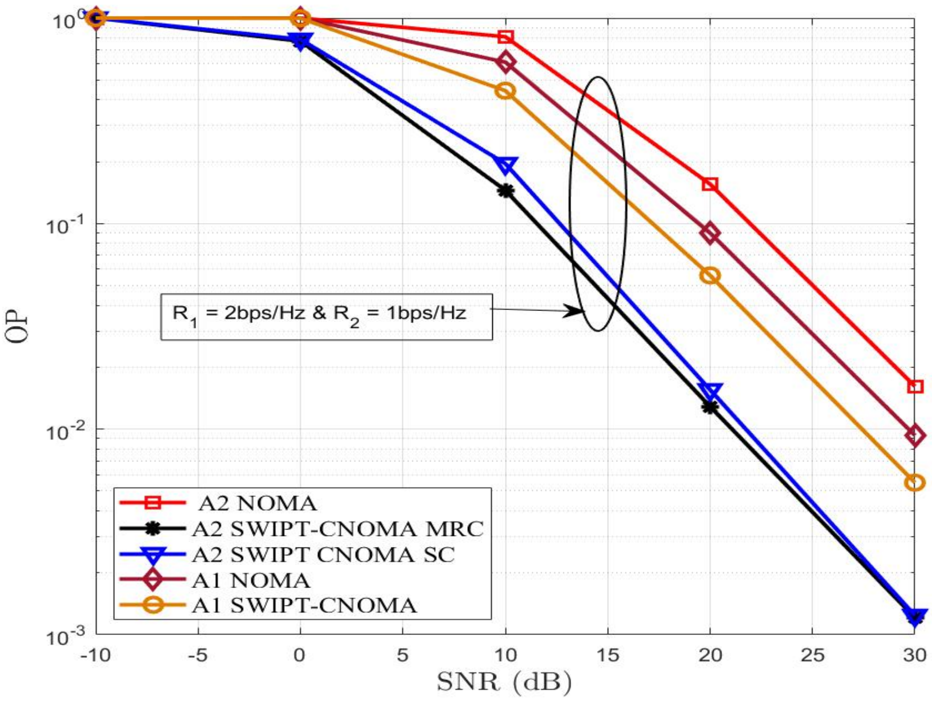

Figure 5.2: Comparison of the OP of cooperative SWIPT-NOMA and conventional-NOMA users as a function of SNR with $\beta = 0.2$, $R_1 = 2bps/Hz, R_1 bps/Hz = 1$

In figure 5.3 we compare OP with different transmission schemes and combine techniques for a given SNR. It shows the cooperative NOMA transmission with different combining techniques outperforms the NOMA direct transmission. We can see from the figure using cooperative SWIPT-NOMA with MRC and SC techniques offer significant performance improvement compared to the conventional NOMA system.

Table 3: SNR Vs OP of cooporetave NOMA and conventional NOMA system

SNR / A_2 OP	NOMA	Relay link only	C-NOMA SC	C-NOMA MRC
0dB	1.000	0.7899	0.6487	0.5902
10dB	0.7757	0.2186	0.1471	0.0712
30dB	0.0156	0.00543	0.00005	0.00001

At 0dBm of SNR, the OP is 1.0 in the case of a conventional NOMA system, 0.7899 in the case of cooperative NOMA without a direct link, 0.6487 in the case of cooperative NOMA with SC technique, and 0.5902 in case of cooperative NOMA with MRC technique. In figure 5.3 we can also see the improvement that MRC offers compared to direct NOMA and relay transmission with the SC technique. cooperative SWIPT-NOMA using MRC has decreased in OP 40% compared to conventional NOMA, 25.98% compared to cooperative NOMA without a direct link, and 9.02% compared to cooperative NOMA with SC technique. For an efficient communication system, the OP of the system should be less, which is observed in cooperative SWIPT-NOMA with MRC technique when compared with cooperative SWIPT-NOMA with SC technique and conventional NOMA system.

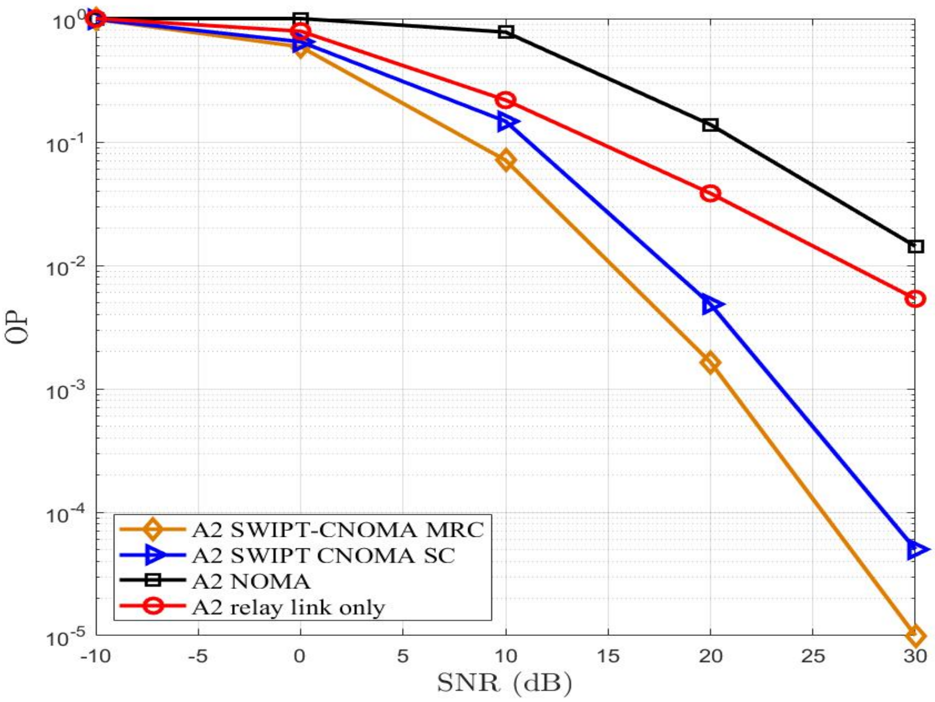

Figure 5.3: Cell-edge user A_2 performance comparison between different scheme as a function of SNR with β =0.3, $R_1 = 2bps/Hz, R_1 bps/Hz = 1$

Generally, in comparison to the other scheme, the cooperative SWIPT-NOMA with the combination of MRC, SC, and TAS outperforms which implicates the goal of the cooperative SWIPT-NOMA system by minimizing the OP of the system.

In figure 5.4 we further investigate the impact of power splitting ratio β on the cooperative SWIPT-NOMA system performance. In cooperative SWIPT-NOMA regarding DF, the OP of the cell-edge user A_2 first decreases, and as the power splitting ratio β increases the OP of A_2 also increases. Regarding the cell-center user, A_1 concerning the power splitting ratio β the OP increase due to the cell-center user employing the RF-EH and relaying transmission. As seen from the figure the result of both non-cooperative NOMA users is constant throughout the β value, this is due to there being no power splitting, energy harvesting, and relaying process taking place in the non-cooperative NOMA system.

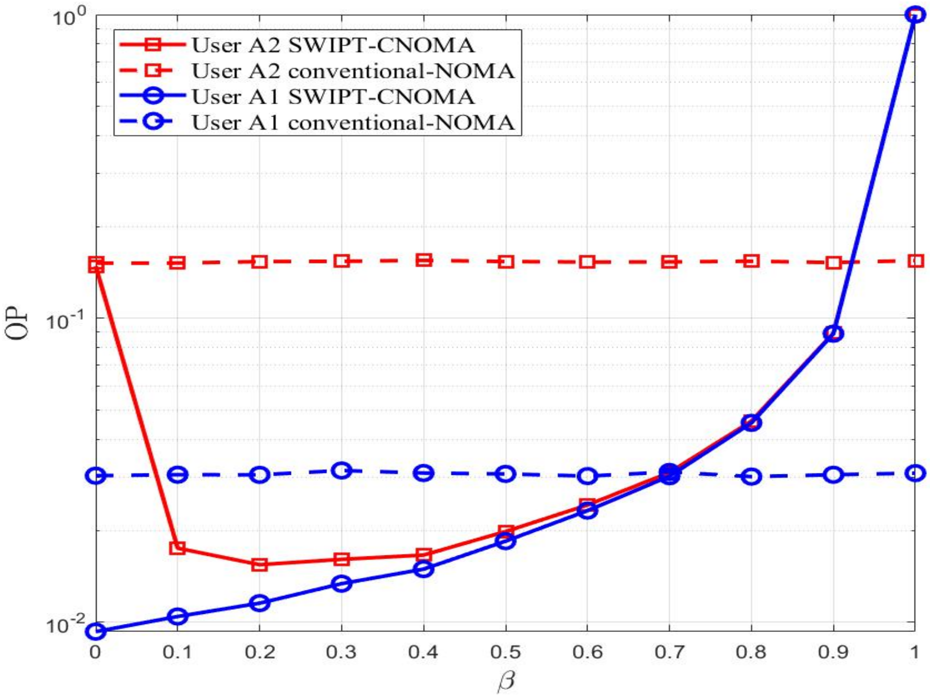

Figure 5.4: OP of user A_2 and user A_1,as a function of power splitting coefficient β with SNR = 30dB

We can see that based on the derived mathematical expression, the optimal power splitting ratio β at which the system OP is the smallest can be determined. Specifically, the optimal value of β in Figure 5.4, corresponding to SNR = 30dBm is between 0.1 to 0.3, it can be explained from the standpoint of the performance of cell-edge user A_2. Varying the power splitting ratio β affects the performance of the cell-center user and relaying operation.

In figure 5.5, we compare the OP of the NOMA user with a variety of distances between BS and cell-center user A_1. The simulation result shows the OP of user A_1 and A_2 without direct link and employing MRC and SC technique, for a given d_{SA_1} distance. From the plotted result we observed the OP of the NOMA user increase as d_{SA_1} increases. One possible reason is that when user A_1 is located distant from BS, the amount of harvested energy becomes smaller, which results in smaller power for relaying information of cell-edge user A_2.

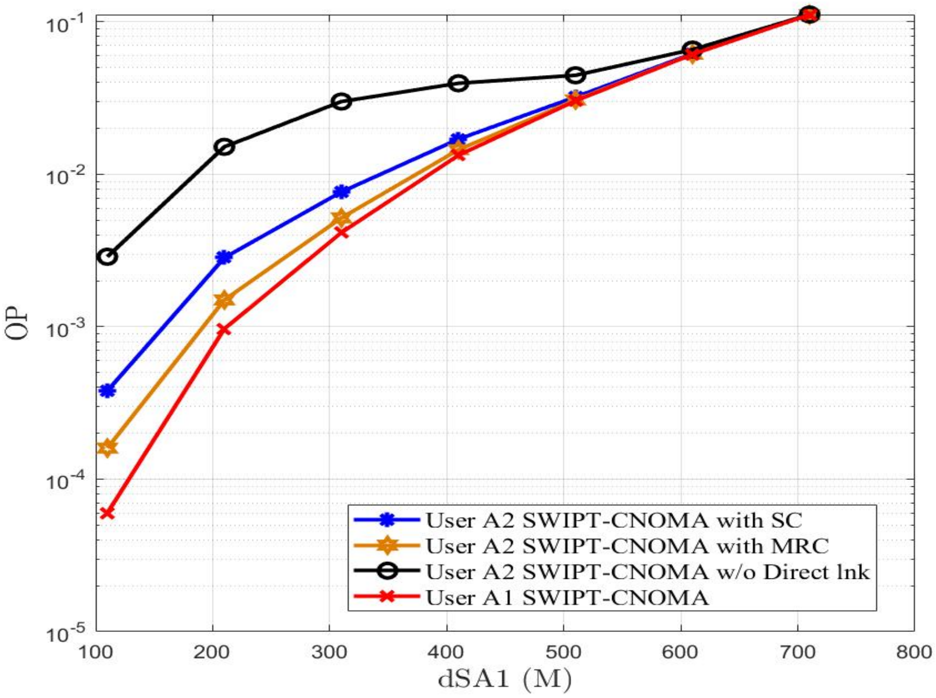

Figure 5.5: OP of user A_2 and user A_1,as a function of distance between S and A_1 with $\beta = 0.3$, and SNR = 30dB

Another possible reason is NOMA uses principles of difference in channel conditions of cell-center and cell-edge user channel from BS, which leads to the SIC receiver working normally, but if cell-center user A_1 is closer to cell-edge user A_2, their channel condition becomes more similar, which leads in decreasing NOMA user performance.

In figure 5.6 we consider the achievable data rate of the NOMA users versus system SNR. The simulation result of cooperative SWIPT-NOMA illustrates that the cell-center user still achieves a higher achievable data rate despite energy harvesting and cell-edge user information relaying. We can notice that cell-edge cooperative NOMA users attain higher achievable capacity using MRC and SC techniques compared to the conventional NOMA system.

In the plot of achievable capacity and SNR, at 10dBm of SNR, the achievable capacity is 1.5737 in the case of conventional NOMA, 2.2308 in the case of cooperative SWIPT-NOMA using SC technique, and 2.3249 in the case cooperative SWIPT-NOMA using MRC technique.

In figure 5.7 we further investigate the achievable sum capacity and SNR. From the figure, it is clear from the plot that the result for cooperative SWIPT-NOMA outperforms the conventional NOMA and conventional OMA. In the plot of achievable capacity and SNR, at 10dBm of SNR, the achievable capacity is 2.909 in the case

Table 4: SNR Vs achievable capacity of NOMA user

SNR/Achievable Capacity(bps/Hz)	A_2 NOMA	A_2 C-NOMA SC	A_2 C-NOMA MRC	A_1 C-NOMA
-10dB	0.1033	0.2512	0.2787	0.3719
10dB	1.5737	2.2308	2.3249	2.7976
30dB	2.2914	5.3619	5.3723	6.0772

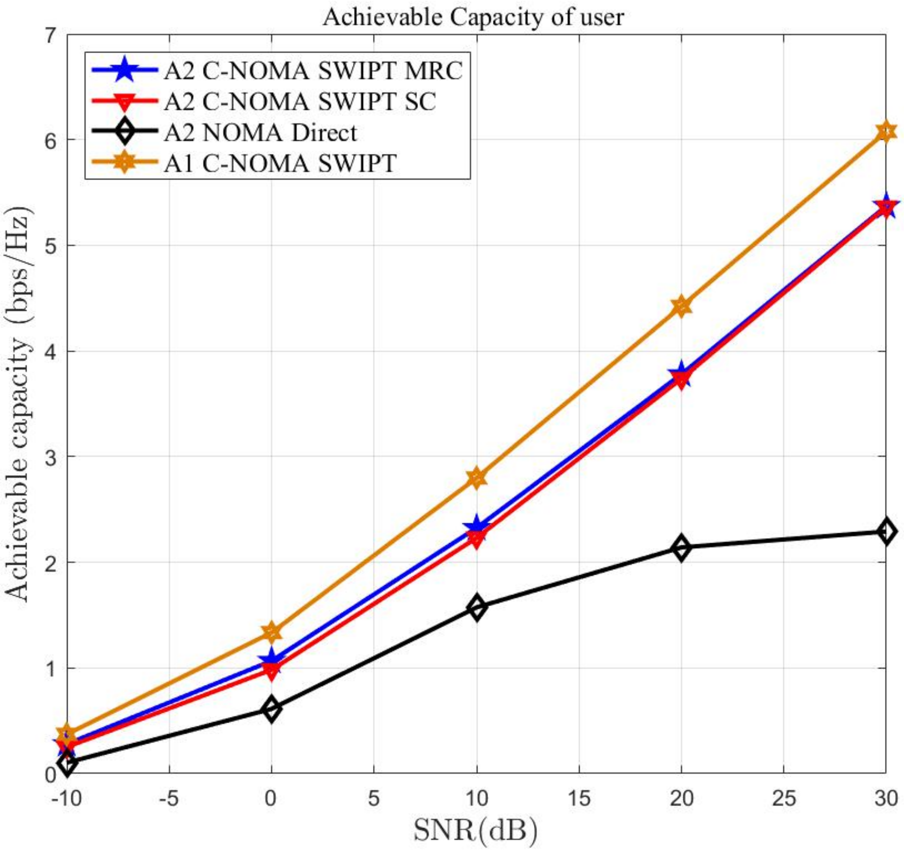

Figure 5.6: Achievable rate comparisons of user A_1&A_2 in different schemes for a given SNR

of conventional OMA, 7.481 in the case of conventional NOMA, 8.3993 in the case of cooperative SWIPT-NOMA using SC technique, and 8.587 in the case cooperative SWIPT-NOMA using MRC technique. In contrast, the achievable capacity increase when SNR increases, this is due to when SNR rises, A_1 performs much better than the A_2, despite the EH technique and relay information. Using MRC offer a significant achievement capacity improvement for a relay transmission.

Cooperative SWIPT-NOMA using MRC has increases 66.12% of achievable sum capacity compared to conventional OMA system, 12.88% compared to conventional NOMA system, and 2.18% improvement than the cooperative SWIPT-NOMA with SC technique. It's known that an achievable capacity rate for an efficient communication system should be more which is observed in cooperative SWIPT-NOMA systems with MRC technique when compared with conventional NOMA and conventional OMA system.

Table 5: SNR Vs Achievable Sum capacity of different systems

SNR / Sum Capacity	OMA	NOMA	C-NOMA SC	C-NOMA MRC
-10dB	0.2703	0.9715	1.478	1.5337
10dB	2.909	7.481	8.3993	8.587
30dB	8.627	14.7709	17.9756	17.9957

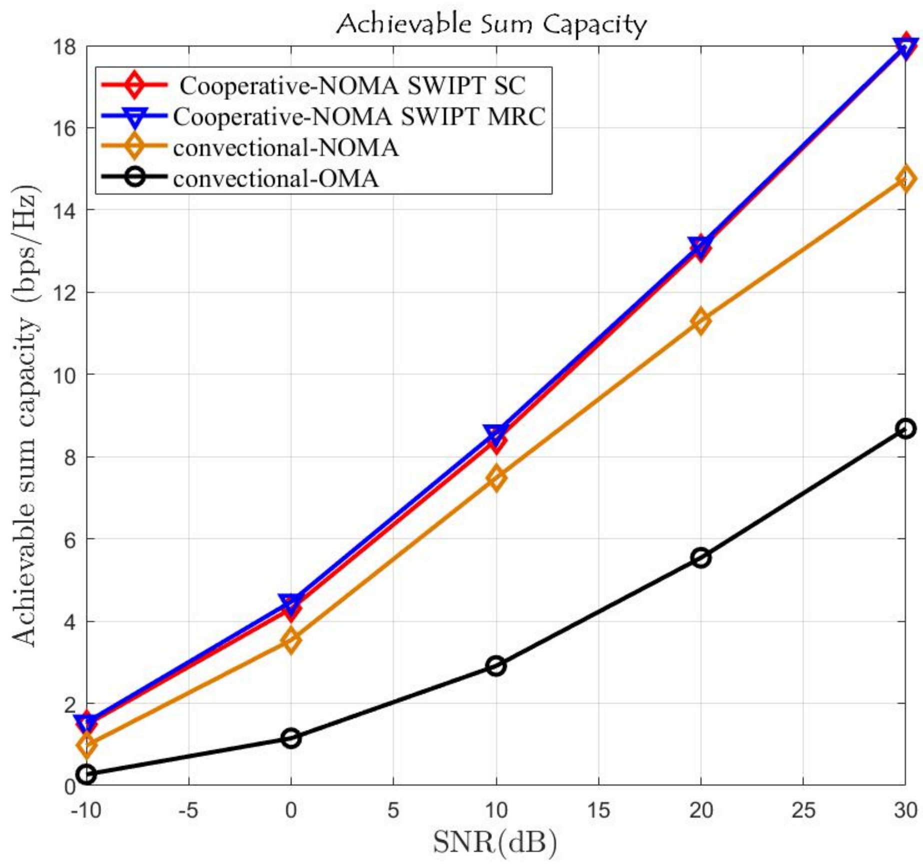

Figure 5.7: Achievable sum rate comparisons of different systems for a given SNR

5.2 Sum-throughput Performance Analysis

In figure 5.8, the simulation result illustrates the result of the gradient descent algorithm for finding the optimal power splitting coefficient. from the simulation result as can be seen the optimal sum-throughput PS coefficient β is concave concerning the objective function obtained from the simulation. The simulation result is very tight to the objective function to obtain the optimal power coefficient for the optimal sum-throughput of the cooperative SWIPT-NOMA system.

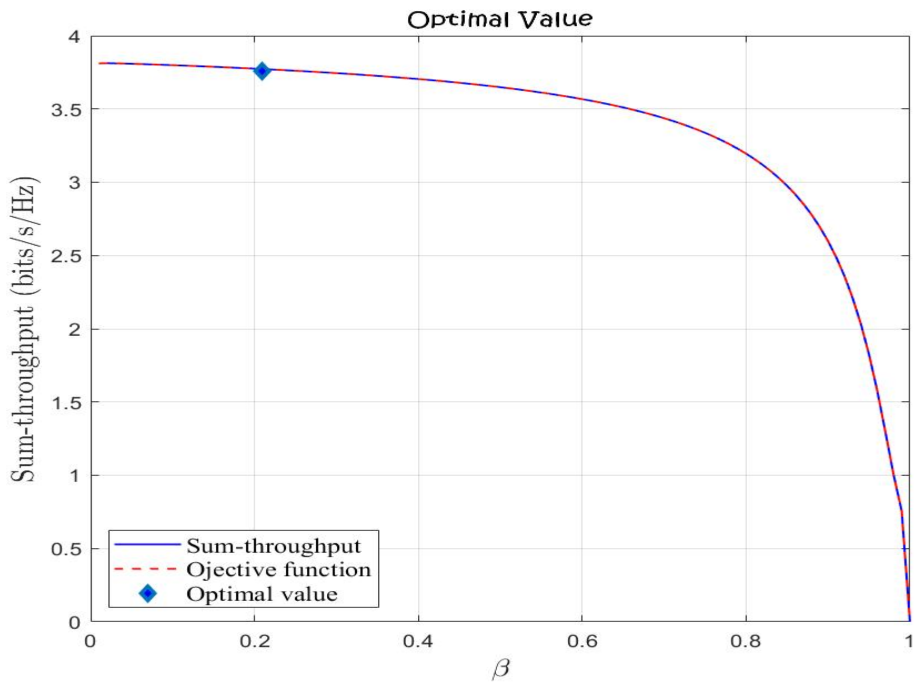

Figure 5.8: Finding Optimal power-splitting coefficient $\beta(\star)$ Obtained by gradient-decent algorithm for a given SNR

In figure 5.9, the simulation result illustrates the throughput comparison of cell-edge users with the non-cooperative NOMA and conventional OMA system. As a result of the throughput simulation, the cooperative SWIPT-NOMA user A_2 outperforms the non-cooperative NOMA and conventional-OMA system. We can observe that the throughput of the cooperative NOMA system is higher than that of non-cooperative NOMA and conventional OMA systems in low SNR areas since the outage performance of users for the cooperative NOMA system is better than that of non-cooperative NOMA and conventional OMA systems. We can also see the improvement that MRC offers over the SC and non-cooperative NOMA system. Cooperative SWIPT-NOMA with MRC has increased in throughput of cell-edge users by 3.18% over cooperative SWIPT-NOMA with SC technique, 35.32% over the non-cooperative

NOMA system and cooperative SWIPT-NOMA with SC technique has 32.87% over the non-cooperative NOMA systems at low SNR. It noted the higher the throughput of cooperative NOMA is more attained at the low SNR area.

In figure 5.10 we consider the sum-throughput performance analysis of the three systems namely optimal cooperative SWIPT-NOMA, non-cooperative NOMA, and conventional OMA.

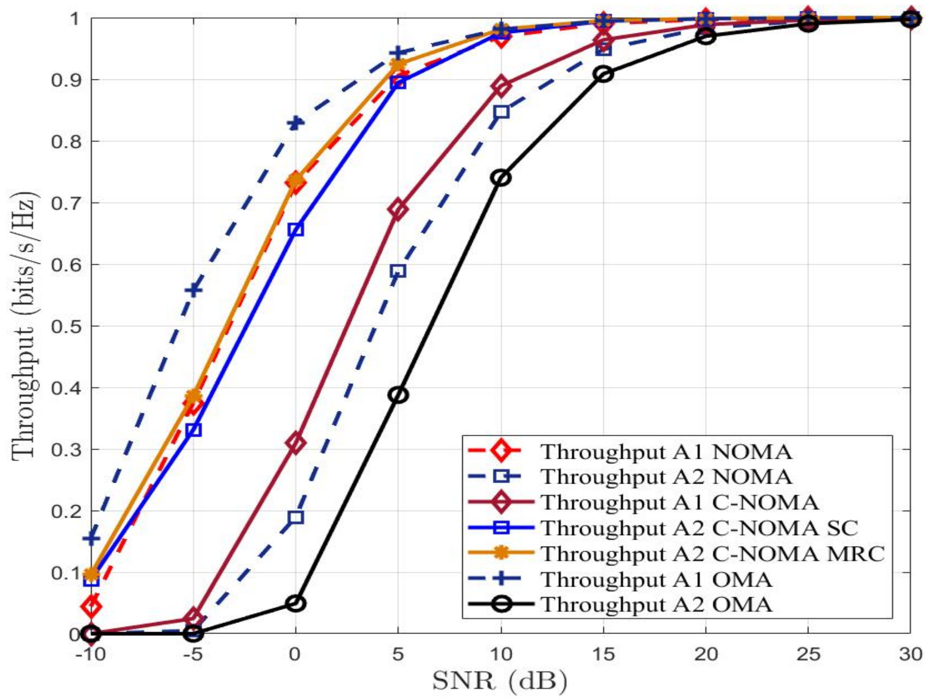

Figure 5.9: Throughput performance comparisons of SWIPT-CNOMA system of cell-edge user A_2 with non-cooperative NOMA and conventional OMA system

Table 6: SNR Vs Throughput of user in different systems

SNR / Throughput	A_2 OMA	A_2 NOMA	A_2 C-NOMA SC	A_2 C-NOMA MRC
-5dB	0.00008	0.0048	0.3293	0.3831
0dB	0.0495	0.1887	0.6529	0.7324
10dB	0.7408	0.846	0.9754	0.9811
20dB	0.9709	0.9833	0.9982	0.9984

As observed from the figure plotted the optimal cooperative SWIPT-NOMA accomplished better sum-throughput performance compared to the non-cooperative NOMA and conventional OMA system. As θ_2 increases A_2 will get more power and its sum-rate increase accordingly, while the sum rate of A_1 degraded. However increasing power allocation of A_2, θ_2, will largely increase the sum rate of cell-edge user A_2, and thus increase the overall sum throughput of the cooperative SWIPT-NOMA system.

Figure 5.9 and Figure 5.10, also demonstrate the existence of throughput and sum throughput. We can also see the capacity advantage of cooperative SWIPT-NOMA with diversity combining techniques. Cooperative SWIPT-NOMA with MRC has a sum throughput improvement of 7.64 % over the SC technique, 11.68% over non-cooperative NOMA system, and 15.58% over the conventional OMA systems at 0dB.

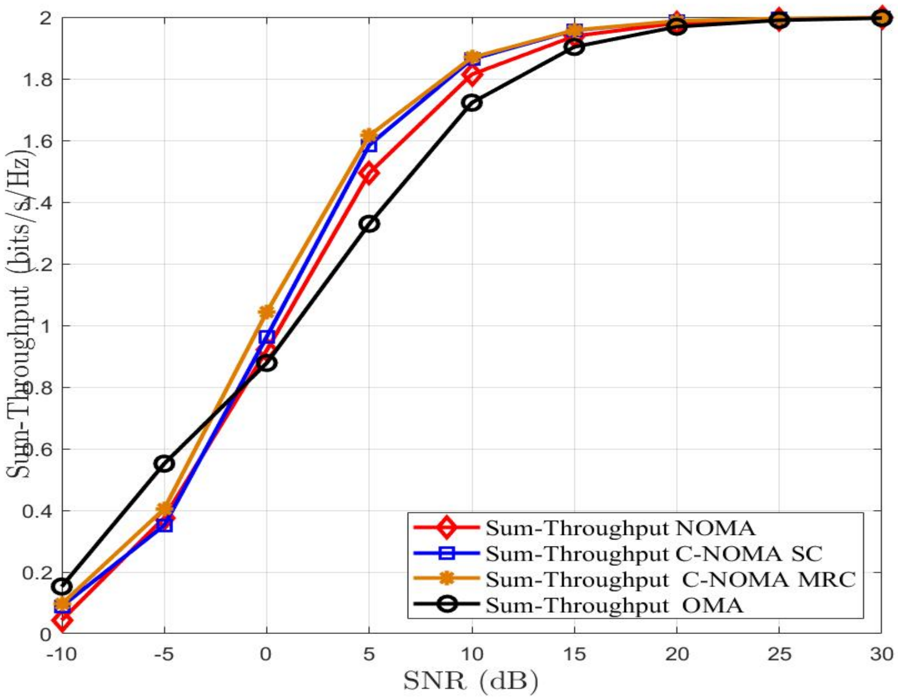

Figure 5.10: Sum-Throughput performance comparisons of SWIPT-CNOMA system with non-cooperative NOMA and conventional-OMA system for a given SNR

However, the sum throughputs of the optimal cooperative SWIPT-NOMA and the non-cooperative NOMA are tight together. This happens due to we are using SWIPT-based relaying transmission in an optimal cooperative SWIPT-NOMA system, this leads to the NOMA transmission operating in half of the block time and the cell-center user operates the energy harvesting and information relaying which degrades the throughput of cell-center user and have its own impact on sum-throughput of system. While in the non-cooperative NOMA system, there is no relaying operation, in which the BS uses the whole block time to perform NOMA transmission.

Generally, from the obtained numerical results, even if the outage probability and

Table 7: SNR Vs Sum-throughput of different systems

SNR / Sum-Throughput	OMA	NOMA	C-NOMA	
			SC	MRC
-5dB	0.5533	0.3781	0.3536	0.4074
0dB	0.8781	0.9187	0.9607	1.0402
10dB	1.7226	1.8153	1.8657	1.8714
20dB	1.9687	1.978	1.9863	1.9865

throughput of cell-center user A_1 is affected due to employing energy harvesting and relaying transmission to balance the data fairness between the two users, we conclude that the use of relaying operation at cell-center user A_1 to assist the cell-edge user A_2 information does not jeopardize the sum-throughput of considered two user NOMA system.

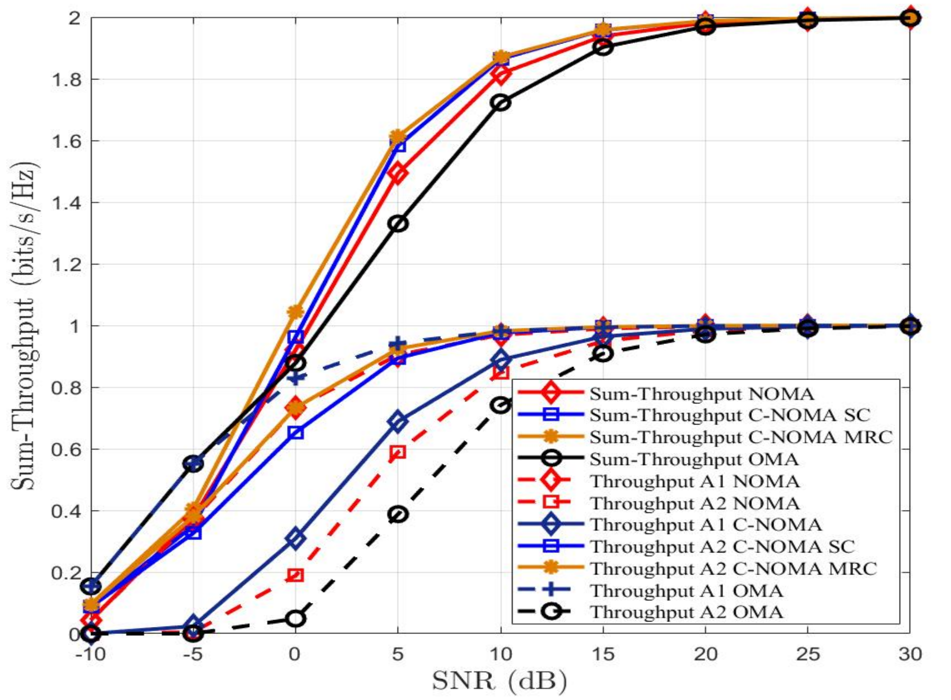

Figure 5.11: Throughput and sum-throughput of SWIPT-CNOMA system performance comparisons with NOMA and OMA

Chapter Six

6 Conclusion and Recommendation

6.1 Conclusion

This paper focuses on the performance analysis of a cooperative NOMA system employing SWIPT and TAS techniques at BS and energy harvesting and information relaying at the cell-center user, also diversity combining techniques like MRC and SC at the cell-edge user. Expression of OP, achievable capacity, and throughput are investigated on which performance of the system can be analyzed in comparison to non-cooperative NOMA and conventional OMA systems. The simulation results are illustrated by simulating the system model in Matlab. The result was validated through Monte-Carlo simulations for each system.

The OP is investigated in a different scheme like direct link and relaying with MRC and SC in terms of SNR, distance, and power splitting ratio. Firstly the OP performance of the user in the cooperative SWIPT-NOMA studied, the OP of the user was decreased as the received SNR increased in comparison to non-cooperative NOMA and conventional OMA systems. In the next scenario, the impact of MRC and SC, and TAS was studied. Another scenario studied as power splitting coefficient β, as β increase, for A_1 the OP increases continuously. But, for A_2 when β increase OP decrease, then after β value is 0.3 OP continuously increase. The achievable capacity and throughput performance of the cooperative SWIPT-NOMA system using different diversity combining techniques with non-cooperative NOMA and conventional OMA was analyzed.

Matlab simulation of numerical results has shown a cooperative SWIPT-NOMA using MRC has decreased in OP 40% compared to non-cooperative NOMA, 25.98% compared to cooperative NOMA without a direct link, and 9.02% compared to cooperative SWIPT-NOMA with SC techniques. The optimal value of the β is between 0.1 to 0.3 from the simulation result. Cooperative SWIPT-NOMA with MRC also provides an increase of achievable capacity, 66.12% compared to conventional OMA system, 12.88% compared to non-cooperative NOMA system and 2.18% improvement over SC techniques. Cooperative SWIPT-NOMA with MRC has a sum throughput improvement of 7.64% over the SC technique, 11.68% over the non-cooperative NOMA system, and 15.58% over the conventional OMA systems at 0dB.

6.2 Recommendation

The following are a few promising future works recommended by the author.

- This thesis was done by assuming perfect channel state information at the base station antennas. while in future work using tools of compressive sensing technique could be an interesting area to investigate.
- The analysis of this thesis focused on the downlink decode and forward single relaying network, single cell two user NOMA and the throughput of PS-SWIPT relaying protocols have been investigated, while future work will consider the uplink scenario and a number of users in Multi-cell of another interesting area to investigate.
- The analysis of this study for relay-assisted SWIPT deals with the half-duplex downlink NOMA system in which two-time slots are required to transmit one data packet since leads to spectral efficiency loss, while the future work will consider the capacity advantage of full-duplex NOMA over the Half-Duplex system which was previously regarded as impractical due to strong self-interference (SI).
- The investigation of this thesis simulation result considers only the Outage Probability, achievable capacity, and Throughput of systems, While in future work it's possible to evaluate the capacity advantage of C-NOMA with amplify and forward(AF) relaying protocol, the impact of relay selection on the performance of HDR system and impact of packet transmission delay during cooperative NOMA.

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7 Appendix

Proof

From the equation (53),the OP of the cell-center user A_1 ,can be written as ,

$$P_{out}^{A_1} = P_r\left(\frac{a_1X}{a_2X+1} < \gamma_{th2}\right) + P_r\left(\frac{a_1X}{a_2X+1} \geq \gamma_{th2}, a_2X < \gamma_{th1}\right)$$

From the expression above,if $\gamma_{th2} > \theta$ it can be observed that,

$$P_{out}^{A_1} = P_r\left(\frac{a_1X}{a_2X+1} < \gamma_{th2}\right) + P_r\left((a_1 - a_2\gamma_{th2}) < \gamma_{th2}\right)$$

is equal to 1, where $\theta = \dfrac{a_1}{a_2} = \dfrac{\theta_2}{\theta_1}$. and also written as ,

$$= \int_0^\infty P_r\left(\left(\frac{a_1X}{a_2X+1} < \gamma_{th2}\right) + P_r\left(\frac{a_1X}{a_2X+1} \geq \gamma_{th2}, a_2X < \gamma_{th1}\right)\right) f_x(x)dx$$

$$= \int_0^\infty P_r\left(\frac{a_1X}{a_2X+1} < \gamma_{th2}\right) f_x(x)dx$$

$$+ \int_0^\infty P_r\left(\frac{a_1X}{a_2X+1} \geq \gamma_{th2}, a_2X < \gamma_{th1}\right) f_x(x)dx$$

$$= \int_0^\infty \left[1 - P_r\left(\frac{a_1X}{a_2X+1} < \gamma_{th2}\right)\right] f_x(x)dx$$

$$+ \int_0^\infty \left[1 - P_r\left(\frac{a_1X}{a_2X+1} \geq \gamma_{th2}, a_2X < \gamma_{th1}\right)\right] f_x(x)dx$$

As can be observed from the proof above, if $\gamma_{th2} \geq \theta$ then $P_{out}^{A_1} = 1$. In the expression above,for the case $\gamma_{th2} < \theta$,let $\mu_a = \dfrac{\gamma_{th2}}{a_1 - a_2\gamma_{th2}}$, then $P_{out}^{A_1}$, can be expressed as

$$P_{out}^{A_1} = \int_0^\infty 1 - \int_{\mu_a}^\infty f_x(x)dx$$

$$+ \int_0^\infty \left[1 - P_r\left(\frac{a_1 X}{a_2 X + 1} < \gamma_{th2}\right) \times P_r\left(X \geq \frac{\gamma_{th1}}{a_2}\right)\right] f_x(x)dx$$

After some Algebraic steps, $P_{out}^{A_1}$ of closed form expression , can be obtained as presented n equation (44).

Proof From the equation (24) & (26), the outage Probability of user A_2, $P_{out}^{A_2}$ in equation (56) can be expressed as,

$$P_{out}^{A_2} = Pr\left(\max_{1\leq i\leq N_s} \min\left\{\frac{a_1 X_i}{a_2 X_i + 1}, \max\left\{\frac{b_1 Z_i}{b_2 Z_i + 1}, cX_iY\right\}\right\} < \gamma_{th2}\right)$$

As expressed the equation above include the same random variable Y,the event of the probability are not mutually exclusive, then conditioning on $Y = y$, $P_{out}^{A_2}$, can be expressed as,

$$P_{out}^{A_2} = \int_0^\infty Pr\left(\max_{1\leq i\leq N_s} \min\left\{\frac{a_1 X_i}{a_2 X_i + 1}, \max\left\{\frac{b_1 Z_i}{b_2 Z_i + 1}, cX_iy\right\}\right\} < \gamma_{th2}\right) f_y(y)dy$$

next, also conditioning on the $X_i = x$, then the OP of the cell-edge user $P_{out}^{A_2}$ can further expressed as,

$$P_{out}^{A_2} = \int_0^\infty \prod_{i=1}^{N_s} \int_0^\infty Pr\left(\min\left\{\frac{a_1 x}{a_2 x + 1}, \max\left\{\frac{b_1 Z_i}{b_2 Z_i + 1}, cX_iy\right\}\right\} < \gamma_{th2}\right) f_x(x)dx f_y(y)dy$$

$$= \int_0^\infty \prod_{i=1}^{N_s} \left[1 - \int_0^\infty Pr\left(\frac{a_1 x}{a_2 x + 1} \geq \gamma_{th2}\right) \times Pr\left(\max\left\{\frac{b_1 Z_i}{b_2 Z_i + 1}, cxy\right\} \geq \gamma_{th2}\right) f_x(x)dx\right] f_y(y)dy$$

from the equation above,we can observed if $\gamma_{th2} \geq \theta$ then $P_{out}^{A_2} = 1$. we also find the outage OP for the case $\gamma_{th2} < \theta$,let $\mu_a = \dfrac{\gamma_{th2}}{a_1 - a_2\gamma_{th2}}$, $P_{out}^{A_2}$ can be expressed as ,

$$P_{out}^{A_2} = \int_0^{\infty} \prod_{i=1}^{N_s} \left[1 - \int_{\mu_a}^{\infty} \left[1 - Pr\left(\max\left\{ \frac{b_1 Z_i}{b_2 Z_i + 1}, cxy \right\} < \gamma_{th2} \right) \right] f_x(x)dx \right] f_y(y)dy$$

$$= \int_0^{\infty} \prod_{i=1}^{N_s} \left[1 - e^{-\frac{\mu_a}{\lambda_{iA_1}}} + \int_{\mu_a}^{\infty} Pr\left(\frac{b_1 Z_i}{b_2 Z_i + 1} < \gamma_{th2} \right) \times Pr\left(x < \frac{\gamma_{th2}}{cy} \right) f_x(x)dx \right] f_y(y)dy$$

Since $\mu_a < x < \frac{\gamma_{th2}}{cy}$, we first consider the case $y < \frac{\gamma_{th2}}{c\mu_a}$, let $\mu_b = \frac{\gamma_{th2}}{b_1 - b_2\gamma_{th2}}$, and after some algebraic steps carried out, $P_{out}^{A_2}$ can be re-written as ,

$$P_{out}^{A_2} = \Xi_1 \triangleq \int_0^{\frac{\gamma_{th2}}{c\mu_a}} \prod_{i=1}^{N_s} \left[1 - e^{-\frac{\mu_a}{\lambda_{iA_1}}} + \int_{\mu_a}^{\frac{\gamma_{th2}}{cy}} \left(1 - e^{-\frac{\mu_b}{\lambda_{iA_2}}} \right) \frac{1}{\lambda_{iA_1}} e^{-\frac{x}{\lambda_{iA_1}}} dx \right] f_y(y)dy$$

$$= \int_0^{\frac{\gamma_{th2}}{c\mu_a}} \left[1 - e^{-\frac{\mu_a}{\lambda_{iA_1}}} + \left(1 - e^{-\frac{\mu_b}{\lambda_{iA_2}}} \right) \times \left(e^{-\frac{\mu_a}{\lambda_{iA_1}}} - e^{-\frac{\gamma_{th2}}{\lambda_{iA_1} cy}} \right) \right]_s^N \frac{1}{\lambda_{A_2}} e^{-\frac{y}{\lambda_{A_2}}} dy$$

We rely on the trinomial coefficient, in order to further simplify the integral equation expressed abov. i.e $(\alpha + \beta + \gamma)_s^N = \sum_{i,j,k}^{N_s = i+j+k} \begin{pmatrix} N_s \\ i, j, k \end{pmatrix} \alpha^i \beta^j \gamma^k$ as illustrated in [38], thus Ξ_1 can be expressed as,

$$\Xi_1 = \sum_{i,j,k}^{N_s = i+j+k} \begin{pmatrix} N_s \\ i, j, k \end{pmatrix} \left(1 - e^{-\frac{\mu_a}{\lambda_{iA_1}} - \frac{\mu_b}{\lambda_{iA_2}}} \right)^i (i)^j e^{-\frac{k\mu_b}{\lambda_{iA_2}}}$$

$$\times \frac{1}{\lambda_{A_2}} \underbrace{\int_0^{\frac{t}{c\mu_a}} e^{-\frac{y}{\lambda_{A_2}} - \frac{(j+k)\gamma_{th2}}{\lambda_{iA_1} cy}} dy}_{I_1}$$

The integral I_1 in equation above can be expressed as

$$I_1 = \int_0^\infty e^{-\frac{y}{\lambda_{A_2}} - \frac{(j+k)\gamma_{th2}}{\lambda_{iA_1} c y}} \, dy \; - \; \int_{\frac{\gamma_{th2}}{c\mu_a}}^\infty e^{-\frac{y}{\lambda_{A_2}} - \frac{(j+k)\gamma_{th2}}{\lambda_{iA_1} c y}} \, dy$$

From the relationship $\int_0^\infty e^{-\chi^x - \frac{\xi}{4x}} = \sqrt{\frac{\xi}{\chi}} K_1\left(\sqrt{\xi\chi}\right)$ [33. Eq.(3.324.1)],where $K_1(.)$ is the first order modified bessel function of the second kind [33.Eq.(8.407.1)] and depending the equation relation in [39], i.e $\int_\mu^\infty e^{-\chi^x - \frac{\xi}{x}} \approx \Omega\left(\mu, \chi, \xi\right)$, where $\Omega\left(\mu, \chi, \xi\right)$ is defined in (59) , I_1 can be obtained as

$$I_1 = \sqrt{\frac{4\xi}{\chi}} K_1\left(4\xi\chi\right) - \Omega\left(\frac{\gamma_{th2}}{c\mu_a}, \frac{1}{\lambda_{iA_1}}, \frac{(j+k)\gamma_{th2}}{\lambda_{iA_1} c}\right)$$

In the next case considering the $y \geq \frac{\gamma_{th2}}{c\mu_a}$, the outage probability of cell-edge user $P_{out}^{A_2}$ can be obtained as

$$P_{out}^{A_2} = \Xi_2 = \int_{\frac{\gamma_{th2}}{c\mu_a}}^\infty \prod_{i=1}^{N_s} \left(1 - e^{-\frac{\mu_a}{\lambda_{iA_1}}}\right) f_y(y) dy$$

$$= \int_{\frac{\gamma_{th2}}{c\mu_a}}^\infty \left(1 - e^{-\frac{\mu_a}{\lambda_{iA_1}}}\right)^{N_s} \frac{1}{\lambda_{A_2}} e^{-\frac{y}{\lambda_{A_2}}}$$

$$= \left(1 - e^{-\frac{\mu_a}{\lambda_{iA_1}}}\right)^{N_s} e^{-\frac{\gamma_{th2}}{\lambda_{A_2} c\mu_a}}$$

After some calculation and combining the equation $\Xi_1 \& \Xi_2$, the outage probability of cell-edge user A_2 in equation (58) can be obtained as expressed in proof above.