الجامعـــة الإسلاميـــة للتكنولوجيا
UNIVERSITE ISLAMIQUE DE TECHNOLOGIE
ISLAMIC UNIVERSITY OF TECHNOLOGY
DHAKA, BANGLADESH
ORGANISATION OF ISLAMIC COOPERATION

ANALYSIS OF FPS AND DPS IN NOMA FOR REAL-TIME AND NON-REAL TIME APPLICATIONS UNDER DIFFERENT MIMO TECHNIQUES

A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Bachelor of Science in Electrical and Electronic Engineering

Academic Year: 2020-21

Presented to the Academic Faculty by

Abdullah Alavi (170021088)
Moontasir Rafique (170021034)
Md. Aadnan Farhad (170021062)

Department of Electrical and Electronic Engineering
Islamic University of Technology (IUT)
Gazipur-1704, Bangladesh

April 2022

A dissertation on

ANALYSIS OF FPS AND DPS IN NOMA FOR REAL-TIME AND NON-REAL TIME APPLICATIONS UNDER DIFFERENT MIMO TECHNIQUES

Approved by

____

Prof. Dr. Md. Raqibul Islam
Head of the Department
Department of Electrical and Electronic Engineering
Islamic University of Technology (IUT)
Gazipur-1704, Bangladesh

Supervised by

____

Dr. Mohammad Tawhid Kawser
Professor
Department of Electrical and Electronic Engineering
Islamic University of Technology (IUT)
Gazipur-1704, Bangladesh

Declaration of Authorship

This is to certify that the work presented in this thesis paper is the outcome of research carried out by the candidates under the supervision of Dr. Mohammad Tawhid Kawser, Professor, Department of Electrical and Electronic Engineering (EEE), Islamic University of Technology (IUT). It is also declared that neither this thesis paper nor any part thereof has been submitted anywhere else for the reward of any degree or any judgement.

Authors

Abdullah Alavi	Moontasir Rafique	Md. Aadnan Farhad
ID: 170021088	**ID: 170021034**	**ID: 170021062**

Dedicated to
our family and friends whose unwavering love and support throughout our academic lives made this work possible.

Acknowledgments

All praises belong to almighty Allah (SWT), the most gracious, and the most merciful, who bestowed upon us the ability to reason and use our intellect to educate ourselves with the knowledge of the world. It is He who grants us the strength and patience to complete our thesis successfully.

Our journey towards the bachelor's degree would not have been possible without the support of many people. It is our great pleasure to take this opportunity to thank them for their endless guidance, support, and advice throughout this journey.

First and foremost, we wish to express our deepest gratitude to our academic and research supervisor, Professor Dr. Mohammad Tawhid Kawser, for his continuous assistance, inspiration, and invaluable suggestions from time to time. His words inspire us to be a genuine scientist and sparks within us a curiosity for the unknown. We could not have imagined a better mentor for our thesis work.

Secondly, we would like to thank all the faculty members of the EEE department for their continuous support and encouragement. They have provided a friendly environment for us to learn and grow.

Finally, our deepest gratitude goes to our family who always listened to our hardships and enchanted us with their delightful words. Last but not the least, we would like to thank our friends who accompanied us through this journey.

Table of Contents

Acronyms

NOMA	Non-Orthogonal Multiple Access
SWIPT	Simultaneous Wireless Information and Power Transfer
FPS	Fixed Power Allocation Scheme (FPS)
DPS	Dynamic Power Allocation Scheme
MIMO	Multiple-Input and Multiple-Output
IoT	Internet of Things
LTE	Long Term Evolution
OFDMA	Orthogonal Frequency Division Multiple Access
SIC	Successive Interference Cancellation
UE	User Equipment
D2D	Device-to-Device
BER	Bit Error Rate
FDMA	Frequency Division Multiple Access
TDMA	Time Division Multiple Access
WCDMA	Wideband Code Division Multiple Access
CDMA	Code Division Multiple Access

List of Figures

List of Tables

List of Symbols

α_n	*Power allocation coefficient for the near user*
α_f	*Power allocation coefficient for the far user*
R_{nu}	*Achievable rate in bps for the near user*
R_{fu}	*Achievable rate in bps for the far user*
σ^2	*Total noise in the system*
h_n	*Rayleigh fading coefficients for near user*
h_f	*Rayleigh fading coefficients for far user*
P	*Transmit power*
R^*	*Target rate*
S	*Signal-to-interference-plus-noise-ratio*
ω	*Amount of power harvested in the first slot*
Ω	*Remaining power harvesting fraction*
P_H	*Total harvested power*
ζ	*Power harvesting efficiency*

Abstract

In 5G wireless communication, Non-Orthogonal Multiple Access (NOMA) is a preferred approach for accommodating a large number of users while also providing significant capacity. The same data is sent to all users via a technique called cooperative relaying, and one user can relay data to another. Energy harvesting systems have been devised to provide enough power for users, with Simultaneous Wireless Information and Power Transfer (SWIPT) gaining popularity in recent years. A comparison of two different power allocation systems in NOMA, Fixed Power Allocation Scheme (FPS) and Dynamic Power Allocation Scheme (DPS), is presented in this work (DPS). The comparisons were developed based on how well they performed and what they were like while undergoing SWIPT. When compared to FPS, it has been discovered that employing DPS results in a nearly 25% boost in peak spectral efficiency. DPS, on the other hand, has a larger risk of outage since increased power causes the signal bandwidth to fall below the goal rate a substantial number of times. Conclusions were reached based on the comprehensive data as to which power allocation coefficient scheme will be employed in real-time and non-real-time communication standards. The findings imply that FPS is better for real-time communication, while DPS appears to work better for non-real-time communication. After incorporating MIMO techniques with NOMA, it was found that the system

performed better for far users consistently. And for near users, MIMO performed better in high power region.

Chapter 1
Introduction

With an ever-increasing number of mobile users, IoT devices, smart cities, and cloud computing, the demand for a faster, more versatile, and reliable wireless network is at an all-time high, and the dawn of the fourth industrial revolution has ushered in an era of massive avalanches of advancements and innovations in the field of technology. This necessitates effective administration and operation of wireless resources, and it is critical to ensure that customers have sufficient data rates for a given task. One of the goals of LTE network operators was to keep inter-cell interference to a minimum while keeping increased capacity.

As a result, Orthogonal Frequency Division Multiple Access (OFDMA) was developed, which assured that users' cellular connectivity was orthogonal to one another. In other words, no two users were given the same amount of wireless bandwidth. However, this resulted in device capacity being constrained. As a result, in today's world, where the needs of mobile users are growing by the day, it became clear that a new scheme would be required, one with appropriate spectral efficiency and number of users supported. As a result, in 5G, a new concept called Non-Orthogonal Multiple Access (NOMA) was created. Unlike OFDMA, users were not required to maintain orthogonality; instead, the same resource was allocated to all users, and it was found that both spectral efficiency and the number of supported devices were higher in the case of NOMA [2]. This could be important in future communication standards. NOMA is built on a technology that allows users to share the same resource under specified constraints [3]. It uses a technique known as superposition coding [4] during transmission, and a technique known as Successive Interference Cancellation (SIC) [5] during reception to decode its own signal from the original. The users are numbered according to their distance from the eNodeB. The greater the distance between the user and the server, the more power is assigned to it. Naturally, the remote user is given more power than the near user. This is referred to as power allocation [6], and the above-mentioned power allocation technique is referred to as the Fixed Power Allocation Scheme (FPS) algorithm [7]. The power allocation coefficients do not alter over time in this case. The Dynamic Power Allocation Scheme (DPS) [8], on the other hand, permits the power assigning coefficients to alter over time.

If there is an obstruction between the eNodeB and the far user, NOMA allows the close user to relay the data to the far user. Cooperative relaying is the name for this method. This can only happen in NOMA since the data of the far user is carried by the near user. In comparison to the eNodeB, the near user is a simple user equipment (UE) with low power supply. As a result, given the UE's short battery life, transmitting information to the far user is an energy-intensive procedure for the close user. A technology known as wireless energy harvesting is employed to solve this problem.

The UE divides the incoming signal power into two parts, one for energy harvesting and the other for data decoding, in this technique. Time switching and energy splitting are the two most common techniques to divide the process. Energy splitting protocols, notably Simultaneous Wireless Information and Power Transfer (SWIPT) [9], are discussed in this study. The receiver harvests energy from a portion of the received signal and uses the remaining power to decode the incoming signal. In the same amount of time, the harvesting and decoding processes are accomplished. The gathered energy is then used to send the signal to the far user in the next time frame.

The algorithm is such that the decoding process yields the data encoded with high power coefficient first. And consecutively it decodes the data with lowest power at the end. Obviously, users situated far away from the eNodeB will require more power than users who are close to the Base Station. So, the near user has to decode the data allocated for far users first then for itself. And after decoding other user's data the near user can relay this information to them. Thus what happens is that the far users gain multiple links containing their allocated data through this process. One from the eNodeB and others from the near users. This ensures low outage.

NOMA incorporated with MIMO technology improves the result. The term 'MIMO' refers to a technique for sending and receiving multiple data signals over the same radio channel at the same time by taking advantage of multipath propagation.

The cellular user will receive the total of the signal from the base station and the signal from the D2D transmitter for downlink MIMO-NOMA transmission. The D2D receiver will receive both the D2D transmitted signal and the interference signal from other D2D users in addition to the D2D transmitted signal. A 2×2 downlink MIMO upgrades the system and yields better results. It decreases the Bit Error Rate (BER); thus diversity gain can be used. For both Far and Near users, MIMO performs better than single antenna configuration

1.1 Evolution of Wireless Systems and Standards

Although the study is focused on the application of NOMA in 5G frequency spectrums, it is always helpful to have some preliminary knowledge on the evolution of wireless networks throughout the decades of development. This section will be aimed to discuss briefly on the existing major technologies that are in development or have been developed in the field of cellular radio networks.

1.1.1 First Generation (1G) Cellular Networks

The first generation (1G) of cellular networks were developed in the 1970s. These networks used frequencies in the 800-900 MHz band. Frequency division multiple access (FDMA) and analogue frequency modulation were implemented by these early generation systems. In FDMA, there is a single traffic channel per carrier.

This means when a user is in a call, two channels or carriers are allocated, one for the forward (from base station to mobile) and one for the backward (from mobile to base station). Thus, a duplexer is required to isolate the forward and backward channels, otherwise the radio transceiver will end up jamming itself. In the 1980s, many countries deployed their own 1G systems. The first analogue cellular system was released in 1979 and was known as Nippon Telephone and Telegraph (NTT). Then, in 1981, the Nordic Mobile Telephone (NMT) 900 system was introduced by Ericsson Radio Systems AB. AT&T followed in 1983 with the introduction of Advanced Mobile Phone Service (AMPS). Many other technologies were developed during that time. Table 1.1 illustrates the different parameters by the different technologies.

Table 1.1 Parameters of different 1G technologies.

<table>
<tr><th>Feature</th><th>NTT</th><th>NMT</th><th>AMPS</th></tr>
<tr><td rowspan="3">Frequency band RL/FL (MHz)</td><td>925-940/
870-885</td><td rowspan="3">890-915/917-950</td><td rowspan="3">824-849/869-894</td></tr>
<tr><td>915-918/
860-863.5</td></tr>
<tr><td>922-925/
867-870</td></tr>
<tr><td rowspan="3">Carrier spacing (KHz)</td><td>25/6.25</td><td rowspan="3">12.5</td><td rowspan="3">30</td></tr>
<tr><td>6.25</td></tr>
<tr><td>6.25</td></tr>
<tr><td rowspan="3">Number of channels</td><td>600/2400</td><td rowspan="3">1999</td><td rowspan="3">832</td></tr>
<tr><td>560</td></tr>
<tr><td>280</td></tr>
<tr><td>Modulation</td><td>Analogue FM</td><td>Analogue FM</td><td>Analogue FM</td></tr>
<tr><td colspan="4">RL = reverse link, FL = forward link</td></tr>
</table>

1.1.2 Second Generation (2G) Cellular Networks

The development of second generation (2G) cellular systems began in the late 1980s and the early 1990s. It was also quickly adopted throughout the world. Different countries adopted different technologies. European countries adopted GSM/ DCS1800/ PCS1900 while the USA adopted the IS-54/136 and IS-95 standards. Japan, on the other hand, went with the Personal Digital Cellular (PDC) standard. Table 1.2 summarises the specifications for these technologies.

Table 1.2 Parameters of different 2G technologies.

Feature	**GSM/DCS1800/PCS1900**	**IS-54/136**	**PDC**	**IS-95**
Frequency band RL/FL (MHz)	GSM: 890-915/ 935-960	824-829/ 869-894	810-826/ 940-956	824-829/ 869-894
	DCS1800: 1710-1785/ 1805-1880	1930-1990/ 1850-1910	1429-1453/ 1477-1501	1930-1990/ 1850-1910
	PCS1900: 1930-1990/ 1850-1910			
Multiple access	FDMA/TDMA	FDMA/TDMA	FDMA/TDMA	FDMA/CDMA
Carrier spacing (KHz)	200	30	25	1250
Modulation	GMSK	π/4-DQPSK	π/4-DQPSK	QPSK
Slots/Frame	8/16	3/6	3/6	1
Handoff	Hard	Hard	Hard	Soft

1.1.3 Third Generation (3G) Cellular Networks

The work on third generation (3G) networks began in 1992 by two groups, namely International Telecommunications Union Radio Communications (ITU-R) and Telecommunications (ITU-T). 3G was expected to operate in the 1885-2200 MHz band. Although no clear requirements were defined for the 3G equipment or providers at the beginning, it was expected that a minimum downlink peak data rate of 2 Megabit/s for walking users, and 384 kbit/s for moving vehicles would be provided. The two most commonly used standards in 3G are cdma2000 (developed by 3GPP2) and Wideband Code Division Multiple Access (WCDMA) (developed by 3GPP). Table 1.3 summarises the parameters of the two standards.

Table 1.3 Parameters of different 3G technologies.

Feature	**WCDMA**	**cdma2000**
Multiple access	DS-CDMA	DS-CDMA
Chip rate	3.84	1.2288
Carrier spacing (MHz)	5	1.25
Frame length (ms)	10	5/20
Modulation	FL: QPSK RL: BPSK	FL: BPSK/QPSK RL: BPSK
Spreading	FL: BPSK RL: QPSK	Complex

1.1.4 Fourth Generation (4G) Cellular Networks

Fourth generation (4G) networks required peak data rates of 1 Gbps in stationary or low mobility scenarios and 100 Mbps in fast moving scenarios. Other requirements included smooth handoff across heterogeneous networks, seamless connectivity across multiple networks, and high quality of service for next generation multimedia. The technology also needed to be backwards compatible with the existing wireless standards. Along with that, 4G is also required to have a flexible channel bandwidth, from 5 and 20 MHz (optionally up to 40 MHz). Two commonly employed 4G systems that have been standardised and deployed commercially are Long Term Evolution (LTE) (standardised by 3GPP) and IEEE 802.16e (standardised by the IEEE). 4G cellular networks use orthogonal frequency division multiple access (OFDMA) and single carrier frequency division multiple access (SC-FDMA) for allocating the resources. Later versions include Long Term Evolution (LTE-A) and IEEE 802-2012. Table 1.3 summarises the parameters of LTE and LTE-A.

Table 1.4 Parameters of different 4G technologies.

Feature	**LTE**	**LTE-A**
Multiple access	FL: OFDMA RL: SC-FDMA	FL: OFDMA RL: Single carrier property
Carrier spacing (MHz)	1, 4, 3, 5, 10, 15, 20	N/A
Duplexing	FDD, TDD, Half-duplex FDD	FDD, TDD, Half-duplex FDD

Modulation	FL: QPSK, 16-QAM, 64-QAM RL: QPSK, 16-QAM, 64-QAM	FL: QPSK, 16-QAM, 64-QAM, 256-QAM RL: QPSK, 16-QAM, 64-QAM
MIMO	FL: 2×2, 4×2, 4×4 RL: 1×2, 1×4	FL: up to 8×8 RL: up to 4×4
Peak data rate	FL: 150 Mbps RL: 75 Mbps	FL: 3Gbps
Latency	≈10	<5

1.1.5 Fifth Generation (5G) Cellular Networks

Fifth generation (5G) networks are being currently researched and deployed in various countries around the world. The goals and requirements of 5G are varied across the spectrum. They range from Internet of Things (IoT) to extremely high capacity networks for the growing population. The technology is expected to connect at least 100 billion devices with extremely low data-rate and machine-to-machine communication. The latency is expected to be less than 1ms and the data rate is expected to peak at 1 Gbps. All these requirements will be used to fulfil the requirements of industrial automation, self-driving cars, virtual reality, streaming and many other applications.

1.2 Evolution of Multiple Access Methods

One of the goals of cellular communication is to make it accessible to the general population. This means that the network should be able to accommodate multiple users to communicate with each other. Thus, various resource sharing techniques have been developed throughout the years of development. The latest development is NOMA which has been discussed before. This section will discuss the various multiple access methods that have been implemented in the past and are currently in use today.

1.2.1 Frequency Division Multiple Access (FDMA)

The idea behind FDMA is to divide the frequencies into different bands and allocate the different frequencies to different users. Each user has a separate frequency band that will be occupied by that particular user during the time of use. The bandwidth of each band ranges from 30 KHz to 200 KHz. Figure 1.1 visualizes the concept of FDMA.

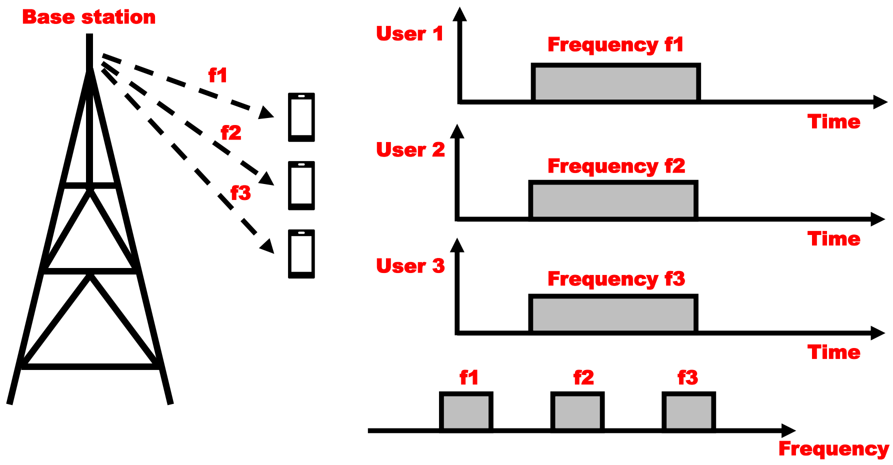

Figure 1.1 FDMA working principle.

1.2.2 Time Division Multiple Access (TDMA)

In TDMA, the idea is to have a single frequency band where the users are allocated the resources in different time slots. Here, the base station transmits data of user 1 in time slot 1 of the timeframe and data of user 2 in time slot 2 of the timeframe and so on. Figure 1.2 visualizes the concept of TDMA.

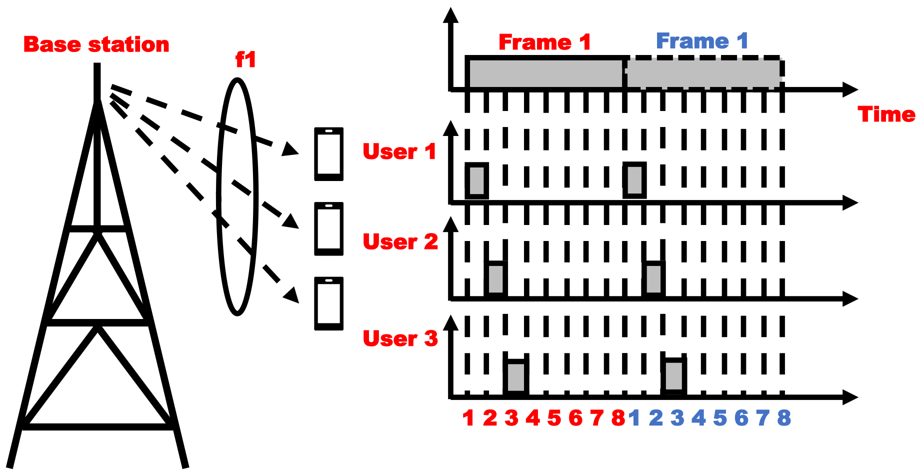

Figure 1.2 FDMA working principle.

1.2.3 Code Division Multiple Access (CDMA)

In CDMA, the users are assigned different codes. The users share the same frequency channel but have to decode the overall signal using the codes assigned to them. The different codes decode the main signal into different messages for the respective users. The frequency channel is wide in CDMA, from 1.25 MHz to 5 MHz. Figure 1.3 visualizes the concept of CDMA.

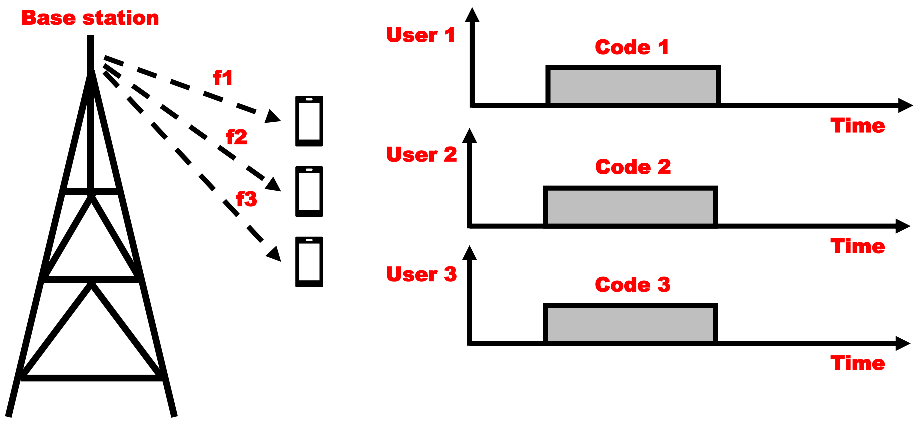

Figure 1.3 CDMA working principle.

1.2.4 Orthogonal Frequency Division Multiple Access (OFDMA)

In OFDMA, the wireless resources or packets are divided into different chunks or packets and sent across different frequencies that are orthogonal to each other. Orthogonal means that the frequencies do not interfere with each other. This allows different packets to be sent efficiently across the available frequencies and time slots.

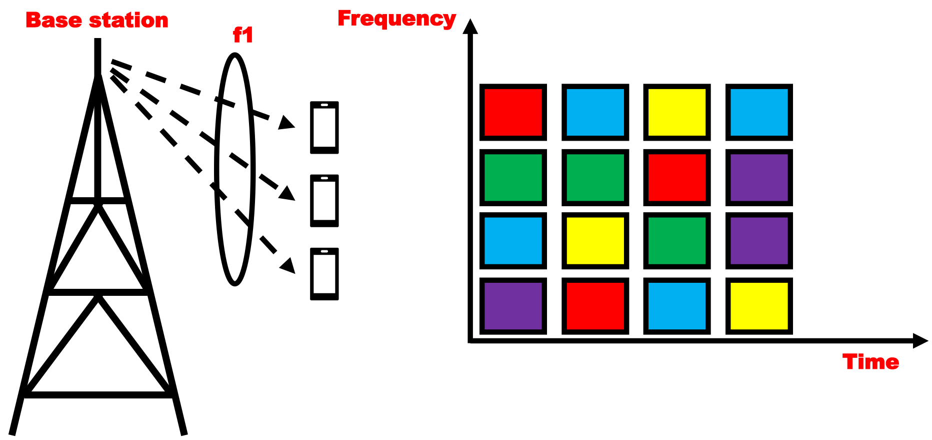

Figure 1.4 OFDMA working principle.

Chapter 2
System Model

A network model is considered consisting of two user equipment (UE) and one eNodeB. The channel considered here is a Rayleigh fading channel. A barrier has been placed between the far user and the eNodeB which creates hindrance to direct information transfer, resulting in cooperative relaying procedures being undertaken. The distance from the far user to the eNodeB has been taken exactly double of the distance from the near user to eNodeB for ease of experimenting. Fig. 2.1 illustrates the scenario which the simulation tries to emulate. In NOMA, different power levels are allocated to the users corresponding to their distances from the eNodeB. This power allocation can be done in a number of manners. In this paper, Fixed Power Allocation (FPS) scheme and Dynamic Power Allocation (DPS) scheme.

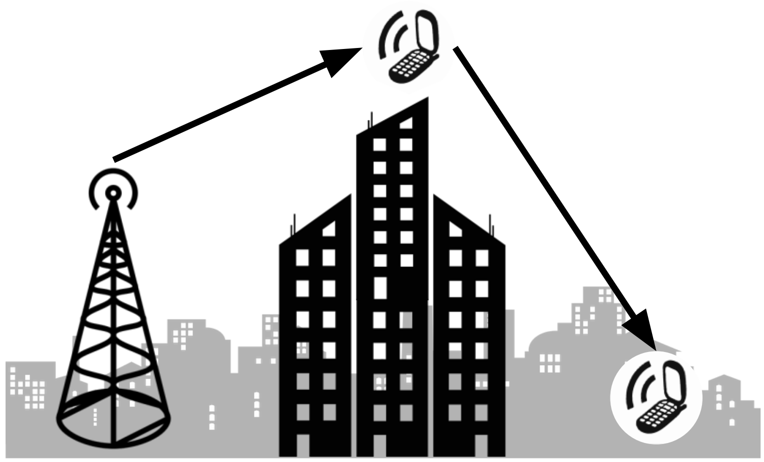

Fig. 2.1 Proposed Network Model comprising of two user equipment and one eNodeB.

2.1 Fixed Power Allocation Scheme (FPS)

In this process, power allocation coefficients were fixed throughout the time. That is, they remained time invariant. The near user remained closer to the eNodeB compared to the far user and thus it has a better signal coming from the eNodeB. For this reason, the power allocation coefficient that is lower than the far user is allotted for the near user. The conditions for fixed power allocation are stated below:

$$\alpha_n = 1 - \alpha_f \quad (1)$$

$$\alpha_f > \alpha_n \quad (2)$$

Where, α_f signifies the power allocation coefficient for the far user; α_n signifies the power allocation coefficient for the near user [10]. The achievable rate in bps for both near user and far user is shown below,

$$R_{fu} = \log_2(1 + \frac{|h_f|^2 P\alpha_f}{|h_f|^2 P\alpha_n + \sigma^2}) \tag{3}$$

$$R_{nu} = \log_2(1 + \frac{|h_n|^2 P\alpha_n}{\sigma^2}) \tag{4}$$

Where, R_{nu} and R_{fu} signifies the achievable rate in bps for the near and far user respectively. The term σ^2 signifies the total noise in the system. Again, h_n and h_f respectively denote the Rayleigh fading coefficients.

2.2 Dynamic Power Allocation Scheme (DPS)

Dynamic Power allocation or Fair power allocation is a very effective form of power allocation where the coefficients are dynamic [11]. In case of FPS, the coefficients remain the same throughout the time. Because of this constraint, when the user is in a mobile state, there arises difficulty in assessing the SIC procedure, as mobility greatly puts an effect on interference as well as the channel quality. Thus, DPS allows flexibility in this regard where the values of coefficients are not limited to a certain value. In order to find the coefficients, we have to set a rate target for the UE to achieve, according to which the powers would be allocated. A target SINR value and rate value should be set in order to find the dynamic coefficients. The goal should be to keep the rate of the far user always higher than the target rate. That is,

$$R_{fu} > R^* \tag{5}$$

For allocating power, equation 1 and 2 has to be true. The target SINR (Signal-to-Interference-plus-Noise-ratio) rate, shown by *S*, where,

$$S = 2^{R^*} - 1 \tag{6}$$

For DPS, the near and far coefficients are shown below,

$$\alpha_f = \frac{S\left(\left|h_f\right|^2 P + \sigma^2\right)}{\left|h_f\right|^2 P(1 + S)} \tag{7}$$

$$\alpha_n = 1 - \alpha_f \tag{8}$$

Where, h_f is the Rayleigh fading coefficient of the far channel, *S* is the Target SINR rate, and σ^2 denoting the noise power. *P* is the transmit power.

2.3 Cooperative Relaying

In NOMA, the eNodeB sends the same coded signal for all the receivers. That is, irrespective of the number of users, the eNodeB sends the same data differentiated by superposition coding to all the user equipment. The user nearer to the base station will have the information for the far user as well. The near user obtains its dedicated information by decoding the data of the far user. This provides an added advantage to

NOMA, that is; in instances where the far user doesn't have a proper connection with the eNodeB, the near user has the capability to relay the information to the far user. This procedure is known as Cooperative Relaying [12]. By this process, more than one connection can be established between the eNodeB and the user equipment. For a two user NOMA scheme, a comparison is shown for the far user where cooperative relay procedure has been used in terms of outage probability and the total transmitted power.

In Fig. 2.2, comparison has been made between far users with cooperative relay and without cooperative relay phenomenon. It is evident from the graph that outage is lower when cooperative relay procedure is used.

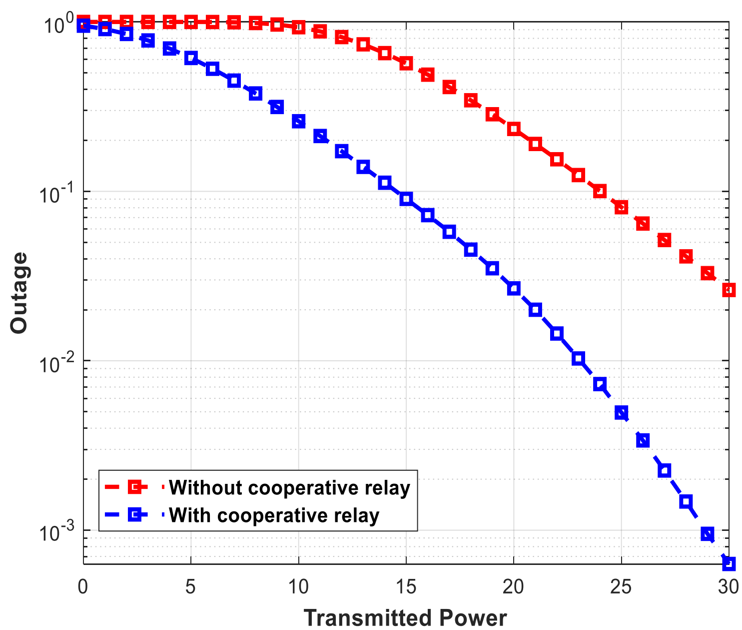

Fig. 2.2 Outage vs Transmitted power for the far user with and without cooperative relay.

2.4 Radio Frequency Harvesting

There are different types of radio frequency harvesting procedures. In this paper, focus has been given to SWIPT (Simultaneous Wireless Information and Power Transfer) [13]. In a Rayleigh channel, there may lie barriers in between the base station and the far user. In a scenario like this where the far user has poor connection from the eNodeB, the near user may relay the information to the far user. This process is known as cooperative relaying. The method used in this paper is SWIPT; where a fraction of the received power is decoded, and the other part is harvested by the user [14]. For SWIPT, two time slots are allotted. The user who is near to the eNodeB, harvests some amount of power. And in the succeeding time slot, the rest of the power obtained is used for information decoding [15]. If the near user harvests ω amount of power in the first slot, for decoding information, the remaining fraction can be used, where Ω signifies the remaining power harvesting fraction [16].

$$\Omega = 1 - \omega \tag{9}$$

If P_H is the total harvested power, it can be written according to the following equation:

$$P_H = P|h_n|^2\zeta\omega \tag{10}$$

Where, ζ is the power harvesting efficiency, ω is the amount of power harvested in the first slot.

2.5 Massive Input Massive Output (MIMO)

MIMO stands for multiple input, multiple output in wireless communications, and it is an antenna technology that makes use of multiple antennas at both the transmitter and receiver ends. By combining the antennas at either end of the communication circuit, data can flow along numerous signal paths simultaneously, reducing errors, increasing data speed, and increasing radio transmission capacity. The transmission's signal-to-noise ratio and error rate are both improved by sending out many copies of the same signal, each with a higher chance of reaching the receiving antenna unaffected by fading. By expanding the capacity of radio frequency (RF) networks, MIMO increases wireless connectivity. As a result, there is less traffic.

2.5.1 Significance of MIMO

The Third Generation Partnership Project (3GPP) integrated MIMO into the Mobile Broadband Standard with Release 8 of the Mobile Broadband Standard, which was the first release to support it. For Wi-Fi networks as well as cellular fourth-generation (4G) Long-Term Evolution (LTE) and fifth-generation (5G) technologies, MIMO technology is used in a range of applications, including law enforcement, broadcast television production, government, and military. Furthermore, it is suitable in wireless local area networks (WLANs), and it is supported by all wireless products that comply with the IEEE 802.11n specification.

A common application of MIMO is for high-bandwidth communications where it is vital that there be no interference from microwave or radio frequency (RF) equipment to be avoided. The usage of satellite communications is common among first responders in the case of a disaster or power failure, or when a cell network is overloaded. This is because they cannot constantly rely on cell networks.

2.5.2 MIMO in LTE

MIMO is one of the most widely used types of wireless communication, and it was essential in the adoption of LTE as well as the wireless broadband technology standard Worldwide Interoperability for Microwave Access (WiMAX). LTE utilizes MIMO and OFDM to increase speeds to 100 Mbps and beyond. These rates are more than twice as fast as the previous 802.11a Wi-Fi standard, which was introduced in 2007. It is utilized in LTE for transmission diversity, spatial multiplexing (which allows for the transmission of distinct channels that are physically separated), and for both single-user and multiuser networks.

MIMO technology in LTE provides for more dependable data transfer while also boosting data throughput in the same time frame. Immediately prior to transmission, it separates the data into distinct streams, which are then transmitted one after the other. Data and reference signals are delivered over the air to a receiver that is already familiar with the signals, which assists the receiver in estimating the channel length and quality of the signal.

2.5.2 MIMO and 5G systems

As the wireless industry seeks to handle more antennas, networks, and devices, MIMO continues to update and develop through its usage in massive new applications, such as those for autonomous vehicles. Massive MIMO and 5G systems are being developed. For example, the introduction of 5G technology, which is presently happening, is one of the most prominent manifestations of this trend.

These massive 5G MIMO systems employ a large number of small antennas to increase the amount of bandwidth available to users — rather than just transmission speeds, as is the case with third-generation (3G) and fourth-generation (4G) cellular technology — and to accommodate more users on a single antenna, as opposed to previous generations of cellular technology. To accommodate numerous devices, 5G massive MIMO use a new arrangement known as time division duplex (TDD) rather than the frequency division duplex (FDD) approach utilized by 4G MIMO to handle many devices (TDD). Several advantages may be seen when comparing this to FDD.
MIMO, in its different configurations, provides a number of advantages over advanced antenna technologies such as MISO and SIMO, including the following:

- MIMO allows for more powerful transmissions. It bounces and reflects signals, allowing a user device to operate without having to be in direct line of sight.
- Video and other big-scale content can be transmitted in massive volumes across a network. Because of the higher throughput provided by MIMO, this content is delivered more quickly.
- Many data streams help to improve the visual and audio quality of a presentation. They also reduce the likelihood of data packets being lost.

Chapter 3
Simulation and Result Analysis

3.1 Single Transmitter and Receiver

The simulation was carried out using log normal shadowing as the path loss model. Since there is no direct line of sight signal, particularly between the far user and the eNodeB, Rayleigh fading channel has been used. For this particular simulation, the path loss exponent was set to 4. The bandwidth was set to 10 GHz with a target spectral efficiency of 1 bps/Hz. As we are considering a simple case of a near user with a far user, the UE number was set to 2. The power allocation coefficient for the near user was set to 0.2 while the far user's was set to 0.8. In addition, the power harvesting factor for the near user was set to 0.7. The transmission power from the base station was repeated from 0 to 30 dBm with 5 dBm increments. The simulation was modeled to keep the far user behind an obstacle. The distance from the base station to the near user and the far user was 10 and 20 meters, respectively. Table 3.1 summarizes the simulation parameters that were used for this simulation.

Table 3.1 Simulation Parameters.

Parameters of Simulation	
Bandwidth	10 GHz
Target Spectral Efficiency	1 bps/Hz
Number of UE	2

BS power	(5, 10, 15, 20, 25, 30) dbm
Path loss exponent	4
Fixed power allocation coefficient of near user	0.2
Fixed power allocation coefficient of far user	0.8
Near user power harvesting factor	0.7
Near user from eNodeB distance	10 m
Far user from eNodeB distance	20 m

In this section, different results based on the simulation model have been analysed. In Fig. 3, we can see the average spectral efficiency of the near and far user in terms of the transmitted power level for both DPS (Dynamic power allocation scheme) and FPS (Fixed power allocation scheme). From Fig. 3, it is evident that the far users maintain a similar trend in both DPS and FPS. That is, the average spectral efficiency remains unchanged for the far user in both dynamic power allocation and fixed power allocation schemes. But, in the case of a nearby user, it can be seen that they vary hugely. In low power level (from the graph, 0-10 dBm), DPS gives better spectral efficiency than FPS. This trend remains the same up to around 12 dBm for DPS, after which it starts to deteriorate. After a specific power level (around 20 dBm from the graph), FPS provides better spectral efficiency than DPS and keeps on increasing. So, for a low power level, it is evident that DPS provides better spectral efficiency than FPS. In terms of percentage, it is seen that for 0-12 dBm region transmit power, DPS provides about 150% of higher bandwidth than FPS. In the middle region

(22-30 dBm in the graph), FPS leads DPS in terms of bandwidth. Finally, DPS becomes higher than FPS again in high power regions (greater than 30 dBm).

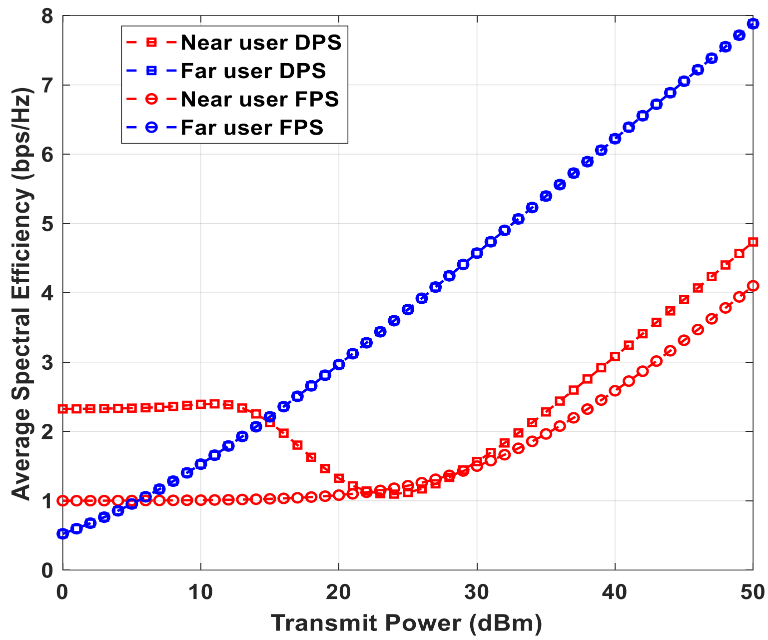

Fig. 3.1 Average Spectral Efficiency vs Transmitted Power for both DPS and FPS.

In Fig. 3.2, a comparative analysis between power outage and transmitted power has been made. It is seen that, for outage too, the far user maintains a similar fashion for both FPS and DPS. That is, its trend remains similar, it decreases as the transmitted power is increased.

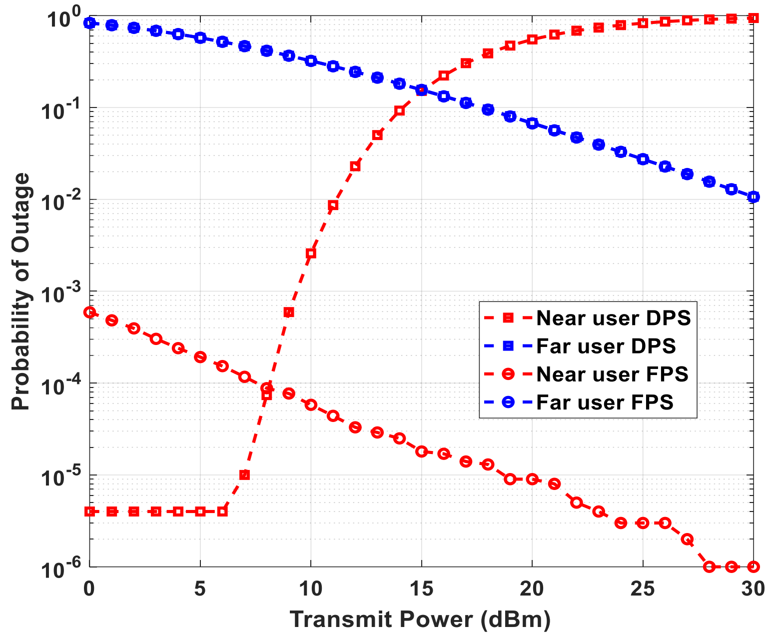

Fig. 3.2 Outage vs Transmitted Power for both DPS and FPS.

So, it can be understood that the power allocation scheme does not have any significant effect on the far user both in terms of spectral efficiency and outage. In the case of nearby users, we can see they vary hugely. For DPS, the near user outage keeps on increasing as the power is increased to its maximum value; that is the outage increases as power is increased continuously after maintaining a constant value (up to 6 dBm from the graph). And, in case of FPS, the near user has higher outage than the far user in low power level (0- 6 dBm from the graph). But as the power is increased, the outage decreases and reaches a minimum value when the power is the maximum. It can be inferred that for lower power level, near users have higher outage in FPS. As we increase the power level, the outage of FPS decreases in comparison to DPS.

In Fig. 3.3 and Fig. 3.4, comparison has been made between the average spectral efficiency and Channel Realization Instances between the near and far user for both DPS and FPS. A reference rate has been set (1bps/Hz).

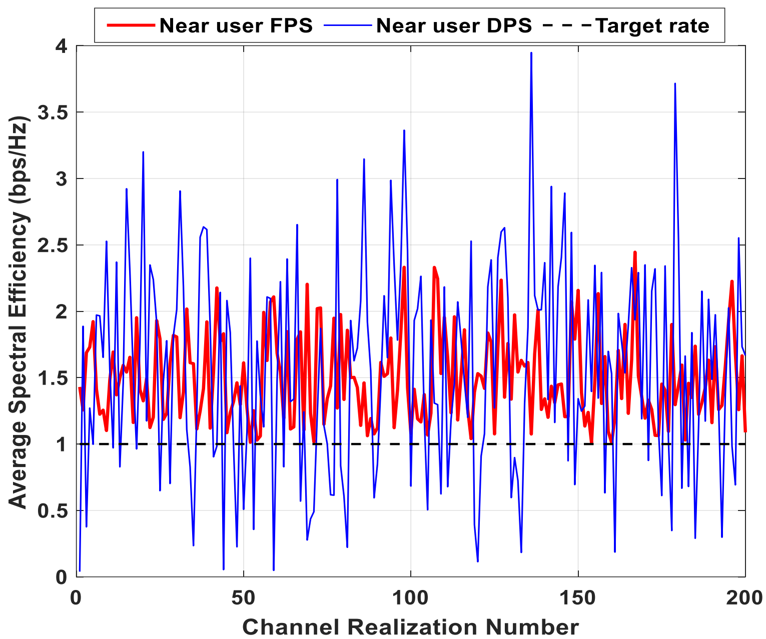

Fig. 3.3 Average Spectral Efficiency vs Channel Realization Number for Near User.

For near user FPS, in Fig. 3.3, the spectral efficiency always remains above the reference rate that had been set earlier (in the graph, coloured in red). And in case of DPS, it can be seen that the rate falls drastically below the average rate for some channel realization instances. But it is also evident that the highest spectral efficiency is obtained for DPS scenario (in the graph, coloured in blue) which is almost greater than 3 bps/Hz compared to 2.5 bps/Hz for FPS (almost 25% increase in Peak Value).

That is, on average, FPS has higher average spectral efficiency peaks than DPS, even though it falls below the reference rate several times. This signifies that there exists severe outage in DPS when compared to FPS scenario.

In Fig. 3.4, in the case of far user, it is apparent that the average spectral efficiency of both DPS and FPS bear a similar trend in terms of the channel realization number. Moreover, they exhibit the same property throughout the graph while decreasing below the target rate only once for both DPS and FPS. Thus, it shows that for the far user, DPS and FPS bear similar characteristics irrespective of the power allocation scheme chosen.

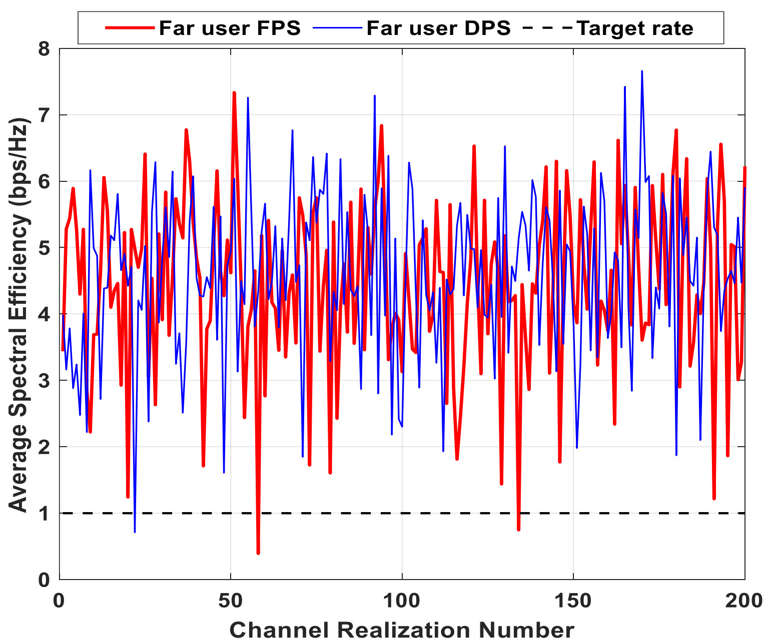

Fig. 3.4 Average Spectral Efficiency vs Channel Realization Number for Near User.

3.2 Multiple Transmitters and Receivers

This section discusses when multiple transmitters and receivers are incorporated into the model (essentially MIMO). Here, MIMO is integrated with NOMA in order to ascertain the properties exhibited by FPS and DPS. MIMO, which uses multiple channels to overcome noise and interference, shows high improvement in throughput and power outage. This results in a higher spectral efficiency. For this study, a 2×2 downlink MIMO system is considered. The distances from the MIMO transmitter are kept the same as the previous work using single transmitter and receiver (d1 and d2). MIMO is used here to decrease the bit error rate (BER). Thus, diversity gain will be used for this. Fig. 3.5 illustrates the configuration of 2×2 MIMO. Rayleigh fading channel serves the purpose of modeling a non-line-of-sight transmission. In this case, the transmission occurs only by reflections since a direct path between two devices does not exist. Here, h_{11}, h_{21}, h_{12} and h_{22} are the four separate distinctive channels for the planned simulation.

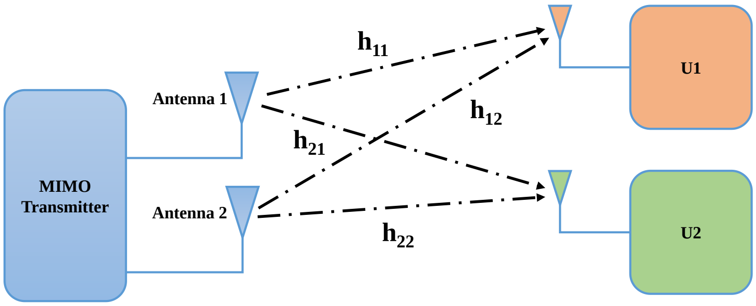

Fig. 3.5 A 2×2 based MIMO.

Fig. 3.6 illustrates the average spectral efficiency vs transmitted power for both near and far user in DPS. As can be observed, for the near users, in low power region (upto 10 dBm) both MIMO and single antenna configuration performs equally in terms of average spectral efficiency. However, in high power region, MIMO performs better than single antenna configuration.

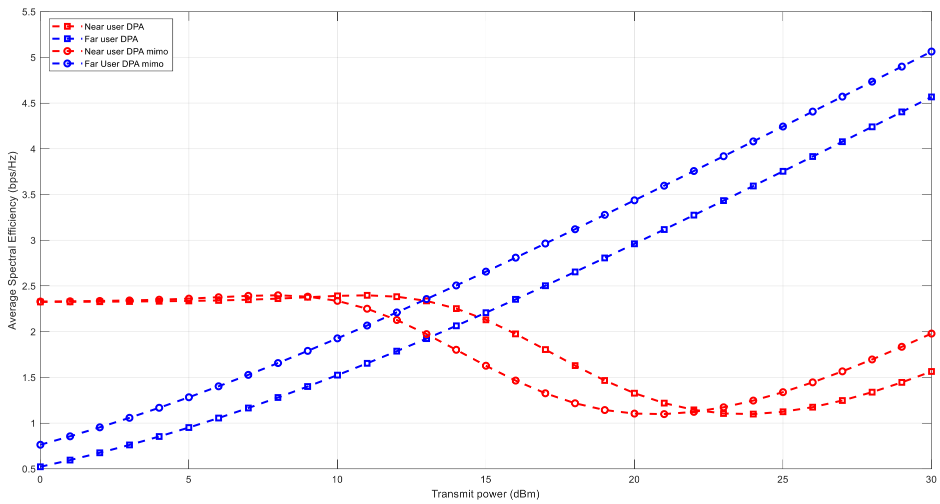

Fig. 3.6 Average spectral efficiency vs transmitted power for both near and far user.

Fig 3.7 illustrates the outage probability vs transmitted power for both near and far user in DPS. From the plots, power outage is same for both MIMO and single antenna configuration in high power region. But in middle-low region, outage is higher in case of MIMO. It is also observed that for far users, MIMO performs better than single antenna configuration consistently .

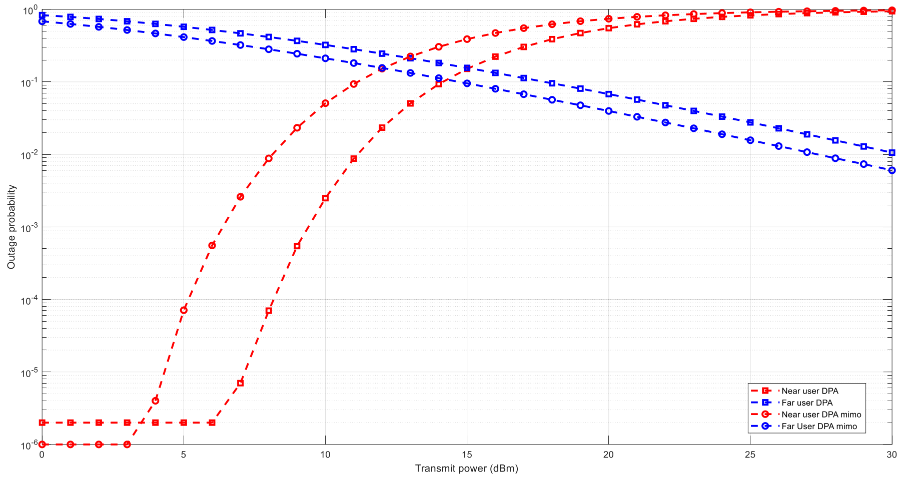

Fig. 3.7 Outage vs transmitted power for both near and far user.

Chapter 4
Conclusion

In this paper, fixed and dynamic power allocation algorithms were compared in SWIPT method. It was seen that even though as per our network model, the far user exhibits similar characteristics for both FPS and DPS method, the near user shows different properties for each. In FPS, the near user never goes below the targeted bandwidth, as a result, proper signal quality is always ensured. But, in the case of DPS, it has been observed that the signal falls below the target rate a number of times, inferring that the target bandwidth is not always maintained in DPS. Moreover, it has also been seen that the peak average spectral efficiency in FPS is almost 25% more than that of DPS; establishing the fact that it provides higher bandwidth compared to DPS in average. Furthermore, it is seen that for low power, DPS provides substantially higher bandwidth compared to FPS. In high power range, DPS is again better in terms of spectral efficiency compared to FPS for the near user. Thus, based on the results, it can be suggested that for real time communication, FPS appears to be more suitable than DPS. In contrast, for non-real time standards, DPS appears to work better than FPS.

For the case of MIMO, two conclusions can be observed. The first is for low power near users, where either MIMO configuration or single antenna configuration can be used as both have similar performance. Cost management is possible. In contrast, for high power near users, MIMO performs better than single antenna device in terms of spectral efficiency, therefore MIMO should be used.

Chapter 5
Application and Discussion

Communication standards can be divided into two types based on time constraints, namely real time, and non-real time. In real time processes, it is of absolute necessity that the target rate is met, i.e., the data rate should always be greater than the threshold value to maintain good quality. In contrast, for non-real time standards, it is not mandatory for the data rate to meet the target demand, rather, how high the data rate is what matters significantly. These kinds of processes do not occur instantly like real time as there are no time constraints involved in this procedure. From the results obtained, it is seen that the far user exhibits similar property both in FPS and DPS scenarios. However, speaking of the near user, they results vary quite considerably. In DPS, the data rate will go below the target rate a number of times, thus establishing the fact that it cannot be used in the case of real time communication. Whereas, in FPS, it can be seen that it always remains above the target rate, suggesting that real time communication can be supported using this scheme. Additionally, the peak average spectral efficiency of DPS is almost 25% greater on average than FPS. Thus, it can be said that for non-real time communication standards where higher data rate is preferred over time constraints, DPS appears to be more suitable compared to FPS.

References

[1] H. Yin and S. Alamouti, "OFDMA: A broadband wireless access technology," 2006 IEEE Sarnoff Symp., 2006, doi: 10.1109/SARNOF.2006.4534773.

[2] L. Dai, B. Wang, Y. Yuan, S. Han, C. L. I, and Z. Wang, "Non-orthogonal multiple access for 5G: Solutions, challenges, opportunities, and future research trends," IEEE Commun. Mag., vol. 53, no. 9, pp. 74–81, 2015, doi: 10.1109/MCOM.2015.7263349.

[3] R. Razavi, M. Dianati, and M. A. Imran, "Non-Orthogonal Multiple Access (NOMA) for future radio access," 5G Mob. Commun., pp. 135–163, 2016, doi: 10.1007/978-3-319- 34208-5_6.

[4] S. Vanka, S. Srinivasa, Z. Gong, P. Vizi, K. Stamatiou, and M. Haenggi, "Superposition coding strategies: Design and experimental evaluation," IEEE Trans. Wirel. Commun., vol. 11, no. 7, pp. 2628–2639, 2012, doi: 10.1109/TWC.2012.051512.111622.

[5] K. Higuchi and A. Benjebbour, "Non-orthogonal Multiple Access (NOMA) with Successive Interference Cancellation for Future Radio Access," IEICE Trans. Commun., vol. E98.B, no. 3, pp. 403–414, 2015, doi: 10.1587/transcom.E98.B.403.

[6] Z. Yang, Z. Ding, P. Fan, and N. Al-Dhahir, "A General Power Allocation Scheme to Guarantee Quality of Service in Downlink and Uplink NOMA Systems," IEEE Trans. Wirel. Commun., vol. 15, no. 11, pp. 7244–7257, 2016, doi: 10.1109/TWC.2016.2599521.

[7] D. T. Do and T. T. T. Nguyen, “Fixed power allocation for outage performance analysis on AF-assisted cooperative NOMA,” J. Commun., vol. 14, no. 7, pp. 560–565, 2019, doi: 10.12720/jcm.14.7.560-565.

[8] Z. Yang, Z. Ding, P. Fan, and Z. Ma, “Outage Performance for Dynamic Power Allocation in Hybrid Non-Orthogonal Multiple Access Systems,” IEEE Commun. Lett., vol. 20, no. 8, pp. 1695–1698, 2016, doi: 10.1109/LCOMM.2016.2581803.

[9] T. Bao, Z. Lu, Y. Chen, X. Wen, and H. Shao, “Simultaneous Wireless Information and Power Transfer in Multi-antenna Systems,” J. Signal Process. Syst., vol. 90, no. 6, pp. 827– 848, 2018, doi: 10.1007/s11265-018-1330-6.

[10] S. Lee, R. Zhang, and K. Huang, “Opportunistic wireless energy harvesting in cognitive radio networks,” IEEE Trans. Wirel. Commun., vol. 12, no. 9, pp. 4788–4799, 2013, doi: 10.1109/TWC.2013.072613.130323.

[11] Z. Yang, Z. Ding, P. Fan, and N. Al-Dhahir, “The Impact of Power Allocation on Cooperative Non-orthogonal Multiple Access Networks with SWIPT,” IEEE Trans. Wirel. Commun., vol. 16, no. 7, pp. 4332–4343, 2017, doi: 10.1109/TWC.2017.2697380.

[12] T. Jing et al., “Cooperative Relay Selection in Cognitive Radio Networks,” vol. 9545, no. c, pp. 1–14, 2014, doi: 10.1109/TVT.2014.2338297.

[13] T. D. P. Perera, S. Member, and D. N. K. Jayakody, “Simultaneous Wireless Information and Power Transfer (SWIPT): Recent Advances and Future Challenges,” no. c, pp. 1–40, 2017, doi: 10.1109/COMST.2017.2783901.

[14] Y. Chen, N. Zhao, and M. S. Alouini, “Wireless Energy Harvesting Using Signals from Multiple Fading Channels,” IEEE Trans. Commun., vol. 65, no. 11, pp. 5027–5039, 2017, doi: 10.1109/TCOMM.2017.2734665.

[15] C. Zhai, J. Liu, and L. Zheng, “Relay-Based Spectrum Sharing with Secondary Users Powered by Wireless Energy Harvesting,” IEEE Trans. Commun., vol. 64, no. 5, pp. 1875–1887, 2016, doi: 10.1109/TCOMM.2016.2542822.

[16] S. Huang, Y. Yao, and Z. Feng, “Simultaneous wireless information and power transfer for relay assisted energy harvesting network,” Wirel. Networks, vol. 24, no. 2, pp. 453–462, 2018, doi: 10.1007/s11276-016-1346-4.