**KARADENIZ TECHNICAL UNIVERSITY**

**INSTITUTE OF NATURAL AND APPLIED SCIENCES**

**DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING**

# THE EFFECTS OF CHANNEL CHARACTERISTICS ON RELAY BEHAVIOR AND POSITION IN COOPERATIVE COMMUNICATIONS

**POSTGRADUATE THESIS**

**Janvier MANIRAGABA**

**MAY 2016**
**TRABZON**

**KARADENİZ TECHNICAL UNIVERSITY**
**THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES**

**ELECTRICAL AND ELECTRONICS ENGINEERING**

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**Janvier MANIRAGABA**

**This thesis is accepted to give the degree of**
**"MASTER OF SCIENCE"**
**By**
**The Graduate School of Natural and Applied Sciences at**
**Karadeniz Technical University**

**The Date of Submission : 10 / 05 / 2016**
**The Date of Examination : 30 / 05 / 2016**

**Supervisor : Assoc. Prof. Dr. Salim KAHVECİ**

**Trabzon 2016**

**KARADENİZ TECHNICAL UNIVERSITY**
**THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES**

**Electrical and Electronics Engineering**
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**Has been accepted as a thesis of**

**MASTER OF SCIENCE**

**after the Examination by the Jury Assigned by the Administrative Board of the Graduate School of Natural and Applied Sciences with the Decision Number 1652 dated 30 / 05 / 2016**

**Approved By**

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**Director of Graduate School**

# PREFACE

This thesis is a project work done at Karadeniz Technical University, Institute of Natural and Applied Science in Electrical and Electronics Engineering Department, program of Electronic Engineering.

First I would like to thank Dr. Salim KAHVECI, Dr. Ismail KAYA and all the professors in Electrical and Electronics Engineering department in Karadeniz Technical University for accepting and guiding me throughout my work. My thanks again goes to everyone that contributed with ideas, advices and any other help through my work until it was done especially my family and all my friends.

Janvier MANİRAGABA

## DECLARATION

I declare that this thesis, “The effects of channel characteristics on relay behavior and position in cooperative communications” is an original report of my research, has been written by me and has not been submitted for any previous degree or professional qualification. I confirm that the work submitted is my own, except where work which has formed part of jointly-authored publications has been included. My contribution and those of the other authors to this work have been explicitly indicated. I confirm that the appropriate credit has been given within this thesis where reference has been made to the work of others. 30/05/2016.

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Karadeniz Technical University
The Graduate School of Natural and Applied Sciences.
Electronics Engineering Graduate Program
Supervisor: Assoc. Prof. Dr. Salim KAHVECİ
2016 79 Pages

Wireless communication is a communication with a lot of challenges like shadowing, multipath fading, noise and cell coverage that make the communication between transmitter and receiver to be unreliable. Recently, a new concept of Cooperative Communication (CC) was suggested in order to help the communication in wireless network. The main idea that comes with the CC was to helps all the mobiles users and nodes in a network to help each other to send the signal between then until it is transmitted to destination in a cooperative way. In this way the information is not send to the destination by only one user itself but also it passes through others users to help the information to reach the destination. In CC the receiver will not receive the information data from only one user but from different users which makes the receiver to choose the coming information data with good conditions because it is very rare in a network to have all the all users with down links to destination.

This project is based on CC in wireless networks. We showed the interest of CC on Bit Error Rate (BER) performance analysis with either an Amplify-and-Forward (AAF) or Decode-and-Forward (DAF) cooperation protocol using Matlab simulation. Through simulation results, it is shown that the best position of a relay node depends on the fading characteristics but also on the distance between the source and the destination.

Keywords: Amplifier-and-Forward (AAF), Decode-and-Forward (DAF), Bit-Error-Rate (BER), Signal-to-Noise-Ratio (SNR), Cooperative Communication.

# ÖZET

İŞBİRLİKLİ HABERLEŞMEDE KANAL KARAKTERİSTİĞİNİN RÖLE DAVRANIŞI VE RÖLE KONUMU ÜZERİNDEKİ ETKİSİ

Janvier MANIRAGABA
Karadeniz Teknik Üniversitesi
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Elektrik Elektronik Mühendisliği Anabilim Dalı
Danışman: Doç. Dr. Salim KAHVECİ

2016 79 Sayfa

Geleneksel noktadan noktaya kablosuz haberleşmede kanal bağlantısı çok yollu sönümlenme nedeniyle oldukça belirsiz olabilir ve bu nedenle verici ve alıcı arasında sürekli bir haberleşme garanti edilemeyebilir. Son zamanlarda, hücresel ağlar ve kablosuz geçici ağlar gibi kablosuz haberleşme ağları için işbirlikli çalışma isimli yeni bir haberleşme kavramı geliştirildi. Bu haberleşme kavramının temel mantığı olarak, kablosuz haberleşme ağı içerisindeki her bir kullanıcı işbirlikli olarak çalışarak mesaj sinyalini göndermek için birbirlerine yardım ederler. Her kullanıcının veri bilgisi hem kendisi hem de diğer kullanıcılar tarafından gönderilir. Böylece doğal olarak alıcı açısından, iletilen bilgiyi algılamak daha güvenilir olacaktır. Çünkü istatiksel açıdan bakıldığında işaretin alıcıya gidecek olan bütün kanallarda sönümlenmesi oldukça nadirdir.

Bu çalışma kablosuz ağlarda işbirlikli haberleşme üzerinedir ve odaklanılan işlem işbirlikli haberleşme protokolü için Matlab kullanılarak hem “yükselt ve gönder” hem de “çözümle ve gönder” yapılarının bit hata oranı(BER) performansının incelenmesidir. Simülasyon sonuçlarına göre belirlenmiştir ki, rölenin bulunması gereken en iyi konum hem kanalın sönümleme karakteristiğine hem de alıcı ve verici arasındaki toplam uzaklığa bağlıdır.

Anahtar Kelimeler: Yükselt ve Gönder, Çözümle ve Gönder, Bit Hata Oranı, Sinyal Gürültü Oranı, İşbirlikli Haberleşme.

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## LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AAF | Amplify-and-Forward |
| ACK | Acknowledgement |
| ARQ | Automatic Repeat Request |
| AWGN | Additive White Gaussian Noise |
| BER | Bit Error Rate |
| BS | Base Station |
| BPSK | Binary Phase-Shift Keying |
| C-DIV | Cooperative Diversity |
| C-STC | Cooperative Space-Time Coding |
| CC | Cooperative Communication |
| CRC | Cyclic Redundancy Check |
| CSI | Channel State Information |
| CSIR | Channel State Information at Receiver |
| CTS | Clear To Send |
| DAF | Decode and Forward |
| dB | Decibel |
| DC-STC | Dual-Antenna Cooperative Space-Time Coding |
| DSSS | Direct Sequence Spread Spectrum |
| DT | Direct Transmission |
| EMI | Electromagnetic interference |
| EU | European Union |
| FCC | Federal Communications Commission |
| FHSS | Frequency Hopping Spread Spectrum |
| IEEE | Institute of Electrical and Electronics Engineers |
| IID | Independent and Identically Distributed |
| I/O | Input Output |
| ISI | Inter Symbol Interference |

| | |
|---|---|
| LOS | Line of Sight |
| MCN | Multi-hop Cellular Network |
| MIMO | Multiple Input Multiple Output |
| MPCC | Multi-Pair Cooperative Communication |
| MRC | Maximal Ratio Combining |
| MS | Mobile Station |
| MT | Mobile Terminal |
| NACK | Negative Acknowledgement |
| OFDM | Orthogonal Frequency Division Multiplexing |
| PSK | Phase Shift Keying |
| PRF | Pulsed Radio Frequency |
| RF | Radio Frequency |
| RNP | Relay Node Position |
| RTS | Request to Send |
| QAM | Quadrature Amplitude Modulation |
| QPSK | Quadrature Phase Shift Keying |
| QoS | Quality of service |
| SC | Single Carrier |
| SM | Spatial Multiplexing |
| SNR | Signal to Noise Ratio |
| STC | Space-Time Coding |
| TDMA | Time Division Multiple Access |
| VAA | Virtual Antenna Array |
| WANETs | Wireless Ad-hoc Networks |
| Wi-Fi | Wireless Fidelity |
| WiMAX | Worldwide Interoperability for Microwave Access |

## LIST OF SYMBOLS

| | |
|---|---|
| $a_{sd}$ | Fading of the channel in source to destination channel |
| $a_1$ | Weight to maximize the SNR at the output of combiner at source relay link |
| $a_2$ | Weight to maximize the SNR at the output of combiner at relay destination link |
| $c_{s-r}$ | Capacity of source-relay link |
| $d$ | Distance between source and destination |
| $d_{sd}$ | Pass loss in source to destination channel |
| $E_b$ | Total energy of the transmitted signal |
| $h(t)$ | Frequency-flat block Rayleigh |
| $h_{sd}$ | Attenuation of the signal in source to destination channel |
| $h_{sr}$ | Attenuation of the signal in source to relay channel |
| $k_r$ | Rician factor |
| $n_{sr}$ | Noise of the source to relay channel |
| $n_{sd}$ | Noise of the source to destination channel |
| $n'_{rd}$ | The equivalent noise |
| $N_0$ | Total power of noise |
| $P$ | Power of the transmission signal from source to destination |
| $P_b$ | The probability of bit error |
| $P1$ | Power of the transmission signal from source to relay |
| $P2$ | Power of the transmission signal from relay to destination |
| R | The average rate of transmission |

| | |
|---|---|
| $x_s$ | Transmission signal |
| $y_d$ | Received signal in single line transmission |
| $y_{sr}$ | Received signal at Relay from source |
| $y_{sd}$ | Received signal at destination from relay |
| $\beta$ | The multiplication factor of the relay |
| $\xi$ | Energy of transmitted signal |
| $\sigma_n^2$ | Variance |
| $\bar{\gamma}_b$ | Signal-to-noise-ration |
| $\gamma_{sr}$ | Signal-to-noise-ration of source relay link |
| $\gamma_{rd}$ | Signal-to-noise-ration of relay destination link |

# 1. INTRODUCTION

CC is a fast growing research area and will the future communication. The Idea of user-cooperation makes them to share resources among them like sharing power consumption that results in savings of the network resources. We talk about the CC when the number of communicating terminals in a network is more than two, therefore the third terminals will help in connection between others. The third terminal is called a Relay, and makes a relay link between the source and itself and another one with the destination. Using CC allows us to increase the reliability of the system, Quality of Service (QoS), data rate, throughput of the system, the coverage of the cell as well as to limit the energy consumption in the system.

Throughput and reliability in cellular networks are generally limited by two phenomena which are shadowing and small scale fading in the channel between the transmitter node and the destination node. A destination node is said to be in a shadow or a deep fade when there is a physical block between the communicating devices, which results in low signal reception at the destination node. In metropolitan environments especially, this results in the signal strength weakening by the separation distance, at a rate far greater than the square law witnessed in free space.

Small scale fading is the phenomena where several copies of the transmitted signal superimpose at the destination node resulting in fluctuation of the strength of the signal at the destination node. These various copies of the signal are generated as a consequence of reflections of the transmitted signal from various scatters such as buildings, trees etc. The received signal strength can then be demonstrated as a random variable. To create a reliable link between transmitter node and destination node with high data rates, these two phenomena must be addressed [1].

In order to deal with small scale fading we can use various diversity techniques. In this case, the transmission relies on the receiver receiving many individually faded copies of the same signal. Due to this independence, the probability that all the copies of the signal are poor is rare. In time diversity the transmitter repeats the transmissions at intervals spaced more than the coherence time of the channel. In frequency diversity techniques, multiple copies of the signal are transmitted in frequency bands separated by the coherence bandwidth of the channel. Clearly, these two techniques are used to help to improve the data rate reliability.

Spatial diversity techniques exploit the fact that the small scale fading at geographically separated points in space is essentially independent of one another. Spatial diversity can thus be harnessed by employing multiple antennas at either one of the transceivers. However, the multiple antennas at each of the transceivers should be distanced by a distance of the order of the wavelength of the carrier signal. When the carrier frequency is about 1 GHz, the distance between the antennas should be greater than 15 cm. Hence, independent of the extra costs involved, having multiple receive antennas on a small handset might not be possible. This space constraint is not critical for deploying several antennas on the base station where there is enough space to separate the antennas but these antennas address the issue of small scale fading, they are not useful in mitigating shadowing. In spatially distributed wireless systems, CC has been suggested as a way of combating both the small scale and the large scale fading. Transceivers, each with a single antenna sent information for one another, thereby result in spatial diversity in the network [2].

## 1.1. Thesis objective

The aim of this research is to examine different cooperative diversity schemes, namely AAF and DAF with cooperative diversity. Their effect on the channel and their performance is compared to that of non-cooperative schemes.

In this thesis, we consider a relay-assisted cellular network where dedicated relays are installed by the service provider to help the users. The relays are analogous to repeaters in a wire line or an optical communication link. They do not have any data of their own for transmission. They listen to the Base Station (BS), amplifier or decode and re-encode the data and re-transmit it to the users, who are scattered in the circular cell around the BS. The installed relays node can certainly provide a diverse set of channels between the transmitter node and the destination node, and hence better performance.

### 1.2. Motivation for the Thesis

In few last decades the idea of a relay appeared, it hasn't been applied until recently, when a lot of results appeared allied to cooperative communications, that they are being thoroughly researched. CC has a lot of advantages like capacity improvement, load balancing or coverage extension of cells, which is interested in for every researcher working on CC. The aim of this thesis is to address the problem of coverage, fading, shadowing and low signal, and design an efficient architecture for relay-assisted cellular networks. In particular, we address issues such as optimal RS placement for cellular coverage extension, system capacity improvement with RSs, and modifications to traditional multihop ARQ protocols to reduce packet loss during handover.

I have chosen to work on relay communication because as my country is still developing the telecommunication sector is better that we can use relay station instead of continue investing a lot of cost in deploying new base station cause as times goes on we are having subscribers in the cells and get congested.

### 1.3. Thesis Outline

This thesis is organized as follows. In Chapter 1 the general introduction is reviewed. In Chapter 2 the non-cooperative communication or the single line communication is reviewed, the simulation of both BPSK and QPSK are done in AWGN channel and Rayleigh Fading channel. Chapter 3 introduces the CC and cooperative relaying networks, relaying schemes cooperative such as AAF and DAF are reviewed and the simulations and also results are done in both AWGN channel and Rayleigh Fading channel. In Chapter 4 the selection of relay nodes and types of selection are addressed. In Chapter 5 the position of relay nodes is reviewed and the simulation and results are done. Chapter 6 presents the conclusion of this work and includes suggestions for future study.

### 1.4. Introduction to Wireless Environment

The wireless environment is very different to other environment like home environment and office environment because of the facts that makes the wireless to be unreliable, among those facts we can say like high temperature, obstacles, and distances between elements that compose the wireless system.

The main challenge faced by a lot of telecommunication companies is how to establish a communication channel that is low costly, reliable, and which will last long. To establish such a communication channel you have to take into consideration of temperature, your machinery, the distance, the level of Electromagnetic Interference (EMI). But most of the time and most of the companies deal only with the distance and the topology so that the signal will not face obstacles when they are connecting the sensors to equipment.

### 1.5. Challenges in Wireless Environments

The a lot of challenges faced by the wireless environment like Input to Output (I/O) distance, Echo, Noise, Channel sharing, interference, Security and Industrial protocols sometimes not supported.

I/O Distance: The distance between the input and output in a wireless communication does not have to be much more miles cause a long distance limits the communication between the control system, sensors and equipment.

Echo: when we talk about signal echo is the fact that the Radio Frequency (RF) used in wireless communication has the ability to pass through the objects like wall, glass, and other object in your office or in your home but the fact that RF are transmitted with a frequency of 900MHz-2.4GHz there are objects that they cannot penetrate like metals, concrete and other larger objects and try to bounce. This bounce of the signal can re transmit the signal like the original signal from the transmitter and result in an echo or multi path. The receiver of the signal will be confused with this type of interference and the result will be radio null [3].

Noise: The noise in a wireless channel can be the results of EMI from large motors, high power generation and usage, large equipment or the noise can be the results of industrial machinery that create a high level of noise. In a wireless noisily channel the transmitter and the receiver cannot be able hear each other which results in a loss of data.

Channel sharing: In a crowded Radio spectrum space the channel sharing is a challenge to wireless cause the Federal Communication Commission (FCC) have approved that in a wireless channel shared by devices using Wi-Fi and others using IEEE 802.15.4 the result is data confusion if those devices are in the same area.

Interference: The interference in wireless is the results of reflection, refraction and diffraction of the signal during the transmission from the source to destination, interference occurs when the unwanted signal arrive to the receiver and interferes with the desired one.

Support of industrial protocols: Most of the wireless devices are designed for home and office to office use which makes some engineers to prefer other industrial protocol like Modbus or to use RS-232, 422 or 485 supports instead of using wireless.

Security: Some wireless standards are not secured which is another challenge for business use of wireless but with the growth of technology in now day’s technology we can use wireless with a Wi-Fi protected access.

So, with all those challenges faced by the wireless industrial environment we can look at the solution to solve the problem faced by the wireless industrial environment [3].

### 1.6. Methods and Technologies to Solve wireless Problems

Recently, a lot of technologies have been developed to solve the problems in wireless industrial environments, among those we are going to have a look at some and their advantages and disadvantages so that one can make a choice to his own the one to use.

Trying to solve the wireless industrial environment problems they are some features you have to take into consideration like:

Interference, Echo and Noise: They are many modulation structures, transmission structures to solve these problems but among them they are two main to take into consideration.

Caution: For your system to perform properly you have to make sure that all your equipment in a system (transmitter node, relay node, receiver node, etc.)  Support the same transmission structure.

FHSS (Frequency Hopping Spread Spectrum): In FHSS all the data are simultaneously transmitted in a single channel, the quickly change of the channel and to keep changing during the transmission result in frequency hopping, so in order to solve the problem we need to use a low bandwidth channel for a reliable system.

DSSS (Direct Sequence Spread Spectrum): In DSSS all the data are simultaneously transmitted over every accessible channel which makes DSSS to be more reliable in environment with noise but the only disadvantage is that it needs an intensive bandwidth.

For a more reliability of our system they are other several standards that are developed to combat the problem of speed, security, system efficiency and distance. Depending on the needs and necessities of the system we can choose which one is better for our system also looking at the advantages and disadvantages.

Wi-Fi (802.11 Standard)

Advantages: Wi-Fi is a wireless standard designed to be used at home, in office, and business areas. The main advantage of Wi-Fi is its high data transfer rate which can be up to 54 Mbits/s.

Disadvantages: The main disadvantages of Wi-Fi are that it always needs a Line of Sight (LOS), and the low penetration of their signals. The range also is another challenge cause like 802.11 b standard can send at only 160 meters [3],[4].

ZigBee (802.15.4 Standard)

Advantages: The most important advantage of ZigBee over Bluetooth and Wi-Fi is a high penetration capacity of ZigBee, and also setting up the home the home wireless management for ZigBee is cheap than Wi-Fi. Another thing is that you can control the remotely home appliance network.

Disadvantages: The data rate of ZigBee is only up to 720Kbits/s which is the main disadvantage of ZigBee it has a small data rate, another point is that being a new technology to replace equipment is costly and is less secured compared to Wi-Fi.

Bluetooth

Advantages: Bluetooth is very popular compared to other wireless standards, their features are very simple cause you don't need to know a lot about technology in order to use Bluetooth and it is free of charge if you have a devices where Bluetooth is installed.

Disadvantages: Bluetooth has a low penetration capacity; always need a LOS between devices that are sending each other's data, the data rate is very small up to only 12Mbits/s and the last is that Bluetooth can only connect two devices at once [4].

Proprietary Radio Frequency

Advantages: The Proprietary RF increase the flexibility, you can modifier the modulation schemes, data rate, distance and the configurations. Buy modifying all these features the Proprietary RF meet your needs and desires. It is rarely interfered by other wireless standards. It has a higher data rate up to 2.4GHz.

Disadvantages: The Proprietary RF does not cooperate with other wireless standards and don't follow any IEEE standards [5].

As we can see in the table below there is comparison of some various aspects and features of wireless industrial environments solutions.

Table 1. Comparison of various aspects of wireless solutions.

| | Wi-Fi | Bluetooth | ZigBee | PRF |
|---|---|---|---|---|
| Frequencies | 2.4GHz and/or 5GHz | 2.45GHz | 915MHz(US) 868MHz (EU) 2.4GHz (global) | 900MHz(US) 868MHz(EU) or 2.4MHz (global) |
| Channels | 16 @ 2.4GHz 80 @ 8GHz | 79 | 10 @ 915MHz 26 @ 2.4GHz | 16 to 79 (can be customized) |
| Range (Indoor) | 70m | Class1=1m Class2=10m Class3=100m | 20m | 1000m |
| Range (Outdoor) | 160m | 100m | 100m | 40 miles (with high-gain antenna) |
| Data Rate (Max) | 54Mbits/s (with12Mbits/s typical) | 3Mbits/s | 250Kbit/s | 721Kbit/s to 72Mbit/s |
| Transmission Scheme | DSSS | Adaptive FHSS | DSSS | FHSS or DSSS |
| Power Sources | Wired | Battery/Wired | Battery/Wired | Battery/Wired (industrial power source compatible) |
| Uses | Cable replacement, large data transfer, networking | Short distance cable replacement | Monitoring and Controlling | Cable replacement, Monitoring, Controlling, Data Transfer |

Considering all those solutions we can combat the problem of data rate, distance of transmission and the frequency of transmission, let take a look at the range consideration, antenna consideration and the system consideration of the wireless industrial environment.

### 1.6.1. Range considerations

The range consideration is treated according to four main elements, Transmission power, Receiver sensitivity, Data volume and LOS.

Transmission power: The transmission power is the amount of power emitted by the antenna of the radio devices. The transmission power is the main point to consider in wireless transmission especially in long distance cause the higher the power the more louder the signal and the signal can travel a long distance.

Receiver sensitivity: The way the receiver can hear to the coming signal is referred to us as the receiver sensitivity and is very affected by the type of antenna and the hardware configuration used in a system.

LOS: This also is another parameter to look at in wireless industrial environment because most of the standards need the LOS between the transmitter and the receiver. For a better wireless communication we need to have few barriers across the distance between devices communicating each other, Frequency and power also are considered but when there is a LOS the signal can face the physical and EMI barriers between transmitter and receiver.

Data Rate: The data rate and the data volume are the features to consider in transmission cause the larger the packets it is difficult to send it reliably, for a better communication the packets have to be small and reduce the range.

### 1.6.2. Antenna considerations

Antenna is among the main features in a wireless communication and the antenna selection depend on the type of communication you need and on the type of standard to determine the range and the array you are going to use in your system. We consider to type of antenna:

Directional Antenna: The directional antenna is the type of antenna that can send and receive signal only in one direction. Directional provide the largest range, and the interference in this type of antenna can occur at any point in the spectrum. We have many type of directional antenna like Yagi antenna, Dish and Panel antenna.

Omni-Directional Antenna: Contrary to Directional antenna Omni-directional antenna can send and receive signal in a linear radius. It allows the biggest number of nodes. Type of Omni-directional antenna is Vertical Omnis, Ceiling Domes and Rubber Ducks.

### 1.6.3. System consideration

The system consideration consists of system, point-to-point system which transmit signal from one point to another point and point-to-multipoint that transmit signal from one point to multiple point.

The wireless technology has minimized the problem was facing in past so that now communication companies can create the wireless network that can take all these advantages. Taking the advantages of wireless communication in general compared to wire one wireless is very advantageous.

Low cost: The wireless system is very low costly because installing the wireless system we do not the cost of the wire and cables.

Longevity: The apparatus and equipment of wireless system like transmitters and sensors are designed to work in environment with the temperature from -40 to 80$^{o}$C and make the wireless installation to last longer than wired system. Wireless system also does not need multiple signal boosters at a long distance transmission.

Swift deployment: Wireless installation saves the human resources because it can be deployed, installed and taken off at any time.

Easy configuration: Devices used in wireless installation have free configuration software that allows them to be self-configuration and self-repairing which makes wireless to be easy configuration [6].

## 2. SINGLE LINK TRANSMISSION

When we talk about the single link transmission is the transmission between the sender and the receiver without passing through the relay link in other word is the direct link transmission.

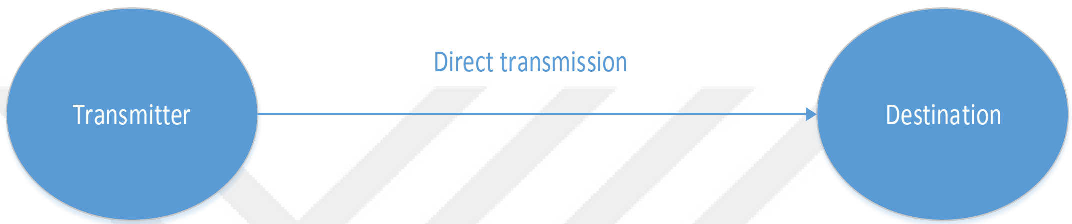


Figure 1. Direct transmission model.

As we can see in the simple representation of the direct transmission in Figure 1 the signal is send from the transmitter passing through the channel to destination there is no other intermediate between the transmitter and the receiver. It a communication between only two points.

### 2.1. Signal Model and Modulation

Signal modeling consist of how the signal is processed from the transmitter until it reaches the destination, it is all the changes done on a signal through the channel for a better communication. The sequence of random bipolar bit is transmitted from the source passing through the channel the signal can be either modulated with Binary Phase Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK).

BPSK: Bipolar Phase Shift Keying (also sometimes called PRK, phase reversal keying, or 2PSK) is the simplest form of phase shift keying (PSK). It uses two phases which are separated by 180° and so can also be termed 2-PSK.

QPSK: Quadrature Phase Shift Keying uses four equispaced points in a circle. With four phases, QPSK can encode two bits per symbol. The Quadrature Phase Shift Keying minimizes the bit error rate (BER) sometimes as twice the BER of BPSK [7].

### 2.2. Channel Model

The channel of wireless network is where all the transformation are made to the signal from the transmitter so that it can reach the destination, Figure 2 shows all the transformation done on the signal like coding, decoding, modulation and demodulation.

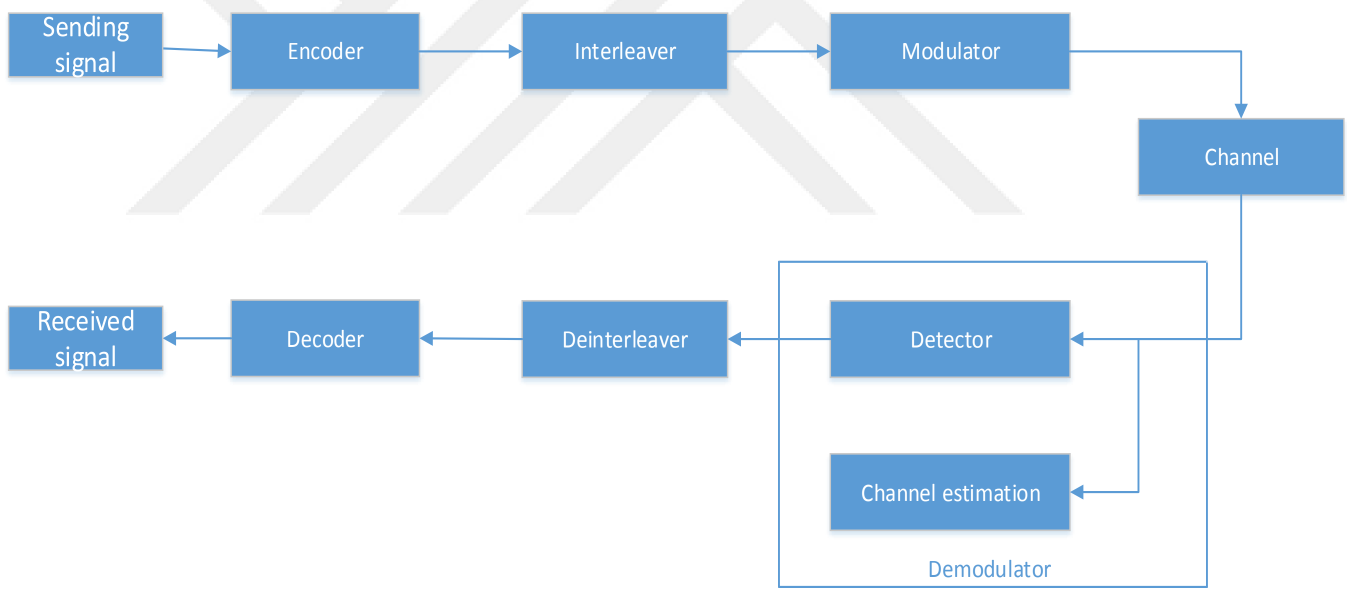


Figure 2. Channel model of a non-cooperative or single line transmission [8].

The propagation medium in wireless network is the air and the signal passing through that type of channel face a lot of distortion through the channel like thermal noise, path loss and fading. The distortion of the signal some are destructive other are constructive to the signal. The received signal at the destination can be modeled as the sum of the signal multiplied by the path loss and the fading and additive noise added by the channel.

$$y_d = h_{sd}x_s + n_{sd} \quad (1)$$

$$y_d = d_{sd}a_{sd}x_s + n_{sd} \quad (2)$$

Where $x_s$ is the transmission signal, $y_d$ is the received signal, $n_{sd}$ is the noise and the $h_{sd}$ the attenuation of the signal which is composed of $d_{sd}$ the pass loss and $a_{sd}$ the fading of the channel [8].

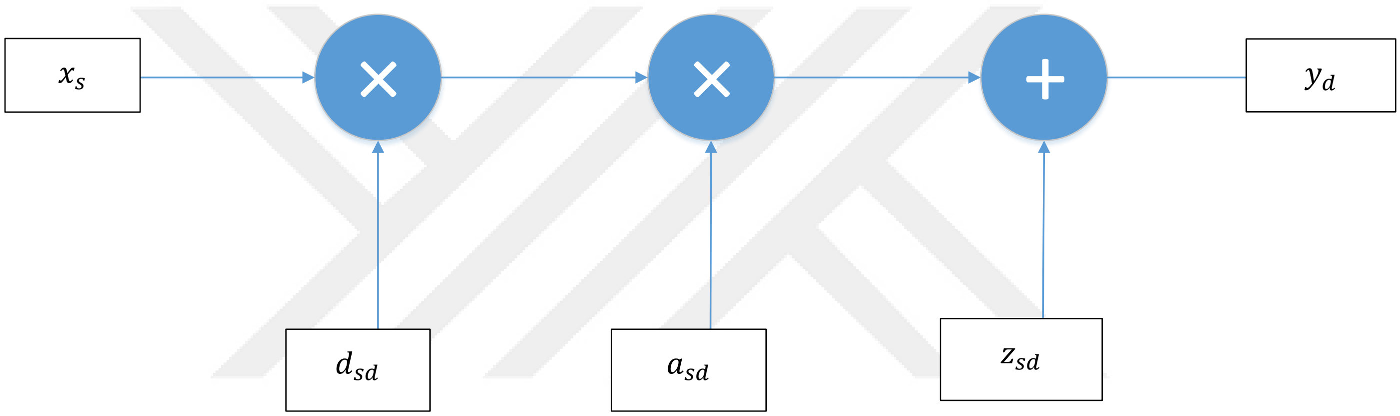


Figure 3. The Path loss, fading and the thermal noise.

For us we will only focus on the channel, modulation and demodulation, how the signal is modulated, demodulated and how it passes through the channel and the effect of the channel to the signal. Among the effects of the channel we can say Noise, in the channel they are additive noise and multiplicative noise as we can see in the Figure 3, the additive one is like AWGN and the multiplicative are the path loss and the fading of the channel.

### 2.2.1. Noise

The main sources of noise in a wireless network are interference and electronic components like amplifiers. Thermal noise can be assumed to be additive, which can be characterized as additive complex Gaussian noise. The scalar $z_{sd}[n]$ can then be simulated as the sum of a real and an imaginary noise vector, both Gaussian distributed, mutually independent and zero mean with variance $\sigma_n^2$. The total noise power will be;

$$N_0 = 2\,\sigma_n^2 \tag{3}$$

### 2.2.2. Signal to Noise Ratio

The signal-to-noise ratio (SNR) is a widely used measure to indicate the signal quality at the destination

$$SNR = \left(\frac{S}{N_0}\right) = \frac{|h_{sr}|^2 \cdot \xi}{N_0} \tag{4}$$

In Equation 4 the energy of the transmitted signal is given by

$$\xi = E[|x_s|^2] \tag{5}$$

In Equation 4 and 5 $N_0$ is the total power of the noise, $x_s$ is the transmitted signal, $h_{sr}$ is the attenuation of the signal in source-relay node channel and $\xi$ is the energy of the transmitted signal.

### 2.2.3. Path Loss and Fading

The signal is attenuated mainly by the effects of free-space path loss and fading, both included in

$$h_{sd} = d_{sd} \cdot a_{sd} \tag{6}$$

The path loss $d_{s,d}$ is proportional to $1/R^4$ [7]. We assume that the distance between the transmitter node and destination node does not change too much through the whole transmission. The received signal at the destination has a power attenuated with the proportional of $1/R^4$.

In the urban environment and cities where they are a lot of obstacles between the transmitter and the receiver that block the LOS of the direct link CC enable different ways for indirect connection between different nodes in a network to reflect the propagation signal. Through those various ways it is very rare for the obstacles to block the LOS of all the links in a wireless network. The effect of passing the propagation signal through different nodes in order to reach the destination with a LOS is referred to us as multi-path propagation.

In wireless network a small change in channel characteristic can change the whole system, it is necessary to maintain the system unchanged in order to have a good quality of the signal. The effect fading, will attenuate the signal by adding phase shift with coefficient $a_{s,d}$ the added phase shift can be modeled as a zero mean, complex Gaussian random variable with variances $\sigma_{sd}^2$.

The added fading shift has an angle $< a_{sd}$ is uniformly distributed on $[0;2\pi)$ and the magnitude $|a_{sd}|$is Rayleigh distributed.

The fading shift with a high Rayleigh distributed magnitude effect on the signal quality at the destination; so that even a system with high SNR might experience significant errors due to fading [7], [8].

### 2.2.4. Rayleigh Fading

Rayleigh fading is a process whereas the signal passing in the transmission channel will vary randomly, that randomly changing of the signal is called fade. If the signal is changing according to the Rayleigh distribution the signal is said to be facing the Rayleigh fading. In a fading environment the receiver has to know the magnitude and the angle of the fading coefficient $a_{sd}$ of the signal so that from the receiving the receiver will removes the fading characteristics and remain with the original message from the source [9].

The transmission in fading channel, we use the interleave in order to prevents the bursts errors or make them interleaved and be distributed uniformly over the whole signal cause in another way those bursts errors are difficultly corrected by the error correcting code.

Through simulation we do not simulate the interleaving and the coding block but we assume that they exist in the system. Therefore, simulating Rayleigh fading transmission, we do not care how the errors are distributed in the signal. Our interest is to simulate and get the average BER. In order to get an accurate result the signal we pass the signal through many different channel characteristics as possible. After passing the signal through many different channels without changing the signal characteristics and block length within the simulation we assume the simulation to be one.

### 2.3. Receiver Model

At the receiver the received signal is detected symbol by symbol. Our concerns for this project are the BPSK and QPSK modulation only. In the case of BPSK modulation the received signal is detected as shown in equation (7) in symbol/bit.

$$y_d[n] = \begin{cases} +1 \ (Re\{y_d[n]\} \geq 0 \\ \\ -1 \ (Re\{y_d[n]\} < 0 \end{cases} \tag{7}$$

In the case of QPSK modulation, we generate a series of binary input message bits. The generated binary inputs contain 2 bits. QPSK symbols are formed by combining generated binary bits are in terms of two bits. To represent the QPSK modulation the symbol ’00’ is represented by 1, ‘01’ by j (90 degrees phase rotation), ‘10’ by -1 (180 degrees phase rotation) and ‘11’ by -j (270 degrees phase rotation). For a QPSK modulated signal there are two bits transferred per symbol, the detected signal ate the receiver is modeled as [10]:

$$y_d[n] = \begin{cases} [+1,+1] & (0^0 \leq y_d[n] < 90^0) \\ [-1,+1] & (90^0 \leq y_d[n] < 180^0) \\ [+1,-1] & (-90^0 \leq y_d[n] < 0^0) \\ [-1,-1] & (-180^0 \leq y_d[n] < -90^0) \end{cases} \quad (8)$$

### 2.4. BER for Single Link Transmission

#### 2.4.1. BER of a Single Link Transmission of BPSK/ QPSK Fading and non-Fading Channel

BPSK representation of the binary digits 1 and 0 can be represented by the analog levels. The system model is as shown in the Figure 4 where the signal in the transmitter is modulated by BPSK or QPSK passing through where it will be added to the signal and then demodulated at the receiver.

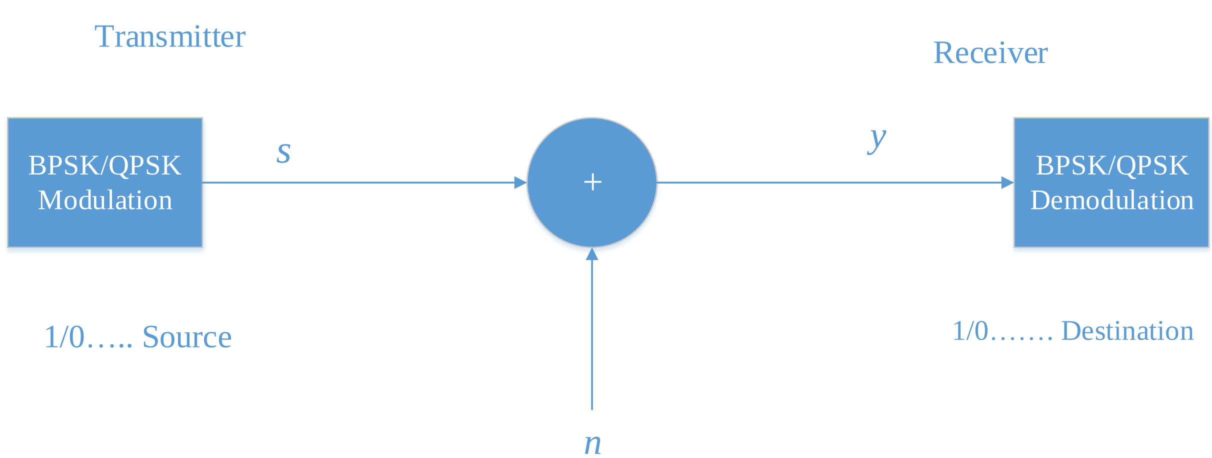


Figure 4. Simplified block diagram with BPSK or QPSK transmitter-receiver.

As we can see in Figure 4 the signal send by the transmitter is in form of a series of discreet values of 0 and 1 which for bits and the number of bits is define as the length of the signal.

The signal received at the destination depends on the SNR of the channel and the way the signal is modulated. The theoretical probability of a bit error is summarized in a table below.

The table 2 shows the BER of the received signal at the destination depending on the type of modulation used weather is QPSK or BPSK and also the type of channel where the signal has pass through weather is a fading channel or if is a non-fading channel

Table 2: BPSK and QPSK in no fading and Rayleigh fading channel.

| Modulation Type | no Fading | Rayleigh Fading |
|---|---|---|
| BPSK | $BER\ no\ fad = Q\left(\sqrt{\frac{\xi}{\sigma^2}}\right)$ | $BER\ Rayleigh = \frac{1}{2}\left(1 - \sqrt{\frac{\bar{\gamma}_b}{1+\bar{\gamma}_b}}\right)$ |
| QPSK | $BER\ no\ fad = Q\left(\sqrt{\frac{\xi}{2\sigma^2}}\right)$ | $BER\ Rayleigh = \frac{1}{2}\left(1 - \sqrt{\frac{\bar{\gamma}_b}{2+\bar{\gamma}_b}}\right)$ |

Where

$$\bar{\gamma}_b = \frac{E_b}{N_o} E[h^2] \quad (9)$$

The equation above is the average signal-to-noise ratio.

For $E[h^2] = 1$ (10)

$\bar{\gamma}_b$ Corresponds to the average $E_b/N_0$ for the fading channel.

By using equations in our table, the BER for a slowly Rayleigh fading channel with BPSK modulation can be expressed as;

$$BER_{BPSK\ Rayleigh} = \frac{1}{2}\left(1 - \sqrt{\frac{\bar{\gamma}_b}{1+\bar{\gamma}_b}}\right) \tag{11}$$

For $E[h^2]$ =1 (12)

The equation (12) can be written as;

$$BER_{BPSK\ Rayleigh} = \frac{1}{2}\left(1 - \sqrt{\frac{\frac{E_b}{N_o}}{1+\frac{E_b}{N_o}}}\right) \tag{13}$$

### 2.4.2. BER for Single Link Transmission of Rician Fading Channel

We talk of Rician fading or Ricean fading when in the arriving signal at the destination there is one path with a stronger LOS than the others. The received signal in Rician fading channel is characterized by the Rician distribution. The error probability of the received signal with BPSK modulation in Rician fading cannel is modeled as [11]:

$$P_{b,Rician} = Q_1(a,b) - \frac{1}{2}\left[1 + \sqrt{\frac{d}{d+1}}\right] exp\left(-\frac{a^2+b^2}{2}\right) I_0(ab) \tag{14}$$

Where

$$a = \left[\sqrt{\frac{k_r^2\left[1+2d-2\sqrt{d(d+1)}\right]}{2(d+1)}}\right] \tag{15}$$

$$b = \left[\sqrt{\frac{k_r^2\left[1+2d+2\sqrt{d(d+1)}\right]}{2(d+1)}}\right] \tag{16}$$

$$k_r = \frac{\alpha^2}{2\sigma^2} \tag{17}$$

$$d = \sigma^2 \frac{E_b}{N_0} \tag{18}$$

The parameter $k_r$ is the Rician factor. The $Q_1(a, b)$ is the Marcum $Q$ function defined as;

$$Q(a,b) = \exp\left(-\frac{a^2+b^2}{2}\right)\sum_{l=0}^{\infty}\left(\frac{a}{b}\right)^l I_0(ab),\ b \geq a > 0 \tag{19}$$

$$Q(a,b) = Q(b-a),\ b \gg 1\ and\ b \gg b-a \tag{20}$$

### 2.5. Simulation and Conclusion

Our simulation was done in Matlab, ours results was obtained by passing the signal through different types of channel and using different types of channel modulation. First result are obtained by passing the signal through AWGN with both BPSK and QPSK modulation, the we pass the signal again through fading channel (Rayleigh fading channel and Rician channel) also with both BPSK and QPSK modulation. All the results are represented in terms of SNR (Eb/No) and BER for practical values of system parameters.

#### 2.5.1. BPSK Modulation in AWGN Channel

First we will generate the a set of random symbols +1′s and -1′s using BPSK modulation we pass them through AWGN channel after passing them in channel we will do the demodulation of the received symbol based on the location in the constellation, count the number of errors and then repeat the same for multiple Eb/No value after repeating the process for many times we have taken the average results.

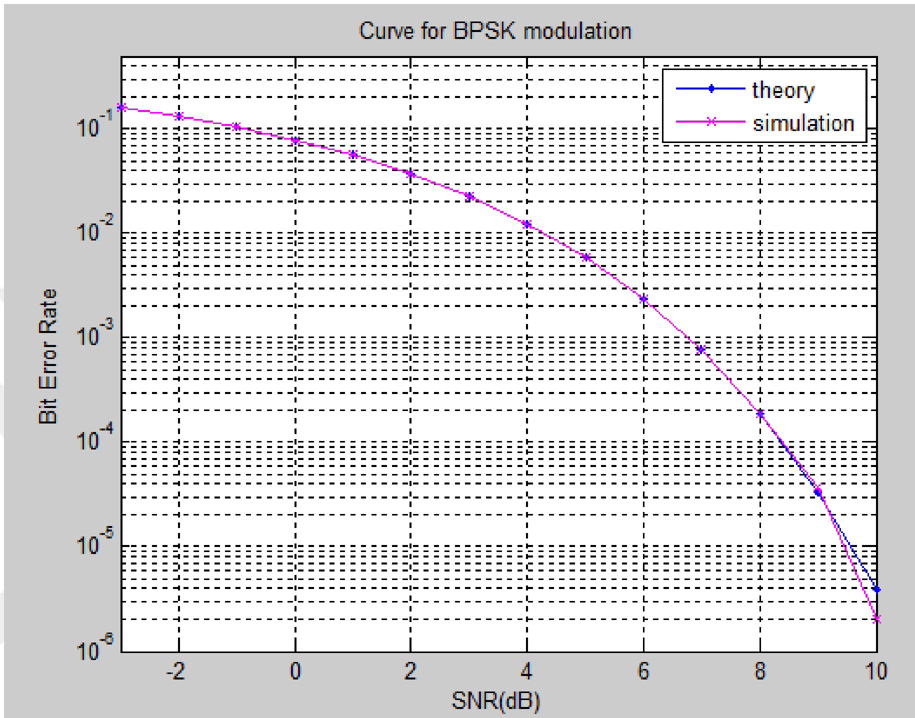


Figure 5. Curve for the BPSK modulation in AWGN channel.

### 2.5.2. QPSK Modulation in AWGN Channel

We generated a set of "randn.m" variables function in Matlab for the transmitting signal and then the noise term to be added to the signal. The noise is generated with unit variance and zero mean.,we use the this equation $\sigma^2 = \frac{N_o}{2}$ is used to generate a noise with sigma σ for the given $Eb/N_0$ ratio, find σ, multiply the 'randn' generated noise with this sigma , we added final noise with the transmitted signal to pass through the channel, the QPSK modulation was used as the modulation by the transmitter. At the receiver QPSK receiver employs two threshold detectors that detect the real and imaginary part of the received signal. The detected signals are then passed through a parallel to serial converter.

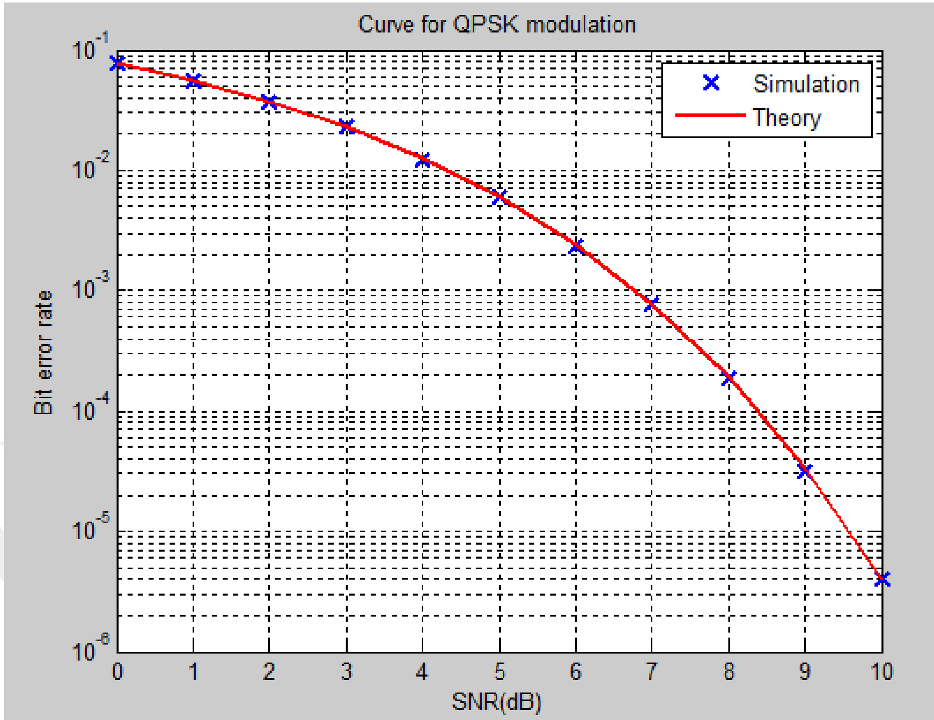


Figure 6. Curve for the QPSK modulation in AWGN channel

The SNR Vs BER Curve for QPSK and BPSK in Figure 5 and Figure 6 are identical. That is because; QPSK modulation scheme is two orthogonal BPSK modulation scheme combine together. The two individual BPSK scheme are orthogonal and they don't interfere with each other during the transmission this is the reason why the SNR Vs BER curved for QPSK and BPSK are identical.

### 2.5.3. BPSK Modulation in Rayleigh Fading Channel

We generated a set random binary sequence of +1′s and -1′s, the generated signal is modulated by BPSK modulation by the transmitter, pass the resulting signal through the channel with Rayleigh fading conditions. The receiver with the known channel conditions, performs a hard decision decoding and counts the bit errors and then perform hard decision decoding and count the bit errors. The results shown in the graph is the average of all the results obtained by doing the process several times.

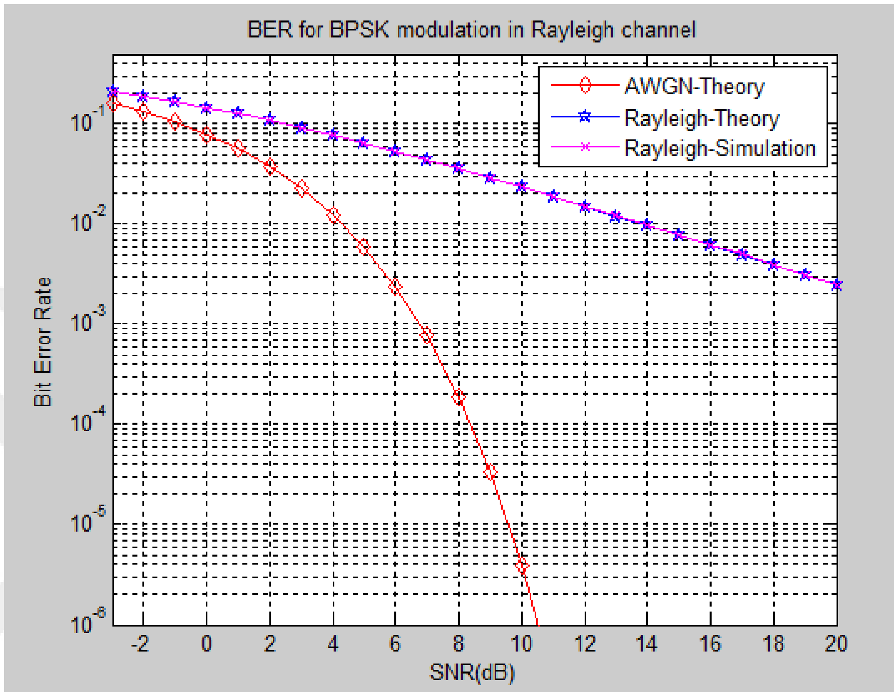


Figure 7. Curve of BPSK modulation in Rayleigh Fading channel.

### 2.5.4. QPSK Modulation in Rayleigh Fading Channel

For QPSK modulation in Rayleigh fading channel, the same generated signal for AWGN modulation is passed through the channel with fading channel and then the results are compared with the results got in AWGN channel.

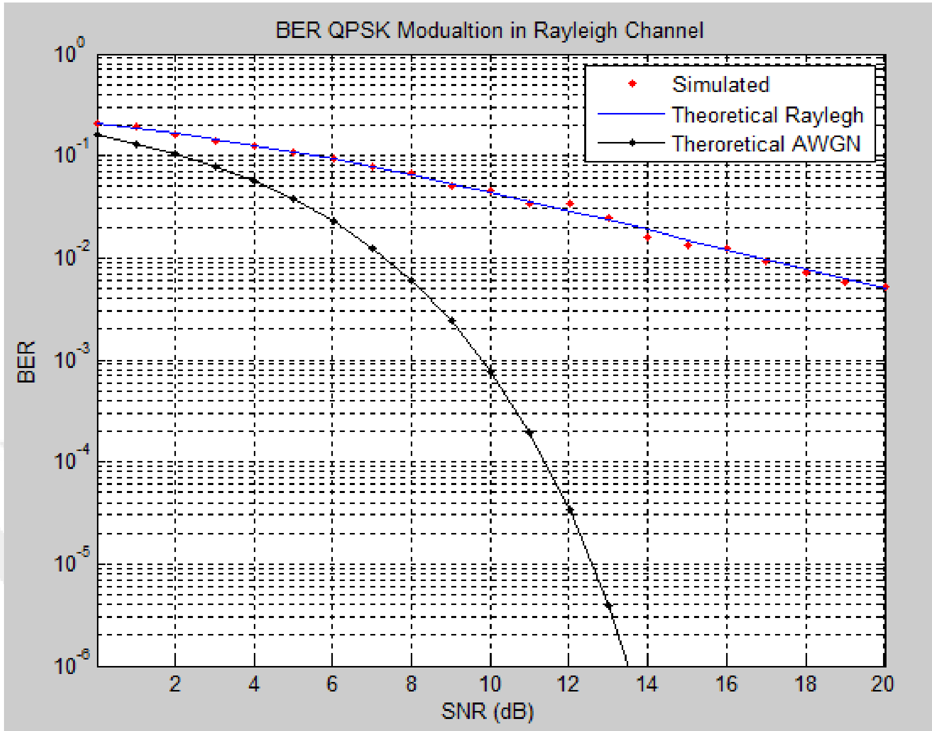


Figure 8. Curve of QPSK modulation in Rayleigh Fading channel.

The results in Figure 8 compare the results of BPSK modulation in AWGN channel and BPSK modulation in Rayleigh Channel around 10 dB degradation it shows that the amount of energy required for transmission over AWGN channel is lesser than the energy required for transmission over Rayleigh channel. We also observed that the BER for transmission over AWGN channel is lesser than that for Rayleigh channel.

From our results, it is shown that with small amount of transmitting energy the QPSK modulation is preferred it offers acceptable BER while transmitting signals with low energy.

### 2.5.5. BPSK Modulation in Rician Fading Channel

We generated a set random binary sequence of +1′s and -1′s, the generated signal is modulated by BPSK modulation by the transmitter, pass the resulting signal through the channel with fading conditions. Cause of the fading conditions destination experience a lot of paths if at least one path has the LOS with the destination it is called Rician fading. The results get from AWGN, Rayleigh and Rician channel are compared after the simulation [11].

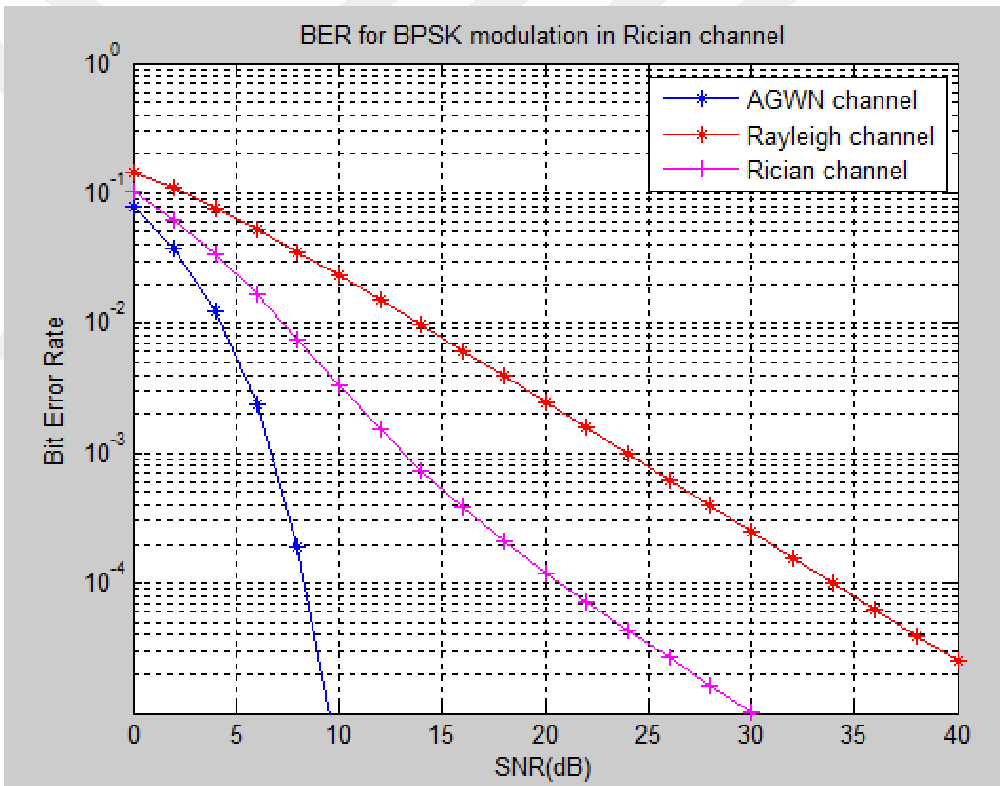


Figure 9. BER for BPSK modulation in Rician channel.

From Figure 9, we can see a big difference in SNR required to obtain a low BER possible for example to obtain a BER of $10^{-4}$, using BPSK, an AWGN channel requires SNR of 8.5 dB, Rician channel requires SNR of 20 dB, and a Rayleigh channel requires SNR of 34 dB. It is clearly indicative of the large performance difference between AWGN channel and fading channels.

# 3. COOPERATIVE TRANSMISSION

## 3.1. Introduction on Cooperative Communication

Wireless communication has experienced a lot of difficult in last years; this is because of a high demand in high data rates every time and everywhere. CC was proposed in 1969 by Van Der Meulen, to combat the challenges in wireless communication like the problem of coverage, the issues of capacity, fading multipath channels and low complexity. CC is also used to enable the efficiency utilization of communications resources and reducing the cost by utilizing relay nodes instead of deploying base station in every area of the cells.

In wireless communications, the CC can be considered as the virtual MIMO channel. All the nodes involved in CC helps each other to sends information in a mutual way which makes the CC to be like a virtual MIMO.

Thus, it make reliable for the destination to detect the transmitted information not from one point of view but from different views so the chance that all the channel links to the destination go down is rare. Several copies of the transmitted signals due to the cooperation among users result in a new type of diversity, cooperative diversity, which improve the system performance and robustness. The idea of CC started back in 1969s, in which a basic three-terminal communication model was first introduced and studied by van der Meulen in the context of mutual information [12]. A more thorough capacity analysis of the relay channel was provided later by Cover and El Gamal, and there are more recent work that further addressed the information-theoretic aspect of the relay channel, for example on achievable capacity and coding strategies for wireless relay channels, on capacity region of a degraded Gaussian relay channel with multiple relay stages, on capacity of relay channels with orthogonal channels, and so on [12].

Recently, many efforts have also been motivated on design of cooperative diversity protocols in order to deal with the effects of severe fading in wireless channels. Precisely, in various cooperation protocols were proposed for wireless networks, in which when a user helps other users to forward information, it serves as a relay node.

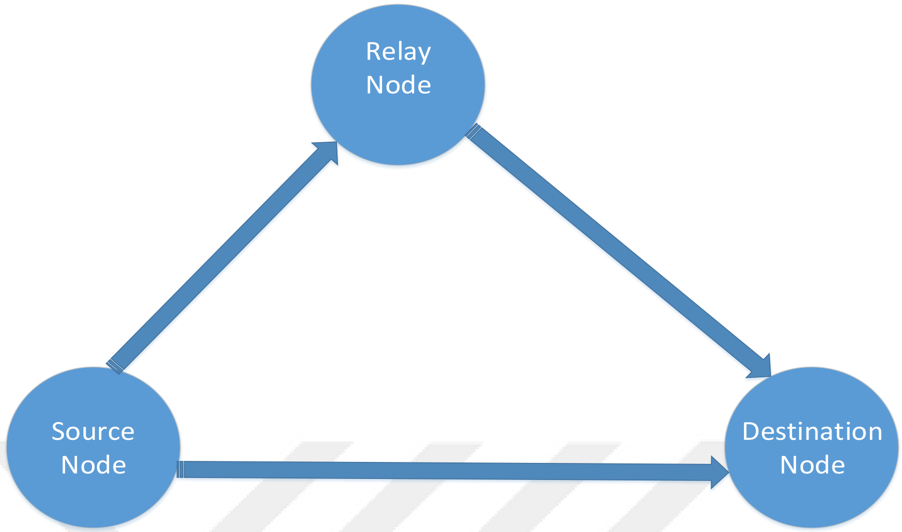


Figure 10. Simple presentation of a cooperative communication

CC research has grown too fast, and it is likely to be a key enabling technology for efficient spectrum use in our future communication technology. The main idea in user-cooperation is the resource-sharing among multiple nodes in a network. The reason behind the exploration of user-cooperation is to willingly share power and computation with neighboring nodes which lead to savings of overall network resources.

There seems to be no consensus in the literature as to the question: Which relaying protocol is better, AAF or DAF?

While some studies find the DAF protocol to be superior, others find the other way around. Indeed, it has been shown in [12] that based on numerical simulations, the AAF multihop relaying outperforms the DAF one under uncoded Bipolar Phase Shift Keying (BPSK) modulation in terms of outage probability and bit error rate (BER), which was explained by the error propagation effect in the DAF relaying outweighing the noise amplification of the AAF relaying. An analysis of a maximum likelihood demodulation presented in [12] for coherent cooperative diversity in uncoded BPSK systems shows that the DAF relaying with more than one relay loses about half of the diversity of the AAF relaying.

### 3.2. Brief History of Relaying

Communication from a single source to a single destination without the help of any other communicating terminal is called direct, single-user or point-to-point communication.

Relaying is a way of creating an intermediate between the transmitter and the receiver when the distance between then are greater than the transmission range or when the transmission power is small to transmit the signal to the destination.

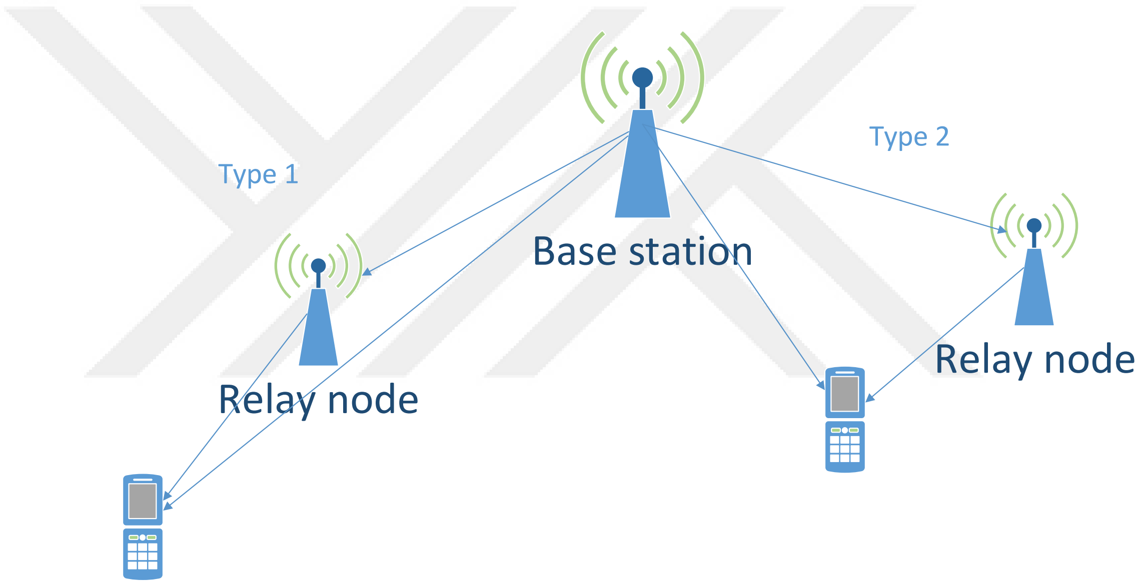


Figure 11. Relaying model in a wireless communication.

Figure 11 shows two types of relay node. In type one the Relay node is between the transmitter and the receiver and there is no direct communication between the transmitter and the receiver they communicate through the relay node but in type two the transmitter and the receiver they can communicate directly or through the relay node.

Consider the mesh network in type 1 with three nodes, each with a single antenna. The communication between the three transceivers. The rate of communication depends on the inter-node channel condition. The rate drops whenever this channel is poor.

Because of the wireless medium, it is possible that these other nodes successfully decode the transmitted data even when the receiver does not. If so, these nodes could potentially forward the decoded data to the receiver. This way, even if the direct source-destination channel is poor, the receiver could still decode the transmitted data. This is the basic idea of cooperation [13].

The nodes can cooperate in the following way. The communication between the nodes is divided into two time slots. In the first time slot the source node transmit the signal. All the other nodes in the system try to decode the data along with the destination node. One of the nodes which correctly decode the data, then acts as a relay and retransmits the data in the second time slot. The destination then uses the two received data to decode the correct data. If the channels between the source and destination and relay and destination are independent, the destination has a higher probability of decoding the data correctly. Thus, cooperation between the nodes could potentially improve the reliability of the reception of data. The splitting of transmission into orthogonal transmissions is necessary if half-duplex transceivers are employed, transceivers which cannot receive and transmit data simultaneously on the same frequency band.

We are inherently assuming that at least one of the other nodes in the system decodes the data successfully, which is a valid assumption when there are a large number of neighboring nodes.

If the source node broadcasts at a low rate, all the nodes can decode the data. In particular, nodes closer to the destination node can decode the data. In the second time slot, the nodes with the best channel to the destination node, could then forward the data. On the other hand, if the source node broadcasts at a high rate, then only the nodes closer to the source node can decode the transmission. Only one of these nodes will have to forward the data in the second time slot. Hence, the rate to the destination depends both on the source-relay and the relay-destination channels. Therefore, when there are multiple potential nodes that can act as a relay, picking the best relay node requires finding the relay which has good channels both from the source and to the destination. The problem of picking the best node to relay the data gets relevant if we constrain that only one of the nodes needs to forward the data. Recent work has shown that only one of the nodes forwarding the data in the second time slot is both bandwidth and power efficient [12], [14].

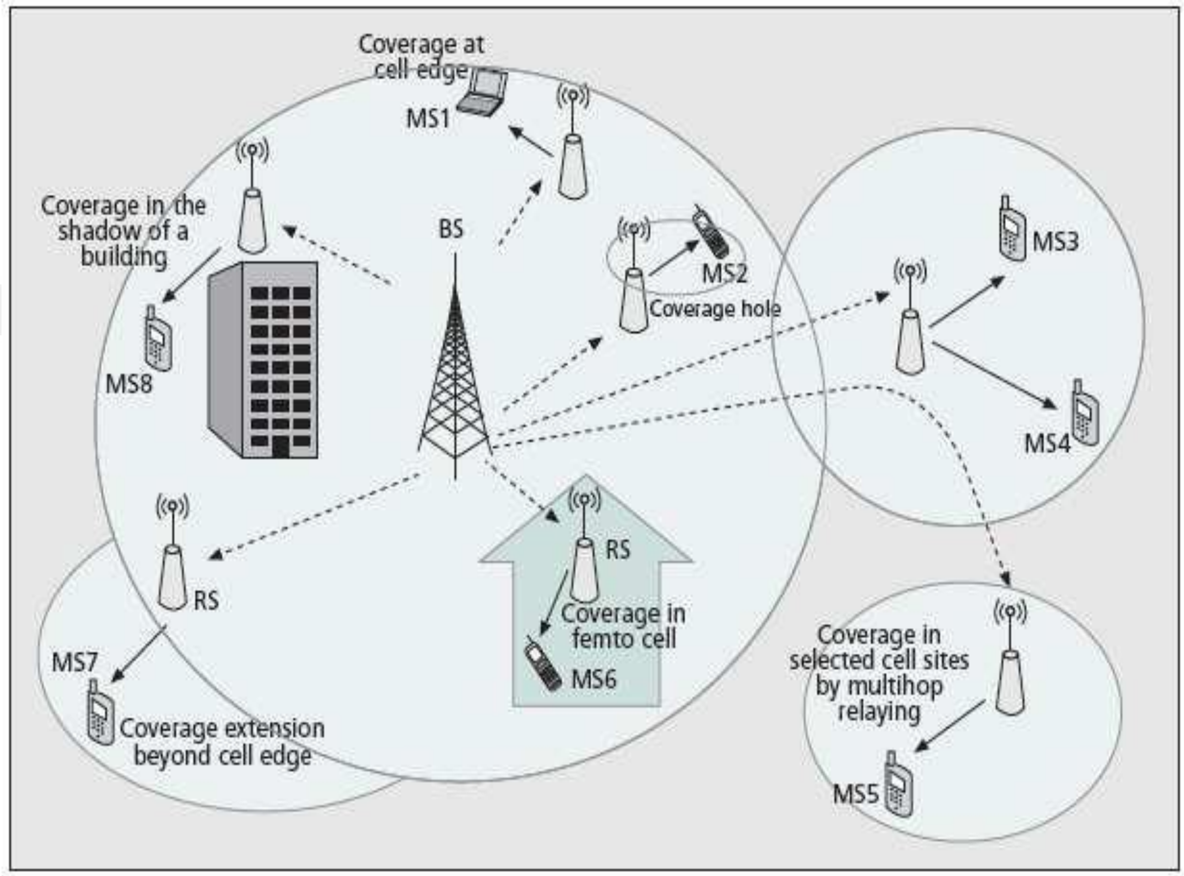


Figure 12. Relay node disposition in a wireless communication [14].

This problem of picking the best relay gets more complicated when the nodes have limited power. Because a relay must now divide its available power between all flows it supports, a relay that is best for a single flow may not remain the best overall and relay selection becomes a combinatorial problem. In these cases, selection of the best relays for every communication stream in a system has to be done jointly.

Our system model, hence, is a broadband access network. We assume that the users are relatively immobile and that the channels vary slowly enough for the users to be able to estimate the channel accurately and feedback this information to the BS.

When users are scattered in the cell, there is a possibility that a user has very poor channel to the BS. This typically is the case when the user is masked by a building. One of the ways a service provider ensures that most of the users, irrespective of their locations, receive high data rates are by increasing the number of BS. Doing so helps in mitigating the effects of large scale fading to some extent. In this thesis, we explore the possibility of installing relays in a cell, as an alternative to installing more base-stations. As mentioned before, these additional relays can help mitigate both the large and small scale fading, resulting in possible increase in data rates for a fixed power expended [15],[16].

These relays are installed at locations where they have a good line of sight (LoS) connection to the BS. They listen to the BS and retransmit the data. Hence, if both the BS and the relays forward the same data to the user, the user has a high probability of decoding the transmitted data correctly. If the installed relays did offer higher data rates, this could be translated to an increase in the area of coverage of a BS [16].

### 3.3. Types of Relay Transmission

Serial relay transmission: The Serial relay transmission is used to provide the power gain in long distance communication and range-extension in shadow regions In this topology signals propagate from one relay to another relay and the channels of neighboring hop are orthogonal to avoid any interference.

Parallel relay transmission: The Parallel relay transmission is used when the serial relay transmission suffers from multi-path fading. For outdoors and non-line-of-sight propagation, signal wavelength may be large and installation of multiple antennas is not difficult sometimes not even possible. To increase the robustness against multi-path fading, parallel relay transmission can be used. It provides power gain and diversity gain at the same time [17].

### 3.4. Benefits of Cooperative-Diversity Systems

Reduced Power: If we trade the signal-quality improvement with the transmission power, the total transmission power of cooperative diversity can be reduced to be significantly less than the transmission power of the traditional direct transmission for the same end-to-end SNR or received power levels

Better Coverage: The extension the signal coverage and communication range to remote users experiencing large path-loss by utilizing the signal-quality improvement (in terms of higher SNR and received power). Also, if the relay locations are carefully chosen, cooperative diversity can overcome large shadowing that may exist in the direct link due to blockage by large objects.

### 3.5. Major Challenges of Cooperative-Diversity Systems

Resources Over-Utilization: cooperative-diversity systems need M+1 channels to send one message from the source to the destination using M relays

Additional Delay: When cooperative-diversity systems (with M relays) use TDMA as the access scheme, M+1 time slots are needed to send the signal from the source to the destination.

Complexity

- Signal Combining and Detection
- Channel Estimation
- Relaying Protocols
- Synchronization
- Resource Management

Unavailability of Cooperating Nodes: there is no guarantee that other nodes will be always available or willing to cooperate.

Security Threats: serious challenge in securing users’ data simply because different users share their data with each other [18].

### 3.5. Relay Automatic Repeat Request (ARQ)

In cooperative communication, the transmission is done in two stages. Here, Mobile Station (MS) transmits a packet in first phase, which is received by the Relay Station (RS) and Base Station (RS). When the direct transmission to Base Station is successful, Base Station sends Acknowledgement (ACK) which is received by MS and RS. After receiving ACK from BS, RS do not forward the received packet and MS transmits the next packet. When the direct transmission is in error, BS stores the erroneously received packet and sends Negative Acknowledgement (NACK) which is received by the MS and RS. On receiving NACK, RS forwards the packet to BS in second stage. BS performs Maximal Ratio Combining (MRC) on the received copies of the packet. If the MRC joint packet is in error, BS request the retransmission of the packet by sending NACK and then MS resend the packet. Here, occurrence of the second stage depends on the successful or unsuccessful reception of the packet in the first stage. If the transmission is effective in first stage, the second stage does not occur. In this type of procedure the information is repeated hardly. In other relaying schemes, the same information is transmitted two times over the entire cooperative transmission period, which leads to inefficient use of bandwidth. Hence there is a saving of bandwidth in incremental relaying scheme. In this model, we assume error free ACK/NACK.

For reliable transmission in multi-hop cellular networks, ARQ protocol is usually employed for the retransmission of erroneously received packets. End-to- end and hop-by-hop ARQ are the habitually implemented multi-hop ARQ procedures.

In the end-to-end ARQ protocol, the RS merely forwards the data and ACK/NACK packets between the BS and the MS. The packet retransmissions are performed by the BS. This protocol ensures end-to-end reliability of the packet transmission, but the retransmission of packets by the BS leads to very low throughput performance as compared to protocols in which RS performs the retransmissions. Also, due to the high transmission error rate on the RS-MS link, the ACK/NACK from the MS to the BS may be delayed. Another disadvantage is that the power of a strong BS-RS link is not utilized by the end-to-end ARQ protocol. The BS schedules packets for transmission based on the ACK/NACK feedback from the MS, Thus, it will avoid transmission when the RS-MS link is bad, even though the BS-RS link might be good[19].

In the hop-by-hop ARQ procedure, ARQ is performed independently on every multi-hop link. Thus, packets sent to the MS are first transmitted by the BS to the RS. In case of packet loss or decoding error, RS sends a NACK to the BS requesting for retransmission of the packet. In case of packet error on the RS-MS channel, the RS performs the retransmissions to the MS. This protocol eliminates the low throughput performance and BS-RS channel underutilization problems of the end to-end ARQ scheme.

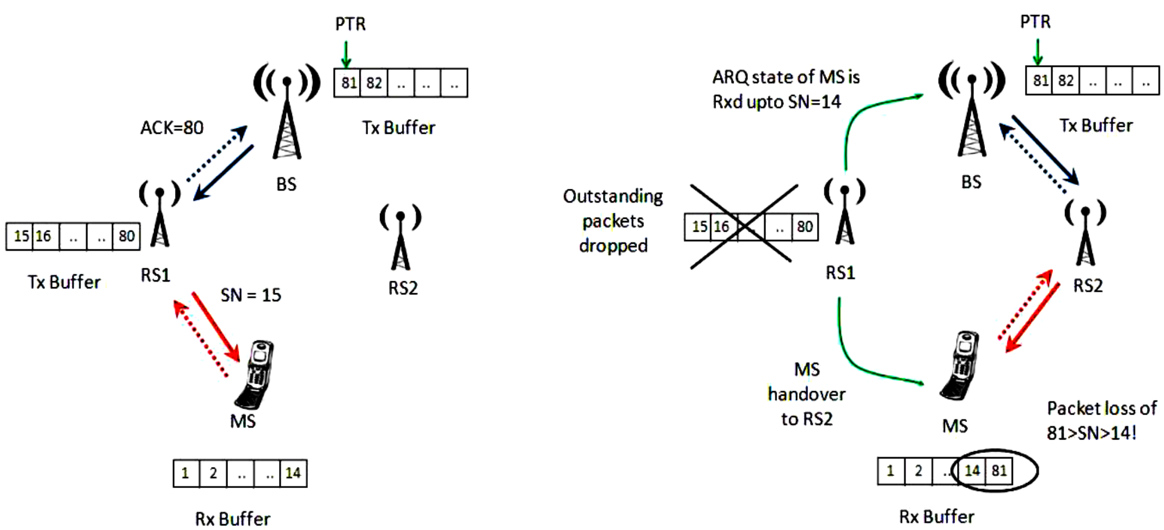


Figure 13. Illustration of packet loss during handover in hop-by-hop ARQ [19].

However, the BS is unaware of whether the packet has successfully reached the MS. It is only concerned with ensuring successful transmission of the packet on the BS-RS link. Due to this, hop-by-hop ARQ presents a major problem of packet loss in case of RS to BS or inter-RS handover. The problem has been illustrated in Fig.13. When the BS receives ACK from the RS, it will clear the packets from its transmit buffer. The RS will maintain a queue of packets pending for transmission to the MS. Now if the MS hands over to the BS or another RS, the handoff target will not have a copy of these pending packets because the BS has already cleared them from its buffer. Transferring these packets from the RS to the BS and then to another RS will cause a huge signaling overhead and thus delay in handover. Thus, using the hop-by-hop ARQ protocol will result in gross packet loss in the event of RS to BS and inter-RS handover. In a relay-assisted cellular network, this packet loss will be high because of frequent handover of the MS between RSs [19, 20].

To avoid packet loss during handover, [21] suggests a scheme in which the BS multicasts the data to all its subordinate RSs, so that when an MS hands over, the target RS has the data pending in queue at the serving RS. However, multicasting the data is a large signaling overhead and requires unnecessary buffer space at all the RSs.

### 3.6. Channel and Handover Model

We consider a single cell scenario with downlink packet transmission from the BS to an MS via RS. For our analysis, we assume a time-slotted system. In each time slot, the wireless channel can be either in the good or bad state. In good state, any transmitted packet is received successfully and in bad state the packet is received in error and discarded. The

BS-RS link will be referred to as the relay link, and the access link as the access link.

We assume a stop-and-wait packet transmission protocol where in every time slot, one packet each is transmitted on the relay and the access links. The relay link channel state is modeled as a Bernoulli independent and identically distributed (i.i.d) random variable across slots, with probability $p_g$ of being in good state and probability $p_b = 1 - p_g$ of being in bad state. Since the BS and RS are stationary, an i.i.d relay channel is a reasonable assumption. We further assume that the relay link and access link channels are independent.

Our objective in this chapter is to determine the packet loss during handover. For this, we need to evaluate the queue length at the RS at the time of handover. However, this is difficult to determine since handover occurs when the signal to noise ratio (SNR) of an MS falls below a threshold for sufficient time. This in turn depends upon the channel condition and the speed of the mobile.

We make a simplifying assumption that if an MS experiences a bad access channel for N consecutive time slots then an inter-RS handover is executed. Further, we assume that a target RS with good access channel is always available for handover. Let p1 and p2 be the good-to-bad and bad-to-good transition probabilities of the channel, and 1−p1 and 1−p2 be the transition probabilities of remaining in good and bad states respectively.

The access link state is modeled by a discrete time Markov chain as shown in Fig.14, where state 0 corresponds to good channel state and state j (for j ∈ [1,N]) indicates that the access channel has been in bad state for j consecutive slots. If the access link is in state j (for j ∈ [1,N)), it can return to state 0 with probability p2 or it can move to state j +1 with probability 1−p2. When the channel reaches state N, a handover is executed, and due to our assumption of target RS being always available, the system returns to state 0 with probability 1.

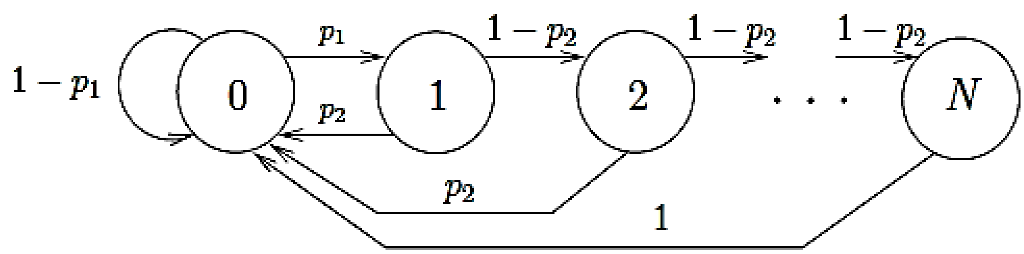


Figure 14. Channel and handover model for the RS-MS link

As already explained, we consider a single cell scenario with downlink packet transmission from the BS to an MS via RS. We assume that the BS always has a packet to transmit. We assume that acknowledgements (ACKs) and negative acknowledgement (NACKs) to the transmitted packets are always received without error. We consider that the buffer at the RS can hold a maximum of M packets. When the buffer is full, the ARQ can signal this to the BS by delaying the ACKs, thus avoiding further queue build-up.

Each time slot is divided into four mini slots, first for an RS to MS packet transmission, followed by an ACK/NACK slot in which the MS sends an ACK to RS if the packet was successfully received and a NACK otherwise. In the third mini slot, the RS sends an ACK or NACK for the packet received from BS in the previous time slot. If the buffer at the RS already full with M packets, the RS does not send an ACK to BS even if the packet has been successfully received. In this case, the BS does not transmit any packet in the fourth mini slot and waits for an ACK or NACK. If an ACK or NACK is received in the third mini slot, the BS sends a new packet or retransmits the previous packet to the RS in the fourth mini slot1. In hop-by-hop ARQ, the packets queued at the RS are lost during inter-RS handover. By employing this mechanism of RS delaying ACKs to BS, there is no packet loss due to buffer overflow at RS and the only cause of packet loss is handover.

### 3.7. Cooperative Transmission Protocols

The CC protocols used in the RS are either AAF or DAF. These protocols define how the received data is processed at the RS before the data is sent to the destination.

Other Relaying Techniques

- Hybrid AAF and DAF: The relay switches between AAF and DAF depending on the channel conditions
- Demodulate-and-forward: The relay demodulates the received signal and then forwards the signal to the destination.
- Incremental Relaying: Limit the cooperation to needed conditions
- Best-Relay Selection: Is used to increase the resource consumption. In this case, the best relay only is selected to forward the signal to the destination.

#### 3.7.1. Amplify and Forward (AAF)

The main idea behind the AAF protocol is that the signal received by the relay node is amplified and then re transmitted to destination node. By amplifying the received signal the relay node amplifier as well the noises in the signal which cause the AAF protocol to suffer from noise.

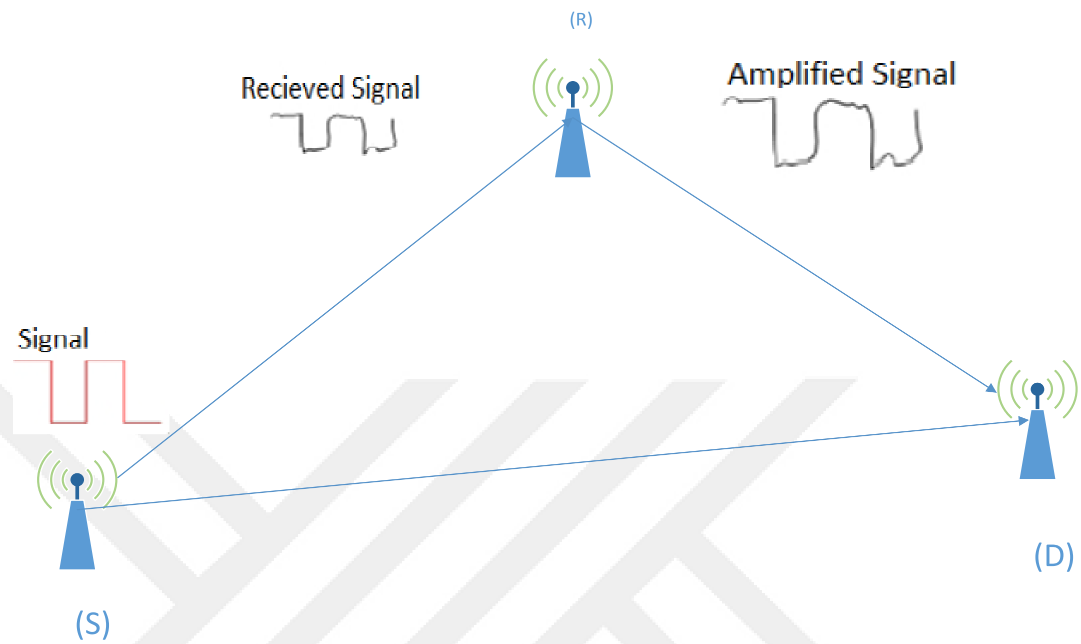


Figure 15. Amplify and Forward System Model [22].

The Figure 15 shows the simple representation of an AAF protocol with a source node, relay node and destination node. The signal at relay node is distorted by the noise and amplifier to be sent to destination node.

The received signal by relay node and destination node can be represented by [22]

$$y_{sr} = \sqrt{P} h_{sr}.x + n_{sr} \tag{21}$$

$$y_{sd} = \sqrt{P} h_{sd}.x + n_{sd} \tag{22}$$

In the equation (21) and (22) $P$ is the signal transmitted power from the source node, transmitted signal information symbol is represented by $x$, and $n_{sr}$ and $n_{sd}$ are additive noise in source to relay link and relay to destination link respectively. The channel fading of source to relay link and relay to destination link are represented by $h_{sr}$ , $h_{sd}$ .

In this protocol, the relay amplifies the signal from the source with the amplification factor $\beta$ which is inversion proportion to the zero –mean complex Gaussian complex variable with a variance $N_o$ from the mathematical representation of real and imaginary part with the equation$z = x + ij$.

$$\beta = \frac{\sqrt{P}}{\sqrt{P|h_{sr}|^2 + N_o}} \tag{23}$$

In our equation (23) $\beta,$ is the amplification factor of the relay node, $P$ is the transmitting power from the source to relay link and $h_{sr}$ is the fading in source to relay link. The received signal at the destination node is given by [23], [24]

$$y_{rd} = \frac{\sqrt{P}}{\sqrt{P|h_{sr}|^2 + N_o}} h_{rd} y_{sr} + n_{rd} \tag{24}$$

From equation (24) $h_{rd}$ represent the channel coefficient from relay to the destination and $n_{rd}$ is the noise from relay to destination channel. The channels source to relay and relay to destination node are independent and the noise in those channels are different, the received signal with the glossary noise is represented by the equation below

$$y_{rd} = \frac{\sqrt{P}}{\sqrt{P|h_{sr}|^2 + N_o}} \sqrt{P} h_{rd} h_{sr} x + n'_{rd} \tag{25}$$

Where,

$$n'_{rd} = \frac{\sqrt{P}}{\sqrt{P|h_{sr}|^2 + N_o}} h_{rd} n_{sr} x + n_{rd} \tag{26}$$

The variance of total noise $n'_{rd}$ wich is the addition of the noise from two different channel is represented by

$$N'_o = \left(\frac{P|h_{rd}|^2}{P|h_{sr}|^2 + N_o} + 1\right) N_o \tag{27}$$

Assuming that the system has one source and N number of relays, the received signal at both the relays and the destination node will be represented by

$$y_{sd} = \sqrt{P} h_{sd} x + n_{sd} \quad (28)$$

$$y_{sri} = \sqrt{P} h_{sri} x + n_{sri} \quad (29)$$

For i = 1, 2, . . . , N, $n_{sd}$ and $n_{sri}$ denote the additive white Gaussian noise at the destination and the $i^{th}$ relay respectively, and $h_{sd}$ and $h_{sri}$ are the channel coefficients from the source to the destination and the $i^{th}$ relay node respectively. Each relay node amplifies the received signal from the source and transmits it to the destination. The received signal at the destination node from $i^{th}$ number of relays will become

$$y_{rid} = \frac{\sqrt{P_i}}{\sqrt{P|h_{sri}|^2 + N_o}} h_{rid} y_{sri} x + n_{rid} \quad (30)$$

From the equation (30), $P_i$ represents the transmitting power of $i^{th}$ relay node. And $P$ is the source to relay transmitting power. The channel coefficients, $h_{sd}$, $h_{sri}$ and $h_{rid}$ represent the channels coefficients of the source to destination, source to $i^{th}$ relays and $i^{th}$ relays to destination respectively.

### 3.7.2. Decode and Forward (DAF)

In DAF relaying, the relay decodes the received signal from the source and forwards it to the destination. In this process, DAF relay re-encode the signal and then retransmits it to the destination. Relay transmits the received information from the source to the destination only when the direct transmission from source to destination fails.

A simple representation of DAF scheme is shown in Figure 16, the representation is made of three node, source node, relay node and destination node. The signal from the source is decoded by the relay check the errors and correct them. After the correction of the errors the relay node will re-encode again the signal and then re transmit it to the destination node. DAF suffer from errors if the relay node fail to decode the signal correctly and only destination node can have the signal from the source only.

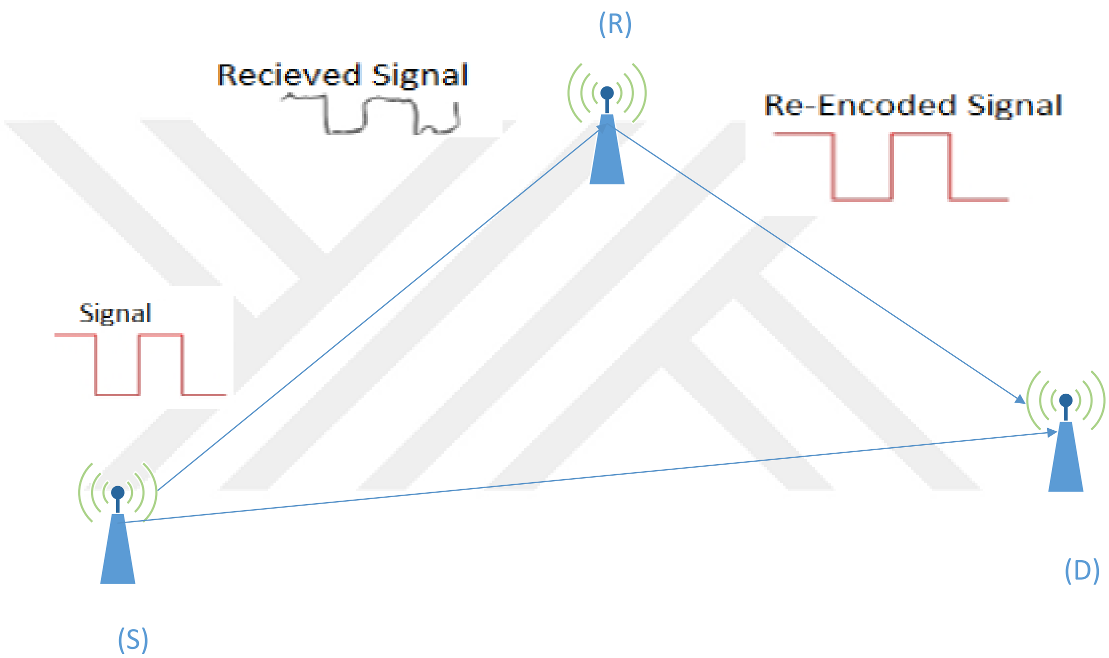


Figure 16. Decode and Forward System Model.

Then $y_{sd}$ and $y_{sr}$ , the received signals at destination and relay respectively, are given by,

$$y_{sd} = \sqrt{P}\, h_{sd}x + n_{sd} \tag{31}$$

$$y_{sr} = \sqrt{P}\, h_{sr}x + n_{sr} \tag{32}$$

SNR at the Transmitter side between the transmitter and relay is given by,

$$\gamma = \frac{P}{N_o} \tag{33}$$

SNR on the source to destination link is,

$$\gamma_{sd} = \frac{P}{N_o}|h_{sd}|^2 \quad (34)$$

Signal Received at the Destination from relay is given by $y_{rd}$. We assume that the noise terms $n_{sr}$ and $n_{rd}$ are independent. We also assume that the channel coefficients $h_{sr}$, $h_{rd}$ and $h_{sd}$ are available at all the nodes [23].

The destination combines the received signal from the source and the signal from relay station. The SNR at the destination is the sum of the received SNRs from both source to relay and relay to destination channel. The output signal at the destination is given by,

$$y = a_1 y_{sd} + a_2 y_{rd} \quad (35)$$

Where weights $a_1$ and $a_2$ are determined to maximize the SNR at the output of combiner. We assume that fading coefficients are circularly symmetric, zero mean, complex Gaussian random variables which model the Rayleigh fading. The source-destination, source-relay and relay-destination links undergo independent Rayleigh fading.

In the Selective DAF relaying scheme if the SNR at the relay increases above certain threshold, the relay decodes the received signal correctly and forwards the decoded information to the destination. If the SNR at the relay falls below the value of threshold, the relay is idle. If the source to relay SNR is below threshold, the relay cannot decode the message correctly and therefore in Selective DAF relaying scheme, the source is allowed to retransmit the message if the relay is not capable to decode the message properly.

To get an end to end rate of R, the message must be encoded with a rate of 2R in cooperative transmission scenario. Hence the source encodes the message with a rate 2R. Decoding at the relay is correct if the transmission rate is less than or equal to the capacity of the source-relay link.

$$2R \leq \log_2(1+\gamma_{sr}) \tag{36}$$

The capacity of source-relay link is given by,

$$c_{s-r}(\gamma_{sr}) = \log_2(1+\gamma_{sr})\text{Bits/channel use} \tag{37}$$

In this equation,

$$\gamma_{sr} = \frac{P|h_{sr}|^2}{\sigma_r^2} \tag{38}$$

From the above description of incremental relaying, it is clear that the rate is random in this protocol. If the first phase is successful, the rate is 2R, if the first phase transmission is in outage, the rate is R. The average rate of transmission is given by,

$$\bar{R} = 2R\ Prob(\gamma_{sd} \geq 2^{2R}-1) + R\ Prov(\gamma_{sd} \leq 2^{2R}-1) \tag{39}$$

Suppose the rate of transmission at source is R, the outage occurs when R > C S-R. Incremental relaying scheme has higher bandwidth efficiency because the phase of relay-destination cooperative transmission occurs only when the transmission fails in phase source-destination. In this scheme, when the transmitted signal is x, the received signal at destination and Relay is given by equation given up. Here, x may be a block of symbols. The transmission in phase source-destination is successful when

$$2R \leq \log_2(1+\gamma_{sd}) \tag{40}$$

Where $\gamma_{sd}$ is the SNR of the direct link from source to destination and is given by

$$\gamma_{sd} = \frac{P|h_{sd}|^2}{\sigma_r^2} \tag{41}$$

In this case end to end rate is 2R. When the direct transmission is in outage,

$$2R > \log_2(1 + \gamma_{sd})\,, \tag{42}$$

The destination will send a NACK to inform the source and relay about the unsuccessful transmission. In this case relay will forward the signal to destination in phase relay-destination. The received signal at destination is given by,

$$y_{rd} = h_{rd}\sqrt{P}\,x + n_{rd} \tag{43}$$

The signal received in phase relay-destination is,

$$y_{rd} = h_{rd}\sqrt{P}x + n_{rd} \qquad \text{if } \gamma_{sr} \geq 2^{2R} - 1 \tag{44}$$

$$y_{sd} = h_{sd}\sqrt{P}x + n_{sd} \qquad \text{if } \gamma_{sr} \leq 2^{2R} - 1 \tag{45}$$

The signals received in phase source to destination and phase relay to destination are combined at the destination. We assume that the source or relay address is appended to the packet in phase relay to destination which will enable the destination to recognize the transmitter and determine the weighing factor for MRC. In this situation the end to end rate is R. The SNR at the output of the MRC is given by [22], [23], [24].

$$\gamma = \gamma_{sd} + \gamma_{rd} \tag{46}$$

Where,

$$\gamma_{rd} = \frac{P|h_{rd}|^2}{\sigma_d^2} \tag{47}$$

### 3.8. Simulation Results and Discussion

#### 3.8.1. Amplify and Forward (AAF)

The total power P of the system is the power used by source to transmit the signal to destination.

$P = Power\ from\ the\ source\ to\ destination,$

The total power of the system is given by the power used by source to transmit signal to relay and the power used by relay to transmit signal to destination.

$P = Power\ from\ \ Source\ to\ Relay + Power\ from\ Relay\ to\ destination = P1 + P2$

For our simulation we will be varying the Power from the Source to Relay($P1$) and the power from the Relay to destination($P2$) and compare the result from the non cooperative result in both AWGN and Releigh fading channel.

When the Transmitting power of Source to relay node($P1$) and the Transmitting power of Relay to Destination($P2$) are the same and are equal to the total transmitting power ($P$).

In the case of $P = P1 = P2$

The results shown in Figure 17 shows the BER of a signal passing in AWGN with and without fading, and with and without line-of-sight with the power of source to receiver channel equal to the power of source to relay channel and power from relay to receiver channel, we can see simple that when there is fading in a system and the power is less is difficult for the signal to reach the receiver with good quality

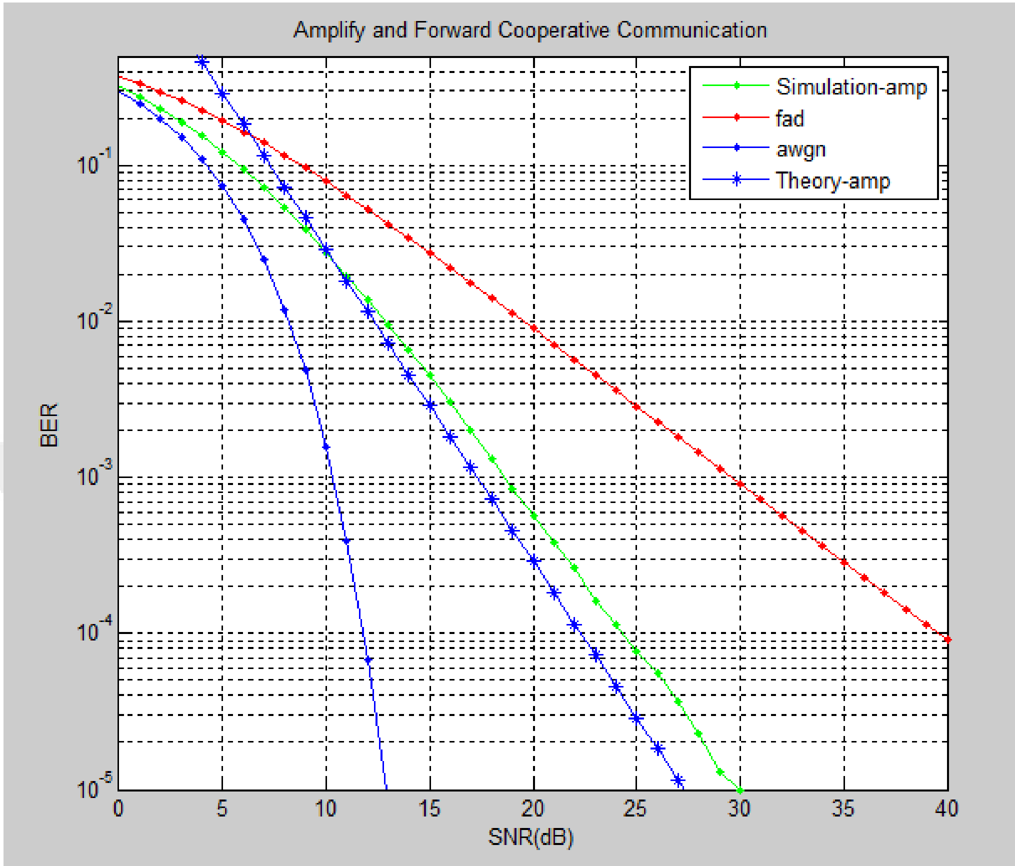


Figure 17. The power of source to destination, source to relay and relay to destination are equal.

When the Transmitting power of Source to Relay node and the Transmitting power of Relay node to Destination are the same and are equal to the half of total transmitting power.

In the case of $P1 = P2 = P/2$

This results in Figure 18 was obtain when the source to relay channel and relay to destination power was reduced to the half of the power of source to receiver channel which is also called the total power, its seen from the results that when you reduce the power of relay receiver channel the BER will increase cause looking at the Figure 17. At SNR of 20 dB the BER was about to reach $10^{-4}$ but in fig. 18 at SNR of 20 dB the BER has increased to $10^{-3}$, we can see that by reducing the power we can increase the BER but our goal is to reduce it.

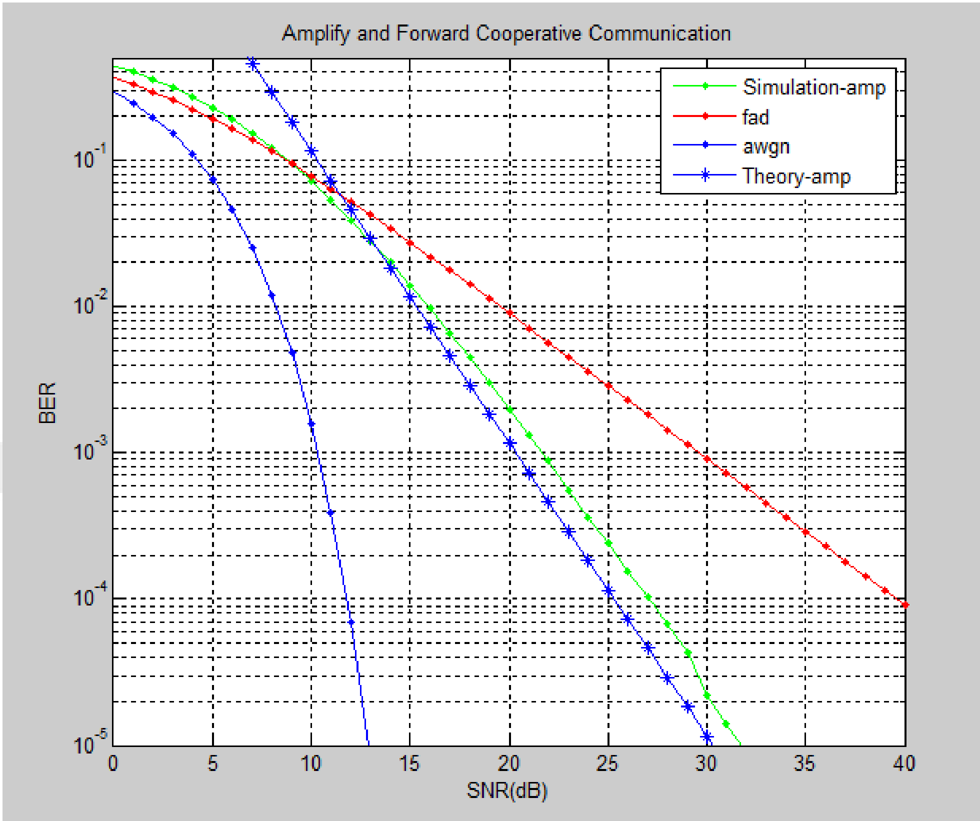


Figure.18. The power of source to relay and relay to destination are same and equal to half of the source destination power.

When the Transmitting power of Source to Relay node and the Transmitting power of Relay node to Destination are the same and are equal to 1/10 of total transmitting power.

In the case of $P1 = P2 = P/10$

The results in Figure 19 is to show how the BER can continue to icrease if we can continue to reduce the power of source relay channel and the power of relay to receiver channel because of the fading of the system.

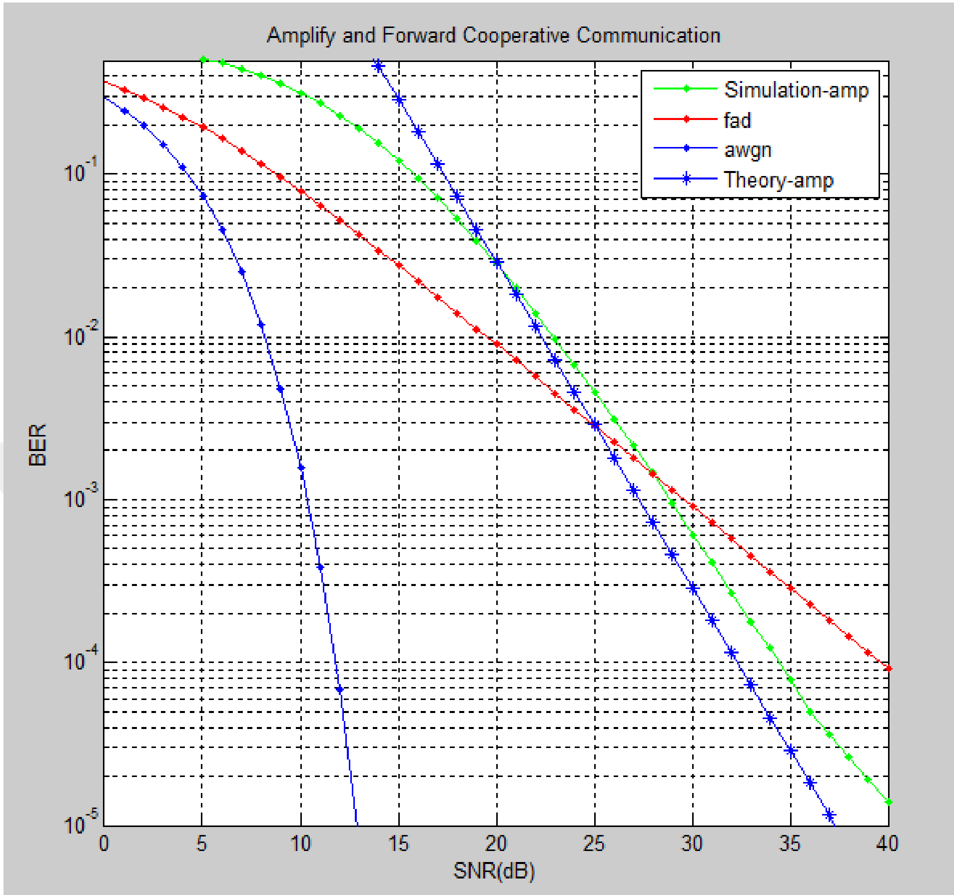


Figure 19. The power of source to relay and relay to destination are same and equal to the source destination power over ten.

When the Transmitting power of Source to Relay node and the Transmitting power of Relay node to Destination are the same and are equal to double of total transmitting power.

In the case of $P1 = P2 = 2P$

The reults in Figure 20 shows how we can reduce the BER by increasing the power of source to relay channel and Relay to receiver channel, by looking at SNR of 20 dB we can see that is below $10^{-4}$ which is better than the results when the power is less than that.

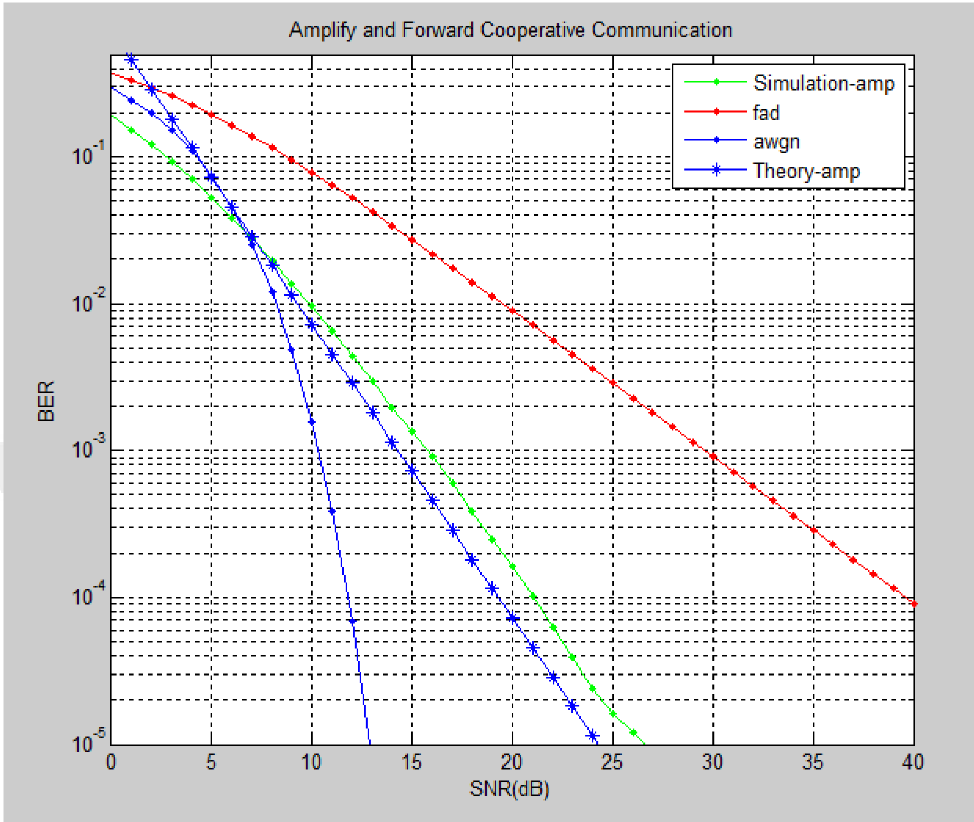


Figure 20. The power of source to relay and relay to destination are same and equal to double of the source destination power.

When the Transmitting power of Source to Relay node and the Transmitting power of Relay node to Destination are the same and are equal to 10 times of the total transmitting power.

In the case of $P1 = P2 = 10P$

The results in Figure 21 is showing again the increasing by 10 times the power of source to Relay and Relay to receiver channel, looking at the SNR 20 dB we can see that the BER is $10^{-5}$ this is showing that the more you increase the power the more the BER is decreasing.

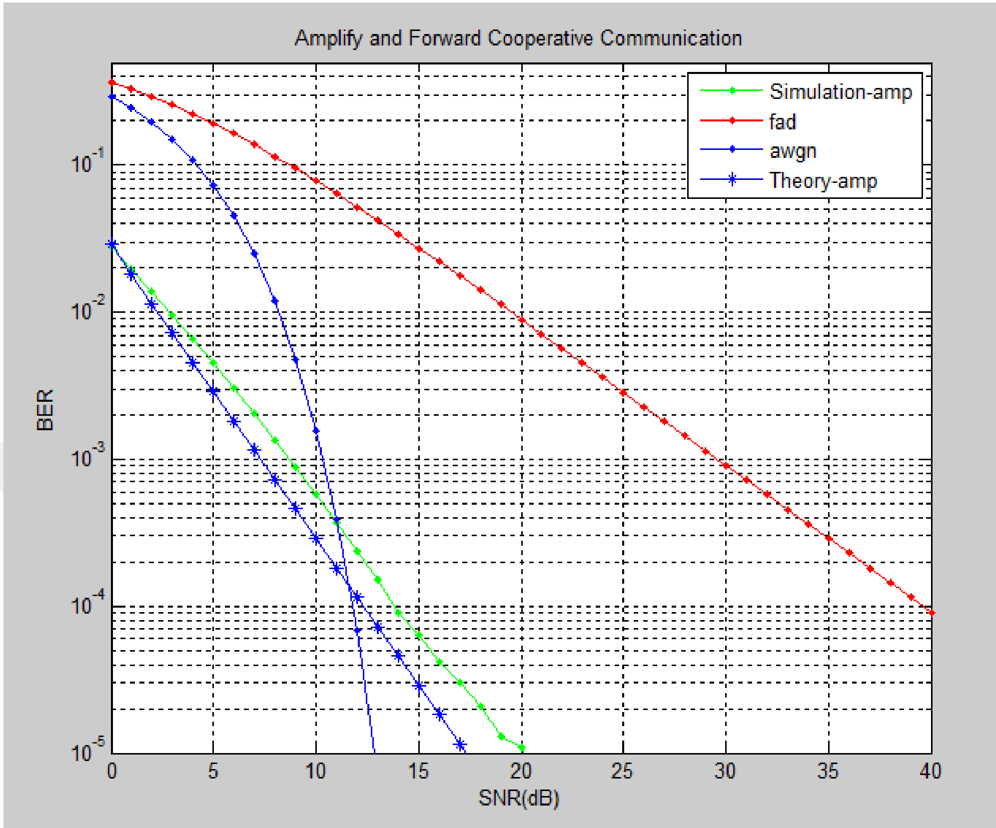


Figure 21. The power of source to relay and relay to destination are same and equal to ten times the source destination power.

When the Transmitting power of Source to Relay node and the Transmitting power of Relay node to Destination are the same and are equal to 100 times of total transmitting power.

In case of $P1 = P2 = 100P$

The results in Figure 22 is showing how the BER is decreasing quickily because of a very high of the power, the power was increased to 100 times, we can see that at only the SNR of 10 dB the BER is about $10^{-5}$, our system goal is to reduce the BER at the low level possible.

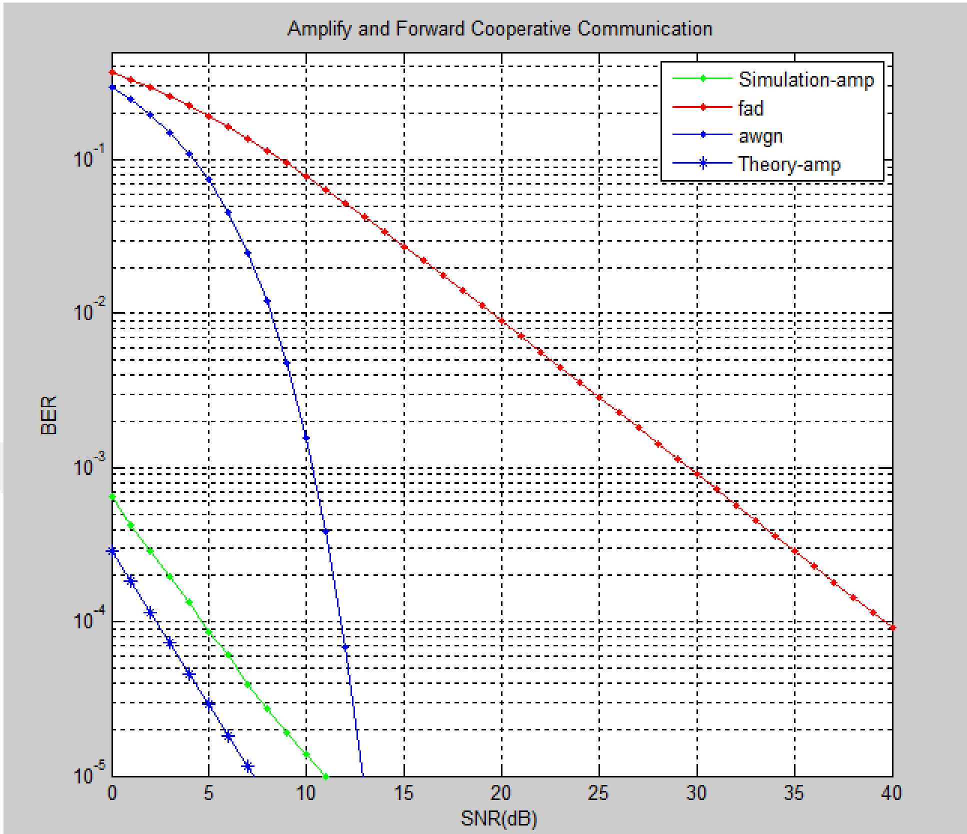


Figure 22. The power of source to relay and relay to destination are same and equal to hundred times the source destination power.

When the Transmitting power of Source to Relay node and the Transmitting power of Relay node to Destination are the same and are equal to 1/100 of total transmitting power.

In the case of $P1 = P2 = P/100$

The results in Figure 23 is showing how the BER is increasing quickily by making the power very low in reducing it to100 times, we can see that the SNR of 40 dB the BER is about $10^{-4}$, our system goal is to reduce the BER at the low level possible so this is the bad results for us.

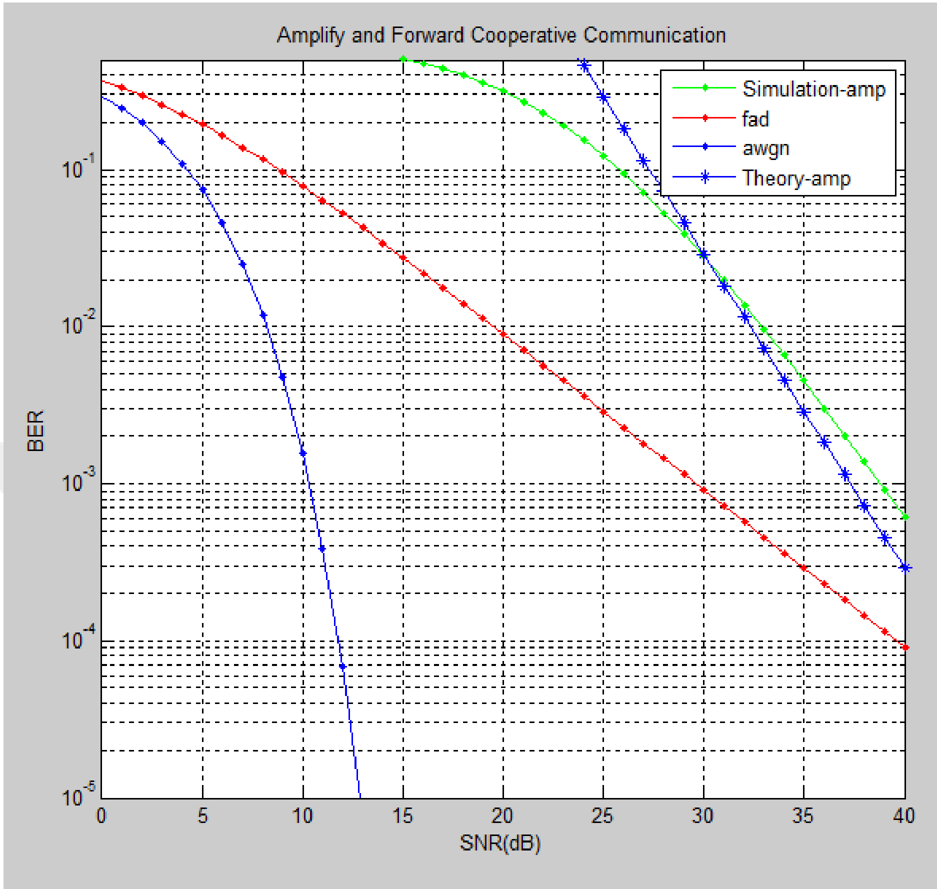


Figure 23. The power of source to relay and relay to destination are same and equal to the source destination power over hundred.

### 3.8.2. Decode and Forward (DAF)

For DAF the received signal at the relay node is first decoded and then re-encoded. While decoding the signal, relay try to remove all the noise the signal got from the source to relay channel so that they will be  no amplified noise in the to be sent to destination. For relay to decode the message from source correctly, it requires a lot of computing time, but has numerous advantages. If the message from the source contains errors, received bit errors might be corrected at the relay node. Depending on the implementation an erroneous message cannot be sent to the destination. But it is not always possible to completely decode the source message.

The additional delay help the relay to complete decoding and processing of the message, if the relay do not have enough computing capacity, so the source message must be coded in order to protect it to sensitive data. At the relay , the incoming signal is just decoded and re-encoded bit by bit. So neither an error correction can be performed nor a checksum calculated.

First we simulate the three node cooperative relay network using the DAF relay. In DAF relaying there is processing capability presented in the relay for decoding the incoming signal and then retransmits the signal to the receiver. In this case we use fixed relaying. In fixed relaying, the relay node transmits the received signal to BS in all channel conditions. The BS combines the signal from RS with the signal from the MS.

Initially we assume there is no fading in our system. We use BPSK and QPSK modulation structures and study the effect of the modulation structure being used. We can extend our structure QAM modulation structure. We compare the BER results for different SNR using QPSK and BPSK modulation structures. Also we compare the BER results without relay and with DAF relay and MRC combining.

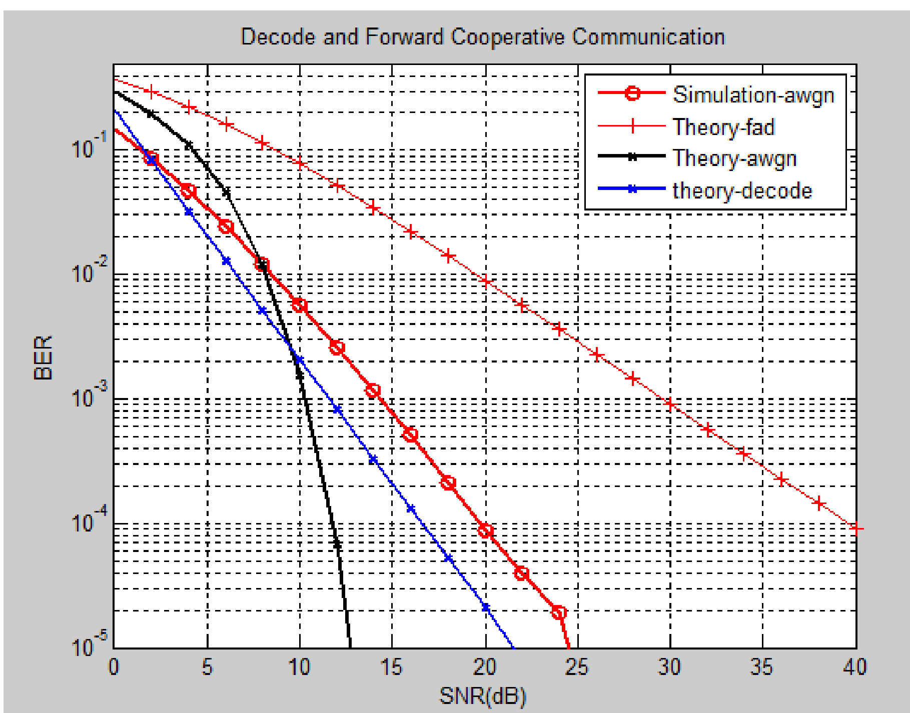


Figure 24. Decode and forward without MRC combiner.

Looking at the results in Figure 24 is showing the BER of Decode and Forward without MCR combiner and compare the results of the signal passing through AWGN with line-of-sight without Relay, at the SNR of 8 dB the results are the same and one signal is passing through AWGN with no fading and with line-of-sight and another is passing in AWGN with fading but with Decode and Forward Relay which shows the advantage of relaying communication in fading channel.

From the simulations on DAF relay without fading as shown in Figure 24, we demonstrated that the BER performance of DAF relay with MRC is better than the performance of DAF relay without MRC.

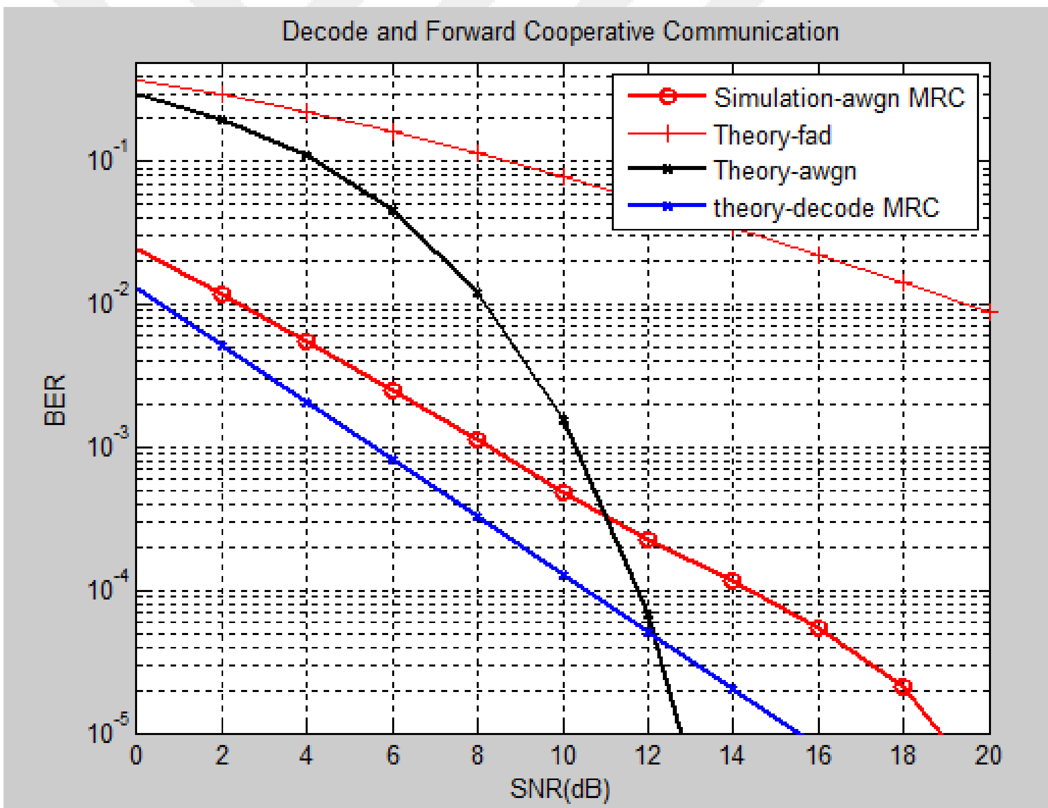


Figure 25. BER vs. SNR with DAF relay and without relay with Rayleigh fading.

The DAF performance in Rayleigh fading channel is as shown in Figure 25. The BER is degraded due to Rayleigh fading. The BER plots demonstrate the improved BER performance with DAF relay and MRC combining.

## 3.9. Comparison between AAF and DAF

While a DAF relay decodes re-modulates and retransmit the received signal, an AAF one simply amplifies and retransmits the signal without decoding. Compared to an AAF relay, the complexity of a DAF one is significantly higher due to its full processing capability. The DAF protocol also requires a sophisticated media access control layer, which is unnecessary in the AAF protocol. Overall, a DAF relay is nearly as complex as a base station. Does the performance improvement of DAF relaying overweight its complexity burden? [25].

# 4. RELAY SELECTION

In CC relay selection is a challenge task because the destination must select the better positioned and good performing relay in order to successively increase the performance of the system in terms of throughput, high data rete, lower power consumption and better BER performance. The relay is not select based only on the performance of source to destination performance but is selected according to the relay indices like Channel State Information (CSI), SNR, and BER of the relay to destination link. The relay selection is classified in three types according on how the selection and when the selection is done [25].

Group Selection: The group selection method is a selection done by the system before the transmission started. This selection is done to achieve the pre-defined performance level of the system.

On-demand selection: On-demand selection is another method done by the destination only when it is needed, this is done only if the source to destination link conditions is below the pre-defined threshold.

Proactive selection: The proactive selection is a relay selection method done during the transmission, it can be done by the source, relay or by the destination itself during the transmission.

The relay selection can be classified also regarding the relation between the bodies of the network; in this case the relay selection is classified in two types

- Cooperative relay selection
- Optimistic relay selection

The Optimistic relay selection is a type of relay selection that is done based on the local measurements. The optimistic relay selection can be also classified into other three types considering how the measurement is done in the system

- Performance based selection
- Measurement based selection
- Threshold based selection

The Figure 26 shows all the relay selection according to how the selection is done and according also to when the selection is done.

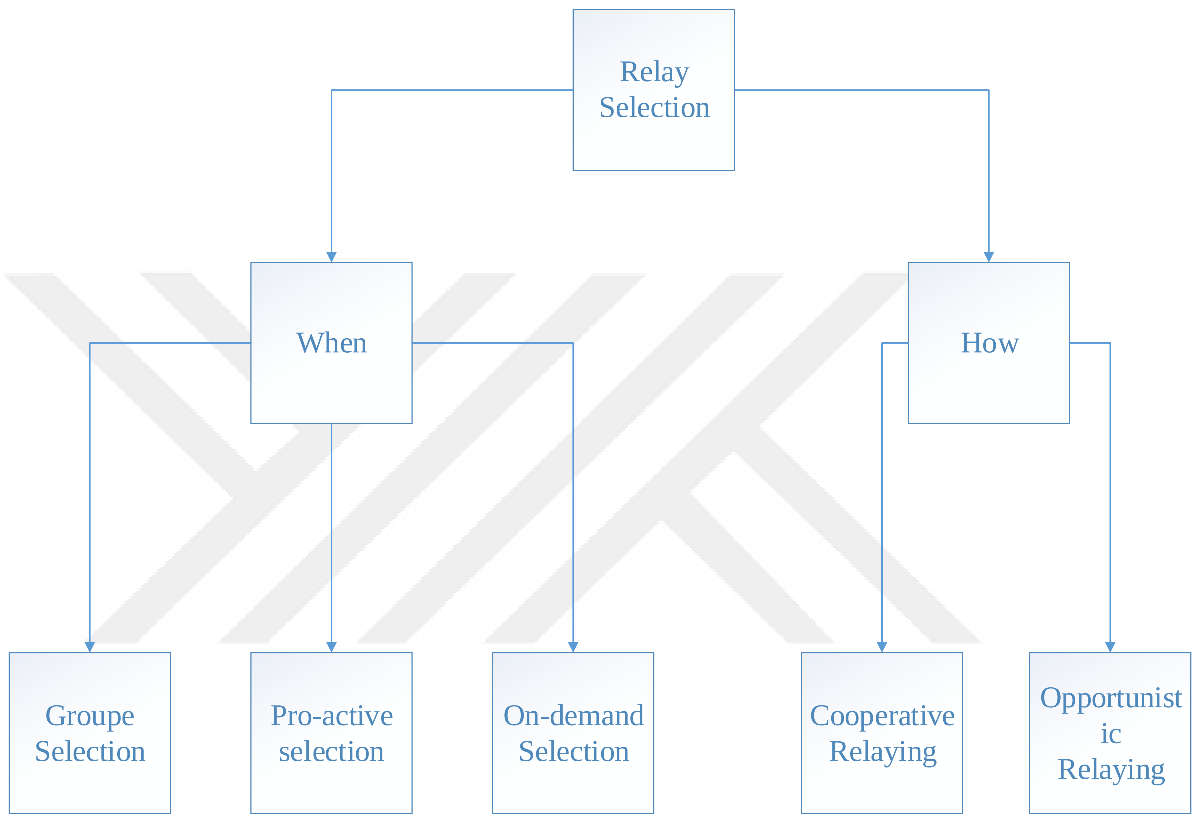


Figure 26. Types of relay selection depending on how or when [25].

The cooperative relay selection is a type of selection where all the communication nodes in the system exchange the information among them, this type of selection can be also divided into two other sub-types.

Contention based relay selection: This cooperative relay selection is done destination by selecting a set of a variable number of relays

Table based relay selection: contrary to contention based relay selection type, table based relay selection is done by the destination by selecting a fixed or controlled number of relays (two or three) according to the information kept by the source.

### 4.1. Measurement Based Relay Selection

Measurements based relay selection is a selection technique proposed by H. Shan [26]. This is a technique that requires the information about the topology in order to know the local measurements of the channel conditions instantaneously. Measurement based relay selection needs 2N channel estimations in order to be able to select the best relay in a series of N relays. In measurement based relay selection each relay by using the Request to Send (RTS) and Clear to Send (CTS) signaling estimate the channel conditions of source to relay channel and relay to destination channel. Each relay has to estimate the Channel State Information (CST) and the estimation is done according to the amplitude fading and the expected performance of the source to relay and relay to destination channel. After that all relay set an inverse value to the estimated value of CSI which is the transmission timer. The destination will select the best relay as the relay with the best suitable CSI to expire earlier. The selected relay will request to the destination to send a notification to all others relay in order to avoid the case of hidden relays.

### 4.2. Performance Based Relay Selection

Performances based relay selection is a technique that looks at the criteria of the relay like the energy efficiency and the delay. Performance based relay selection is done into two step, in the first step the source will transmit to all the relay their performance level and in the second step all the relay in response will estimates their performance level and their channel conditions. The relay with the best performance level and good channel conditions will be selected, the only problem occurs when there is no relay with the required performance level the transmission will occurs but with only the direct link of the source to destination link.

### 4.3. Threshold Based Relay Selection

Threshold based relay selection is a selection types that is based threshold. The destination set a certain threshold level in order to reduce the number of relay to enter into competition. Threshold based relay selection is done into two steps, in the first step all the relay will compare the quality of the signal received from the source with the threshold set such as BER and SNR and in the second step the relays that satisfy the threshold will enter into competition. The destination will select the relay with a lower value of SNR in the source to relay and relay to destination link. The challenge that Threshold based relay selection face is that when there is a number N of relay that satisfy the threshold they will be 2N channels estimations. Threshold based relay selection can be both cooperative and optimistic [28],[29].

### 4.4. Adaptive Based Relay Selection

Adaptive based relay selection is a selection techniques done to help only when it is need when the BER of the source to destination link decrease below the threshold due to the change in changing in conditions in that link. The adaptive based relay selection is performed into two steps as follows; in the first step the destination will compare the threshold with the received signal from the source. If the quality of the received signal from the source is below the pre-defined threshold then the adaptive based relay selection will occurs but in another way there is no need for relaying communication [30].

### 4.5. Table Based Relay Selection

Table based relay selection is a cooperative relay selection not an optimistic relay selection. Table based relay selection is a selection done according to the time of transmission between the source to destination link and source-relay-destination link. As a cooperative relay selection, the destination will check at the CSI of the source to destination link and if are not well for the performance will send the RTS/CTS to the relay to see if the relay is willing to cooperate. If the relay is read to cooperate the next step will be for the destination to compare the time of transmission in source to destination link and source-relay-destination link, if the time of source-relay-destination is lesser than the time for direct link from source to relay then the destination will choose the relay to send the information received from the source. The challenge in table based relay selection is the period of transmission and the hard handshaking of the signals and the long period transmission limit the efficiency [31].

### 4.6. Multi-Hop Based Relay Selection

Multi-hop based relay selection is a relay selection based on the repetition of relay selection for every hop from the source to destination. Multi-hop based relay selection is done into two steps, the first steps all relay try to get the information in the in the routing system and communicate between each other so that every relays get the information, in the next step the relay with a better information will communicate with the destination and retransmit the information. In multi-hop based relay selection the transmitting relay may even not have the link with the source but has a better link with the transmission, the relay will sends the information got from the intermediate relay node. In multi-hop based relay selection the repetition of relay selection in every hop send by the source will reduce the network capacity. In case the destination got different signal one from direct source link and other from the selected relay node the destination this will increase the performance and the robustness.

By conclusion we have seen that the best selection of the relay by the destination increase the performance of the system not only in BER performance but also in less power consumption, throughput, and higher data rate.

# 5. POSITION OF RELAY NODE

CC was shown in the literature and results got from the previous chapters to be the main reason to help the wireless network in terms of reliability, increase data rate, reduce power consumption and increase the capacity between two wireless devices in a network [33].

Although CC increases the capacity between two devices in a network, a wrong placement of relay node can result in a smaller capacity than the direct link between the source and destination. Therefore, the proper placement of relays involving in a network is the most important issues to gains the potential in capacity enhancement [34].

Relay Node Placement (RNP) is the main problem to determine the relays locations for better wireless coverage maintenance and a better performance of a wireless network, this problem of RNP is accounted by all the sensors involving in wireless network [35],[36]. RNP is a problem found in different wireless standards and has been a lot of research undergoing in WiMAX networks, Multi-hop Cellular Network (MCNs) and Wireless Ad hop Networks (WANETs). In all these standards and many others in wireless communication, RNP was the main idea to determine the position of all the sensors and devices involving in wireless network like the relay position, BS position and subscribers station [37],[38],[39].

Shannon’s channel capacity [43] and the distance between relay node and destination node are used to determine the SNR of the received signal at destination. For the capacity enhancement and energy efficiency we need to take into consideration the two parameter for maximize our system capacity [40].

## 5.1. Relay Position Protocol Architecture

Our network architecture consists of three nodes: a source node, a relay node and a destination node. We suppose that all the nodes are half-duplex transceivers, working on the same frequency and with the same data transmission rate. For different simulations made in this work we used different positions where the relay node is close to source at a distance of 0.25d, when the relay node is between the source and destination 0.5d and when the relay node is closer to destination at a distance of and 0.75d. The distance between the source node and the destination node is considered as d.

The Figure 27 shows the relay close to source with the distance of 25% of the total distance between the source and the destination. In this case the relay has a higher chance to have the LOS with the source rather than the destination node [41].


Figure 27. Relay node close to source.

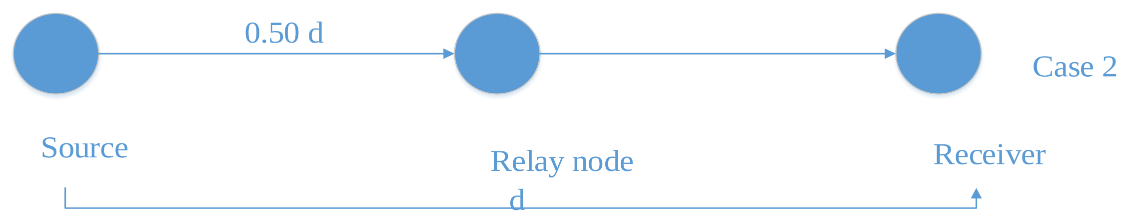


Figure 28. Relay node in the middle of source and destination.

As seen on the Figure 28 the relay node is in between the transmitter node and the destination node at the distance of 50% of the total distance between the transmitter and the receiver. At this point the relay has the same chance to have the LOS with the source and the destination.

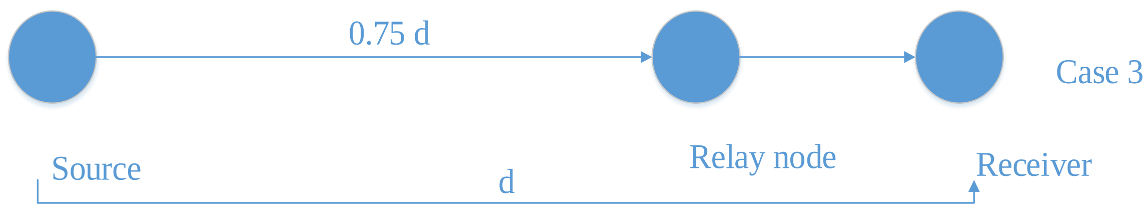


Figure 29. Relay node close to the destination case.

From the Figure 29 the relay node is close to the destination, in this case the relay has a high chance to have the LOS with the destination node rather than the source but also for the source to send to relay is more simple than to destination because the relay is closer to source compared to the distance source destination.

In our protocol we have assumed that both the source node and the relay node know if the retransmission is needed, and the source node knows if the relay node is capable of retransmitting if not source to retransmit through the direct link. We took this assumption for our system to have lower bound of Packet Error Rate (PER) [42].

The second assumption is that all the nodes in network are fixe and the channel conditions between the do not change through the whole transmission. The interference of the system with other system is not taken in to account.

The third assumption is that the frequency-flat block Rayleigh $h(t)$,on each path-loss AWGN channel stays constant through the whole period of one packet transmission.

The received signal at the destination is expressed as

$$r(t) = l(d)h(t)x(t) + n(t) \tag{48}$$

Where *x(t)* is the transmitted signal, *h(t)* frequency-flat block Rayleigh, ), *l(d)* is the path-loss and $n(t)$ is the noise. The received signal is obtained by passing the generated signal into the channel where the value of frequency-flat block Rayleigh is maintained constant during the duration of transmission.

### 5.2. Performance Measure

The performance measure is referred to us as the per cent of packets that are correctly received before their deadline. The performance measurement is a function of the distance between the node and the final destination node, d.

The retransmission of the signal is assumed to be done before the deadline of the signal if the receiver fails to decode the signal for the first received signal from the source.

### 5.3. Protocol Design

The protocol design consist of how the relaying schemes are structured, how the relay node decides if it should retransmit the packet or if it is better to let the source node retransmit.

In our protocol design we have three different situations ARQ but no Relay where the direct link only is allowed to retransmit, Always Relay where the relay retransmit the received signal even though they might be errors in it , and Only Relay when Correct where the relay node retransmit the received signal only if there is no error in it. The terms Always Relay and Only Relay when Correct, instead AAF and DAF because we only have access to the decoded bits and not the received observables, due to the usage of commercial transceivers.

#### 5.3.1. ARQ but no Relay

In ARQ but no relay scheme, the retransmission is allowed only from the source node, if the destination node detects any bit errors in the received packet it send the ARQ only through the direct link. The PER in this scheme is

$$P_{noRelay} = P_{noARQ}(d)^2 \tag{49}$$

Where

$$P_{noARQ}(d, L) \approx 1 - (1 - P_b(d))^2 , \tag{50}$$

In equation (50) $Pb$ is the probability of bit error without retransmissions, d is the distance between the source node and the destination node and $L$ is the length of the packet.

The expression in equation (49) is used assuming that all the bit errors are uniformly distributed between the packets, and when the errors appears in bursts the estimation in equation (50) is used.

### 5.3.2. Always Relay

Always relay scheme the relay will retransmit the signal if requested by the destination node but without checking the correctness of the signal. Always relay scheme is done into two steps. For the first step the source node transmits the information packet, the relay node and the destination node listen to it. In the second step the destination node checks the correctness of the received signal if not correct the relay will transmit the received signal weather the CRC have succeeded or failed. The destination node can receive packet error either if the direct transmission between source node and destination node fail or if the CRC at the relay node fail and the relay node retransmit the error packet. The PER in always node scheme is expressed as,

$$P_{always}(d) = P_{noARQ}(d)P_{noARQ}(d_{SR}) + P_{noARQ}(d)\left(1 - P_{noARQ}(d_{SR})\right)P_{noARQ}(d_{RD}) \qquad (51)$$

Where $d_{SR}$ and $d_{RD}$ are the distances between the source and relay node and the relay node and destination node respectively.

### 5.3.3. Only Relay When Correct

The only relay when correct, contrary to the always relay scheme the relay before retransmitting the signal will check the correctness of the packet, if the CRC succeed relay will retransmit the received packet if not the source node will transmit the signal for the second time.

Only relay when correct is done into two steps, for the first step the source node will transmit the information packet and both the relay node and destination node will listen to it. In the second step if the direct link fails the relay will retransmit the signal but only if the CRC has succeeded meaning relay node has a correct copy. If relay node fail to get a correct copy the source node will retransmit the signal. At the destination node errors can only occur from the direct transmission link because relay does not sends the erroneous signal.

## 5.4. Simulation Results and Discussions

The simulation was carried out according to three different protocols. Relay node close to the source node, the relay node close to the destination node and the relay node in the middle of the source node and destination node.

### 5.4.1. Relay Node Close to Source

In the previous section we have seen two scenario always relay and only relay when correct it means when the relay node is close to the source the probability of having the line of sight and get the correct bits from the source is high but the only problem will be to send that message again cause the remaining distance to the destination is long.

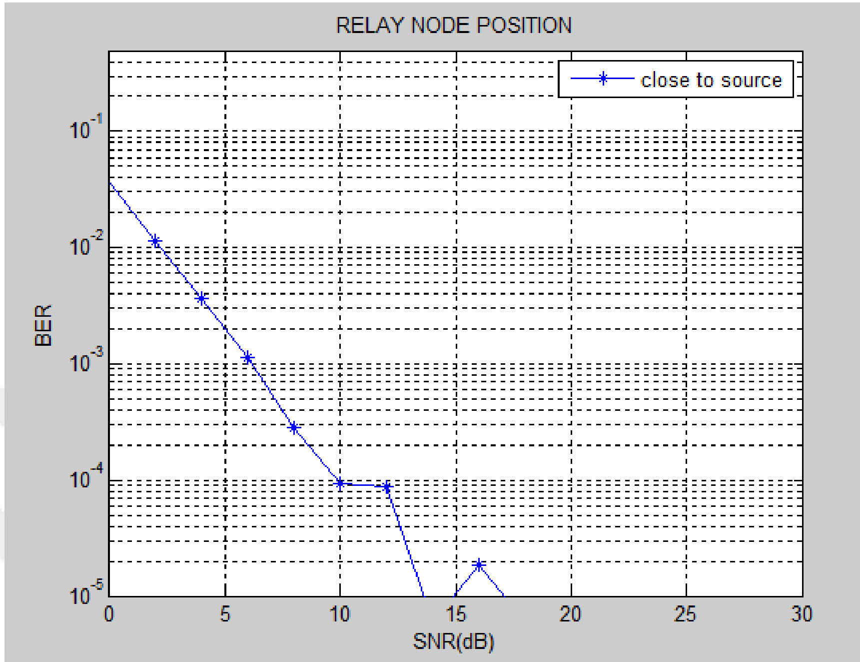


Figure 30. Relay node close to source 1.

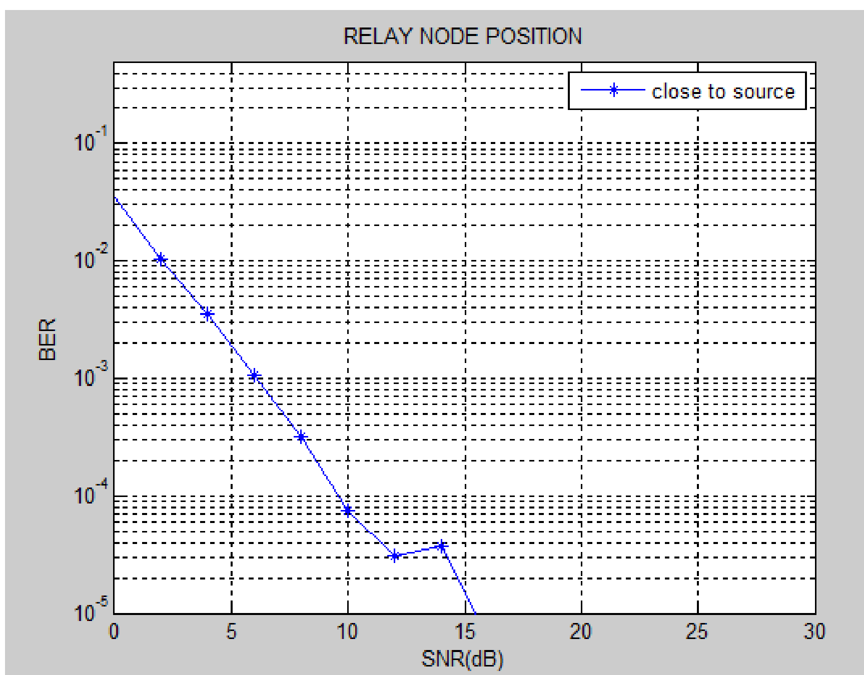


Figure 31. Relay node close to source 2.

From the results we obtain in Figure 30 and Figure 31 we can see that when the Relay node is close to the source the results we get at SNR of 12.5, 15 because the relay to destination channel is not fixe and because of the long distance between them they would be a lot of disturbance and make the signal to arrive at the destination with a lot of errors. But because the Relay node is close to the destination it requires small amount of SNR to reduce the amount of BER to $10^{-4}$.

### 5.4.2. Relay Node in Middle of Source and Destination

When the relay node is in the middle of the source and the destination it seems to have the same probability of having the same signal the relay and the destination cause the system is assumed to be working on the same power, if the signal received by the relay is of good quality the destination also will probably have the same quality as the relay cause they are on same distance unless there is a lot of fading conditions in the relay-destination channel.

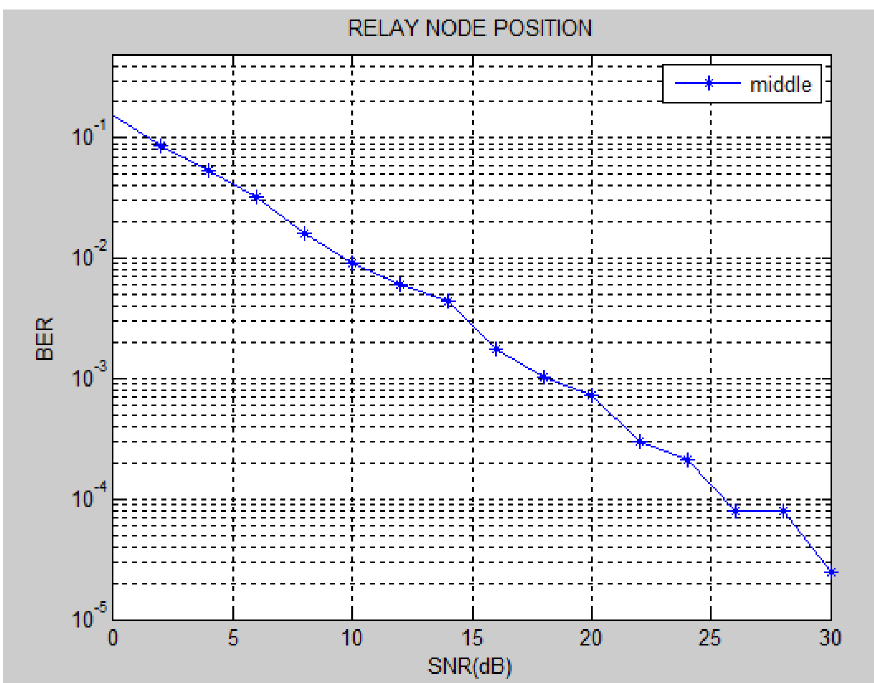


Figure 32. Relay node in middle of source and destination 1.

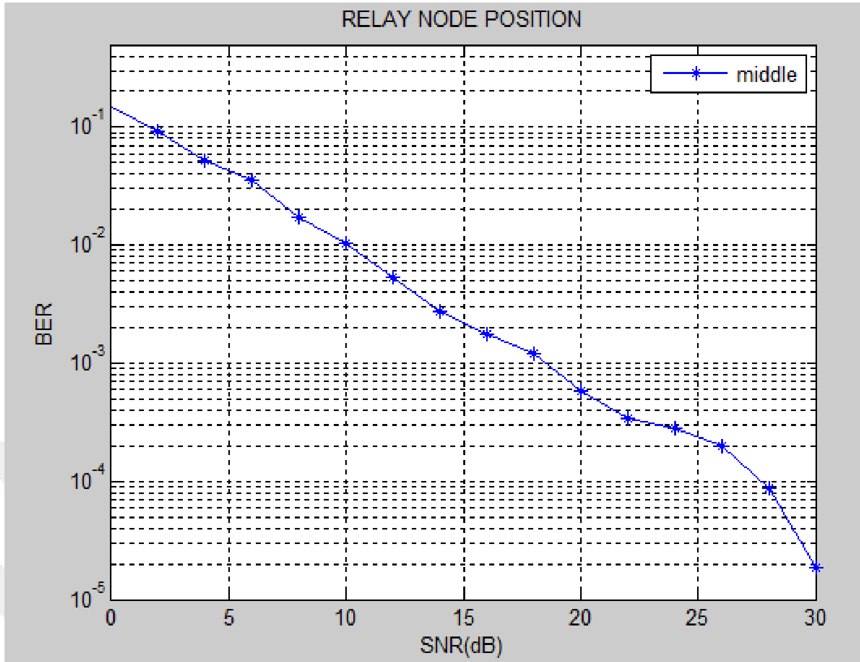


Figure 33. Relay node in middle of source and destination 2.

When we look at the results in Figure 32 and Figure 33 we can see that the results we obtain at different times when the relay node is in the middle are somehow similar like the results at SNR 10, 15, 20 dB they are very close, which means when the relay node is in the middle because of the distance to be the same the probability of getting a good signal from the source and transmitting the same signal to the destination is the same, even though it requires a lot of amount of SNR to bring down the BER but is better than when the relay node is close to source.

### 5.4.3. Relay Node Close to Destination

When the relay node is far from the source it’s very difficult to the relay to receive a signal with a good quality but to transmit the received signal to destination is simple because of the small distance.

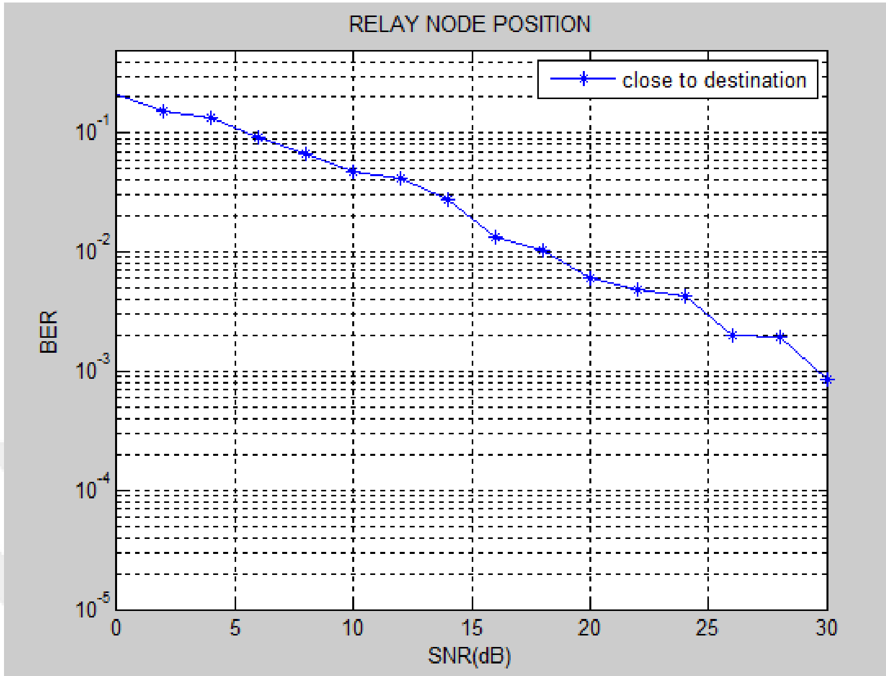


Figure 34. Relay close to the destination 1.

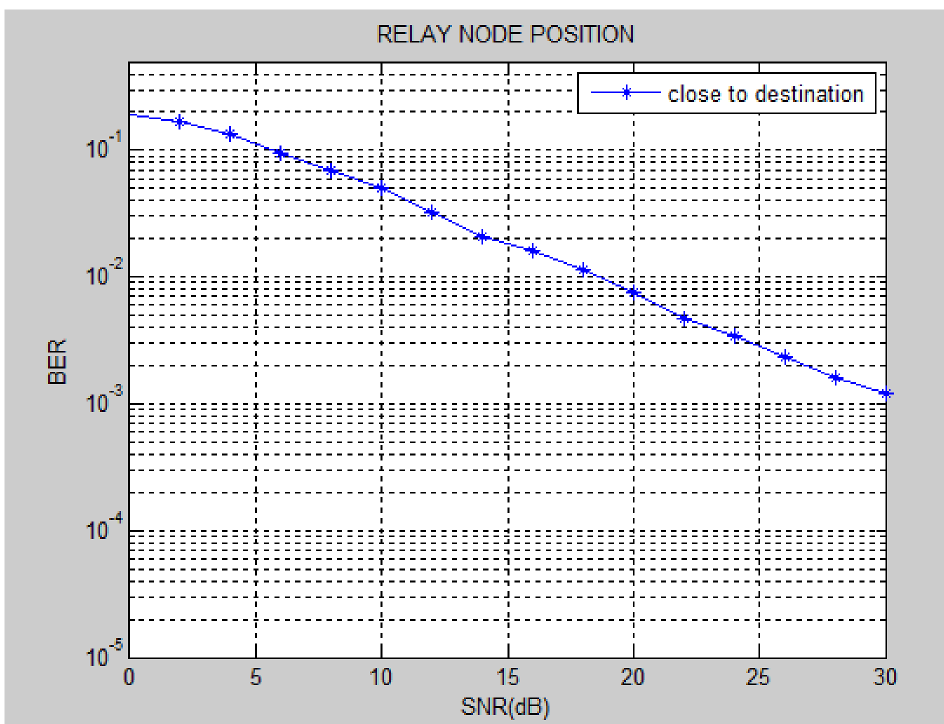


Figure 35. Relay close to destination 2.

Considering the results in Figure 34 and Figure 35 we can notice that the signal send from diffrent time has the same or very close values of BER at 10, 20, and 30 dB of SNR but at 30 dB of SNR we still have a big number of errors which makes this position of Relay node to be a bad choice for our work cause we want to have a small number of errors at a small amout of dB of SNR.

# 6. CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

In a CC system a cell is shared by two or multiple active users jointly sharing their antennas to transmit their messages. When the users are helping each other in retransmitting the message signal they benefit from reliability and efficiency than they could obtain independently. I discuss how this technique can be used to exploit MIMO benefits in a distributed way. Several relaying schemes for CC are presented. With the results in my research my conclusion is that the main points to consider for a wireless communication system to have a better throughput, low power consumption, a higher data rate and in general a good reliability is to choose a best relay selection method and a better position of the relay node.

My future work will focus on relay selection cause through my research I focused only on two protocols which are AAF and DAF and only on the position of the relay node in order to have a system reliability and a better throughput. Through this research I mentioned only the types of relay selection in my future work I want to continue finding out which selection is better than other and look at numerical results through some simulation results. I will try to work also on CC in other modulation type like OFDM because through this research I have used only BPSK and QPSK modulation.

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