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Performance Evaluation of Cooperative Transmission Techniques in Wireless Ad-Hoc and Sensor Networks

A Research Submitted In Partial Fulfillment for the Requirements of the Degree of B.Sc. (Honors) in Electronics Engineering

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إستهلال

قال تعالى:

﴿ اللَّهُ نُورُ السَّمَوَاتِ وَالأَرْضِ مَثَلُ نُورِهِ كَمِشْكَاةٍ فِيهَا مِصْبَاحٌ الْمِصْبَاحُ فِي زُجَاجَةٍ الزُّجَاجَةُ كَأَنَّهَا كَوْكَبٌ دُرِّيٌّ يُوقَدُ مِنْ شَجَرَةٍ مُبَارَكَةٍ زَيْتُونِةٍ لا شَرْقِيَّةٍ وَلا غَرْبِيَّةٍ يَكَادُ زَيْتُهَا يُضِيءُ وَلَوْ لَمْ تَمْسَسْهُ نَارٌ نُورٌ عَلَى نُورٍ يَهْدِي اللَّهُ لِنُورِهِ مَنْ يَشَاءُ وَيَضْرِبُ اللَّهُ الأَمْثَالَ لِلنَّاسِ وَاللَّهُ بِكُلِّ شَيْءٍ عَلِيمٌ ﴾.

صدق الله العظيم

[سورة النور:35]

Dedication

We are lovingly dedicate this research to our

Parents

Sisters and brothers

Colleagues and professors at electronics school

Supervisor Dr. Salaheldin M. I. Edam

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We avail this opportunity to extend our hearty indebtedness to our guide Dr. Salaheldin M. I. Edam , Telecommunication Department, for his valuable guidance, constant encouragement and kind help at different stages for the execution of this work.

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Abstract

The Cooperative transmission is technique that allows multiple nodes to simultaneously transmit data, and these nodes can be used as relays to forward information to the destination. Virtual antenna arrays concluded it is an attractive option to overcome the drawbacks of traditional relaying systems. The examined network consisting of one source, one destination and one relay and considered scenario in it which destination or relay can have various processing limitations. Performance of Relay channel analyzed under principle of amplify-and-forward (AF), decode-and-forward (DF) by comparing between them in the bit error rate (BER) and signals to noise ratio (SNR).Simulation results of comparison between amplify-and-forward, decode-and-forward and direct transmission found that in direct transmission BER is very high as it expected, and the AF is better than DF in BER. Also in amplify-and-forward found that the BER decrease when doubling the amplification factor value, and when using different modulation techniques found that in BPSK and QPSK the BER inversely proportional to SNR and in16QAM it is directly proportional when increase the values of SNR .The simulation done by using MATLAB programming language.

المستخلص

إن الإرسال التعاوني هو تقنية تسمح لعدة عقد إرسال بيانات بشكل آني، و هذه العقد يمكن ان تستخدم كمقويات لإرسال المعلومات إلى المقصد. صفوف الهوائيات الإفتراضية استنتجت بانها خيار مفضل للتغلب على عوائق أنظمة النقل التقليدية. الشبكة المستخدمة تشمل مصدر واحد،مقصد واحد ومقوي واحد و إعتبرت سيناريو فيه اي مقصد أو ناقل يمكن ان يأخذ تقنيات معالجة مختلفة. آداء قناة التقوية حلل تحت مبدأ يكبر - و- يرسل، يفك شفرة- و- يرسل بالمقارنة بينهم في نسبة الخطأ في الاشارة و نسبة الإشارة للتشويش. نتائج المحاكاة في المقارنة بين المقوي الذي يكبر- و- يرسل ، يفك شفرة –و-يرسل ويوجه الارسال مباشرة وجد انه في الارسال المباشر نسبة الخطأ في الاشارة عالي جدا كما هو متوقع. المقوي الذي يكبر ويرسل وجد انه عند مضاعفة عامل التكبير يتناقص معدل الخطأ ،ايضا عند استخدام تقنيات التحوير المختلفة وجد انه عند استخدام قفل تغيير المرحلة الثنائي وقفل تغيير مرحلة التربيع معدل الخطأ يتناسب عكسيا مع نسبة التشويش في الاشارة وفي تعديل المطال التربيعي السادس عشر معدل الخطأ يتناسب طرديا مع نسبة التشويش في الاشارة ، تمت المحاكاة باستخدام لغة برمجة الماتلاب.

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$y_{s,d}$	The received signal at the destination from the source.
$y_{s,r}$	The received signal at the relay from the source.
$y_{r,d}$	The received signal at the destination from the relay.
p_s	Transmitted power of source.
$h_{s,d}$	Channel coefficients between the source and destination.
$h_{s,r}$	Channel coefficients between the source and relay.
$h_{r,d}$	Channel coefficients between the relay and destination.
x	The transmitted data.
$n_{s,d}$	The additive white Gaussian noise in the channel between source and destination.
$n_{s,r}$	The additive white Gaussian noise in the channel between source and relay.
$n_{r,d}$	The additive white Gaussian noise in the channel between relay and destination.
No	Transmission noise.
y	The combined signal at the destination.
β	The amplification factor.
p_r	Transmitted power of relay.
$\hat{x}$	The hypothesis data detected by the relay.
BER	The BER
N_{err}	Total number of error
N_{tot}	Total number of symbols

Abbreviations

AF	Amplify-and-Forward.
BER	Bit Error Rate.
BS	Base-Station.
CPU	Central Processing Unit.
DF	Decode-and-Forward.
DSP	Digital Signal Processing.
ERC	Equal Ratio Combining.
ESNRC	Equal Signal to Noise Ratio Combining.
FRC	Fixed Ratio Combining.
GPS	Global Positioning System.
ID	Identifier.
MANET	Mobile Ad-hoc NETwork.
MRC	Maximum Ratio Combining.
MWSN	Mobile Wireless Sensor Network.
PAN	Personal Area Network.
PDA	Personal Digital Assistant.
QoS	Quality of Service.
RF	Radio Frequency.
SC	Selection Combing.
SNR	Signal to Noise Ratio.
SNRC	Signal to Noise Ratio Combining.
VANET	Vehicular Ad-hoc NETwork.
WSN	Wireless Sensor Network.

Chapter One

Introduction

Chapter One: Introduction

1.1. Background:

The network may be defined as a connection between two or more computers either through cables, telephone lines, satellites, radio waves or infrared beams [1].The wireless network architecture is be classified in two ways, infrastructure and infrastructure less (Ad-hoc network) [2].Ad-hoc network is a network formed without any central administration which consists of mobile nodes that use a wireless interface to send packet data [2, 3].

Ad-hoc network consist of a collection of wireless nodes, which communicate over a common wireless medium. It is a multi-hop network that use wireless communication for transmission without any fixed infrastructure, routes with low energy consumption (energy/bit), may provide less rapid transmission links, it is easy to setup, especially in a small or temporary network. In an ad-hoc network, node acts as a router to send and receive the data [4, 5].

Ad-hoc networks are expected to significantly facilitate civilian applications such as industry sector, disaster relief , emergency rescue operations, patient monitoring, drug inventory management and home networking; as well as military applications such as surveillance networks, target monitoring and real-time information distribution [2, 5, 6].

Ad-hoc network is a personal area network is ,it has short range, localized network where nodes are usually associated with a given range; so another application of Ad-hoc is Bluetooth for personal use and enables communication between the nodes such as a laptops [5, 7].

Ad-hoc networks classified according to their application as Mobile Ad-hoc Network (MANET), Vehicular Ad-hoc Network (VANET) and Wireless Sensor Network (WSN) [2, 8].

WSNs gain more and more attention as an instrument for fine-granular measuring of a physical parameter in a given area .Wireless sensor network consist of small nodes that have to be placed in the area of interest with sensing, computation, and wireless communications capabilities called sensor nodes [9, 10],instead of manually placing each single node, mass-processes have been proposed to simplify and accelerate this task. On often cited example is to use a plane or helicopter and drop the nodes over a certain area. Then, the sensor nodes randomly distribute in the area [10] These sensor nodes have the ability to communicate either among each other or directly to an external base-station (BS),also each of these scattered sensor nodes has the capability to collect and route data either to other sensors or back to an external base station. The BS may be a fixed node or a mobile node capable of connecting the sensor network to an existing communications infrastructure or to the Internet where a user can have access to the reported data. A greater number of sensors allows for sensing over larger geographical regions with greater accuracy.

Sensor nodes are usually scattered in a sensor field, which is an area where the sensor nodes are deployed. Sensor nodes coordinate among themselves to produce high quality information about the physical environment, sensor nodes that are small in size and communicate in short distances, the idea of sensor networks based on collaborative effort of a large number of nodes [9].

Since large numbers of sensor nodes are densely deployed, neighbor nodes may be very close to each other. Hence, multi-hop communication in sensor networks is expected to consume less power than the traditional single hop communication [11].

The sensor node is made up of four basic components: a sensing unit, a processing unit, a transceiver unit and a power unit.

WSNs can be static or mobile. A mobile wireless sensor network (MWSN) owes its name to the presence of mobile sink or sensor nodes within the network. The advantages of mobile wireless sensor network over static wireless sensor network are better energy efficiency, improved coverage, enhanced target tracking and superior channel capacity.

Depending on the architecture of WSN there are two types: flat and hierarchical; in flat the sensor nodes any one spends with itself, hierarchical sensor nodes spend in group called cluster.

Sensor networks have a variety of applications. Examples include environmental monitoring – which involves monitoring air soil and water, condition based maintenance, habitat monitoring (determining the plant and animal species population and behavior), seismic detection, military surveillance, inventory tracking, smart spaces [12].

Multiple input multiple output system (MIMO) adapts multiple antennas in the transmit side and receive side to exploit spatial diversity [13].MIMO systems in wireless networks difficult to implement; In order to overcome this practicality problem of MIMO systems while also taking advantage of its basics, which is referred to as cooperative transmission [14].

Cooperative transmission allows single antenna mobiles to act as MIMO systems, where users share and coordinate their resources to enhance the transmission quality by encouraging single antenna devices to share their antennas cooperatively such that a virtual and distributed antenna array can be constructed, in a manner that creates a virtual MIMO system [15, 16].

The Idea of cooperative communications is particularly attractive in wireless environment due to achieve higher efficiency and network capacity, extended coverage and lowered power consumption, higher throughput-lower delay [16] [17].Different users or nodes in a wireless ad-hoc and sensor network share resources to create collaboration through distributed transmission, which can significantly improve the performance of wireless ad-hoc and sensor network [18].

1.2 Problem Statement:

In wireless transmission systems when the direct link from source to destination is too weak the SNR become very low, which mean high BER.

1.3. Proposed Solution:

In traditional communication networks all nearly nodes overhead transmission between any two nodes .These neighbors could be great assistance if they used as relays. Using cooperative transmission aims to process and forward overhead information to the respective destination, this must reduce the BER.

1.4. Aim and Objectives:

The aim of this thesis is to enhance the quality of transmission in wireless system in order to reduce the probability of error by using different approach.

1.5. Methodology:

This methodology details the features of the different stages through which a research of *“performance Evaluation of cooperative* *transmission techniques in wireless ad hoc and sensor networks "*is achieved. The objective of this study is to reduce the BER by using cooperative transmission.

At the first stage background reviewed about wireless networks, cooperative transmission and its protocols in order to achieving objectives. This thesis focused in AF and DF cooperative protocols.

The simulation applied in a network scenario consisting of three nodes communicated cooperatively using AF and DF relaying protocols. This scenario simulated using MATLAB program to check and evaluate the performance of the networks to derive conclusions and results based on tangible comparative study.

1.6. Research Outlines:

The outlines of research are as following:

Chapter two represent literature review , chapter three talks about the proposed system design, Chapter four discuss testing, cases study and evaluation. Finally the last chapter will talk about the conclusion and future work.

Chapter Two

Literature Review

Chapter Two: Literature Review

2.1. Wireless Networks:

Since their emergence in 1970's, wireless networks have become more popular in the communication industry. These networks provide mobile users with computing capability and information access regardless of the user's location [19].

The packet between the source and destination relaying on either single-hop or multi-hop, whether multi-hopping is necessary, suitable or even possible depends on factors such as the number and the distribution of terminals in the network.

The wireless network architecture is be classified in two ways, infrastructure and infrastructure-less (ad-hoc).

2.2. Multi-hop Relays:

Through multi-hop connections, the terminals act as routers/relays for each other and extend the range and coverage, a multi-hop network might actually degenerate into a single-hop network; multi-hopping is employed to provide connectivity or there are some terminals out of range of each other, and cannot therefore form a single-hop network [3, 7].

2.3. Infrastructure Network:

The infrastructure networks have fixed and wired gateways or the fixed Base-Stations which are connected to other Base-Stations through wires. Each node is within the range of a Base-Station. A "Hand-off" occurs as mobile host travels out of range of one Base-Station and into the range of another and thus, mobile host is able to continue communication seamlessly throughout the network [19].

Figure (2-1):Infrastructure Network.

2.4. Ad-hoc Networks:

Ad-hoc network consists of versatile flat forms which are free to move expeditiously. Ad-hoc networks are multi-hop network that use wireless communication for transmission without any fixed infrastructure, Ad-hoc structure does not require an access point, it is easy to setup, especially in a small or temporary network. Each node in the network forwards the packet without the need of central administration. In ad-hoc network, nodes act as a router to send and receive the data [2].

Figure (2-2):Ad-hoc Network

2.4.1. Advantages of Ad-hoc Networks:

There are many reasons better to use Ad-hoc than infrastructure. The biggest ad-hoc strength is its independency from any infrastructure. Therefore, it is possible to establish an ad-hoc network in any difficult situations. The following are the advantages of ad-hoc networks:

- No infrastructure and lower cost: using a service from an infrastructure can be expensive for specific applications. In an area with very low density, it is not impossible to establish an Infrastructure. But if we compare how often the people there are using service of infrastructure and how many data per day transmitted with cost of installation, maintenance, and repair, it is maybe too expensive [5].
- Mobility: In the next generation of wireless communication systems, there will be a need for the rapid deployment of independent mobile users. So we can't rely on centralized connectivity. Ad-hoc support nodes mobility. We can still communicate with our mobile devices as long as the destination is reachable [5].
- Decentralized and robust: Another advantage of ad-hoc networks is that they are inherently very robust In the ad-hoc networks if one node leaves the network or is not working, the connectivity between other will not corrupted as long as there is at least one way to desired node [5].
- Easy to build: Malfunction of a network infrastructure is sometimes not avoidable. It is obviously difficult to repair or replace the malfunction infrastructure in short time, while the network's existence must be maintained all-time. Establishing an ad-hoc is a good deal in such situation. The network participants can act as ad-hoc nodes and hop the messages [5].

2.4.2. Disadvantages of Ad-hoc Networks:

The wireless communication is very famous nowadays; using wireless can make rooms look better, because fewer cables are used. Lower data rate, security, and medium access control are common problems in the wireless communications. Ad-hoc strengths cause also some problems. The following are the disadvantages of ad-hoc networks:

- Higher error rate: the wireless transmission may deal with problem the characteristic of the electronic wave. There is seldom such a situation. The obstacle causes shadowing, reflection, scattering, fading, refraction, diffraction of the wave. This propagation may lead to transmitted packets being garbled and thus received in error [5].
- Lower data rate: the characteristic of wave, which is used for wireless communication, prevents wireless communication to transmit data better than wired communication. A higher frequency can transmit more data, but then it is more vulnerable to interference and performs well in short range [5].
- Dynamic topology and scalability, since the nodes are mobile, the routing changes as the nodes move. Current connectivity Information must to be propagated to all network's participant. Control messages have to send around the network frequently. The increased number of control messages burdens the available bandwidth [5].
- Security: Due to dynamic distributed infrastructure-less nature and lack of centralized monitoring points, the ad-hoc networks are vulnerable to various kinds of attacks [5].

2.4.3. Ad-hoc Network Application:

The ad-hoc networks can be classified according to their application as:

- MANET: Is a system of wireless mobile nodes that dynamically self-organize in arbitrary and temporary network topologies [2, 8].

- VANET: Uses travelling cars as nodes in a network to create a mobile network consist of some sensors embedded on the vehicles [20]
- WSN: Wireless sensors network is a network of distributed sensors which monitor the condition of the surrounding environment. The data acquired from these sensors are transmitted through the network to a gateway node, where the data will be stored or used [13].

There are many fields in which ad-hoc network applied:

- Military arena: It is used to communicate a large number of soldiers spreads out in a large battlefield [5].
- Bluetooth: The Idea of a personal area network (PAN) is to create a localized network populated by some network nodes that are closely associated with a single person. The Bluetooth technology support this scenario; Bluetooth is a wireless local network, which has only small range area transmission and doesn't need infrastructure or cable to connect the end terminals [5].
- Provincial level*:* Ad-hoc networks can build instant link between multimedia network using notebook computers or palmtop computers to spread and share information among participants such as Conferences [2].

2.5. Wireless Sensor Network:

The WSN usually consists of tens to thousands of such nodes that communicate through wireless channels for information sharing and cooperative processing sensor nodes are responsible for self-organizing an appropriate network infrastructure, often with multi-hop connections between sensor nodes. Each node consists of processing capability such as one or more microcontrollers, CPUs or DSP chips may contain multiple types of memory such as program, data and flash memories, have a RF transceiver usually with a single Omni-directional antenna, have a power source such as batteries and solar cells, and accommodate various sensors and actuators. The nodes communicate wirelessly and often self-organize after being deployed in an ad hoc fashion. The onboard sensors then start collecting acoustic, seismic, infrared or magnetic information about the environment, using either continuous or event driven working modes. Location and positioning information can also be obtained through the global positioning system (GPS) or local positioning algorithms.

The basic philosophy behind WSNs is that, while the capability of each individual sensor node is limited, the aggregate power of the entire network is sufficient for the required mission .In a typical scenario, users can retrieve information of interest from a WSN by injecting queries and gathering results from the so-called base stations or sink nodes, which behave as an interface between users and the network.

This WSN or new technology is exciting with unlimited potential for numerous application areas including environmental, medical, military, transportation, entertainment, crisis management, homeland defense, and smart spaces. For WSN, which are often deployed in an ad hoc fashion, routing typically begins with neighbor discovery. Nodes send rounds of messages (packets) and build local neighbor tables. These tables include the minimum information of each neighbor’s ID and location. This means that nodes must know their geographic location prior to neighbor discovery. Other typical information in these tables include nodes’ remaining energy, delay via that node, and an estimate of link quality [21].

2.5.1. Types of WSN:

WSNs can be static or mobile. Static WSN has static sink or sensors within network, and mobile MWSN owes its name to the presence of mobile sink or sensor nodes within the network. There are many advantages of mobile wireless sensor network over static wireless sensor network such as: better energy efficiency, improved coverage, enhanced target tracking and superior channel capacity.

2.5.2. Mobile Wireless Sensor Network:

Mobile WSNs consist of a collection of sensor nodes that can move on their own and interact with the physical environment. Mobile nodes have the ability sense, compute, and communicate like static nodes. A key difference is mobile nodes have the ability to reposition and organize itself in the network. The MWSN can start off with some initial deployment and nodes can then spread out to gather information. Information gathered by a mobile node can be communicated to another mobile node when they are within range of each other. Another key difference is data distribution. In a static WSN, data can be distributed using fixed routing or flooding while dynamic routing is used in a mobile WSN. Challenges in MWSN include deployment, localization, self-organization, navigation and control, coverage, energy, maintenance, and data process.

Applications of MWSN include but are not limited to environment monitoring, target tracking, search and rescue, and real-time monitoring of hazardous material. For environmental monitoring in disaster areas, manual deployment might not be possible. With mobile sensor nodes, they can move to areas of events after deployment to provide the required coverage. In military surveillance and tracking, mobile sensor nodes can collaborate and make decisions based on the target. Mobile sensor nodes can achieve a higher degree of coverage and connectivity compared to static sensor nodes. In the presence of obstacles in the field, mobile sensor nodes can plan ahead and move appropriately to obstructed regions to increase target exposure [22].

2.5.3. Challenges of Wireless Sensor Network:

In spite of the diverse applications, sensor networks pose a number of unique technical challenges due to the following factors:

- Ad hoc deployment: Most sensor nodes are deployed in regions which have no infrastructure at all. A typical way of deployment in a forest would be tossing the sensor nodes from an aero plane. In such a situation, it is up to the nodes to identify its connectivity and distribution.
- Unattended operation: In most cases, once deployed, sensor networks have no human intervention. Hence the nodes themselves are responsible for reconfiguration in case of any changes.
- Untethered: The sensor nodes are not connected to any energy source. There is only a finite source of energy, which must be optimally used for processing and communication. An interesting fact is that communication dominates processing in energy consumption. Thus, in order to make optimal use of energy, communication should be minimized as much as possible.
- Dynamic changes: It is required that a sensor network system be adaptable to changing connectivity due to addition of more nodes, failure of nodes.

2.5.4. Sensor Nodes:

These sensors are small, with limited processing and computing resources, and they are inexpensive compared to traditional sensors. These sensor nodes can sense, measure, and gather information from the environment and, based on some local decision process, they can transmit the sensed data to the user. Smart sensor nodes are low power devices equipped with one or more sensors, a processor, memory, a power supply, a radio, and an actuator. A variety of mechanical, thermal, biological, chemical, optical, and magnetic sensors may be attached to the sensor node to measure properties of the environment. Since the sensor nodes have limited memory and are typically deployed in difficult-to access locations, a radio is implemented for wireless communication to transfer the data to a base station .Battery is the main power source in a sensor node. Secondary power supply that harvests power from the environment such as solar panels may be added to the node depending on the appropriateness of the environment where the sensor will be deployed. Depending on the application and the type of sensors used, actuators may be incorporated [22].

2.5.5. Unique Features of Sensor Networks:

It should be noted that sensor networks do share some commonalities with general ad hoc networks. Protocol design for sensor networks must account for the properties of ad hoc networks, including the following:

- Lifetime constraints imposed by the limited energy supplies of the nodes in the network [23].
- Unreliable communication due to the wireless medium.
- Need for self-configuration, requiring little or no human intervention. However, several unique features exist in wireless

sensor networks that do not exist in general ad hoc networks. These features present new challenges and require modification of designs for traditional ad hoc networks.

- While traditional ad hoc networks consist of network sizes on the order of 10s, sensor networks are expected to scale to sizes of 1000s [23].
- Sensor nodes are typically immobile, meaning that the mechanisms used in traditional ad hoc network protocols to deal with mobility may be unnecessary and overweight.
- Since nodes may be deployed in harsh environmental conditions, unexpected node failure may be common [23].
- Sensor nodes may be much smaller than nodes in traditional ad hoc networks such as PDAs and laptop computers, with smaller batteries leading to shorter lifetimes, less computational power, and less memory [23].
- Additional services, such as location information, may be required in wireless sensor networks [23].
- While nodes in traditional ad hoc networks compete for resources such as bandwidth, nodes in a sensor network can be expected to behave more cooperatively, since they are trying to accomplish a similar universal goal, typically related to maintaining an application-level quality of service (QoS), or fidelity [23].
- Communication is typically data-centric rather than address-centric, meaning routed data may aggregated, compressed or dropped depending on the description of the data [23].
- Communication in sensor networks typically takes place in the form of very short packets, meaning that the relative overhead

imposed at the different network layers becomes much more important [23].

- Sensor networks often have a many-to-one traffic pattern, which leads to a “hot spot” problem [23].

2.5.6. Low-Power Wireless Sensor Networks:

Wireless distributed micro sensor systems will enable fault tolerant monitoring and control of a variety of applications. Due to the large number of micro sensor nodes that may be deployed and the long required system lifetimes, replacing the battery is not an option. Sensor systems must utilize the minimal possible energy while operating over a wide range of operating scenarios [24].

2.6. MIMO System:

The MIMO system is a natural extension of developments in antenna array communication. While the advantages of multiple receive antennas, such as gain and spatial diversity, have been known and exploited for some time , the use of transmit diversity has only been investigated recently [25].

Signal transmitted by an antenna will propagate through different channel, This was called spatial multiplexing, and this technique is used to increase channel capacity by increasing the spectral efficiency of the transmission [13].

MIMO systems enable high spectral efficiency at much lower required energy per information bit. Sensitivity to fading is reduced by the spatial diversity provided by multiple spatial paths. In some cases, providing more antennas to the receive side or the transmit side might not be possible because of hardware limitation such as in sensor networks.

Cooperative transmission could become a virtual MIMO system by using relay nodes as virtual antennas, thus allowing the application of MIMO without having to add multiple antennas to a device [13].

2.7. Diversity:

The most effective technique to mitigate the fading effects in wireless communications is diversity. Diversity techniques mainly operate by transmitting the signals over uncorrelated channels. These techniques can be classified as time-diversity, frequency-diversity, or space-diversity techniques:

- **Time diversity**: In this technique, the signal is repeated over different time intervals [14, 26].
- **Spatial diversity**: The signal is transmitted and/or received over different antennas [14, 26].
- **Frequency diversity**: With this technique the signal is transmitted over different carrier frequencies [14, 26].

2.8. Cooperative Transmission:

Extensive research has been done in the area of cooperative transmission the basic idea is the use of single-antenna nodes in a multi-user scenario to share their antennas to create virtual multiple-input multiple-output system. Cooperative transmission can potentially combine the following advantages: the power savings provided by multi-hopping, the spatial diversity provided by the antennas of separate mobile nodes, and node cooperation can also lead to increased data rates [27].

In cooperative communication, each wireless user is assumed to transmit its own data as well as act as a cooperative relay for the other user [28].

2.8.1. Relay Channel:

The relay channel consists of three nodes: source, destination, and relay. It was assumed that all nodes operate in the same band, so the system can be decomposed into a broadcast channel from the viewpoint of the source and a multiple access channel from the viewpoint of the destination (Figure (2-3)) [29, 30].

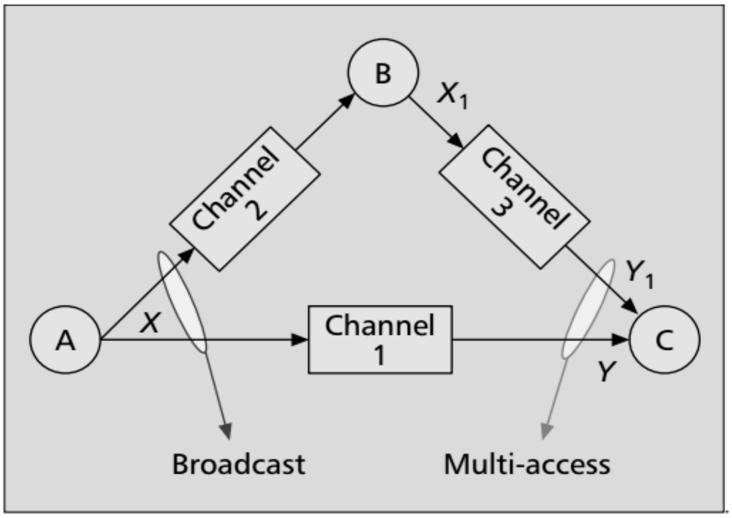


Figure (2-3):Relay channel

2.8.2. Benefits of Cooperative Transmission:

From the perspective of the network, cooperation can benefit not only the nodes involved, but the whole network in many different aspects. For illustration purposes, we choose to explain only a few potential benefits below [29]:

- Higher spatial diversity.
- Higher throughput-lower delay.
- Lower power consumption and lower interference.
- Adaptability to network conditions.

2.8.3. Relaying Types:

There are five common forwarding schemes that are used for data forwarding at a relay terminal:

- Amplify-and-forward: the relay terminal amplifies the received signal from a source terminal and forwards it to a destination terminal [4, 13, 26].
- Decode-and-forward: instead of being amplified, the received signal transmitted by the source terminal is decoded at the relay terminal. Then, the relay re-encodes the data and forwards it to the destination terminal [4, 13, 26].
- Compress-and-forward : relays compress the received signal based on the side information from the direct link and then forward the compressed signal to destination [31].
- Coded cooperation :is a method that integrates cooperation into channel coding; it is works by sending different portions of each user's code word via two independent fading paths, the basic idea is that each user tries to transmit incremental redundancy to its partner [15, 30].

2.9. Combining Techniques:

Diversity combing technique is needed at the destination to combine multi-branch signals to one improved signal. Some of these techniques:

- Selection combing (SC): The SC selects the best signal among all the branches. It is very simple to implement and gives worse performance by ignoring other branches [32].
- Equal Ratio Combining (ERC): This is the easiest way to combine the signals, where all the received signals are just added up [32].
- Fixed Ratio Combining (FRC): In this method, all the branches are weighted with a constant ratio and summed as one signal. By using this method, we can achieve better performance than the previous method, but by giving the same weight to all branches, the weak

signal may destroy the information carried by the strong signal [32].

- Signal to Noise Ratio Combining (SNRC): This method uses the same idea of the previous one (FRC), except that, this method uses SNR to weight the received signals. Using SNR that characterizes the quality of link leads to much better performance compared to former methods [32].
- Maximum Ratio Combining (MRC): Assuming that the channels' phase shift and attenuation are perfectly known at the receiver, the best performance can be achieved by using MRC. The key idea of MRC method is that each input signal is multiplied by its corresponding conjugated channel gain. It means that the branches with strong signal are further amplified while weak signals are attenuated [32].

2.10. Related Works:

In [33] authors derive expressions for the error rate performance of relaying protocols in quasi-static Rayleigh fading when the success/failure of a transmission on a link can be modeled using an SNR-threshold model. They also analyze a new hybrid AF/DF protocol that achieves diversity against fading without the need for adaptively at the source (and the associated overhead), and that avoids noise amplification when the source-relay transmission succeeds. Authors found that the optimal position of the relay is midway between the source and destination between the source and destination , also direct, two-hop, and fixed DF transmission do not achieve diversity, as expected, whereas AF, DF, and hybrid AF/DF do exhibit 2nd-order diversity. Simulation results show that the SNR-threshold model is useful for predicting performance with turbo codes, although the slight differences in the diversity schemes are only perceptible in the analytical results.

In [34] consider a multi-relay network operating in DF mode and propose a novel relay selection method with a low implementation complexity. Also derive a closed-form symbol error rate (SER) expression for multi-relay network under consideration and demonstrate that the proposed selection method is able to extract the full diversity. Extensive Monte Carlo simulations are also presented to confirm the derived SER expressions and to compare the performance of the proposed scheme with its competitors the proposed method avoids the use of error detection methods at relay nodes and does not require close-loop implementation with feedback information to the source. Its implementation however requires channel state information of source-to-relay channels at the destination. This can be easily done in practice through a feed forward channel from the relay to the destination. The SER performance analysis it shown that the proposed relay-selection method is able to extract the full diversity, and the simulation results have further demonstrated the superior performance of the proposed scheme over its competitors.

In [35] author give an introduce overview of cooperative communications, a new trend in this field of wireless Communications and compare the new idea of cooperative communications, also discussed the concepts of cooperative communications and relay technology & analysis the Bit Error Rate (BER) performance of AF Protocol. The aim of this paper is to provide the basic concepts of cooperative and relay technology & analyze the BER performance of different cooperative communication protocol it is a well-known fact that under fading conditions, the BER/SER can be improved considerably by increasing the diversity gain as compared to boosting of received signal to noise ratio (SNR). In a network environment, cooperative relaying can provide extension of range and better coverage in shadow zones. An author found that through cooperation both terminals are able to simultaneously increase their throughputs and reliabilities even when they are connected via low quality links, or when one terminal has a much better link then the other.

In [36] author based on cooperative communications in wireless networks, and focus on BER performance analysis of cooperative communications with either an AF or DF cooperation protocol using MATLAB , also consider the single and multi-relay scenario in these simulations.

In [37] the performance of a cooperative communication system is analyzed under different diversity protocol, also two retransmission protocols AF and DF are implemented at the relays and four diversity combining techniques such as equal ratio combining (ERC), fixed ratio combining (FRC), signal to noise ratio combining (SNRC) and equal signal to noise ratio combining (ESNRC) are used at the destination for each protocol. After MATLAB simulations of both of retransmission protocols AF and DF and four diversity combining techniques (ERC, FRC, SNRC and ESNRC) have been studied and implemented at the relays and destination, respectively for each exclusive system, and the numerically calculated BER versus SNR curves have been compared to see the relative performance of the single relay system for different diversity protocols and various diversity combining methods, and found the single-relay cooperative system offers better performance than that of direct transmission irrespective of the implementation of retransmission protocols and diversity combining techniques .

Chapter Three

System Model

Chapter Three: System Model

3.1. Cooperative Model:

The system consists of three terminals (source, relay and destination) the transmission cooperatively has two phases:

In phase I the source broadcasts its information to both relay and destination as shown in (Figure (3-1)).

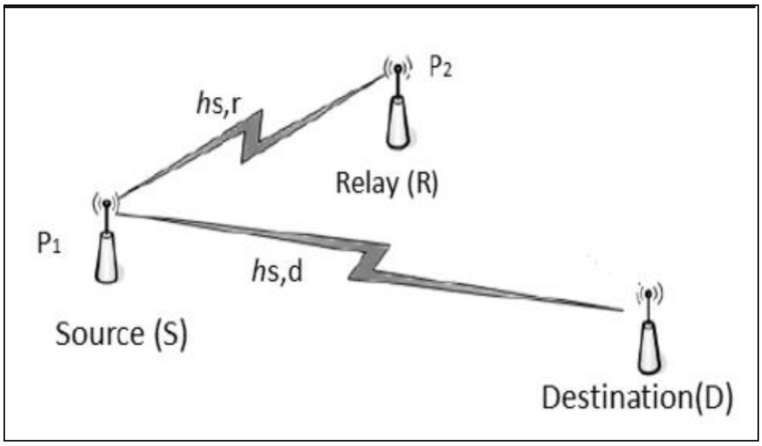


Figure (3-1): phase I in cooperative transmission

The received signals $y_{s,d}$ and $y_{s,r}$ at the destination and the relay, respectively, can be written as:

$$y_{s,d} = \sqrt{p_s} h_{s,d} x + n_{s,d} \sqrt{No} \tag{3.1}$$

$$y_{s,r} = \sqrt{p_s} h_{s,r} x + n_{s,r} \sqrt{No} \tag{3.2}$$

Where $h_{s,d}$ and $h_{s,r}$ are the channel coefficients between the source and destination/ relay, respectively. x the transmitted data. $n_{s,d}$ and $n_{s,r}$ are additive white Gaussian noise in the channel between source and destination/ relay, p_s Transmitted power of source, No transmission noise.

In phase II the relay performs some processing to the signal or data and then forwards it to destination, as shown in (Figure (3-2)).

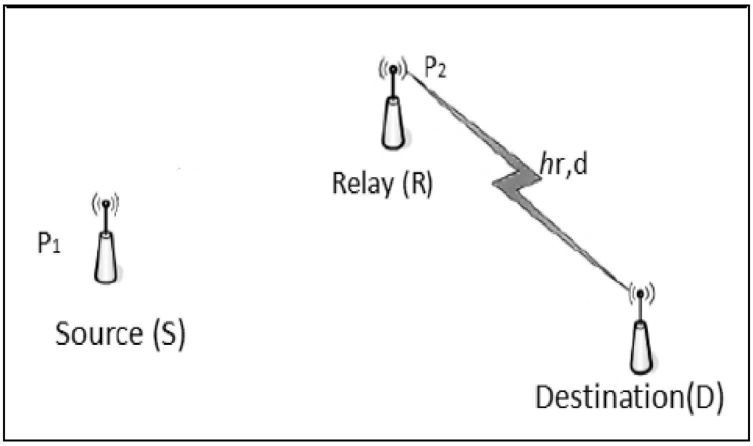


Figure (3-2):phase II in cooperative transmission

The destination combine signals come from relay and source using MRC as shown below:

$$y = \frac{y_{r,d} h_{s,r}^{*} h_{r,d}^{*} + y_{s,d} h_{s,d}^{*}}{\sqrt{No}} \tag{3.3}$$

Where y is the combined signal at the destination.

The BER is calculated using the following equation:

$$BER = \frac{N_{err}}{N_{tot}} \tag{3.4}$$

BER the bit error rate, N_{err} the total number of error, N_{tot} the total number of symbols.

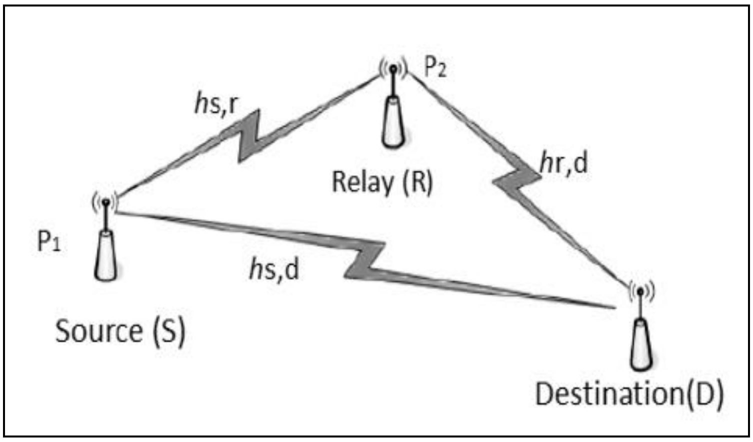


Figure (3-3):cooperative model

3.2. Amplify-and-Forward:

Amplify-and-forward protocol, which is often simply called an AF protocol. As the name implies, the relay amplifies and retransmits this noisy version, It is clear from this protocol that the noise will be amplified[38]**.** This protocol is presented below:

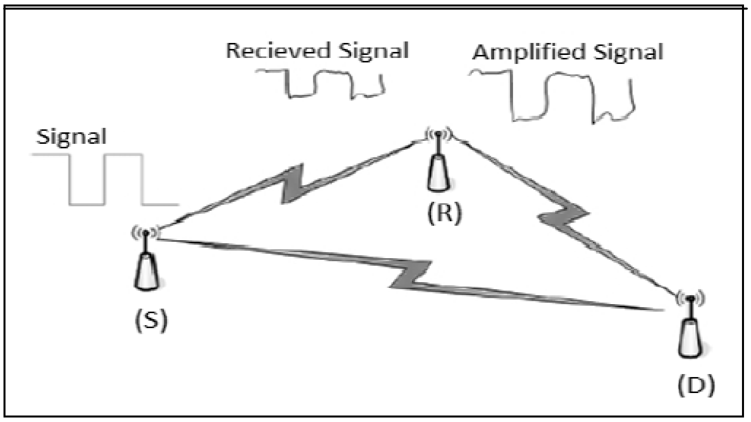


Figure (3-4):AF model

3.2.1. Characteristics of Amplify-and-Forward:

- AF is an analog scheme which works in non- regenerative mode.
- Operation in this mode puts less processing burden on the relay, so it causes much smaller delay, and hence is often preferred for delay sensitive traffic such as voice and live video.
- Noise amplification is a major issue for such schemes.

3.2.2. Amplify-and-Forward Operation:

Due to the broadcast nature of the wireless medium, the relay and the destination nodes will receive a noisy copy of the signal as mentioned in (3.1)and (3.2). The relay amplified the received signal using gain**:**

$$\beta = \sqrt{\frac{p_r}{|h_{s,r}|^2 p_s + No}} \qquad (3.5)$$

Where β is the amplification factor, p_r Transmitted power of relay.

Thus, the received signal at the destination in Phase II from the relay as shown below:

$$y_{r,d} = \beta y_{s,r} h_{r,d} x + n_{r,d} \sqrt{No} \qquad (3.6)$$

3.2.3. Amplify-and-Forward System model:

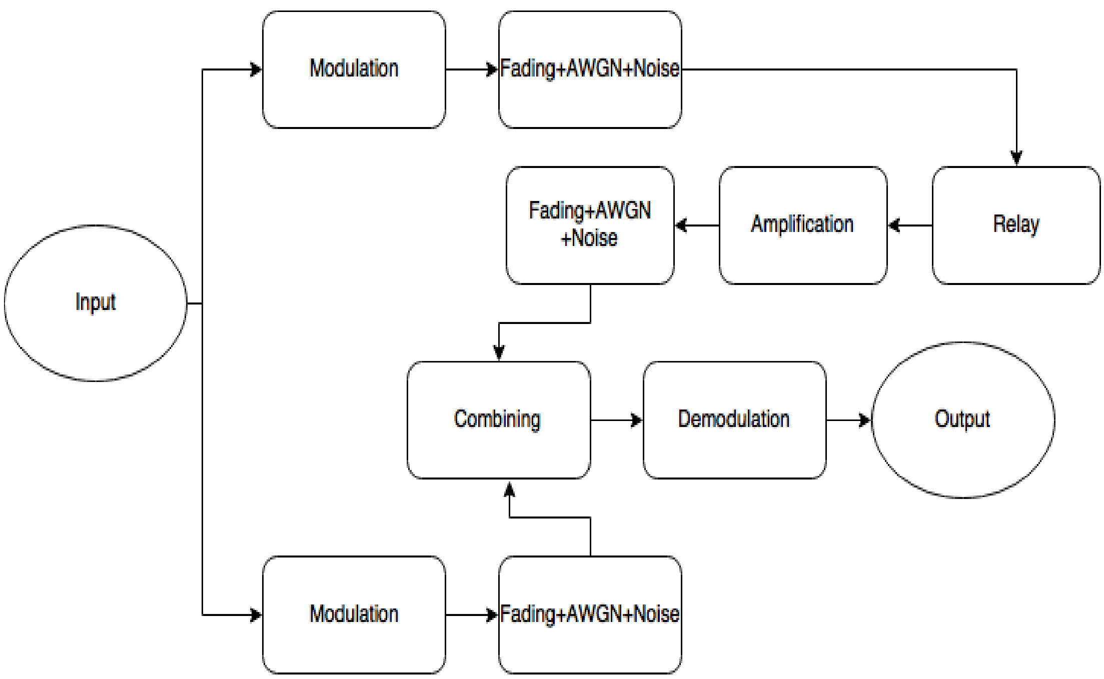


Figure (3-5): Model for AF cooperative communication.

3.3. Decode-and-Forward:

With the decode-and-forward protocol, the relay node decodes the received signal to get the original information. Next, the decoded information encoded and retransmitted to the destination as shown in Figure (3-6).

It is clear from this protocol that the noise will not be amplified because it is excluded by the decoding process. However, when a decoding error occurred at the relay node due to the deep fading in the channel between the source and the relay, this can be considered as the major problem with decode-and-forward protocol. The problem will be worsen if detection at the relay node unsuccessful too and will give bad performance.

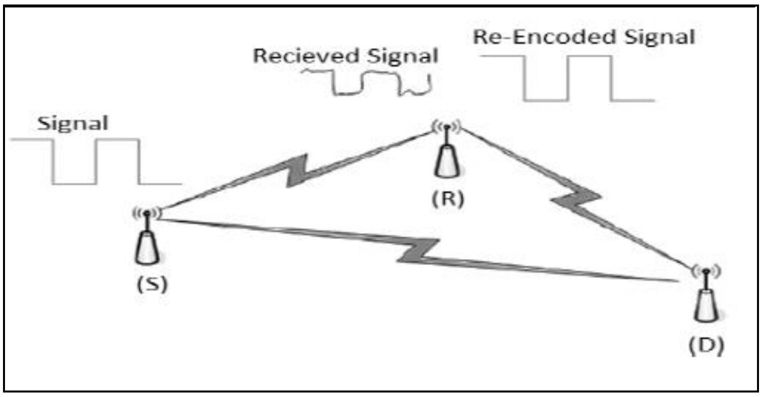


Figure (3-6):DF model

3.3.1. Characteristics of Decode-and-Forward:

- Re-generative mode.
- Noise does not prorogate to next stage, but error may propagate.
- Processing time is high, so it is not suitable for delay sensitive traffic.

3.3.2. Decode-and-Forward Operation:

Due to the broadcast nature of the wireless medium, the relay and the destination nodes will receive a noisy copy of the signal as mentioned in (3.1) and (3.2). Thus, the received signal at the destination in Phase II from the relay as shown below:

$$y_{r,d} = y_{s,r} h_{r,d} \hat{x} + n_{r,d} \sqrt{No} \quad (3.7)$$

When $\hat{x}$ is the hypothesis data detected by the relay.

3.3.3. Decode-and-Forward System Model:

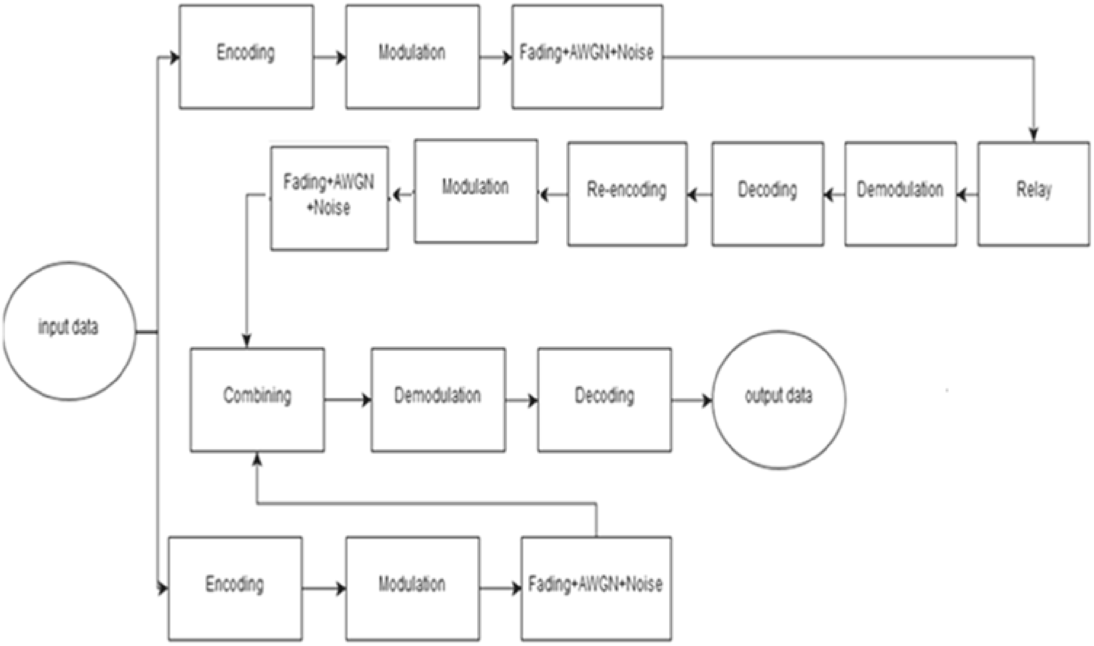


Figure (3-7): Model for DF cooperative communication.

Chapter Four

Simulation and Results

Chapter Four: Simulation and Results

4.1. Simulation Model:

The simulation goal is to compare between cooperative AF and DF relaying schemes in order to evaluate the performance of them .The MATLAB simulation for AF and DF cooperative communication is modeled using the following parameters:

Table (4-1): parameters of simulation:

Number of relays	1
Combining techniques	MRC
Channel type	AWGN

The simulation code in (Appendix A) simulates direct transmission and cooperative transmission using DF and AF protocols to study the effect of transmission through direct path and cooperative path in the BER and SNR using the following parameter:

Table (4-2): parameters of simulation in Appendix A:

Protocol used/relay mode	DF/AF
Number of bits	2^{10} bits
Modulation scheme	BPSK
Encoding method	Hamming code
Amplification factor	β
SNR vector	(from 0 to 18) dB

The simulation code in (Appendix B) simulates AF to study the effect of the amplification factor in the BER and SNR using the following parameter:

Table (4-3): parameters of AF simulation using different amplification factor:

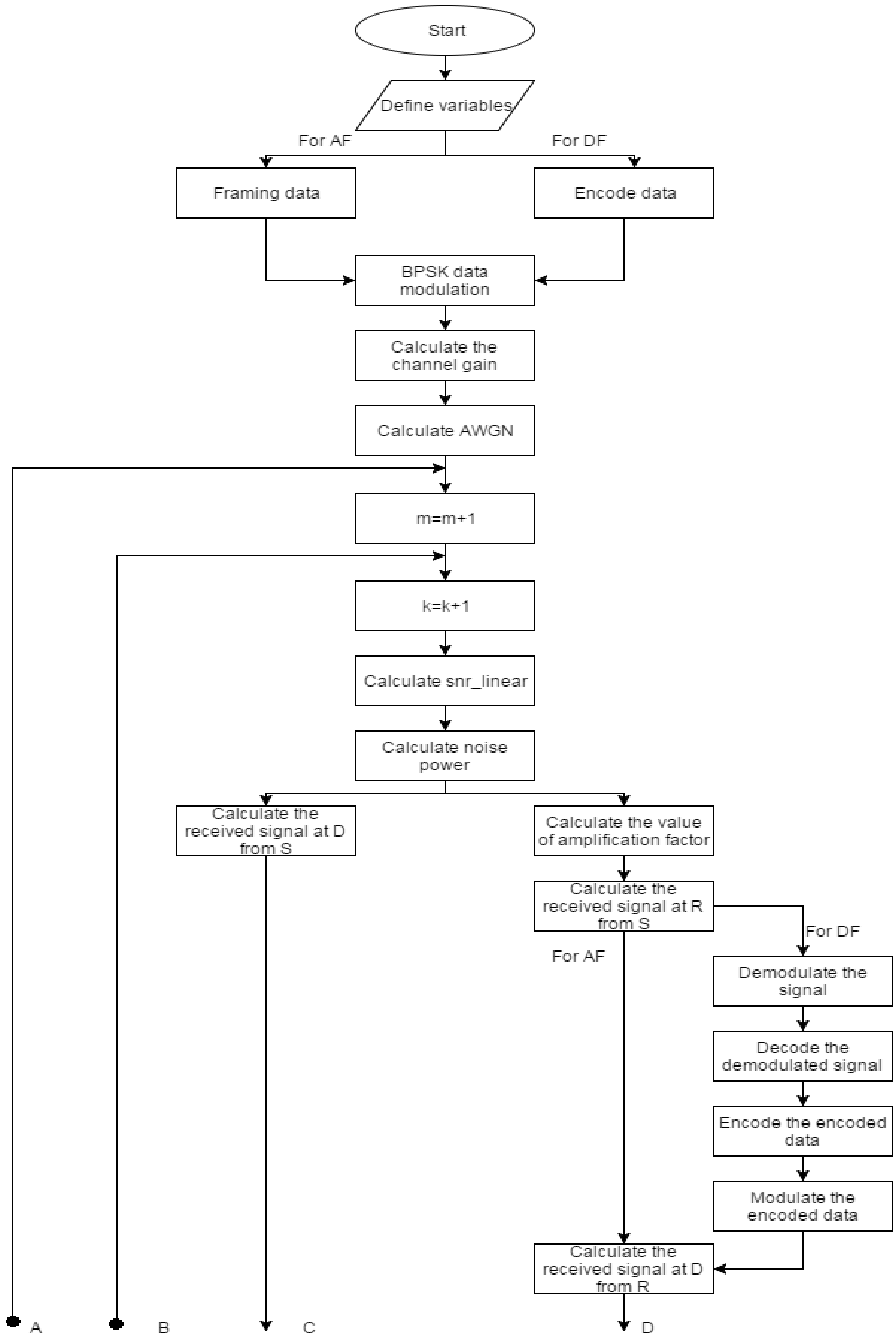
Protocol used/relay mode	AF
Number of bits	10^4 bits
Modulation scheme	BPSK
Amplification factor	β ,2 β ,0.5 β
SNR vector	(from 0 to 18) dB

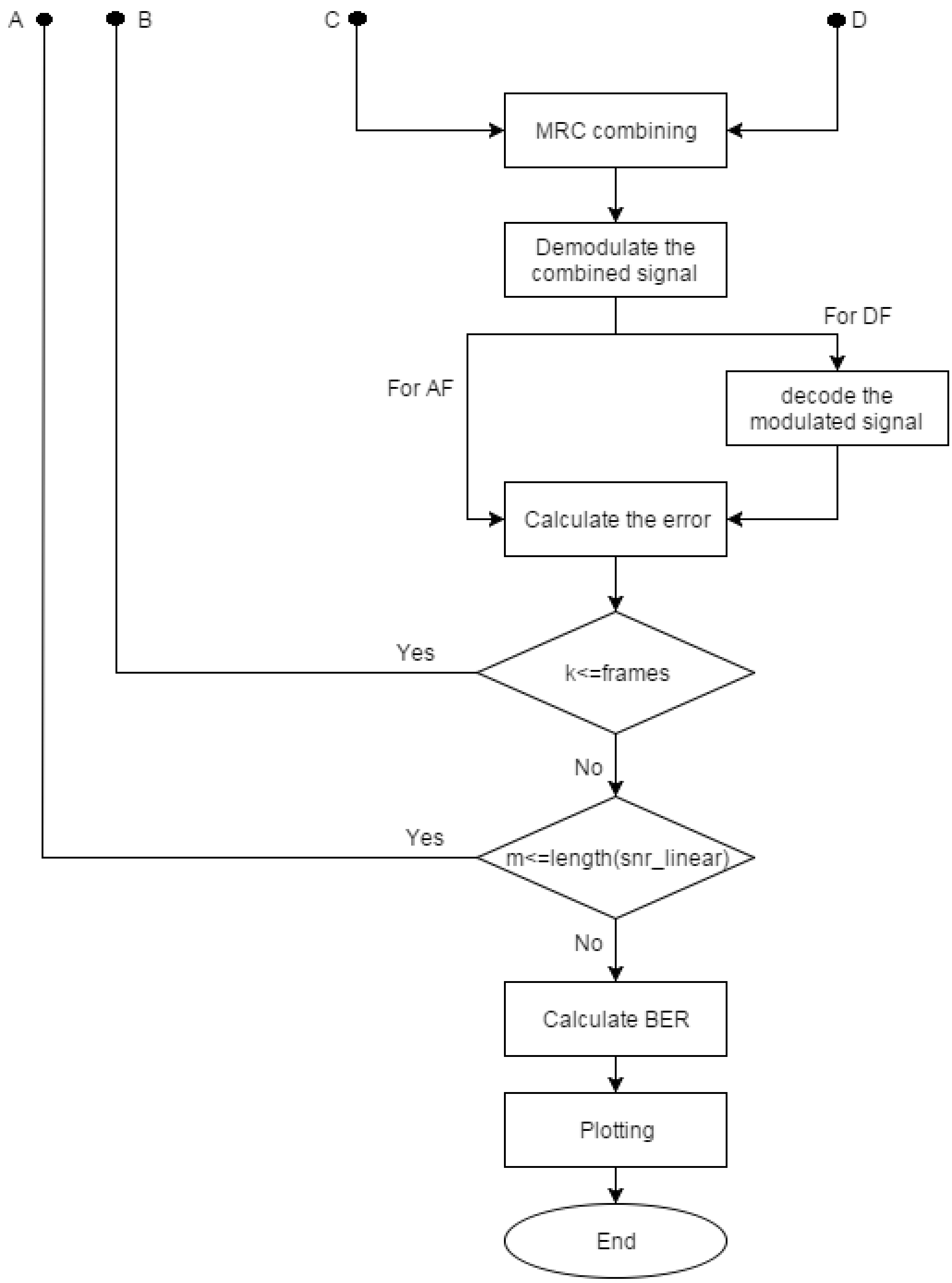
The simulation code in (Appendix C) simulates AF to study the effect of the modulation in the BER and SNR using the following parameter:

Table (4-4): parameters AF using different modulation level simulation:

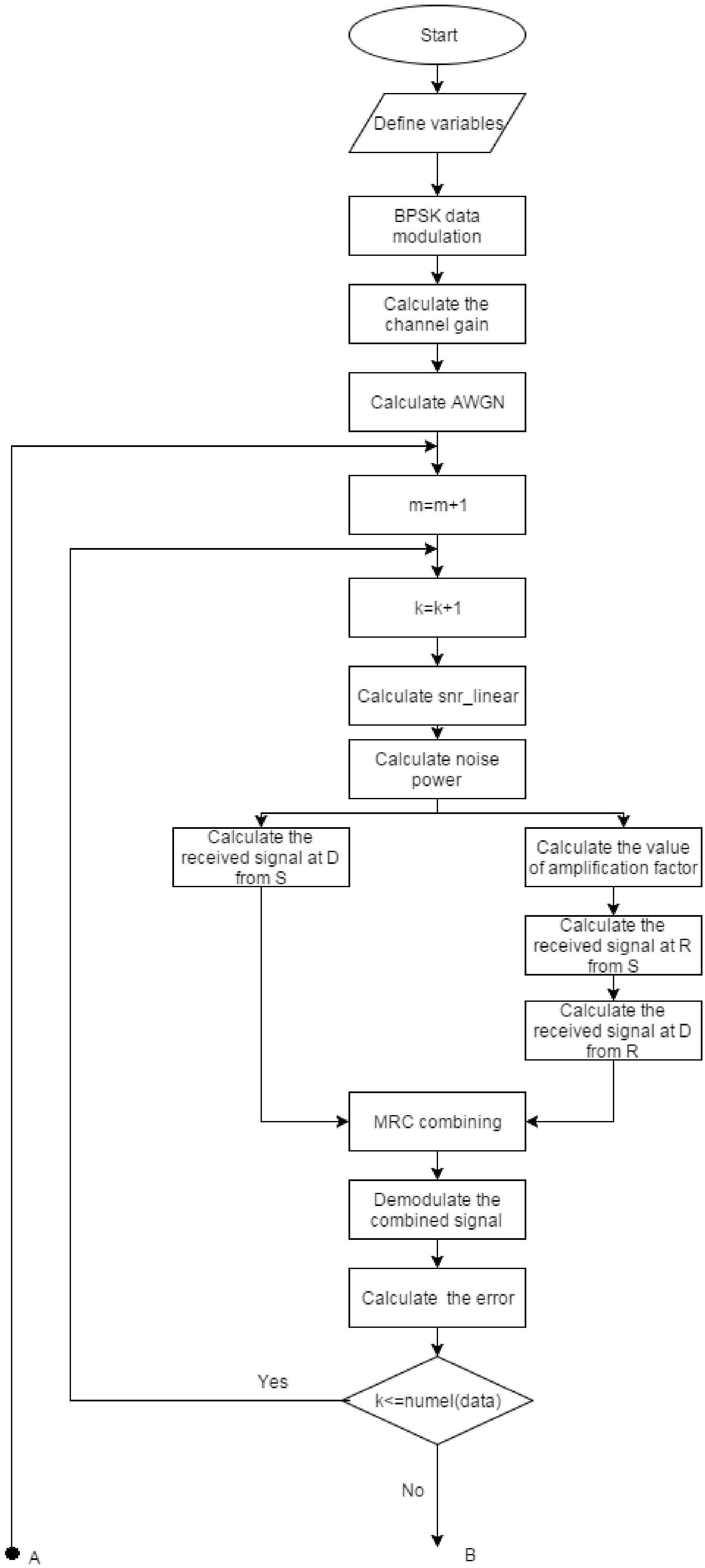
Protocol used/relay mode	AF
Number of bits	10^5 bits
Modulation scheme	BPSK,QPSK,16QAM
Amplification factor	1
SNR vector	(from 0 to 20) dB

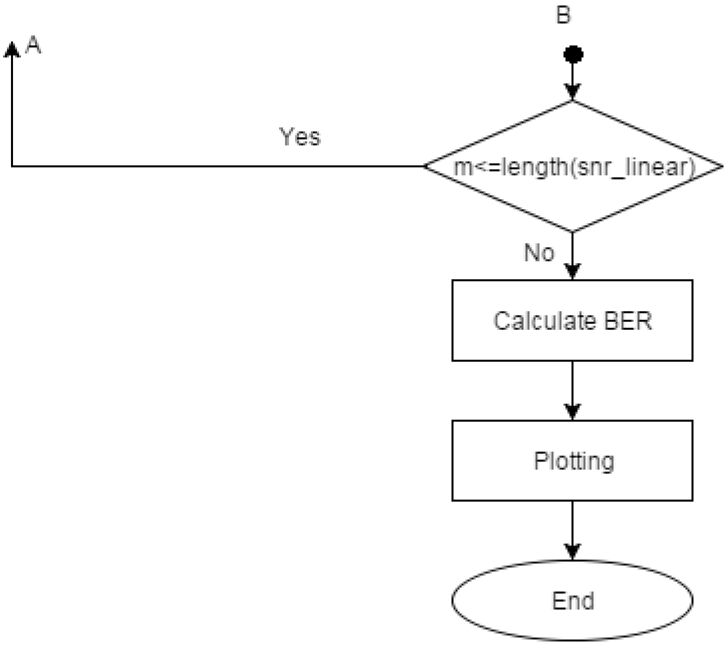
4.2. Flow Charts:



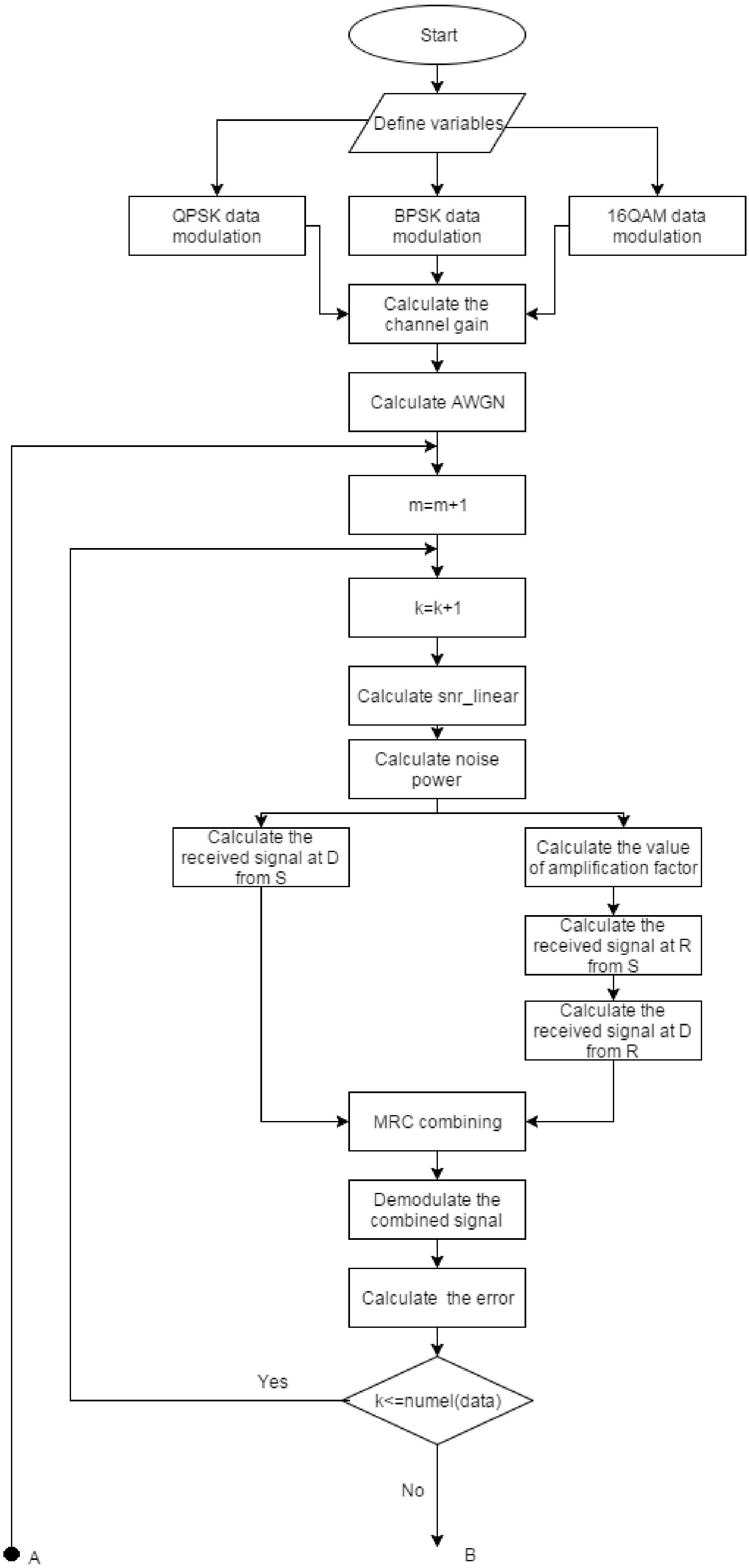


Appendix A flow chart

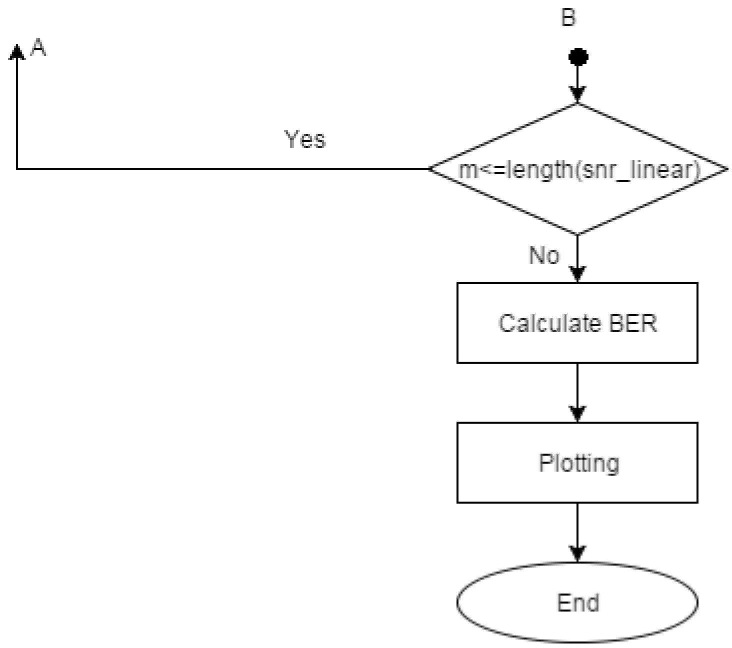

Start
Define variables
BPSK data modulation
Calculate the channel gain
Calculate AWGN
m=m+1
k=k+1
Calculate snr_linear
Calculate noise power
Calculate the received signal at D from S
Calculate the value of amplification factor
Calculate the received signal at R from S
Calculate the received signal at D from R
MRC combining
Demodulate the combined signal
Calculate the error
k<=numel(data)
Yes
No
A
B



Appendix B flow Chart



Start
Define variables
QPSK data modulation
BPSK data modulation
16QAM data modulation
Calculate the channel gain
Calculate AWGN
m=m+1
k=k+1
Calculate snr_linear
Calculate noise power
Calculate the received signal at D from S
Calculate the value of amplification factor
Calculate the received signal at R from S
Calculate the received signal at D from R
MRC combining
Demodulate the combined signal
Calculate the error
k<=numel(data)
Yes
No
A
B



Appendix C flow chart

4.3. Results and Discussion:

In the Simulation result of direct path and cooperative path which is shown in (figure (4-1)) we notice that:

In direct path the BER is highest than cooperative path, and in cooperative path AF is better than DF in BER.

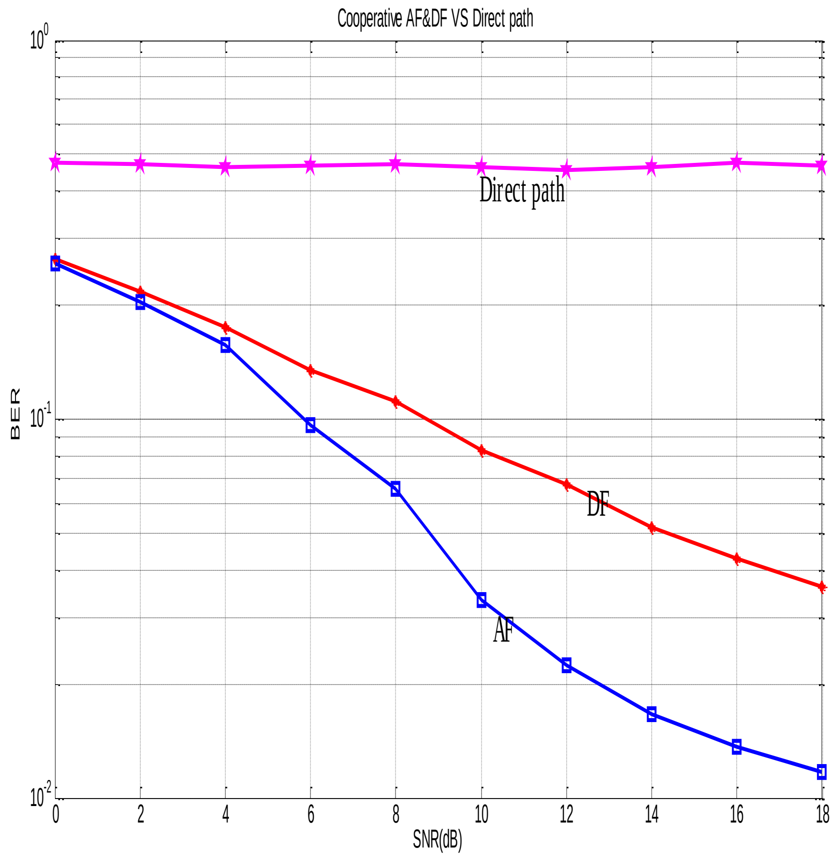


Figure (4-1): Simulation result of direct path and cooperative path

The simulation result of AF with different amplification factor in (figure (4-2)) show the BER as a function of the SNR to study the effect of amplification factor in the BER notice that:

The BER inversely proportional to the amplification factor

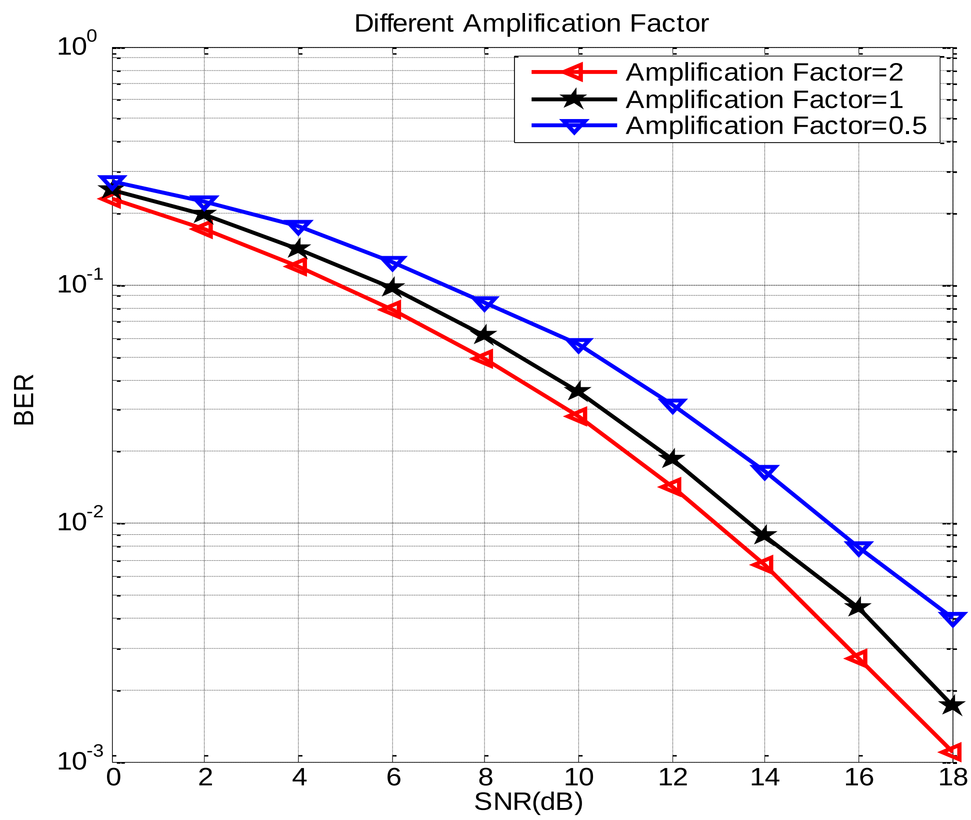


Figure (4-2): simulation result of AF with different amplification factor

The BER improvement which is achieved with the AF cooperation of Single relay, for example at 9dB:

- With amplification factor equal to 1 the BER is equal to 0.0052.
- With amplification factor equal to 2 the BER is equal to 0.0035.
- With amplification factor equal to 0.5 the BER is equal to 0.0110.

Also in simulation result of AF with different modulation schemes as shown in (Figure (4-3)) we notice that:

- In 16 QAM the BER directly proportional to SNR.
- In BPSK and QPSK the BER inversely proportional to SNR

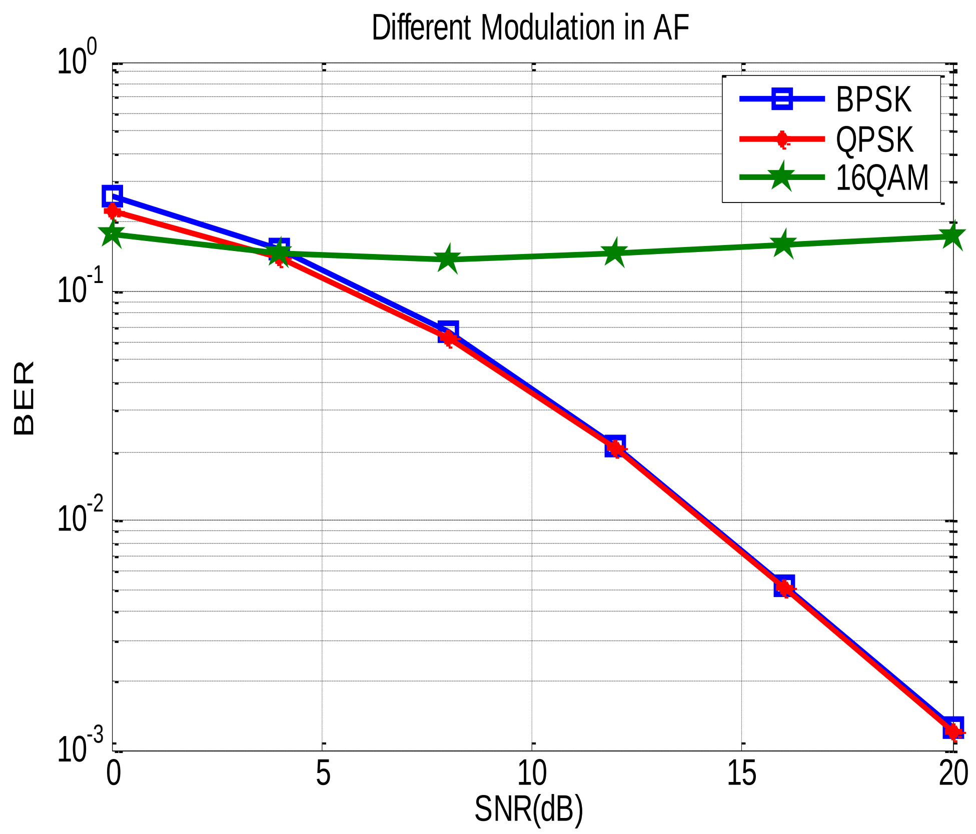


Figure (4-3): simulation result of AF with different modulation schemes

In applications which sensitive to the BER, BPSK and QPSK are the best choice for modulation, although the 16QAM has high BER but it is best to use in applications that is sensitive to the power consumption and need high data rate.

Chapter Five

Conclusion and Recommendation

Chapter Five: Conclusion and Recommendation

5.1. Conclusion:

This thesis introduced single-relay cooperative communication using decode-and-forward and amplify-and-forward protocols. In order to evaluate the system performance, several parameters have been identified including bit error rate (BER) and SNR gains of the single-relay cooperative communication.

Simulation results in amplify-and-forward show the effects of using different amplification factors once, and of using different modulation techniques, also to compare between amplify-and-forward and decode-and-forward and non-cooperative transmission which is best in bit error rate, the simulation done by using MATLAB programming language.

5.2. Recommendation:

In the future we recommend implementing this thesis using mobile nodes, also we hope to do modification in this thesis by make hybrid between DF and AF to study the effects of them in SNR and BER, or to use different combining techniques and study there role in elimination the effect of fading and noise

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Appendices

Appendix A: Direct path VS Cooperative path

```
clear all
close all
clc
data=randint(2^10,1,2); %Original Data
code1 = encode(data,7,4,'hamming/binary');
pt=1;
ps=pt/2;% Transmitted power of source
pr=pt/2; % Transmitted power of Relay
snr_db=[0:2:18];% SNR in dB
amplified=[];
for ii=1:4:numel(data)
amplified=[amplified; 0 0 0 data(ii) data(ii+1) data(ii+2)
data(ii+3)];
end
%bpsk modulation
tr_data=[2*amplified-1];
z=[2*code1-1]  ;
n=7;
[rows columns] =size(z);
frames=rows/n;
tr_data_DF=[];
for ii=1:n:numel(z)
tr_data_DF=[tr_data_DF ;transpose(z(ii:ii+n-1))];
end

%Channel gains
 hsr=(1/sqrt(2)).*(randn(1,frames)+j*randn(1,frames));% Channel
coefficients for Soure-Relay Link
 a11=sum((abs(hsr)))/frames; %Average channel gain for Soure-Relay
Link Channel

hrd=(1/sqrt(2)).*(randn(1,frames)+j*randn(1,frames));% Channel
coefficients for Relay-Desination Link
b11=sum((abs(hrd)))/frames; %Average channel gain for Relay-
Desination Link Channel

hsd=(1/sqrt(2))*(randn(1,frames)+j*randn(1,frames));% Channel
coefficients for Soure-Desination Direct Link
c11=sum((abs(hsd)))/frames; %Average channel gain for Soure-
Desination Link Channel

%% AWGN
nsr=(1/sqrt(2)).*(randn(1,frames)+j*randn(1,frames));%AWGN for at
Relay for Soure-Relay Link
nrd=(1/sqrt(2)).*(randn(1,frames)+j*randn(1,frames));%AWGN for at
Desination  for Relay-Desination Link
nsd=(1/sqrt(2)).*(randn(1,frames)+j*randn(1,frames));%AWGN for at
Desination  for source-Desination Link
```

```
        error_bpsk_df=zeros(length(snr_db));;
        error_bpsk_af=zeros(length(snr_db));
        error_direct_dsd_bpsk=zeros(length(snr_db));
for m=1:length(snr_db)
zr_df=[];
rrdata_bpsk_df=[];

zr_af=[];
rdata_bpsk_af=[];

zr_direct=[];
rdata_bpsk_direct=[];


for k=1:frames
                snr_linear(m)=10.^(snr_db(m)/10);    % Linear value of
SNR
                No(m)=pt./snr_linear(m);             % Noise power

                Beta=sqrt(pr./(a11^2.*ps+No(m)));


    %% RECEIVED DATA AT RELAY FROM SOURCE

dsr_bpsk_DF(k,:)=sqrt(ps/2).*tr_data_DF(k,:).*hsr(k)+sqrt(No(m))*nsr(
k);

dsr_bpsk_AF(k,:)=sqrt(ps/2).*tr_data(k,:).*hsr(k)+sqrt(No(m))*nsr(k);

%data demodulation
               g= dsr_bpsk_DF(k,:);
               c=real(g);
               d=imag(g);
               rdata_r_bpsk(find(c<0))=0;
               rdata_r_bpsk(find(c>0))=1;
%data decoding
      decoded_dsr_bpsk= decode(rdata_r_bpsk,7,4,'hamming');
%data encoding
     encoded_dsr_bpsk= encode(decoded_dsr_bpsk,7,4,'hamming/binary');
%bpsk modulation

     modulated_dsr_bpsk(find( encoded_dsr_bpsk==0))=-1;
modulated_dsr_bpsk(find( encoded_dsr_bpsk==1))=1;

   %% RECEIVED DATA AT DESTINATION FROM RELAY

Df_drd_bpsk(k,:)=modulated_dsr_bpsk.*hrd(k)+sqrt(No(m))*nrd(k);

Af_drd_bpsk(k,:)=Beta.*dsr_bpsk_AF(k,:).*hrd(k)+sqrt(No(m))*nrd(k);



   %% RECEIVED DATA AT DESTINATION FROM SOURCE

dsd_bpsk_DF(k,:)=sqrt(ps/2).*tr_data_DF(k,:).*hsd(k)+sqrt(No(m))*nsd(
k);

dsd_bpsk_AF(k,:)=sqrt(ps/2).*tr_data(k,:).*hsd(k)+sqrt(No(m))*nsd(k);
```

```
 %%   MRC AT RECEIVER

dataMRC_bpsk_DF(k,:)=( Df_drd_bpsk(k,:).*conj(hsr(k).*hrd(k))+
dsd_bpsk_DF(k,:).*conj(hsd(k)))/sqrt(No(m));
dataMRC_bpsk_AF(k,:)=( Af_drd_bpsk(k,:).*conj(hsr(k).*hrd(k))+
dsd_bpsk_AF(k,:).*conj(hsd(k)))/sqrt(No(m));


 %% DEMODULATION
 %% bpsk demodulation
        g1= dataMRC_bpsk_DF(k,:);
        g2=dataMRC_bpsk_AF(k,:);
        g3=dsd_bpsk_AF(k,:);
        c1=real(g1);
        d1=imag(g1);
        c2=real(g2);
        d2=imag(g2);

        c3=real(g3);
        d3=imag(g3);



          zr_df(find(c1>0))=1;
          zr_df(find(c1<0))=-1;
          zr_af(find(c2>0))=1;
          zr_af(find(c2<0))=-1;
          zr_direct(find(c3>0))=1;
         zr_direct(find(c3<0))=-1;


            rdata_bpsk_df(find(zr_df==-1))=0;
            rdata_bpsk_df(find(zr_df==1))=1;
            rdata_bpsk_af(find(zr_af==-1))=0;
            rdata_bpsk_af(find(zr_af==1))=1;
            rdata_bpsk_direct(find(zr_direct==-1))=0;
            rdata_bpsk_direct(find(zr_direct==1))=1;

%data decoding
decoded_d_bpsk= decode(rdata_bpsk_df,7,4,'hamming');
original_data=decode(code1(7*(k-1)+1:7*(k-1)+7),7,4,'hamming');

amplified_data=rdata_bpsk_af(4:7);
 direct_dsd_bpsk=rdata_bpsk_direct(4:7);

        %% CALCULATING ERRORS

error_bpsk_af(m)=error_bpsk_af(m)+size(find(transpose(original_data)-
amplified_data),2);

error_bpsk_df(m)=error_bpsk_df(m)+size(find(transpose(original_data)-
decoded_d_bpsk),2);

error_direct_dsd_bpsk(m)=error_direct_dsd_bpsk(m)+size(find(transpose
(original_data)-direct_dsd_bpsk),2);
end



end
%% PLOTTING THE SIMULATION AND THEORATICAL RESULTS
```

```
figure
%% SIMULATION RESULTS
BER_bpsk_df=error_bpsk_df/numel(data);
BER_bpsk_af=error_bpsk_af/numel(data);
BER_direct_dsd_bpsk=error_direct_dsd_bpsk/numel(data);

 %% PLOTTING
semilogy(snr_db,BER_bpsk_df,'r*-')
hold on
semilogy(snr_db,BER_bpsk_af,'b.-')
semilogy(snr_db,BER_direct_dsd_bpsk,'m>-')
hold off
legend('cooperativ DF','cooperative AF','Direct path')
title('Cooperative VS Non cooperativ & Direct path ')
grid
xlabel('SNR(dB)')
ylabel('BER')
```

Appendix B: different_amplification_factor.m

```
clear all
clc
data=randint(10^4,1,2); %Original Data
pt1=1;
pt2=pt1;
pt3=pt1;
ps1=pt1/2;% Transmitted power of source
ps2=pt2/2;
ps3=pt3/2;
pr1=pt1/2; % Transmitted power of Relay
pr2=pt2/2;
pr3=pt3/2;
snr_db=[0:2:18];% SNR in dB




%bpsk modulation
z=[2*data-1]

%Channel gains
 hsr=(1/sqrt(2)).*(randn(1,numel(data))+j*randn(1,numel(data)));%
Channel coefficients for Soure-Relay Link
        a11=sum((abs(hsr)))/numel(data); %Average channel gain for
Soure-Relay Link Channel


hrd=(1/sqrt(2)).*(randn(1,numel(data))+j*randn(1,numel(data)));%
Channel coefficients for Relay-Desination Link
        b11=sum((abs(hrd)))/numel(data); %Average channel gain for
Relay-Desination Link Channel

hsd=(1/sqrt(2))*(randn(1,numel(data))+j*randn(1,numel(data)));%
Channel coefficients for Soure-Desination Direct Link
        c11=sum((abs(hsd)))/numel(data); %Average channel gain for
Soure-Desination Link Channel
 %% AWGN

nsr=(1/sqrt(2)).*(randn(1,numel(data))+j*randn(1,numel(data)));%AWGN
for at Relay for Soure-Relay Link

nrd=(1/sqrt(2)).*(randn(1,numel(data))+j*randn(1,numel(data)));%AWGN
for at Desination  for Relay-Desination Link

nsd=(1/sqrt(2)).*(randn(1,numel(data))+j*randn(1,numel(data)));%AWGN
for at Desination  for source-Desination Link
for m=1:length(snr_db)

zr1=[];
zr2=[];
zr3=[];
rdata_bpsk=[];

    for k=1:numel(data)
                snr_linear(m)=10.^(snr_db(m)/10);   % Linear value of
SNR
```

```
              No1(m)=pt1./snr_linear(m);            % Noise power
               No2(m)=pt2./snr_linear(m);
                No3(m)=pt3./snr_linear(m);
   %% AMPLIFICATION FACTOR
             Beta1=sqrt(pr1./(a11^2.*ps1+No1(m)));
             Beta2=2*Beta1;
             Beta3=0.5*Beta1;

    %% RECEIVED DATA AT RELAY FROM SOURCE

dsr_bpsk1(k)=sqrt(ps1/2).*z(k).*hsr(k)+sqrt(No1(m))*nsr(k);

dsr_bpsk2(k)=sqrt(ps2/2).*z(k).*hsr(k)+sqrt(No2(m))*nsr(k);

dsr_bpsk3(k)=sqrt(ps3/2).*z(k).*hsr(k)+sqrt(No3(m))*nsr(k);

   %% RECEIVED DATA AT DESYINATION FROM RELAY
        drd_bpsk1(k)=Beta1.*dsr_bpsk1(k).*hrd(k)+sqrt(No1(m))*nrd(k);
        drd_bpsk2(k)=Beta2.*dsr_bpsk2(k).*hrd(k)+sqrt(No2(m))*nrd(k);
        drd_bpsk3(k)=Beta3.*dsr_bpsk3(k).*hrd(k)+sqrt(No3(m))*nrd(k);

   %% RECEIVED DATA AT DESTINATION FROM SOURCE
     dsd_bpsk1(k)=sqrt(ps1/2).*z(k).*hsd(k)+sqrt(No1(m))*nsd(k);
     dsd_bpsk2(k)=sqrt(ps2/2).*z(k).*hsd(k)+sqrt(No2(m))*nsd(k);
     dsd_bpsk3(k)=sqrt(ps3/2).*z(k).*hsd(k)+sqrt(No3(m))*nsd(k);

        end




   %%   MRC AT RECEIVER
  for k = 1:numel(data)
        dataMRC_bpsk1(k)=(drd_bpsk1(k).*conj(hsr(k).*hrd(k))+
dsd_bpsk1(k).*conj(hsd(k)))/sqrt(No1(m));
         dataMRC_bpsk2(k)=(drd_bpsk2(k).*conj(hsr(k).*hrd(k))+
dsd_bpsk2(k).*conj(hsd(k)))/sqrt(No2(m));
          dataMRC_bpsk3(k)=(drd_bpsk3(k).*conj(hsr(k).*hrd(k))+
dsd_bpsk3(k).*conj(hsd(k)))/sqrt(No3(m));

   end
 %% DEMODULATION
        g1= dataMRC_bpsk1;
        c1=real(g1);
        d1=imag(g1);
          zr1(find(c1>0))=1;
          zr1(find(c1<0))=-1;
          rdata_bpsk1(find(zr1==-1))=0;           %bpsk demodulation
          rdata_bpsk(find(zr1==1))=1;
        error_bpsk1(m)=size(find(transpose(z)-zr1),2); %% CALCULATING
ERRORS
       g2= dataMRC_bpsk2;
        c2=real(g2);
        d2=imag(g2);
          zr2(find(c2>0))=1;
          zr2(find(c2<0))=-1;
            rdata_bpsk(find(zr2==-1))=0;           %bpsk demodulation
            rdata_bpsk(find(zr2==1))=1;
```

```
        error_bpsk2(m)=size(find(transpose(z)-zr2),2); %% CALCULATING
ERRORS
       g3= dataMRC_bpsk3;
        c3=real(g3);
        d3=imag(g3);
          zr3(find(c3>0))=1;
          zr3(find(c3<0))=-1;
            rdata_bpsk3(find(zr3==-1))=0;           %bpsk
demodulation
            rdata_bpsk3(find(zr3==1))=1;

        error_bpsk1(m)=size(find(transpose(z)-zr1),2); %% CALCULATING
ERRORS
       error_bpsk2(m)=size(find(transpose(z)-zr2),2);
       error_bpsk3(m)=size(find(transpose(z)-zr3),2);


end
    figure
    %% SIMULATION RESULTS
    BER_bpsk1=error_bpsk1/numel(data);
    BER_bpsk2=error_bpsk2/numel(data);
    BER_bpsk3=error_bpsk3/numel(data);


    semilogy(snr_db,BER_bpsk2,'r<-')
    hold on

    semilogy(snr_db,BER_bpsk1,'k*-')

    semilogy(snr_db,BER_bpsk3,'b.-')
    hold off
    legend('Amplification Factor=2','Amplification
Factor=1','Amplification Factor=0.5')
    title('Different Amplification Factor')
    grid
    xlabel('SNR')
    ylabel('BER')
```

Appendix C: different_modulation.m

```
clear all
clc
data=randint(10^5,1,2); %Original Data
pt=2;
ps=pt/2;% Transmitted power of source
pr=pt/2; % Transmitted power of Relay
snr_db=[0:4:20];% SNR in dB

dh_qpsk = [1+i -1+i 1-i -1-i] ;% Possible symbols QPSK
qamOrder = 16;temp = 0:1:15;dh_16qam = qammod(temp,qamOrder);%16QAM

x=[];
y=[];
%bpsk modulation
z=[2*data-1] ;
for cn=1:2:numel(data)
    if (data(cn)==0)&&(data(cn+1)==0)
        x=[x dh_qpsk(4)];
    elseif (data(cn)==0)&&(data(cn+1)==1)
        x=[x dh_qpsk(2)];
    elseif (data(cn)==1)&&(data(cn+1)==0)
        x=[x dh_qpsk(3)];
    else
        x=[x dh_qpsk(1)];
    end
end
for cn=1:4:numel(data)
    if
(data(cn)==0)&&(data(cn+1)==0)&&(data(cn+2)==0)&&(data(cn+3)==0)
        y=[y dh_16qam(7)];
    elseif
(data(cn)==0)&&(data(cn+1)==0)&&(data(cn+2)==0)&&(data(cn+3)==1)
        y=[y dh_16qam(3)];
    elseif
(data(cn)==0)&&(data(cn+1)==0)&&(data(cn+2)==1)&&(data(cn+3)==0)
        y=[y dh_16qam(11)];
    elseif
(data(cn)==0)&&(data(cn+1)==0)&&(data(cn+2)==1)&&(data(cn+3)==1)
        y=[y dh_16qam(15)];
    elseif
(data(cn)==0)&&(data(cn+1)==1)&&(data(cn+2)==0)&&(data(cn+3)==0)
        y=[y dh_16qam(8)];
    elseif
(data(cn)==0)&&(data(cn+1)==1)&&(data(cn+2)==0)&&(data(cn+3)==1)
        y=[y dh_16qam(4)];
    elseif
(data(cn)==0)&&(data(cn+1)==1)&&(data(cn+2)==1)&&(data(cn+3)==0)
        y=[y dh_16qam(12)];
    elseif
(data(cn)==0)&&(data(cn+1)==1)&&(data(cn+2)==1)&&(data(cn+3)==1)
        y=[y dh_16qam(16)];
    elseif
(data(cn)==1)&&(data(cn+1)==0)&&(data(cn+2)==0)&&(data(cn+3)==0)
        y=[y dh_16qam(6)];
    elseif
(data(cn)==1)&&(data(cn+1)==0)&&(data(cn+2)==0)&&(data(cn+3)==1)
        y=[y dh_16qam(2)];
```

```
    elseif
(data(cn)==1)&&(data(cn+1)==0)&&(data(cn+2)==1)&&(data(cn+3)==0)
        y=[y dh_16qam(10)];
    elseif
(data(cn)==1)&&(data(cn+1)==0)&&(data(cn+2)==1)&&(data(cn+3)==1)
        y=[y dh_16qam(14)];
    elseif
(data(cn)==1)&&(data(cn+1)==1)&&(data(cn+2)==0)&&(data(cn+3)==0)
        y=[y dh_16qam(5)];
    elseif
(data(cn)==1)&&(data(cn+1)==1)&&(data(cn+2)==0)&&(data(cn+3)==1)
        y=[y dh_16qam(1)];
    elseif
(data(cn)==1)&&(data(cn+1)==1)&&(data(cn+2)==1)&&(data(cn+3)==0)
        y=[y dh_16qam(9)];

    else
        y=[y dh_16qam(13)];
    end
end

%% CHANNEL GAIN
 hsr=(1/sqrt(2)).*(randn(1,numel(data))+j*randn(1,numel(data)));%
Channel coefficients for Soure-Relay Link
        a11=sum((abs(hsr)))/numel(data); %Average channel gain for
Soure-Relay Link Channel


hrd=(1/sqrt(2)).*(randn(1,numel(data))+j*randn(1,numel(data)));%
Channel coefficients for Relay-Desination Link
        b11=sum((abs(hrd)))/numel(data); %Average channel gain for
Relay-Desination Link Channel

hsd=(1/sqrt(2))*(randn(1,numel(data))+j*randn(1,numel(data)));%
Channel coefficients for Soure-Desination Direct Link
        c11=sum((abs(hsd)))/numel(data); %Average channel gain for
Soure-Desination Link Channel
 %% AWGN

nsr=(1/sqrt(2)).*(randn(1,numel(data))+j*randn(1,numel(data)));%AWGN
for at Relay for Soure-Relay Link

nrd=(1/sqrt(2)).*(randn(1,numel(data))+j*randn(1,numel(data)));%AWGN
for at Desination  for Relay-Desination Link

nsd=(1/sqrt(2)).*(randn(1,numel(data))+j*randn(1,numel(data)));%AWGN
for at Desination  for source-Desination Link
for m=1:length(snr_db)
    xr=[];
yr=[];
zr=[];
rdata_bpsk=[];
rdata_qpsk=[];
rdata_16qam=[];
    for k=1:numel(data)
                snr_linear(m)=10.^(snr_db(m)/10);   % Linear value of
SNR
                No(m)=pt./snr_linear(m);            % Noise power

   %% AMPLIFICATION FACTOR
```

```
               Beta=sqrt(pr./(a11^2.*ps+No(m)));

    %% RECEIVED DATA AT RELAY FROM SOURCE

ysr_bpsk(k)=sqrt(ps/2).*z(k).*hsr(k)+sqrt(No(m))*nsr(k);
               if k<=numel(data)/2

ysr_qpsk(k)=sqrt(ps/2).*x(k).*hsr(k)+sqrt(No(m))*nsr(k);
               end
               if k<=numel(data)/4

ysr_16qam(k)=sqrt(ps/2).*y(k).*hsr(k)+sqrt(No(m))*nsr(k);
               end



   %% RECEIVED DATA AT DESTINATION FROM SOURCE

        yrd_bpsk(k)=Beta.*ysr_bpsk(k).*hrd(k)+sqrt(No(m))*nrd(k);
        if k<=numel(data)/2
            yrd_qpsk(k)=Beta.*ysr_qpsk(k).*hrd(k)+sqrt(No(m))*nrd(k);
        end
        if k<=numel(data)/4

yrd_16qam(k)=Beta.*ysr_16qam(k).*hrd(k)+sqrt(No(m))*nrd(k);
        end
   %% RECEIVED DATA AT DESTINATION FROM SOURCE
     ysd_bpsk(k)=sqrt(ps/2).*z(k).*hsd(k)+sqrt(No(m))*nsd(k);
        if k<=numel(data)/2
            ysd_qpsk(k)=sqrt(ps/2).*x(k).*hsd(k)+sqrt(No(m))*nsd(k);
        end
        if k<=numel(data)/4
            ysd_16qam(k)=sqrt(ps/2).*y(k).*hsd(k)+sqrt(No(m))*nsd(k);
        end

    end



   %%   MRC AT RECEIVER
  for k = 1:numel(data)
        yMRC_bpsk(k)=(yrd_bpsk(k).*conj(hsr(k).*hrd(k))+
ysd_bpsk(k).*conj(hsd(k)))/sqrt(No(m));
        if k<=numel(data)/2
            yMRC_qpsk(k)=(yrd_qpsk(k).*conj(hsr(k).*hrd(k))+
ysd_qpsk(k).*conj(hsd(k)))/sqrt(No(m));
        end
        if k<=numel(data)/4
            yMRC_16qam(k)=(yrd_16qam(k).*conj(hsr(k).*hrd(k))+
ysd_16qam(k).*conj(hsd(k)))/sqrt(No(m));
        end
   end
 %% DEMODULATION
        g1= yMRC_bpsk;
        g2= yMRC_qpsk;
        g3= yMRC_16qam;
        c1=real(g1);
        d1=imag(g1);
        c2=real(g2);
        d2=imag(g2);
        c3=real(g3);
        d3=imag(g3);
```

```
  zr(find(c1>0))=1;
  zr(find(c1<0))=-1;
xr(find(c2>=0 & d2>=0))=dh_qpsk(1);
xr(find(c2>=0 & d2<0))=dh_qpsk(3);
xr(find(c2<0 & d2>=0))=dh_qpsk(2);
xr(find(c2<0 & d2<0))=dh_qpsk(4);
    yr(find(c3<=-2 & d3>2))=dh_16qam(1);
    yr(find(c3<=-2 & d3<=2 & d3>0))=dh_16qam(2);
    yr(find(c3<=-2 &d3<=0 & d3>-2 ))=dh_16qam(3);
    yr(find(c3<=-2 & d3<=-2))=dh_16qam(4);
    yr(find(c3<=0 & c3>-2 & d3>2))=dh_16qam(5);
    yr(find(c3<=0 & c3>-2 & d3<=2 & d3>0))=dh_16qam(6);
    yr(find(c3<=0 & c3>-2 & d3<=0 & d3>-2))=dh_16qam(7);
    yr(find(c3<=0 & c3>-2 & d3<=-2))=dh_16qam(8);
    yr(find(c3<=2 & c3>0 & d3>2))=dh_16qam(9);
    yr(find(c3<=2 & c3>0 & d3<=2 & d3>0))=dh_16qam(10);
    yr(find(c3<=2 & c3>0 & d3<=0 & d3>-2))=dh_16qam(11);
    yr(find(c3<=2 & c3>0 & d3<=-2))=dh_16qam(12);
    yr(find(c3>2 & d3>2))=dh_16qam(13);
    yr(find(c3>2 & d3<=2 & d3>0))=dh_16qam(14);
    yr(find(c3>2 & d3<=0 & d3>-2))=dh_16qam(15);
    yr(find(c3>2 & d3<=-2))=dh_16qam(16);



    rdata_bpsk(find(zr==-1))=0;           %bpsk demodulation
    rdata_bpsk(find(zr==1))=1;
for cn=1:numel(xr)                        %qpsk demodulation
    if xr(cn)==dh_qpsk(1)
        rdata_qpsk=[rdata_qpsk 1 1];
    elseif xr(cn)==dh_qpsk(2)
        rdata_qpsk=[rdata_qpsk 0 1];
    elseif xr(cn)==dh_qpsk(3)
        rdata_qpsk=[rdata_qpsk 1 0];
    else
        rdata_qpsk=[rdata_qpsk 0 0];
    end
end
for cn=1:numel(yr)
    if yr(cn)==dh_16qam(1)
        rdata_16qam=[rdata_16qam 1 1 0 1];
    elseif yr(cn)==dh_16qam(2)
        rdata_16qam=[rdata_16qam 1 0 0 1];
    elseif yr(cn)==dh_16qam(3)
        rdata_16qam=[rdata_16qam 0 0 0 1];
    elseif yr(cn)==dh_16qam(4)
        rdata_16qam=[rdata_16qam 0 1 0 1];
    elseif yr(cn)==dh_16qam(5)
        rdata_16qam=[rdata_16qam 1 1 0 0];
    elseif yr(cn)==dh_16qam(6)
        rdata_16qam=[rdata_16qam 1 0 0 0];
    elseif yr(cn)==dh_16qam(7)
        rdata_16qam=[rdata_16qam 0 0 0 0];
    elseif yr(cn)==dh_16qam(8)
        rdata_16qam=[rdata_16qam 0 1 0 0];
    elseif yr(cn)==dh_16qam(9)
        rdata_16qam=[rdata_16qam 1 1 1 0];
    elseif yr(cn)==dh_16qam(10)
        rdata_16qam=[rdata_16qam 1 0 1 0];
```

```
            elseif yr(cn)==dh_16qam(11)
                rdata_16qam=[rdata_16qam 0 0 1 0];
            elseif yr(cn)==dh_16qam(12)
                rdata_16qam=[rdata_16qam 0 1 1 0];
            elseif yr(cn)==dh_16qam(13)
                rdata_16qam=[rdata_16qam 1 1 1 1];
            elseif yr(cn)==dh_16qam(14)
                rdata_16qam=[rdata_16qam 1 0 1 1];
            elseif yr(cn)==dh_16qam(15)
                rdata_16qam=[rdata_16qam 0 0 1 1];
            elseif yr(cn)==dh_16qam(16)
                rdata_16qam=[rdata_16qam 0 1 1 1];
            end
        end


        error_bpsk(m)=size(find(zr-transpose(z)),2); %% CALCULATING
ERROrelay
        error_qpsk(m)=size(find(xr-x),2);
        error_16qam(m)=size(find(yr-y),2);



end
    figure

    %% SIMULATION RESULTS
    BER_bpsk=error_bpsk/numel(data);
    BER_qpsk=error_qpsk/numel(data);
    BER_16qam=error_16qam/numel(data);

    semilogy(snr_db,BER_bpsk,'k*-')
    hold on
    semilogy(snr_db,BER_qpsk,'r>-')

    semilogy(snr_db,BER_16qam,'b.-')
    hold off
    legend('BPSK','QPSK','16QAM')
xlabel('SNR')
ylabel('BER')
grid
title('Different modulation in AF')
```