CHAPTER ONE

INTRODUCTION

Eyes are now turning towards the next development that of the truly fourth generation (4G) and beyond mobile wireless broadband communication systems. A single smartphone or a single tablet can generate as much traffic as 35 or 121 basic-feature phones respectively. Overall mobile data traffic is expected to grow to 10.8 exabytes per month by 2016 [1].

The International Telecommunications Union Radio communications (ITU-R) defines the requirements for the International Mobile Telephony - Advanced (IMT-A), in order to enable the standardization process for 4th generation wireless cellular technologies. Two working group have been developed; Third Generation Partnership Project (3GPP) who initiated Long Term Evolution-Advanced (LTE-A) standards and IEEE.802.16 Working Group with its WiMAX 802.16m standards. These technologies promise to achieve high spectral efficiency with improved peak data rates and enable enhanced network coverage with good throughput both in downlink and uplink. In the 3rd Generation Partnership Project (3GPP) community, the LTE-A Release-10 compliant networks are termed as to fulfill the IMT-A requirements [1][5]. The standards of LTE-A propose several enhancement techniques to provide a quality-of-service (QoS) to the mobile users with low deployment constraints including Carrier Aggregation (CA), Extended-Multiple-Input Multiple- Output (E-MIMO), Coordinated Multi-point Transmission (CoMP), Relaying, and so on.

One of the main challenges faced by the developing standard is providing high throughput at the cell edge. Cell edge performance is becoming more important as cellular systems employ higher bandwidth with the same amount of transmit power and use higher carrier frequencies with infrastructure designed for lower carrier frequencies.

One solution to improve coverage as component included in LTE-A is to use the fixed relays to transmit data between the eNodeB and the Mobile Stations or User Equipment through multi hop communication [2].

Relay transmission can be seen as a kind of collaborative communications, in which a Relay Node (RN) helps in forwarding the data-information from a local eNode-B to the neighboring user equipment (UE), therefore, deploying RNs near the cell edge will help to increase the capacity or alternatively to extend the cell coverage area [3][4].

Over the past decade, numerous relay transmission schemes have been developed to be implemented in our cellular network technology. In [5], the transmission techniques include:

i. Analog repeater which repeats transmitted signal using combination of directional antennas and a power amplifier.

ii. Amplify-and-forward (AF) that directly transforms the received signal.

iii. Decode-and-forward (DF) this decodes the received signal then re-encodes it for transmission.

iv. Compress-and-forward.

v. Demodulate-and-forward.

1.1 Motivation and Problem Statement

3GPP includes the LTE air interface specifications in releases 8 to 10. Several interesting features have been introduced, among them relaying transmission. The main challenge and important issue of the cooperative relaying is the design of appropriate forwarding strategy at the relay which achieves the required performance. Evaluating performance of Amplify and forward (AF) relay deployment in an LTE-Advanced network for different channel environments of WINNER II Channel model was performed in study [2].

However, AF has limited performance compared with Decode and Froward (DF) protocol. DF is more distinguished performance protocol [7] where Error correction technique could be applied for more enhancements, therefore this research will evaluate the performance using mainly DF.

1.2 Objectives

The aim of this thesis is evaluating performance of relay in LTE Advanced network using basically DF. The sub objectives are as follow:

- Increase signal to noise ratio by deploying relay nodes through 4 scenarios, one scenario without relay and others with one or two relays.
- Apply error correction technique, the convolutional code with Viterbi algorithm to eliminate noise effect, or reduce bit error rate.
- Optimizing the transmission rate by applying high modulation level to exploit the reliable link between eNodeB and fixed relay for high data rates and leaving low modulation level to the link between relay and user equipment.

1.3 Methodology:

To study effect of relays number on LTE-A network performance using DF protocol, four scenarios contain no-relay or one/two relays will be designed. For comparing between DF and AF protocols two scenarios contain two relays will considered. Convolutional code of 1/2 rate and Viterbi algorithm will be used for coding and decoding respectively. Optimizing the transmission rate between relay and access links will discuss by deploying two relays scenario with four combinations of two modulation levels. QPSK, 16-QAM and 64-QAM with Gray-coding are selected for generating different modulation rates and the Log-Likelihood Ratio (LLR) for demodulation. To combine signals of different modulation levels soft-bit maximum ratio combiner (SBMRC) will be applied. All Network simulations are based on MATLAB program and WINNER II channel model MATLAB source code.

1.4 Organization of the Thesis

The organization of this thesis is as follows. Chapter two of this thesis provides comprehensive literature review on LTE and LTE-Advanced technology and thesis related work. Chapter three presents the design of the work, stating the main components used in this simulation. Chapter four showcases the results from each scenario and environment of the simulation with an analysis of interpretation and deduction of the results and in Chapter five, conclusion of the proposed work and possible future work topics are stated.

CHAPTER TWO

LITERATURE REVIEW

This chapter introduces LTE standard, LTE Advanced and thesis related work. Firstly LTE system requirements and the used multiple access techniques OFDM and SC-FDMA. Then LTE Advanced components are coming with details on relay classification, finally the related work is introduced.

2.1 Introduction to LTE

Long Term Evolution (LTE) standardization within the 3rd Generation Partnership Project (3GPP) has reached a mature state. Since end 2009, LTE mobile communication systems are deployed as a natural evolution of GSM (Global system for mobile communications) and UMTS (Universal Mobile Telecommunications System). The evolution towards LTE in principle began with Release 98 specifying GSM and then continued with Release 99. Release 99 specifies UMTS with CDMA air interface. The technology moved to all-IP network development in Release 4. UMTS 4 networks development moved to HSPA introduced in 2002 by Release 5 (HSDPA) and Release 6 (HSUPA). The improvements in mobile technologies went on by HSPA+ which is described in Release 7 and together with Release 8, LTE was introduced in 2008[6].

2.2 LTE System Requirements

The LTE system needs to provide long term efficient solutions comparatively to its predecessor's technologies, in order to enable improved network coverage and capacity. The LTE system requirements are enlisted as follow [8] [9]:

2.1 LTE System Capability

a) Peak data rates

The LTE system aims to provide instantaneous peak data rates of 50 Mbps (with spectral efficiency of 2.5 bps/Hz) and 100 Mbps (with spectral efficiency of 5bps/Hz) in uplink (UL) and downlink (DL) respectively, within a 20 MHz spectrum allocation.

b) Latency

The reduction of the system latency (in terms of control-plane and user plane latencies), is also included in LTE main targets. The former refers to the time required for transition from non-active states to active state. The transition should be less than 100ms and 50ms respectively. The user-plane latency is defined as the required one-way transmit time for Internet Protocol (IP) packet from UE to Radio Access Network (RAN) edge node or vice versa.

2.2 LTE System Performance

a) Cell edge user throughput

The cell edge user throughput is defined as the 5% point of the cumulative density function (CDF) of the user throughput normalized with the overall cell bandwidth [10]. The LTE system seeks to enable a uniform user experience over the cell area, by improving the cell edge performance. Comparatively, it provides 2 to 3 times of HSDPA Release 6 cell-edge user throughput in DL while 2 to 3 times of HSUPA in UL. In terms of averaged user throughput, it is 3 to 4 times of HSDPA Release 6 in DL while 2 to 3 times of HSUPA in UL.

b) Spectrum Efficiency

Average spectrum efficiency is defined as the aggregate throughput of all users (the number of correctly received bits over a certain period of time) normalized by the overall cell bandwidth divided by the number of cells [10].

In DL case, LTE aims to achieve 3 to 4 times the spectrum efficiency of HSDPA Release 6, with 2 Tx and Rx antennas at the Node B and UE, respectively.

While for UL, it is 2 to 3 times of Release HSUPA 6. It has the ability to coexist with the earlier 3GPP technologies.

c) Mobility

The LTE allow the user mobility across cellular network. It needs to provide low speed (0-15 km/h) as well as at high speed (150 to 350 km/h) mobility.

d) Coverage

The LTE system should attain the performance targets for 5 km of cell radius in terms of throughput, spectral efficiency and mobility. However, there might be a minor degradation in throughput and spectral efficiency for 30 km cell range.

e) Enhanced MBMS

The LTE system should allow the simultaneous provisioning of voice calls and Multimedia Broadcast/Multicast Services (MBMS). The MBMS enables the multicast/broadcast services in the mobile cellular networks.

2.3 LTE Spectrum Allocation

The LTE system supports the inter-system handover with the existing deployed GSM and UMTS networks under the constraint of acceptable impact on terminal complexity. Moreover, it should operate in both, paired and unpaired spectrum, i.e. Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD). It also provides bandwidth scalability to operate at different frequency bandwidth i.e. 1.25, 1.6, 2.5, 5, 10, 15, 20MHz.

2.4 LTE Architecture

Though having all IP based architecture, LTE system also needs to support real time and conversational class traffic. Comparatively, LTE reduces the number of network interfaces exiting in other technologies, such as, Evolved Node B (eNB) is the only radio interface between the UE and Core Network (CN), which acts as base station reducing the network signaling and jitters.

2.5 LTE Cost

The Self-organizing Network (SON) features will enable the LTE systems of doing self-configuration and self-optimization of its network which will reduce the network planning and optimization cost.

2.3 LTE Physical Layer

2.3.1 Orthogonal Frequency Division Multiplexing

The core of the LTE down link radio transmission (physical layer) exploits Orthogonal Frequency Division Multiplexing (OFDM) with data being transmitted on a large number of parallel narrow-band sub carriers. In the frequency domain, narrow-band sub carriers are equally spaced around a central RF carrier, so the frequency $f_{n,rf}$ of the n_{th} subcarrier out of N can be expressed in equation (2.1):

$$f_{n,rf} = f_c + n.f_d \tag{2.1}$$

Where:

$f_{d:}$ is the frequency spacing between the subcarriers, and

$f_{c:}$ is the center frequency of the OFDM signal.

$$n \in \left[\frac{-N-1}{2}, \frac{N-1}{2}\right] \qquad \text{if N is odd, and}$$

$$n \in \left[\frac{-N}{2}, \frac{N}{2}-1\right] \qquad \text{if N is even.}$$

In the frequency domain, narrow-band sub carriers are equally spaced around a central RF carrier, so the baseband frequency f_n of the n_{th} subcarrier out of N can be expressed as:

$$f_n = n.f_d \tag{2.2}$$

In OFDM symbol, each subcarrier has its own phase p_n and amplitude a_n. The whole baseband signal looks like this:

$$S = \sum_{n=n_{min}}^{n_{max}} a_n.e^{j p_n}.f_n = \sum_{n_{min}}^{n=n_{max}} c_n.n.f_d (2.3)$$

Due to the use of relatively narrow band sub carriers in combination with a cyclic prefix, OFDM transmission is inherently robust to time dispersion on the radio channel without having to resort to advanced and often relatively complex receiver-side channel equalization. Also in an OFDM symbol the cyclic prefix, transmitted during the guard interval, consists of the end of the OFDM symbol [2].

In OFDM, the frequency-selective wideband channel is subdivided into non-frequency selective narrowband orthogonal subcarriers, thus modulating the data symbols on these subcarriers. The subcarrier spacing is 15 kHz. For efficient spectrum utilization and avoiding the Inter-Carrier Interference (ICI), the peak of each subcarrier spectrum coincides with nulls of the spectra of remaining subcarriers as shown in Figure 2.1.

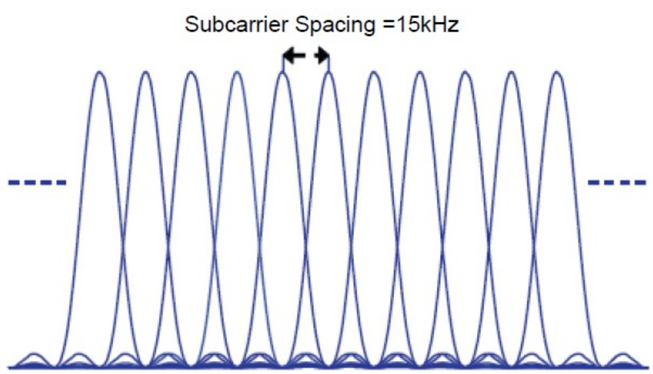


Figure 2.1: OFDM Subcarrier Spacing [11]

However, the OFDM transmitter has a drawback of high Peak to Average Power Ratio (PAPR). The practical Power Amplifier (PA) of RF transmitters is linear only within a limited dynamic range. In PAPR, PA starts operating in nonlinear region, which leads to significant spectral spreading and in-band distortion. Thus to operate linearly, PA need to use Power Back Off technique. Here the PA output power handling is over-design such that the power amplifier can meet the linearity specification at a reduced power level, but at the cost of low power efficiency. Hence, this results in expensive transmitter equipment and reduces the user’s terminal battery life. These disadvantages suggest that OFDM is suitable to use in DL, because the eNB transmitter has no issue with power consumption [8].

2.3.2 Single Carrier-Frequency Division Multiple Access

The LTE system exploits the Single Carrier-Frequency Division Multiple Access (SCFDMA) for UL transmission due to high PAPR in OFDMA. Here the subcarrier mapping can be done in two different ways namely as localized or distributed. In the former case, mapping is enabled on the consecutive subcarriers, while in the latter case; it performs on regular spaced subcarriers. The distributed SC-FDMA can exploits the frequency diversity but at the cost of system complexity. Hence, the localized SC-FDMA has been adopted for UL transmission while the frequency diversity is derived with Channel Dependent Scheduling (CDS) or Frequency Hopping scheme.

In OFDM, FFT is applied on the receiver side on each block of symbols, and IFFT on the transmitter side. In SC-FDMA, both FFT and IFFT are applied on the transmitter side, and also on the receiver side. However SC-FDMA requires transmissions in consecutive bands, and thus introduces restrictions on the frequency domain packet scheduling for individual users compared to OFDMA.

2.4 LTE-Advanced

The LTE-A is backward compatible with existing LTE system and support the existing LTE enabled UEs. In LTE-A focus is on higher capacity: The driving force to further develop LTE towards LTE–Advanced - LTE Release10 was to provide higher bitrates in a cost efficient way and, at the same time, completely fulfill the requirements set by ITU for IMT Advanced (4G) [12]:

- Increased peak data rate, Down Link 3 Gbps, Up Link 1.5 Gbps.
- Higher spectral efficiency, from a maximum of 16bps/Hz in Release8 to 30bps/Hz in Release10.
- Increased number of simultaneously active subscribers.
- Improved performance at cell edges, e.g. for Down Link 2x2 MIMO at least 2.40 bps/Hz/cell.

2.4.1 LTE Advanced Components

The main new functionalities introduced in LTE-Advanced are [12]: Carrier Aggregation (CA), enhanced use of multi-antenna techniques and support for Relay Nodes (RN).

2.4.1.1 Carrier Aggregation

The most straightforward way to increase capacity is to add more bandwidth. Since it is important to keep backward compatibility with R8 and R9 mobiles the increase in bandwidth in LTE-Advanced is provided through aggregation of R8/R9 carriers. Carrier aggregation can be used for both FDD and TDD.

Each aggregated carrier is referred to as a component carrier. The component carrier can have a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz and a maximum of five component carriers can be aggregated. Hence the maximum bandwidth is 100MHz. The number of aggregated carriers can be different in DL and UL; however the number of UL component carriers is never larger than the number of DL component carriers. The individual component carriers can also be of different bandwidths, see figure 2.2.

When carrier aggregation is used there is a number of serving cells, one for each component carrier. The coverage of the serving cells may differ – due to e.g. component carrier frequencies. The Radio resource Control (RRC) connection is handled by one cell, the Primary serving cell, served by the Primary component carrier (DL and UL PCC). The other component carriers are all referred to as Secondary component carrier (DL and possibly UL SCC), serving the Secondary serving cells.

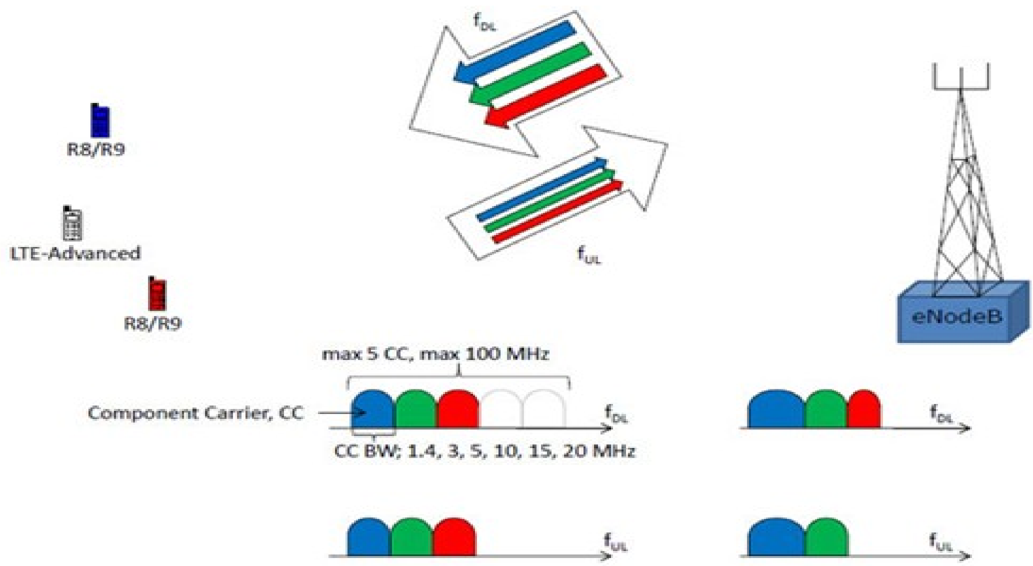


Figure 2.2: Carrier Aggregation –up to five Component Carriers (CC) [12]

2.4.1.2 MIMO, Multiple Input Multiple Output – or Spatial Multiplexing

MIMO is used to increase the overall bit rate through transmission of two (or more) different data streams on two (or more) different antennas using the same resources in both frequency and time, separated only through use of different reference signals to be received by two or more antennas, refer to figure 2.3.

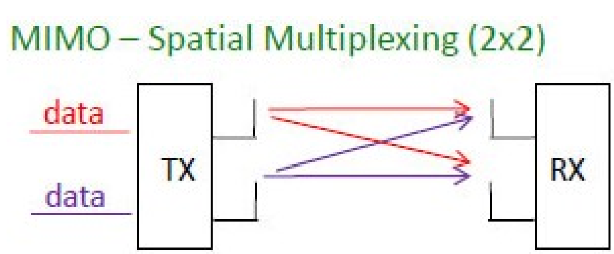


Figure 2.3: Simplified illustration of 2x2 MIMO [12]

MIMO can be used when SNR (Signal to Noise ratio) is high, i.e. high quality radio channel. For situations with low S/N it is better to use other types of multi-antenna techniques to instead improve the SNR [12], e.g. by means of TX-diversity.

2.4.1.3 Coordinated Multi Point Operation (CoMP)

The main reason to introduce CoMP in R11 is to improve network performance at cell edges. In CoMP a number of TX (transmit) points provide coordinated transmission in the DL, and a number of RX (receive) points provide coordinated reception in the UL. A TX/RX-point constitutes of a set of co-located TX/RX antennas providing coverage in the same sector. The set of TX/RX-points used in CoMP can either be at different locations, or co-sited but providing coverage in different sectors, they can also belong to the same or different eNBs. CoMP can be done in a number of ways, and the coordination can be done for both homogenous networks as well as heterogeneous networks. In figure 3 two simplified examples for DL CoMP is shown. In both these cases DL data is available for transmission from two TX-points.

When two, or more, TX-points, transmit on the same frequency in the same subframe it is called Joint Transmission. When data is available for transmission at two or more TX-points but only scheduled from one TX-point in each subframe it is called Dynamic Point Selection. For UL CoMP there is for example Joint Reception, a number of

RX-points receive the UL data from one UE, and the received data is combined to improve the quality. When the TX/RX-points are controlled by different eNBs extra delay might be added, since the eNBs must communicate, for example in order to make scheduling decisions. When CoMP is used additional radio resources for signaling is required e.g. to provide UE scheduling information for the different DL/UL resources.

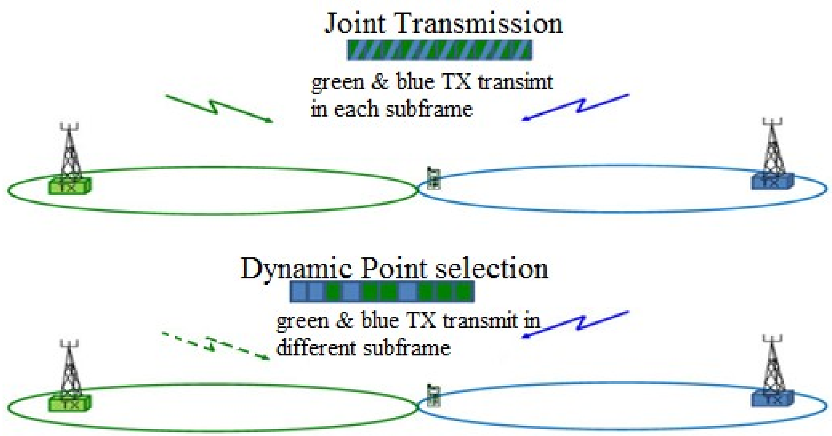


Figure 2.4: Joint Transmission and Dynamic Point Selection [12]

2.4.1.4 Relay in LTE-Advanced

In LTE-Advanced, the possibility for efficient heterogeneous network planning – i.e. a mix of large and small cells - is increased by introduction of Relay Nodes (RNs). The Relay Nodes are low power base stations that will provide enhanced coverage and capacity at cell edges, and hot-spot areas and it can also be used to connect to remote areas without fiber connection.

2.5 Relays Classification

The RN classification can be done according to different criterion as follow [8][5];

2.5.1 Forward relaying protocol: As mentioned in chapter one transmission technique can includes: Amplifying, decoding, decompress, demodulation and repeating signal.

2.5.2 Infrastructure Based Relaying: RN can be classified from the deployment perspective [13], refer to figure 2.5:

- **Fixed RNs** are used to extend the network coverage to users outside the cell area also coverage holes due to shadowing.
- **Nomadic RN** being semi-static allows temporary RN deployment. One example may be the emergency/disaster recovery where the rescue authorities experience network congestion problem due to excessive calls made by the affected people in the emergency area.
- **Mobile RN** aims to provide the coverage within the moving vehicle.

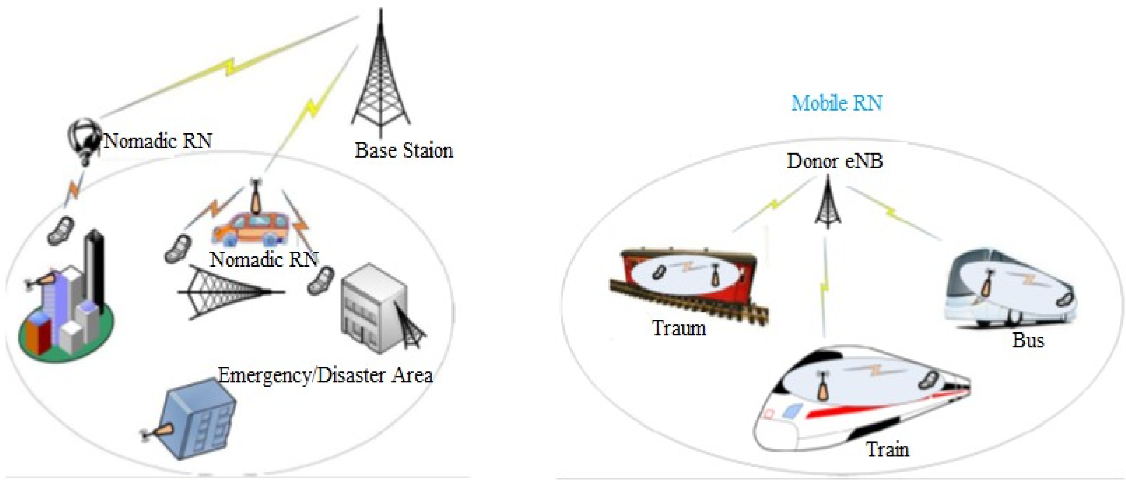


Figure 2.5: Nomadic and Mobile RNs [8]

5.3 **protocol layers used**

- **Layer 1** (L1) RN may be considered as an analogue repeater or booster, possesses part of physical layer functionalities. It simply receives the DeNB signal, amplify it and retransmit to UE.
- **Layer 2** RN incorporates the Layer 2 (L2) functionalities, medium access control (MAC) layer. It provides a higher link quality in the RN coverage area by decoding the received signals from DeNB, re-encode it and retransmit it to UEs.
- **Layer 3** (L3) RN includes all the eNB protocol functionalities, demodulation and decoding of received signal from eNB, process the data by ciphering, combining/ dividing and encoding/modulation to retransmit it to UEs. It possesses a good system performance, as compared to L1 and L2 RNs, but at

the cost of system complexities and user-data processing delay [14].

5.4 network resource usage strategy

- **Inband** Relaying: relay and access links share the same radio resources. It affects the peak data rates achieved by relay users due to the allocation of radio subframes for relay link. Moreover, relay link can be operated with direct link on the same spectrum resources, but will also create interference towards the non-relay UEs and deteriorating the UE throughput [15].
- **Outband** Relaying: the relay and access links are operated on different carrier frequency spectrum. This type of relaying improves the network capacity at the expense of larger spectrum demand for relay link. Here the relay link can be operated with direct link on the same spectrum resources [15].

5.5 UE’s knowledge

- **Transparent** RN: UE is unaware of, whether the communication with eNB is done directly or via a RN, when the UE is present in eNB coverage area receives data traffic via RN, while it receives the control signaling directly from eNB, which cause to increase the relay performance as more resources are available for data traffic. Transparent RN is normally deployed for throughput enhancement purpose [8].

- **Non-transparent** RN: UE is aware the communication with eNB is carried out via a RN. In this mode, all UE-eNB related data traffic and control signaling are carried out via RN. The non-transparent relay usually deployed at the cell edge, to obtain the network coverage extension. Transparent and non-transparent relays are possible to deploy in the same network.

5.6 Type 1 and Type 2

- **Type 1** relay creates its own cell, i.e. transmits its own Cell_ID and own synchronization and reference signals. The UE communicates only with the RN.

- **Type 2** RN is viewed as part of donor cell having no physical cell identity (ID)[8].

2.6 Related Works

Previous studies have considered performance of relay protocols in practical systems. A study [16] of cooperative relaying system is implemented on Matlab then DSP boards to compare the performance of different relaying protocols: amplify-and-forward (AF), decode-and-forward (DF), detect-and-forward (DeF) concluded that the relay system performs much better than the SISO system. On other hand for the performances among three forwarding protocols, using optimal Maximum likelihood detection for all the protocols, DF performs better than both AF and DeF. And when the simplest combing method MRC is applied, AF has the best performance.

Study [7] discussed amplify-and-forward (AF), and decode-and forward (DF) relaying within LTE-Advanced framework and carried out performance comparison based on analytical evaluations. It showed that while full duplex AF relays provide a straightforward mean to increase signal strength they also amplify noise and interference, and require careful and costly installation due to loop back interference between transmit and receive antennas. Performance results indicate that concurrently transmitting DF RNs are more attractive in both cell middle and edge deployments. However, AF RNs outperform DF ones for very high access and backhaul links SNR.

Studying of reference [17] demonstrates the effects of RNs deployment in an LTE-Advanced network, for three proposed deployment scenarios. It showed how the use of RNs increases network capacity and how this increase depends on both the number and the positions of RNs, and an efficient relay location scheme can guarantee better performance with less relays per cell. Among the analyzed configuration scenarios the two Relay per Cell (2RPC) guarantee a good compromise between costs and capacity enhancement, while the 3RPC scenario appears to give no meaningful gains with respect to the 2RPC, and it employs more RNs per each cell. The 6RPC scenario gives the best performance, at the price of a greater costs compared to other scenarios. Therefore, number of relays in the thesis's scenarios will not exceed two relay.

In [2], a study evaluates the performance of the relay-enhanced LTE-Advanced network considered only the Amplify and Forward relay. The evaluation performed through design of several environments for LTE-Advanced networks involving relays incorporating the channel model from the *Wireless World Initiative New Radio* (WINNER) project Matlab based source, four environments were designed among them one environment considers no relay at all and the rest of the environments considered relay deployments. The simulation results in terms of Symbol Error Rate (SER) versus the Signal to Noise Ratio (SNR) show that relay technologies can effectively improve service performance.

In [18], [19], it is shown that the average throughput of the wireless network can be significantly increased by combining two strategies; cooperative relaying and adaptive modulation and coding.

If full channel state information (CSI) is available at BS, deciding whether to communicate through relays or directly, and optimizing the modulation levels for all the transmitting nodes, can improve the end-to-end throughput drastically, such optimization is studied extensively (for instance, [18], [19]) and will not be repeated here. The cases when only the relays are used are studied in [20]. However, in this thesis both relay and direct links are used for transmission.

The larger constellations are used between eNB and RN link to achieve high data rates at relay. However, because of the mobility of the users, the link(s) from RNs to UE is smaller constellations to ensure reliable transmission. Study [20] proposed the “soft-bit maximum ratio combiner” (SBMRC) as a low complexity diversity combining scheme for signals with different modulation levels. SBMRC exhibits BER performance that is very close to the optimal maximum likelihood detector (MLD), but with much reduced complexity. SBMRC will be applied in this thesis.

CHAPTER THREE

SYSTEM DESIGN AND SIMULATION

This chapter aims to give an overview of the simulation; it examines LTE Advanced performance through deploying relay nodes using mainly decode and forward protocol. Also it describes all the system parameters.

3.1 Simulation Overview

Three main simulators are designed using Matlab program and WINNER_II Matlab coded source used for channel modeling, refer to appendix (A) for simulation code, simulators were as follow:

a) The first simulator studies the effect of relay deployment in LTE Advanced using decode and forward protocol, it compares performance of four scenarios: first scenario eNB and UE without relay, secnd scenario eNB and UE with relay but without cooperation, thirdrd scenario eNB and UE with relay and cooperation and the last scenario eNB and UE with two cooperative relays.

b) The second simulator compares between Amplify and forward and Decode and forward relaying protocols, it consists of two scenarios, for AF and DF protocol both using two cooperative relays with QPSK modulation.

c) The third simulator showed the transmission optimization by using high modulation level in link between eNB and RN while using low modulation in the link between RN and UE. Four scenarios of two cooperative relays with different modulation levels were taken: 64QAM-16QAM, 64QAM-QPSK, 16QAM-QPSK and QPSK-QPSK.

3.2 The Main Simulator Algorithm

Figure 3.1 depicts the first Main simulator algorithm; the first step shows initiating antenna array type, then specifying the environment for propagation parameters, then, defining network layout by choosing positions of eNB, RN and UE, after that declare pairing matrix for RN where RNs are combination of eNB and UE. Initial count is set to zero to start a loop, the first step in the loop generation of radio links according to network layout; these generated links are used to calculate path loss power to Direct, Access and Relay links, next step is calling specific simulation scenario or function which returns BER, the BER is cumulated, then the count is increased one, if the number of count reach fifty, the loop end otherwise the loop restart by generation radio links. Finally the BER of the scenarios are averaged.

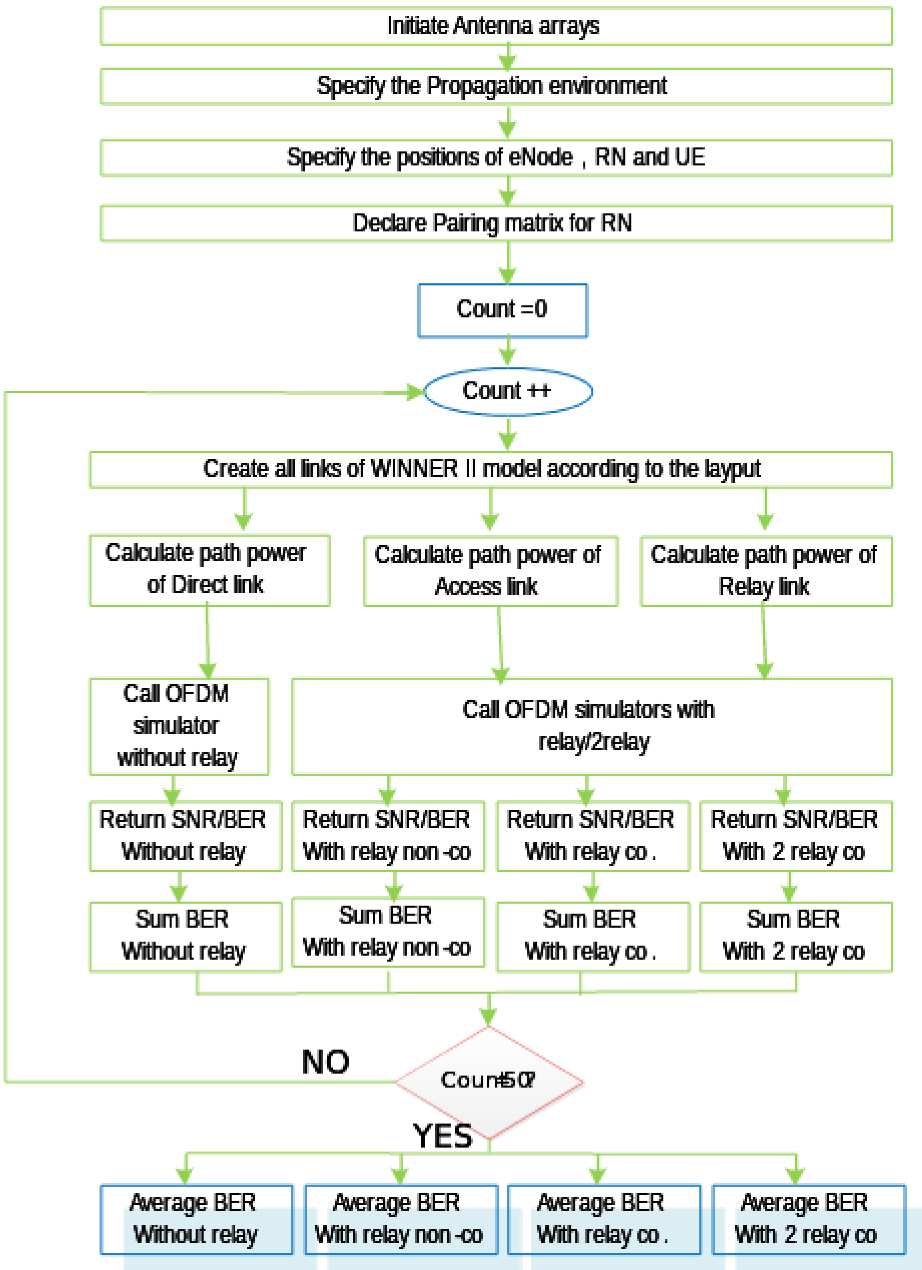


Figure 3.1: First Main Simulator algorithm

3.3 Block Diagram of OFDM Simulator

Figure 3.2 represents block diagram of the OFDM simulator the without relay scenario, the diagram illustrates the processes performed in transmission and receiving terminals.

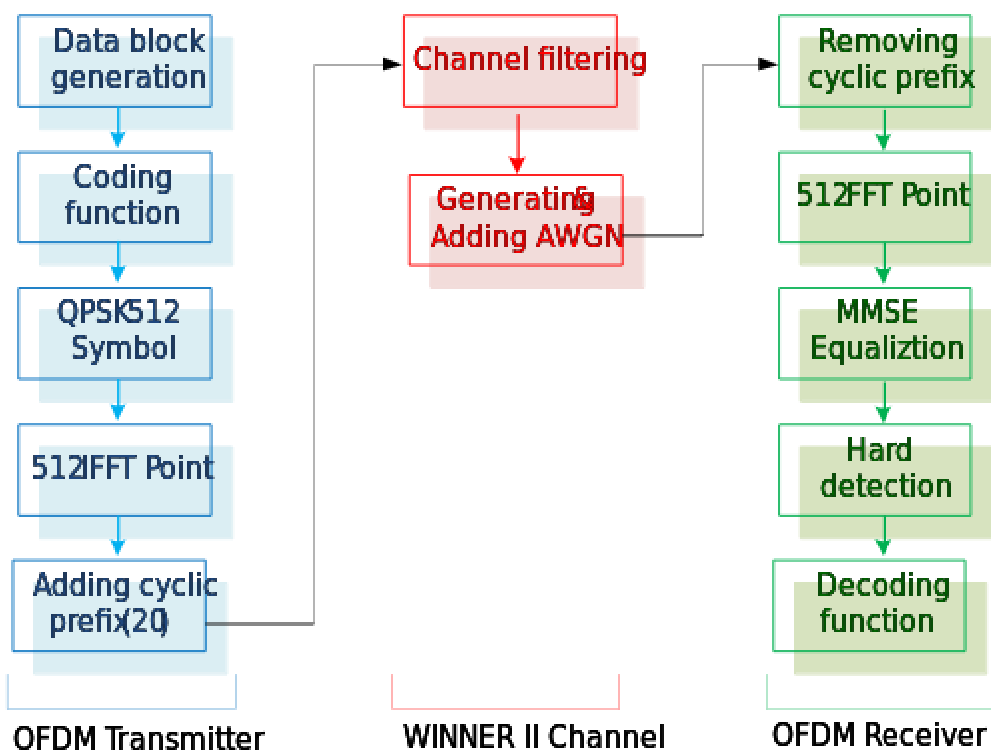


Figure 3.2: Block diagram of OFDM simulator

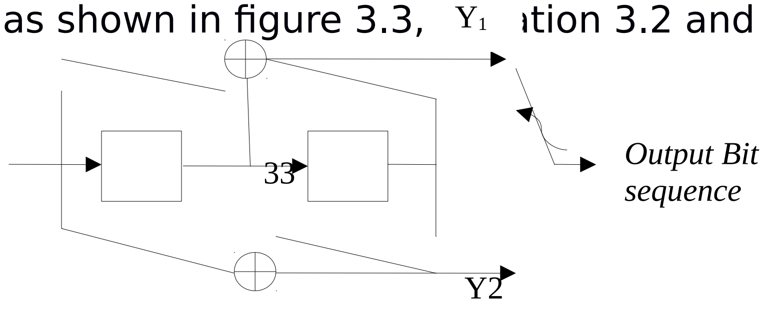
For certain SNR value, firstly the data block of size 512 is generated, then data block is coded by calling convolutional encoder function, the coded data is modulated into QPSK symbols. Then Inverse Fast Fourier Transform (IFFT) is applied on 512 QPSK symbols and Cyclic Prefix (CP) is added. Then the signal is transmitted through the channel by channel filtering of specified Winner-II propagation environment and Additive white Gaussian noise (AWGN) is added. After receiving OFDM signal at receiver the Cyclic Prefix is removed and FFT is applied. Then MMSE equalization is done to remove channel effect. After that the hard detection is performed then decoding step by call decoder function that using Viterbi algorithm. By comparing original data with the decoded data, Bit Error Rate is calculated. This process is iterating until all the SNR values of the given range is end.

3.4 Coding Algorithm

For decode and forward protocol, convolutional code of 1/2 rate is applied as in [16], equation (3.1),

$$\text{Code rate} = k/n = \frac{No.\ of\ message\ symbols}{No.\ of\ codeword\ symbols} \qquad (3.1)$$

The convolutional encoder has two shifts register (m) connected with XOR gates, so inputs to encoder(constraint length) K are 3 as shown in figure 3.3, equation 3.2 and 3.3.



Input Bit sequence

Figure 3.3: convolutional encoder

$$Y_1 = 1 + x + x^2 \quad (3.2)$$

$$Y_2 = 1 + x^2 \quad (3.3)$$

Where:

Y_1 : output1, Y_2: output2, X: 1'st register and X^2: 2'nd register

Table 3.1 illustrates transition of shift registers states and output as respond input 0 or 1.

Original state	Input	Output	Final State
00	0 1	00 11	00 10
01	0 1	11 00	00 10
10	0 1	10 01	01 11
11	0 1	01 10	01 11

Table 3.1

Figure 3.4 represents state diagram of coding encoder also transition of shift registers states and output as respond input.

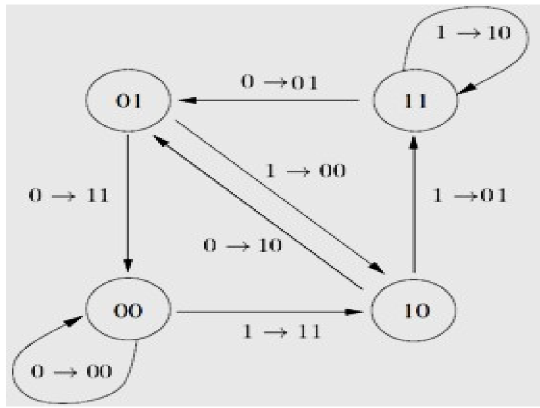


Figure 3.4: State diagram of the coding algorithm

3.5 Decoding algorithm

For decoding convolutional code Viterbi algorithm is used based on trellis diagram figure (3.5). The bubble shows the states at each time interval. The solid arrow means input is 1 and dashed arrow means input is 0, at t =1 if input is 0 state remain in state 00 and output is 00 but if input is 1 state are turn 10 and output is 11. The Viterbi decoder finds a maximum likelihood path through the Trellis, constraint length (L) is 3 so possible states are $2^{(L-1)}$ i.e. four [24].

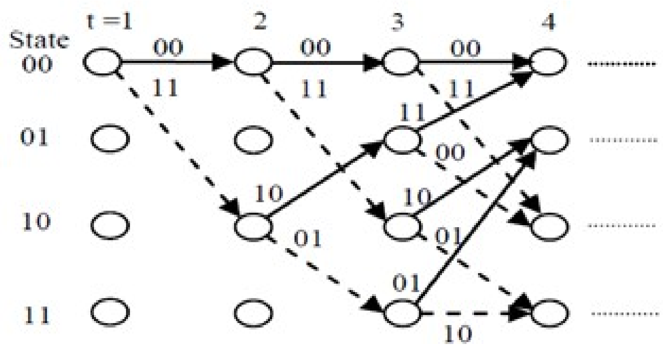


Figure 3.5: Trellis diagram for hard decision Viterbi decoder

3.6 M-QAM Modulation

For a given sequence of bits { $s_0, s_1, \ldots, s_{k-1}$ }, where $s \in \{1, -1\}$ the following mathematical model maps K bits into a Gray coded M-QAM symbol [20][21], for different modulation rates, 4-QAM, 16-QAM, and 64-QAM Gray coded symbols shown in equations (3.4), (3.5) and (3.6):

$$S^4(s_0, s_1) = s_0 d_4 - j s_1 d_4 \tag{3.4}$$

$$S^{16}(s_0, s_1, s_2, s_3) = s_0(-s_1+2) d_{16} - j s_2(-s_3+2) d_{16} \tag{3.5}$$

$$S^{64}(s_0, s_1, s_2, s_3, s_4, s_5) = s_0(-s_1(-s_2+2)+4) d_{64} - j s_3(-s_4(-s_5+2)4) d_{64} \tag{3.6}$$

where :

d_M is a constant used to fix the energy per bit to unity and it is given by

$$d_M = \sqrt{\frac{3\log_2 M}{2(M-1)}} \tag{3.7}$$

For example, $d_4 = 1$, $d_{16} = 0.6325$, and $d_{64} = 0.378$

3.7 M-QAM Demodulation

For the Gray coded M-QAM schemes to extract soft-bits from soft-symbols the Log-Likelihood Ratio (LLR) can be well approximated by equation (3.8) the recursive expression [20] [21] [22] [23]:

$$\tilde{s}_{i,jk_i+k} = \left\{ \begin{array}{c} d_{M_i} \Re\left\{ \alpha_i^{*} r_{i,j}^{M_i} \right\}, k=0 \\ 2^{\frac{k_i}{2}-k} d_{M_i}{}^2 \left|\alpha_i\right|^2 - \left|\tilde{s}_{i,jk_i+k} - 1\right|, 0 < k \leq \frac{k_i}{2} - 1 \\ -d_{M_i} \Im\left\{ \alpha_i^{*} r_{i,j}^{M_i} \right\}, k = \frac{k_i}{2} \\ 2^{k_i-k} d_{M_i}{}^2 \left|\alpha_i\right|^2 - \left|\tilde{s}_{i,jk_i+k} - 1\right|, \frac{k_i}{2} < k \leq k_i - 1 \end{array} \right\} \quad (3.8)$$

Where,

$\tilde{s}_{i,jk_i+k}$: the extracted soft bit.

α_i: is the channel coefficient.

$r_{i,j}^{M_i}$: received vector.

3.8 Diversity Combining Scheme

Soft-bit maximum ratio combiner (SBMRC) is used to combine signals of different modulation levels, which exhibits BER performance that is very close to the optimal maximum likelihood detector (MLD), but with less complexity [20] [21], the SBMRC decides on the bit $\hat{s}$ l, for $l \in \{0, 1, \ldots, C - 1\}$, according to the equation (3.9) criterion:

$$\begin{cases} \hat{s}=1, if\ \acute{s}\ l>0, \\ \hat{s}=-1, otherwise, \end{cases} \quad (3.9)$$

Where $\acute{s}\ l$ is a sum of the soft-bits received from different links and is given by equation (3.10)

$$\acute{s}\ l=\sum_{i=0}^{L-1} \tilde{s}_i, l (3.10)$$

3.9 Description of Simulator Components

WINNER channel model is used to design the physical layer of the simulator. The simulator components are: the environmental conditions, eNodeB, relay node and mobile station.

3.9.1 **The environmental conditions**: WINNER II comes with different scenarios cover many environmental conditions. The simulation work confined in the following, refer to appendix (B):

- Indoor to outdoor.
- Typical urban micro-cell.
- Bad urban micro-cell.

- Suburban macro-cell.
- Typical urban macro-cell.
- Bad urban macro-cell.

Path loss models for the various WINNER environmental conditions have been developed based on results of measurements carried out within WINNER, as well as results from the open literature. These path loss models are typically of the following form equation (3.7), for frequencies in the range from 2 ~ 6 GHz [25]:

$$PL = A\log_{10}(d) + B + C\log_{10}\left(\frac{f_c}{5}\right) + X \quad (3.7)$$

Where d: is the distance between the transmitter and the receiver in [m].

f_c: is the system frequency in [GHz].

A: the fitting parameter which includes the path-loss exponent.

B: is the intercept, it is a fixed quantity based on empirical observations.

C: describes the path loss frequency dependence.

X: is an optional, environment-specific term (e.g., wall attenuation in the A1 NLOS scenario).

(With the aid B and C frequency range is extended from 2~5GHz to 2~6GHz).

3.9.2 eNodeB :

The eNodeB used in this design are 3 sectored omnidirectional antennas. This means, the antenna pattern that has been used at the eNode is 3-sector antenna used for each sector. The channel models don't depend on the eNodeB.

3.9.3 The User Equipment

The User Equipment is one sectored directional antenna. This simulation considers static UE (the velocity is zero). The UE does not affect the Channel Model, which means the channel model is independent of the UE.

3.9.4 The Relay Node

By default the WINNER channel model comes with no relay. Relays used in this simulation are combination of a UE as the receiving terminal and a eNB as the transmitting terminal positioned in same place as depicted in figure (3.6). It is considered that no scheduling is involved in the relay as well as no time delay occurred by the relays.

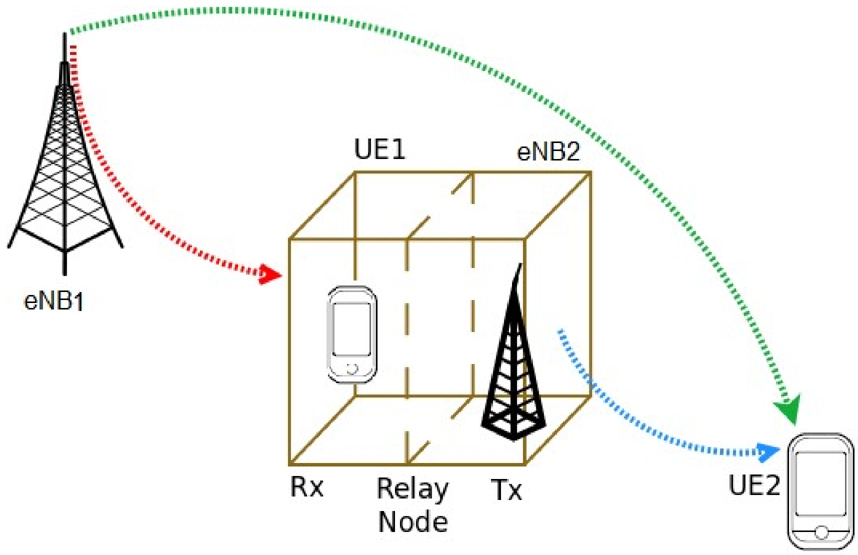


Figure 3.6: Relay Node with a combination of eNB and a UE

3.10 Simulation Parameters

The simulation performed only for down link, simulation parameters are summarized in table (3.2):

Table 3.2: Simulation parameters

Parameter	Value
•Number of Cell is:	1
• eNB height:	32m
• Number of eNB sector:	1
• eNB antenna per sector:	1
• eNB transmitted power:	1 W
• RN height:	25 m
• RN antennas:	1
• RN transmitted power:	1 W
• UE height:	1.5m
• Channel coding:	convolutional coding
• Carrier Frequency is:	5 GHz
• System bandwidth:	5 MHz

Parameter	Value
• Data modulation format:	QPSK, 16QAM and 64QAM
• Pulse shaping:	None
• Cyclic prefix:	20 samples (4µs)
• Transmitter IFFT size:	512
• Sub carrier (tone) spacing:	9.765625 kHz (= 5 MHz/512)
• Channel estimation:	Perfect
• Diversity combining:	soft-bit maximum ratio combiner” (SBMRC)
• Equalization:	Minimum Mean Square Error (MMSE)
• Detection:	Hard Decision

3.11 Network Layout

Different scenarios were considered in the simulation:

• **Without Relay Scenario**: Where there is no relay in between the eNB and UE see figure (3.7). The only way of communication is the direct way from the eNB to the UE.

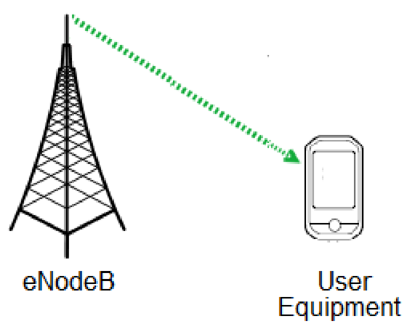


Figure 3.7: Without Relay Scenario

• **Non co-operative Scenario**: It is a two hop communication between the eNB and the UE. A RN is introduced in between the eNB and UE. So the BeNB communicates via the RN with the UE, as in figure (3.8):

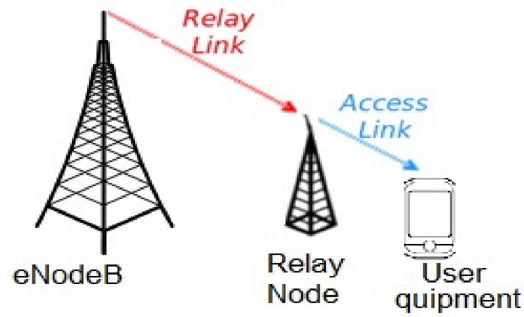


Figure 3.8: Non co-operative Scenario

• **Co-operative Scenario**: In this environment Figure (3.9), the eNB can communicate with the UE using both direct link and indirect link (via RN). The link between the eNB and the UE is referred to the Direct Link, the link between eNB and the RN is referred to the Relay Link and the link between the RN and the UE is referred to the Access Link. For the simulation purpose, the distance between the UE and eNB is 1000m and the RN is deployed just in the middle of those two nodes. This makes the RN to be situated in a distance of 500m from the UE and eNB.

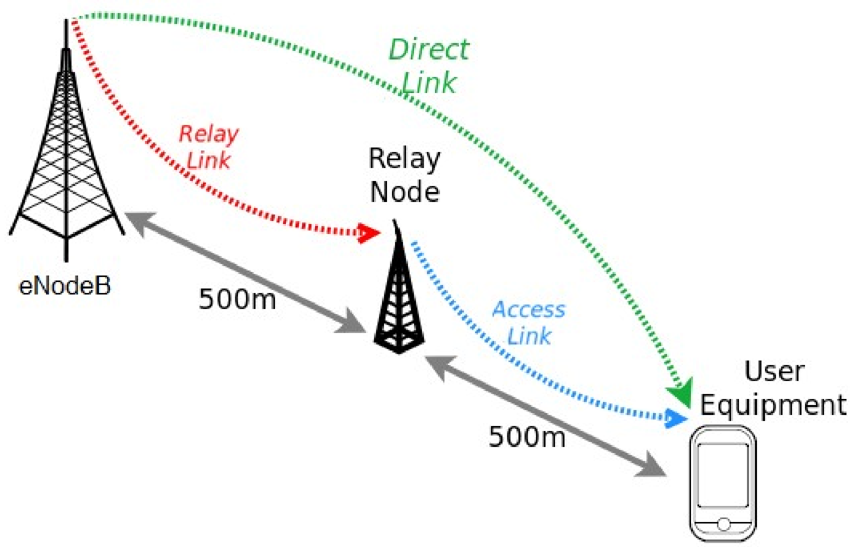


Figure3.9 Co-operative Scenario with one relay

• **Co-operative Scenario with two relays**: Instead of one relay, two relays are deployed in this environment. Figure (3.10) shows the general idea of this environment. As there are two relays, so the number of relay link and access link will be two in each case, which leads the environment to have total 5 links.

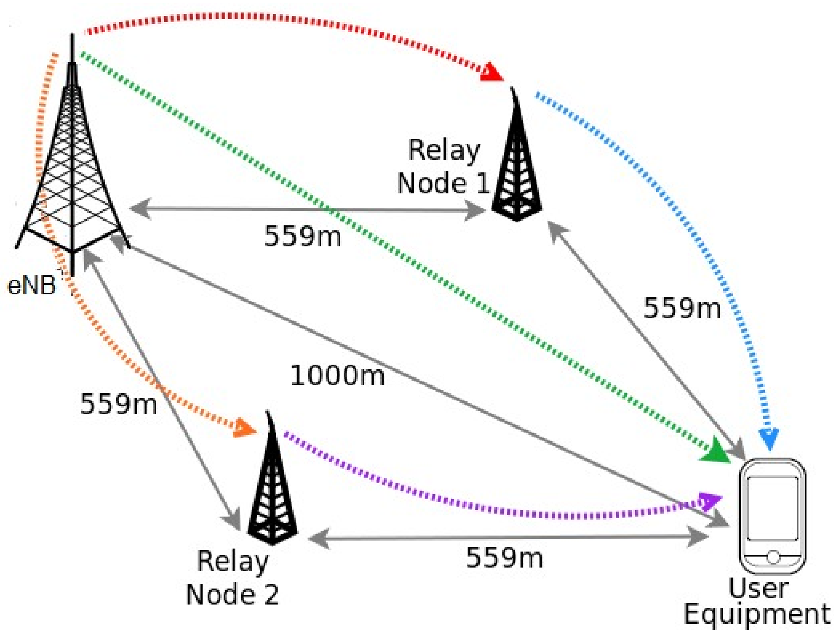


Figure 3.10: Co-operative Environment with two relays

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter showcases the result of Matlab simulations, and analytic discussion of results, where interpretation and deductions of the results are also discussed. As mentioned before three main simulators were designed, every one consists of different scenarios:

4.1 The First Simulator consists of: first scenario eNB and UE without relay, secnd scenario eNB and UE with relay but without cooperation, thirrd scenario eNB and UE with cooperative relay and the last scenario eNB and UE with two cooperative relays.

4.1.1 Typical Urban Macro Cell

Typical Urban macro cell of Figure (4.1) showed that the less Bit Error Rate (BER) appears with higher Signal to Noise Ratio (SNR) in all scenarios. Also it’s noticeable that, without-relay scenario exhibits the worst BER, next come with-one relay without cooperation scenario, then, with-one cooperative relay and when two cooperative relays are deployed the results becomes even better, the average reduction in BER of two cooperative relays scenario over the three previous scenarios is 82%, 74% and 66% respectively.

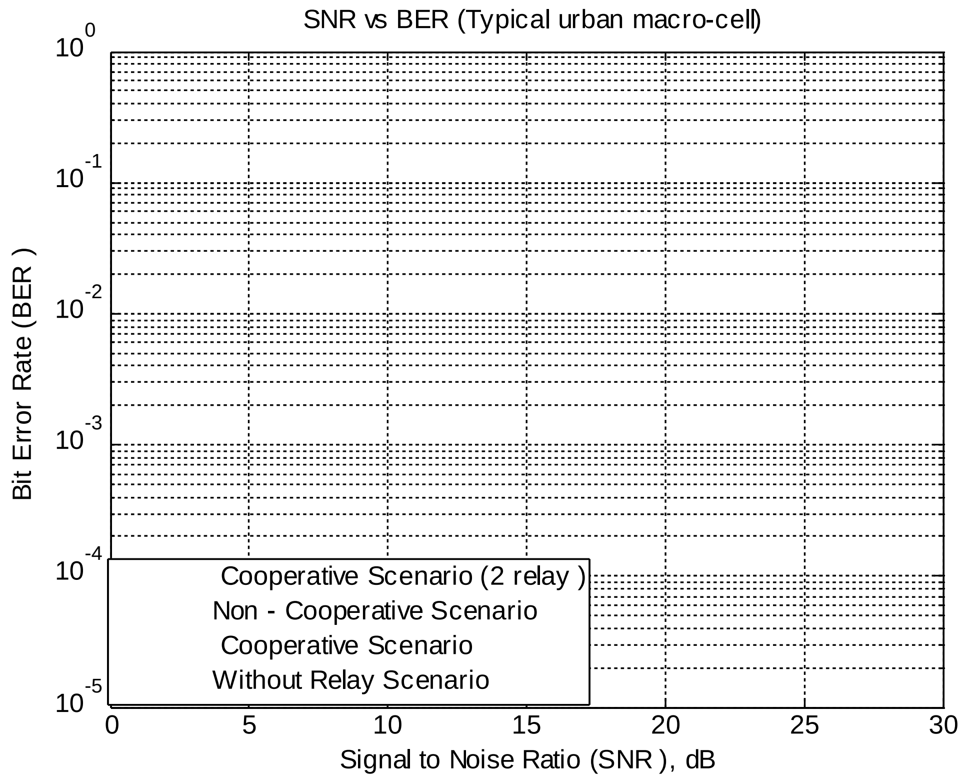


Figure 4.1: First Simulator- SNR vs. BER (Typical urban macro cell)

4.1.2 Bad Urban Macro Cell

Figure (4.2) shows that in bad Urban macro cell environment scenario of without-relay has higher BER through varying values of SNR, then Non-cooperative scenario, then cooperative-with one relay scenario and lastly cooperative-with two relay. The average reduction in BER of two cooperative relays scenario over three scenarios as follow: over without-relay scenario is more than 74%, over with relay but without cooperation is 64% and over with cooperative relay is 51%. It’s clear that by comparing the Typical Urban macro cell with the Bad, the BER in the former achieved with less SNR than that of the later in the four scenarios.

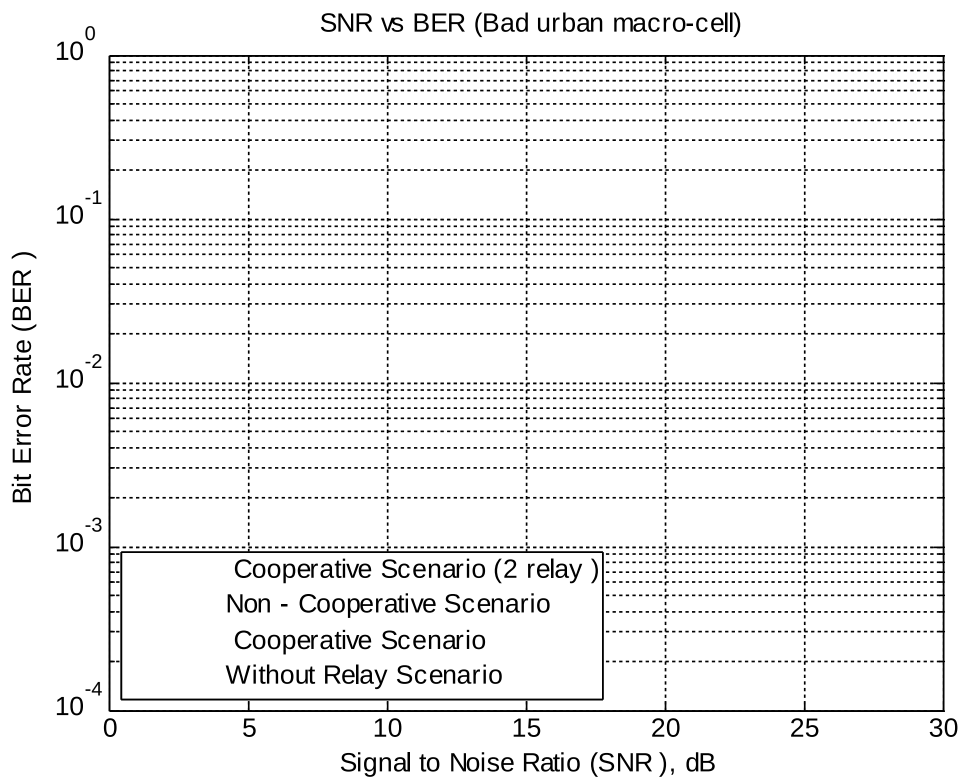


Figure 4.2: First Simulator -SNR vs. BER (Bad urban macro cell)

4.1.3 Suburban Macro Cell

The average reduction related to figure (4.3) of suburban macro cell in BER of two cooperative relays scenario over without-relay, with-relay but without cooperation and with cooperative relay are 75%, 63% and 49% respectively. By comparing figure (4.3) of suburban macro cell to figures (4.1) and (4.2), it’s clear that all the relay scenarios perform much better than the without relay scenario and increasing the number of cooperative relays enhance SNR vs. BER.

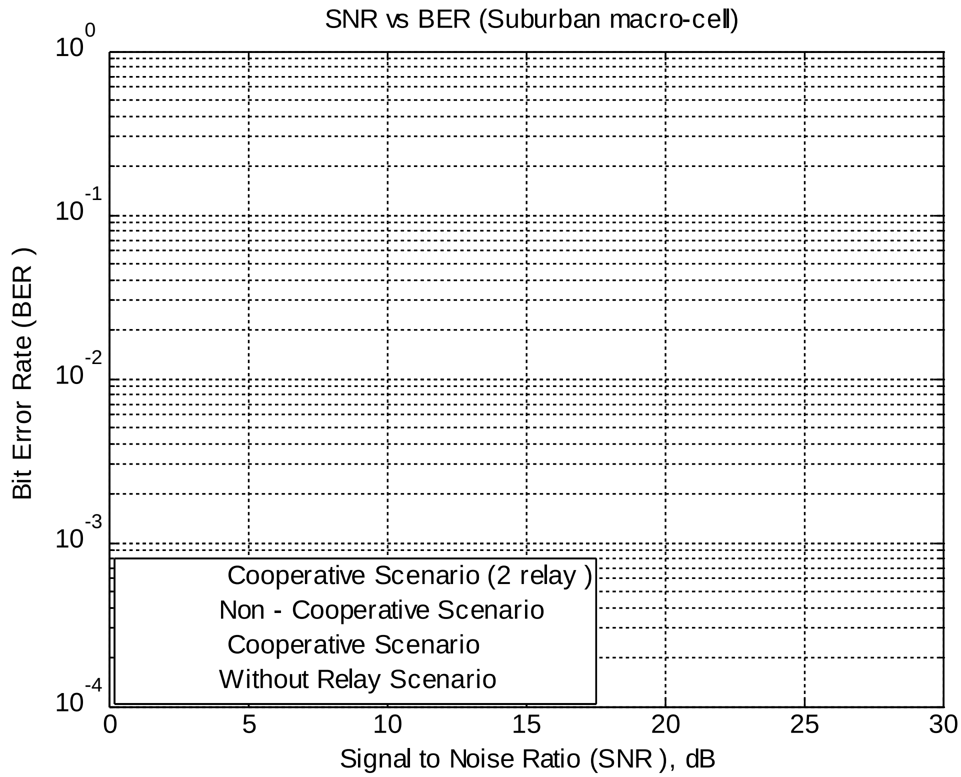


Figure 4.3: First Simulator- SNR vs. BER (Suburban macro cell)

4.2 The Second Simulator

4.2 The Second Simulator consists of two scenarios both have eNB and UE with two cooperative relays and apply QPSK modulation but with either DF protocol or AF protocol.

4.2.1 Bad Urban Macro Cell

In bad macro cell environment of figure (4.4) DF outperforms AF by average BER reduction of 29%, but for SNR value above 15dB with equivalent BER 10^{-2}. AF has average reduction in BER over DF of 24% and by increasing SNR value DF protocol achieved BER less than 10^{-3}, while for AF BER didn’t reach 10^{-3}.

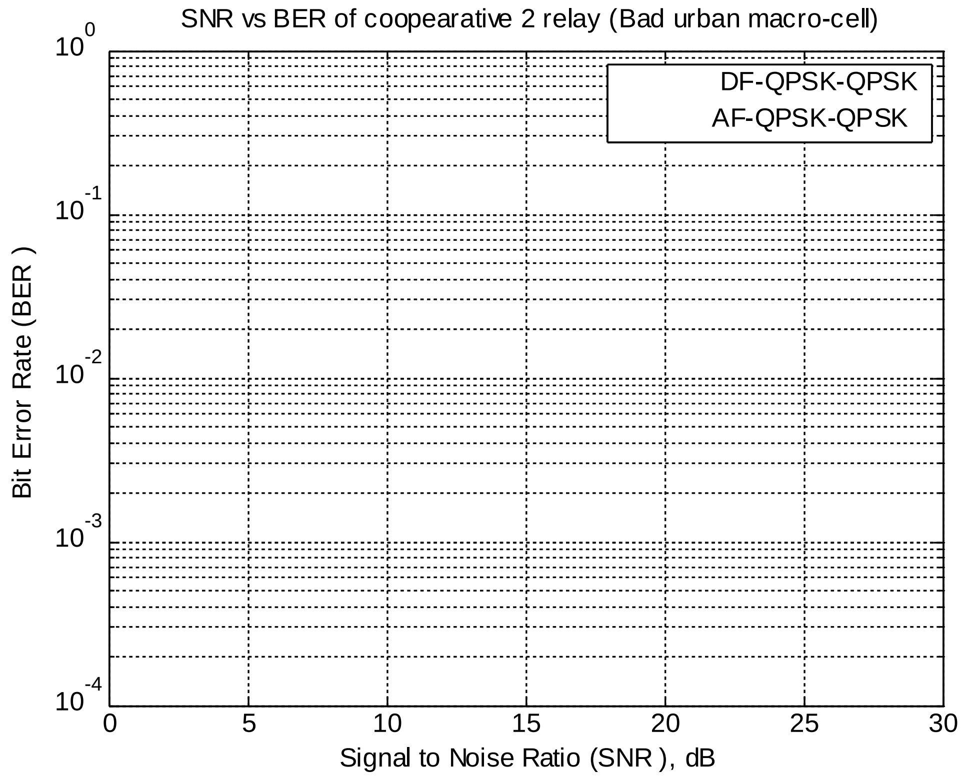


Figure 4.4: SNR vs. BER of cooperative 2 relay (Bad Urban Macro cell)

4.2.2 Typical Urban Macro Cell

In typical urban macro cell figure (4.5) the average reduction in BER for AF over DF is 28% up to SNR value of 16 dB where BER more than 10^{-3}, and above 16 dB the average reduction in BER of DF over AF is 31%.

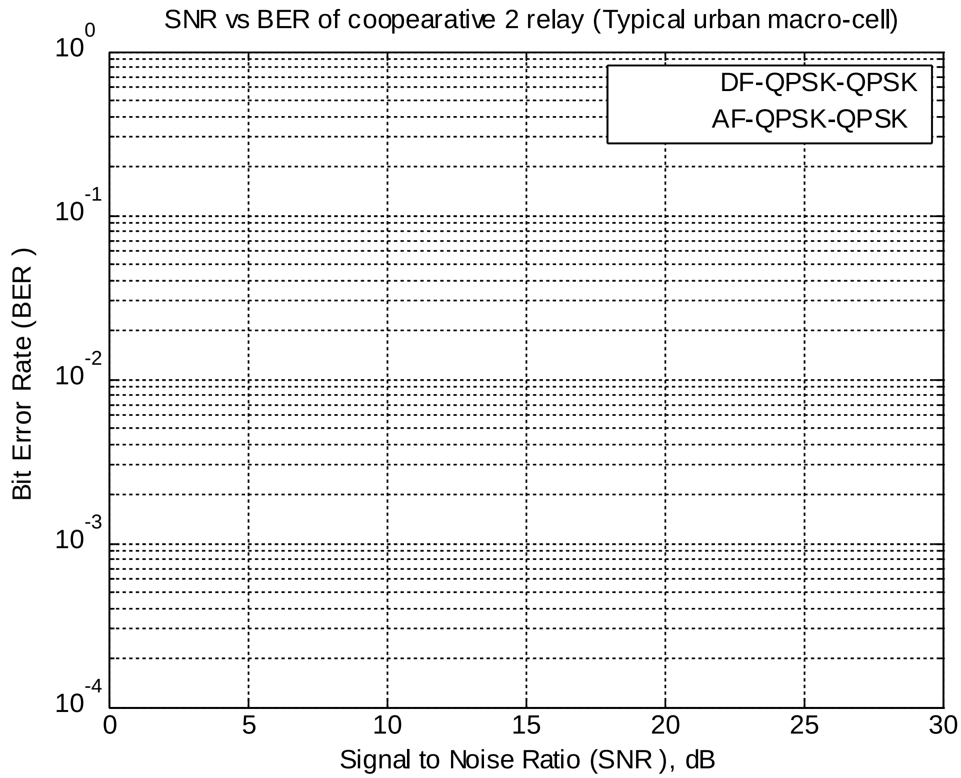


Figure 4.5: SNR vs. BER of cooperative 2 relay (Typical Urban Macro cell)

4.2.3 Bad Urban Micro Cell

In bad urban micro cell figure (4.6) for SNR up 15dB AF achieved less BER than DF where BER didn’t reach 10^{-2}, the average reduction in BER is 28%. Above SNR 15 dB DF protocol outperforms AF protocol the average reduction in BER is 19%.

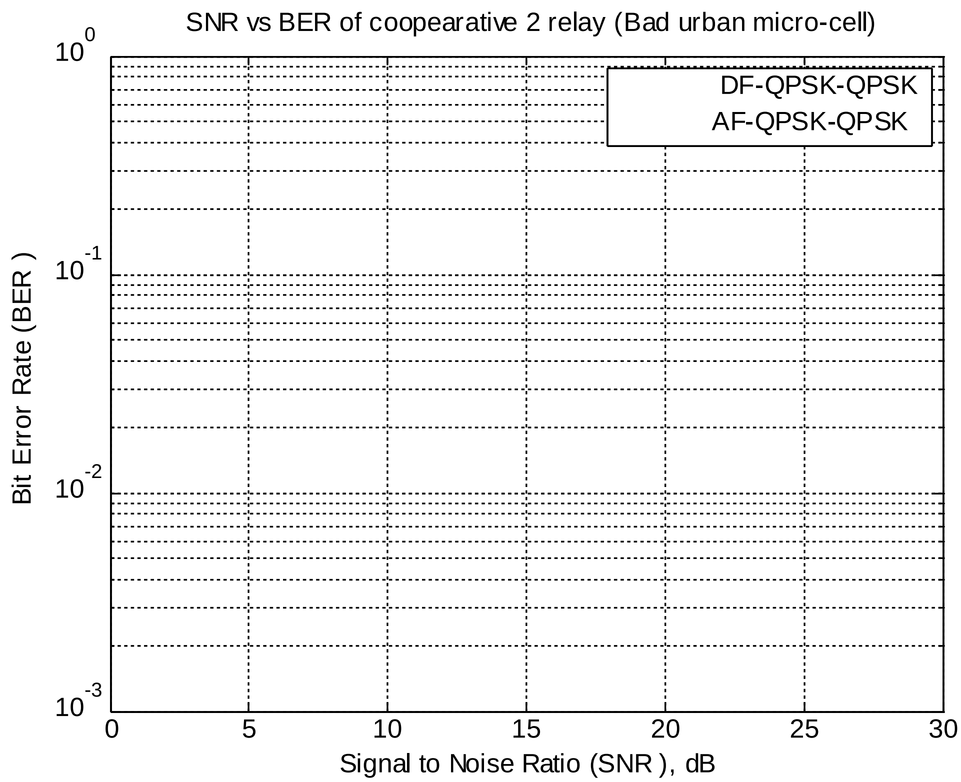


Figure 4.6: SNR vs. BER of cooperative 2 relay (Bad Urban Micro cell)

4.2.4 Typical Urban Micro Cell

In figure (4.7) of typical urban micro cell below SNR 15 dB AF has average reduction in BER over DF about 27%. Above SNR 15 dB, the average reduction in BER for DF over AF is 43%.

By comparing figures from 4.4 to 4.7, the average BER reduction in typical environments of DF over AF is more than AF over DF BER reduction. While in bad environments BER reduction in AF over DF is better than DF over AF. But the most advantage of DF that, DF performs better than AF in the less BER range while AF performs better in the high BER range.

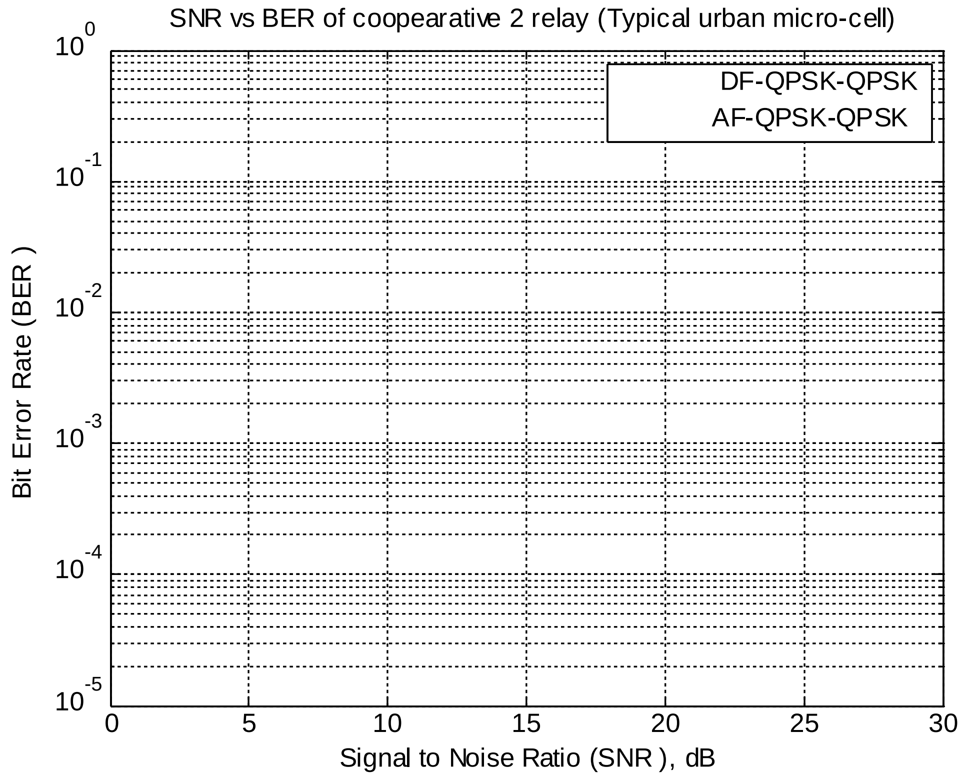


Figure 4.7: SNR vs. BER of cooperative 2 relay (Typical Urban Micro cell)

4.3 The Third Simulator consists of: four scenarios consist of eNB and UE and two cooperative relays use DF protocol with different modulation as follow:

- The First scenario uses QPSK modulation in relay and access links.
- The Second scenario is 64QAM in relay links and QPSK in access links.
- The Third scenario is 16QAM in relay links and QPSK in access links.

- The Fourth scenario is 64QAM in relay links and 16QAM in access links.

The direct link in all scenarios uses QPSK modulation.

Figure (4.8) shows different values of data rate (Mbps) vs. SNR (dB) which could be achieved in relay link for the different modulation levels.

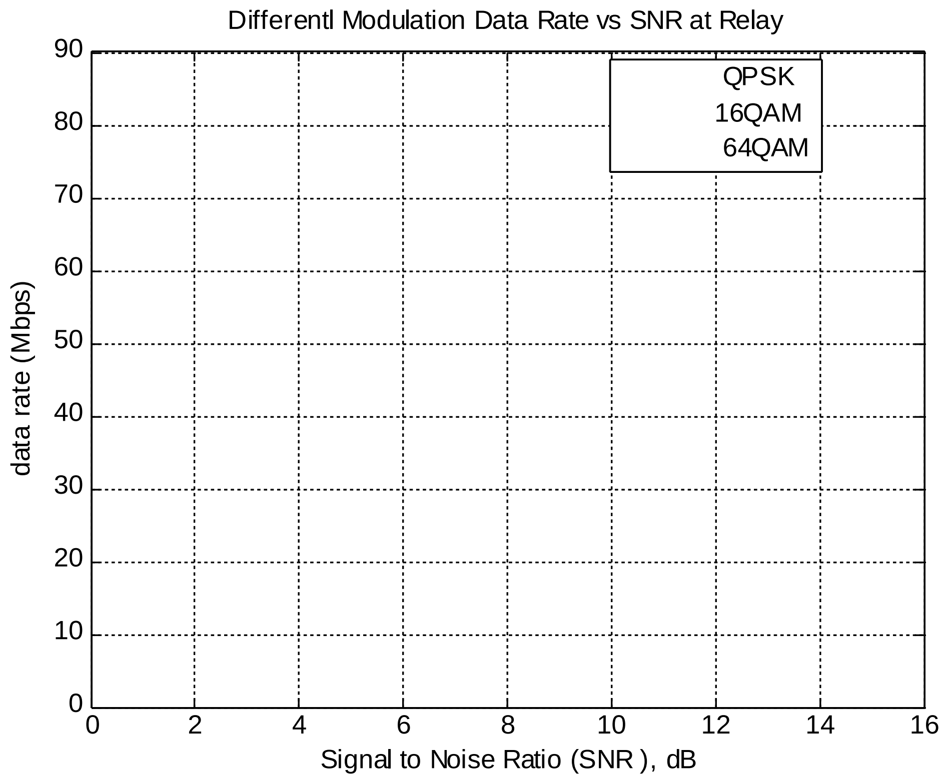


Figure 4.8: Different Modulation Data rate vs. SNR

4.3.1 Typical Urban Micro Cell

Figure (4.9) of typical urban micro cell shows variations in curves of SNR vs. BER for the combination of two modulation levels. 64QAM-16QAM scenario has the much BER, and BER remains constant above SNR 12dB, then, 64QAM-QPSK scenario come with BER near $5*10^{-3}$ and BER remains constant above 15dB SNR, then, QPSK-QPSK scenario and at last 16QAM-QPSK scenario. The average reduction in BER of 16QAM-QPSK over QPSK-QPSK is 57% up to 16 dB, and above 16dB the average reduction in BER of QPSK-QPSK over 16QAM-QPSK is 54%.

From figure (4.8), data rate of different modulation levels, it's noticeable that up to SNR (12dB) the data rate in relay link of 16QAM-QPSK scenario is about 40Mbps with equivalent BER $4*10^{-3}$ for 12 dB as in figure (4.9), and the data rate at relay increases by increasing SNR value, but that degrade BER compared to QPSK-QPSK scenario.

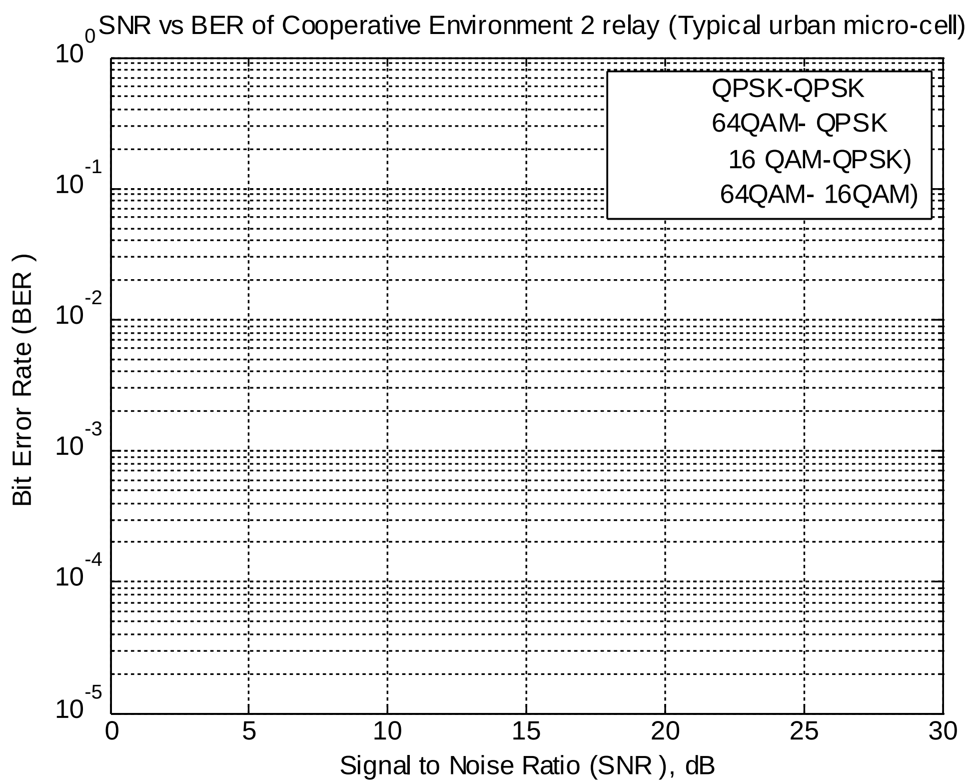


Figure 4.9: SNR vs. BER of cooperative 2 relay (Typical Urban Micro cell)

4.3.2 Bad Urban Micro Cell

The typical urban micro cell of figure (4.9) is near from bad urban micro cell figure (4.10) but the BER achieved in the former with less SNR values than that in the later. For example, in the typical environment best BER near to 10^{-5} while in bad environment BER near 10^{-3}. The average reduction in BER of 16QAM-QPSK over QPSK-QPSK is 48% up to 16 dB, and above 16dB the average reduction in BER of QPSK-QPSK over 16QAM-QPSK is 60%.

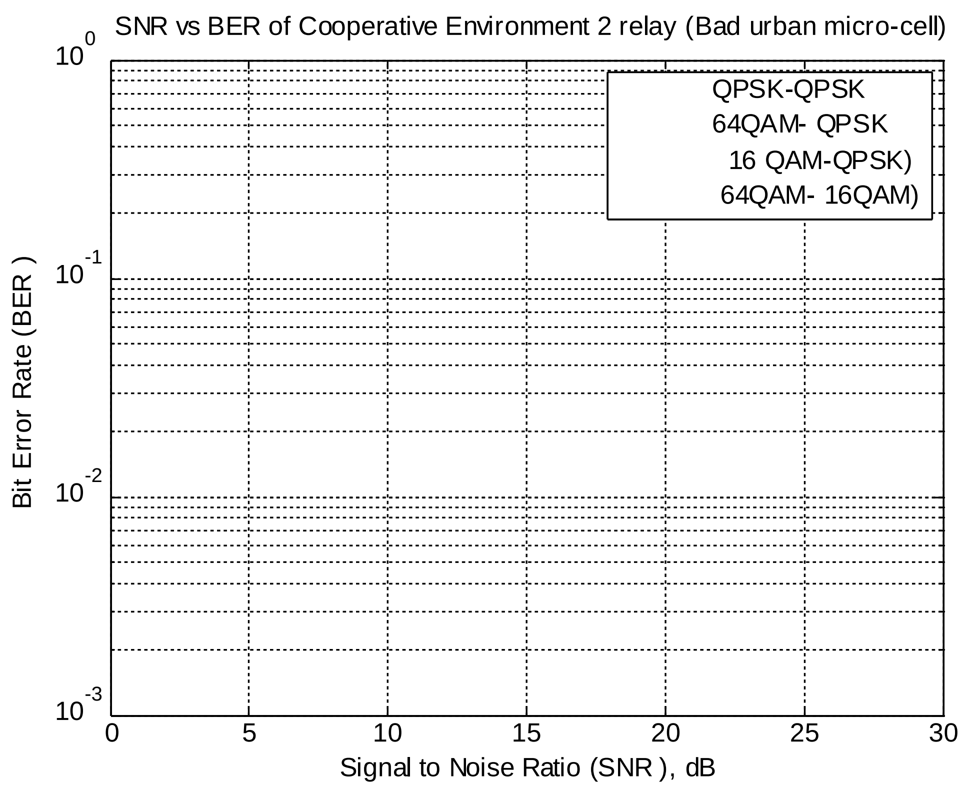


Figure 4.10: SNR vs. BER of cooperative 2 relay (Bad Urban Micro cell)

4.3.3 Indoor to Outdoor

The indoor to outdoor environment shown in figure (4.11) is agreed somewhat with the previous figures 4.9 and 4.10, where in the two 64QAM scenarios increasing of SNR above 15 dB has trivial effect on BER, while in 16QAM-QPSK and QPSK-QPSK scenarios SNR vs. BER has semi linear relation, i.e. increase of SNR causes decrease of BER.

The average reduction in BER of 16QAM-QPSK over QPSK-QPSK is 58% up to 16 dB, and above 16dB the average reduction in BER of QPSK-QPSK over 16QAM-QPSK is 63%.

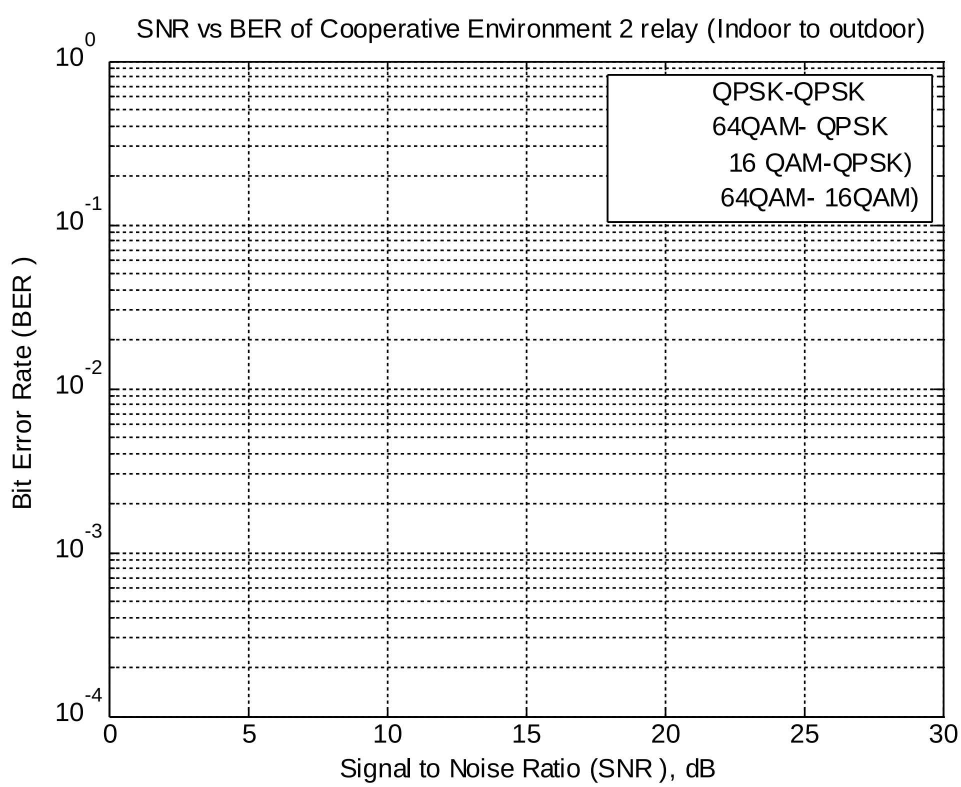


Figure 4.11: SNR vs. BER of cooperative 2 relay (Indoor to Outdoor)

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

This chapter highlights the key aspects of the proposed work and the possible ways to improve performance that lead to conduct a further study in the future.

5.1 Conclusion

This thesis has studied performance of LTE Advanced through deployment of relays using mainly decode and forward protocol in down link. Matlab program is used for simulation with aid of WINNER-II Matlab coded source to introduce different channel models.

Three main simulators were designed; every one consists of different propagation scenarios. The output result of the first simulator which contains four scenarios, illustrated that relay scenarios perform much better than without-relay scenario and increasing the number of cooperative relays enhance SNR vs. BER in all simulated environments. The average reduction in BER of two relays scenario over less relay scenarios was about 66%.

The second simulator contains two scenarios both use two cooperative relays, the simulations clarified the out performance of DF over AF exactly for the higher SNR and the lower of BER range the more safe communication. The average reduction in BER for DF over AF in typical environments was 37% and in bad environments was 21%.

The third simulator consists of two cooperative relays that use DF protocol with different combinations of modulation levels in relay and access links. The results have explained by using 64QAM modulation in spite of the fact that increasing Data rate at relay, but the BER is high and constant even when increasing SNR. When 16QAM or QPSK are used in relay link the BER enhanced and decreased more with increase of SNR. By increasing of SNR QPSK performs better than 16QAM but with less data rate at relay and the average reduction of BER of QPSK over 16QAM was 59%.

5.2 Recommendations for the Future Research

There are some improvements that can be implemented in the future to improve the performance of the system and conduct a further study.

- Decoding algorithm with constraint length 3 is used, for more immune to noise the Constraint Length can be increased.
- The basic model for simulating LTE-Advanced scenarios is constructed by deploying one eNB, one UE and two RNs. Further development can be carried out to introduce multiple eNBs and relays with multi user scenarios for multiple cells.
- For simplicity of the simulation, UE with (velocity = 0) is considered, further study can introduce UE with velocity with aid of WINNER-II propagation scenarios where some of these scenarios are modeled for UE with velocity.

References

[1] Z. Mayer, “Optimizing Coordinated Multi-Point Transmission under Unreliable Backhaul”, MSC thesis at Chalmers University of Technology, Gothenburg, Sweden 2013.

[2] A. Quaium, “Evaluation of Relay-Enhanced LTE-Advanced Networks”, MSC thesis at Delft University of Technology, April 2011, available at link: http://repository.tudelft.nl/view/ir/uuid%3A37ef8678-061f-43f4-af2b-b96f9093f140/. Access date: 30-jun-2013.

[3] T. Beniero, S. Redana, J. Hämäläinen, B. Raaf; “Effect of Relaying on Coverage in 3GPP LTE-Advanced:; IEEE 69th Vehicular Technology Conference, VTC Spring 2009, Barcelona.

[4] Y. Yang, Honglin Hu and Jing Xu, Guoqiang Mao; “Relay Technologies for WiMAX and LTE-Advanced Mobile Systems”; IEEE Communications Magazine, October 2009.

[5] A. Ghafar, N. Satiman, N. Fisal, S. Maharum, A. Saparudin, Rozeha, “Relay Architectures for LTE-Advanced Network”, Universiti Teknologi Malaysia, http://trg.fke.utm.my/members/nurulashikin/paper5.pdf. Access date: 25-jul-2013.

[6] U. ÖZTÜRK “Coordinated Multipoint Transmission in Femtocell Systems”, M.Sc thesis, School of Electrical Engineering, Aalto University 2011.

[7] A. Bou Saleh, S. Redana, B. Raaf, Taneli Riihonen, RistoWichman, J. H¨am¨al¨ainen. : ”Performance of

amplify-and-forward and decode-and-forward relays in LTEadvanced", IEEE 70th Vehicular Technology Conference (VTC 2009-Fall), pp. 1-5, September 2009.

[8] I. Ullah, "Performance Analysis of LTE-Advanced Relay Node in Public Safety Communication", MSC thesis, School of Electrical Engineering, Aalto University 2012.

[9] 3GPP TR 25.913, "Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN)", version 9.0.0., December 2009. Available: www.3gpp.org. Access date: July 2014

[10] M. Kottkamp, A. Roessler, J. Schlienz "LTE-Advanced Technology Introduction", Rohde and Schwarz, Application note 2012.

[11] E. Dahlman, S. Parkvall, J. Sk¨old, "4G LTE/LTE-advanced for mobile broadband", Elsevier Ltd, first Edition. 2011.

[12] J. Wannstrom, 3GPP "LTE-Advanced", June 2013, available at: http://www.3gpp.org/technologies/keywords-acronyms/97-lte-advanced. Access date: July 2014.

[13] J. Sydir,: Harmonized contribution on 802.16j (Mobile Multihop Relay) usage models, IEEE 802.16 Broadband Wireless Access Working Group, September, 2006.

[14] Nagata, S.; Yan, Y.; Gao, X.; Li, A.; Kayama, H.; Abe, T.; Nakamura, T.:"Investigation on system performance of

L1/L3 relays in LTE-advanced downlink”, IEEE 73rd Vehicular Technology Conference (VTC Spring), May 2011.

[15] 3GPP TR 36.814, ”Requirements for further advancements for Evolved UTRA (EUTRA Release 9)”, physical layer aspects version 9.0.0., March 2010. Available: www.3gpp.org. Access date: July 2014.

[16] Y. Yang, B.Castel, P. MV, K. Kittichokechai, M. Yousofshahi and B. Asl, “Cooperative relaying”, Royal Institute of Technology (KTH) in Stockholm, Sweden, spring of 2008.

[17] M. Minelli, M. Coupechoux, J. Kelif, Maode P. Godlewski; “Relays-Enhanced LTE-Advanced Networks Performance Studies”, http://perso.telecom-paristech.fr/~coupecho/publis/sarnoff11relays.pdf. Access date: 22-jun-2013.

[18] S. Hares, H. Yanikomeroglu, and B. Hashem, “Diversity- and AMC (adaptive modulation and coding)-aware routing in TDMA multihop networks," in Proc. IEEE GLOBECOM, San Francisco, CA, USA, Dec. 2003.

[19] B. Can, H. Yanikomeroglu, F. Onat, E. Carvalho, and H. Yomo, “Efficient cooperative diversity schemes and radio resource allocation for IEEE 802.16j," in Proc. IEEE WCNC, Las Vegas, USA, Apr. 2008.

[20] A. Bin Sediq and H. Yanikomeroglu, “Performance Analysis of Soft-Bit Maximal Ratio Combining in Cooperative

Relay Networks" in IEEE Transactions on Wireless Communications, Vol. 8, No. 10, October 2009.

[21] A. Bin Sediq and H. Yanikomeroglu, “Diversity combining of signals with different modulation levels in cooperative relay networks," in Proc. IEEE VTC2008-Fall, Calgary, Alberta, Canada, Sept. 2008.

[22] S. L. Goff, A. Glavieux, and C. Berrou, “Turbo-codes and high spectral efficiency modulation," in Proc. ICC’94, New Orleans, LA, USA, May 1994.

[23] K. S. Kim, K. Hyun, C. W. Yu, Y. O. Park, D. Yoon, and S. K.Park, “General log-likelihood ratio expression and its implementation algorithm for Gray-Coded QAM signals," ETRI J., vol. 28, no. 3, pp. 291–300, June 2006.

[24] R. Pednekar,“Design and Implementation of Convolution Encoder with Viterbi Decoder”, International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS), September-November, 2013, pp. 84-89.

[25] P. Kyösti, J. Meinilä, L. Hentilä, X. Zhao, T. Jämsä, C. Schneider, M. Narandzic, M. Milojevic, A. Hong, J. Ylitalo, V. Holappa, M. Alatossava, R. Bultitude, Y. de Jong, T. Rautiainen; Part I: Channel Models, IST-4-027756, WINNER II D1.1.2 V1.1, WINNER II Channel Models, 2007.

Appendix (A)

Simulation Code

The source code of WINNER II channel model is free and open sourced and can be downloaded from *http://www.ist-winner.org/phase_2_model.html*

Appendix A contains first main simulator, the second and third simulator can easy driven by amendment in the code of the first main simulator. Also appendix A contains OFDM_QPSK (without-relay), OFDM_QPSK (two relay) and

OFDM_two_relay_64QAM_16QAM; all other scenarios can be driven by change in these codes.

A.1 Main Simulator

```
clear all;
clc;
 %% Defining the antenna arrays
Arrays = arrayparset ;
%% Defining the Environment with eNB , MS , Relays
BsAAIdxCell = {[1]; [2]} ;
MsAAIdx = [2 3];
L=3; % Number of links
S =11; % Identification Environment number S=10 >Suburban macro-cell, S=12
>Bad urban macro-cell
layoutpar = layoutparset ( MsAAIdx , BsAAIdxCell , L, Arrays );
layoutpar . ScenarioVector =S*ones(1,L);
layoutpar . Stations (1).Pos = [0;0;32]; % Position of eNB1
layoutpar . Stations (2).Pos = [250;250;32]; % Position of eNB2
layoutpar . Stations (3).Pos = [250;250;32]; % Position of MS1
layoutpar . Stations (4).Pos = [0;500;1.5]; % Position of MS2
 % Defining the pairing of eNB , MS , Relays
 layoutpar . Pairing = [1 2 1;3 4 4];
NTlayout(layoutpar);%Visualisation of network layout
%% Defining the initial conditions for the iteration
 BER_tot_nc = zeros (16 ,1);
BER_tot_c = zeros (16 ,1);
BER_tot_wor = zeros (16 ,1);

for n =1:50% deleted is :5000
      wimpar = wimparset ; % Generation the Winner parameters
      wimpar.NumTimeSamples=1000; % 100 time samples per link
      [H, delays , out ]= wim(wimpar , layoutpar) % Generation of all the radio
      links according to the layout
      % define some parameters
       SP. FFTsize = 512; % The size of the FFT and IFFT
       SP. CPsize = 20; % CP length
      SP.SNR = [0:2:30]; % Simulated SNR range is from 0 dB to 40 dB with an
increament of 4 dB.
       SP. numRun = 10; % The number of simulation iterations is 10^4
        a= isnan (out. path_powers);% convert NaN in out.path_powers to 0
       out. path_powers (a)=0;
       SP.equalizerType = 'MMSE ';
        %% Calculation of path powers for Non - cooperative
        h_1=out. path_powers (1 ,:); % Relay Link
       SP. channel_1 = h_1 ;
       SP. channel_1 = h_1 / sqrt (sum (h_1 .^2) );
```

```
 h_2= out. path_powers (2 ,:); % Access Link
 SP. channel_2 = h_2 ;
 SP. channel_2 = h_2 / sqrt (sum (h_2 .^2) );

% Calculation of BER for Non - cooperative
BER_ofdm_nc = ofdm_wr_nc_qpsk (SP); %ofdm_wr_nc_16qam
//ofdm_wr_nc_qpsk
BER_tot_nc = BER_tot_nc + BER_ofdm_nc ;
 %% Calculation of path powers for Cooperative
 h_1=out. path_powers (1 ,:); % Relay Link
 SP. channel_1 = h_1 ;
 SP. channel_1 = h_1 / sqrt (sum (h_1 .^2) );
 h_2= out. path_powers (2 ,:); % Access Link
 SP. channel_2 = h_2 ;
 SP. channel_2 = h_2 / sqrt (sum (h_2 .^2) );
 h_3= out. path_powers (3 ,:); % Direct Link
 SP. channel_3 = h_3 ;
 SP. channel_3 = h_3 / sqrt (sum (h_3 .^2) );
 % Calculation of BER for Cooperative
 BER_ofdm_c = ofdm_wr_c_qpsk (SP);
 BER_tot_c = BER_tot_c + BER_ofdm_c ;
 %% Calculation of path powers Without relay
 h=out. path_powers (3 ,:); %  Direct Link
 SP. channel = h;
 SP. channel = h/ sqrt (sum (h .^2) );
 % Calculation of BER for Without relay
 BER_ofdm_wor = ofdm_qpsk(SP);
 BER_tot_wor = BER_tot_wor + BER_ofdm_wor;
end
%% Taking Average of the data
BER_wor = BER_tot_wor /n; % BER for without relay environment
BER_nc = BER_tot_nc /n; % BER for non co - operative environment
BER_c = BER_tot_c /n; % BER for co - operative environment (with one relay )
%% Defining the MS and eNB positions for the co – operative environments
with 2 relays
BsAAIdxCell = {[1];[2];[2]};
MsAAIdx = [2 2 3];
L=5;
layoutpar = layoutparset ( MsAAIdx , BsAAIdxCell , L, Arrays );
layoutpar . ScenarioVector = S*ones(1,L);
layoutpar . Stations (1).Pos = [0;250;32]; % BS1
layoutpar . Stations (2).Pos = [500;500;25]; % BS2
layoutpar . Stations (3).Pos = [500;0;25]; % BS3
layoutpar . Stations (4).Pos = [500;500;25]; % MS1
layoutpar . Stations (5).Pos = [500;0;25]; % MS2
layoutpar . Stations (6).Pos = [1000;250;1.5]; % MS3
```

```
 % Defining the pairing of eNB , MS , Relays
layoutpar . Pairing = [1 1 2 1 3 ; 6 4 6 5 6];
%NTlayout(layoutpar);%Visualisation of network layout
 % Defining the initial condictions for the iteration
BER_tot_c_two = zeros (16 ,1);
 for n =1:50
% Generation the Winner parameters
wimpar = wimparset ;
wimpar.NumTimeSamples=1000; % 100 time samples per link
[H2 , delays2 , out2 ]= wim(wimpar , layoutpar )
% Processing the bits for Calculation
SP. FFTsize = 512;
SP. CPsize = 20;
SP.SNR = [0:2:30];
SP. numRun = 10;
a= isnan ( out2 . path_powers );
out2 . path_powers (a)=0;
SP. equalizerType ='MMSE';
 %% Calculation of path powers for Cooperative environment with two relays
 h_1 = out2 . path_powers (1 ,:); % direct link
SP. channel_1 = h_1 ;
SP. channel_1 = h_1 / sqrt (sum (h_1 .^2) );
 h_2 = out2 . path_powers (2 ,:); % relay link 1
SP. channel_2 = h_2 ;
SP. channel_2 = h_2 / sqrt (sum (h_2 .^2) );
 h_3 = out2 . path_powers (3 ,:); % access link 1
SP. channel_3 = h_3 ;
SP. channel_3 = h_3 / sqrt (sum (h_3 .^2) );
 h_4 = out2 . path_powers (4 ,:); % relay link 2
SP. channel_4 = h_4 ;
SP. channel_4 = h_4 / sqrt (sum (h_4 .^2) );
 h_5 = out2 . path_powers (5 ,:); % access link 2
SP. channel_5 = h_5 ;
SP. channel_5 = h_5 / sqrt (sum (h_5 .^2) );
 % Calculation of BER for coperative two relays
 BER_ofdm_c_two = ofdm_wr_c_qpsk_two (SP); %% ofdm_wr_c_qpsk_two //
ofdm_wr_c_16qam_two
BER_tot_c_two = BER_tot_c_two + BER_ofdm_c_two ;
end

 %% Taking Average of the data

BER_c_two = BER_tot_c_two /n; % BER for co – operative environment with 2
relays

figure
```

```
 semilogy (SP.SNR ,BER_c_two ,'kx -' );
 hold on
 semilogy (SP.SNR , BER_nc ,'mo -');
 semilogy (SP.SNR ,BER_c ,'rd -');
semilogy (SP.SNR , BER_wor ,'bh -');
 grid on
 legend (' Cooperative Scenario (2 relay ) ', 'Non - Cooperative Scenario ', '
Cooperative Scenario ','Without Relay Scenario');
 xlabel (' Signal to Noise Ratio (SNR ), dB ');
 ylabel (' Bit Error Rate (BER ) ');
 title (' SNR vs BER (Typical urban macro-cell) ');
 %% percentage of reduction of BER in two- relay
z1 = 1-BER_c_two./BER_wor;
BER_decrease1= 100*sum(z1)/16  %over without relay
z2 = 1-BER_c_two./BER_nc;
BER_decrease2= 100*sum(z2)/16  % over relay without cooperation
z3 = 1-BER_c_two./BER_c;
BER_decrease3= 100*sum(z3)/16  % over with cooperative relay
```

A.2 OFDM_QPSK:

```
function BER = ofdm (SP)
numSymbols = SP. FFTsize ; % The size of the data block is equal to the FFT
size
H_channel = fft(SP. channel ,SP. FFTsize ); % Frequency domain version of the
Direct Link channel response
for n = 1: length (SP.SNR);
    errCount = 0; % Initialize the error count
    for k = 1: SP.numRun ,
            data = round ( rand (1, numSymbols)); % Generate random data
block .
            % convolutional encoder
            tmps = Encoder_conv(data);
            data1 = tmps *2 - 1;
            inputSymbols = (data1 (1 ,:) + i*data1 (2 ,:))/ sqrt(2);%QPSK signal
            TxSamples = 0.5*sqrt (SP. FFTsize )*ifft (inputSymbols,SP. FFTsize );
% Generation of transmission signal% add gurd
            ofdmSymbol = [ TxSamples ( numSymbols -SP.CPsize +1:
numSymbols ) TxSamples ]; % OFDM Symbol generation
            RxSamples = filter (SP. channel , 1, ofdmSymbol ); %Recieved signal
through Direct Link
            tmp = randn (2, numSymbols +SP. CPsize/2);% Generation of Noise
            complexNoise = (tmp (1 ,:) + i*tmp (2 ,:))/ sqrt(2);
            noisePower = 10^( - SP.SNR(n) /10) ;
            complexNoise = [ complexNoise complexNoise];
```

```
            RxSamples = RxSamples + sqrt ( noisePower )*complexNoise ; %
Noise added to the signal
             EstSymbols = RxSamples (1:numSymbols);
            Y = fft( EstSymbols , SP. FFTsize );
             % Selecting the equalization Type
             if SP. equalizerType == 'MMSE '
             C = conj ( H_channel )./( conj (H_channel ).* H_channel + 10^( -
SP.SNR(n) /10) );
                EstSymbols = Y.*C;
                elseif SP. equalizerType == 'ZF '
                EstSymbols = Y./ H_channel ;
            end
             % Hard decision detection .
            a(1,:) =sign(real(EstSymbols));
            a(2,:) =sign(imag(EstSymbols));
           a=(a+1)./2;
           % convolutional Decoder
           R = Decoder_conv(a(1,:),a(2,:));
           errCount = errCount +biterr(data,R);
   end
     BER(n ,:) = errCount / ( numSymbols *SP. numRun ); %Calculation of Bit
error rate
    [SP.SNR(n) BER(n ,:)]
    end
```

A.3 OFDM-2relay_QPSK

```
function BER = ofdm_wr_c_two (SP)
 numSymbols = SP. FFTsize ;
 H_channel_1 = fft(SP. channel_1 ,SP. FFTsize ); % Frequency domain channel
response of the Direct Link
H_channel_2 = fft(SP. channel_2 ,SP. FFTsize ); % Frequency domain channel
response of the Relay Link 1
H_channel_3 = fft(SP. channel_3 ,SP. FFTsize ); % Frequency domain channel
response of the Access Link 1
H_channel_4 = fft(SP. channel_4 ,SP. FFTsize ); % Frequency domain channel
response of the Relay Link 2
H_channel_5 = fft(SP. channel_5 ,SP. FFTsize ); % Frequency domain channel
response of the Access Link 2
 for n = 1: length (SP.SNR),
   errCount = 0;
   for k = 1: SP.numRun ,
             %% Data transmission through Relay link and Direct link STARTS
          data = round ( rand (1, numSymbols)); % Generate random data block .
         % convolutional encoder
          tmps = Encoder_conv(data);
```

```
        data1 = tmps *2 - 1;
         inputSymbols = (data1 (1 ,:) + i*data1 (2 ,:))/ sqrt(2);%QPSK signal
        TxSamples = sqrt (SP. FFTsize )* ifft (inputSymbols );% Generation of
Transmission signal
        ofdmSymbol = [ TxSamples ( numSymbols -SP.CPsize +1: numSymbols
) TxSamples ];% OFDM Symbol generation
         RxSamples_DL = filter (SP. channel_1 , 1,ofdmSymbol ); % Recieved
Signal through Direct Link
        RxSamples_RL1 = filter (SP. channel_2 , 1,ofdmSymbol ); % Recieved
Signal through Relay Link 1
        RxSamples_RL2 = filter (SP. channel_4 , 1,ofdmSymbol ); % Recieved
Signal through Relay Link 2
        tmp = randn (2, numSymbols +SP. CPsize/2);% Noise generation
        complexNoise = (tmp (1 ,:) + i*tmp (2 ,:))/ sqrt(2);
        noisePower = 10^( - SP.SNR(n) /10) ;
        complexNoise = [ complexNoise complexNoise];
        RxSamples_DL = RxSamples_DL + sqrt ( noisePower )*complexNoise ;
% Noise Added to Direct Link
        %% Relay Link 1
         tmp = randn (2, numSymbols +SP. CPsize/2);% Generation of noise
        complexNoise = (tmp (1 ,:) + i*tmp (2 ,:))/ sqrt(2);
        noisePower = 10^( - SP.SNR(n) /10) ;
        complexNoise = [ complexNoise complexNoise];
        RxSamples_RL1 = RxSamples_RL1 + sqrt (noisePower )*
complexNoise ; % Noise added
        EstSymbols_1 = RxSamples_RL1 (1:numSymbols);
        Y = fft( EstSymbols_1 , SP. FFTsize );
         % Selection of channel equalization
       %   if SP. equalizerType == 'MMSE '
        C = conj ( H_channel_2 )./( conj (H_channel_2 ).* H_channel_2 + 10^(
-SP. SNR (n) /10) );
        Y = Y.*C;
        %elseif SP. equalizerType == 'ZF '
        %Y = Y./ H_channel_2 ;
        %end
         EstSymbols_1 = Y;
        % Hard decision detection
        EstSymbols_RL1 = sign ( real ( EstSymbols_1 )) + i* sign ( imag
( EstSymbols_1 ));
        a(1,:) =real(EstSymbols_RL1);
        a(2,:) =imag(EstSymbols_RL1);
        a=(a+1)./2;
        % convolutional Decoder
        RL1 = Decoder_conv(a(1,:),a(2,:));
         %% Relay link 2
         tmp = randn (2, numSymbols +SP. CPsize/2);% Generation of noise
```

```
        complexNoise = (tmp (1 ,:) + i*tmp (2 ,:))/ sqrt(2) ;
        noisePower = 10^( - SP.SNR(n) /10) ;
        complexNoise = [ complexNoise complexNoise];
        RxSamples_RL2 = RxSamples_RL2 + sqrt (noisePower )*
complexNoise ; % Noise added
        EstSymbols_2 = RxSamples_RL2 (1:numSymbols);
        Y = fft( EstSymbols_2 , SP. FFTsize );
         % Selection of channel equalization
        %if SP. equalizerType == 'MMSE '
        C = conj ( H_channel_4 )./( conj (H_channel_4 ).* H_channel_4 + 10^(
-SP. SNR (n) /10) );
        Y= Y.*C;
        %elseif SP. equalizerType == 'ZF '
        %Y = Y./ H_channel_4 ;
       % end
         EstSymbols_2 = Y;
        EstSymbols_RL2 = sign ( real ( EstSymbols_2 )) + i* sign ( imag
( EstSymbols_2 ));
         % Hard decision detection
        a(1,:) =real(EstSymbols_RL2);
        a(2,:) =imag(EstSymbols_RL2);
        a=(a+1)./2;
        % convolutional Decoder
        RL2 = Decoder_conv(a(1,:),a(2,:));
         % Data transmission through Relay link and Direct link ENDS
         %% Data transmission through Access link and Direct link STARTS
         %% Access link 1
         tmps = Encoder_conv(RL1(1,:));
        data1 = tmps *2 - 1;
        inputSymbols = (data1 (1 ,:) + i*data1 (2 ,:))/ sqrt(2);%QPSK signal
        TxSamples = sqrt (SP. FFTsize )* ifft (inputSymbols ); % Generation of
transmitted signal
        ofdmSymbol = [ TxSamples ( numSymbols -SP.CPsize +1: numSymbols
) TxSamples ]; % OFDM Symbol generation
        RxSamples_AL1 = filter (SP. channel_3 , 1,ofdmSymbol ); % Recieved
signal through Access Link 1
         tmp = randn (2, numSymbols +SP. CPsize/2);% Generation of noise
        complexNoise = (tmp (1 ,:) + i*tmp (2 ,:))/ sqrt(2);
        noisePower = 10^( -2* SP.SNR(n) /10) ;
        complexNoise = [ complexNoise complexNoise];
        RxSamples_AL1 = RxSamples_AL1 + sqrt ( noisePower )
*complexNoise ; % Noise Added to Access Link1

         %% Access link 2

        tmps = Encoder_conv(RL2(1,:));
```

```
%tmps2 = Encoder_conv(RL2(2,:));
data1 = tmps *2 - 1;

inputSymbols = (data1 (1 ,:) + i*data1 (2 ,:))/ sqrt(2);%QPSK signal
TxSamples = sqrt (SP. FFTsize )* ifft (inputSymbols ); % Generation of
transmitted signal
ofdmSymbol = [ TxSamples ( numSymbols -SP.CPsize +1: numSymbols
) TxSamples ];
RxSamples_AL2 = filter (SP. channel_5 , 1,ofdmSymbol ); % Recieved
signal through Access Link2

 tmp = randn (2, numSymbols +SP. CPsize/2);% Generation of noise
complexNoise = (tmp (1 ,:) + i*tmp (2 ,:))/ sqrt(2);
noisePower = 10^( -2* SP.SNR(n) /10) ;
complexNoise = [ complexNoise complexNoise];
RxSamples_AL2 = RxSamples_AL2 + sqrt ( noisePower )
*complexNoise ; % Noise Added to Access Link2
 %% Combibed data of three links
          EstSymbols = RxSamples_DL (1:numSymbols);
Y = fft( EstSymbols , SP. FFTsize );
       EstSymbols = RxSamples_AL1 (1:numSymbols);
Y1 = fft( EstSymbols , SP. FFTsize );
EstSymbols = RxSamples_AL2 (1:numSymbols);
Y2 = fft( EstSymbols , SP. FFTsize );
             % Selection of channel equalization
%   if SP. equalizerType == 'MMSE '
C = conj ( H_channel_1 )./( conj (H_channel_1 ).* H_channel_1 + 10^(
-SP. SNR (n) /10) );
EstSymbols_DL = Y.*C;
C1 = conj ( H_channel_3 )./( conj (H_channel_3 ).* H_channel_3 + 10^(
-SP. SNR (n) /10) );
EstSymbols_AL1 =  Y1.*C1;
C2 = conj ( H_channel_5 )./( conj (H_channel_5 ).* H_channel_5 + 10^(
-SP. SNR (n) /10) );
EstSymbols_AL2 =  Y2.*C2;
%elseif SP. equalizerType == 'ZF '
%Y = Y./ H_channel_2 ;
%end
 EstSymbols =  EstSymbols_AL1 +  EstSymbols_AL2 + EstSymbols_DL
; % Signals of all links are added
  EstSymbols = sign ( real ( EstSymbols )) + i*sign ( imag
( EstSymbols ));% Hard decision detection
%EstSymbols = EstSymbols / sqrt (2);
 % Data transmission through Access link and Direct link ENDS
a(1,:) =real(EstSymbols);
a(2,:) =imag(EstSymbols);
```

```
          a=(a+1)./2
        % convolutional Decoder
        R2c = Decoder_conv(a(1,:),a(2,:));
         errCount = errCount +biterr(data,R2c);
   end
   BER(n ,:) = errCount / ( numSymbols *SP. numRun );
   [SP.SNR(n) BER(n ,:)]
   %toc
end
```

A.4 OFDM_2relay_64QAM_16QAM

```
function BER = ofdm_wr_c64qam_two (SP)
numSymbols = SP. FFTsize ;
H_channel_1 = fft(SP. channel_1 ,SP. FFTsize ); % Frequency domain channel
response of the Direct Link
H_channel_2 = fft(SP. channel_2 ,SP. FFTsize ); % Frequency domain channel
response of the Relay Link 1
H_channel_3 = fft(SP. channel_3 ,SP. FFTsize ); % Frequency domain channel
response of the Access Link 1
H_channel_4 = fft(SP. channel_4 ,SP. FFTsize ); % Frequency domain channel
response of the Relay Link 2
H_channel_5 = fft(SP. channel_5 ,SP. FFTsize ); % Frequency domain channel
response of the Access Link 2
for n = 1: length (SP.SNR),
   errCount = 0;
   for k = 1: SP.numRun ,
            %% Data transmission through Relay link and Direct link STARTS
         data = round ( rand (3, numSymbols)); % Generate random data block .
         % convolutional encoder
         tmps = Encoder_conv(data(1,:));
         tmps2 = Encoder_conv(data(2,:));
         tmps3 = Encoder_conv(data(3,:));
         data1 = tmps *2 - 1;
         datas2 = tmps2 *2 - 1;
         datas3 = tmps3 *2 - 1;
         inputSymbols16 =  data1(1,:).* (-data1(2,:)+2)*0.6325 -
i*datas2(1,:).*(-datas2(2,:)+2)*0.6325 ;
         TxSamples =ifft (inputSymbols16 ); % Generation of Transmission signal
         ofdmSymbol = [ TxSamples ( numSymbols -SP.CPsize +1: numSymbols
) TxSamples ]; % OFDM Signal generation
         RxSamples_DL = filter (SP. channel_1 , 1,ofdmSymbol ); % Recieved
Signal through Direct Link
          tmp = randn (4, numSymbols +SP. CPsize/2 );% Noise generation
```

```
        complexNoise = tmp(1,:).* (-tmp(2,:)+2)*0.6325 -
i*tmp(3,:).*(-tmp(4,:)+2)*0.6325 ;
        complexNoise = [ complexNoise complexNoise];
        noisePower = 10^( - 4*SP.SNR(n) /10) ;
        RxSamples_DL = RxSamples_DL + sqrt ( noisePower )*complexNoise ;
% Noise added to Direct link signal
        EstSymbols_DL = RxSamples_DL (1:numSymbols);
        Y = fft( EstSymbols_DL , SP. FFTsize );
        % Selection of channel equalization
       %  if SP.equalizerType == 'MMSE '
            EstSymbols_DL(1,:) = 0.6325*real(conj(H_channel_1 ).*Y);
            EstSymbols_DL(2,:) = 2*0.6325^2*abs(H_channel_1).^2 -
abs(EstSymbols_DL(1,:));
            EstSymbols_DL(3,:) = -0.6325*imag(conj( H_channel_1).*Y);
            EstSymbols_DL(4,:) = 2*0.6325^2*abs(H_channel_1).^2 -
abs(EstSymbols_DL(3,:));
         %    elseif SP. equalizerType == 'ZF '
           % EstSymbols_DL = Y./ H_channel_1 ;
            %end
          %% Relay Link 1
        inputSymbols64 =  data1(1,:).* (-data1(2,:).*(-datas2(1,:)+2)+4)*0.378 -
i*datas2(2,:).*(-datas3(1,:).*(-datas3(2,:)+2)+4)*0.378 ;
        TxSamples =ifft (inputSymbols64 ); % Generation of Transmission signal
        ofdmSymbol = [ TxSamples ( numSymbols -SP.CPsize +1: numSymbols
) TxSamples ]; % OFDM Signal generation
        RxSamples_RL1 = filter (SP. channel_2 , 1,ofdmSymbol ); % Recieved
Signal through Relay Link 1
        EstSymbols_1 = RxSamples_RL1 (1:numSymbols);
        Y = fft( EstSymbols_1 , SP. FFTsize );
          % Selection of channel equalization
       %  if SP.equalizerType == 'MMSE '
            EstSymbols_RL1(1,:) = 0.378*real(conj(H_channel_2 ).*Y);
            EstSymbols_RL1(2,:) = 4*0.378^2*abs(H_channel_2).^2 -
abs(EstSymbols_RL1(1,:));
            EstSymbols_RL1(3,:) = 2*0.378^2*abs(H_channel_2).^2 -
abs(EstSymbols_RL1(2,:));
            EstSymbols_RL1(4,:) = -0.378*imag(conj( H_channel_2).*Y);
            EstSymbols_RL1(5,:) = 4*0.378^2*abs( H_channel_2).^2 -
abs(EstSymbols_RL1(4,:));
        EstSymbols_RL1(6,:) = 2*0.378^2*abs( H_channel_2).^2 -
abs(EstSymbols_RL1(5,:));
        %end
        EstSymbols_RL1= sign(EstSymbols_RL1);
        EstSymbols_RL1=(EstSymbols_RL1+1)./2;
        % convolutional Decoder
```

```
        data1_RL1 =
Decoder_conv(EstSymbols_RL1(1,:),EstSymbols_RL1(2,:));
        data2_RL1 =
Decoder_conv(EstSymbols_RL1(3,:),EstSymbols_RL1(4,:));
         %% Relay link 2
         inputSymbols64 =  data1(1,:).* (-data1(2,:).*(-datas2(1,:)+2)+4)*0.378 -
i*datas2(2,:).*(-datas3(1,:).*(-datas3(2,:)+2)+4)*0.378 ;
        TxSamples =ifft (inputSymbols64 ); % Generation of Transmission signal
        ofdmSymbol = [ TxSamples ( numSymbols -SP.CPsize +1: numSymbols
) TxSamples ]; % OFDM Signal generation
        RxSamples_RL2 = filter (SP. channel_4 , 1,ofdmSymbol ); % Recieved
Signal through Relay Link 1
         EstSymbols_2 = RxSamples_RL2 (1:numSymbols);
        Y = fft( EstSymbols_2 , SP. FFTsize );
          % Selection of channel equalization
        %  if SP.equalizerType == 'MMSE '
            EstSymbols_RL2(1,:) = 0.378*real(conj(H_channel_4 ).*Y);
            EstSymbols_RL2(2,:) = 4*0.378^2*abs(H_channel_4).^2 -
abs(EstSymbols_RL2(1,:));
            EstSymbols_RL2(3,:) = 2*0.378^2*abs(H_channel_4).^2 -
abs(EstSymbols_RL2(2,:));
            EstSymbols_RL2(4,:) = -0.378*imag(conj( H_channel_4).*Y);
            EstSymbols_RL2(5,:) = 4*0.378^2*abs( H_channel_4).^2 -
abs(EstSymbols_RL2(4,:));
            EstSymbols_RL2(6,:) = 2*0.378^2*abs( H_channel_4).^2 -
abs(EstSymbols_RL2(5,:));
        %end
        EstSymbols_RL2 = sign (EstSymbols_RL2);
        EstSymbols_RL2=( EstSymbols_RL2+1)./2;
        % convolutional Decoder
        data1_RL2 = Decoder_conv( EstSymbols_RL2(1,:),
EstSymbols_RL2(2,:));
        data2_RL2 = Decoder_conv( EstSymbols_RL2(3,:),
EstSymbols_RL2(4,:));
         % Data transmission through Relay links ENDS
          %% Data transmission through Access link and Direct link START
        %% Access link 1
         tmp1_AL1 = Encoder_conv(data1_RL1);
        tmp2_AL1 = Encoder_conv(data2_RL1);

        data16 =tmp1_AL1*2-1;
        datas16 = tmp2_AL1*2-1;

        inputSymbols16 =  data16(1,:).* (-data16(2,:)+2)*0.6325 -
i*datas16(1,:).*(-datas16(2,:)+2)*0.6325 ;
        TxSamples =ifft (inputSymbols16 ); % Generation of Transmission signal
```

```
        ofdmSymbol = [ TxSamples ( numSymbols -SP.CPsize +1: numSymbols
) TxSamples ]; % OFDM Signal generation
        RxSamples_AL1 = filter (SP. channel_3 , 1,ofdmSymbol ); % Recieved
Signal through Access Link 1
         tmp = randn (4, numSymbols +SP. CPsize/2 );% Noise generation
        complexNoise = tmp(1,:).* (-tmp(2,:)+2)*0.6325 -
i*tmp(3,:).*(-tmp(4,:)+2)*0.6325 ;
        complexNoise = [ complexNoise complexNoise];
        noisePower = 10^( - 4*SP.SNR(n) /10) ;
        RxSamples_AL1 = RxSamples_AL1 + sqrt ( noisePower )
*complexNoise ; % Noise added to Access link 1
        EstSymbols_1 = RxSamples_AL1 (1:numSymbols);
        Y = fft( EstSymbols_1 , SP. FFTsize );
         % Selection of channel equalization
        %if SP. equalizerType == 'MMSE '
        EstSymbols_AL1(1,:) = 0.6325*real(conj(H_channel_3 ).*Y);
        EstSymbols_AL1(2,:) = 2*0.6325^2*abs(H_channel_3).^2 -
abs(EstSymbols_AL1(1,:));
        EstSymbols_AL1(3,:) = -0.6325*imag(conj( H_channel_3).*Y);
        EstSymbols_AL1(4,:) = 2*0.6325^2*abs( H_channel_3).^2 -
abs(EstSymbols_AL1(3,:));
                %end
          %% Access link 2
        tmp1_AL2 = Encoder_conv(data1_RL2);
        tmp2_AL2 = Encoder_conv(data2_RL2);
        data16 =tmp1_AL2*2-1;
        datas16 = tmp2_AL2*2-1;
        inputSymbols16 =  data16(1,:).* (-data16(2,:)+2)*0.6325 -
i*datas16(1,:).*(-datas16(2,:)+2)*0.6325 ;
        TxSamples =ifft (inputSymbols16 ); % Generation of Transmission signal
        ofdmSymbol = [ TxSamples ( numSymbols -SP.CPsize +1: numSymbols
) TxSamples ]; % OFDM Signal generation
        RxSamples_AL2 = filter (SP. channel_5 , 1,ofdmSymbol ); % Recieved
Signal through Access Link 2
         tmp = randn (4, numSymbols +SP. CPsize/2 );% Noise generation
        complexNoise = tmp(1,:).* (-tmp(2,:)+2)*0.6325 -
i*tmp(3,:).*(-tmp(4,:)+2)*0.6325 ;
        complexNoise = [ complexNoise complexNoise];
        noisePower = 10^( - 4*SP.SNR(n) /10) ;
        RxSamples_AL2 = RxSamples_AL2 + sqrt ( noisePower )
*complexNoise ; % Noise added to Access link 2
        EstSymbols_2 = RxSamples_AL2 (1:numSymbols);
        Y = fft( EstSymbols_2 , SP. FFTsize );
         % Selection of channel equalization
        %if SP. equalizerType == 'MMSE '
         EstSymbols_AL2(1,:) = 0.6325*real(conj(H_channel_5 ).*Y);
```

```
           EstSymbols_AL2(2,:) = 2*0.6325^2*abs(H_channel_5).^2 -
abs(EstSymbols_AL2(1,:));
                 EstSymbols_AL2(3,:) = -0.6325*imag(conj( H_channel_5).*Y);
                 EstSymbols_AL2(4,:) = 2*0.6325^2*abs( H_channel_5).^2 -
abs(EstSymbols_AL2(3,:));
                  %end
                     % Combined data of three links (SBMRC)

          EstSymbols(1,:) = EstSymbols_AL1(1,:) + EstSymbols_AL2(1,:)
+EstSymbols_DL(1,:) ;
          EstSymbols(2,:) = EstSymbols_AL1(2,:) + EstSymbols_AL2(2,:)
+EstSymbols_DL(2,:) ;
         EstSymbols =sign(EstSymbols);
         EstSymbols = ( EstSymbols+1)./2;
          % convolutional Decoder
         R2c = Decoder_conv(EstSymbols(1,:),EstSymbols(2,:));
         errCount = errCount +biterr(data(1,:),R2c);
   end
   BER(n ,:) = errCount / ( numSymbols *SP. numRun );
   [SP.SNR(n) BER(n ,:)]
   %toc
end
```

Appendix (B)

Propagation Scenarios

The used Propagation scenarios in this thesis of WINNER-II are briefly mentioned:

B.1 Indoor to outdoor

In indoor-to-outdoor scenario the MS antenna height is assumed to be at 1–2m, and eNB antenna height at 2 – 2.5 m + floor height. The corresponding outdoor and indoor environments are B1 an A1, respectively. It is assumed that the floors 1 to 3 are used in simulations, floor 1 meaning the ground floor.

B.2 Urban micro-cell

Both antennas are assumed to be outdoors in an area where streets are laid out in a Manhattan-like grid. The streets in the coverage area are classified as “the main street”, where there is the LOS from all locations to the BS, with the possible exception in cases where the LOS is temporarily blocked by traffic (e.g. trucks and buses) on the street. Streets that intersect the main street are referred to as perpendicular streets, and those that run parallel to it are referred to as parallel streets. This scenario is defined for both the LOS and the NLOS cases. Cell shapes are defined by the surrounding buildings, and energy reaches NLOS streets as a result of the propagation around corners, through buildings, and between them.

B.3 Bad Urban Micro-cell

Bad urban micro-cell scenarios are identical in layout to Urban Micro-cell scenarios, as described above. However, propagation characteristics are such that multipath energy from distant objects can be received at some locations. This energy can be clustered or distinct, has significant power (up to within a few dB of the earliest received energy), and exhibits long excess delays. Such situations typically occur when there are clear radio paths across open areas, such as large squares, parks or bodies of water.

B.4 Suburban macro-cell

In suburban macro-cells base stations are located well above the rooftops to allow wide area coverage, and mobile stations are outdoors at street level. Buildings are typically low residential detached houses with one or two floors, or blocks of flats with a few floors. Occasional open areas such as parks or playgrounds between the houses make the environment rather open. Streets do not form urban-like regular strict grid structure. Vegetation is modest.

B.5 Urban macro-cell

In typical urban macro-cell mobile station is located outdoors at street level and fixed base station clearly above surrounding building heights. As for propagation conditions, non- or obstructed line-of-sight is a common case, since street level is often reached by a single diffraction over the rooftop. The building blocks can form either a regular Manhattan type of grid, or have more irregular locations.

Typical building heights in urban environments are over four floors. Buildings height and density in typical urban macro-cell are mostly homogeneous.

B.6 Bad urban macro-cell

Bad urban environment describes cities with buildings with distinctly inhomogeneous heights or densities, and results to a clearly dispersive propagation environment in delay and angular domain. The in homogeneities in city structure can be e.g. due to large water areas separating the built-up areas, or the high-rise skyscrapers in otherwise typical urban environment. Increased delay and angular dispersion can also be caused by mountains surrounding the city. Base station is typically located above the average rooftop level, but within its coverage range there can also be several high-rise buildings exceeding the base station height.