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Evaluation of Relay Technology in LTE-Advanced
التقييم الادائي للتتابع التعاوني في الجيل الرابع المتقدم

A thesis submitted in partial fulfillment of the Requirements for the Degree of
Master of Electronics Engineering (Communication).

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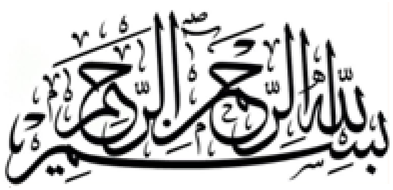
الاستهلال



قال تعالى:

" إِنْ أُرِيدُ إِلاّ الإِصْلاَحَ مَا اسْتَطَعْتُ وَمَا تَوْفِيقِيَ إِلاّ بِاللّهِ عَلَيْهِ تَوَكَّلْتُ وَإِلَيْهِ أُنِيبُ "

صدق الله العظيم

سورة هود

الآية (٨٨)

DEDICATION

To

Endless love

My mother

To

My father

To

My brother and Sisters

To

My teachers & My colleagues & My friends

Acknowledgments

First of all I need to thankfully my god (Allah) that without his blessing this work will not complete.

Then all thanks for my supervisor Dr. Ibrahim Elkhedeir to his patience with me and countless hours and valuable efforts to guide and advise me to complete the work in his fair way.

Lastly, I need to thank my teachers in electronic engineering school for their efforts in helping and support.

ABSTRACT

The Third Generation Partnership Program’s Long-Term Evolution Advanced (3GPP LTE-Advanced) group is developing a new standard for mobile broadband access that will meet the throughput and coverage requirements of a fourth-generation cellular technology. The key goals for this evolution are increased data rate, improved spectrum efficiency, improved coverage and reduced latency. The ultimate results of these goals are significantly improving service provisioning and reduction of operator costs for different traffic scenarios. 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 bandwidths with the same amount of transmit power and use higher carrier frequencies with infrastructure designed for lower carrier frequencies. One solution to improve coverage is to use the fixed relays to transmit data between the Base Stations and the Mobile Stations or User Equipment through multi hop communication. For this reason, relay technologies have been actively studied and considered in the standardization process of next-generation mobile broadband communication system. As a next-generation 3GPP standard, LTE-Advanced exclusively takes the relay technology into account. This thesis focuses the relay technologies for the LTE-Advanced systems and evaluates the performance of the relay-enhanced LTE-Advanced network.

المستخلص

المتقدمة) بتطوير معيار جديد gpp LTEتقوم مجموعه الجيل الثالث من التطور المتقدم (3 للوصول إلى النطاق العريض المتنقل ليلبي متطلبات الانتاجيه والتغطية لتقنية الجيل الرابع من التكنولوجيا الخلوية. وتتمثل الأهداف الرئيسية لهذا التطور في زيادة معدل البيانات، وتحسين كفاءه الطيف، وتحسين التغطية، وتقليل زمن الكمون. وتؤدي النتائج النهائية لهذه الأهداف إلى تحسن كبير في توفير الخدمات والحد من تكاليف المشغلين بالنسبة لسيناريوهات المرور المختلفة. واحد من التحديات الرئيسية التي تواجهها المعايير النامية هو توفير إنتاجيه عاليه علي حافه الخلية. أصبح أداء حافه الخلية أكثر اهميه حيث تستخدم الانظمه الخلوية عروض نطاقات اعلي بنفس المقدار من طاقة الإرسال وتستخدم ترددات حامله اعلي مع بنيه أساسيه مصممه للترددات المنخفضة للناقل. ويتمثل أحد الحلول لتحسين التغطية في استخدام المرحلات الثابتة لنقل البيانات بين محطات القاعدة والمحطات المتنقلة أو معدات المستعملين من خلال الاتصالات المتعددة القفزات. ولهذا السبب، درست تكنولوجيات التتابع بنشاط ونظرت في عمليه توحيد الجيل التالي المتقدمة LTE الجيل القادم ، gppمن نظام الاتصالات المتنقلة العريضة النطاق. كمعيار 3 حصريا ياخذ تكنولوجيا التتابع في الاعتبار. تركز هذه الاطروحه علي تقنيات التتابع للانظمه المحسنة للترحيل.lte وتقيم أداء الشبكة المتطورة lteالمتطورة

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LIST OF ABBERVATION

3G	Third Generation.
4G	Fourth Generation.
3GPP	Third Generation Partnership Project.
ARQ	Automatic Repeated Request.
Bs	Base station.
CA	Carrier aggregation.
CDD	Cyclic delay diversity.
CoMP	Coordinated multipoint transmission and reception.
CS/CB	Coordinated scheduling and coordinated beamforming.
CSI	Channel state information.
DeNB	Donor-evolved Node B.
DL	Downlink.
Enb	ENodeB.
FDD	Frequency Division Duplexing.
Gbps	Gaga bit per second.
HARQ	Hybrid Automatic Repeat Request.
HetNet	Heterogeneous Network.
IMT	International Mobile Telecommunications.
ITU-R	International Telecommunication Union Radio Communication Sector.
Km/h	Kilo meter per hour.
LTE	Long-Term Evolution.

MHz	Megahertz's.
MIMO	Multiple input multiple output.
Mbps	Mega bit per second.
OFDM	Orthogonal Frequency Division Multiplexing.
OFDMA	Orthogonal Frequency Division Multiple Access.
QPSK	Quadrature Phase Shift keying.
RN	Relay node.
SNR	Signal to Noise Ratio.
SINR	Signal to Interference and Noise Ratio.
TDD	Time Domain Multiplexing.
TP	transmission point.
UE	User Equipment.
UL	Uplink.

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CHAPTER ONE

INTRODUCTION

1.1 Preface:

- Long Term Evolution (LTE) is a 4G wireless broadband technology developed by the Third Generation Partnership Project (3GPP), an industry trade group.
- Long Term Evolution-Advanced (LTE-Advanced) is a cellular networking standard that offers higher throughput than its predecessor, the Long Term Evolution (LTE) standard. Deliver significantly higher speeds.
- LTE-Advanced networks use multiple-input, multiple-output (MIMO) technology to deliver data faster via more than one signal. MIMO requires multiple antennas to receive those signals, which can limit its use in compact mobile devices such as smart phones and tablets.
- Cooperative communications enable efficient utilization of communication resources, by allowing nodes or terminals in a communication network to collaborate with each other in information transmission. It is a promising technique for future communication systems. In this thesis, we first survey cooperative communication schemes and discuss their advantages in improving system capacity and diversity. Following that, we examine the applications of cooperative relaying schemes in LTE-advanced systems.

1.2 PROBLEM STATEMENT

One of the main drivers for the use of LTE-A is the high data rates that can be achieved. However, all technologies suffer from reduced data rates at the cell edge where signal levels are lower and interference levels are typically higher.

1.3 PROPOSED SOLUTION

One solution that is being investigated and proposed is that of the use of LTE-A relays.

1.4 AIM AND OBJECTIVES

- ✓ Coverage extension.
- ✓ Increase Peak data rate.
- ✓ Higher spectral efficiency.
- ✓ Improved performance at cell edges.

1.5 Methodology (Scenarios)

- LTE relay nodes can be deployed very easily in situations where the aim is to increase network Coverage and capacity.
- LTE relays are easy to install as they require no separate backhaul and they are small enabling them to be installed in many convenient areas, e.g. on street lamps, on walls, etc.
- Further, we will analyze the performance of the model by comparing symbol-error-rate versus signal-to-noise ratio for direct and cooperative scenarios, using them to determine the ideal position of the relay; and the effect of path loss and variation in eNB-UE distance. Thus, we will show that coverage extension can be achieved in a reliable manner without any hardware addition, through this scheme using MATLAB.

1.6 Thesis Outlines

The rest of the thesis is organized as follows:

- **Chapter 2.** Literature review: This chapter presents some basic background on wireless technologies and describes its main features.
- **Chapter 3.** Cooperative technique and relay: include all the details of methodology such as algorithms, blocks diagram and mathematical Equation.
- **Chapter 4**. Results and discussion: design simulation code by using MATLAB language and in this chapter, results will be provided.
- **Chapter 5**. Conclusions and Recommendations: explain the result that can be achieved and remained future works.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

Long Term Evolution-Advanced (LTE-A) is an emerging wireless communication standard developed by the Third Generation Partnership Project (3GPP) in order to keep up with the ever-increasing demand for higher data rate. [2]. Relay technology is implemented in LTE-A so as to enhance capacity, extends cell coverage area and increase overall throughput of the network, Coverage, in particular, is of prime importance in a Long-Term Evolution network. However, both come at a significant cost. Deployment of additional eNodeBs (macro layer) to cover small dead zones might often result in a negative return on investment. Instead a scheme that augments the macro layer by making use of low power relay nodes can satisfy coverage and capacity demands in a satisfactory manner. The same being proven across a number of studies, Research in this domain has so far dealt with the deployment of relay nodes with LTE over either licensed or unlicensed spectrum. In this research, we present a non-transparent amplify and forward relaying scheme based on the use of Wi-Fi access points as relays. The link between the eNodeB and the relay node (backhaul) is wireless. In both the uplink and the downlink, the Wi-Fi access point serves as the relay. In the downlink, the eNodeB is the source, while, in the uplink, the user equipment is the source. While the use of LTE for relay nodes causes' interference with the macro base station, Wi-Fi based nodes present a lesser probability of interference due to the different bands (2.4 GHz and 5 GHz) in which they operate. [3]

2.2 Evolution of wireless standards

Wireless communications have evolved from the so-called second generation (2G) systems; the second-generation mobile network was based on low-band digital data signaling. The most popular 2G wireless technology is known as Global Systems for Mobile Communications (GSM). The first GSM systems used a 25MHz frequency spectrum in the 900MHz band. [4]

FDMA (Frequency Division Multiple Access), which is a standard that lets multiple users access a group of radio frequency bands and eliminates interference of message traffic, is used to split the available 25MHzof bandwidth into 124 carrier frequencies of 200 kHz each. Each frequency is then divided using a TDMA (Time Division Multiple Access) scheme into eight timeslots and allows eight simultaneous calls on the same frequency. This protocol allows large numbers of users to access one radio frequency by allocating time slots to multiple voice or data calls. TDMA breaks down data transmission, such as a phone conversation, into fragments and transmits each fragment in a short burst, assigning each fragment a time slot. With a cell phone, the caller does not detect this fragmentation. [5]. UMTS Projections of increasing demand for wide-area communications supporting new applications requiring high data rates led to the development of a new generation of cellular communication system in the late 1980s and the 1990s. These systems became known as 3rd Generation systems, aiming to fulfill the requirements set out by the International Telecommunication Union for the so-called IMT-2000 family. Broadly speaking, such systems aimed to achieve data rates up to 2 Mbps.The 3rd Generation system which has become dominant worldwide was developed in the 3rd Generation Partnership Project (3GPP) and is known as the Universal Mobile Telecommunication System (UMTS). 3GPP is a partnership of six regional Standards Development Organizations covering Europe, Japan, Korea, North America, and China. In contrast to the time division multiple access used by GSM, UMTS used a new paradigm in multiple access technology, being based on code division multiple access (CDMA) technology. CDMA permits several radios to

share the same frequencies. Unlike TDMA, all radios can be active all the time, because network capacity does not directly limit the number of active radios. Since larger numbers of phones can be served by smaller numbers of cell-sites, CDMA-based standards have a significant economic advantage over TDMA-based standards, or the oldest cellular standards that used frequency-division multiplexing. The first release of the UMTS specifications became available in 1999, and it was followed by extensions known as high-speed packet access (HSPA). The main stimulus for this was the rapid growth of packet data traffic, necessitating both much higher data rates and a switch from constant data-rate circuit-switched traffic (chiefly voice) toward Internet Protocol (IP)—based packet-switched traffic. The first enhancement was to the downlink, where high-speed downlink packet access (HSDPA) was introduced in Release 5 of the UMTS specifications, driven predominantly by the growth of Internet download traffic; this was followed in Release 6 by high-speed uplink packet access (HSUPA), as
Attention began to focus on services requiring a more symmetric uplink/downlink traffic ratio such as e-mail, file sharing (including photographs and videos), and interactive gaming. [7]

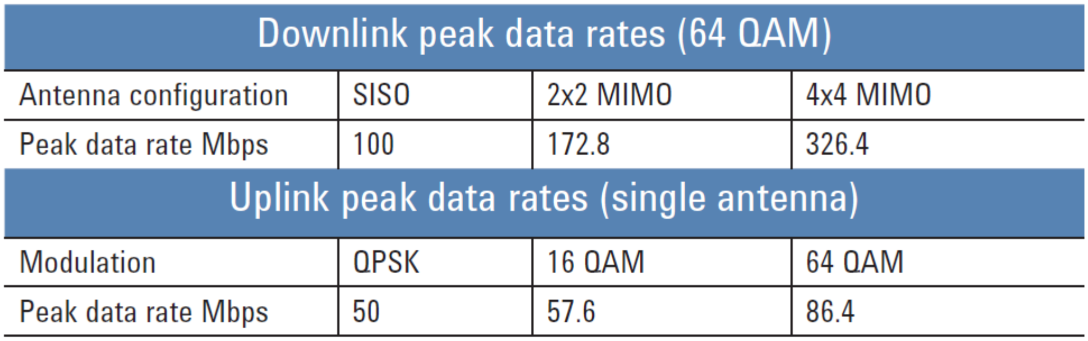
2.3 LTE Technology

The Long Term Evolution project was initiated in 2004 [2]. The motivation for LTE included the desire for a reduction in the cost per bit, the addition of lower cost services with better user experience, the flexible use of new and existing frequency bands, a simplified and lower cost network with open interfaces, and a reduction in terminal complexity with an allowance for reasonable power consumption.

These high-level goals led to further expectations for LTE, including reduced latency for packets, and spectral efficiency improvements above Release 6 high speed packet access (HSPA) of three to four times in the downlink and two to three times in the uplink. Flexible channel bandwidths a key feature of LTE is specified at 1.4, 3, 5, 10, 15, and 20 MHz in both the uplink and the downlink. This allows LTE to be flexibly deployed where other systems exist today, including narrowband systems such as GSM and some systems in the U.S. based on 1.25 MHz[2-3].

Speed is probably the feature most associated with LTE. Examples of downlink and uplink peak data rates for a 20 MHz channel bandwidth are shown in Table 2.1. Downlink figures are shown for single input single output (SISO) and multiple input multiple output (MIMO) antenna configurations at a fixed 64QAM modulation depth, whereas the uplink figures are for SISO but at different modulation depths. These figures represent the physical limitation of the LTE frequency division duplex (FDD) radio access mode in ideal radio conditions with allowance for signaling overheads. Lower rates are specified for specific UE categories, and performance requirements under non-ideal radio conditions have also been developed. Figures for LTE’s time division duplex (TDD) radio access mode is comparable, scaled by the variable uplink and downlink ratios.

Table 2.1: Peak data rates for LTE.



Downlink peak data rates (64 QAM)			
Antenna configuration	SISO	2x2 MIMO	4x4 MIMO
Peak data rate Mbps	100	172.8	326.4
Uplink peak data rates (single antenna)			
Modulation	QPSK	16 QAM	64 QAM
Peak data rate Mbps	50	57.6	86.4

Unlike previous systems, LTE is designed from the beginning to use MIMO technology, which results in a more integrated approach to this advanced antenna technology than does the addition of MIMO to legacy system such as HSPA. Figure 2.2 shows the general network architecture of LTE Release 8.

2.4 LTE Architecture

There are different types of functions in a cellular network. Based on them[4], network can be split into two parts: a radio access network part and a core network part. Functions like modulation, header compression and handover belong to the access network, whereas other functions like charging or mobility management are part of the core network. In case of LTE, the radio access network is E-UTRAN and the core network EPC.

The radio access network of LTE is called E-UTRAN and one of its main features is that EURASIP Journal on Wireless Communications and networking all services, including real-time, will be supported over shared packet channels. This approach will achieve increased spectral efficiency which will turn into higher system capacity with respect to current UMTS and HSPA. An important consequence of using packet access for all services is the better integration among all multimedia services and among wireless and fixed services. The main philosophy behind LTE is minimizing the number of nodes. Therefore, the developers opted for a single-node architecture. The new base station is more complicated than the Node B in WCDMA/HSPA radio access networks, and is consequently called eNB (Enhanced NodeB). eNBs have all necessary functionalities for LTE radio access network including the functions related to radio resource management. Core Network, the new core network is a radical evolution of the one of third generation systems and it only covers the packet-switched domain. Therefore, it has a new name: Evolved Packet Core. Following the same philosophy as for the E-UTRAN, the number of nodes is reduced. EPC divides user data flows into the control and the data planes. A specific node is de fined for each plane plus the generic gateway that connects the LTE network to the internet and other systems. The EPC comprises several functional entities.

(i) The MME (Mobility Management Entity): is responsible for the control plane functions related to subscriber and session management.

(ii) The Serving Gateway: is the anchor point of the packet data interface towards E-UTRAN. Moreover, it acts as the routing node towards other 3GPP technologies.

(iii) The PDN Gateway (Packet Data Network): is the termination point for sessions towards the external packet data network. It is also the router to the Internet. (IV)The PCRF (Policy and Charging Rules Function):

Controls the tariff making and the IP Multimedia Subsystem (IMS) configuration of each user. The overall structure of LTE is shown in Figure 2.2[5]

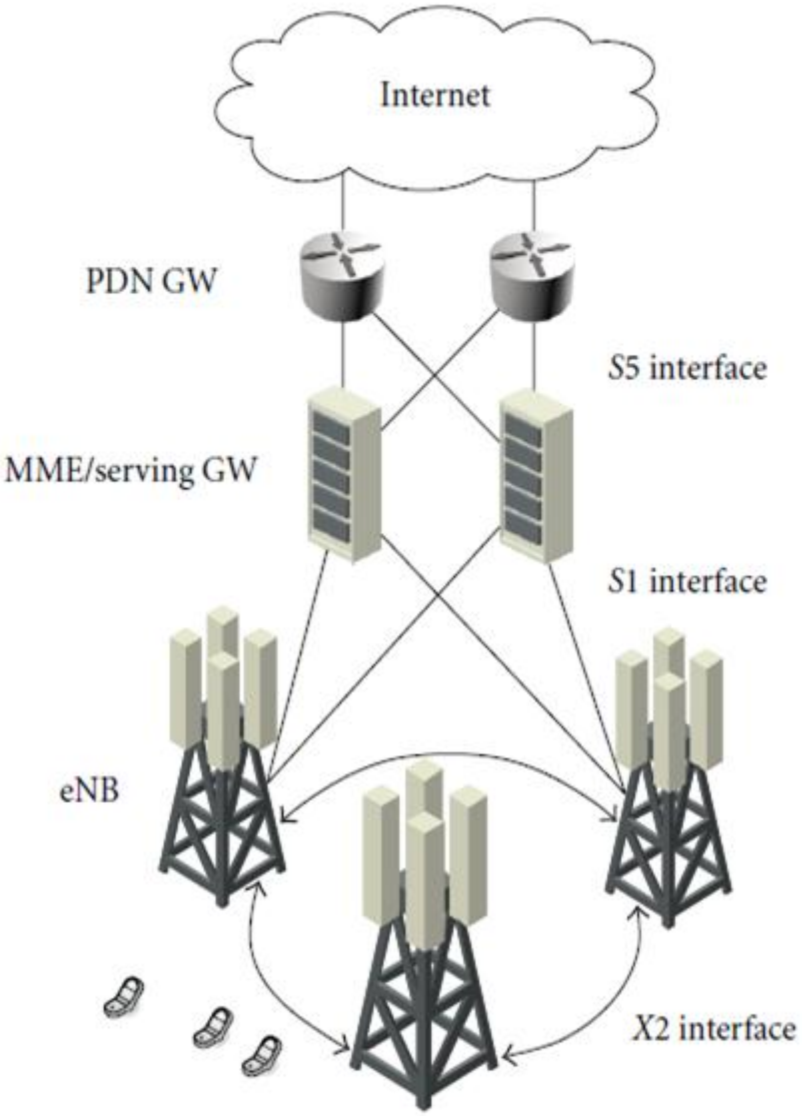


Figure 2.1: LTE Release 8 architecture.

Finally, in terms of mobility, LTE is aimed primarily at low mobility applications in the 0 to 15 km/h range, where the highest performance will be seen. The system is capable of working at higher speeds and will be supported with high performance from 15 to 120 km/h and functional support from 120 to 350 km/h. Support for speeds of 350 to 500 km/h is under consideration.

2.5 What’s new in LTE-Advanced?

3GPP determined that LTE-Advanced would meet the ITU-R requirements for 4G. The results of the study are published in 3GPP Technical Report (TR) 36.912. Further, it was determined that3GPP Release 8 LTE could meet most of the 4G requirements apart from uplink spectral efficiency and the peak data rates. These higher requirements are addressed with the addition of the following LTE-Advanced features:

- Wider bandwidths, enabled by carrier aggregation
- Higher efficiency, enabled by enhanced uplink multiple access and enhanced multiple antenna transmission (advanced MIMO techniques)

Other performance enhancements are under consideration for Release 10 and beyond, even though they are not critical to meeting 4G requirements:

- Coordinated multipoint transmission and reception (CoMP).
- Relaying.
- Support for heterogeneous networks.
- LTE self-optimizing network (SON) enhancements.
- Home enhanced-node-B (He-NB) mobility enhancements.
- Fixed wireless customer premises equipment (CPE) RF requirements.

These features and their implications for the design and test of LTE-Advanced systems will be discussed in details later in this chapter.

2.6 LTE Advanced Overview

LTE-Advanced will be an evolution of LTE. Therefore[4]LTE-Advanced must be backward compatible with LTE Release 8. LTE-Advanced requirements will meet or even exceed IMT-Advanced requirements following the ITUR agenda.

LTE-Advanced should support significantly increased instantaneous peak data rates Peak data rate of 1 Gbps for downlink (DL) and500 Mbps for uplink (UL). Primary focus should be on low mobility users. Moreover, it is required a further improvement of cell edge data rates. The LTE-Advanced system will support scalable bandwidth and spectrum aggregation with transmission bandwidths up to100MHz in DL and UL. LTE-Advanced must guarantee backward compatibility and interworking with LTE and with other 3GPPlegacy systems.[5]

LTE-Advanced enhances the cell edge user throughput (5% user throughput) in order to achieve a homogeneous user experience in cell. It will support the mobility across the cell from 350 km/h to 500 km/h depending on operating frequency band.

The LTE-A is backward compatible with existing LTE system and support the existing LTE enabled UEs. LTE-Advanced is expected to be bandwidth scalable and support wider bandwidth up to 100 MHzIt should also support the FDD and TDD duplexing for the existing paired and unpaired band, respectively. It enables network sharing and handover with existing legacy radio-access technologies. LTE-Advanced also considers a low-cost infrastructure deployment. It will allow the backhauling using LTE spectrum in order to reduce the cost per bit.[3]

2.7 LTE-Advanced key technologies

2.7.1 Carrier Aggregation

In carrier aggregation[6], multiple carrier components are aggregated, to provide wider bandwidths for transmission purposes both in DL and UL. It allows the transmission bandwidths up to 100 MHz, by adding five component carriers of 20MHz bandwidth, three different modes of carrier aggregation exist within LTE-

Advanced: intra-band contiguous, intra-band non-contiguous and inter-band carrier aggregation.[3]

Rel-10 already covers intra-band contiguous and inter-band CA, whereas intra-band non-contiguous CA will not be realized until Rel-11. Intra-band describes the aggregation of component carriers within the same frequency band in a contiguous or non-contiguous way. For inter-band carrier aggregation, the two component carriers reside in different frequency bands. Figure 1 shows the different modes being defined for carrier aggregation.

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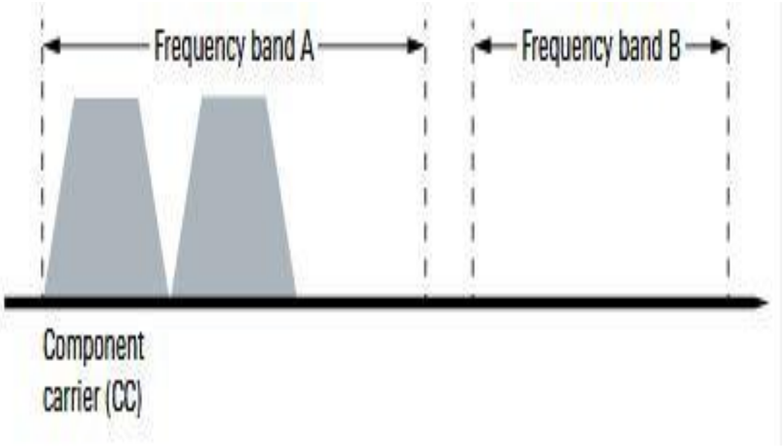

Figure 2.2: illustrate Intra-band contiguous

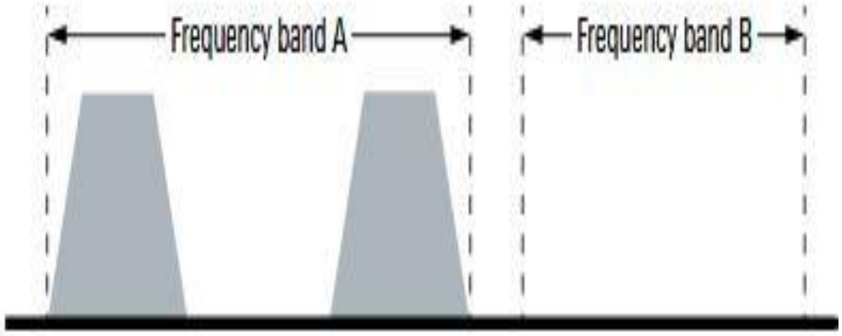

Figure 2.3: illustrate Intraband non-contiguous

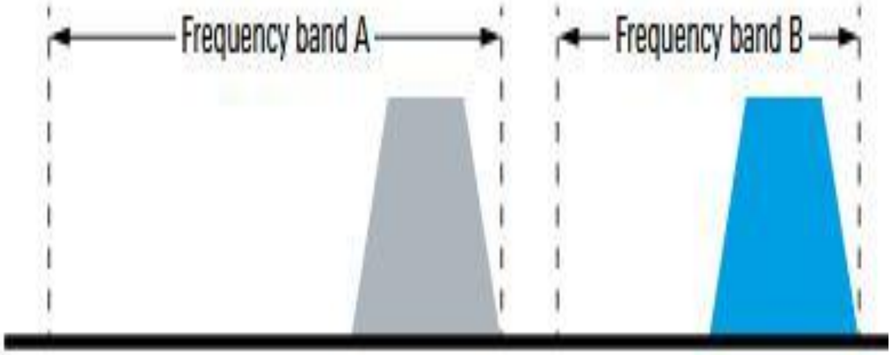

Figure 2.4: illustrate Interband

2.7.2 Enhanced MIMO

Multiple input multiple output (MIMO) techniques support multiple antennas at the transmitter and at the receiver. The aim [7]of MIMO is to achieve different kinds of gains namely: spatial diversity and spatial multiplexing, spatial multiplexing allows to increase the capacity by transmitting different streams of data simultaneously in parallel from different antennas as shown in figure 2.4. Spatial diversity can be used to increase the robustness of communication in fading channels by transmitting multiple replicas of the transmitted signal from different antennas. Thus, MIMO can be used to improve the cell capacity. Furthermore beam-forming can be used to shape the antenna beam in the direction of certain UEs.

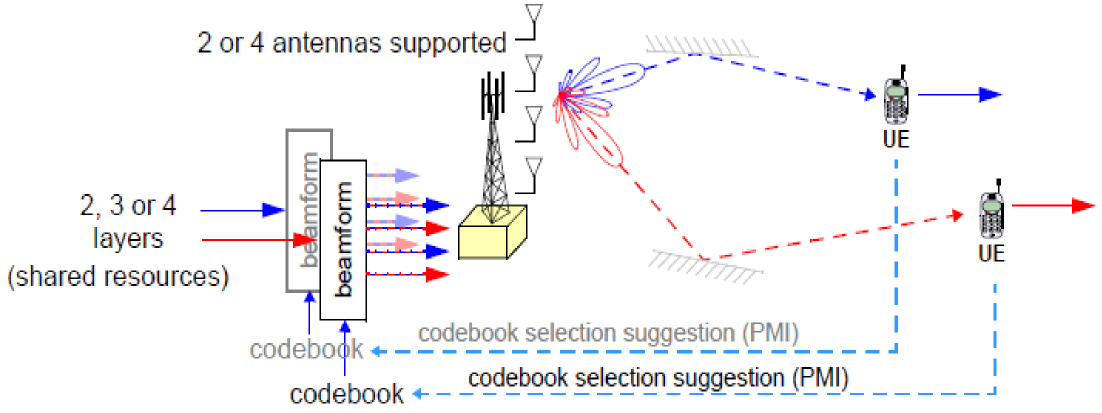

Figure2.5: Multiple Input Multiple Output (MIMO)

2.7.3 Heterogeneous Network (Het-Net)

It is a multi-layered network deployment scheme[6], comprising lower-power nodes, overlaid under the coverage area of a macro-cell. It aims to increase the network capacity as well as achieve peak data rates. Examples are Pico base station [6]and home-eNB (Femto base stations), relaying as shown in figure2.5.

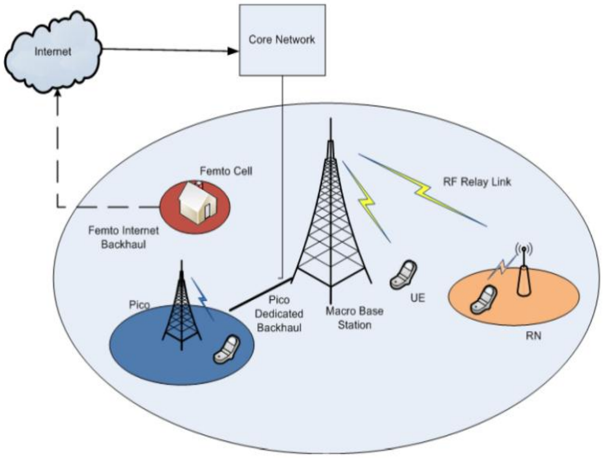

Figure 2.6: Heterogeneous Network.

2.7.4 Coordinated Multipoint Transmission and Reception

Coordinated multipoint (CoMP) is an advanced variant of MIMO being studied as a means of improving performance for high data rates, cell-edge through-put, and system throughput in high load and low load scenarios.

Figure 2.7 compares traditional MIMO downlink spatial multiplexing with coordinated multipoint. The most obvious different between the two systems is that with coordinated multipoint, the transmitters do not have to be physically co-located, although they are linked by some type of high-speed data connection and can share payload data.

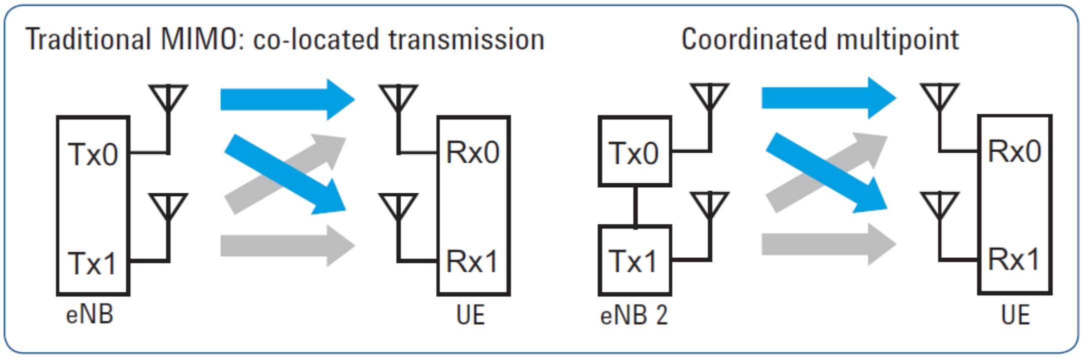

Figure 2.7: Comparison of traditional downlink MIMO and coordinated multipoint.

In the downlink, coordinated multipoint enables coordinated scheduling and beamforming from two or more physically separated locations. These features do not make full use of CoMP's potential, because the data required to transmit to the mobile needs to be present at only one of the serving cells. However, if coherent combining, also known as cooperative or network MIMO, is used, then more advanced transmission is possible [2].

The CoMP approach to MIMO requires high speed, symbol-level data communication between all the transmitting entities, as indicated on the right hand-side of Figure 11 by a line between eNB1 and eNB2. Most likely the physical link carrying the LTE X2 interface, a mesh-based interface between the base stations, will be used for sharing the baseband data.

The coherent combining used in CoMP is somewhat like soft combining or soft handover, a technique that is widely known in CDMA systems in which the same signal is transmitted from different cells. With coherent combining, however, the data streams that are being transmitted from the base stations are not the same. These different data streams are pre-coded in such a way as to maximize the probability that the UE can decode the different data streams. In the uplink, the use of coordination between the base stations is less advanced, simply because when two or more UEs are transmitting from different places, there is no realistic mechanism for sharing the data between Uses for the purposes of precoding. Thus, the uplink is restricted to using the simpler technique of coordinated scheduling. On the other hand, there is considerable opportunity at the eNB receivers to share the received data prior to demodulation to enable more advanced demodulation to be performed. The downside is the consequence that for a 10 MHz signal, the backhaul could be as much as 5 Gbps of low latency connections between the participating eNBs.

2.7.5 Relaying

Another method of improving coverage in difficult conditions is the use of relaying[3]. The main use cases for relays are to improve urban or indoor throughput, to add dead zone coverage, or to extend coverage in rural areas.

3GPP study item phase us a relatively open discussion period when various potential techniques can be proposed. In LTE-A relay study item, technical proposals encompass the resource partition between hops, relay categorizations, in band versus out band operation. The effort was later narrowed down to two major relay types: Type 1 relay and Type 2 relay, during which companies conducted extensive simulation evaluation and proposed high-level design guidance.

Relay study activities were not limited to the time frame of LTE-A study item which began in January and ended in December 2010. Some research topics, for example carrier aggregation for the backhaul link, continued into the work item of LTE-A, although not gaining much attention. Outside 3GPP, there has been quite a lot of research on the carrier aggregation operation and multi-hops for relay. These potential techniques. Though not specified in LTE-A Release 10. Are valuable references for future relay work. There are a few inter-connections between relay and other LTE-A technologies, where the study and specification of one technology would affect the other. To facilitate the understanding of the contents in next few chapters, we also briefly describe the related topics in LTE-A: carrier aggregation, downlink reference signal. Enhanced ICIC and CoMO.

2.8 RELAY CATEGORIZATION BASED ON PROTOCOL ARCHITECTURE:

The most straightforward way to categorize a relay node in by checking the protocol architecture. For that prospective, three types can be defined: Layer 1, Layer 2 and Layer 3. As the understanding went deeper regarding how relaying would actually operate, pure protocol layer-based categorization lost it significance in RAN 1, and were replaced by more relevant relay types such as type 1 relay a type 2 relay, Nevertheless, the discussion of layer protocols for relay in helpful in understanding the basic operation of a relay node and higher layer of relays.

2.8.1 LAYER 1 RELAY:

consists of relay technology called a booster or repeater, this is an Amplifier and Forward (AF) type of relay which Radio Frequency (RF) signals received on the downlink from the base station are amplified and transmitted to the mobile station. In a similar manner, RF signals received on the uplink from the mobile station are amplified and transmitted to the base station. The equipment functions of a layer 1 relay are relatively simple, which makes for low-cost implementation and short processing delays associated with relaying. With these features, the layer 1 relay has already found widespread use in 2G and 3G mobile communication systems. It is being deployed with the aim of improving coverage in mountainous regions, sparsely populated areas and urban areas as well as in indoor environments. The RF performance specifications for repeaters have already been specified in LTE, and deployment of these repeaters for the same purpose is expected. The layer 1 relay, however, amplifies inter-cell interference and noise together with desired signal components thereby deteriorating the received Signal to Interference plus Noise power Ratio (SINR) and reducing the throughput- enhancement gain.

2.8.2 LAYER 2 RELAY:

meanwhile, is a Decode and Forward (DF) type of relay technology by which RF signals received on the downlink from the base station are demodulated and decoded and then encoded and modulated again before being sent on to the mobile station. This demodulation and decoding processing performed at the radio relay station overcomes the drawback in layer 1 relays of deteriorated received
SINR caused by amplification of inter-cell interference and noise. A better throughput-enhancement effect can therefore be expected compared with the layer 1 relay. At the same time, layer 1 relay causes a delay associated with modulation/demodulation and encoding/decoding processing. In this type of relay, moreover, radio functions other than modulation/demodulation and encoding/decoding (such as mobility control, retransmission control by Automatic Repeat request (ARQ), and user-data concatenation/segmentation/reassembly) are performed between the base station and mobile station transparently with respect to the radio relay, which means that new radio-control functions for supporting this relay technology are needed. Layer 3 Relay Technology.

2.8.3 LAYER 3 RELAY:

also performs demodulation and decoding of RF signals received on the downlink from the base station, but then goes on to perform processing (such as ciphering and user-data concatenation/segmentation/reassembly) for retransmitting user data on a radio interface and finally performs encoding/modulation and transmission to the mobile station. Similar to the layer 2 relay, the layer 3 relay can improve throughput by eliminating inter-cell interference and noise, and additionally, by incorporating the same functions as a base station, it can have small impact on the standard specifications for radio relay technology and on implementation. Its drawback, however, is the delay caused by user-data processing in addition to the delay caused by modulation/demodulation and encoding/decoding processing. In 3GPP, it has been agreed to standardize specifications for layer 3 relay technology in LTE Rel. 10 because of the above features of improved received SINR due to noise elimination, ease of coordinating standard specifications, and ease of implementing the technology. Standardization of this technology is now moving forward. Layer 3 radio relay technology is shown in Figure 2. In addition to performing user data regeneration processing and modulation/demodulation and encoding/ decoding processing as described above, the layer 3 relay station also features a unique Physical Cell ID (PCI) on the physical layer different than that of the base station. In this way, a mobile station can recognize that a cell provided by a relay station differs from a cell provided by a base station.

CHAPTER THREE

COOPERATIVE TECHNIQUES

3-1 Relay Scenarios:

A number of potential deployment scenarios are of interest to major operators can be:

3-1-1 Rural Area:

Given the limited number of UEs served by each relay node (RN), the coverage, rather than the capacity improvement per RN cell would be the major concern. As Fig. 3.1 shows, the rural service features wide coverage area and low user density. The low user density leads to rather uniform and thin distribution of users where ubiquitous coverage becomes crucial. So, the first question of interest to the operators is how to lower the deployment cost. In this sense, relay would provide an efficient solution in reducing the number of macro eNBs.

The long distance between eNB and RN means low signal to noise ratio (SNR) at RN receiver. The situation prompts the need for decode and forward relay to improve the SNR at the UEs served by RNs. Amplify and forward repeater is not suitable here as the noise at RN receiver is also amplified by the repeater, i.e., no SNR improvement. To reach out more UEs without deploying too many relay nodes, the transmit power of RN can be relatively high, and the coverage of each RN can be several kilometers. The actual coverage depends on the operating band, and the propagation environment. In general, due to the low–rise morphology, the line of sight (LOS) propagation would be dominant. NLOS is relatively rare unless the terrain is very hilly and/or covered with tall vegetations. The high transmit power deployment favors fixed location of relay node, and the site planning is very crucial.

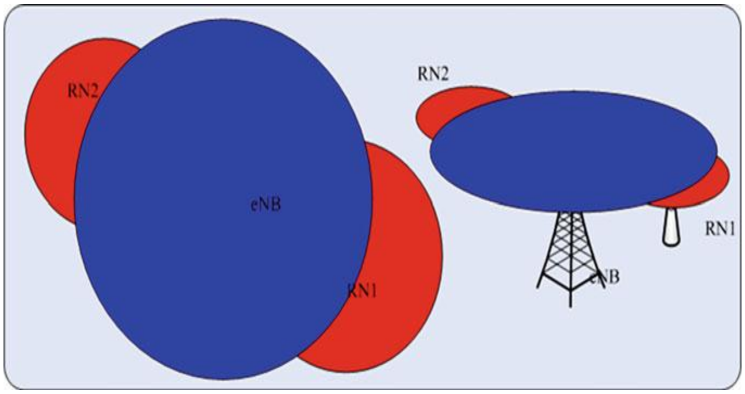

Fig 3.1: Rural area scenario for relay

3-1-2 Urban Hot Spot:

Urban hot spot is just opposite to rural area scenario. The user density is quite high and often non-uniformly distributed, as illustrated in Fig. 3.2. The main objective is to enhance the capacity. Therefore, the coverage of each RN is relatively small and many RNs could be deployed within a macro eNB coverage area. There could be a lot of coverage overlaps between RNs. Due to the densely deployed macro eNBs and RNs, interference scenarios become very complex and difficult to predict. HARQ is crucial to ensure reliable transmissions. The challenging interference environment makes conventional repeater unsuitable in this scenario.

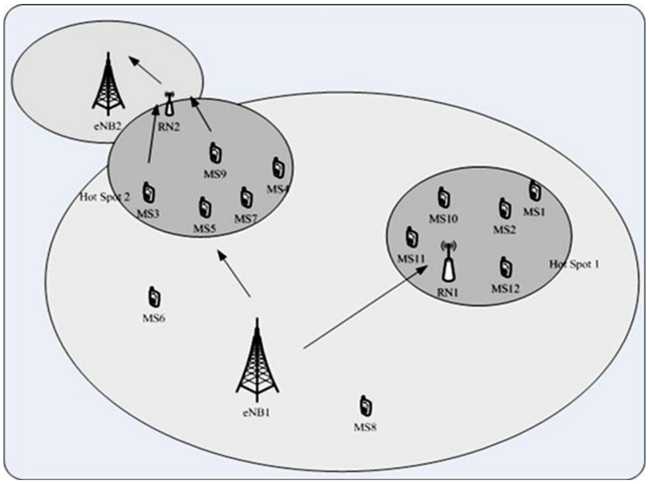

Fig 3.2: Urban hot spot scenario for relay

Either fixed location or nomadic relay node can be deployed to alleviate the zoning regulation and renting cost for the installation. Transmit power of RN tends to be low, so that the interference to neighboring cells is small. High–rise building in urban area results in strong non-line-of-sight (NLOS) propagation environment. Channel modeling, both for the backhaul and the access link, needs to capture dominant NLOS and the shadow fading.

3-1-3 Indoor Hot Spot:

Relay could be used to achieve high data throughput for indoor hot spot, as Fig. 3.3 shows. This scenario is different from the urban hot spot in the sense that majority of users are indoors and stationary.

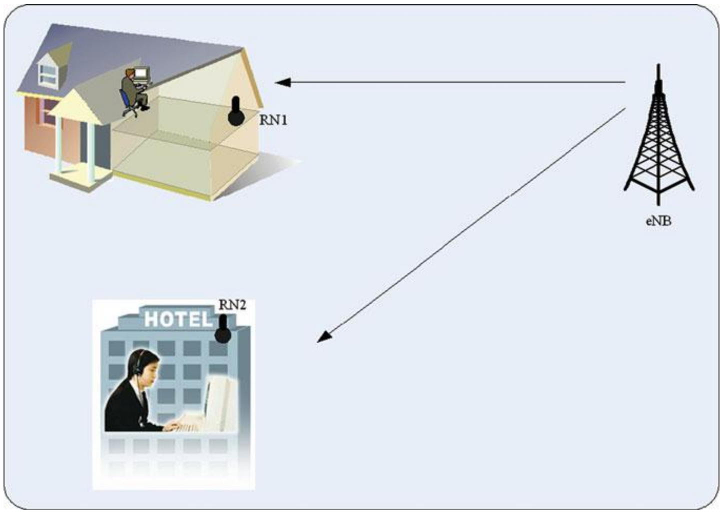

Fig 3.3: Indoor hot spot scenario for relay

The shadow fading tends to be high due to the wave reflection and refraction against the walls. The relay is supposed to provide enhanced throughputs and to serve indoor users in low coverage areas (e.g. deep indoor, or in buildings far from the donor eNB).

3-1-4 Group Mobility:

As the penetration rate of mobile phones especially smart phones keeps increasing, users on public transportations would have more propensity to access high speed wireless services. Voice services on buses or trains are typically cacophony and the data rate are low. Battery life is shortened, in particular to overcome the penetration loss through the vehicles and the high Doppler. The battery powers drain is also due to the continuous measurement carried out by on-board UEs, in both idle and active mode to accommodate the frequent handover caused by the group mobility. In such condition, UEs would experience excessive rate of broken connections since the mass number of on-board UEs frequently trigger the simultaneous handover and cause serious signaling congestions, leading to higher call-drop rate. such case, a relay node can be deployed on the roof-top of the moving train or bus as Fig. 3.4 shows, to serve on board passengers, and to alleviate the problem of vehicle penetration loss. The challenging link seems to be the backhaul which suffers fast fading due to the movement of the vehicle. Passengers are supposed to rather stationary relative to the vehicle, so that the access link would be strong and stable.

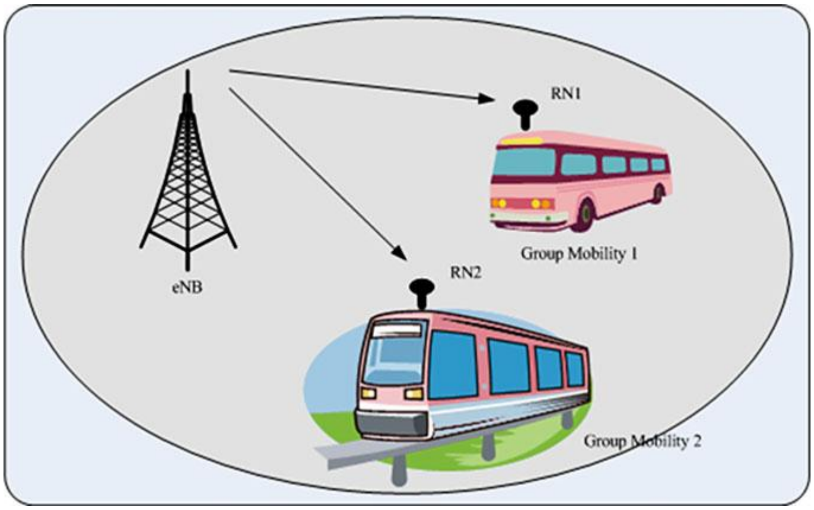

Fig. 3.4: High group mobility scenario for relay

The key usage of relay in this scenario is to ‘‘aggregate’’ multiple UEs’ connections on a vehicle to a single access point. Obviously, it cannot be achieved by conventional repeaters that are totally transparent to on-board UEs. Recently, relay for high speed trains has gained significant interest. Building high speed rail has become the national key projects in some countries. To provide the high-speed communications for on-board passengers is also part of those national-key projects. Fast communications are crucial as passengers on high speed trains are more likely to be data-hunger professionals and would access the internet and emails when on-board. The capacity requirement for relay backhaul is expected to be very high, considering the high density of users on a train. So the demand for high data rate is high for both downlink and uplink traffic.

3-2 Channel Modeling:

During LTE Release 8 study, a single pathloss model was used for macro eNB to UE connection which is based on the traditional formulae for NLOS propagation environment, with minor correction to account for the contribution of LOS component. That assumption makes sense for homogeneous networks in which the site-to-site distance is constant and the topology of the entire cell grid is regular. However, using single pathloss model may not be accurate enough in heterogeneous deployment as macro eNBs and relay/pico/femto/RRH have quite different transmit powers. The antenna gains, antenna heights and down-tilts are different too. Also, cell topology becomes more diversified in HetNet, which demands more sophisticated channel models to represent the actual propagation environment.

3.1 The Wireless Channel Characteristics

Communication through a wireless channel is a challenging task because the medium introduces much impairment to the signal. Wireless transmitted signals are affected by effects such as noise, attenuation, and interference. It is then useful to briefly summarize the main impairments that affect the signals.

3.1.1 Additive White Gaussian Noise

Some impairments are additive in nature, meaning that they affect the transmitted signal by adding noise. Additive white Gaussian noise (AWGN) and interference of different nature and origin are good examples of additive impairments. The additive white Gaussian channel is perhaps the simplest of all channels to model. The relation between the output y(t) and the input s(t) signal is given by

$$y(t) = s(t) + w(t) \qquad (3.1)$$

Where w (t) is noise. The additive noise w (t) is a random process with each realization modeled as a random variable with a Gaussian distribution. This noise term is generally used to model background noise in the channel as well as noise introduced at the receiver front end [1].

3.1.2 Large-Scale Propagation Effects

1.Path Loss

Path loss is an important effect that contributes to signal impairment by reducing its power. Path loss is the attenuation suffered by a signal as it propagates from the transmitter to the receiver. Path loss is measured as the value in decibels (dB) of the ratio between the transmitted and received signal power. The value of the path loss is highly dependent on many factors related to the entire transmission setup. In general, the path loss is characterized by a function of the form

$$PL(d) = 10vlog\left(\frac{d}{d_\circ}\right) + c \qquad (3.2)$$

where PL is path loss function measured in dB, d is the distance between transmitter and receiver, v is the path exponent, c is a constant, and do is the distance to a power measurement reference point (sometimes embedded within the constant c). In many practical scenarios this expression is not an exact characterization of the path loss, but is still used as a sufficiently good and simple approximation. The path loss exponent v characterizes the rate of decay of the signal power with the distance, taking values in the range of 2 to 6. The constant c includes parameter related to the physical setup of the transmission such as signal wavelength, antennas height, etc.

I. Shadowing

In practice, path losses of two receive antennas situated at the same distance from the transmit antenna are not the same. This is, in part, because the transmitted signal is obstructed by different objects as it travels to the receive antennas. Consequently, this type of impairment has been named shadow loss or shadow fading. Since the nature and location of the obstructions causing shadow loss cannot be known in advance, path loss introduced by this effect is a random variable. Denoting by X the value of the shadow loss, this effect can be added to path loss equation by writing

$$PL(d) = 10vlog\left(\frac{d}{d_{\circ}}\right) + \chi + c \tag{3.3}$$

It has been found through experimental measurements that X when measured in dB can be characterized as a zero-mean Gaussian distributed random variable with variance σ_x^2 (also measured in dB). Because of this, the shadow loss value is a random value that follows a log-normal distribution and its effect is frequently referred as log-normal fading[1].

3.1.3 Small-Scale Propagation Effects

From the explanation of path loss and shadow fading it should be clear that the reason why they are classified as large-scale propagation effects is because their effects are noticeable over relatively long distances. There are other effects that are noticeable at distances in the order of the signal wavelength; thus, being classified as small-scale propagation effects. We now review the main concepts associated with these propagation effects. In wireless communications, a transmitted signal encounters random reflector, scatters, and attenuators during propagation, resulting in multiple copies of the signal arriving at the receiver after each has traveled through different paths. Such a channel where a transmitted signal arrives at the receiver with multiple copies is known as a multipath channel. Several factors influence the behavior of a multipath channel. One is the already mentioned random presence of reflectors, scatters, and attenuators. In addition, the speed of the mobile terminal, the speed of surrounding objects, and the transmission bandwidth of the signal are other factors determining the behavior of the channel. Furthermore, due to the presence of motion at the transmitter, receiver, or surrounding objects, the multipath channel changes over time. The multiple copies of the transmitted signal, each having different amplitude, phase, and delay, are added at the receiver creating either constructive or destructive interference with each other. This results in received signal whose shape changes over time[1].

I. Slow and Fast Fading

The distinction between slow and fast fading is important for the mathematical modeling of fading channels and for the performance evaluation of communication systems operating over these channels. The coherence time Tc of the channel is the key factor to distinct between slow and fast fading. The coherence time measures the period of time over which the fading process is correlated. In other words, coherence time is the period after which the correlation function of two samples of the channel response taken at the same frequency but different time instants drop below a certain predetermined threshold. The coherence time is also related to the channel maximum Doppler spread *fdmax*by [2]

$$T_c \approx \frac{9}{16\pi f_{d,max}} \tag{3.4}$$

where Doppler spread is caused by the relative movements of the transmitter, receiver, and/or the objects in between, which cause the carrier frequency of the received signal gets altered. The maximum Doppler spread (in units of Hz) is given as [3],

$$f_{d,max} = \frac{v}{\lambda} \tag{3.5}$$

Where v and λ denote the relative speed (m/s) of the receiver with respect to the transmitter and the wavelength (m) of the carrier signal, respectively. The fading is said to be slow if the symbol time duration Ts is smaller than the channel's coherence time Tc; otherwise it is considered to be fast. In slow fading a particular fade level will affect many successive symbols, which leads to burst errors, whereas in fast fading the fading de-correlates from symbol to symbol.

II. Frequency-Flat and Frequency-Selective Fading

Frequency selectivity is also an important characteristic of fading channels. If all the spectral components of the transmitted signal are affected in a similar manner, the fading is said to be frequency-non-selective or equivalently frequency-flat. This is the case for narrowband systems, in which the transmitted signal bandwidth is much smaller than the coherence bandwidth fc of the channel. Coherence bandwidth measures the frequency range over which the fading process is correlated and is defined as the frequency bandwidth over which the correlation function of two samples of the channel response taken at the same time but different frequencies falls below a suitable value. In addition, the coherence bandwidth is related to the maximum delay spread *tmax*by

$$f_c \approx \frac{1}{\tau_{max}} \tag{3.6}$$

where the delay spread, by definition, quantifies the average length of overlapping received multipath pulses over which most of energy is concentrated [4]. On the other hand, if the spectral components of the transmitted signal are affected by different amplitude gains and phase shifts, the fading is said to be frequency selective. This applies to wideband systems in which the transmitted bandwidth is bigger than the channel's coherence bandwidth.

3.7 System Description:

In this section an overall description for the proposed system used in the simulation is given, and the different mathematical models and measurements is described.

3.7.1 Data Rate

The data rate is calculated based on the modulation technique as

$$R = BW\ r\ log_2(M) \tag{3.7}$$

Where BW is the bandwidth for N users, M is the modulation order which is always 2n, and r is the coding rate which is determined by the measured SINR and depends on the used adaptive modulation.

3.7.2 Throughput

Throughput is a measurement of the average rate that data (in bits) can be sent between one user and another and is typically reported in kilobits per second or megabits per second which are often used to define data sizes as in kilobytes or megabytes). As with latency, care must be taken in the definition of this term. The throughput of the same network connection can vary greatly depending on the protocol used for transmission, the type of data traffic being sent (e.g., HTTP, FTP, VoIP or other traffic) as well as the quality and data bandwidth of a network connection. This is quite different from latency which generally does not vary for different protocols or traffic types. Throughput is measured at the highest protocol level possible to reflect as accurately as possible the performance that will be experienced a user. Throughput is, thus, computed using the amount ofdata in the payload area of the highest protocol layer (e.g., the UDP payload size) of the transmitted packets

3.7.3 Spectral Efficiency

The spectral efficiency is calculated as

$$SE = r\, log_2(M) \tag{3.8}$$

3.7.4 Bandwidth Utilization

The Bandwidth utilization is calculated as

$$BU = \frac{\sum_{i=1}^{N} BW_i}{BW} \tag{3.9}$$

Where BWi is the bandwidth allocated for the i^{th} user.

3.7.5 Transmission Delay

The transmission delay is calculated as

$$d = \frac{Number\ of\ bits}{R} \tag{3.10}$$

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the main results which reflect the system performance are been calculated, presented and analyzed. This result is conducted by simulated a simple LTE-advanced link using MATLAB to study the relaying scheme performance in term of data rate, throughput, spectrum efficiency, bandwidth utilization, and delay.

4.2 Simulation Parameters

Table 4.1 shows the general simulation parameters used in the different scenarios of the simulation.

Table 4.1: Simulation parameters.

Parameter	**Value**
Carrier frequency	1.5 GHz
Bandwidth	20 MHz
Number of Relay nodes	0, 1
Tx power	16 dB
Distance between Tx and Rx	300 – 3000 m
Shadowing	8 – 9 dB
Interference	1 – 3 dB
Noise Figure	7 dB
Number of bits	50000
Penetration Loss	20 dB
Tx, Rx antenna height	3, 100 m
Tx, Rx antenna gain	0, 14 dB
Temperature	290 k
Relay node power	10 dB

4.3 Performance by Number of Users

The performance of the DF in this simulation is evaluated in as the relationship between the increasing in user number and the deferent link parameters.

4.3.1 Data rate

The performance of the simulated system was first evaluated in term of data rate for both cases with and without relaying. Notice that data rate is decreased when the number of users is increased at the same time, This problem can be solved by using relaying nodes, which cannot influenced by number of users, here the data rate be high always and constant, Figure 4.1 shows the relationship between the number of users and the data rate of the user, and it can be noted the increasing in the data rate in case of cooperation compared to the same system with direct link without cooperation.

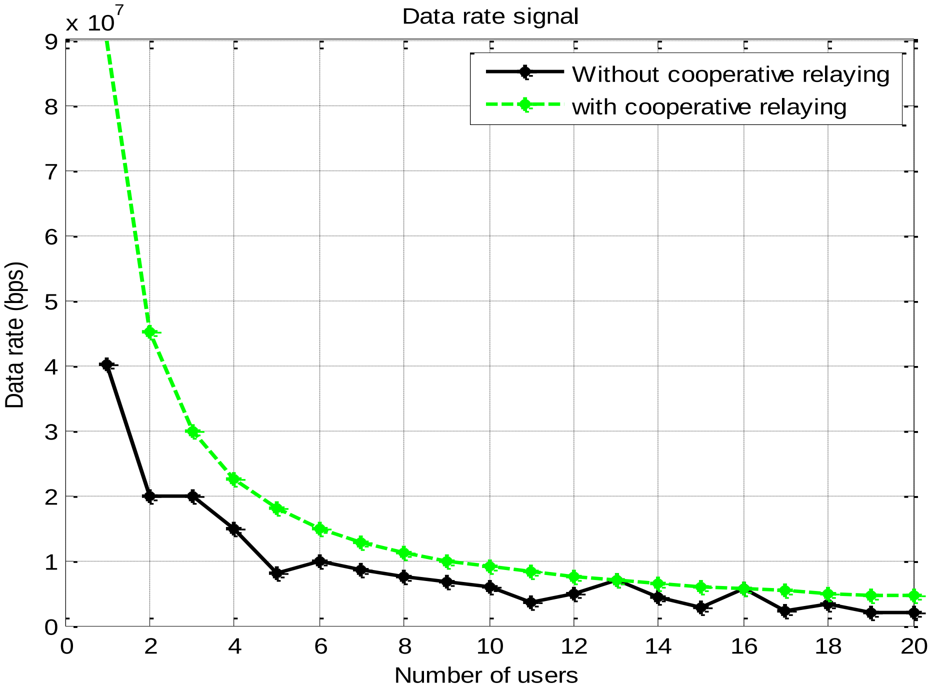

Figure 4.1: Data rate performance compression of the link with cooperative relaying and without cooperative relaying.

4.3.2 Throughput

The second result conducted from this simulation evaluates the performance of the system using the throughput.

Figure 4.2 is obtained by simulating the system throughput against the number of users for both cases, the enhancement in the system throughput can be easily observed in the case of cooperative relaying with Decode-and-forward scheme compared to the system without relaying.

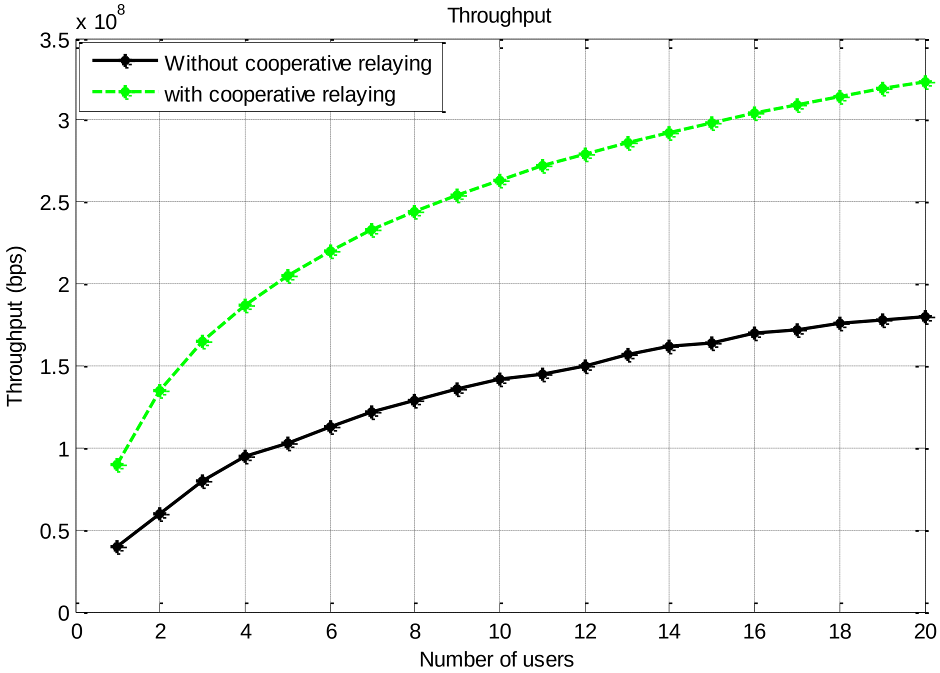

Figure 4.2: Throughput performance compression of the link with cooperative relaying and without cooperative relaying with increasing in number of users.

4.3.3 Spectral Efficiency

Furthermore, the Spectral efficiency was also evaluated for the simulated LTE-advanced link to investigate the effect of the cooperative relaying in spectral efficiency of the system. Figure 4.3 represents the relationship between the spectral efficiency and the number of users, and it's clear that the spectral efficiency of the system is higher in case of relaying with DF scheme than exact same system without cooperation.

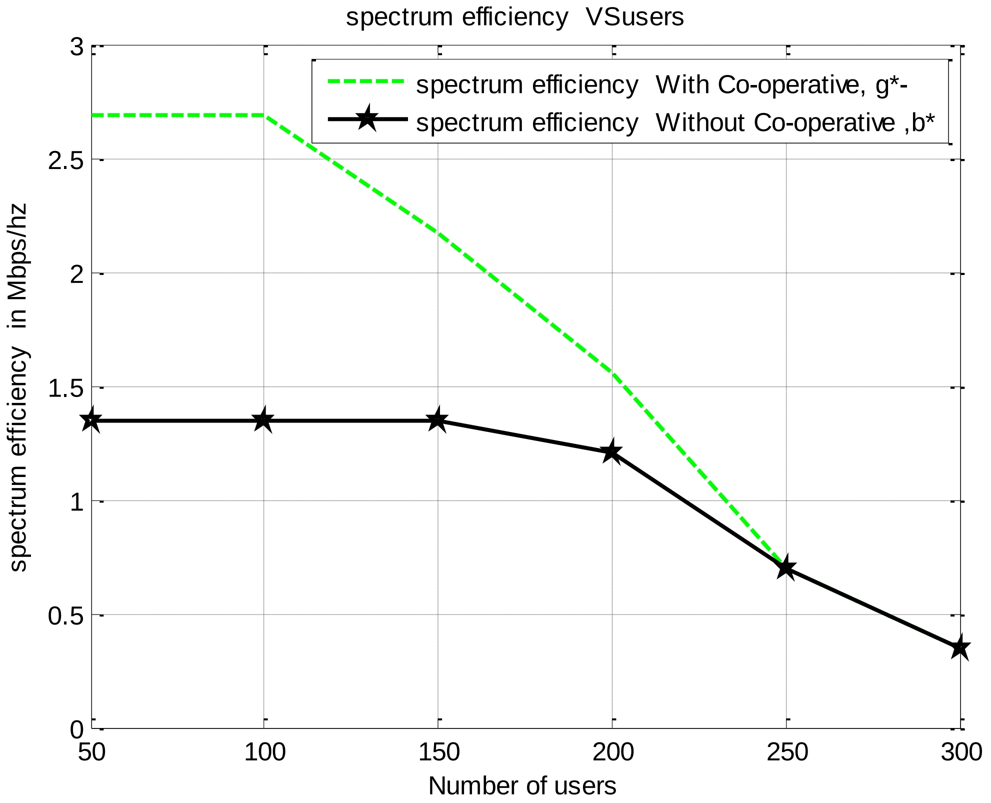

Figure 4.3: Spectral efficiency performance compression of the link with cooperative relaying and without cooperative relaying with increasing in number of users.

4.3.4 Bandwidth Utilization

Figure 4.4 shows the performance of the relaying scheme compared to direct (non-cooperative) link using bandwidth utilization, as compared to non-cooperative scheme, the bandwidth utilization of the cooperative scheme is improved.

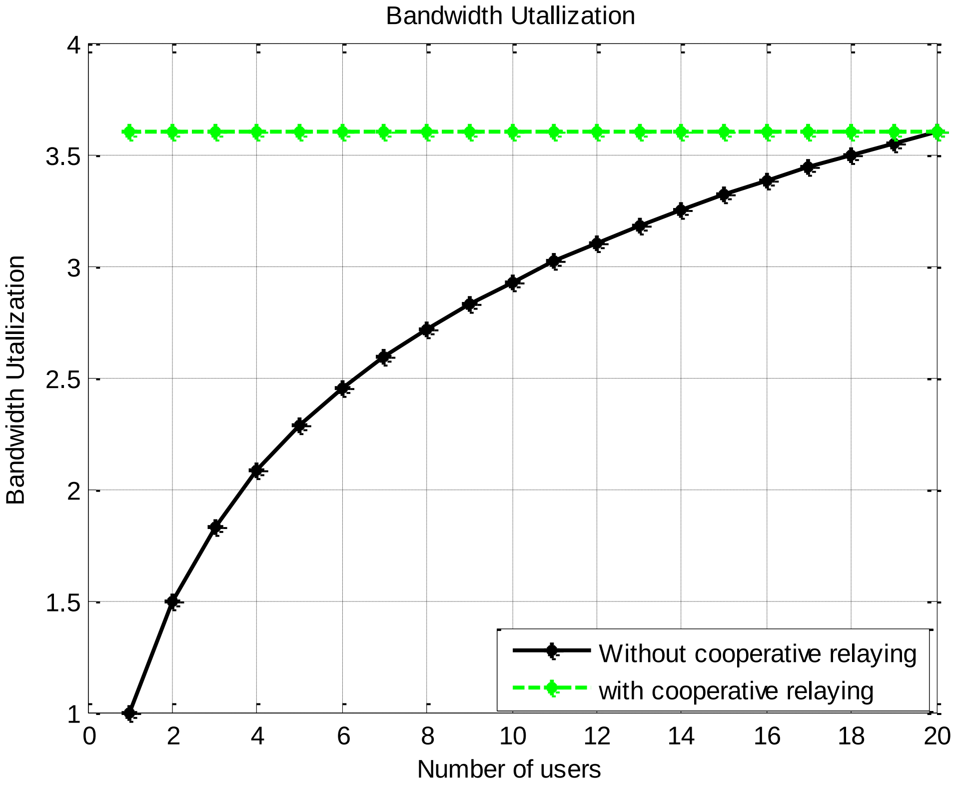

Figure 4.4: Bandwidth utilization performance compression of the link with cooperative relaying and without cooperative relaying with increasing in number of users.

4.3.5 Delay

In Figure 4.5 the performance of the simulated cooperative scheme is shown, we donate that the delay performance is also improved as the delay in case cooperative relaying is lower and it increases with the number of users.

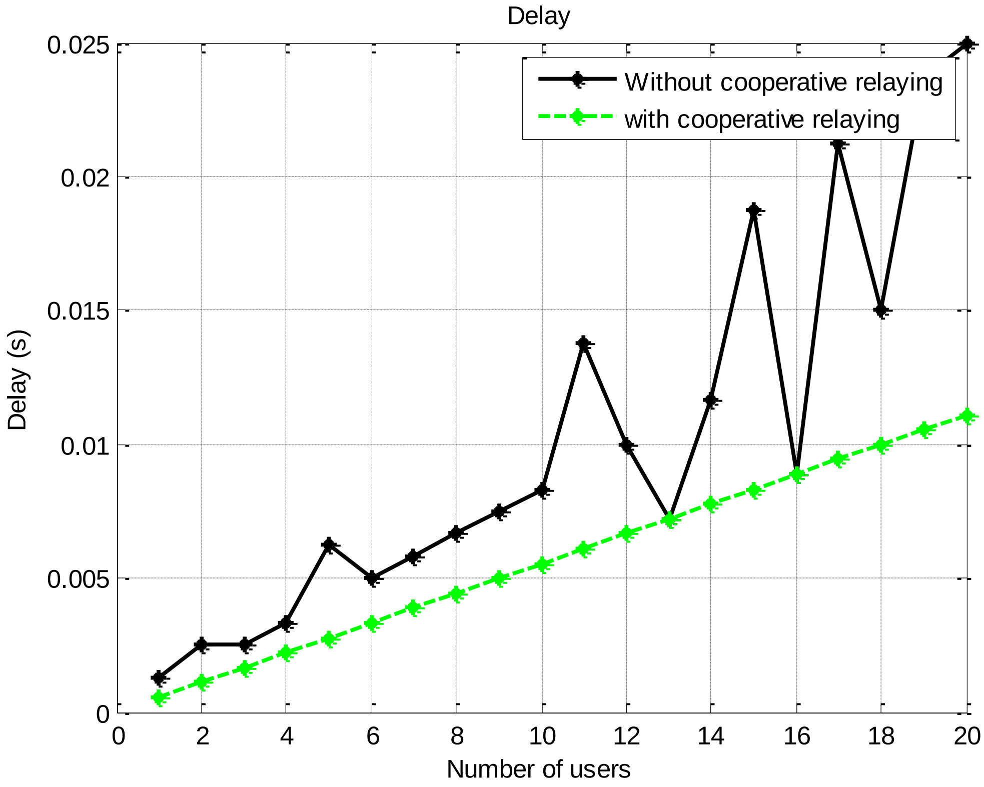

Figure 4.5: Delay performance compression of the link with cooperative relaying and without cooperative relaying with increasing in number of users.

4.3.6 Signal to Interference and Noise Ratio

The SINR was a fundamental factor in this simulation because the calculation of the data rate depends on adaptive modulation in LTE-advanced. Figure 4.6 shows the relationship between the SINR and the number of user, it is noted that the performance of the system is improved when cooperation with DF scheme is applied to the simulated system.

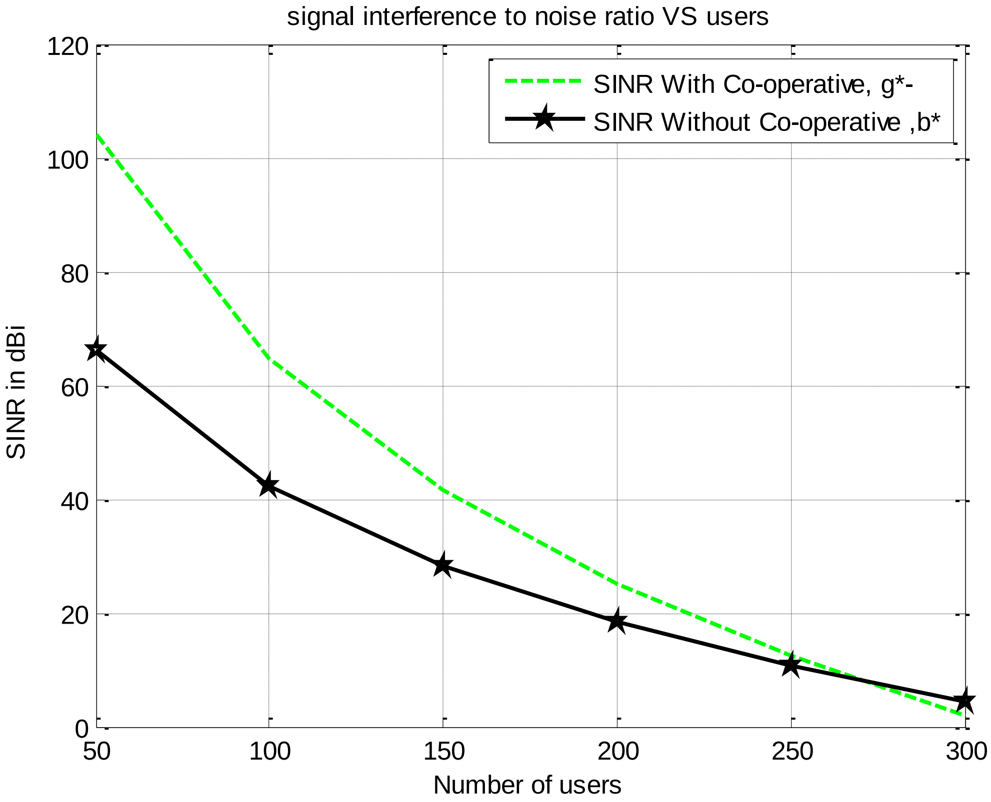

Figure 4.6: SINR performance compression of the link with cooperative relaying and without cooperative relaying with increasing in number of users.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The overall objective of this research is to study and investigate the cooperative relaying and its application in LTE-Advanced system. the work is mainly divided into two parts, the first part involved studying the up-to-date cooperative techniques for wireless communication with greater focus on cooperative relaying techniques and protocols, a number of concepts related to cooperation as well as LTE-Advanced is also addressed including wireless channel characteristics that cooperation deal with, the concept of diversity and cooperation diversity and different types of cooperation schemes. In the second part, however, we conducted a MATLAB simulation to investigate and evaluate the.

In the simulation the system performance was compared for cooperative and non-cooperative system with same parameters in terms of SINR, the data rate, the throughput, the spectral efficiency, the bandwidth utilization and the transmission delay of the wireless link. The simulation results show that the cooperative relaying can greatly enhance the network capacity of LTE advanced system.

5.2 Recommendations

During this research, many important issues have not been dealt with, or been sometimes considered with simplified assumptions. Hence, there are many areas to extend the work of this dissertation. In this section, we suggest some topics for future research in the direction of this dissertation. We recommend the following issues for further study.

- The work can be extended to include a channel estimator with a study of the effect on the overall performance and adding the channel fading effect instead of assuming complete knowledge of the channel state information at the receiver.

- The work can be extended by considering other LTE-Advanced techniques that works hand by hand with cooperative relaying like MIMO, CoMP and HetNet deployment, to provide more diversity and make the simulation more realistic.

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06.07 2010.

Appendices

APPENDIX A: THE MATLAB CODE

```
clear all

close all

clc


v=3*10^8;

fc=1500*10^6;

w=v/fc;

d1=300; %30

d2=3000;


ptl=20; % penetration loss

NOB= 50*10^3; % No of bits


K=1.38*10^-23;

T=290;

NF=7;


sh1 =8;

sh2=9;

sh1r =4;

sh2r=5;

I1=1;

I2=3;

I1sr = 0;

I2sr = 2;

I1rd = 0;

I2rd = 1;


BWt=20*10^6;

Pt=16;
```

```
Gt=0;
Gr=14;

Garea=10;
Amu=25;
Ht=3 ;
Hr=100;
Ght=20*log10(Ht/3);
Ghr=20*log10(Hr/200);

Ht_r=20;
Hr_r=100;
Ght_r=20*log10(Ht_r/200);
Ghr_r=20*log10(Hr_r/3);

N = 0:1; % number of relay nodes
Pr = 10;
dr1 = 10;
dr2 = 500;
Gt_r=14;
Gr_r=10;
users = 20;

for i=1:length(N)

   DR = zeros(1,users);
   SE = zeros(1,users);
   THP = zeros(1,users);
   Dt = zeros(1,users);
   BU = zeros(1,users);
%BW = zeros(1,users);
```

```
for n=1:users;
        d=round(d1+(d2-d1)*(rand(1,1)));
        sh=round(sh1+(sh2-sh1)*(rand(1,1)));
        I=round(I1+(I2-I1)*(rand(1,1)));
        Lf=-10*log10((w^2*2.67)./(4*3.14*d)^2);
        Lp=Lf+Amu-Ght-Ghr-Garea;
        BW(n) = BWt/n;
        No = 10*log10(K*T*BW(n))+NF;
        Psd=Pt+Gt+Gr-sh-Lp-ptl;
        SINRsd = Psd-No-I;



        SINRrd = zeros(1,N(i));
        SINRsr = zeros(1,N(i));
        SINRr = zeros(1,N(i));
if(i > 1 ) %&& n > 2
for j=1:N(i)
                dr=round(dr1+(dr2-dr1)*(rand(1,1)));
                dsr = d - dr;
                shr=round(sh1r+(sh2r-sh1r)*(rand(1,1)));
                Isr=round(I1sr+(I2sr-I1sr)*(rand(1,1)));
                Ird=round(I1rd+(I2rd-I1rd)*(rand(1,1)));

                Lfr=-10*log10((w^2*2.67)./(4*3.14*dr)^2);
                Lfsr = -10*log10((w^2*2.67)./(4*3.14*dsr)^2);
                Lpr=Lfr+Amu-Ght_r-Ghr_r-Garea;
                Lpsr=Lfsr+Amu-Ght_r-Ghr_r-Garea;

                Prd = Pr+Gt_r+Gr_r-shr-Lpr-ptl;
                Psr = Pt+Gt+Gr-sh-Lpsr-ptl;
```

```
            SINRsr(j) = Psr - No - Isr;
            SINRrd(j) = Prd -No-Ird;
            SINRr(j) = min(SINRsr(j), SINRrd(j));
end
end

%Pd = Psd + sum(Prd);
    SINR = SINRsd+sum(SINRr);



if (SINR > 24)
      Rc=3/4;
      M=64;
elseif (SINR > 18)
      Rc=1/2;
      M=16;
elseif (SINR > 12)
      Rc=3/4;
      M=16;
elseif (SINR > 9)
      Rc=1/2;
      M=16;
elseif (SINR > 6)
      Rc=3/4;
      M=4;
end

    DR(n)= BW(n)*Rc*log2(M);
    SE(n)= Rc*(log2(M));
    THP(n)=sum(DR);
    Dt(n)= NOB/DR(n);
```

```
        BU(n)=(sum(BW))/(BWt);

end

    SINRi(i,:) = SINR;
    DRi(i,:) = DR;
    SEi(i,:) = SE;
    THPi(i,:) = THP;
    Dti(i,:) = Dt;
    BUi(i,:) = BU;
end

% plots
values = 1:users;

figure
plot(values,SINRi(1,:),'-k*',values,SINRi(2,:),'g--*','linewidth',2);
title('SINR');
xlabel('Number of users'); ylabel('SINR');
legend('Without cooperative relaying','with cooperative relaying');
grid on

figure
plot(values,DRi(1,:),'-k*',values,DRi(2,:),'g--*','linewidth',2);
title(' Data rate signal');
xlabel('Number of users');ylabel('Data rate (bps)');
legend('Without cooperative relaying','with cooperative relaying');
grid on

figure
plot(values,SEi(1,:),'-k*',values,SEi(2,:),'g--*','linewidth',2);title('Spectral Efficiency');
```

```
xlabel('Number of users');ylabel('Spectral Efficiency (bps/Hz)');
legend('Without cooperative relaying','with cooperative relaying');
grid on

figure
plot(values,THPi(1,:),'-k*',values,THPi(2,:),'g--*','linewidth',2);title('Spectral Efficiency');
title('Throughput');
xlabel('Number of users');ylabel('Throughput (bps)');
legend('Without cooperative relaying','with cooperative relaying');
grid on

figure
plot(values,Dti(1,:),'-k*',values,Dti(2,:),'g--*','linewidth',2);title('Spectral Efficiency');
title('Delay');xlabel('Number of users');ylabel('Delay (s)');
legend('Without cooperative relaying','with cooperative relaying');
grid on

figure
plot(values,BUi(1,:),'-k*',values,BUi(2,:),'g--*','linewidth',2);title('Spectral Efficiency');
title('Bandwidth Utallization');
xlabel('Number of users');ylabel('Bandwidth Utallization');
legend('Without cooperative relaying','with cooperative relaying');
grid on
```