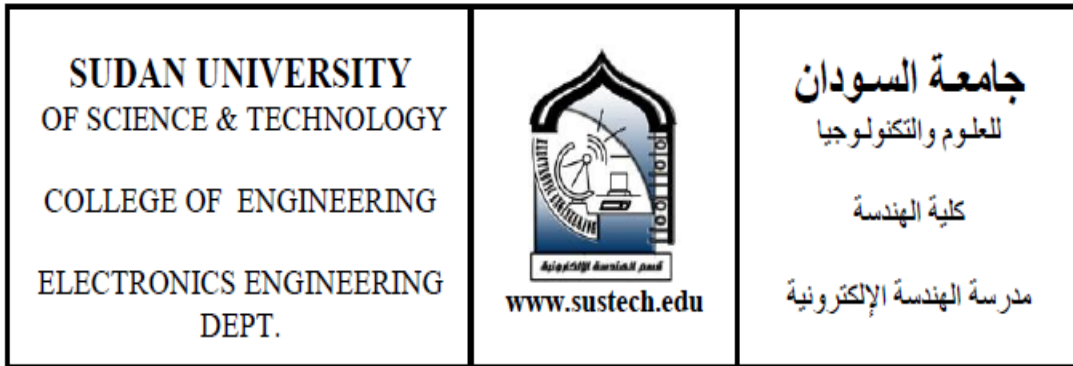


بسم الله الرحمن الرحيم



# **Performance Evaluation of Cooperative Relaying in LTE-Advanced**

## **التقييم الأدائي للتتبع التعاوني في الجيل الرابع المتقدم**

A Research Submitted in Partial fulfillment for the Requirements of

The Degree of B.Sc. (Honors) in Electronics Engineering

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بسم الله الرحمن الرحيم

## الآية

قال تعالى :

( اللَّهُ نُورُ السَّمَاوَاتِ وَالْأَرْضِ مِثْلُ نُورِهِ كَمِشْكَاةٍ فِيهَا مِصْبَاحٌ الْمِصْبَاحُ فِي زُجَاجَةٍ الزُّجَاجَةُ كَأَنَّهَا كَوْكَبٌ دُرِّيٌّ يُوقَدُ مِنْ شَجَرَةٍ مُبَارَكَةٍ زَيْتُونَةٍ لَا شَرْقِيَّةٍ وَلَا غَرْبِيَّةٍ يَكَادُ زَيْتُهَا يُضِيءُ وَلَوْ لَمْ تَمْسَسْهُ نَارٌ نُورٌ عَلَى نُورٍ يَهْدِي اللَّهُ لِنُورِهِ مَنْ يَشَاءُ وَيَضْرِبُ اللَّهُ الْأَمْثَالَ لِلنَّاسِ وَاللَّهُ بِكُلِّ شَيْءٍ عَلِيمٌ )

صدق الله العظيم

سورة النور

الآية 34

# الاهداء

إلى حبيبنا وقرة أعيننا وإمامنا وقدوتنا معلم البشرية الخير  
ومخرجها من الظلمات إلى النور سيد الكون وسيد الوجود

سيدنا مُحَمَّد بن عبد الله ﷺ...

وإلى آباءنا العظماء الذين أعطونا الكثير.. مبتهلين لهم بالدعاء

(ربي أرحمهما كما ربياني صغيراً) أطال الله في أعمارهم ومتعهما

بالصحة ودوام العافية..

وإلى أساتذتنا وإخواننا ومن ساهم في تعليمنا ونصحنا

وإلى كل أصحاب الفضل..

نهدي ثمرة هذا العمل عرفاناً بفضلهم علينا...

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## **Abstract**

Recently, it has been shown that cooperative communication schemes can solve many of the issues faced by mobile cellular network and other future broadband WWAN networks , mobile cellular network have a lot of problems such as low capacity and data rate ,high delay , power consumption ,much antenna's , narrow bandwidth ,and more problems which we explained it in chapter 1 .

In chapter 2 which is present some basic background on LTE, LTE Advanced and describes the main features and their main technology, In chapter 3 present the cooperative technique and relay which include all the details of methodology such as algorithms, blocks diagram and mathematical Equation. We can solve this problems using cooperative communication systems, In this thesis we used cooperative relaying communication system to enhance diversity and capacity . To achieve this solutions by using MATLAB code with it results we can notice there is enhancing in data rate , delay , low cost ,no power consumption, and wide bandwidth which we explained it in chapter 4.In chapter 5 which present Conclusions and Recommendations and explain the results can be achieved and remained future works.

## المستخلص

في الاونة الأخيرة، فقد تبين أن خطط الاتصالات التعاونية يمكن أن تحل الكثير من القضايا التي تواجهها الشبكات الخلوية المتنقلة وشبكات العرض الأخرى في المستقبل القريب. ومفهوم التواصل رواية تقوم على تقاسم الموارد والتنسيق بين وحدات الشبكة اللاسلكية، والشبكات الخلوية المتنقلة لديها الكثير من المشاكل منها قلت السعة وتدفق البيانات، واستهلاك الطاقة، وضيق حزمة البيانات، وهناك كميه كبيره من التأخير، وكثرة عدد الهوائيات لدي النظام والكثير من المشاكل.. والتي سوف نتحدث عنها في الفصل الاول.

اما الفصل الثاني فهو يتحدث عن الخلفيه الاساسية والاعمال والبحوث السابقة لأنظمة الجيل الثالث والرابع المتقدم والمزايا المهمه والتقنيه المستخدمة. اما الفصل الثالث فهو يتحدث عن التعاون التقني والمنتقل لدي الجيل الرابع المتقدم بالتفصيل من الخوارزميات والمعادلات الرياضية. اما في الفصل الرابع تمكنا من حل المشاكل السابقه واستخدمت طريقة التعاون بين المتنقلات التي يستخدم فيها تقنية التشفير والي الامام، ولقد استخدم كذلك لغة الماتلاب لدعم وتاكيد النتائج التي حصلنا عليها، اما في الفصل الخامس والاخير فقد قمنا بتوضيح وشرح النتائج بصورة مفصلة والتوصيات المستقبلية.

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## **LIST OF ABBREVIATION**

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 beam forming.
CSI	Channel state information.
DeNB	Donor-evolved Node B.
DL	Downlink.
Enb	ENodeB.
FDD	Frequency Division Duplexing.
Gbps	Giga bit per second.
HARQ	Hybrid Automatic Repeat Request.
HetNet	Heterogeneous Network.
IMT	International Mobile Telecommunications.
ITU-R	International Telecommunication Union Radio Communication Sector.
JP	Joint Processing.
JT	Joint transmission.
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.
Pc	Power control.
QPSK	Quadrature Phase Shift keying.
RN	Relay node.
SC-FDMA	Single Carrier-Frequency Division Multiple Access.
SFN	single-frequency network.
SNR	Signal to Noise Ratio.
SINR	Signal to Interference and Noise Ratio.
TDD	Time Domain Multiplexing.
TP	transmission point.
TPS	Transmission Point Selection.
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

- system capacity and data rate.
- Enhancing the bandwidth utilization and delay performance of the Improving system.
- Adding more cooperative diversity to enhance the reliability.

## 1.3 Proposed Solution

- Enhancing system diversity and capacity by employing cooperative relaying.
- Using DF scheme for cooperative relaying.

## 1.4 Aim and Objective

The aim of this thesis is to study cooperative Techniques and investigate its application in LTE-Advanced network.

The detailed objectives include:

- Improving system capacity.
- Improving system diversity.
- Extend the network coverage.

## 1.5 Methodology

The operation was carried out being the code use MATLAB, by improve the data rate ,bandwidth utilization , spectral efficiency, signal

to interference and noise ,throughput ,delay with the results in the end performing a discussion on the matter.

## 1.6 Thesis Outlines

The rest of the thesis is organized as follows:-

- **Chapter 2.** Literature review: This chapter presents some basic background on LTE, LTE – Advanced and describes the main features and technology.
- **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 provides results.
- **Chapter 5.** Conclusions and Recommendations: explain the result can be achieved and remained future works.

**CHAPTER TWO**  
**LITERATURE REVIEW**

## 2.1 Background

This chapter presents a general description of the most important topics related to this work. Overview of LTE and LTE-Advanced are first described including architecture, feature and technology.

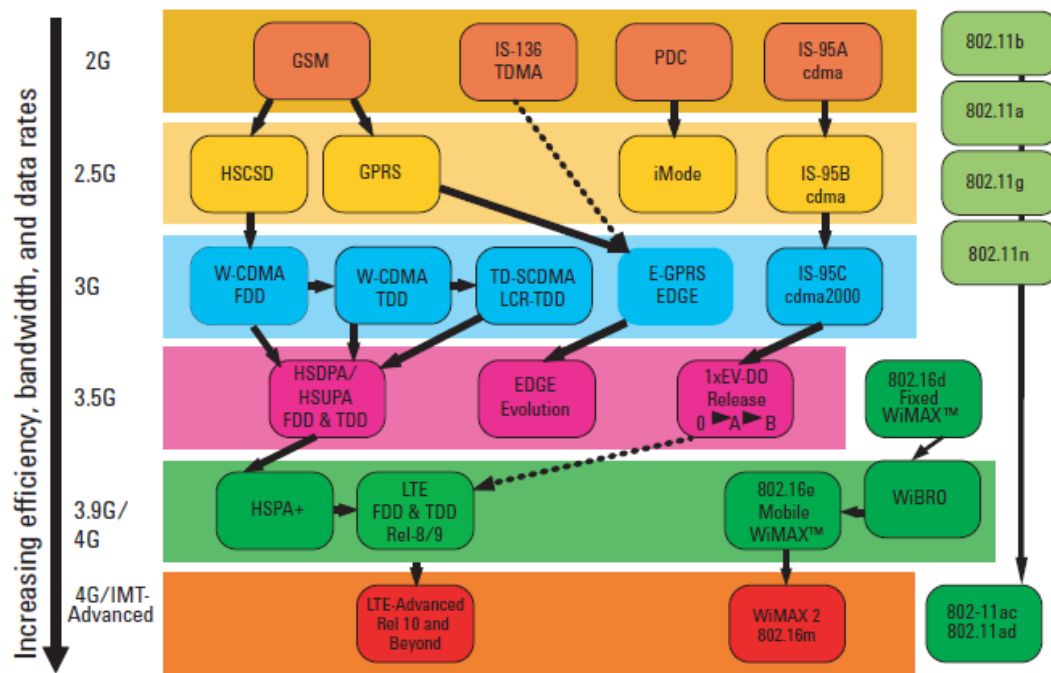
LTE-Advanced (LTE-A) is the project name of the evolved version of LTE that is being developed by 3GPP. LTE-A will meet or exceed the requirements of the International Telecommunication Union (ITU) for the fourth generation (4G) radio communication standard known as IMT-Advanced. LTE-Advanced is being specified initially as part of Release 10 of the 3GPP specifications, with a functional freeze targeted for March 2011. The LTE specifications will continue to be developed in subsequent 3GPP releases. In October 2009, the 3GPP Partners formally submitted LTE-Advanced to the ITU Radio communication sector (ITU-R) as a candidate for 4G IMT-Advanced[1]. Fourth generation wireless technology has been anticipated for quite some time.

To understand the evolutionary changes in 4G and LTE-Advanced, it may be helpful to summarize what came before.

## 2.2 Evolution of wireless standards

Wireless communications have evolved from the so-called second generation (2G) systems of the early 1990s, which first introduced digital cellular technology, through the deployment of third generation

(3G) systems with their higher speed data networks to the much-anticipated fourth generation technology being developed today. This evolution is illustrated in Figure 2.1, which shows that fewer standards are being proposed for 4G than in previous generations, with only two 4G candidates being actively developed today: 3GPP LTE-Advanced and IEEE 802.16m, which is the evolution of the WiMAX standard known as Mobile WiMAX™.



**Figure 2.1:** Wireless evolution 1990-2011 and beyond.

Early 3G systems, of which there were five, did not immediately meet the ITU 2 Mbps peak data rate targets in practical deployment although they did in theory. However, there have been improvements to

the standards since then that have brought deployed systems closer to and now well beyond the original 3G targets.

### 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—are 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 are 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.

### (A)Radio Access Network

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 Node B). eNBs have all necessary functionalities for LTE radio access network including the functions related to radio resource management.

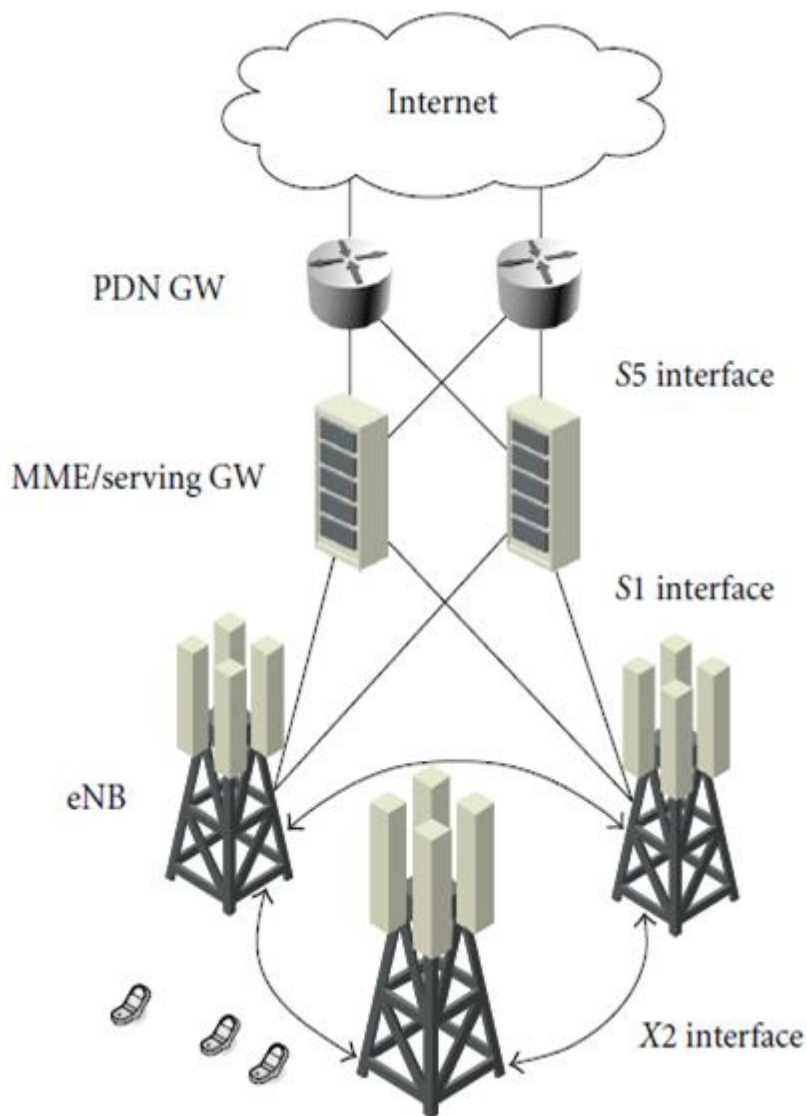
Core Network, The new core network is a radical evolution of the one of third generation systems and it only covers the packet-switched domain. Therefore it has a new name: Evolved Packet Core. Following the same philosophy as for the E-UTRAN, the number of nodes is reduced. EPC divides user data flows into the control and the data planes. A specific node is defined 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 2.2:** 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 that 3GPP 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 (HeNB) 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.

## **2.6LTE 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 ITU Ragenda. 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]

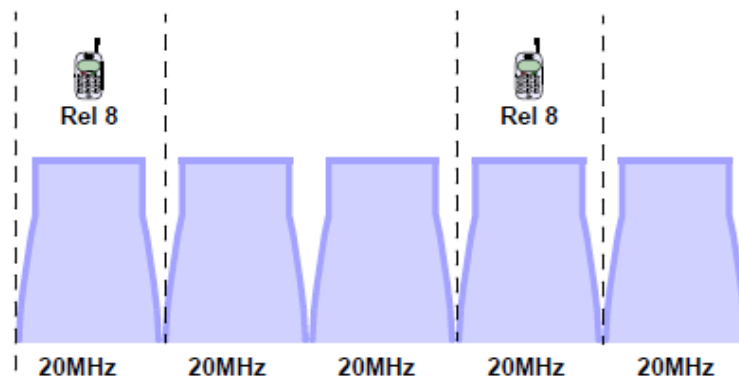
LTE-Advanced enhances the cell edge user throughput (5% user throughput) in order to achieve a homogeneous user experience in cell. It will support the mobility across the cell from 350 km/h to 500 km/h depending on operating frequency band.

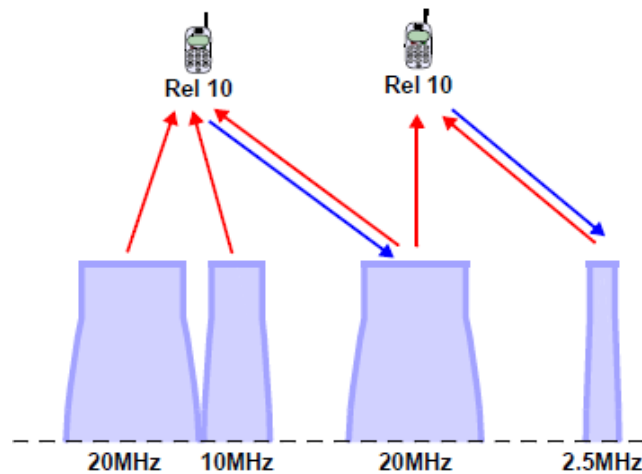
The LTE-A is backward compatible with existing LTE system and support the existing LTE enabled UEs. LTE-Advanced is expected to be bandwidth scalable and support wider bandwidth up to 100 MHz. It should also support the FDD and TDD duplexing for the existing paired and unpaired band, respectively. It enables network sharing and handover with existing legacy radio-access technologies. LTE-Advanced also considers a low cost infrastructure deployments. 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. CA exploits the fragmented spectrum by aggregating non-contiguous component carriers, as shown in figure2.3.[3]



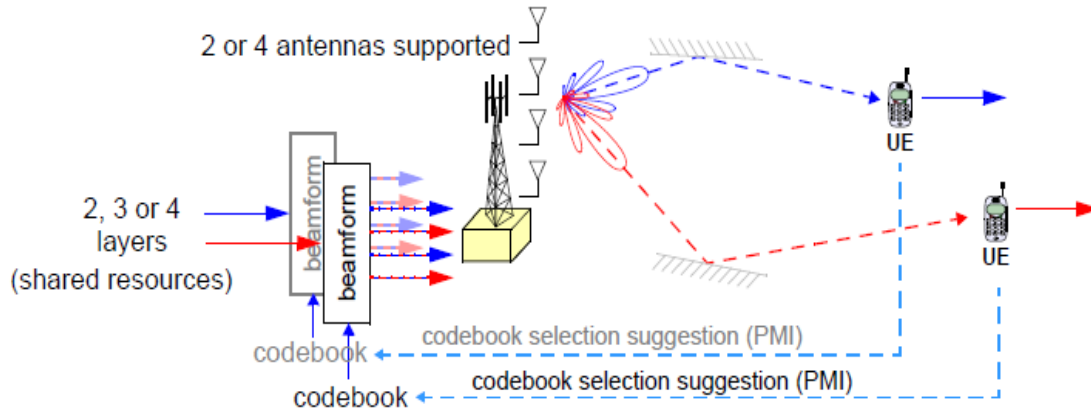


**Figure 2.3:** (A) Intra band carrier aggregation.

(B) Inter band carrier aggregation.

### 2.7.2 Enhanced MIMO

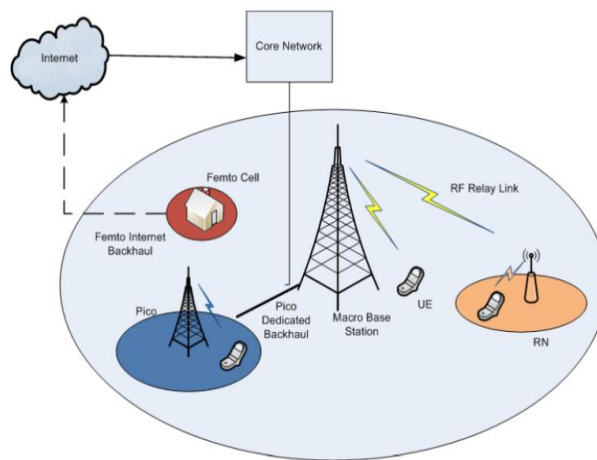
Multiple input multiple output (MIMO) techniques support multiple antennas at the transmitter and at the receiver. The aim [7] of MIMO is to achieve different kinds of gains namely: spatial diversity and spatial multiplexing, spatial multiplexing allows to increase the capacity by transmitting different 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.



**Figure2.4:** Multiple Input Multiple Output(MIMO)

### 2.7.3 Heterogeneous Network (HetNet)

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.

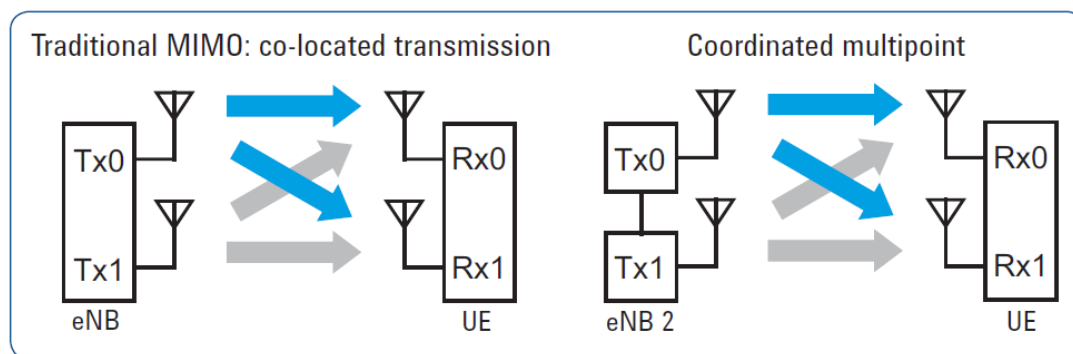


**Figure2.5:** Heterogeneous Network.

### 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 throughput, and system throughput in high load and low load scenarios.

Figure 2.6 compares traditional MIMO downlink spatial multiplexing with coordinated multipoint. The most obvious difference 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 2.6:** Comparison of traditional downlink MIMO and coordinated multipoint.

In the downlink, coordinated multipoint enables coordinated scheduling and beam forming 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 Ues for the purposes of pre coding. 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

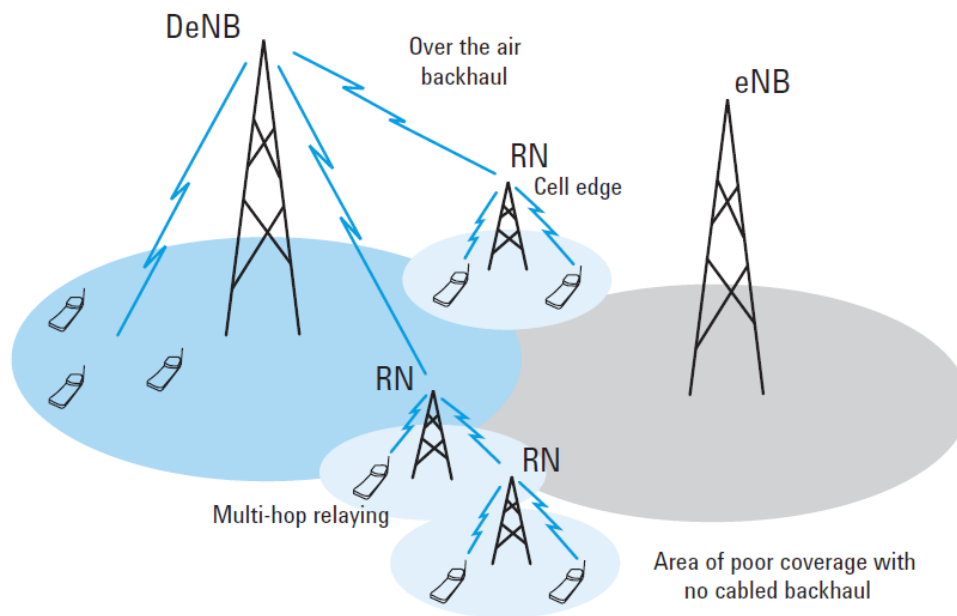
Another method of improving coverage in difficult conditions is the use of relaying[3]. The main use cases for relays are to improve urban or indoor throughput, to add dead zone coverage, or to extend coverage in rural areas.

The concept of relaying is not new[8] but the level of sophistication continues to grow. Figure 2.7 shows a typical scenario. A relay node (RN) is connected wirelessly to the radio access network via a donor cell. In the proposals for Release10, the RN will connect to the donor cell's eNB (DeNB) in one of two ways:

- In-band (in-channel),[9] in which case the DeNB-to-RN link shares the same carrier frequency with RN-to-UE links.
- Out-band, in which case the DeNB-to-RN link does not operate in the same carrier frequency as RN-to-UE links.

The most basic and legacy relay method is the use of a radio repeater, which receives, amplifies and then retransmits the downlink

and uplink signals to overcome areas of poor coverage. In the figure, the repeater could be located at the cell edge or in some other area of poor coverage. Radio repeaters are relatively simple devices operating purely at the RF level. Typically they receive and retransmit an entire frequency band, so they must be sited carefully. In general, repeaters can improve coverage but do not substantially increase capacity.



**Figure2.7:**In-channel relay and backhaul.

More advanced relays at layer 2 can decode transmissions before retransmitting them. Traffic can then be forwarded selectively to and from the UE local to the RN[10], thus minimizing the interference created by legacy relays that forward all traffic. Depending on the level at which the protocol stack is terminated in the RN, such types of relay may require the development of relay-specific standards. This can be

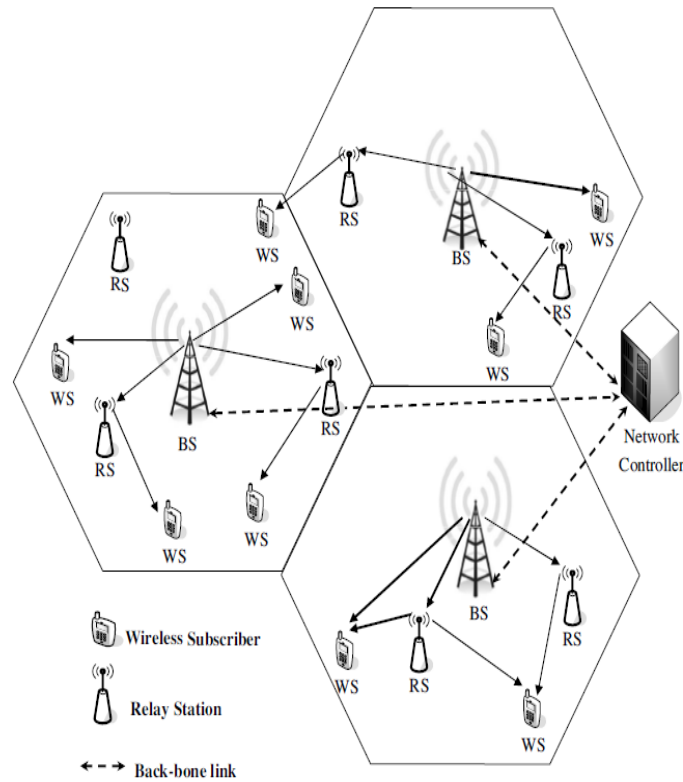
largely avoided by extending the protocol stack of the RN up to Layer 3 to create a wireless router that operates in the same way that a normal eNB operates, using standard air interface protocols and performing its own resource allocation and scheduling.

The concept of the relay station can be applied in low density deployments where a lack of suitable backhaul would otherwise preclude use of a cellular network. The use of in-band or in-channel backhaul can be optimized using narrow, point-to-point connections to avoid creating unnecessary interference in the rest of the network. Multi-hop relaying is also possible, as Figure 12 shows. In this case a signal is sent from the DeNB to the first RN and then on to the next RN and finally down to the UE. The uplink signal coming back from the UE gets transmitted up through the RNs and back to the DeNB. This technique is possible to do in-channel in an OFDMA system because the channel can be split into UE and backhaul traffic. The link budget between the DeNB and the RN can be engineered to be good enough to allow the use of some of the sub frames for backhaul of the relay traffic. These sub frames are the ones which otherwise could have been allocated for use with multimedia broadcast in a single frequency network (MBSFN).

In Release 10 progress is being made on the RAN aspects of relaying but it is likely that the network security aspects will be delayed until Release

11. This delay may not affect RAN standardization but may impact deployment.

Relays were initially thought as coverage extension devices mainly. With the data traffic increase operators are facing in their networks, a solution to improve the bitrates in specific area is the densification of the transmitted power per surface unit. However increasing the number of base stations is costly and operators have probably reached a density limit which is difficult to overcome. People do not welcome the idea of having antennas installed on rooftops. In addition, densification is a very expensive operation mainly due to the site acquisition, as shown in Figure 2.8. Relays can be mounted outdoor, on e.g. walls and lamp posts, thus cutting the site cost. This situation prompted the study of relays, viewed as capacity improvement devices, at a reduced cost. Whether the backhaul link of relays would be in-band or out-of-band was a first question. Out-of-band relays are not considered in 3GPP, and are anyway less complex than in-band relays.



**Figure2.8:** multicellular relay networks.

## 2.8Related Works

In[11] the standardization of LTE Advanced, which is an enhanced version of LTE, is currently in progress at the 3GPP, LTE Advanced will maintain backward compatibility with LTE, while realizing considerable higher spectral efficiency and cell\_ edge user throughput than the LTE, Extensions the MIMO technology as well as CoMP technology are being studied for LTE Advanced to accomplish these goals.

In 3GPP has completed a study on coordinated multipoint transmission and reception techniques to facilitate cooperative communications across multiple transmission and reception points (e.g., cells) for the LTE-Advanced system. In CoMP operation, multiple points coordinate with each other in such a way that the transmission signals from/to other points do not incur serious interference or even can be exploited as a meaningful signal. The goal of the study is to evaluate the potential performance benefits of CoMP techniques and the implementation aspects including the complexity of the standards support for CoMP. This article discusses some of the deployment scenarios in which CoMP techniques will likely be most beneficial and provides an overview of CoMP schemes that might be supported in LTE-Advanced given the modern silicon/DSP technologies and backhaul designs available today. In addition, practical implementation and operational challenges are discussed. We also assess the performance benefits of CoMP in these deployment scenarios with traffic varying from low to high load.

In [12] Relaying is standardized in 3rd Generation Partnership Project (3GPP) Long-Term Evolution (LTE)-Advanced Release 10 as a promising cost-efficient enhancement to existing radio access networks. Relay deployments promise to alleviate the limitations of conventional

macro cell-only networks such as poor indoor penetration and coverage holes. However, to fully exploit the benefits of relaying, power control (PC) in the uplink should be readdressed. In this context, PC optimization should jointly be performed on all links, i.e., on the donor-evolved Node B (DeNB)-relay node (RN), the DeNB-user equipment (UE) link, and the RN-UE link. This ensures proper management of interference in the network besides attaining a receiver dynamic range which ensures the orthogonality of the single-carrier frequency-division multiple access (SC-FDMA) system. In this article, we propose an automated PC optimization scheme which jointly tunes PC parameters in relay deployments. The automated PC optimization can be based on either Taguchi's method or a meta-heuristic

optimization technique such as simulated annealing. To attain a more homogeneous user experience, the automated PC optimization scheme applies novel performance metrics which can be adapted according to the operator's requirements. Moreover, the performance of the proposed scheme is compared with a reference study that assumes a scenario-specific manual learn-by-experience optimization. The evaluation of the optimization methods within the LTE-Advanced uplink framework is carried out in 3GPP-defined urban and suburban propagation scenarios by applying the standardized LTE Release 8 PC scheme. Comprehensive results show that the proposed automated PC optimization can provide similar performance compared to the reference

manual optimization without requiring direct human intervention during the optimization process.

Furthermore, various trade-offs can easily be achieved; thanks to the new performance metrics.

In[13] 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 article, 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. Specifically, we investigate two intra-cell coordinated multi-point schemes in LTE-advanced systems, and evaluate the performance of the schemes. It is shown that cooperative relaying leads to both network coverage extension and capacity expansion in LTE advanced systems. Cooperative communications can significantly improve the system spectrum efficiency and performance.

In [14] Coordinated Multi-Point Transmission (CoMP) was presented in LTE-Advanced standard to enhance the LTE performance and reduce the effect of inter cell interference. In the downlink, there are two CoMP techniques used; one of these techniques is the Joint Processing (JP) technique. In this paper, a modified-JP technique is proposed. In the conventional JP, the second best base station (BS) is used to enhance the quality of the user signal while in the modified-JP, the second best BS is used so that the users are prevented from service blocking. Extensive simulations are conducted to illustrate the benefits achieved by applying the modified-JP techniques compared to the conventional JP one.

**CHAPTER THREE**  
**COOPERATIVE TECHNIQUES**

### 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

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

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

##### I. 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

$$PL(d) = 10v \log \left( \frac{d}{d_0} \right) + c \quad (3.2)$$

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  $d_0$  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.

## II. 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

$$PL(d) = 10v \log \left( \frac{d}{d_0} \right) + \chi + c \quad (3.3)$$

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  $\sigma_x^2$  (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 reflectors, scatterers, 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, scatterers, 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  $T_c$  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 drops below a certain predetermined threshold. The coherence time is also related to the channel maximum Doppler spread  $f_{d,max}$  by [2]

$$T_c \approx \frac{9}{16\pi f_{d,max}} \quad (3.4)$$

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],

$$f_{d,max} = \frac{v}{\lambda} \quad (3.5)$$

Where  $v$  and  $\lambda$  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  $T_s$  is smaller than the channel's coherence time  $T_c$ ; 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  $f_c$  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  $t_{max}$  by

$$f_c \approx \frac{1}{\tau_{max}} \quad (3.6)$$

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.

### 3.2 Diversity in Wireless Channels

As we have explained, wireless fading channels present the challenge of being changing over time. In communication systems designed around a signal path between transmitter and receiver, a crippling fade on this path is a likely event that needs to be addressed with such techniques as increasing the error correcting capability of the channel coding block, reducing the transmission rate, using more elaborate detectors, etc.

Nevertheless, these solutions may still fall short for many practical channel realizations. Viewing the problem of communication through a fading channel with

a different perspective, the overall reliability of the link can be significantly improved by providing more than one signal path between transmitter and receiver, each exhibiting a fading process as much independent from the others as possible. In this way, the chance that there is at least one sufficiently strong path is improved. Those techniques that aim at providing multiple, ideally independent, signal paths are collectively known as diversity techniques. The concept of diversity means receiving redundantly the same information-bearing signal over two or more fading channels, then combining these multiple replicas at the receiver in order to increase the overall received signal-to-noise ratio. The intuition behind this concept is to exploit the low probability of concurrence of deep fades in all the diversity channels to lower the probability of error and of outage. These multiple replicas can be obtained by extracting the signals via different radio paths...

- in time by using multiple time slots separated by at least the coherence time of the channel,
- in frequency by using multiple-frequency channels separated by at least the coherence bandwidth of the channel, and/or,
- in space by using multiple-receiver antennas.

In its simplest form, the multiple paths may carry multiple distorted copies of the original message. Nevertheless, better performance may be achieved by applying some kind of coding across the signals sent over the multiple paths and by combining in a constructive way the signals received through the multiple paths. Also important is the processing performed at the receiver, where the signals arriving through the multiple paths are constructively combined. The goal of combining is to process the multiple received signals so as to obtain a resulting signal of better quality or with better probability of successful reception than each of the received ones.

For any diversity technique, the performance improvement is manifested by the communication error probability decreasing at a much larger rate at a high channel signal-to-noise ratio than systems with less or no diversity. When using log–log scales, this rate of decrease in the communication error probability becomes the slope of the line representing the communication error probability at high signal-to-noise ratio and is known as the diversity gain. This definition establishes an implicit behavior at high signal-to-noise ratio for the probability of symbol error as being a linear function of the signal-to-noise ratio when seen in a plot with log–log scales. Then it can be seen that, as previously stated, in these conditions the diversity gain is the slope of the linear relation. It is better to have as large a diversity gain as possible, since it means that the probability of symbol error is reduced at a faster rate. Also, it is important to note that, depending on the particular diversity scheme and the system setup, other measures of probability of error can be used. For example, the outage probability is used in some cases, instead of the probability of symbol error.

### 3.2.1 Temporal Diversity

It is quite common to find communication scenarios where the channel coherence time equals or exceeds several symbol transmission periods. This implies that two symbols transmitted with a separation in time longer than the coherence time will experience channel realizations that are highly uncorrelated and can be used to obtain diversity. The simplest way to achieve this is to form the two symbols by using a repetition coding scheme.

### 3.2.2 Frequency Diversity

Analogous to time diversity, in wideband systems where the available bandwidth exceeds the channel coherence bandwidth, it is possible to realize diversity by using channels that are a partition of the available bandwidth and that are separated by more than the channel coherence bandwidth.

Realizing frequency diversity as a partition of the whole system bandwidth into channels with smaller bandwidth and independent frequency response is perhaps the most intuitively natural approach. This approach is applicable in multicarrier systems, where transmission is implemented by dividing the wideband channel into non-overlapping narrowband sub-channels. The symbol used for transmission in each sub-channel has a transmission period long enough for the sub-channel to appear as a flat fading channel. Different sub-channels are used together to achieve frequency diversity by ensuring that each is separated in the frequency domain from the rest of the sub-channels in the transmission by more than the coherence bandwidth. In this way, the fading processes among the sub-channels show small cross-correlation. Examples of these systems are those using orthogonal frequency division multiplexing (OFDM). Frequency diversity can also be achieved through processing based on a time domain phenomenon.

### 3.2.3 Spatial Diversity and MIMO Systems

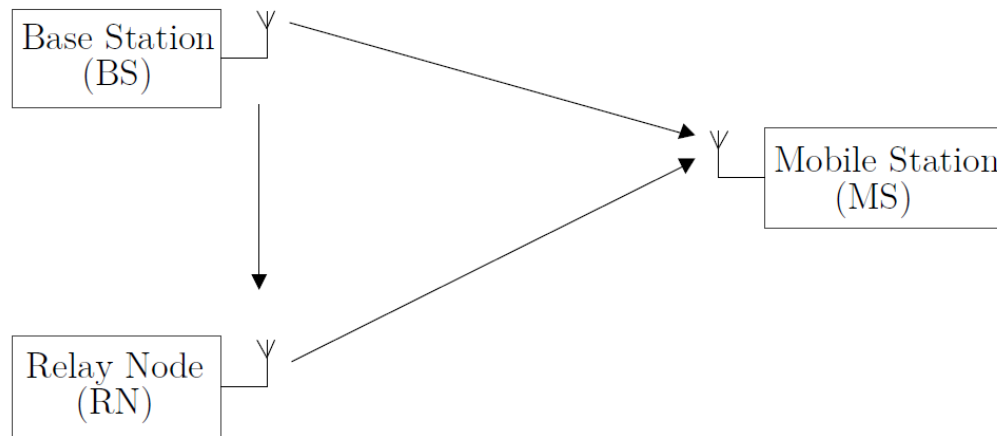
By using multiple transmit antennas and multiple receive antennas, we may exploit diversity in the spatial domain which is called spatial diversity. Systems utilizes spatial diversity are often referred as multiple-input multiple-output (MIMO) systems. Spatial diversity or MIMO improves the performance of communication systems. Signal will not suffer the same level of attenuation as it propagates along different paths. Spatial diversity can be efficiently exploited when the antenna

array configuration at receive and transmit sides is properly performed to the propagation environment characteristic. This could be achieved if multiple branches which are combined are ideally uncorrelated in order to reduce probability for deep fades in fading channels.

### 3.3 Cooperation Diversity

The continually increasing number of users and the rise of resource-demanding services require a higher link data rate than the one that can be achieved in current wireless networks [5]. Wireless cellular networks, in particular, have to be designed and deployed with unavoidable constraints on the limited radio resources such as bandwidth and transmit power [6]. As the number of new users increases, finding a solution to meet the rising demand for high data rate services with the available resources has become a challenging research problem. The primary objective of such research is to find solutions that can improve the capacity and utilization of the radio resources available to the service providers [7]. While in additional infrastructure networks the upper limit of the transmitter – receiver link's data capacity is determined by the Shannon capacity [8], advances in radio transceiver techniques such as MIMO architectures and cooperative or relay assisted communications have led to an enhancement in the capacity of contemporary systems.

In the MIMO technique diversity relies on uncorrelated channels, and is achieved by employing multiple antennas at the receiver side, the transmitter side, or both, and by sufficiently separating the multiple antennas. The MIMO technique can be used to increase the robustness of a link as well as the link's throughput. Unfortunately, the implementation of multiple antennas in most modern mobile devices may be challenging due to their small sizes [7].



**Figure 3.1:** Illustration of cooperative diversity.

Cooperative diversity or relay-assisted communication has been proposed as an alternative solution where several distributed terminals cooperate to transmit/receive their intended signals. In this scheme, Figure 3.1, the base station (BS) wishes to transmit a message to the mobile station (MS), but obstacles degrade the BS-MS link quality. The message is also received by the relay terminals, which can retransmit it to the MS, if needed. The mobile station may combine the transmissions received by the base station and relays in order to decode the message.

The limited power and bandwidth resources of the cellular networks and the multipath fading nature of the wireless channels have also made the idea of cooperation particularly attractive for wireless cellular networks. Moreover, the

desired ubiquitous coverage demands that the service reaches the users in the most unfavorable channel conditions (e.g., cell-edge users) by efficient distribution of the high data rate across the network [9]. In conventional cellular architectures (without relay assistance) increasing capacity along with coverage extension dictates dense deployment of base stations which turns out to be a cost-wise inefficient solution for service providers [10]. A relay node (RN), which has less cost and functionality than the base station, is able to extend the high data rate coverage to remote areas in the cell under power and spectral constraints.

By allowing different nodes to cooperate and relay each other's messages to mobile stations, cooperative communication also improves the transmission quality [11]. This architecture exhibits some properties of MIMO systems; in fact a virtual antenna array is formed by distributed wireless nodes each with one antenna. Since channel impairments are assumed to be statistically independent, in contrast to conventional MIMO systems, the relay-assisted transmission is able to combat these impairments caused by shadowing and path loss in BS-MS and RN-MS links. To this end, an innovative system has been proposed in which the communication between transmitter and receiver is done in multiple hops through a group of relay nodes. This cooperative MIMO relaying scheme creates a virtual antenna array by using the antennas of a group of relay nodes. These relay nodes transmit the signal received from the base station cooperatively on a different channel to the mobile station.

### 3.3.1 Cooperative Relaying Protocols

The performance of relay transmissions is greatly affected by the rules or conventions, called cooperative relaying protocols, which control the exchange of information between terminals on the network [12]. Many cooperative relaying

protocols have been proposed to establish a two-hop communication between a base station and a mobile station through a relay.

#### **I. Amplify-and-Forward (AF)**

In this relay-assisted protocol, the relay amplifies the received signal from the base station and retransmits it to the mobile station without doing any decoding. For this reason, it is also called non-regenerative relaying. The main drawback of this strategy is that the relay terminal amplifies the received noise at the same time. Applying this strategy to cooperative communication leads to a lower bit error rate (BER) than direct transmission. The outage probability of the cooperative communication derived in [13], demonstrates that a diversity order of 2 is obtained for two cooperative users.

#### **II. Decode-and-Forward (DF)**

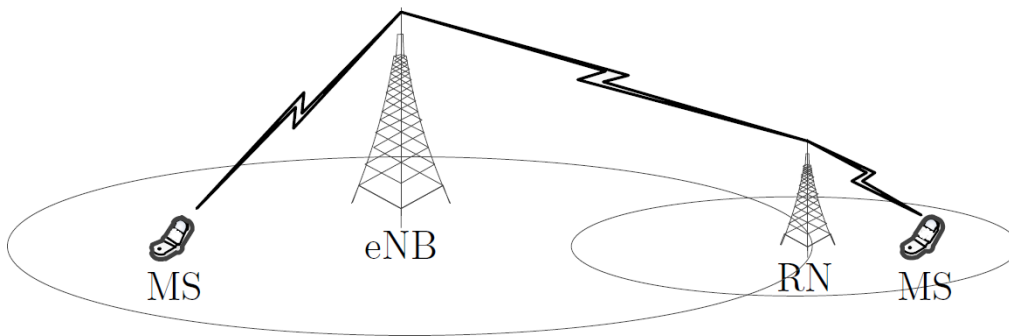
In this relaying protocol, relay terminal has to decode the message received from the base station. Therefore, the total performance depends on the success of this message decoding [13]. Depending on the type of symbols retransmitted, the strategy at the relay is repetition coding (RC) or unconstrained coding (UC). In RC, the relay retransmits the same symbols previously estimated, while in UC the symbols transmitted are not the same as the received ones, but are related to the same information sent by the source. Hence, this protocol is also called regenerative relaying. The DF can effectively avoid error propagation through the relay, but the processing delay is quite long.

### 3.4 Relay Technologies in LTE-A Cellular Systems

When introducing LTE-A systems, 3GPP considered relay technologies in the standardization process . The relay transmission can be achieved by forwarding information from a local evolved-base station (eNB) to a neighboring mobile station using a relay node. In doing this, an RN can effectively extend the signal and service coverage of an eNB and enhance the overall throughput performance of a wireless communication system [11]. Figure 3.2 shows an example of deploying a relay node in a cellular LTE-A system. The figure shows that the relay nodes can be placed at the cell-edge to increase the transmission range of the cell.

#### 3.4.1 Relays classifications

A variety of different classifications have been used to categorize relay nodes in the LTE-A standard. In[14] one category, relays may be distinguished based on the functionality as ...

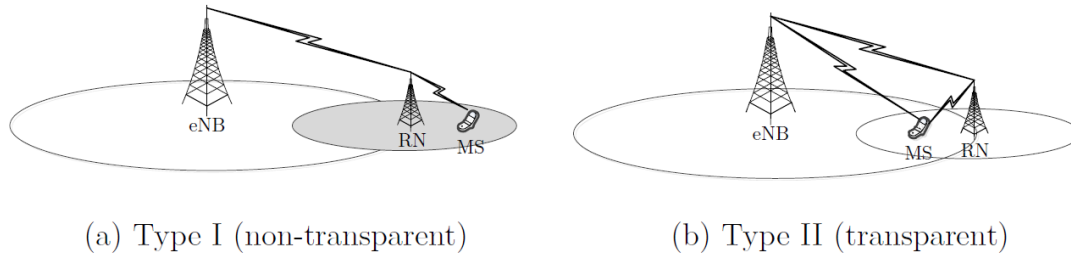


**Figure 3.2:** Relaying in LTE-A systems.

- **A repeater:** This type of relays is the simplest in terms of implementation and functionality. The relay simply receives the signals from the base station, amplifies it and then forwards it to the mobile station.
- **A decoder/encoder:** This relay is able to decode the received signals and recode the transmit signals in order to achieve higher RN-MS link quality. The advantage of achieving higher link quality comes at the expense of higher cost and complexity of the relay and also adds delay to the communication link.
- **A base station:** This type of relay has the functionality of a base station like mobility management, session set-up, and handover. Such functionality adds more complexity to the implementation of this relay and the delay budget is further increased.
- 

A different classification is used in 3GPP standardization where two types of relays have been defined in 3GPP LTE-A standard, Type I and Type II in, or non-transparency and transparency in [15].

- **Type I (or non-transparent):** This relay type can help a remote mobile station unit, which is located far away from a base station, to access the base station. So a Type I relay needs to transmit the common reference signal and the control information for the base station, and its main objective is to extend signal and service coverage, as shown in Figure 3.3 (a). Type I relays can mainly make some contributions to the overall system capacity by enabling communication services and data transmissions for remote mobile station units.



**Figure 3.3:** Relay types.

- **Type II (or transparent):** the relays can help a local mobile station unit, which is located within or outside the coverage of a base station and has a direct communication link with the base station, to improve its service quality and link capacity, as shown in Figure 3.3 (b). So a Type II relay does not transmit the common reference signal or the control information, and its main objective is to increase the overall system capacity by achieving diversity and transmission gains for local mobile station units.

### 3.5 Relay Terminals in Cellular Systems

Relay technology is considered in cellular networks to assist base stations for coverage extension and throughput enhancement. The information theoretical properties of the relay channel have already been studied in the 1970s by Cover[16]. However the integration of relays into a cellular system has only gained attention around the year 2000 for example in [17] when the concepts of Single-hop Cellular Network (SCN) and Multi hop Cellular Network (MCN) were introduced. In SCN, base and mobile stations in the same cell are always mutually reachable in a single hop. When having data to send, mobile stations always send them to the base within the same cell. If the destination and the sources are in the

same cell, the base directly forwards packets to the destination. On the other hand, the architecture of MCN resembles that of SCN except that bases and mobile stations are not always mutually reachable in a single hop. Similar to ad-hoc network, a key feature of MCN is that mobile stations can directly communicate with each other if they are mutually reachable. This feature leads to multi hop routing.

### 3.6 Coordinated Multipoint Transmission and Reception

Conventionally[18], a set of geographically collocated antennas that correspond to a particular sectorization are configured as a cell. A UE terminal is connected to a single cell at a given time based on associated maximum received signal power. This cell then becomes its serving cell. Given the new definitions of CoMP scenarios as introduced earlier, the antennas configured as a cell may not be geographically collocated. The term transmission point (TP) can then be used to refer to a set of collocated antennas, and a cell can correspond to one or more of such TPs. Note that a single geographical site location may contain multiple TPs in case of sectorization, with one TP corresponding to one sector. CoMP techniques can also be defined in a more straightforward manner as the coordination between TPs. CoMP studies performed in 3GPP generally categorized three different types of CoMP techniques depending on the required constraints on the backhaul link between coordinated points and the level of scheduling complexity. These types of CoMP techniques can be broadly classified into coordinated scheduling and coordinated beam forming (CS/CB), joint transmission (JT), and TP selection (TPS) as shown in figure 3.4

**I. Coordinated scheduling and coordinated beam forming (CS/CB)**

CS/CB can be characterized by multiple coordinated TPs sharing only channel state information (CSI) for multiple UE terminals, while data packets that need to be conveyed to a UE terminal are available only at one TP as shown in figure 3.4 (a).

CS/CB reduces the interference level experienced by [18] a UE terminal by appropriately selecting the beam forming weights of interfering points to steer the interference toward the null space of the interfered UE as represented by the dotted red arrow and coordinated beam forming and scheduling is done between cells to reduce the interference caused to other cells.

**II. Joint Transmission (JT)**

JT [19] can be characterized by the same data transmission from multiple coordinated TPs with appropriate beam forming weights. JT can be regarded as a special form of JT, where transmission of beam formed data for a given UE terminal is performed at a single TP at each time instance, while the data is available at multiple coordinated TPs.

JT allows one or more neighboring points to transmit the desired signal rather than interference signals from the point of view of the selected UE.

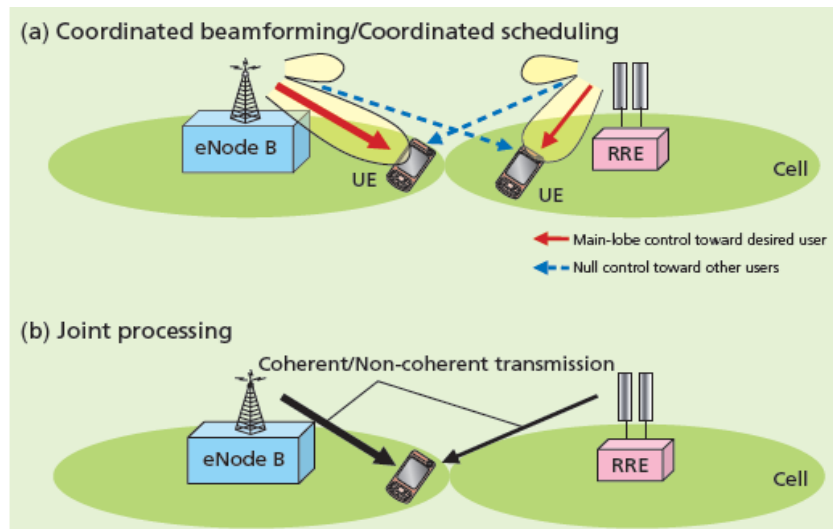
Joint transmission by multiple cells to given UE, in which they transmit at the same time using the same time and frequency radio resource, and dynamic cell selection, in which cells can be selected at any time in consideration of interference, are being studied as shown in figure 3.1(b). For joint transmission, two methods are being studied:

- **Non-coherent transmission**

Non-coherent JT may use techniques like single-frequency network (SFN) or cyclic delay diversity (CDD) schemes, which target diversity gains and also enable increased transmit power to the UE.

- **Coherent transmission**

Coherent transmission could be based on spatial CSI feedback relative to two or more TPs, which can be used to perform MIMO transmissions from the corresponding antennas.



**Figure 3.4:** CoMP Transmission.

### III. Transmission Point Selection (TPS)

In [18] LTE-Advanced, transmission point selection (TPS) is investigated by extending to an orthogonal frequency-division multiplexing (OFDM) system the idea of site selection diversity transmission power control proposed for high speed HSDPA. With TP selection, the signal to a given UE is transmitted from a single

transmission point within the CoMP cooperating set on a certain time-frequency resource. The UE basically reports the index of its preferred TP (e.g. the TP with the highest received SINR) and corresponding CSI, which is subsequently used for transmission. The selected TP may dynamically change from one sub frame, which is the minimum signal transmit time unit equivalent to 1ms, to another sub frame via time-frequency domain dynamic scheduling. In addition, if the neighboring TPs remain silent by not transmitting any data, the received SINR of the UE can be further improved.

### 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

$$R = BW r \log_2(M) \quad (3.7)$$

Where BW is the bandwidth for N users, M is the modulation order which is always  $2^n$ , 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 a 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 of data 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

$$SE = r \log_2(M) \quad (3.8)$$

### 3.7.4 Bandwidth Utilization

The Bandwidth utilization is calculated as

$$BU = \frac{\sum_{i=1}^N BW_i}{BW} \quad (3.9)$$

Where  $BW_i$  is the bandwidth allocated for the  $i^{\text{th}}$  user.

### 3.7.5 Transmission Delay

The transmission delay is calculated as

$$d = \frac{\text{Number of bits}}{R} \quad (3.10) \text{Type equation here.}$$

**CHAPTER FOUR**  
**RESULTS AND DISCUSSION**

### 4.1 Introduction

In this chapter, the main results that give support to the concepts explained along this thesis are presented and analyzed. This results is conducted by simulated a simple LTE-advanced link using MATLAB to study the DF 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 .

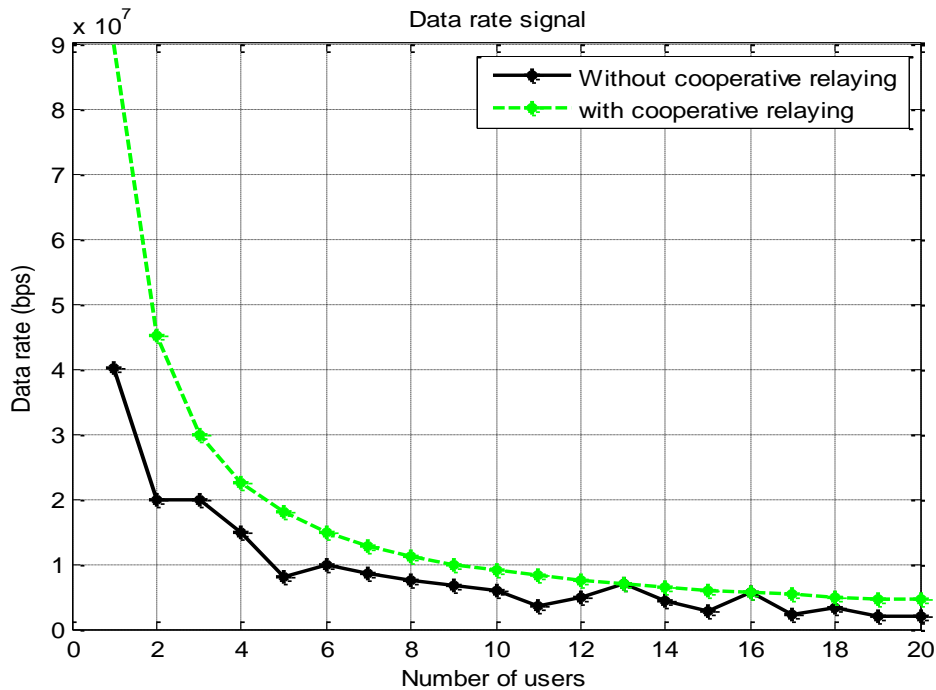
Parameter	Value
Carrier frequency	1.5 GHz
Bandwidth	20 MHz
Number of Relay nodes	0, 1
Tx power	16 dB
Distance between Tx and Rx	300 – 3000 m
Shadowing	8 – 9 dB
Interference	1 – 3 dB
Noise Figure	7 dB
Number of bits	50000
Penetration Loss	20 dB
Tx, Rx antenna height	3, 100 m
Tx, Rx antenna gain	0, 14 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, so we solved this problem by using relaying which it cannot influenced by number of users state, 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.

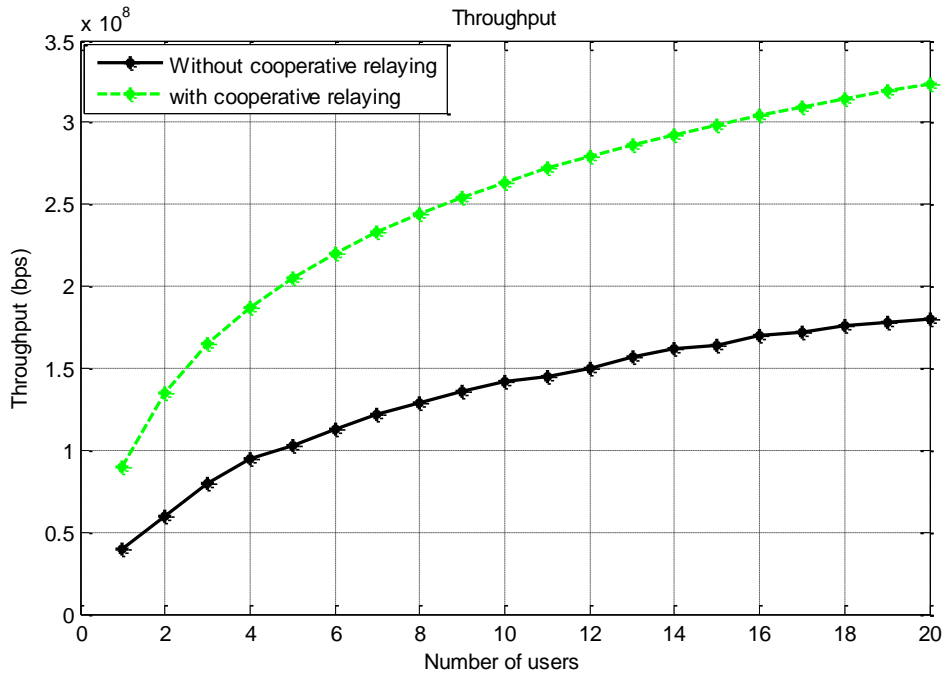


**Figure 4.1:** Data rate performance compression of the link with cooperative relaying and without cooperative relaying.

### 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.

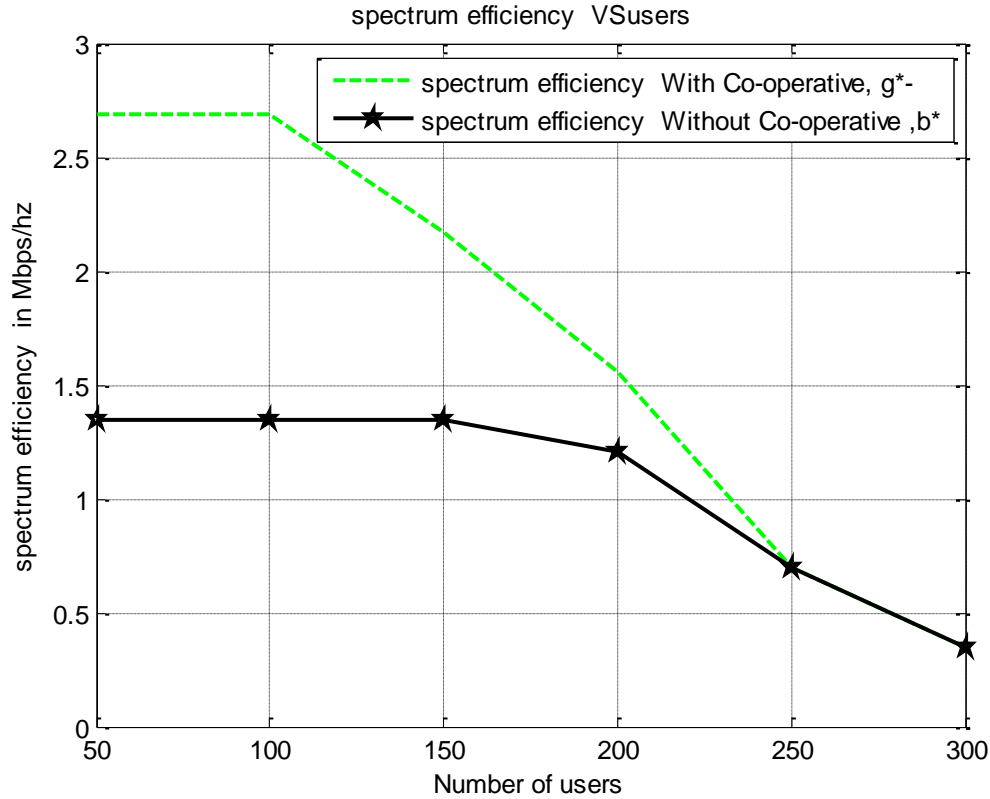


**Figure 4.2:** Throughput performance comparison of the link with cooperative relaying and without cooperative relaying with increasing in number of users..

### 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

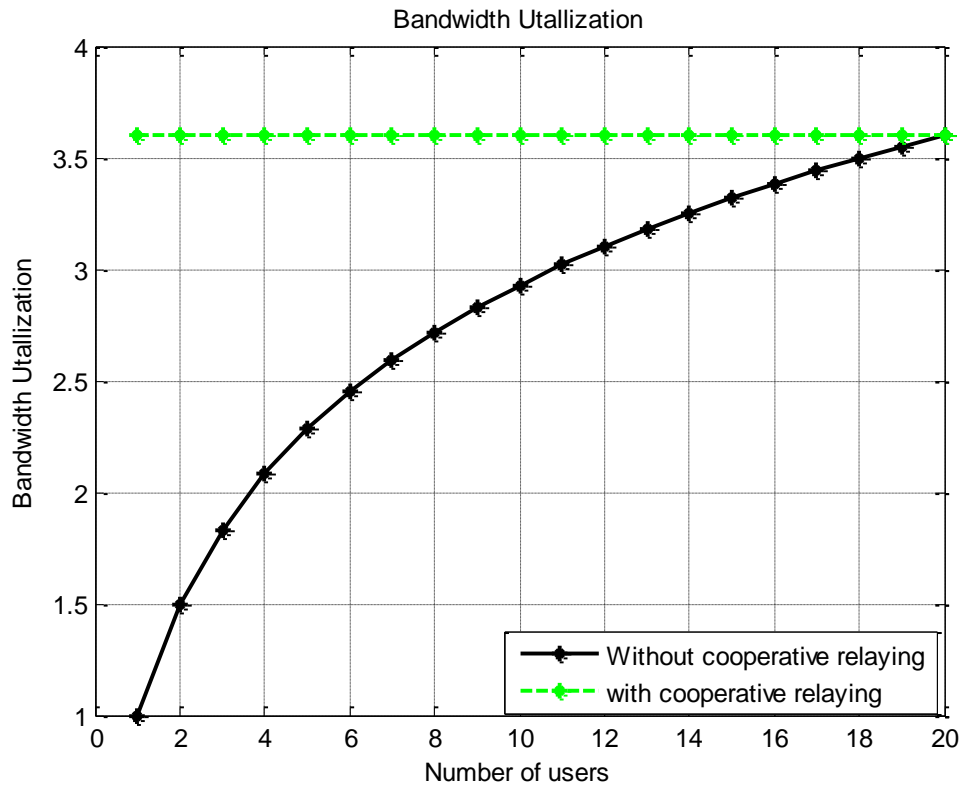
efficiency and the number of users, and it's clear that the spectral efficiency of the system is higher in case of relaying with DF scheme than exact same system without cooperation.



**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

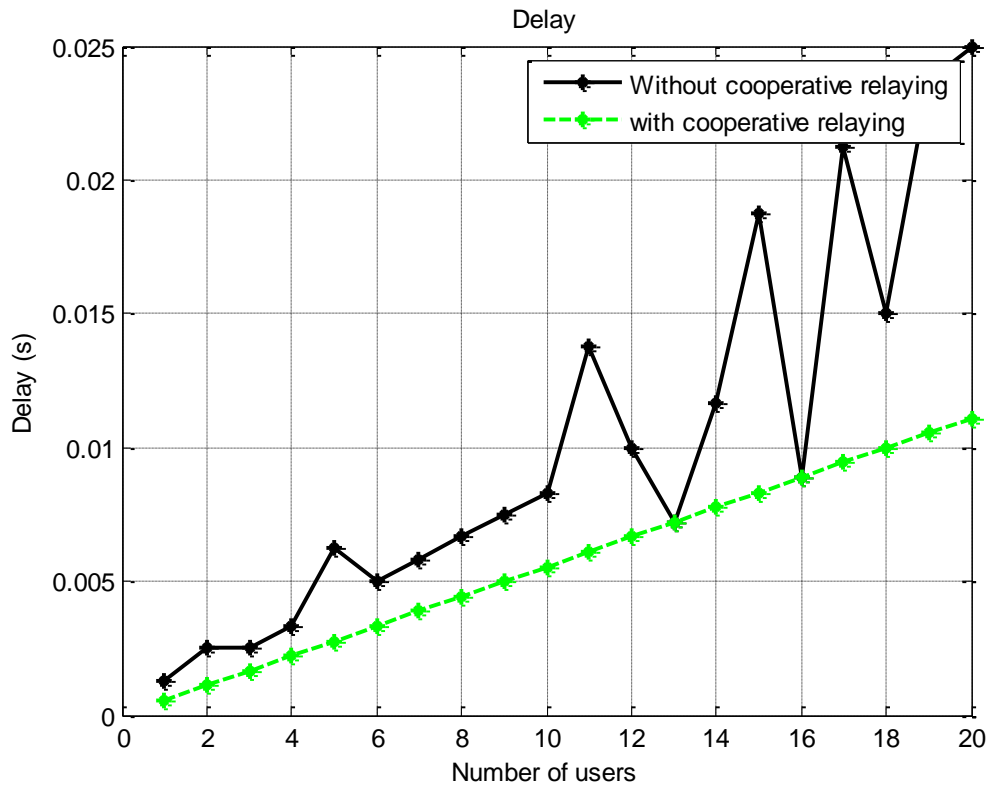
Figure 4.4 shows the performance of the relaying scheme compared to direct (non-cooperative) link using bandwidth utilization, as compared to non-cooperative scheme, the bandwidth utilization of the cooperative scheme is improved.



**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

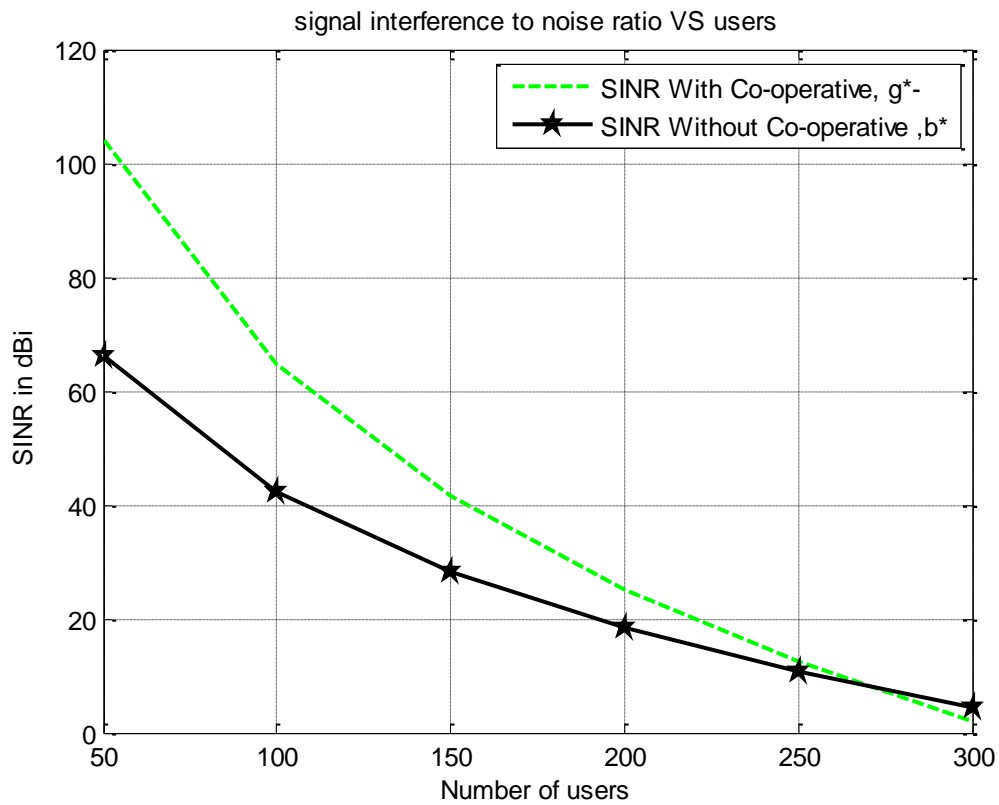
In Figure 4.5 the performance of the simulated cooperative scheme is shown, we donate that the delay performance is also improved as the delay in case cooperative relaying is lower and it increases with the number of users.



**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 performance of DF scheme as the most used cooperative relaying protocol in relation to the conventional systems without cooperation.

In the simulation the system performance was compared for cooperative DF and non cooperative system with same parameters for the 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 the time frame of this research, many important issues have not been dealt with, or e 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 Het Net deployment, to provide more diversity and make the simulation more realistic.
- Comparing the performance of in-band and out-band relaying.

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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;
```

## APPENDICES

---

```
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
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);
```

$$BU(n) = (\text{sum}(BW)) / (BW_t);$$

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
```