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Sudan University of Science and Technology

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Performance Evaluation of Pico-cell Range Expansion with Interference Mitigation using Smart Antenna

تقييم اداء توسيع النطاق للخلايا الصغيرة جداً مع تخفيف التداخل باستخدام الهوائي الذكي

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of M.Sc.in Electronic Engineering (Communications Engineering)

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استهلال

" على هذه الأرض ما يستحق الحياة "

محمود درويش

DEDICATION

To everybody that without whom none of my success would be possible.

ACKNOWLEDGMENT

I would like to express my thanks to my supervisor

***Dr. Fath Elrahman Ismael Khalifa** and I am gratefully indebted to him for his very valuable comments on this thesis.*

*My very profound gratitude goes to my **family**, **friends** and **you**.*

Finally, sincere thanks to GOD for absolutely every things.

Abstract

In Long Term Evolution-Advanced heterogeneous networks, pico-eNBs are added to existing macro cells networks that contain macro eNBs in order to offload traffic from macro layer and bring users closer to the picoeNBs to enhance the cell edge user experience. Moreover, Cell Range Expansion (CRE) is a way to increase the percentage of users that associate to pico BSs which leads to reduce the imbalance traffic load between cells .However, there is strong interference which is caused by macro-eNB to pico cell edge users due to its higher transmission power. Hence, inter-cell interference is the biggest challenge in LTE-A HetNets. In order to further reduce the macro interference while using the CRE approach, the smart antenna is combined with CRE to improve system performance using features of both techniques. The simulation results using Matlab show that system performance could be enhanced when smart antenna is used. This enhancement could be presented by significant improvement on SINR by 24% which leads to 3.41% higher capacity with slight reduction on number of outage users that makes more than 50% improvement on throughput that give rise of 57% enhancement on spectral efficiency.

المستخلص

في شبكات التطور بعيد الامد للجيل الثالث وغير المتجانسة ، تُضاف الخلايا الصغيرة جداً الي شبكة مكونة من خلايا كبيرةاساسية بغرض تفريغ وتقليل حجم الحركة من الخلايا الكبيرة الي الخلايا الصغيرة جداً وجذب المستخدمين لمسافة اقرب للخلية الخادمة الجديدة ، مما يزيد في تحسين تجربة المستخدم الموجودين على حافة الخلية الصغيرا جداً. من ناحية اخرى، فإن توسع نطاق الخلية الصغيرة جداً هو وسيلة لزيادة نسبة المستخدمين المنتسبين إليها ،الأمر الذي يؤدي إلى تقليل الازدحام و حجم الحركة في الخلية الكبيرة الاساسية وتقليل عدم التوازن في عدد المستخدمين بين الخلايا. ومع ذلك، هناك تداخل قوي من الخلية الكبيرة الاساسية الي الخلية الصغيرة جداً و ذلك بسبب طاقة الإرسال العالية للخلية الكبيرة مقارنة مع طاقة الخلية الصغيرة جداً المنخفضة مما يؤثر على المستخدمين الموجودين على حافة الخلية الصغيرة جداً. وبالتالي، فأن التداخل بين الخلايا يعتبر هو التحدي الأكبر فيالشبكات التطور بعيد الامد وغير المتجانسة .ولتقليل التداخل بين الخلايا ، تم استخدام الهوائي الذكي في حالة تطبيق توسع نطاق الخلية الصغيرة جداً، لتحسين أداء النظام باستخدامتقنية تكوين الشعاع . وتشير النتائج باستخدام برنامج المحاكاة ماتلاب أن استخدام التقنيتين يمكن ان يعزز من أداء الشبكة عند استخدتم الهوائي الذكي ،حيث يتمثل ذلك في التحسن الكبير فينسبة الاشارة الي التداخل والضوضاءبنسبة 24٪، زيادة عدد المستخدمين المخدومين بنسبة 3.41٪ مع انخفاض في عدد المستخدمين خارج الشبكة ، والذي أدى بدوره الي تحسين انتاجية الشبكة بنسبة 50٪ مما أحدث زيادة في الكفاءة الطيفية بنسبة 57٪.

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List of abbreviations

2G	Second Generation
3G	Third Generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
AAS	Adaptive array systems
ABS	Almost Blank Subframes
BS	Base Station
CA	Carrier Aggregation
CoMP	Coordinated Multi-Point Transmission and Reception
CQI	Channel Quality Indicator
CRE	Cell Range Expansion
CSG	closed subscriber group
CSI	Channel State Information
DL	Downlink
DOA	Direction of Arrival
eNodeB	Evolved Node B
HetNets	Heterogeneous Networks
ICIC	Intercell interference coordination
IMT-Advanced	International Mobile Telecommunications-Advanced
ITU	International Telecommunication Union
LCS	location services
LLCs	Lightly loaded controlling channel transmission Subframes
LPN	Low Power Node
LTE	Long Term Evolution

LTE-A	LTE-Advance
MBMS	multimedia broadcast multicast services
MBS	Macro Base Station
MCL	Minimum Coupling Loss
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
OFDMA	Orthogonal Frequency Division Multiple Access
PBS	Pico Base Station
PC	Personal Computer
PF	Proportional Fair
PMI	Precoding Matrix Index
RE	Range Expansion
REB	Range Expansion Bias
RI	Rank Indicator
ROI	Rang Of Interest
RRU	Remote Radio Unit
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSRQ	Reference Signal Received Quality
RSS	received signal strength
SIMO	Single Input Multiple Output
SINR	Signal to Interference and Noise Ratio
SISO	Single Input Single Output
SLS	System Level Simulator
SONs	self-organizing networks
UE	User Equipment

UL	Uplink

List of Symbols

A_m	maximum attenuation
D_{hb}	base station antenna height
G_{UE}	UE antenna gain
G_{eNB}	eNodeB antenna gain
P_{Rx}	eNodeB received power
P_i	loss of wall number i
P_{therm}	Thermal noise
P_{tx}	eNodeB transmit power
$x^{(q)}(i)$	input layers prior to precoding
$y^{(q)}(i)$	output precoded signals
θ_{3dB}	3dB beam width
$\emptyset$	phase
$A(\theta)$	antenna radiation pattern
H	MIMO channel
PL	Path Loss
R	distance between base station and UE in Km
W	weighting matrix
f	carrier frequency
i	Slot
n	number of penetrated walls
p	Power
s	input signal
v	antenna weight vector

y	receive vector
z	interference plus noise
log	logarithm
argmax	Arguments of maxima
θ	Theta
log_{10}	Logarithm base 10

Chapter one

Introduction

1.1 Preface

In recent years, data traffic demand in cellular networks and mobile broadband services with higher data rates is growing rapidly, specially, mobile broadband traffic has seen almost exponential increases, and the revenue growth for network operators is exponentially increased due to data traffic usage when more and more consumers use data traffic generating devices such as smartphones and PCs. During the same period, Ericsson measurements show that traffic in 3G networks usage overweight 2G networks [1] with global traffic figures expected to double annually in the next few years [2].

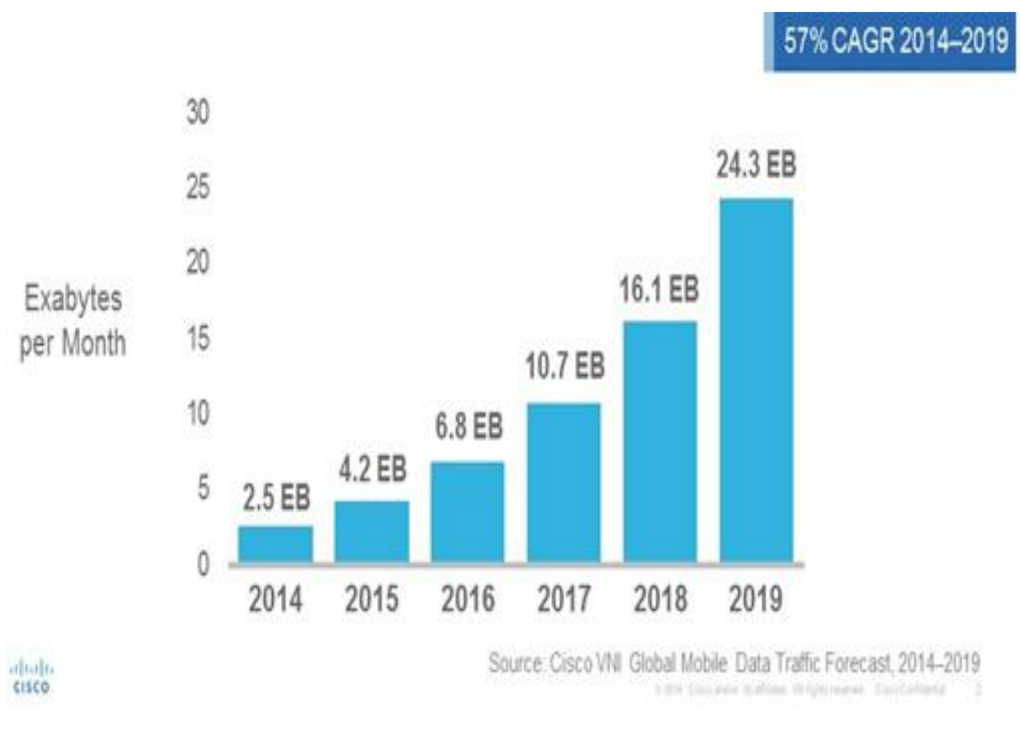

Figure 1–1: Forecast yearly data traffic [3]

As illustrated in Figure 1-1 and according to the latest annual update of [3], 88 percent of mobile data traffic in 2014 was “smart” traffic, with advanced computing/multi-media capabilities and a minimum of 3G connectivity , it is expected to rise to 97 percent by 2019 ,and 3G is expected to surpass 2G as the top cellular technology in 2017 according to global mobile network perspective. By 2019, 3G and 4G networks will support 44 percent of global mobile devices and connections; with 4G networks 26 percent of connections respectively, though will generate 68 percent of traffic.

To satisfy extremely high data rate demand of mobile communications, the additional lower-power nodes (or transmission/reception points) are deployed under the coverage area of the macro layer. The result is heterogeneous network (HetNets) where the layer of low-power node does not need to provide full-area coverage. Actually , they can be deployed to increase capacity and achievable data rates where needed [4] this make HetNets as a suitable approach to increase system performance. Heterogeneous networks defined as a combination of large and small cells (macro, pico, fimto…etc.) with different transmission power working together to provide the best coverage and optimal capacity[5, 6].The deployment of Using nodes with different transmission powers comes up whit new challenges in HetNets which are interference and coverage limitation[7].The goal of using low power (Picocell) nodes is one of the important solutions which to offload the traffic from the macrocells, enhance coverage and improves the overall system capacity[8].

1.2 Problem Statement

Pico-cell coverage is quite limited due to its transmission power and hence, only a small percentage of users can connect to pico cell which leads to imbalance users between cells[7].Pico-cell Range Expansion is considered as a solution to increase the capacity .However ,the strong interference from macro cells will occur for UE located in the picocells which is a challenge has to be overcome.

1.3 Proposed Solution

Deploying smart adaptive antennas at pico cells to reduce the interference between high power and low power base stations antenna at Pico cell in order to reduce intercell interference and increase system capacity.

1.4 Objectives

The main objectives of this research are to achieve the following:

1- Reduce Inter cell interference in Pico-Macro Scenario using smart adaptive antenna.
2- Increase System Capacity.
3- Increase Throughput.
4- Improve the spectral efficiency.

1.5 Research Scope

This project focuses on how to reduce the interference between Macro cell and Pico cell especially in Pico cell edge when the Pico cell range expansion technique is used that is by using Smart antenna mechanism at Pico node and how system performance is improved considering the SINR, system capacity and spectral efficiency and throughput.

1.6 Methodology

This thesis considers Pico cell range expansion combined with interference mitigation in heterogeneous network using smart antenna which is implemented at Pico cell., LTE System level simulator is used to evaluate the impact of using smart antenna in order to reduce intercell interference in HetNets in case of macro-pico scenario, consider a simple scenario that a network consisting of one Pico cell that is placed at the edge of the each sector in macro base station and UE is located randomly between both base stations, then expanding the Pico cell coverage range by adding bais value to Reference Signal Received Power(RSRP) which is received from Pico cell to the users. However in HetNets, the cell with higher RSRP is selected as a serving cell [9].In order to achieve the main objectives of this thesis smart adaptive antenna is implemented at a pico cell using precoding scheme which is transmitting in a narrow beam directed to the desired user instead of a sector wide beam. The antenna radiation pattern for picocells is assumed to be omnidirectional with constant gain. To evaluate the performance of pico cell range expansion with and without smart antenna, two performance metrics were measured and evaluated (spectral efficiency and Signal to interference ratio).The network performance evaluation is based on Matlab which simulates performance of a network that consists one pico cell and one macro cell, the performance metrics were evaluated for a SINR before and after using smart antenna in a pico cell.

1.7 Thesis Outlines:

The structure of this Thesis is organized as follows:

Chapter two presents the introduction and background of LTE Releases, Heterogeneous network including range expansion, interference scenario and different of antennas techniques toward interference issue and then provides the related works. The system parameters and simulation stages of this project is described in chapter three. Chapter four, analyses Macro-Pico scenario performance and evaluates the performance results with and without using smart antenna. The conclusions and recommendation are presented in chapter 5.

Chapter Two

Literature Review

2.1 Overview of LTE Evolution

LTE Release 8 which is the first release of LTE that has been standardized by 3GPP international standardization organization is completely released in March 2009 after about five years since has been proposed in 2004 [10]. In LTE Release 9, the studies have been continued to improve system performance by developing different functions and services such as improved functions for Home enhanced nodes B (eNodeB) such as the management of closed subscriber group (CSG) which identifies subscribers of an operator who are allowed to access a particular Home eNodeB, and self-organizing networks (SONs), location services (LCS) and multimedia broadcast multicast services (MBMS). Since that, the LTE standard has been developed toward commercialization in various countries in the world [11] [12] . In April 2008 3GPP initiated work on LTE Release 10 which is also known as LTE-Advanced in order to extend the performance and capabilities of the LTE radio-access technology and to ensure that LTE fully meet the IMT-Advanced requirements for 4G technologies, defined by ITU. However, all LTE Released from LTE Release 10 and beyond is known as LTE -Advanced [13] [14].

LTE Release 10, also known as LTE-Advanced, is an evolution of LTE Release 8 to further improve performance. The Figure 2-1 includes all the features of Release 8/9 and adds several new features that are used to fulfill all IMT-Advanced requirements in order to approve LTE Release 10 as an IMT-Advanced technology [15].

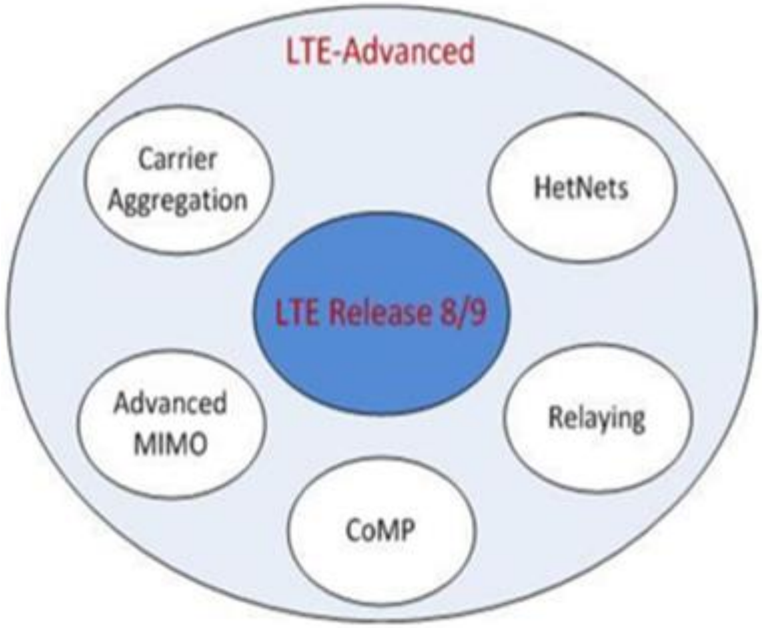

Figure 2–1: LTE-Advanced Technology [15]

This includes the possibility of peak data rates of 1 Gbit/s in the DL and 500 Mbit/s in the UL, which will be achieved by enhanced MIMO and a transmission bandwidth of up to 100 MHz [15]. Moreover, it is possible to provide high data rates over a larger portion of the cell. The peak spectral efficiency of LTE Release 10 is 30 /15 bps/Hz in the DL/UL, respectively, while the capacity and cell-edge user throughput targets for LTE-Advanced were set considering 1.4 to 1.6 times gain increase from LTE Release 8 performance[14]. The following Table 2-1 shows key IMT-Advanced requirements and current LTE Release 8 and LTE Release 10 capabilities

Table 2-1: Key IMT-Advanced Requirements

	IMT-Advanced Requirement	**LTE Release8**	**LTE Release 10**
Transmission Bandwidth	At least 40 MHz	Up to 20 MHz	Up to 100 MHz
Peak Spectral Efficiency -Downlink -Uplink	 15 b/s/Hz 6.75 b/s/Hz	 16 b/s/Hz 4 b/s/Hz	 16.0 [30.0] b/s/Hz 8.0 [16.0] b/s/Hz
Latency -Control Plane -User Plane	 Less than 100 ms Less than 10 ms	 50 ms 4.9 ms	 50 ms 4.9 ms

3GPP submitted LTE Release 10 to ITU in 2010, ITU approved LTE Release 10 as one of two IMT-Advanced technologies, that LTE Release 10 meets all the requirements of IMT-Advanced in terms of data rates, capacity, and low-cost deployment which means the possibility of deploying LTE Release 10 in spectrum which is already used by LTE Release 8 without any effect on existing LTE terminals, this feature is very important for a low cost and smooth transition to LTE Release 10 capabilities within the existing network [15].

2.2 Heterogeneous Networks Concepts

HetNets have been introduced in the LTE-Advanced standardization as mentioned, in order to provide a significant network performance when other advanced technologies (CA, MIMO, and CoMP) are incompetent to achieve the IMT-Advanced requirements. Such techniques may not always work well either, especially under low SINR conditions, where received powers is low ; due to deployment of new low power eNodeBs within existing macro layer would enhance the SINR levels for users off-loaded to new eNodeBs and also for users that remain connected to the macro cells, and extend traffic and data rate capabilities when needed. These new eNodeBs are LPNs pico cells, femto cells, relays and remote radio units (RRUs) which delivers high capacity per-user and rate coverage in areas covered by LPNs, with the potential to improve performance in the macro network by offloading traffic generated in hotspots. The combination of all these different types of eNodeBs makes it called HetNets [2] [16] . Figure 2-2 demonstrates the different components in a LTE-Advanced heterogeneous network

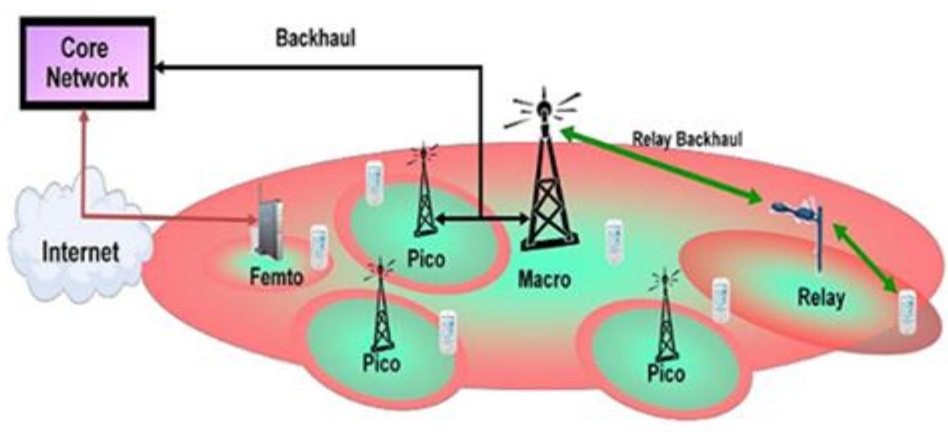

Figure 2–2: Homogeneous Network Deployment

HetNets improve the overall capacity as well as provide a cost-effective coverage extension and higher data rates to hot spots such as airports and shopping malls by deploying additional network nodes within the local-area range. In addition, they also increase overall cell-site performance and cell-edge data rates by bringing the network closer to end users. In that way, radio link quality can be enhanced due to the reduced distance between transmitter and receiver, and the larger number of eNodeBs allows for more efficient spectrum reuse and therefore larger data rates[17].

These LPNs can be either operator deployed or user deployed, share the same spectrum, and may coexist in the same geographical area. The following Table 2-2 shows specification of different elements in HetNets according to typical transmit power, coverage area, typical backhaul features and access [18] [19] .

Table 2-2: Specification of different elements in HetNets

Type of Node	**Typical Transmit Power**	**Coverage**	**Typical Backhual Feature**	**Access**
Macro cell	46 dBm	Few Km	S1 Interface	Open to all UEs
Pico cell	23-30 dBm	< 100 m	X2 Interface with Macro	Open to all UEs
Femto	< 23 dBm	< 50 m	User local loop	CSG
Relay	30 dBm	300	Wireless link with donor node	Open to all UEs
RRU	46 dBm	Few Km	Fiber link with parent site	Open to all UEs

2.2.1 Interference in HetNets

As mentioned in a previous section that HetNets deployment is a way of solving the coverage and capacity problems by adding low power nodes (such a pico-eNB) to cover areas where the macro cell signal cannot reach or where the weak signal is received. However, this scenario leads to create the inter-cell interference in downlink and uplink. In downlink (DL), the same frequency band (frequency reuse 1) is normally used by pico cells and macro-eNBs. Therefore, UE of macro cell which is closer to pico cell may receive a stronger signal from the pico-eNB than from its serving Base Station (BS) that causes low Signal to Interference and Noise Ratio (SINR) and vise-versa for pico UEs closer to macro cell [19]. In uplink (UL), when the UE locates far away from cell center or approximately in cell edge the higher power it transmits gets from serving eNB to reach the eNB. Also, when pico cell is close to macro-eNB, the pico UEs can generate interference towards macro-eNB [20].

2.2.2 Range Expansion

Coverage of low power node (LPN) is extremely limited according to its transmission power and the strong interference from macro cells; that means only a small percentage of users can benefit from LPN deployment, particularly in cell edges where there is no many UEs as in hotspots case which leads to an unbalance coverage so, a new technique was needed to attract more users to LPNs, offload the more macro cell traffic to solve coverage unbalance in order to increase HetNets efficiency[7]. Moreover, the performance of LPNs is significantly improved if UEs are allowed to connect to a weaker SINR LPNs, which refers to extend LPNs boundaries for load balancing purposes and take advantage of the spectrum which is offered by them.

For these objectives, Range Expansion (RE) is introduced for LPNs, particularly for pico cells and relays, to enhance HetNets efficiency, which adds an offset to the pico cell received signal strength (RSS) in order to increase its DL coverage footprint[15].

This thesis focuses on downlink 3GPP LTE-Advanced multilayered network with a macro cell accompanied by a pico cell for improved network capacity and performance .Pico base stations (PBSs) are taken into consideration because they can improve the capacity in addition of having the same backhaul as macro base station (MBS) [21] [22].Picocells usually work in open access mode that means any user in the network can automatically connect to the hotspots. Picocells are used to improve capacity as well as the coverage of outdoor or indoor regions in environments with inadequate macro penetration. Moreover, the X2 interface is used when macrocells communicate with picocells [7]. Figure 2-3 presents the numbers of picocells deployement in excesiting Macro cell infrustrcture which is focused on this thesis .

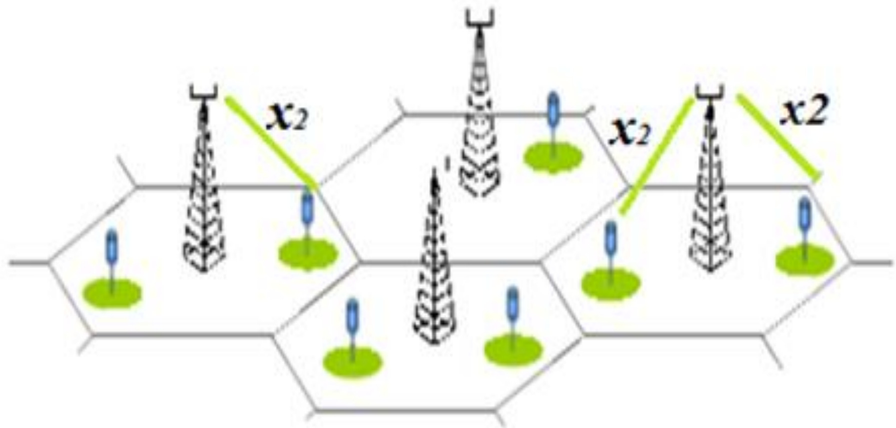

Figure 2–3: Deployment of pico nodes inside macro cells.

PBS has low transmission power (in range from 23dBm to 30dBm) [23] , and serves tens of UE within a coverage range of up to 300 m. However, MBSs transmit power is about 46dBm [19] . The difference between transmission power of each cell which is about 16dBm causes PBSs coverage within tens of meters, whereas MBS within hundreds or thousands of meters [18]. Therefore, in this thesis we consider only downlink (DL) because for uplink (UL), reference signal strengths (RSSs) from a UE at different base station depend on the UE transmission powers. One of the HetNets challenges is, for example, making the pico layer works with the macro layer as efficiently as possible, cell selection mechanism should being place to decide which base station that UEs can be connected to at any time.

In 3GPP LTE, cell selection is mostly done using Reference Signal Received Power (RSRP) or Reference Signal Received Quality (RSRQ)[24]. These two parameters are measured by a User Equipment (UE), these measurements are also used when a cell re - selection or handover decisions are made. RSRP is defined as the linear average over the power contributions of their source elements that carry cell-specific reference signals within the considered measurement frequency bandwidth. RSRQ is calculated based on RSRP which provides additional information and reliable cell selection decision when RSRP is not sufficient [25] [26]. As illustrated in Figure 2-4 [27]: in the grey area, the macro node is selected based on the downlink RSRP, but for the uplink the LPN is better since the transmission power is the same and the pathloss is lower towards the LPN[28]. That is to say, a better cell selection for the uplink is minimum pathloss cell section [29].

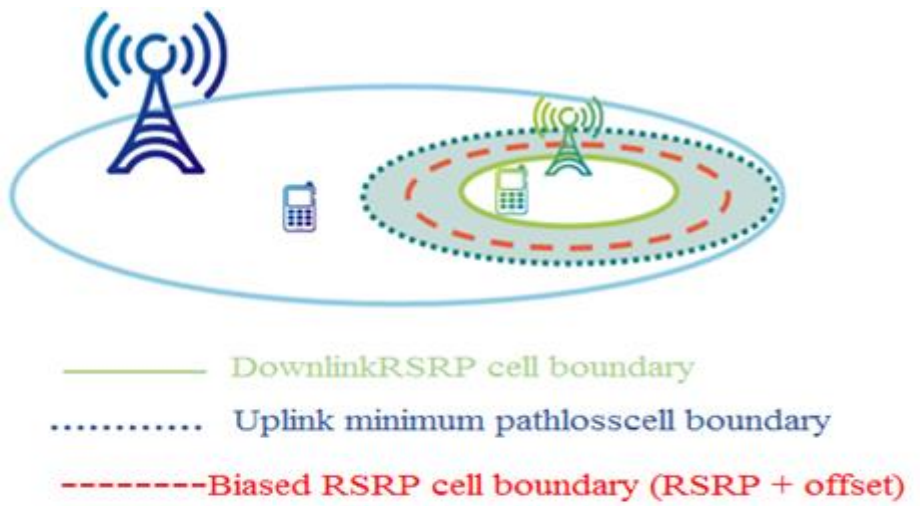

Figure 2–4: Cell selection in 3GPP LTE HetNets [28].

As shown in Figure 2-4, the cell boundary of uplink and downlink is not similar; to solve this, the RSRP of the LPN should be extended. That is could be by most straightforward way by increasing the LPN transmission power, but this method reduces site availability since it affects the site size and the cost [28]. Another way instead of increasing the output power is to add an offset value to the RSRP from the LPNs which will affect the cell selection and increase the pico cell range – Biased RSRP cell selection[29] [28]. Figure 2-5 illustrates the RE concept as follows, desired signals are illustrated in lines, while the interference signals are illustrated in red dashed lines [30].

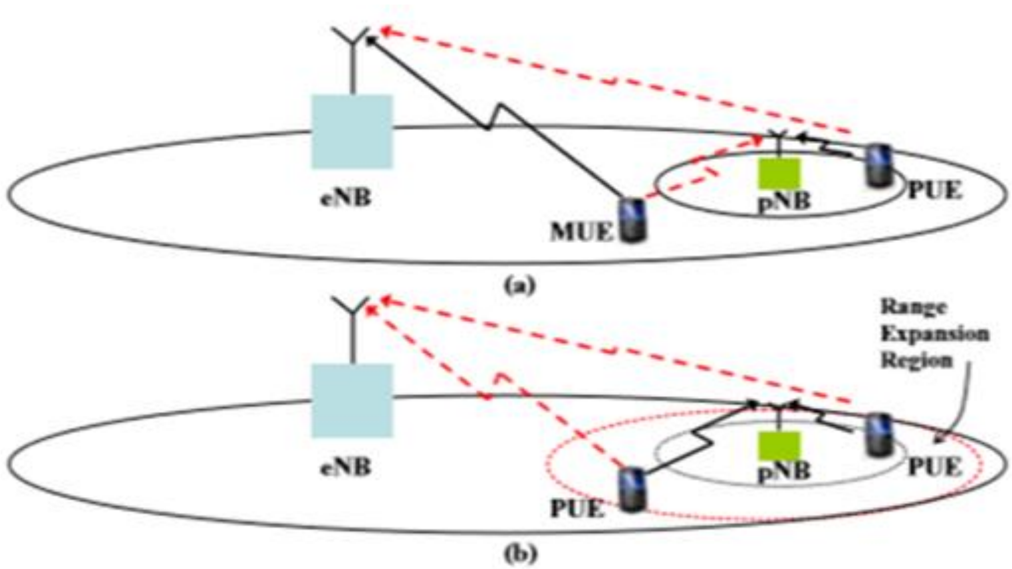

Figure 2–5: Range Expansion Concept; (a) before range expansion, and (b) after range expansion.

In the general case without RE,as shown in Figure 2-5 (a) the UE selects its serving cell based on its measurements of Reference Signal Received Power (RSRP) of the downlink signal so the cell with highest DL received power is being selected by UE and determined as the serving cell , this technique is referred as maximum reference signal received power (Max RSRP) [31]. Open access lets users connect to the strongest cells. The formula 2.1 explains the cell selection criteria based on RSRP is given by [32],

$$Serving\ cell\ selected = arg\,max(RSRP) \qquad (2.1)$$

With RE technique as shown in figure 5(b), the DL serving cell is determined based on the equation 2.2 [32]

$$Serving\ Cell = \ arg\ max\ (RSRP + Bias\ ) \qquad (2.2)$$

Where bias = 0 for macro-eNB and a few dBs for pico-eNB.

When the RE technique is utilized such users would suffered from inter-layer interference and it could be strong and varied significantly when the increased LPN footprint [9]. To overcome the interference issue which is the one of the objectives of this thesis; smart adaptive antenna using beamforming concept is used at the picocell which is discussed in the following section.

2.3 Antenna type towards interference mitigation

There are different manners for using smart antennas in a wireless communication system in order to mitigate inter-cell interference. They typically use the directivity and/or diversity features of the spatial processing which could be achieved with the multiple antenna concept [33].

2.3.1 Antenna Theory

The antenna functionality based on number of factors including physical size of an antenna, impedance (radiation resistance), beam width, beam shape, directivity or gain, polarization [34]. According to definition, an antenna array consists of more than one antenna element. The radiation pattern of an antenna array depends on number of antenna elements that used in array. The more elements there are, the narrower beam can be formed.

2.3.2 Smart Antenna

Actually antennas are not smart antenna; systems are smart. Generally, a smart antenna system combines an antenna array with a digital signal-processing with ability to transmit and receive in an adaptive, spatially sensitive manner[35]. By this intelligent system, smart adaptive antenna can automatically direct its beam in correspondence to the user location by employing Direction of Arrival (DOA) algorithm to monitor the signal which is received from the user, and places nulls in the direction of interfering users and maxima in the direction of desired user in order to achieve maximum gain in desired direction while rejecting interference coming from other directions to increase the wireless system performance[36] [37] [38].when it is compared with traditional antennas the overall capacity gain of smart antennas is expected to be in the range of 100% to 200% [39]. Figure 2-6 describe the block diagram of a smart antenna system. Incident signals on the array are weighted and then combined to form the radiation pattern of the antenna system. Array weights are adjusted using adaptive beamforming algorithms in order to optimize the operation of smart antenna with respect to the signal environment.

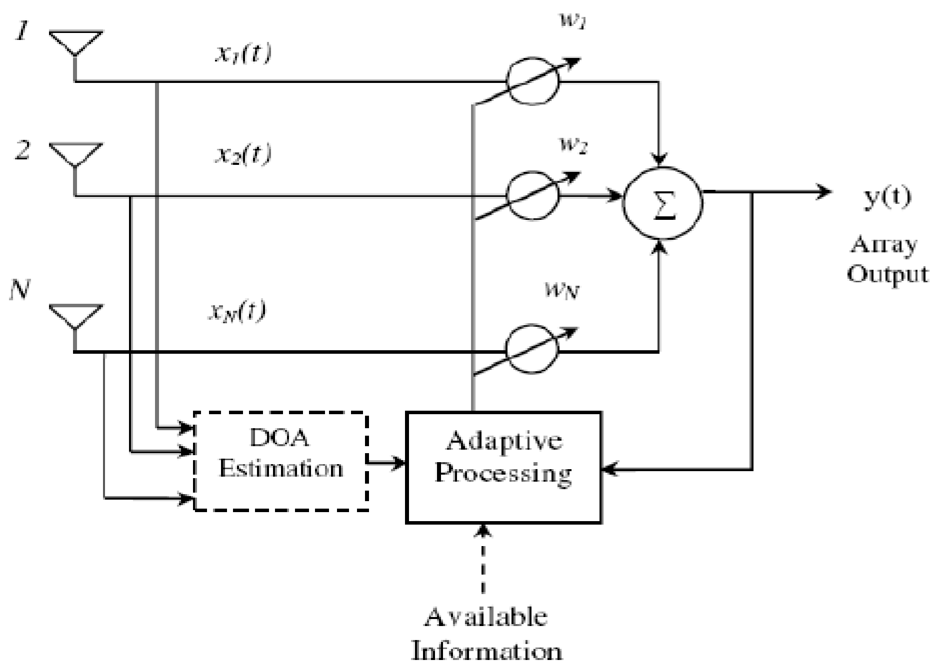

Figure 2–6: Block diagram of a smart antenna system.

Smart antennas are divided into two groups:

1. Phased array systems and also known by switched beamforming; which has a fixed predefined patterns, then the Direction of Arrival (DOA) is electrically calculated and switched on the fixed beam and user has the optimum signal strength along the centre of the beam.
2. Adaptive array systems (AAS) (adaptive beamforming) with an infinite number of patterns which is adjusted for transmission in a narrow beam according to UE moving in order to reduce the interference spread in the system [33]. Figure 2-7 shows the smart antenna categories.

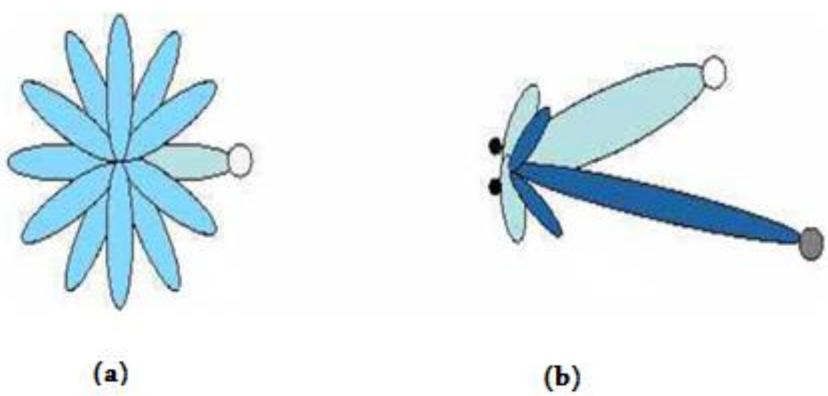

Figure 2–7: Smart Antenna Group; Switched Beamforming (a), Adaptive Beamforming.

There are several techniques investigated to use antenna to mitigate the interference. These techniques are beamforming and diversity for both transmission and reception.

Beamforming techniques is the procedure used to make the radiation pattern of an antenna array. It can be applied in all antenna array systems as well as

MIMO systems which is known as precoding [40] which would be discussed in the following section .

2.3.3 Multiple Antenna System

Multiple antennas at transmitter and receiver, popularly known as multiple-input multiple-output (MIMO) typically consists of m transmit and n receive antennas (Figure 2-8).

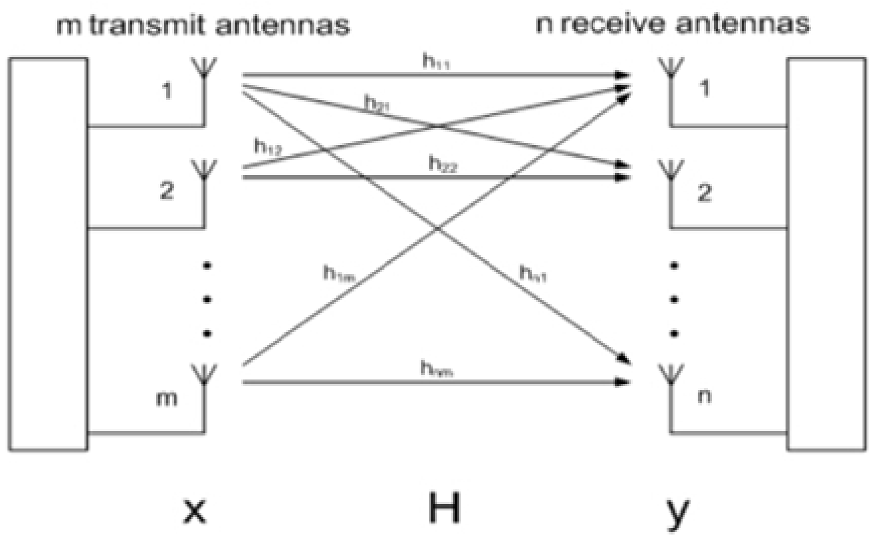

Figure 2–8: General MIMO Configuration.

The following formula 2.3 of MIMO transmission results from receive vector y, transmit vector x, and noise n.

$$y = Hx + n \tag{2.3}$$

1.3.1.1 MIMO Types

As illustrated figure 9 MIMO could be classified to different cases that degenerate MIMO case according to the number of antenna at the transmiter and the recievre ; Single-input single-output (SISO) where the transmitter and the receiver have only single antenna each. In (SIMO) case, the transmitter has a single antenna while multiple antenna for the receiver, and finally multiple antenna at the transmitter and only single antenna at the receiver that generates MISO case. Figure 2-9 shows the MIMO Types.

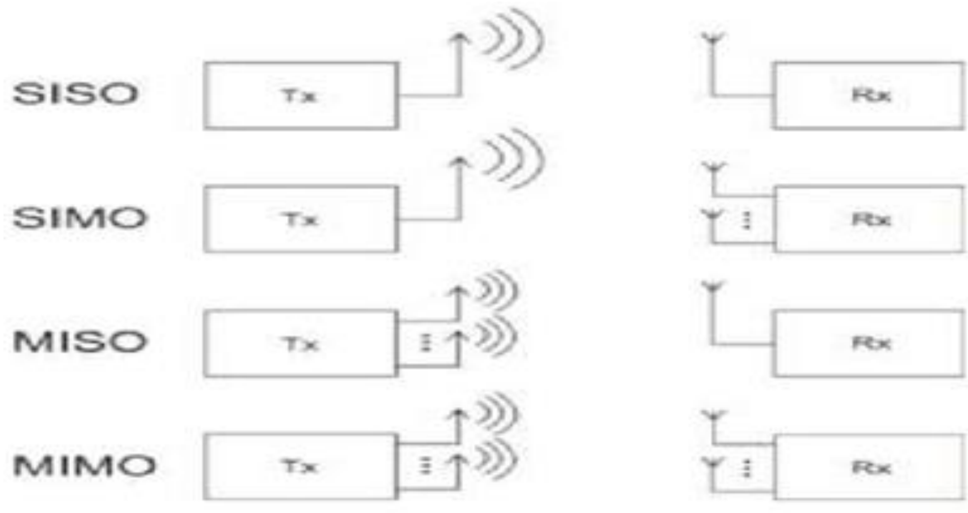

Figure 2–9: MIMO System Configuration.

1.3.1.2 MIMO Functions

MIMO services could be sub-divided to three major categories;

1. ***precoding*** which is based on the concepts of transmit beamforming with the ability of allowing multiple beams to be simultaneously transmitted in the MIMO system in a narrow beams to particular directions of the desired transmission and also possible to put nulls in certain directions where strong interferers are located, all these processes happen according to the channel knowledge or channel state information (CSI) at the transmitter in order to reduce the interference and the effect of multipath fading in the system. In general precoding is used to

maximize the signal level in all the receiver antennas. Figure 2-10 illustrates the beamforming concept.

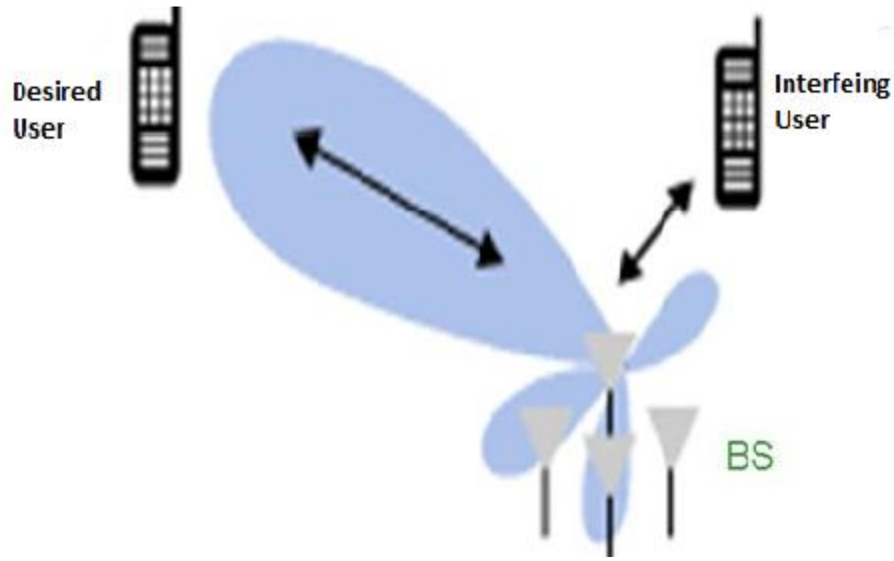

Figure 2–10: Transmit beamforming concept.

In this thesis the downlink of a wireless communication system using MIMO is considered. Beamforming in a MIMO channel H with an input signal s is transmitted with the power p and the antenna weight vector v, resulting in the receive vector y in the existence of interference plus noise z, according to equation 2.4:

$$\underbrace{y}_{M_R\times 1} = \underbrace{H}_{M_R * M_T} \underbrace{v}_{M_T\times 1} \underbrace{p}_{1\times 1} \underbrace{s}_{1\times 1} + \underbrace{z}_{M_R\times 1} \tag{2.4}$$

Where M_R, M_T are dimension of MIMO receiver and transmitter respectively.

2. ***Spatial multiplexing*** which needs a configuration of MIMO antenna, a high rate signal is divided into several lower rate streams and each of them will be transmitted from a different

transmit antenna in the same frequency channel. Spatial multiplexing is a very effective technique to increase channel capacity at higher Signal to Noise Ratio (SNR).

3. The ***Signal Diversity Coding*** is used when there is no channel knowledge at the transmitter. In this method a single stream is transmitted and coded using space-time coding techniques. The main objective of using spatial diversity is to make the transmission more powerful by using redundant data on different paths.

1.3.1.3 MIMO and Precoding

MIMO system performance is mainly linked to the received signal to interference and noise ratio (SINR). However, MIMO system may not be capable to recover the transmitted data streams properly if there is the very low SINR at any of the receive antennas and to improve system performance the beamforming could be applied at the transmitter. Because of that and according to the 3GPP Long Term Evolution (LTE) specification There are several transmit beamforming techniques which is included in; The precoding is a one of these techniques that is designed to raise or/and equalize the received signal to interference and noise ratio (SINR); Precoding as mentioned above it is based on transmit beamforming concept of which allows a multiple beams to be transmitted simultaneously in the MIMO system [40].

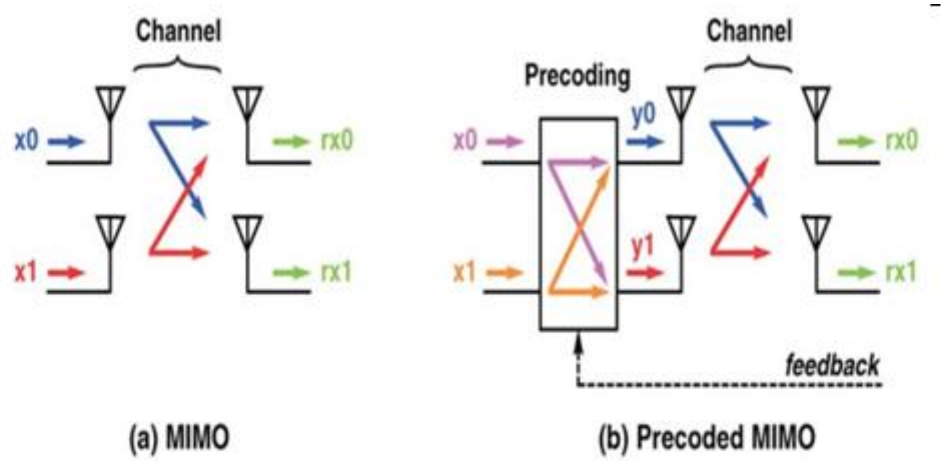

Figure 2–11: Simplified block diagram showing the difference between (a) MIMO without precoding and (b) MIMO with precoding.

For LTE preceded downlink transmission, user equipment (UE) is going to measure the channel conditions ,determine the precoding matrix index (PMI),channel quality indicator (CQI) and/or Rank Index (RI) [40] to send them to the base station (eNB) to select the suitable precoding codebook to make the system performance more efficient. As illustrated in figure 2-11 (b) the transmitter having knowledge or feedback about the current channel conditions creating a closed-loop system.

For MIMO configuration and as illustrate on equation 2.5, the weighting matrix W, would be multiplied by the input signal to create the precoded signals and to transmit them.

$$\begin{bmatrix} y^{(0)} & (i) \\ y^{(1)} & (i) \end{bmatrix} = W(i) \begin{bmatrix} x^{(0)} & (i) \\ x^{(1)} & (i) \end{bmatrix} \tag{2.5}$$

Where , $x^{(q)}(i)$are the input layers prior to precoding (q = 0, 1) and $y^{(q)}(i)$ are the output precoded signals which is applied to each transmit antenna.

Precoding matix provides a linear combination of the sums and differences of the two input layers respectively. The weighting matrix is

$$W(i) = \frac{1}{2}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \quad (2.6)$$

resulting in the following transmitted data as

$$y^{(0)}(i) = \frac{1}{2}x^{(0)}(i) + \frac{1}{2}x^{(1)}(i) \quad (2.7)$$

$$y^{(1)}(i) = \frac{1}{2}x^{(0)}(i) - \frac{1}{2}x^{(1)}(i) \quad (2.8)$$

Precoding schemes have been identified clearly for transmit-diversity and spatially-multiplexed applications. The precoding in spatially-multiplexed MIMO systems is considered in this research; in an ***open loop transmit-diversity coding*** there is no feedback from the receiver to the transmitter is implemented. Hence, there is no knowledge about the channel state at the transmitter that leads to no information to adjust the transmit antenna weights. While in a ***closed loop spatial multiplexing*** scheme allows the transmitter or eNB to generate the weight vector adaptively when it is receiving a feedback information from the UE. The selection of one of these precoding will be based on UE mobility.

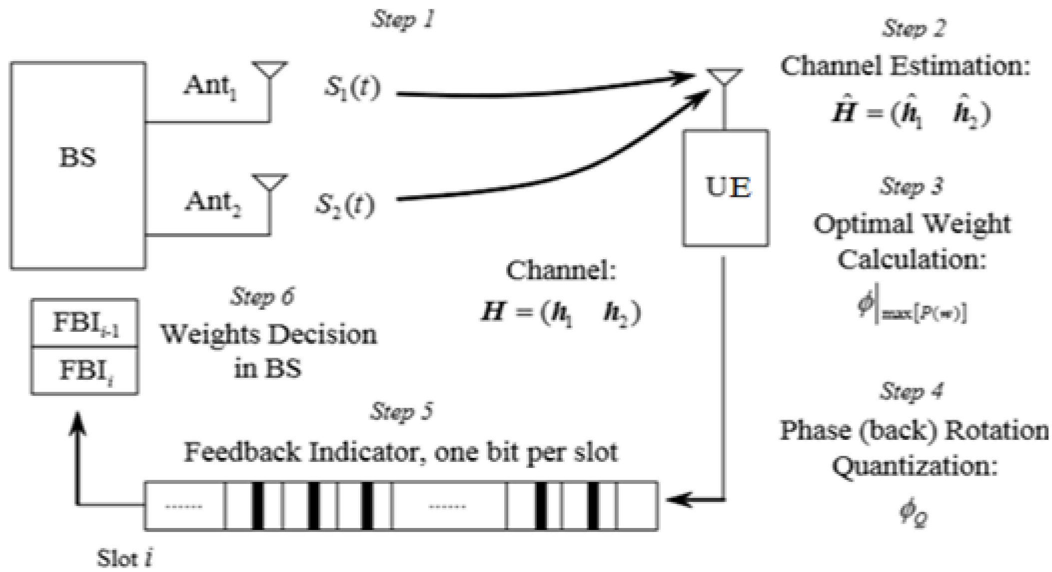

Figure 2–12: closed loop schemes.

As shown in figure 2-12, UE uses the both signals which is transmitted from antenna 1 and antenna 2 to calculate the adjusted phase to apply at or eNB side in order to maximise the UE's power received. UE will measure the optimum phase adjustment $\emptyset$, in each slot i for antenna 2, by using the current channel estimation result to realize the maximal received power. The optimum phase adjustment $\emptyset$ is then quantised into $\emptyset_Q$ having four possible values in $\pi/2$ resolution. Then the weight W_2 is measured by averaging the received phases over two slots respectively. W_2 is calculated Algorithmically as follow:

$$W_2 = \frac{1}{2} \sum_{i-n-1}^{n} cos(\emptyset_i) + \frac{j}{2} \sum_{i-n-1}^{n} sin(\emptyset_i) \quad (2.9)$$

Where, $\emptyset_i \in \left\{ 0\ \pi \frac{\pi}{2} \ \ -\frac{\pi}{2} \right\}$ For antenna 1, W_1 is constant,

$$W_1 = 1/\sqrt{2} \quad (2.10)$$

2.4 Related works

Different studies and contribution have already been done about the use of Heterogeneous Networks and interference coordination focus on employing Pico-cell range expansion technique with intercell interference coordination (ICIC) to manage the strong interference from macro layer in order to improve the system performance.

The researcher in [6] discussed the advanced technique which is required to enhance system capacity and user throughput in HetNets when the macro-pico scenario is used and range expansion is deployed in pico cell that allows more users equipment to get benefit directly from low-power base stations such as picos, femtos and relays. The simulation showed that by applying RE technique in sum rate can improve both cell-median and cell-edge UEs in a HetNets by connecting UEs to the cells with the lowest path-loss but large range expansion bais may cause overload issues.

The author of [41] analyzed the benefits of range expansion with ICIC technique and investigated performance of CRE From fairness and the results shows that the best range of bias values which will be used for expanding the range is from 6−8 dB with no ICIC, however range expansion bias (REB) values of 3−5 dB are become more efficient with ICIC. In either case, after a certain bias value, picocell may become over-loaded. For most REB values, and whenever range expansion and ICIC is provided to HetNets, the overall user capacity is increased and the higher user throughput could be achieved when the 16dB biased CRE with ICIC is applied. The Cell Range expansion (CRE) technique is combined with eICIC-time domain scheme by proposing the almost-blank subframes (ABS)framework in [7] to reduce the interference in macro-pic cell scenario in order to improve system performance. In[42] the DL performance of UEs is analyzed with various bias values under CRE with ICIC technique. Results proved that the moderate bias settings enhance the user throughput. Therefore, 8dB biased CRE with ICIC using LLCS can enhance the user throughput gain compared to 4dB biased CRE without ICIC. In this configuration with the high offered traffic condition, 16dB biased CRE with ICIC using ABS can achieve the higher user throughput than that of 8dB biased CRE with ICIC. Author in [8] investigates the throughput performance of different offset values for CRE and different amounts of protected resources for ICIC in a system level simulation to obtain comprehensive results. Offloading is effectively performed by applying an offset value higher than 4 dB. Furthermore, it was shown that when the CRE offset value is set between 8 to 20 dB, almost the same user throughput performance is obtained by allocating the appropriate resources to protect UEs connecting to picocells.

Researcher in [9] presented a downlink inter-layer interference coordination scheme for an OFDMA co-channel macro-pico HetNets where the CRE technique is used. Author compare this proposed scheme as a joint power and frequency coordination technique with the reference reuse-1 scheme, and the simulation result shows that the proposed scheme can greatly reduce the outage rate in the system which is a good choice to enhance system capacity and mitigate user outage in macro-pico HetNets with CRE.

Chapter Three

Simulation Approach

3.1 Introduction

This chapter presents the brief overview about simulator which is used. The macro-pico network scenario is presented with description for propagation path loss models was used for macro cell and pico cell and several parameters that are assumed to solve the problem of this thesis. The SINR distribution within pico cell is studied when the smart precoded antenna would/would not be used. The results presented in this thesis have been obtained by the Matlab implementation of the SLS model.

3.2 Overview

In general, MATLAB programming has being used as the main platform to execute the simulation which is designed using LTE Vienna system level simulator (SLS) which is created and developed by the Institute of Telecommunications of Vienna University, in order to evaluate the performance of a wireless network system according to the 3GPP standard technical specification of LTE-Advanced Release 10 [43].

SLS is a complex simulations including a great number of network elements; a lot of base stations (different types of cells) and users (UEs) which are approximately a hundred UEs may be attached per base stations, interference mitigation techniques, radio resource management algorithms, coverage estimation and it is also used for testing and evaluating the algorithms which are controlling the PHY and MAC layers[17, 44]. Rather than this complexity SLS is capable of evaluating the performance of the Downlink Shared Channel of LTE SISO and MIMO networks using Open Loop Spatial Multiplexing and Transmission Diversity transmit modes[44, 45].

3.3 Simulation Flow

The simulator would consist many functions and classes as shown at Figure 3-1 to implement several procedures to evaluate and achieve the objectives of this thesis. The simulation parameters have being put in a launcher script file to describe the assumption of network scenario. Then, the main function of simulator and the parameters would be applied to execute the simulation. Finally the results will be saved in the traces files.

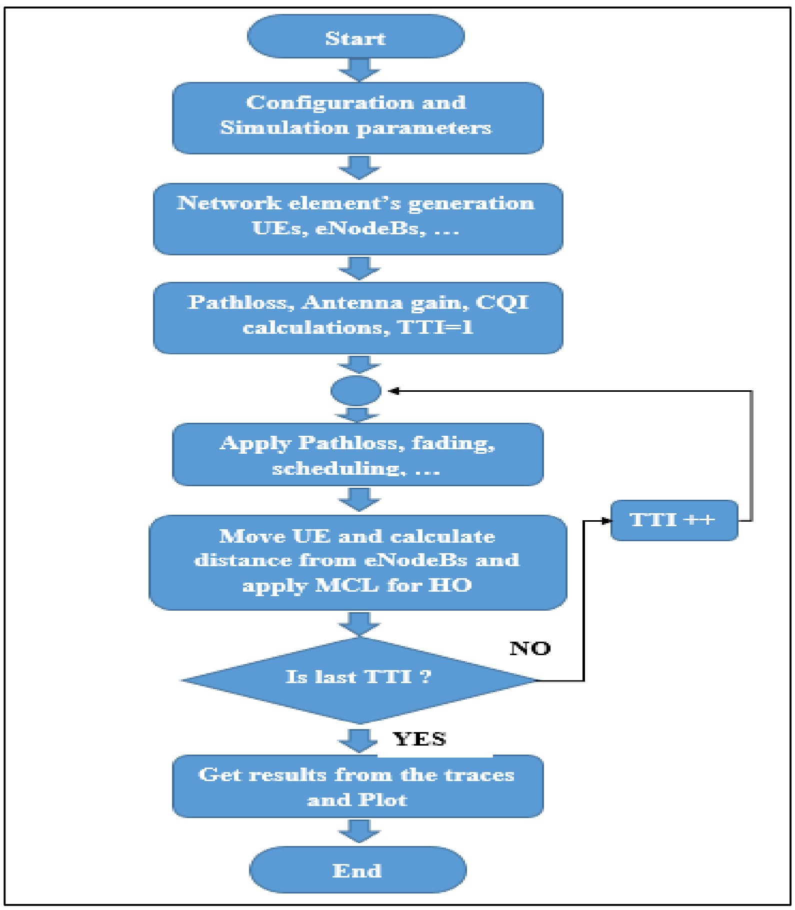

Figure 3–1: Simulation flowchart.

3.4 Simulation description

3.4.1 Network Layout

Generally a tri-sectorized hexagonal cell layout with at least two rings of sites, each with three sectors is deployed in order to make an interference-limited scenario identical to a network deployment, such as the setup which is depicted in figure 3-2. The main scenario in this simulation performs range expansion in macro-pico cell scenario in a high density network considering urban environment with fixed number of users. simulation employs the mentioned cell layout with a higher bandwidth (LTE supports a transmission bandwidth of up to 20MHz; there are two rings of sites which consist of 19 cells or sites, each site consist of three sectors (eNBs) (19 sites, 3 eNBs/site), these eNodeBs are acting as the main serving Macrocells and the number of 3000 users (UEs) are placed randomly over the Rang Of Interest (ROI) which is covering in this case a rectangle of roughly 6000×4000 meters. Figure 3-2 below shows the network topology including users and macrocells distribution.

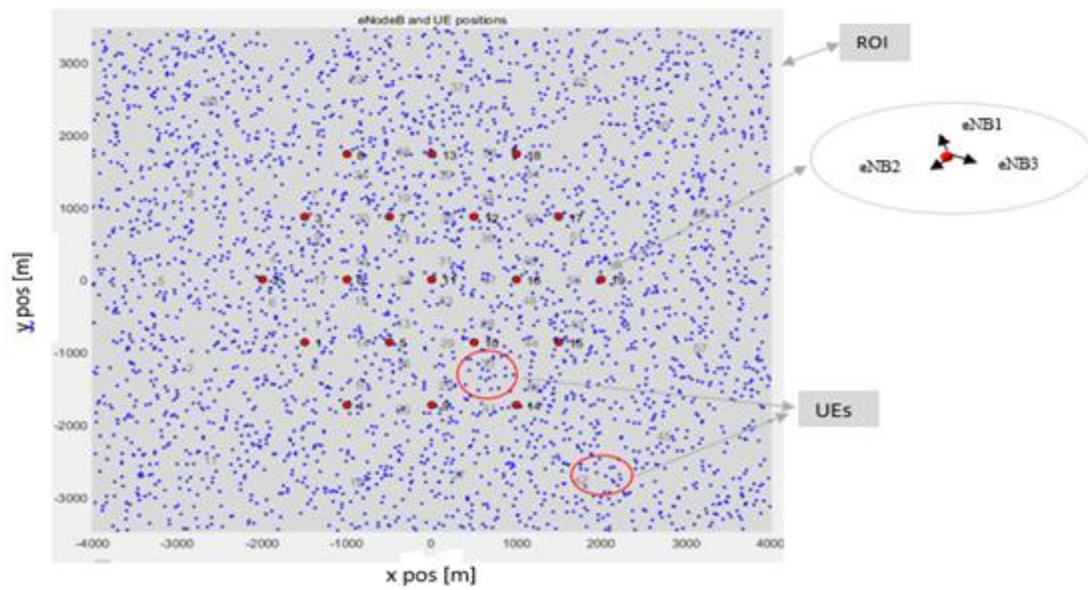

Figure 3–2: Network Deployment (UEs and Macrocells distribution).

The typically approach that is used in the SLS development is the so-called Monte-Carlo approach, which means that several independent photos (snapshots) of the system are evaluated in order to get statistics about the general system behavior. Whenever one snapshot is evaluated, several modules are carried out. Figure 3-3 gives the essential results (snapshot) of simulator such as the current network macroscopic fading for CQI mapping, ROI max SINR, SINR difference, and the eNodeB assignment.

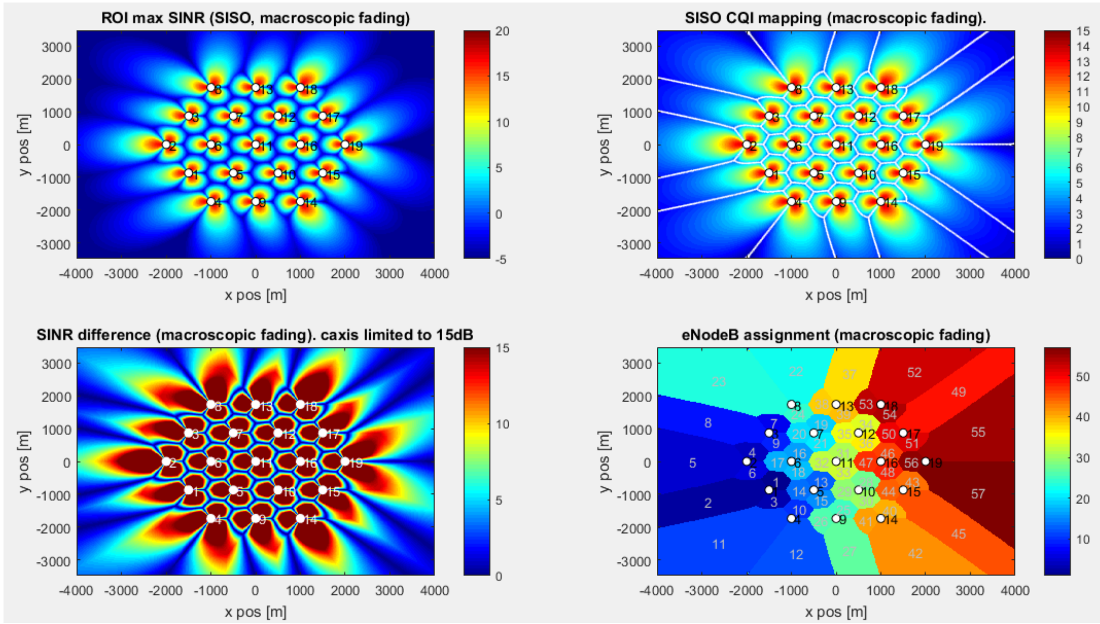

Figure 3–3: SINR mapping and Microscopic fading without Picocells.

Then picocells shown as diamond red shapes are added to macrocells (one pico for macro-eNB each) in a same ROI which was illustrated in Figure 3-2. This deployment could be shown in Figure 3-4. And the essential results of macroscopic fading for the new network configuration are shown in Figure 3-5.

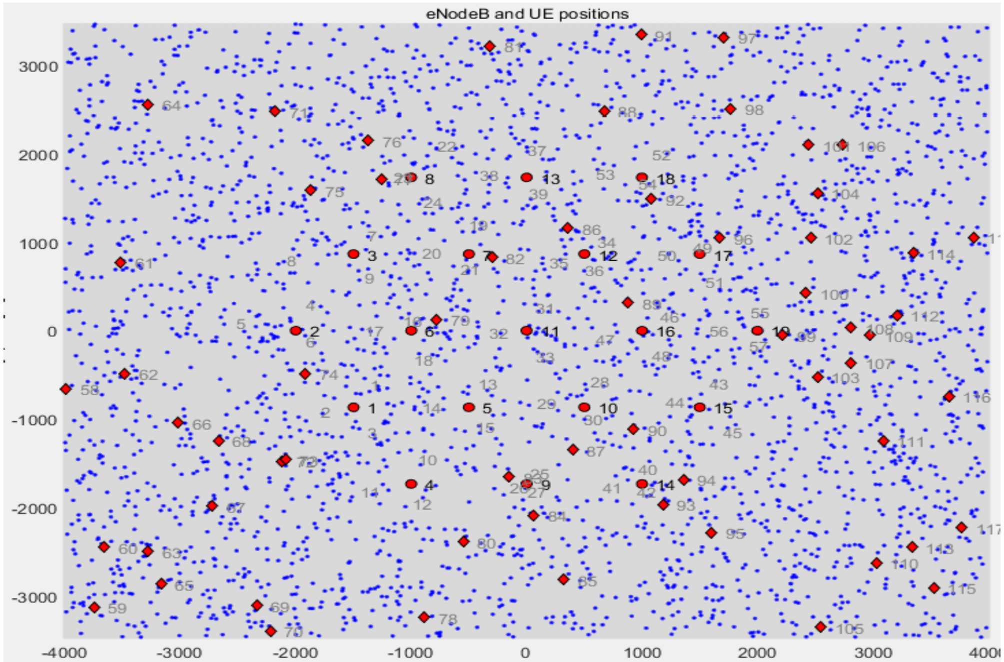

Figure 3–4: UE, Macrocells, Picocells distribution

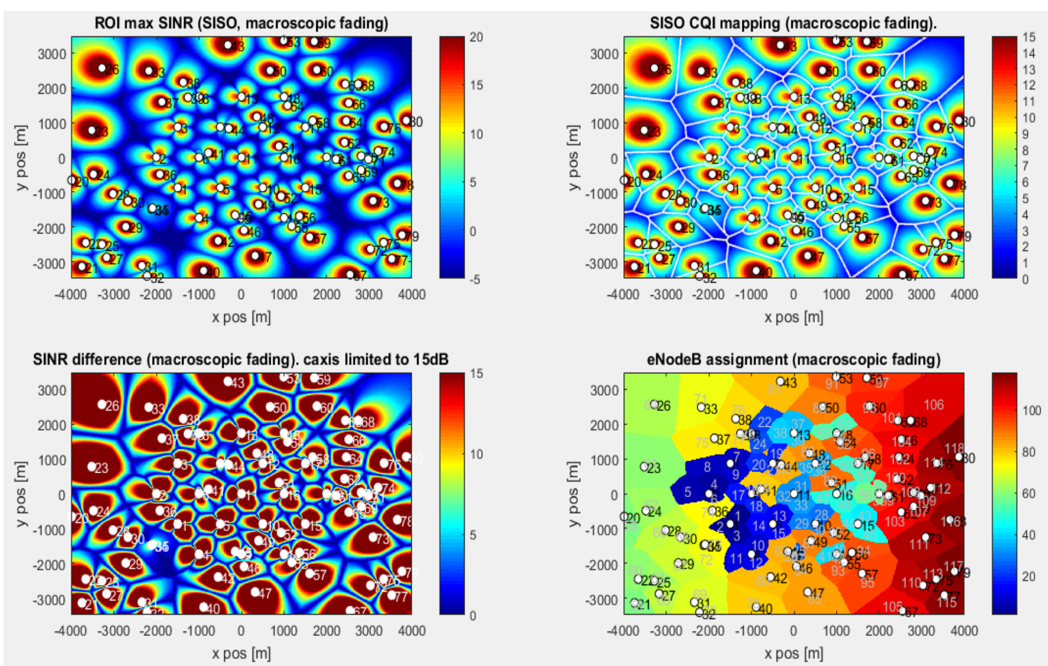

Figure 3–5: SINR mapping and Microscopic fading with Picocells.

3.4.2 Antenna Radiation Pattern

For macro base station the antenna radiation pattern the file of antenna radiation pattern that is provided by antennas manufacturers has been done as SLS input and used for each 3-sector sites as is plotted in Figure 3-6 which is identical defined as:

$$A(\theta) = -min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right] \ where -180 \leq \theta \leq 180 \quad (3.1)$$

θ_{3dB} is the 3dB beam width which corresponds to 65 degrees, and $A_m = 20dB$ is the maximum attenuation.

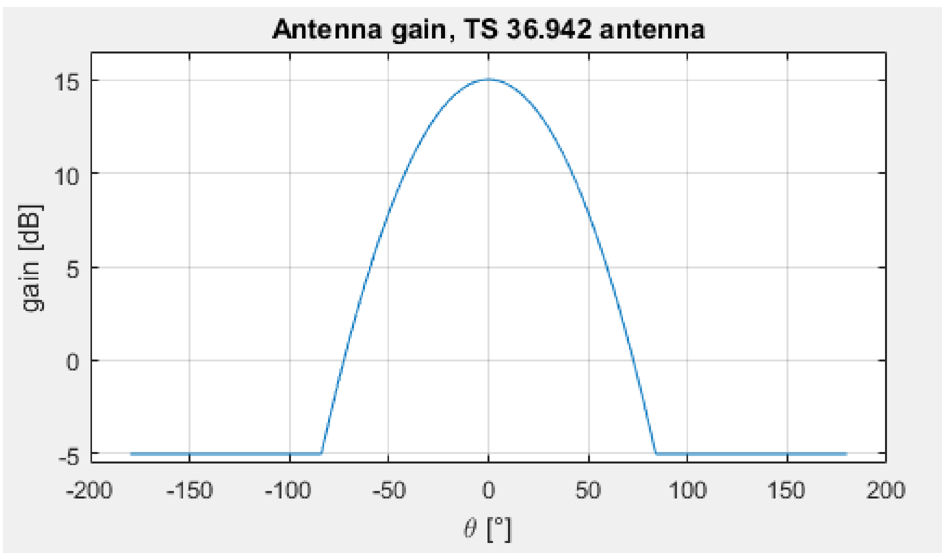

Figure 3–6**:** Macrocell antenna gain pattern.

Note that the assumption of antenna radiation pattern for LPNs is to be an omnidirectional with constant gain.

3.4.3 Propagation Model

An applicable propagation model which is used for testing this scenario in urban and suburban areas between macro cell and UEs at distance R in km is modelled as

$$L = 40(1 - 4x10 - 3D_{hb})Log_{10}(R) - 18\ Log_{10}(D_{hb}) + 21Log_{10}(f) + 70\ dB \quad (3.2)$$

Where: L is loss model type of wireless communication , Ri s a distance between base station and UE in Km, f isthe carrier frequency of 2.14GHz, $D_{hb}$is the base station antenna height, in meters, measured from the average rooftop level.

R would be calculated randomly according to the UE positions. The antenna height of base station is assumed to be 20 meters above the average rooftop (D_{hb} = 20 m). Considering a carrier frequency of 2.14GHz and a base station antenna height of 20 meters, the above formula becomes:

$$PL(R) = 128.1 + 37.6Log_{10}\,(R) \quad (3.3)$$

For pico node and according to Keenan-Motley and ITU-R P.1238[46] the indoor propagation model will be expressed in dB as the following formula when a carrier frequency of 2.14 GHz is used.

$$PL(dB) = 20\ Log(f) + 20Log(R) - 28dB + \sum_{i=0}^{n} P_i \quad (3.4)$$

Where R is a transmitter-receiver distance in meters, f is the carrier frequency given in MHz , n is a number of penetrated walls, P_i is a loss of wall number i.

For convenience with simulation and according to the parameters given for specific environment in ITU-R P.1238[46] , the indoor path loss model is represented by the following formula when considering a carrier frequency of 2.14 GHz.

$$PL(dB) = 38 + 30Log(R) \tag{3.5}$$

Where R = transmitter-receiver separation given in meters

Note that slow fading deviation for Pico environment is assumed to be 6 dB.

3.4.4 Signal to Interference plus Noise Ratio (SINR) averaging

The amount of useful signal in any transmission divided by the interference combined with noise is so-called SINR and it is measured in dB[17] .Referring to LTE parameters, the received power from a given eNodeB in dB is given as:

$$P_{Rx}(eNB) = P_{tx}(eNB) + G_{eNB}(\theta) + G_{UE} - PL(R) - Shadowing \tag{3.6}$$

Where $P_{tx}(eNB)$denotes the eNodeB transmit power in dB,

$G_{eNB}(\theta)$denotes the eNodeB antenna gain in dBi, $G_{UE}$is the UE antenna gain in dB which is equal to zero.

Now, SINR could be measured for the whole points in the network layout, as follows:

$$SINR = \frac{P_{Rx}(eNB)}{(\sum_{interference} P_{Rx}(eNB) + P_{therm})} \tag{3.7}$$

Where, P_{therm} is the thermal noise in dB.

3.4.5 Throughput

Network throughput is the rate of message that successfully delivered through a communication channel which is measured in data packet per second or in bits per second as illustrated at (3.8). Throughput is the accumulated data rate, and the data rate will obviously increase due to the increasing in the bandwidth utilization; accordingly the throughput will increase.

References for all equation

$$Throughput = \sum \frac{daterate}{second} \quad (3.8)$$

3.4.6 Spectral Efficiency

Spectral Efficiency Refers to the information rate that can be transmitted over a given bandwidth in specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized by the physical layer protocol and sometimes by the media access control.

$$Spectral\ efficiency = \frac{data\ rate}{bandwidth} \quad (3.9)$$

3.4.7 Enhancement Percentage

According to the increasing in the bandwidth the data rate rata will increase. Thus the spectral efficiency will increase.

Where the enhancement percentage (EP) was calculated as (3.10)

$$Enhacement\ Precentage = \frac{the\ value\ before\ - the\ value\ after}{the\ value\ before} \qquad (3.10)$$

Where, $Before/after$ means before/after using specific technique at different scenario for enhancement and achieve the objectives

3.5 Simulation parameters

The Table 3-1 below summarize the general assumptions and parameters which are being used in SLS for macro layer and pico layer.

Separation macro or pico parameters in two tables

Table 3-1: Simulation Parameters

Parameter	Value
Simulation time	25 TTI
Total Number of users	3000
Frequency	2.14 GHz
Bandwidth	20 MHz
Environment	Urban
Network ROI size	8 x 6 km
UE distribution	Constant No Per ROI
Channel model type	TU
Scheduler	PF
UE speed	50/3.6 m/s
Number of Macrocells	2 rings = 19 cell
Distance between Macrocells	1 km
Transmission modes	CLSM
No of Tx and Rx	1,4
Macro Tx power	40 W = 46 dBm
Pico Tx power	2 W = 33 dBm

Macro cells distribution	Regular hexagonal grid
Pico cells distribution	Homogenous density 1 picocell per km^2
Macro Pathloss model	TS36942 (outdoor)
Pico Pathloss model	dual slope (indoor)
Macro MCL	70 dB
Pico MCL	45

Chapter Four

Results and Discussion

4.1 Introduction

The system performance was evaluated through three scenarios, first one before CRE and the two other scenarios after CRE with and without deploying smart precoded antenna

4.2 Macro picocell scenario

Firstly and according to macro-pico cell scenario that pico cells are added to existing macro cells network system. As mentioned the number of users are placed randomly at ROI. Then system capacity was evaluated and the served users and to which cell are associated would be considered. Figure 4.1 shows the number of served users in whole system configuration before and after adding pico cells and the result shows that when the pico cell deployed the number of served users increased from 2731 users to 2893 users and numbers of not served users reduced from 269 to 107 users that means served users increase by 5.93%.

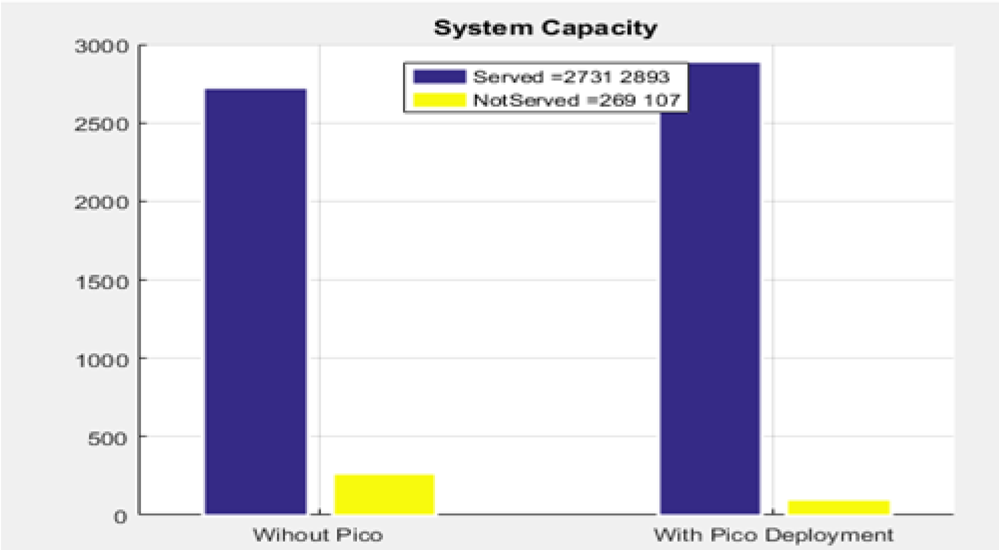

Figure 4–1: served vs not served Users.

After adding pico cells, amount of users which connected to macro cells were offloaded to pico cells .Figure 4.2 gives that the offloading of 1231 users occurred from macrocells to picocells and this means 41%from all users are associated with the new picocells.

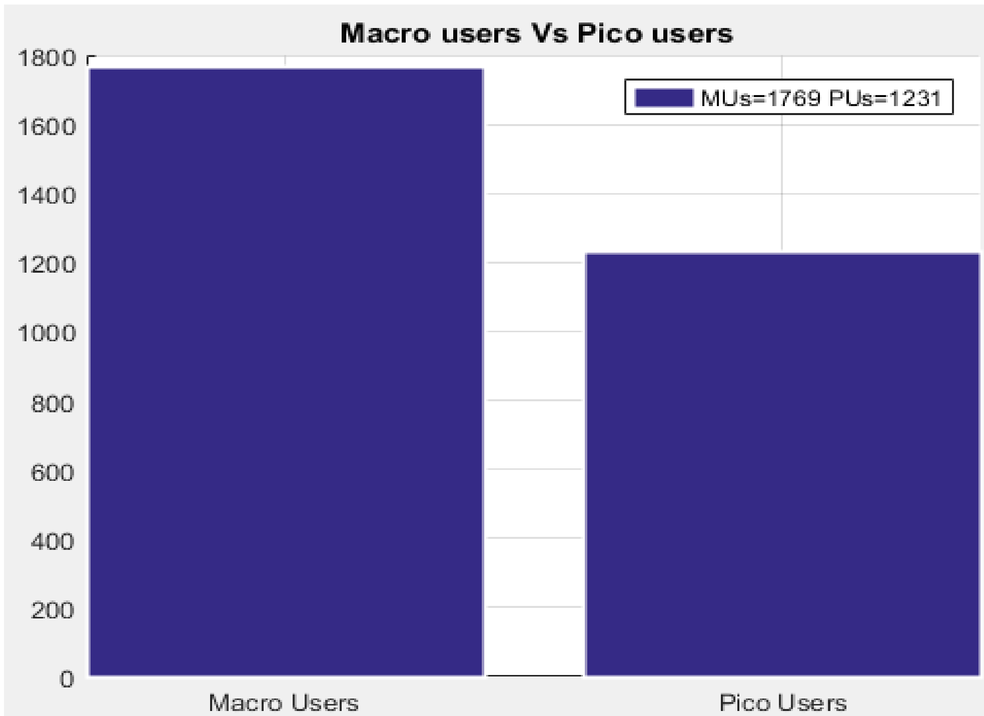

Figure 4–2: No. of macrocell and picocell users at Macro-Pico scenario.

In macro-pico cell scenario the average throughput per user was evaluated before and after adding picocells and the Figure 4.3 below illustrates the minimum, mean and maximum throughput and the result show when the picocells are deployed the average throughput increase from 0.02 Mbit/s to 0.04 Mbit/s for minimum, 0.05 Mbit/s to 0.25 Mbit/s for mean and from 0.26 to 1.28 Mbit/s, that throughput dramatically increased by more than 50% when the picocells are added.

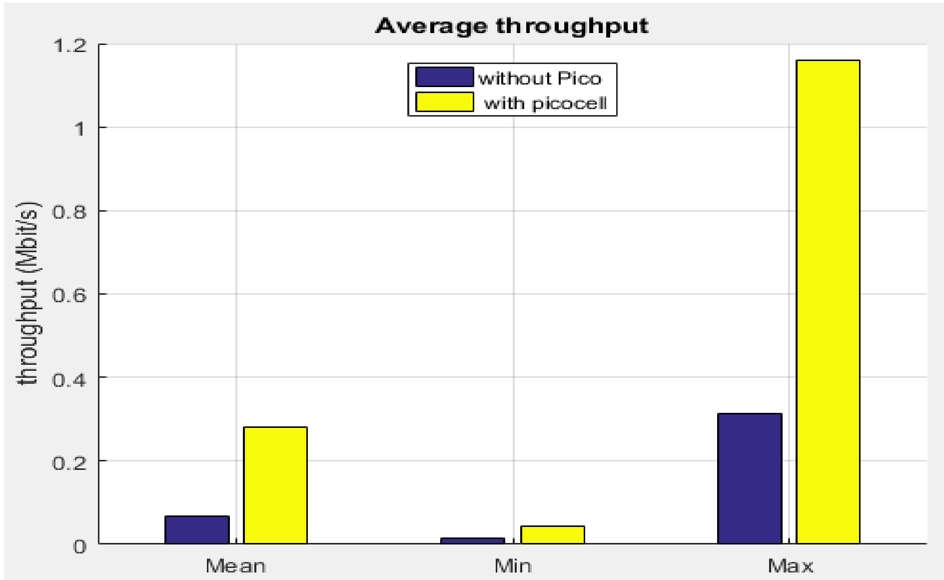

Figure 4–3: Average Throughput at Macro-Pico Scenario.

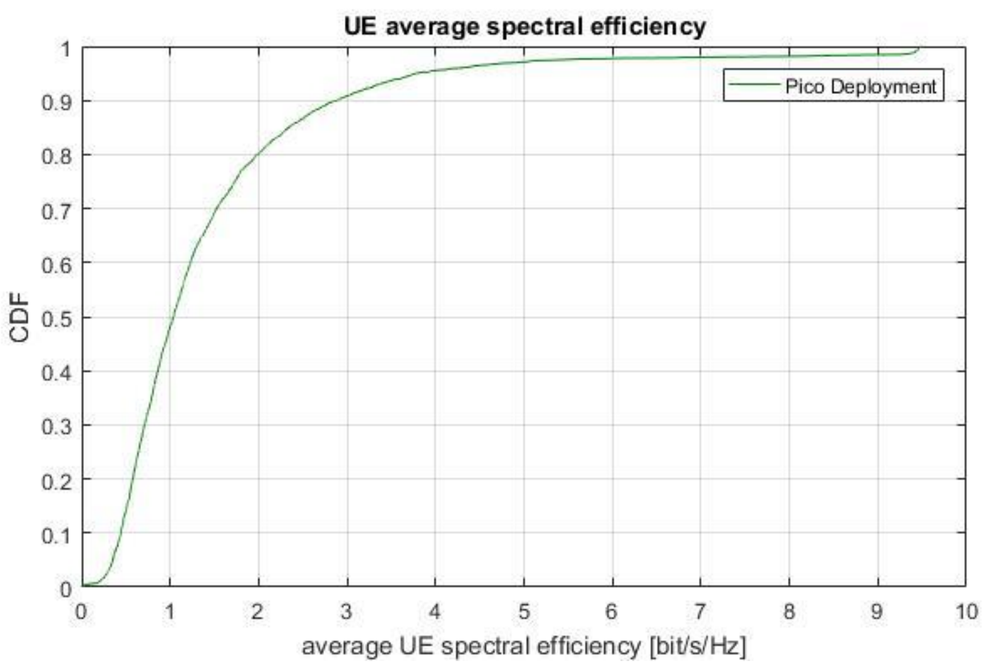

Figure 4–4: Average UE Spectral efficiency of Macro-pico Scenario.

Figure 4.4 presents the spectral efficiency of system when the RE is used and the result presents 0.002 bit/s/Hz for the minimum and 0.0124 bit/s/Hz for mean value while 0.064 bit/s/Hz for maximum value.

4.3 Expansion Case:

After applying range expansion technique the number of served users is increasing due to expanding the region of pico cell coverage. Figure 4.5 shows that the total number of served users increased to reach 2960 users while outage users are 40 users.

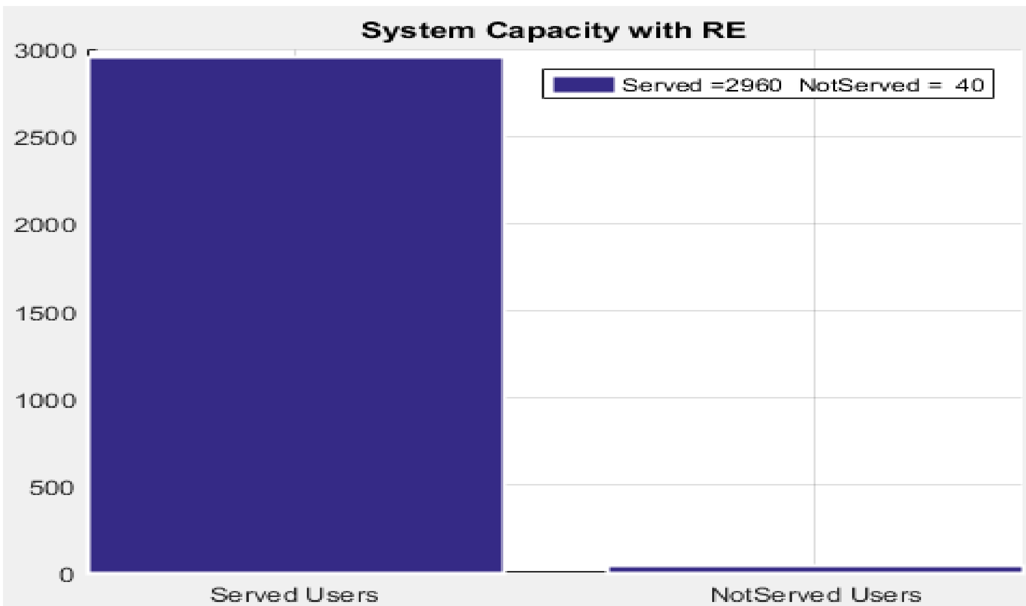

Figure 4–5: No. Of served users and not_served Users at RE case.

Figure 4.6 below demonstrates number of users that associated to the picocells and to macrocells in case of expanding range, and the results shows that the number of users that associated with picocell are about 1287 users and 1718 users for macro cell .that means the users of picocell go up by 4.51% while the number of macro users reduced.

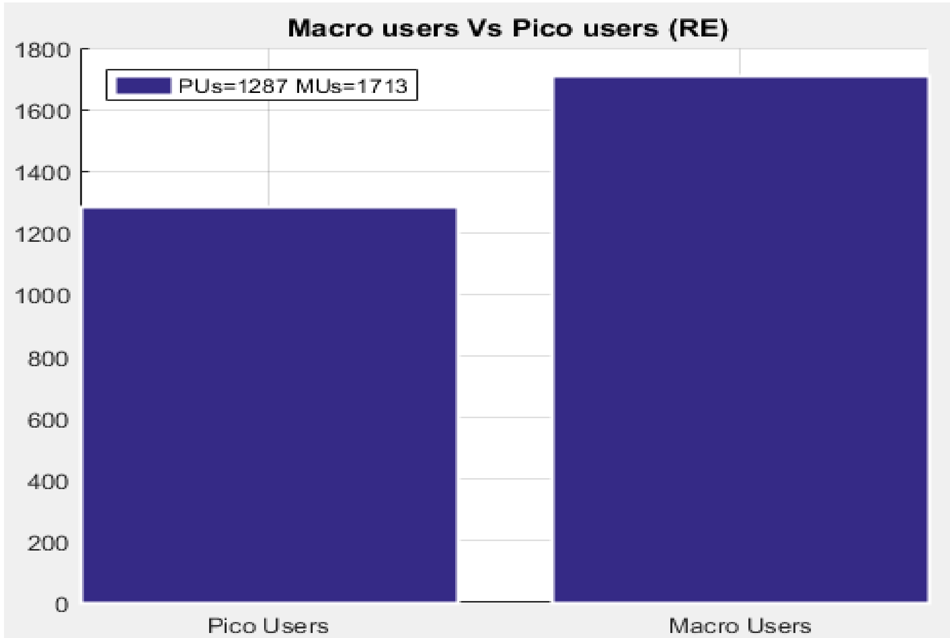

Figure 4–6: No. of macrocell and picocell users at RE scenario.

Figure 4.7 below explains the average throughput for RE case and the results presents 0.4Mbits/s,0.7 Mbit/s and 2.3 Mbit/s for minimum, mean and maximum UE throughput respectively.

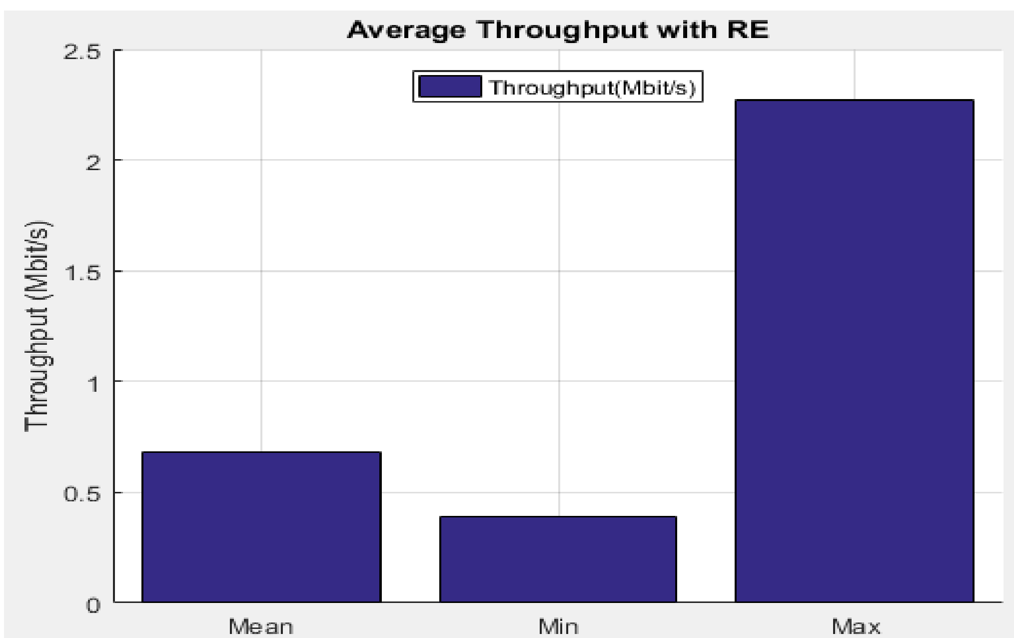

Figure 4–7: Average Throughput at RE case.

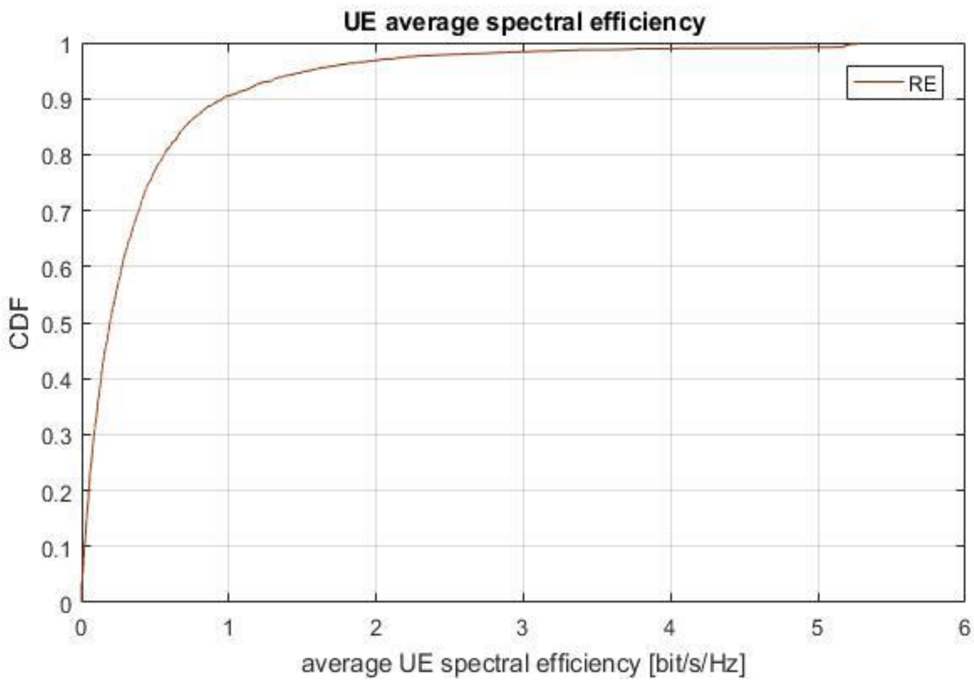

Figure 4–8: Average UE Spectral efficiency of RE case.

The Figure 4.8 illustrates the spectral efficiency of system when the RE is used and the result of 0.02 bit/s/Hz present the minimum and 0.035 bit/s/Hz for mean and 0.115 bit/s/Hz for maximum value

4.4 Smart antenna

In this case precoding technique has been used and the result on Figure 4-9 presents that when the smart antenna is applied at picocell the number of served user grow to reach 2993 users while not served users fall to just 7 users.

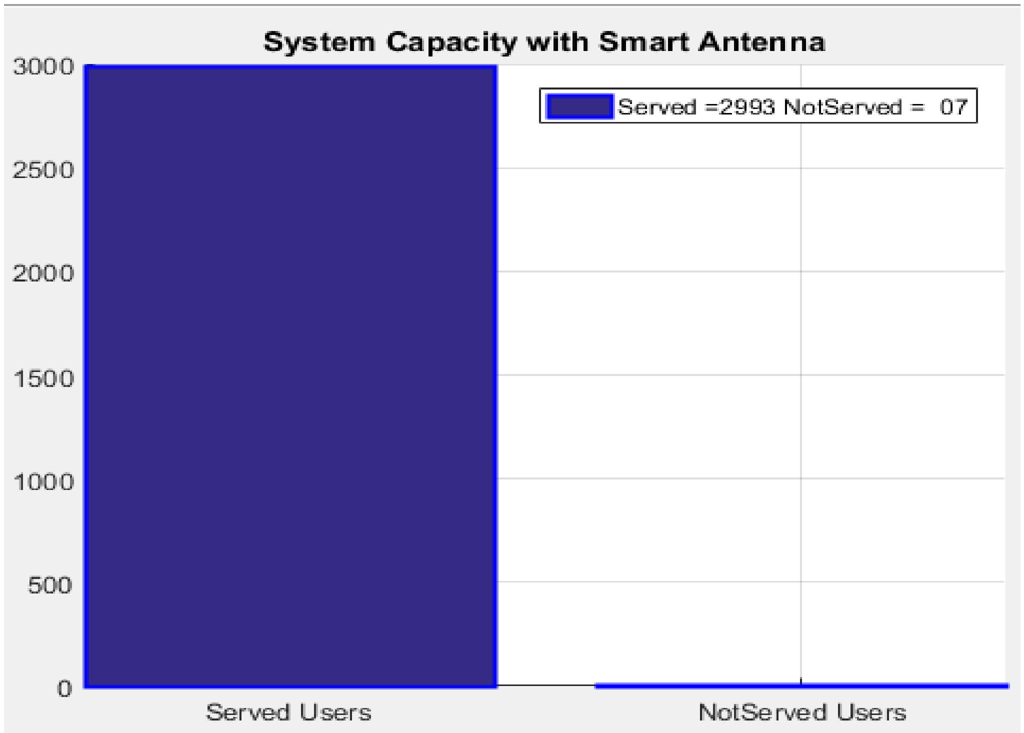

Figure 4–9: No. Of served users and not_served Users at RE case.

On Figure 4.10 shows the number of users that associated to the picocells and to macrocells in this case of using smart antenna are go up to reach 1461 users while 1539 users connected to macrocells. This result means the using of smart antenna could be attractive more users and more offloading from macro to picocell may occur in order to reduce macrocell traffic load that means that 48.7% from all users connected to new cell.

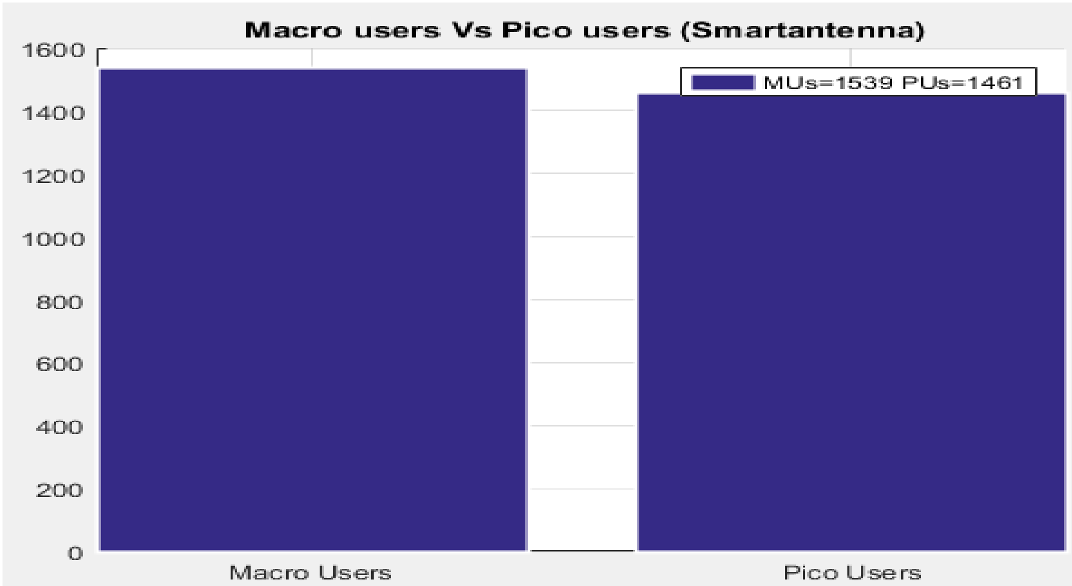

Figure 4–10: No. of macrocell and picocell users at RE scenario.

Figure 4.11 gives the average throughput when smart antenna is used and the result present that 0.49 Mbits/s for minimum value, 0.8 Mbit/s for mean and 2.57 Mbit/s for maximum UE throughput.

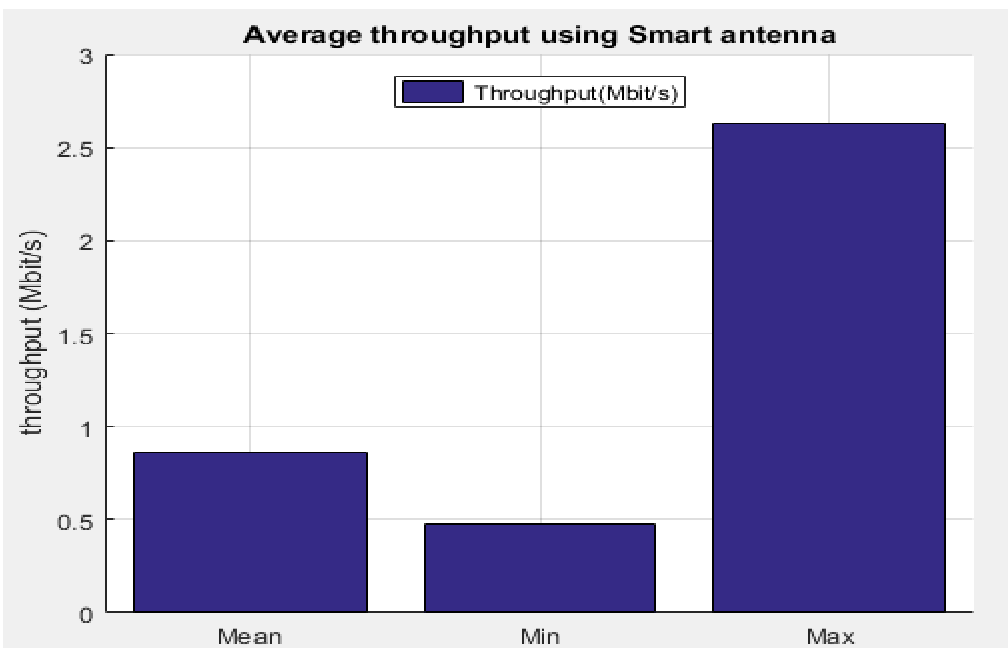

Figure 4–11: Average Throughput at smart antenna case.

The figure 4.12 gives the spectral efficiency of system when the RE is used and the result shows that the value of 0.0245 bit/s/Hz present the minimum and 0.04 bit/s/Hz for mean and 0.1285 bit/s/Hz for maximum values.

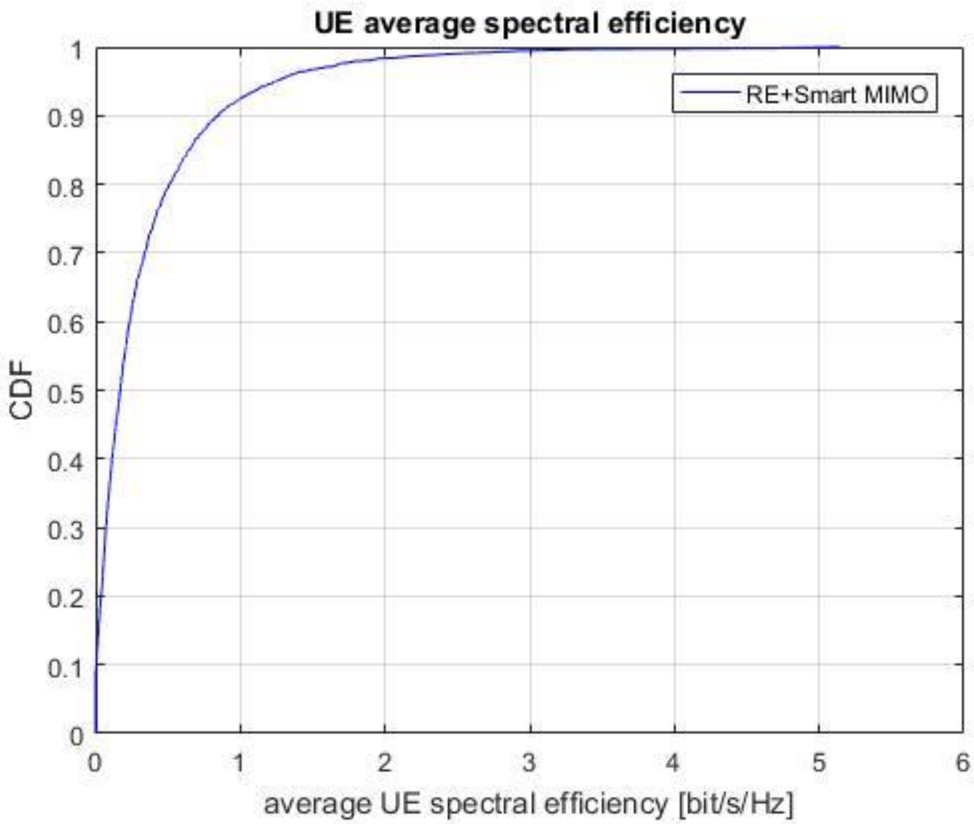

Figure 4–12: Average UE Spectral efficiency of smart antenna case.

4.5 Comparison between all three cases

Four parameters would be evaluated at macro-pico scenario, when the range expansion technique was used and finally when smart antenna is deployed at picocell while using rang expansion, these parameters are SINR, system capacity, spectral efficiency and throughput.

4.5.1 SINR

SINR parameter is evaluated for all cases and the result on Figure 4.15 shows the minimum, mean, and maximum SINR recorded from the UE and there dramatic reduction by 3.9% and more than 100% increase in minimum of SINR value when the RE and then smart antenna are used respectively, for mean of SINR value the gradual fall of more than 100% appears when the RE is used and then smart antenna. For maximum value of SINR, the SINR decrease by 15% and that means the interference increase when the RE technique is applied and the SINR grows again by 24% when smart antenna is used which means intercell interference is reduced which reflect good enhancement on user experience.

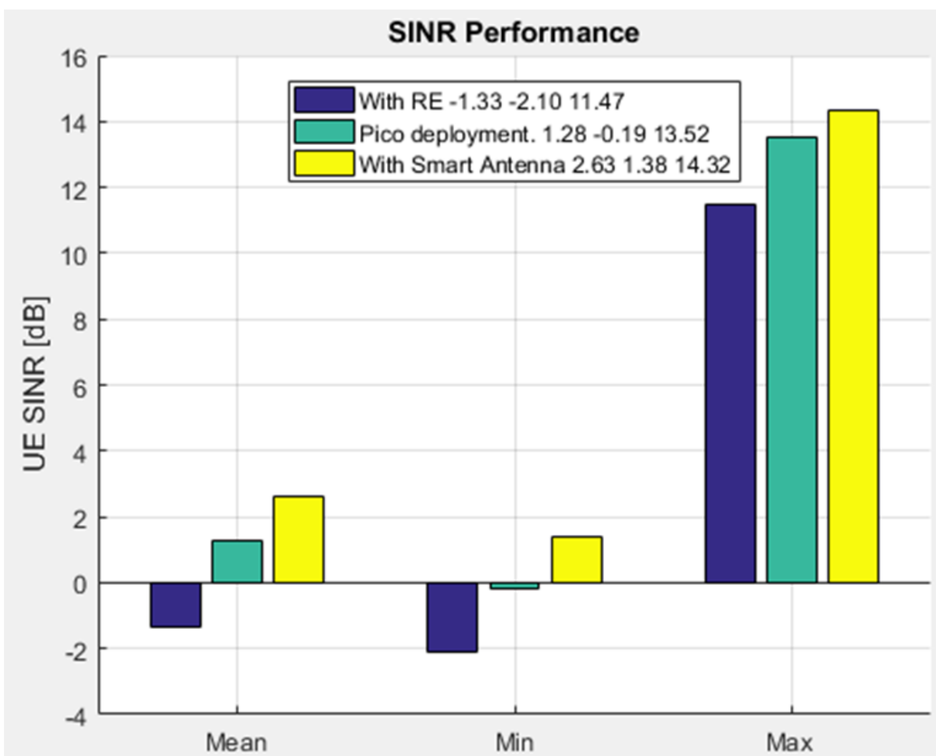

Figure 4–13: Average UE SINR of all cases.

4.5.2 System Capacity

The total number of served users that located randomly on ROI on whole system is showed on Figure 4.13 which presents slight increase on served users by 2.3% after applying RE technique and by 1.11 % for smart antenna case, while the outage users are fall by 62.6% and 82.5% for RE technique and smart antenna case respectively.

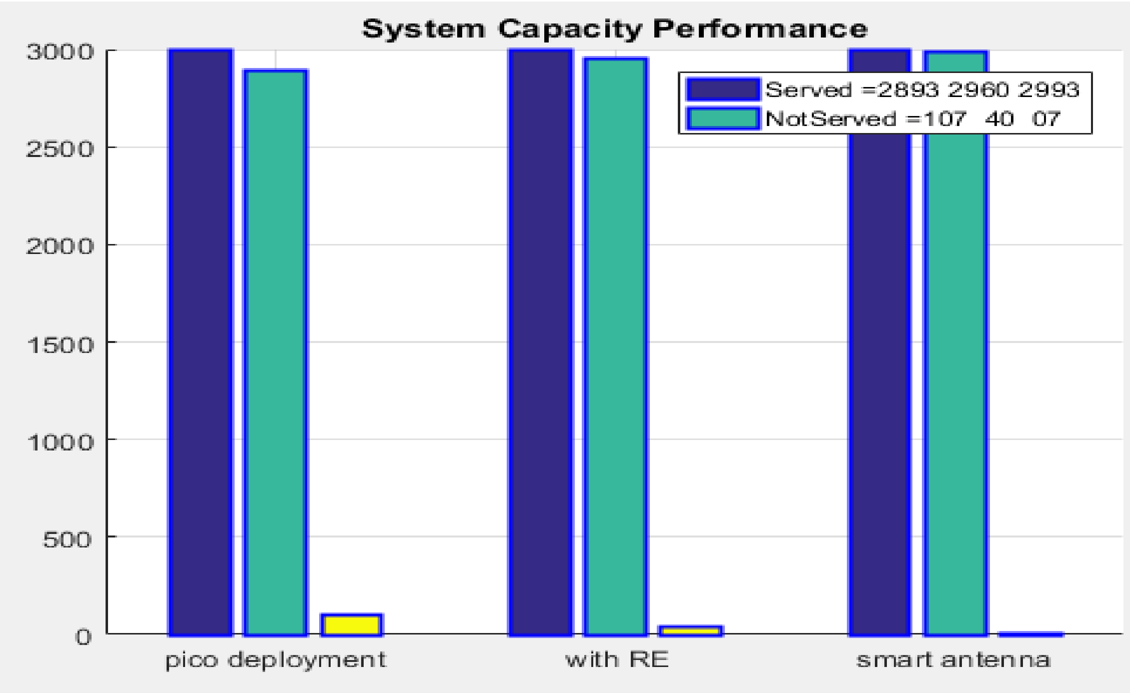

Figure 4–14: system capacity for Pico deployment, RE and Smart antenna.

4.5.3 System Throughput

The average throughput for all cases has been evaluated and the Figure 4.14 Shows the final network throughput performance which increase by more than 50% for minimum, mean and maximum value after RE is applied .Moreover the improvement of SINR reflects on enhancement of throughput which appears in gradual growth when the smart antenna is used at picocell with RE by 22.5% at minimum value, 14% for mean value and 13% for maximum value this increase of throughput means large numbers of message and more data rates would be delivered successfully to terminals and better reliable user experience would be achieved.

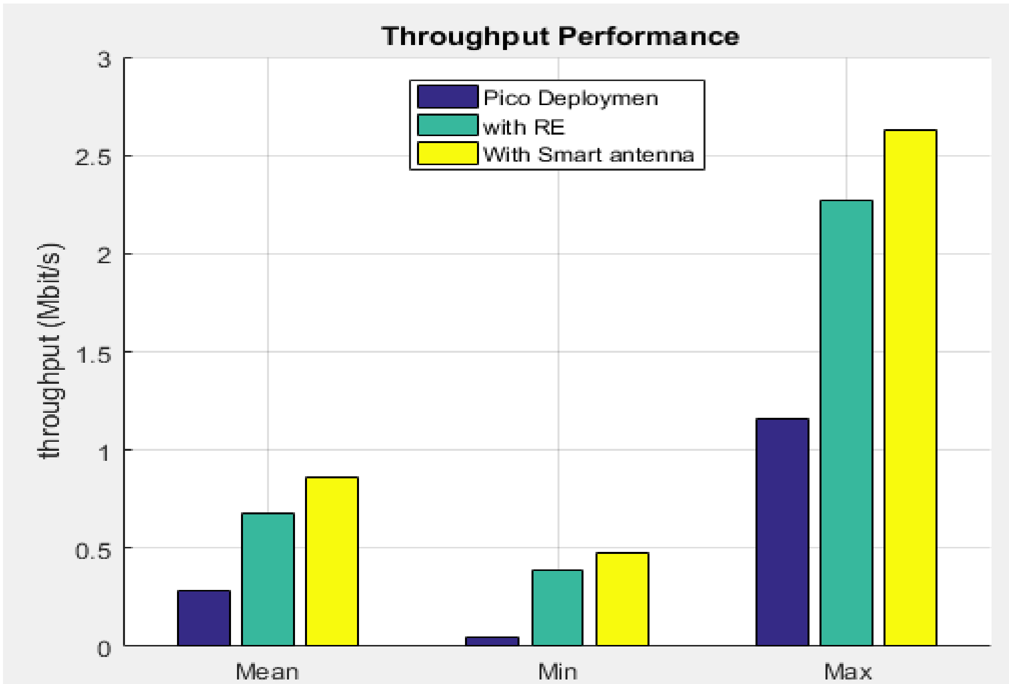

Figure 4–15: System Throughput for all cases.

4.5.4 Spectral efficiency

Figure 4-16 shows the variation of spectral efficiency on three cases. The spectral efficiency is enhanced by more than 100 % in minimum value when the RE is used and 22.5% by deploying smart antenna. The mean value is 100 % enhanced and increased by 14% when RE and smart antenna are used respectively. The maximum value gradually climb by 79.75 % by using RE and 11.7 % by using smart antenna which means more information rate could be transmitted over a given network when these techniques are used.

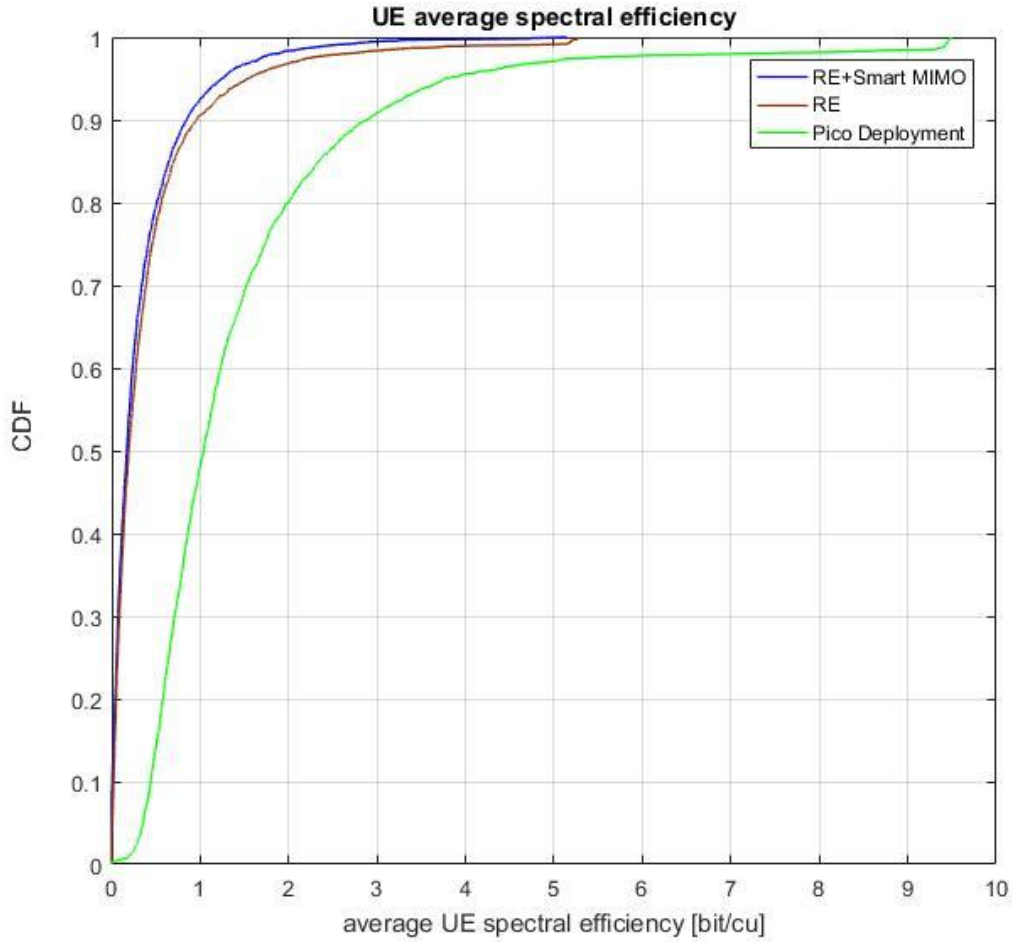

Figure 4–16: Average UE Spectral efficiency of all cases. (Revised +titled).

Chapter Five

Conclusion and Recommendations

5.1 Conclusion

In this thesis the evaluation of heterogeneous networks concentrates on picocell range expansion in LTE-A and deploying of smart antenna has been introduced in order to enhance overall system performance considering SINR and capacity. To summarize that firstly simulation result showed the combination of range expansion and smart antenna that uses precoding technique is a significant techniques to improve heterogonous networks which enhances system capacity by attracting more users to Pico cell to reduce the imbalance of load and traffic between macro cell and Picocell ; the network performance and the user experiences would be enhanced through achieving the main objectives ,system capacity increased by 3.41% with gradual reduction of the outage case, more than 50% improvement on throughput, the spectral enhanced by 57% ,finally there is significant improvement by 24% on SINR and we can say that the main aims of thesis are successfully achieved.

5.2 Recommendations and future works

By the end of this study the combination of these techniques are recommended to be used to:

- Evaluate network system performance on various capacities (number of users on ROI). More illustrated
- Using smart antenna with ICIC to reduce intercell interference.

References

1. Press, E., *Mobile Data Traffic Surpasses Voice*, 2010.
2. Landström, S., et al., *Heterogeneous networks–increasing cellular capacity*. The data boom: opportunities and challenges, 2011. **4**.
3. Cisco, C.V.N.I., *Global mobile data traffic forecast update, 2013–2018.* White paper, 2014.
4. Dahlman, E., S. Parkvall, and J. Skold, *4G: LTE/LTE-advanced for mobile broadband*. 2013: Academic press.
5. Atayero, A.A., et al., *Heterogeneous wireless networks: a survey of interworking architectures.* International Journal of Engineering and Technology, 2012. **2**(1): p. 16-21.
6. Khandekar, A., et al. *LTE-advanced: Heterogeneous networks*. in *Wireless Conference (EW), 2010 European*. 2010. IEEE.
7. Daeinabi, A. and K. Sandrasegaran. *A Proposal for an Enhanced Inter-Cell Interference Coordination Scheme with Cell Range Expansion in LTE-A Heterogeneous Networks*. in *Workshop on Advances in Real-time Information Networks*. 2013.
8. Shirakabe, M., A. Morimoto, and N. Miki. *Performance evaluation of inter-cell interference coordination and cell range expansion in heterogeneous networks for LTE-Advanced downlink*. in *Wireless Communication Systems (ISWCS), 2011 8th International Symposium on*. 2011. IEEE.
9. Chiu, C.-S. and C.-C. Huang. *An interference coordination scheme for picocell range expansion in heterogeneous networks*. in *Vehicular Technology Conference (VTC Spring), 2012 IEEE 75th*. 2012. IEEE.
10. Family, A., *3GPP Long Term Evolution.*
11. Scheme, B.T., *LTE: the evolution of mobile broadband.* IEEE Communications magazine, 2009. **45**.
12. Iwamura, M., A. Umesh, and W.A. Hapsari, *Further Enhancements of LTE─ LTE Release 9─.* NTT DOCOMO Technical Journal, 2010. **12**(1): p. 45-53.
13. SG05, I., *Invitation for submission of proposals for candidate radio interface technologies for the terrestrial components of the radio interface (s) for IMT-Advanced and invitation to participate in their subsequent evaluation,* Circular Letter.
14. ITU, I., *2134, Requirements related to technical performance for IMT-Advanced radio interface (s).* International Telecommunications Union, 2008.

15. Parkvall, S., A. Furuskar, and E. Dahlman, *Evolution of LTE toward IMT-advanced.* IEEE Communications Magazine, 2011. **49**(2): p. 84-91.
16. Parkvall, S., et al. *LTE-Advanced-Evolving LTE towards IMT-Advanced*. in *VTC Fall*. 2008.
17. Joud, M.A., *Pico Cell Range Expansion toward LTE-Advanced Wireless Heterogeneous Networks.* 2013.
18. López-Pérez, D. and X. Chu. *Inter-cell interference coordination for expanded region picocells in heterogeneous networks*. in *Computer Communications and Networks (ICCCN), 2011 Proceedings of 20th International Conference on*. 2011. IEEE.
19. Lopez-Perez, D., et al., *Enhanced intercell interference coordination challenges in heterogeneous networks.* IEEE Wireless Communications, 2011. **18**(3): p. 22-30.
20. Salihu, B.A., Z. Suleiman, and M. Mustapha, *Advances in inter-cell interference coordination for realization of robust Heterogeneous Networks in lte-a systems.* Int. Journal of Eng. Scencei. Invent, 2013. **2**(2): p. 40-48.
21. Sara, L., M. Hideshi, and S. Arne. *Deployment Aspects of LTE Pico Nodes*. in *Proc. IEEE ICC*. 2011.
22. Kudo, T. and T. Ohtsuki, *Cell range expansion using distributed Q-learning in heterogeneous networks.* EURASIP Journal on Wireless Communications and Networking, 2013. **2013**(1): p. 1.
23. Access, E.U.T.R., *Further advancements for E-UTRA physical layer aspects.* 3GPP Technical Specification TR, 2010. **36**: p. V2.
24. Holma, H. and A. Toskala, *LTE for UMTS: Evolution to LTE-advanced*. 2011: John Wiley & Sons.
25. Lee, K.-W., J.-Y. Ko, and Y.-H. Lee, *Fast cell site selection with interference avoidance in cellular packet based OFDM systems.* 2005.
26. Amzallag, D., et al. *Cell planning of 4G cellular networks: Algorithmic techniques, and results*. in *Proceedings of the 6th IEE International Conference on 3G & Beyond G*. 2005.
27. Cong, G., *Pico Cell Densification Study in LTE Heterogeneous Networks*. 2012.
28. Landström, S., et al., *Heterogeneous Networks (HetNets)–an approach to increasing cellular capacity and coverage.* Ericsson review, 2011(1).
29. Landstrom, S., H. Murai, and A. Simonsson. *Deployment aspects of LTE pico nodes*. in *2011 IEEE International Conference on Communications Workshops (ICC)*. 2011. IEEE.

30. Guvenc, I., et al. *Range expansion and inter-cell interference coordination (ICIC) for picocell networks*. in *Vehicular Technology Conference (VTC Fall), 2011 IEEE*. 2011. IEEE.
31. Okino, K., et al. *Pico cell range expansion with interference mitigation toward LTE-Advanced heterogeneous networks*. in *2011 IEEE International Conference on Communications Workshops (ICC)*. 2011. IEEE.
32. Tandel, D. and T. Shah, *Cell Selection Techniques in Heterogeneous LTE-Advanced System.* International Journal on Recent and Innovation Trends in Computing and Communication, 2014. **2**(1): p. 88-91.
33. Bublin, M., et al., *IST-4-027756 WINNER II D4. 7.3 v1. 0 Smart antenna based interference mitigation.*
34. Kraus, J.D. and R.J. Marhefka, *Antenna for all applications.* Upper Saddle River, NJ: McGraw Hill, 2002.
35. Jain, R., S. Katiyar, and N. Agrawal, *Smart antenna for cellular mobile communication.* arXiv preprint arXiv:1204.1790, 2012.
36. Rani, C.S., P. Subbaiah, and K. Reddy, *Smart antenna algorithms for WCDMA mobile communication systems.* International Journal of Computer Science and Network Security (IJCSNS), 2008. **8**(7): p. 182-186.
37. MUBEEN, S., A.J. Rani, and A. Prasad, *Mobile Communication Using SMART Antenna.*
38. Kawitkar, R. *Issues in deploying smart antennas in mobile radio networks*. in *Proceedings of World Academy of Science, Engineering and Technology*. 2008.
39. Stevanovic, I., A. Skrivervik, and J.R. Mosig, *Smart antenna systems for mobile communications*, 2003.
40. Becker, R.T., *Precoding and spatially multiplexed MIMO in 3GPP long-term evolution.* High Frequency Electronics, 2009: p. 18-26.
41. Güvenç, Í., *Capacity and fairness analysis of heterogeneous networks with range expansion and interference coordination.* Communications Letters, IEEE, 2011. **15**(10): p. 1084-1087.
42. Okino, K., et al. *Pico cell range expansion with interference mitigation toward LTE-Advanced heterogeneous networks*. in *Communications Workshops (ICC), 2011 IEEE International Conference on*. 2011. IEEE.
43. Mehlführer, C., et al., *The Vienna LTE simulators-enabling reproducibility in wireless communications research.* EURASIP Journal on Advances in Signal Processing, 2011. **2011**(1): p. 1.

44. Ikuno, J.C., *System level modeling and optimization of the LTE downlink*. 2013: na.
45. Ikuno, J.C., M. Wrulich, and M. Rupp. *System level simulation of LTE networks*. in *Vehicular Technology Conference (VTC 2010-Spring), 2010 IEEE 71st*. 2010. IEEE.
46. Access, E.U.T.R., *LTE physical layer*. General description (Release 10), 2010.

Appendices: System Level Simulation using MATALB

- Launcher for Macrocell Network:

```
clc;
clear;
close all force;

simulation_type = 'tri_sector_tilted';

%% Base configuration
LTE_config = LTE_load_params(simulation_type);
LTE_config.nTX      = 1;
LTE_config.nRX      = 1;
LTE_config.tx_mode = 1;
LTE_config.eNodeB_tx_power               = 10^(46/10)*1/1000;
LTE_config.frequency        = 2.14e9;         % Frequency in Hz
LTE_config.bandwidth        = 20e6;
LTE_config.network_source                = 'generated';
LTE_config.macroscopic_pathloss_model_settings.environment = 'urban';
LTE_config.macroscopic_pathloss_model = 'TS36942';
LTE_config.map_resolution = 10; % In meters/pixel. Also the resolution
used for initial user creation
LTE_config.minimum_coupling_loss = 70; % Minimum Coupling Loss: the
parameter describing the minimum
                    % loss in signal [dB] between BS and UE or UE and
UE in the worst
                    % case and is defined as the minimum distance loss
including
                    % antenna gains measured between antenna
connectors.
                    % Recommended in TS 36.942 are 70 dB for urban
areas, 80 dB for rural.
LTE_config.scheduler                     = 'prop fair Sun'; % prop fair
Sun % round robin
LTE_config.channel_model.type            = 'TU';
LTE_config.UE_speed                      = 50/3.6;
LTE_config.UE_distribution               = 'constant UEs per ROI';
LTE_config.network_geometry                = 'regular_hexagonal_grid';
LTE_config.shadow_fading_type              = 'none';
LTE_config.simulation_time_tti = 25;
LTE_config.feedback_channel_delay=1;
LTE_config.inter_eNodeB_distance = 1000; % In meters. When the network
is generated, this determines the distance between the eNodeBs.
LTE_config.nr_eNodeB_rings = 2;
LTE_config.nUEs = 3000;
% % Misc options
% LTE_config.non_parallel_channel_trace    = true;
LTE_config.show_network                  = 2;
% LTE_config.channel_model.trace_length    = 1;
LTE_config.keep_UEs_still                = true;
LTE_config.compact_results_file          = true;
% LTE_config.compact_results_file          = 3;
LTE_config.delete_ff_trace_at_end        = true;
% LTE_config.UE_cache                        = false;
```

```
% LTE_config.pregenerated_ff_file         = 'auto';
% LTE_config.cache_network = false;

ticIdx = tic;
output_results_file = LTE_sim_main(LTE_config);
time = toc(ticIdx);

simulation_data                   = load(output_results_file);
GUI_handles.aggregate_results_GUI =
LTE_GUI_show_aggregate_results(simulation_data);
GUI_handles.positions_GUI         =
LTE_GUI_show_UEs_and_cells(simulation_data,GUI_handles.aggregate_result
s_GUI);
```

- Picocell Deployment Launcher

```
close all force;
clc;

simulation_type = 'tri_sector_plus_picocells';

%% Base configuration
LTE_config = LTE_load_params(simulation_type);
LTE_config.nTX     = 1;
LTE_config.nRX     = 1;
LTE_config.tx_mode = 1;
LTE_config.eNodeB_tx_power              = 10^(46/10)*1/1000;
LTE_config.frequency       = 2.14e9;          % Frequency in Hz
LTE_config.bandwidth       = 20e6;
LTE_config.network_source               = 'generated';
LTE_config.macroscopic_pathloss_model_settings.environment = 'urban';
LTE_config.macroscopic_pathloss_model = 'TS36942';
LTE_config.map_resolution = 10; % In meters/pixel. Also the resolution
used for initial user creation
LTE_config.minimum_coupling_loss = 70; % Minimum Coupling Loss: the
parameter describing the minimum
                    % loss in signal [dB] between BS and UE or UE and
UE in the worst
                    % case and is defined as the minimum distance loss
including
                    % antenna gains measured between antenna
connectors.
                    % Recommended in TS 36.942 are 70 dB for urban
areas, 80 dB for rural.
LTE_config.scheduler                    = 'prop fair Sun'; % prop fair
Sun % round robin
LTE_config.channel_model.type           = 'TU';
LTE_config.UE_speed                     = 50/3.6;
LTE_config.UE_distribution              = 'constant UEs per ROI';
LTE_config.network_geometry               = 'regular_hexagonal_grid';
LTE_config.shadow_fading_type             = 'none';
LTE_config.simulation_time_tti = 25;
LTE_config.feedback_channel_delay=1;
LTE_config.inter_eNodeB_distance = 1000; % In meters. When the network
is generated, this determines the distance between the eNodeBs.
```

```
LTE_config.nr_eNodeB_rings = 2;
LTE_config.nUEs = 3000;
% % Misc options
% LTE_config.non_parallel_channel_trace    = true;
LTE_config.show_network                    = 2;
% LTE_config.channel_model.trace_length    = 1;
LTE_config.keep_UEs_still                  = true;
LTE_config.compact_results_file            = true;
% LTE_config.compact_results_file           = 3;
LTE_config.delete_ff_trace_at_end          = true;
% LTE_config.UE_cache                       = false;
% LTE_config.pregenerated_ff_file           = 'auto';
% LTE_config.cache_network = false;
LTE_config.add_picocells = true;
LTE_config.picocells_config.spatial_distribution                     =
'homogenous density';
LTE_config.picocells_config.picocells_per_km2 = 1;
LTE_config.picocells_config.minimum_coupling_loss                    =
45; % Minimum coupling loss as specified in TS 36.104
LTE_config.picocells_config.tx_power_W         = 10^(33/10)*1/1000;
LTE_config.picocells_config.macroscopic_pathloss_model               =
'dual slope';
LTE_config.picocells_config.macroscopic_pathloss_model_settings.indoorP
athlossExponent = 0;
LTE_config.picocells_config.macroscopic_pathloss_model_settings.indoorA
reaRadius       = 20; % Radius of indoor area in meter
LTE_config.picocells_config.macroscopic_pathloss_model_settings.wall_lo
ss              = 0; % Wall loss between outdoor and indoor environment
LTE_config.picocells_config.macroscopic_pathloss_model_settings.penetra
tion_loss       =
LTE_config.picocells_config.macroscopic_pathloss_model_settings.wall_lo
ss; % Desired signal experiences penetration loss

ticIdx = tic;
output_results_file = LTE_sim_main(LTE_config);
time = toc(ticIdx);

simulation_data                  = load(output_results_file);
GUI_handles.aggregate_results_GUI =
LTE_GUI_show_aggregate_results(simulation_data);
GUI_handles.positions_GUI         =
LTE_GUI_show_UEs_and_cells(simulation_data,GUI_handles.aggregate_result
s_GUI);
```

Range Expansion Launcher

```
clc;
clear;
close all force;

simulation_type = ''tri_sector_plus_picocells'';
%% Base configuration
LTE_config = LTE_load_params(simulation_type);
LTE_config.nTX     = 1;
LTE_config.nRX     = 1;
LTE_config.tx_mode = 1;
```

```
LTE_config.eNodeB_tx_power                  = 10^(46/10)*1/1000;
LTE_config.eNodeBPico_tx_power              = 10^(40/10)*1/1000;
LTE_config.frequency         = 2.14e9;           % Frequency in Hz
LTE_config.bandwidth         = 20e6;
LTE_config.network_source                   = 'generated';
LTE_config.macroscopic_pathloss_model_settings.environment = 'urban';
LTE_config.macroscopic_pathloss_model = 'TS36942';
LTE_config.map_resolution = 10; % In meters/pixel. Also the resolution
used for initial user creation
LTE_config.minimum_coupling_loss = 70; % Minimum Coupling Loss: the
parameter describing the minimum
                    % loss in signal [dB] between BS and UE or UE and
UE in the worst
                    % case and is defined as the minimum distance loss
including
                    % antenna gains measured between antenna
connectors.
                    % Recommended in TS 36.942 are 70 dB for urban
areas, 80 dB for rural.
LTE_config.scheduler                        = 'prop fair Sun'; % prop fair
Sun % round robin
LTE_config.channel_model.type               = 'TU';
LTE_config.UE_speed                         = 50/3.6;
LTE_config.UE_distribution                  = 'constant UEs per ROI';
LTE_config.network_geometry                   = 'regular_hexagonal_grid';
LTE_config.shadow_fading_type                 = 'none';
LTE_config.simulation_time_tti = 25;
LTE_config.feedback_channel_delay=1;
LTE_config.inter_eNodeB_distance = 1000; % In meters. When the network
is generated, this determines the distance between the eNodeBs.
LTE_config.nr_eNodeB_rings = 2;
LTE_config.nUEs = 3000;
% % Misc options
% LTE_config.non_parallel_channel_trace    = true;
LTE_config.show_network                     = 2;
% LTE_config.channel_model.trace_length    = 1;
LTE_config.keep_UEs_still                   = true;
LTE_config.compact_results_file             = true;
% LTE_config.compact_results_file            = 3;
LTE_config.delete_ff_trace_at_end           = true;
% LTE_config.UE_cache                        = false;
% LTE_config.pregenerated_ff_file            = 'auto';
% LTE_config.cache_network = false;
LTE_config.generate_RSRP_cell                  = true;
 LTE_config.generate_serving_cell               =true;
%received power from %pico cell expanded range)

%expanded grange

LTE_config.generate_serving_cell= RSRP+8;

ticIdx = tic;
output_results_file = LTE_sim_main(LTE_config);
time = toc(ticIdx);

simulation_data                   = load(output_results_file);
```

```
GUI_handles.aggregate_results_GUI =
LTE_GUI_show_aggregate_results(simulation_data);
GUI_handles.positions_GUI         =
LTE_GUI_show_UEs_and_cells(simulation_data,GUI_handles.aggregate_result
s_GUI);
```

Smart Antenna Launcher

```
clc;
clear;
close all force;

simulation_type = 'tri_sector_plus_picocells';

%% Base configuration
LTE_config = LTE_load_params(simulation_type);
LTE_config.nTX     = 4;
LTE_config.nRX     = 4;
LTE_config.tx_mode = 4;
LTE_config.eNodeB_tx_power              = 10^(46/10)*1/1000;
LTE_config.eNodeBPico_tx_power              = 10^(40/10)*1/1000;
LTE_config.frequency       = 2.14e9;          % Frequency in Hz
LTE_config.bandwidth       = 20e6;
LTE_config.network_source               = 'generated';
LTE_config.macroscopic_pathloss_model_settings.environment = 'urban';
LTE_config.macroscopic_pathloss_model = 'TS36942';
LTE_config.map_resolution = 10; % In meters/pixel. Also the resolution
used for initial user creation
LTE_config.minimum_coupling_loss = 70; % Minimum Coupling Loss: the
parameter describing the minimum
                    % loss in signal [dB] between BS and UE or UE and
UE in the worst
                    % case and is defined as the minimum distance loss
including
                    % antenna gains measured between antenna
connectors.
                    % Recommended in TS 36.942 are 70 dB for urban
areas, 80 dB for rural.
LTE_config.scheduler                    = 'prop fair Sun'; % prop fair
Sun % round robin
LTE_config.channel_model.type           = 'TU';
LTE_config.UE_speed                     = 50/3.6;
LTE_config.UE_distribution              = 'constant UEs per ROI';
LTE_config.network_geometry               = 'regular_hexagonal_grid';
LTE_config.shadow_fading_type             = 'none';
LTE_config.simulation_time_tti = 25;
LTE_config.feedback_channel_delay=1;
LTE_config.inter_eNodeB_distance = 1000; % In meters. When the network
is generated, this determines the distance between the eNodeBs.
LTE_config.nr_eNodeB_rings = 2;
LTE_config.nUEs = 3000;
% % Misc options
% LTE_config.non_parallel_channel_trace   = true;
LTE_config.show_network                 = 2;
% LTE_config.channel_model.trace_length   = 1;
LTE_config.keep_UEs_still               = true;
```

```
LTE_config.compact_results_file          = true;
% LTE_config.compact_results_file          = 3;
LTE_config.delete_ff_trace_at_end        = true;
LTE_config.UE_cache                      = false;
% LTE_config.pregenerated_ff_file          = 'auto';
% LTE_config.cache_network = false;
LTE_config.add_picocells = true;
LTE_config.picocells_config.spatial_distribution                     =
'homogenous density';
LTE_config.picocells_config.picocells_per_km2 = 1;
LTE_config.picocells_config.minimum_coupling_loss                    =
45; % Minimum coupling loss as specified in TS 36.104
LTE_config.picocells_config.tx_power_W         = 10^(33/10)*1/1000;
LTE_config.picocells_config.macroscopic_pathloss_model               =
'dual slope';
LTE_config.picocells_config.macroscopic_pathloss_model_settings.indoorP
athlossExponent = 0;
LTE_config.picocells_config.macroscopic_pathloss_model_settings.indoorA
reaRadius       = 20; % Radius of indoor area in meter
LTE_config.picocells_config.macroscopic_pathloss_model_settings.wall_lo
ss              = 0; % Wall loss between outdoor and indoor environment
LTE_config.picocells_config.macroscopic_pathloss_model_settings.penetra
tion_loss       =
LTE_config.picocells_config.macroscopic_pathloss_model_settings.wall_lo
ss; % Desired signal experiences penetration loss

ticIdx = tic;
output_results_file = LTE_sim_main(LTE_config);
time = toc(ticIdx);

simulation_data  = load(output_results_file);
GUI_handles.aggregate_results_GUI =
LTE_GUI_show_aggregate_results(simulation_data);
GUI_handles.positions_GUI         =
LTE_GUI_show_UEs_and_cells(simulation_data,GUI_handles.aggregate_result
s_GUI);
clc;
clear;
close all force;

simulation_type = 'tri_sector_plus_picocells';

%% Base configuration
LTE_config = LTE_load_params(simulation_type);
LTE_config.nTX     = 4;
LTE_config.nRX     = 4;
LTE_config.tx_mode = 4;
LTE_config.eNodeB_tx_power              = 10^(46/10)*1/1000;
LTE_config.frequency       = 2.14e9;          % Frequency in Hz
LTE_config.bandwidth       = 20e6;
LTE_config.network_source               = 'generated';
LTE_config.macroscopic_pathloss_model_settings.environment = 'urban';
LTE_config.macroscopic_pathloss_model = 'TS36942';
LTE_config.map_resolution = 10; % In meters/pixel. Also the resolution
used for initial user creation
```

```
LTE_config.minimum_coupling_loss = 70; % Minimum Coupling Loss: the
parameter describing the minimum
                    % loss in signal [dB] between BS and UE or UE and
UE in the worst
                    % case and is defined as the minimum distance loss
including
                    % antenna gains measured between antenna
connectors.
                    % Recommended in TS 36.942 are 70 dB for urban
areas, 80 dB for rural.
LTE_config.scheduler                    = 'prop fair Sun'; % prop fair
Sun % round robin
LTE_config.channel_model.type           = 'TU';
LTE_config.UE_speed                     = 50/3.6;
LTE_config.UE_distribution              = 'constant UEs per ROI';
LTE_config.network_geometry               = 'regular_hexagonal_grid';
LTE_config.shadow_fading_type             = 'none';
LTE_config.simulation_time_tti = 25;
LTE_config.feedback_channel_delay=1;
LTE_config.inter_eNodeB_distance = 1000; % In meters. When the network
is generated, this determines the distance between the eNodeBs.
LTE_config.nr_eNodeB_rings = 2;
LTE_config.nUEs = 3000;
% % Misc options
% LTE_config.non_parallel_channel_trace   = true;
LTE_config.show_network                 = 2;
% LTE_config.channel_model.trace_length   = 1;
LTE_config.keep_UEs_still               = true;
LTE_config.compact_results_file         = true;
% LTE_config.compact_results_file         = 3;
LTE_config.delete_ff_trace_at_end       = true;
LTE_config.UE_cache                     = false;
% LTE_config.pregenerated_ff_file         = 'auto';
% LTE_config.cache_network = false;
LTE_config.add_picocells = true;
LTE_config.picocells_config.spatial_distribution                     =
'homogenous density';
LTE_config.picocells_config.picocells_per_km2 = 1;
LTE_config.picocells_config.minimum_coupling_loss                    =
45; % Minimum coupling loss as specified in TS 36.104
LTE_config.picocells_config.tx_power_W         = 10^(33/10)*1/1000;
LTE_config.picocells_config.macroscopic_pathloss_model               =
'dual slope';
LTE_config.picocells_config.macroscopic_pathloss_model_settings.indoorP
athlossExponent = 0;
LTE_config.picocells_config.macroscopic_pathloss_model_settings.indoorA
reaRadius       = 20; % Radius of indoor area in meter
LTE_config.picocells_config.macroscopic_pathloss_model_settings.wall_lo
ss              = 0; % Wall loss between outdoor and indoor environment
LTE_config.picocells_config.macroscopic_pathloss_model_settings.penetra
tion_loss       =
LTE_config.picocells_config.macroscopic_pathloss_model_settings.wall_lo
ss; % Desired signal experiences penetration loss

ticIdx = tic;
output_results_file = LTE_sim_main(LTE_config);
```

```
time = toc(ticIdx);

simulation_data  = load(output_results_file);
GUI_handles.aggregate_results_GUI =
LTE_GUI_show_aggregate_results(simulation_data);
GUI_handles.positions_GUI         =
LTE_GUI_show_UEs_and_cells(simulation_data,GUI_handles.aggregate_result
s_GUI);



clc;
clear;
close all force;

simulation_type = 'tri_sector_plus_picocells';

%% Base configuration
LTE_config = LTE_load_params(simulation_type);
LTE_config.nTX     = 4;
LTE_config.nRX     = 4;
LTE_config.tx_mode = 4;
LTE_config.eNodeB_tx_power              = 10^(46/10)*1/1000;
LTE_config.frequency       = 2.14e9;         % Frequency in Hz
LTE_config.bandwidth       = 20e6;
LTE_config.network_source               = 'generated';
LTE_config.macroscopic_pathloss_model_settings.environment = 'urban';
LTE_config.macroscopic_pathloss_model = 'TS36942';
LTE_config.map_resolution = 10; % In meters/pixel. Also the resolution
used for initial user creation
LTE_config.minimum_coupling_loss = 70; % Minimum Coupling Loss: the
parameter describing the minimum
                    % loss in signal [dB] between BS and UE or UE and
UE in the worst
                    % case and is defined as the minimum distance loss
including
                    % antenna gains measured between antenna
connectors.
                    % Recommended in TS 36.942 are 70 dB for urban
areas, 80 dB for rural.
LTE_config.scheduler                    = 'prop fair Sun'; % prop fair
Sun % round robin
LTE_config.channel_model.type           = 'TU';
LTE_config.UE_speed                     = 50/3.6;
LTE_config.UE_distribution              = 'constant UEs per ROI';
LTE_config.network_geometry               = 'regular_hexagonal_grid';
LTE_config.shadow_fading_type             = 'none';
LTE_config.simulation_time_tti = 25;
LTE_config.feedback_channel_delay=1;
LTE_config.inter_eNodeB_distance = 1000; % In meters. When the network
is generated, this determines the distance between the eNodeBs.
LTE_config.nr_eNodeB_rings = 2;
LTE_config.nUEs = 3000;
% % Misc options
% LTE_config.non_parallel_channel_trace   = true;
LTE_config.show_network                 = 2;
```

```
% LTE_config.channel_model.trace_length   = 1;
LTE_config.keep_UEs_still                = true;
LTE_config.compact_results_file          = true;
% LTE_config.compact_results_file         = 3;
LTE_config.delete_ff_trace_at_end        = true;
LTE_config.UE_cache                      = false;
% LTE_config.pregenerated_ff_file         = 'auto';
% LTE_config.cache_network = false;
LTE_config.add_picocells = true;
LTE_config.picocells_config.spatial_distribution                     =
'homogenous density';
LTE_config.picocells_config.picocells_per_km2 = 1;
LTE_config.picocells_config.minimum_coupling_loss                    =
45; % Minimum coupling loss as specified in TS 36.104
LTE_config.picocells_config.tx_power_W          = 10^(33/10)*1/1000;
LTE_config.picocells_config.macroscopic_pathloss_model               =
'dual slope';
LTE_config.picocells_config.macroscopic_pathloss_model_settings.indoorP
athlossExponent = 0;
LTE_config.picocells_config.macroscopic_pathloss_model_settings.indoorA
reaRadius       = 20; % Radius of indoor area in meter
LTE_config.picocells_config.macroscopic_pathloss_model_settings.wall_lo
ss              = 0; % Wall loss between outdoor and indoor environment
LTE_config.picocells_config.macroscopic_pathloss_model_settings.penetra
tion_loss       =
LTE_config.picocells_config.macroscopic_pathloss_model_settings.wall_lo
ss; % Desired signal experiences penetration loss

ticIdx = tic;
output_results_file = LTE_sim_main(LTE_config);
time = toc(ticIdx);

simulation_data  = load(output_results_file);
GUI_handles.aggregate_results_GUI =
LTE_GUI_show_aggregate_results(simulation_data);
GUI_handles.positions_GUI          =
LTE_GUI_show_UEs_and_cells(simulation_data,GUI_handles.aggregate_result
s_GUI);
```