Indoor Models of Heterogeneous Networks

Khaled Ardah

Master of Science (120 credits)  
Computer Science and Engineering

Luleå University of Technology  
Department of Computer Science, Electrical and Space Engineering
Indoor Models of Heterogeneous Networks

Khaled Ardah
Mobile Systems Master Program
Department of Computer Science, Electrical and Space Engineering
Luleå University of Technology
S-97187, Luleå, Sweden
September, 2012

Supervisors
Magnus Thurfjell
Ericsson Research AP, Luleå
Professor Christer Åhlund
Luleå University of Technology
Abstract

Technology evolution over the last few years added many demands on mobile networks. To be able to support and handle the new technologies requirement and keep the customers satisfied, network operators need to increase the capacity, coverage, and performance of their networks. Low power nodes considered a promising method to satisfy future demands. This thesis work describes implementation of the 3GPP indoor pico models (TR36.814) for LTE heterogeneous networks and investigations by means of simulation for different scenarios to better understand the impacts of deployment position, interference, and load balance on system performance. The simulator is MATLAB based provided from Ericsson Research AP.

It has found that, pico nodes coverage area is limited to indoor. In most of the cases, the transition zone area (i.e. where the optimal cell selections differ between downlink and uplink) is covered by the building wall. The users in the transition zone area indoors have acceptable performance, comparing with the ones outdoor, since degrade in their SINR level is less. In addition, low power nodes are able to handle larger load traffic share than macro nodes since they are more protected thus they have better channel conditions than macro nodes.
Acknowledgements

This master thesis work was carried out at Wireless IP Optimization, Ericsson Research AP, Luleå. My sincere gratitude goes to Mr. Magnus Thurnejell, who was my supervisor at Ericsson, for all advice, guidance, and supports that given to me. I am very much thankful to my manager at Ericsson, Mr. Sven Olof Jonsson, for giving me the opportunity to gain experience and knowledge at Ericsson research and for continued support and understanding.

The support and feedback received from the staff at Ericsson research during the meetings and review presentation had been invaluable. I am very much thankful to Mr. Arne Simonsson and Mr. Per Burström, just to name a few.

I am thankful to my supervisor at university, Professor Christer Åhlund for initial advice, guidance and for reviewing my work.
List of figures

Figure 3.1: Expected users’ data growth ..................................................................................................................... 18
Figure 3.2: Heterogeneous networks deployment ..................................................................................................... 19
Figure 3.3: Handover in homogenous networks vs. Heterogeneous networks .......................................................... 21
Figure 3.4: Downlink and uplink pico coverage ........................................................................................................ 23
Figure 3.5: Dominant DL and UL cross-tier interference scenarios in heterogeneous networks ............................. 24
Figure 3.6: LTE resource block ..................................................................................................................................... 25
Figure 3.7: LTE Rel-8 ICIC .......................................................................................................................................... 25
Figure 3.8: PCFICH control channels .......................................................................................................................... 26
Figure 3.9: PHICH control channels ............................................................................................................................ 26
Figure 3.10: PDCCH control channels ......................................................................................................................... 26
Figure 3.11: Frequency domain eICIC ......................................................................................................................... 27
Figure 3.12: Time domain eICIC .................................................................................................................................. 28
Figure 3.13: Picocells throughputs comparing with WI-FI throughputs ................................................................. 29
Figure 4.1: Sketch of indoor hotspot environment ...................................................................................................... 32
Figure 4.2: Pathloss analysis for pico coverage area at different positions with two ISD systems ......................... 34
Figure 4.3: Reference Case, description of building and hotspot deployment .......................................................... 36
Figure 4.4: Users distribution for the reference case .................................................................................................. 37
Figure 4.5: Downlink bit rates for the reference case .................................................................................................. 38
Figure 4.6: 5th percentile of users downlink bits rates for the reference case .......................................................... 39
Figure 4.7: Downlink average SINR curves for the reference case ........................................................................... 40
Figure 4.8: Uplink bit rates for the reference case ........................................................................................................ 40
Figure 4.9: Uplink Average SINR for the reference case ........................................................................................... 41
Figure 4.10: Macro-Pico downlink bit rates compared with Macro-Only downlink bit rates for the reference case ......................................................................................................................................................... 42
Figure 4.11: Macro-Pico downlink average SINR compared with Macro-Only downlink average SINR for the reference case ................................................................................................................................................................................................................................. 42
Figure 4.12: Macro-Pico uplink bit rates compared with Macro-Only uplink bit rates for the reference case ...... 43
Figure 4.13 Macro-Pico uplink average SINR compared with Macro-Only uplink average SINR for the reference case ................................................................................................................................................................................................................................. 43
Figure 4.14: Deployment scenario for varying building position ................................................................................. 44
Figure 4.15: Users distribution for varying building position ................................................................. 45
Figure 4.16: Downlink bit rates for varying building position ................................................................. 45
Figure 4.17: Downlink average SINR for varying building position ......................................................... 46
Figure 4.18: Uplink bit rates for varying building position ................................................................. 47
Figure 4.19: Uplink average SINR for varying building position ............................................................ 47
Figure 4.20: Macro-Pico downlink bit rates compared with Macro-Only downlink bit rates for varying building position ............................................................................................................ 48
Figure 4.21: Macro-Pico downlink average SINR compared with Macro-Only downlink average SINR for varying building position ............................................................................................................ 48
Figure 4.22: Overall systems uplink bit rates for varying building position ............................................. 49
Figure 4.23: Overall systems uplink average SINR for varying building position ........................................ 49
Figure 4.24: Users distribution for varying hotspot density with lower density ........................................ 50
Figure 4.25: Downlink bit rates for varying hotspot density with lower density ....................................... 51
Figure 4.26: Downlink average SINR for varying hotspot density with lower density ................................ 52
Figure 4.27: Uplink bit rates for varying hotspot density with lower density ........................................... 52
Figure 4.28: Uplink average SINR for varying hotspot density with lower density .................................... 53
Figure 4.29: Users distribution for varying hotspot density with higher density ........................................ 54
Figure 4.30: Downlink bit rates for varying hotspot density with higher density ..................................... 55
Figure 4.31: Downlink average SINR for varying hotspot density with higher density ............................. 55
Figure 4.32: Uplink bit rates for varying hotspot density with higher density .......................................... 56
Figure 4.33: Uplink average SINR for varying hotspot density with higher density .................................. 56
Figure 4.34: 50th percentile Downlink bit rates for different systems with different hotspot density ........ 57
Figure 4.35: Downlink bit rates for different systems with different hotspot density ................................. 58
Figure 4.36: 50th percentile Uplink bit rates for different systems with different hotspot density ............. 58
Figure 4.37: Uplink bit rates for different systems with different hotspot density ....................................... 59
Figure 4.38: Sketch of indoor deployment with different hotspot size ..................................................... 60
Figure 4.39: Users distribution for varying hotspot size with smaller size ................................................. 61
Figure 4.40: Downlink bit rates for varying hotspot size with smaller size ............................................. 61
Figure 4.41: Downlink SINR for varying hotspot size with smaller size ................................................ 62
Figure 4.42: Uplink bit rates for varying hotspot size with smaller size ................................................ 62
Figure 4.43: Uplink average SINR for varying hotspot size with smaller size ........................................ 63
Figure 4.44: Users distribution for varying hotspot size with larger size

Figure 4.45: Downlink bit rates for varying hotspot size with larger size

Figure 4.46: Downlink SINR for varying hotspot size with larger size

Figure 4.47: Uplink bit rates for varying hotspot size with larger size

Figure 4.48: Uplink average SINR for varying hotspot size with larger size

Figure 4.49: 50th percentile downlink bit rates for different systems with different hotspot size

Figure 4.50: Downlink bit rates for different systems with different hotspot size

Figure 4.51: 50th percentile uplink bit rates for different systems with different hotspot size

Figure 4.52: Uplink bit rates for different systems with different hotspot size
List of Tables

Table 1.1: Mobile networks road map .......................................................................................................................... 13

Table 2.1: LTE specifications ........................................................................................................................................ 16

Table 3.1: Heterogeneous networks nodes characteristics .......................................................................................... 20

Table 4.1: Channel model 1 of indoor pico nodes ........................................................................................................ 32

Table 4.2: System deployment parameters ................................................................................................................... 33

Table 4.3: Deployment parameters for the reference case .......................................................................................... 36

Table 4.4: Deployment parameters for varying building position .............................................................................. 44

Table 4.5: Deployment parameters for varying hotspot density with smaller size ......................................................... 50

Table 4.6: Deployment parameters for Varying hotspot density with larger size ............................................................ 53

Table 4.7: Deployment parameters for varying hotspot size with smaller size ........................................................... 60

Table 4.8: Deployment parameters for varying hotspot size with larger size ............................................................... 63
## List of Abbreviations

1G: First Generation  
2G: Second Generation  
3G: Third Generation  
4G: Fourth Generation  
3GPP: 3rd Generation Partnership Project  
ABSF: Almost Blank Sub-Frames  
AMPS: Advanced Mobile Phone System  
CDMA: Code-Division Multiple Access  
DL: Downlink  
EGPRS: Enhanced General Packet Radio Services  
eNB: eNodeB  
E-UTRAN: Evolved-UMTS Terrestrial Radio Access Network  
FDD: Frequency-Division Duplex  
GPRS: General Packet Radio Services  
HeNB: Home eNodeB  
HSDPA: High-Speed Downlink Packet Access  
HSPA: High-Speed Packet Access  
HSPA+: High-Speed Packet Access Plus  
ICIC: Inter-Cell Interference Coordination  
IMT: International Mobile Telecommunication  
LTE: Long Term Evolution  
MIMO: Multiple-Input Multiple-Output  
NMT: Nordic Mobile Telephony  
NTT: Nippon Telegraph and Telephone  
OFDM: Orthogonal Frequency-Division Multiplexing  
OFDMA: Orthogonal Frequency-Division Multiple Access  
PCFICH: Physical Control Format Indicator Channel  
PDCCH: Physical Downlink Control Channel  
PHICH: Physical Hybrid ARQ Indicator Channel  
QAM: Quadrature Amplitude Modulation  
QPSK: Quadrature Phase-Shift Keying  
RAN: Radio Access Network  
RB: Resource Block  
PDC: Personal Digital Cellular  
IS: Interim Standard  
RE: Range Extension  
SC-OFDM: Single Carrier OFDM  
SINR: Signal-to-Interference plus Noise Ratio  
TDD: Time-Division Duplex  
TACS: Total Access Communications System  
TDMA: Time-Division Multiple Access  
UE: User Equipment  
UL: Uplink  
UMTS: Universal Mobile Telecommunication System  
WCDMA: Wide Band Code-Division Multiple Access  
SCM: Spatial Channel Model  
ISD: Inter-Site Distance  
PL: minimal Pathloss cell selection  
RSRP: Reference Signal Received Power  
LOS: Line Of Sight  
NLOS: None Line Of Sight  
EDGE: Enhanced Data rates for GSM Evolution
1 Background

1.1 Roadmap to 4G Mobile Networks

Since the introduction of the first mobile network in 1980, the development process went through many phases and generations driving the mobile networks to better performance, coverage, capacity, user throughputs, and simplified networks for easy deployments and cost reduction.

The first generation (1G) was analog system using circuit switching, providing up to 1.9 kbps for voice communication. NMT and TACS were in Europe, NTT in Japan, and AMPS in USA. The 2G was the first step for digital mobile communications which is more spectral efficient. The second generation (2G) provide higher data throughput up to 14.4 kbps for voice communication and short messaging. GSM system was the European one, where IS-54/136/95 systems and PDC system were in USA and Japan respectively. Data communication was firstly introduced in 1999 by the introduction of GPRS over the GSM, that was called 2.5G by using circuit switching for the access network, and air interface, as long packet switching for the core network and data, provides 14.4 kbps for voice and data communications [3].

Third Generation Partnership Project (3GPP) started in 1998 with a scope of making a globally applicable third generation mobile networks based on evolved GSM/GPRS/EDGE applications within the scope of IMT-2000 ITU. 3GPP standards are structured as Releases for both FDD and TDD modes. Table 1.1 shows the evolution process till the introduction of the 4G LTE-Advanced in Release-10/11 driven by data rates and latency requirements [4].

<table>
<thead>
<tr>
<th>FDD evolution</th>
<th>WCDMA (UMTS)</th>
<th>HSDPA/ HSUPA</th>
<th>HSPA+</th>
<th>LTE &amp; HSPA+</th>
<th>LTE-Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDD evolution</td>
<td>TD-SCDMA</td>
<td>TD-HSDPA</td>
<td>TD-HSUPA</td>
<td>TD-LTE &amp; TD-HSPA+</td>
<td></td>
</tr>
<tr>
<td>3GPP release</td>
<td>Rel-99/4</td>
<td>Rel-5/6</td>
<td>Rel-7</td>
<td>Rel-8</td>
<td>Rel-10/11</td>
</tr>
<tr>
<td>App year of network rollout</td>
<td>2003/4</td>
<td>2005/6 (HSDPA)</td>
<td>2007/8(HSUPA)</td>
<td>2008/9</td>
<td>2010</td>
</tr>
<tr>
<td>Downlink data rate</td>
<td>384 kbps</td>
<td>14 Mbps</td>
<td>28 Mbps</td>
<td>LTE 150 Mbps*</td>
<td>100 Mbps high mobility</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HSPA+ 42 Mbps</td>
<td>1 Gbps low mobility</td>
</tr>
<tr>
<td>Uplink data rate</td>
<td>128 kbps</td>
<td>5.7 Mbps</td>
<td>11 Mbps</td>
<td>LTE 75 Mbps</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HSPA+ 11 Mbps</td>
<td></td>
</tr>
<tr>
<td>Round time trip</td>
<td>~ 150 ms</td>
<td>&lt; 100 ms</td>
<td>&lt; 50 ms</td>
<td>LTE ~10 ms</td>
<td></td>
</tr>
</tbody>
</table>

* based on 2x2 MIMO and 20 MHz operation

Table 1.1: Mobile networks road map
1.2 Problem Statement

We are living in the communication generation, ubiquitous networking, pervasive computing, and Internet of things where everything is connected anywhere anytime. Everything is developing fast, new technologies born every day as long more capable smart phones and users are getting more experience. All of these developments add more demands on the wireless mobile networks; thereby the network operators have to be prepared to satisfy the users and the new technologies demands.

Many operators are migrating to LTE to meet these requirements, but are preparing also for further capacity improvements. Typically, the starting point is a macro cell network where each base station serves a relatively large geographical area. To increase the capacity; macro base station functionality can be improved and more macro base stations can be deployed, decreasing the distance to the users to be served. Increasing capacity and coverage using this way is time and money consumption and in some places it is even hard to deploy. An alternative way where it should be more flexible, cheap, and easy to deploy is needed. LTE introduce such a deployment in Rel-10 called Heterogeneous Networks.

Complementing macrocells with different types of low power nodes such as Femtocells, Picocells, and Relays where they have different backhaul connectivity, antenna patterns, and processing schemes, will improve the system performance. Ideally, low power nodes offload traffic from macrocells so that it will improve the performance for the remaining macrocell users as fewer users share the resources, also the low power nodes users will have better channel conditions thus better data rates per resource block.

Interference and imbalanced network traffic are the main challenges in heterogeneous networks deployment. In LTE-Advanced, new techniques introduced to support heterogeneous networks deployment. Enhanced ICIC introduced as new resources coordination as long with a new cell selection called Range Expansion for further increase the low power nodes coverage areas and reduce the uplink interference. Low power nodes location related to the macrocell, and cell selection strategy being used control their coverage area and performance. Extending the low power nodes coverage by using the minimal pathloss as the cell selection enhance the uplink performance but on the other hand it sacrifices the downlink performance, thereby users in heterogeneous networks should be connected to the cell that make sense to them in both links; downlink and uplink.

The aim of this master thesis is to:

- Implement the indoor models for heterogeneous networks picocells specified in the 3GPP TR36.814 [18].
- Investigates and verify these models focusing on deployment aspects like interference situations, coverage area, and performance.
1.3 Thesis Outline

The structure of this thesis report is organized as follow: Chapter 2 gives a brief introduction about 3GPP LTE. Chapter 3 gives the detail information about heterogeneous networks in LTE. Chapter 4 presents the deployment aspects and simulation results. Chapter 5 discus, conclude the thesis and list the future works.
2 Introduction to LTE

LTE is accepted worldwide as the long-term evolution perspective for today’s 2G and 3G networks based on WCDMA/HSPA, GSM/EDGE, TD-SCDMA, and CDMA-2000 technologies. Works on LTE was initiated as a 3GPP Rel-7 study item “Evolved UTRA and UTRAN” in 2004 [7].

“With enhancements such as HSDPA and enhanced uplink, the 3GPP radio access technology will be highly competitive for several years. However, to ensure competitiveness in an even longer time frame, i.e. for the next 10 years and beyond, along term evolution of 3GPP radio access technology needs to be considered”

Reduce latency, higher data throughputs, improves system capacity and coverage, with cost reduction and more simplify networks was the key driven parameters for 3GPP LTE.

LTE based on Rel-8 seen as an evolution of its predecessors standards operating on the same spectrum with new radio interfaces for downlink using OFDMA to providing a peak rate up to 100 Mbps and SC-FDMA for uplink with peak rate up to 50 Mbps.

LTE operates in both paired (FDD) and unpaired (TDD) spectrums, where it supports a wide range of spectrums (1.4, 3, 5 10, 15, and 20) MHz with different type of modulation techniques. Table 2.1 shows the LTE specifications [1,4].

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>UMTS FDD &amp; TDD bands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel BW 1 RB = 180kHz</td>
<td>1.4MHZ 3MHZ 5MHZ 10MHZ 15MHZ 20MHZ</td>
</tr>
<tr>
<td>6 RB</td>
<td>15 RB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Modulation Schemes</th>
<th>Downlink: QPSK, 16QAM, 64QAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uplink: QPSK, 16QAM, 64QAM (optional for handset)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Multiple Access</th>
<th>Downlink: OFDMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uplink: SC-FDMA</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MIMO</th>
<th>Downlink: Wide choice of MIMO configuration options for transmit diversity and spatial multiplexing (max of 4x4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uplink: Multi user collaborative MIMO</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak data rate</th>
<th>Downlink: 150 Mbps (2x2 MIMO, 20 MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 Mbps (4x4 MIMO, 20 MHz)</td>
<td></td>
</tr>
<tr>
<td>Uplink: 75 Mbps (20 MHz)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1: LTE specifications

LTE provides a smooth introduction towards 4th Generation (4G) networks to satisfy the requirements of International Mobile Telecommunications (IMT-Advanced) defined by the International Telecommunication Union (ITU). The first release of LTE (Rel-8) did not fulfill all the ITU requirements; where the recent releases (Rel-10/11 also known as LTE-Advanced) in many cases even surpass them.
LTE Rel-9 adds more enhancements to Rel-8 like support for broadcast/multicast services, positioning services, enhanced emergency-call functionality, and downlink dual-layer beam forming.

LTE-Advanced seen as an evolution of LTE-8/9 contains all the features with more added techniques and enhancements to achieve higher system performance with bandwidth up to 100MHz and peak throughputs of 1Gbps. LTE-Advanced ensure backward compatibility with previous releases to enable continuous enhancements and deployments. LTE-Advanced added many features to the ones already known in LTE-Rel-8/9. The most important features are support for wider bandwidth (Carrier Aggregations CA), support for heterogeneous networks, advanced MIMO, and relaying [3,6,10].
3 Heterogeneous Networks

3.1 Motivations

Since the introduction of the wireless mobile networks, improving the networks performance and capacity was the main task so that they can meet the users’ requirements and new demands that new technologies adds like, video streaming, Internet browsing, and cloud-based services etc. Many approaches have been taken for such improvements, but with the exponential traffic growth as shown in figure 3.1 [9], they become insufficient and the need for new approaches become more demanding.

![Figure 3.1: Expected users' data growth.](image)

The traditional approaches are:

- **Improving macrocell layer**: Improving radio access channels by adding more spectrums, more antennas, and using advance processing techniques within and between nodes are considered efficient ways that can be used to improve the system performance. After the improvements that have been done in 3G and 4G systems, the radio link improvements are slowing and approaching the theoretical limits [1,2,6].

- **Densifying the Macro network**: By reducing the Inter-Site Distance (ISD) of the system, the network capacity, coverage, and user throughput will be improved. Densify macro layers require new network planning which might take long time, and not cost effective. In some places, it could be very hard or impossible to deploy new macro cells especially in the urban areas, or it could be not enough to solve the problem like for the indoor and the cell-edges users.

For all these limitations, a new flexible, easy, fast, and cost effective approach required. And that's what heterogeneous networks deployment introduced in LTE-Advanced offers [1,2].
3.2 Introduction to the Heterogeneous Networks

Approaching the theoretical limits for the radio links performance, time and cost limitations for macrocells deployment, exponential growth for users data over the years with new technologies that require very low latency like real-time applications (e.g. online games) was behind the heterogeneous networks introduction in LTE-Advanced [1,2].

Heterogeneous networks are a new deployment method by complementing the macrocells with low power nodes as shown in figure 3.2. It has many advantages where it is cost effective and flexible, no or less network planning required, ability to be deployed where it is needed (e.g. cell-edges, indoors, or hotspots) to eliminate coverage holes, increase network capacity, and improves users experience [1,2]. Bringing the users closer to the base stations will solve also the power limits for the UEs battery life where it is consumed less power from the UEs. All of these features and advantages make the heterogeneous networks deployment a promising way that can be used to satisfy the new traffic demands and technologies [8,9].

![Heterogeneous networks deployment](image)

**Figure 3.2: Heterogeneous networks deployment**

Heterogeneous networks concepts in 3GPP increase the spectrum reuse per area. Normally, spectral efficiency is measured in bits/second/hertz (bits/s/Hz), by deploying the low power nodes, we add another dimension to the measurement namely bits/second/hertz/km2.

3.3 Heterogeneous Networks Nodes Characteristics

Heterogeneous networks consists of different type of nodes, each of them have different capabilities and operation functionality. Table 3.1 shows more details about heterogeneous networks nodes [10].
<table>
<thead>
<tr>
<th>Node Type</th>
<th>TX Power</th>
<th>Backhaul</th>
<th>Access</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro cells</td>
<td>46 dBm</td>
<td>S1 interface</td>
<td>Open to all UEs</td>
<td>Few km</td>
</tr>
<tr>
<td>Pico cells</td>
<td>23 – 30 dBm</td>
<td>X2 interface</td>
<td>Open to all UEs</td>
<td>&lt; 300 m</td>
</tr>
<tr>
<td>Femto cells (HeNB)</td>
<td>&lt; 23 dBm</td>
<td>No X2 as baseline (Internet IP)</td>
<td>Open, Closed, or Hybrid Subscriber Group (CSG)</td>
<td>&lt; 50 m</td>
</tr>
<tr>
<td>Relay nodes</td>
<td>30 dBm</td>
<td>Through air-interface with a macro-cell</td>
<td>Open to all UEs</td>
<td>&lt; 300 m</td>
</tr>
</tbody>
</table>

Table 3.1: Heterogeneous networks nodes characteristics

As we can see in table 3.1, low power nodes differ in transmission power, backhaul connectivity, access methods, and coverage area. Macrocells are meant to be open to all users with high power and antenna length. Picocells are almost the same as the macrocells except that they have lower power and antenna length, thus coverage area is smaller comparing with macrocells. Femtocells are usually users deployed for indoor purpose. Network operators do not need to provide power and backhaul connections where they are using the Internet connection like xDSL. They have the functionality to be open, closed or hybrid. A closed access femtocells maintain a Closed Subscriber Group (CSG), so that users need to be in the white list to get access. Hybrid access femtocells allow limited access to non-subscribed UEs and higher quality of service to CSG users. Open access femtocells provide the same quality of service for all users. Relay nodes are used to improve capacity and performance for hotspots using air-interface to connect to the macrocells; they are more beneficial in the areas where it is hard to deploy wired backhaul [10].

3.4 Technical Challenges

A simple introduction of the new cells does not always bring straightforward gains to the network. The new cells improve radio conditions for the users they are connected to them. At the same time, a new challenges raise up facing the heterogeneous networks deployments. Self-Organization, backhauling, handover, load-balance, and interference are the main technical challenges.

3.4.1 Self-Organization

One of the key feature of heterogeneous networks is that the nodes are users deployed or by operators without network planning. Thereby, the network could have many nodes that the operator does not even know about them. Self-Organization is very important in this case, where the nodes need to be [10,12]:

- **Self-Configuration**: Newly deployed nodes are automatically configured by running software before they enter the operational mode.

- **Self-Healing**: in case of failure, the nodes should be able to heal it-self and recover automatically.
• **Self-Optimization**: the node should monitor the network so it can optimize its settings for better coverage and less interference.

### 3.4.2 Backhauling

The key design of heterogeneous networks shows that each type of node has its own characteristics. The backhaul design will face a major issues because of the network complexity, thus Quality of Service (QoS) will be hardly to maintain. The backhaul transport network might become the next bottleneck, where the congestion will just be shifted from the cell-edge to the core network [12].

### 3.4.3 Handover

Handover is a process of changing the serving cell form one to another without losing the connection, due to user movements between the cells or due to the congestion. In the case when the serving cell become congested, it handover some of the cell-edge users to the neighbor cells. In the heterogeneous networks, the handover is more challenging due to large number of cells and big power difference with macrocells.

In the heterogeneous networks, due to the big difference between macrocells and picocells power, the received signal strength increment from the picocell is larger than the received signal strength decrement from the macrocell. Using the same configuration parameters for handover between macrocells and picocells will increase the probability of failure, see figure 3.3. A new handover procedure thus required taking into account the different characteristics between both node types [12,13].

![Figure 3.3: Handover in homogenous networks vs. Heterogeneous networks](image-url)
3.4.4 Load-balance and Rang Expansion

In heterogeneous networks deployment, where there is so big difference in the transmitting power between macro and pico stations, the downlink coverage area of macrocells is much larger than picocells. This causes an imbalance in network traffic where the users tend to connect to the macrocells. In this case, it could be that the user is connected to a base-station that does not have enough resources, where the other base-stations are almost free. For uplink coverage, it remains the same since the transmitter is the UEs. The downlink converge will vary depending on the picocell position regarding the macrocell position. Closer to the macrocells, smaller downlink coverage, and vice versa [14,15].

Cell selection is the strategy that decides to which base-station the UE will be connected [18]. For LTE Rel-8, cell selection based on comparing the Reference Signal Received Power (RSRP) of downlink signaling received from the neighboring cells. Cell that provides largest RSRP is select as a serving cell by the UE as:

\[
\text{CELL}_\text{id (serving)} = \arg \max \{i\} \{\text{RSRP}_i\}
\]

The optimal cell for downlink is when the UE is serving by the cell that has the highest transmitting signal power. For uplink, the optimal cell is when UE has the minimal path loss to the serving cell. The natural cell-boundaries for downlink and uplink are different in heterogeneous networks, which are opposed to homogenous networks.

The imbalance traffic between macrocells and picocells motivate the needs to offload more users to picocells. This done by adding a handover bias to the picocell RSRP in the cell selection mechanism so that the users preferentially select the picocell node even when it is not the strongest cell. This method is called Range Expansion (RE) [1,14]. By doing so, the downlink coverage area will be extended few meters depends on the bias value used to compensate uplink coverage area. The area that extends the downlink coverage called Transition Zone (TZ) area, see figure 3.4.

\[
\text{CELL}_\text{id serving} = \arg \max \{i\} \{\text{RSRP}_i + \text{bias}_i\}
\]

Where bias = 0 for macrocells and bias = > 0 for picocells

Using this new cell selection in heterogeneous networks, more users will be offloaded toward picocells, which improve load balance. As we increase the bias value, the new offloaded users will suffer severe interference from the macrocell and downlink SINRs below 0 dB. In order to improve the offloading gain, interference coordination between cells should be used for users in the transition zone area. The aggressor nodes should reduce their transmission power in specific time or frequency resources to protect the victim users. LTE Rel10 ICIC addresses this issue by suggesting interference coordination mechanisms in time and frequency domains, namely Carrier Aggregation (CA) based ICIC in frequency domain and Almost Blank Sub-frames (ABS) in time domain [12].
3.4.5 Interference

In heterogeneous networks, the interference is more challenging than the homogeneous networks where interference issue is handled by carefully network and frequency reuse planning. In heterogeneous networks, the cells differ in their own characteristics. The use of different backhaul links add more challenges for the interference coordination schemes where each link supports different bandwidth and delay constraints [15]. Picocells and relays are using X2 interface for exchanging signals, while femtocells are using Internet connection (xDSL), thus delay issue may appear. In general, the main reasons that cause the interference in heterogeneous networks are:

- **Power Difference**: In heterogeneous networks, the base-stations differ strongly in downlink transmit power, which leads to particular interference challenges. The near-far problem arises from the imbalance in path-gains and transmission power between the macrocells and low power nodes. Several interference scenarios might happen, see figure 3.5. When UE is connected to one node (serving node) and become close to another node (non-serving node) it will receive high power from the non-serving node interfering its downlink. With the same scenario, the UE will transmit at higher power so that it will interfere the uplink of the non-serving node. The uplink interference problem solved by using a new cell selection called Range Expansion by offloading the near macro users. In this case the users in that rang might suffer from DL SINR below 0 dB [2,12].

- **Closed Subscriber Group (CSG) Access**: With close access nodes, the outsider users will not be able to connect to the nearest or highest receive power, which cause a cross-tire interference effect the DL rates for that victim. In this case, the user will transmit at higher power to compensate for the path loss to its far serving macrocell, jamming the UL of the nearby CSG femtocells [12,16].
- **Unplanned Deployment**: Typical deployments for heterogeneous network nodes are by subscriber. The network operators have no control on them, which causes load-neighbor effect. Network planning and optimization is this case become inefficient which raises the need for decentralized interference avoidance scheme that operates independently in each cell using the local information to achieve efficient gain for the entire network [12].

Figure 3.5: Dominant DL and UL cross-tier interference scenarios in heterogeneous networks

### 3.5 Understanding the Control Channels

The minimal transmission entity in LTE called resource block RB [8]. One RB is 12 sub-carriers in frequency domain, and 14 OFDM symbol in time domain, see figure 3.6.
As shown in the figure, the complete RB is divided into two regions, one for control channels, and one for data channels. Control region is not fixed, it can vary from 1 to 3 OFDM symbol depending on the serving number of users [4]. LTE Rel-8 frequency domain ICIC support resource coordination for the data region employing RNTP, but it did not support the control region part, see figure 3.7 [16].

In LTE, the data channel is multiplexed in limited bandwidth i.e. at RB level to obtain multi-user diversity in the frequency domain, but the control channel is multiplexed in the entire bandwidth to obtain frequency diversity. Therefore, we can do resource partitioning in the data region to reduce the interference between macrocell and picocell, but for the control region, we still have a full interference between them [16].

There are three control channels in LTE, and they have to be received correctly in order to decode data channels [8]. The first one called Physical Control Format Indicator Channel (PCFICH), used to indicates the control region length. It is 32-bits and it always occur in the first symbol and repeated 4-time in the frequency domain, see figure 3.8. It is very robust and can be tolerable to the interference and even it can perform in very low SNR.
Figure 3.8: PCFICH control channels

The second control channel is called Physical Hybrid IRQ Channel (PHICH), used by the base station to acknowledge the UE that the UL data has been received. It has the same structure as PCFICH except it occurs in one symbol or across the ones they are used, and it is repeated three times in frequency domain, figure 3.9.

Figure 3.9: PHICH control channels

Finally, the Physical Downlink Control Channel (PDCCH) used for scheduling, so that the UE should decode it to know where it can find its resources in data region. Since LTE is multi-user, PDCCH can be used to schedule several users. In figure 3.10, three users are scheduled, each color represents one user.

Figure 3.10: PDCCH control channels

We can see that the control channels are very important, and if the UEs are unable to decode them, they will not find their resources in the data region. And since the ICIC in Rel-8 didn't address this issue, Rel-10 enhanced the ICIC in both domains, time and frequency to eliminate the interference in the control channels [6,16].
3.6 Interference Coordination in LTE-Advanced (eICIC)

The introduction of heterogeneous networks improve the network performance and user experience in hot-spots and cell-edges, but besides that a new interference imposed to the network that can extremely effect the network performance if it doesn’t deal with it. A set of techniques has been developed in the latest releases of LTE to mitigate the interference issue. The techniques can be group into three categories as follows:

3.6.1 Frequency Domain Techniques

ICIC originally relies on partitioning of the system spectrum and allocation of the resources for the interfering nodes, and it does so by exchanging messages between eNBs.

Recent introduction of Carrier Aggregation (CA) features brings additional opportunities for frequency domain interference mitigation. In CA, user can transmit/receive on multiple carriers simultaneously. For the interference coordination (CA-based ICIC), CA creates protected component carrier for users in victim layers to allow reliable reception for the control payload, where the data can be received on scheduled cross-carrier components, figure 3.11 [4].

![Figure 3.11: Frequency domain eICIC](image)

As we can see in the figure, for macro-pico deployment, the macro node is the aggressive node, and the pico-users especially in the RE region are the victim users. By using this CA-based ICIC, and as we can see in the figure above, the macro-cell mute its control channel transmission on one carrier (CC1) for the cell-edge users, and thanks to the cross-carrier scheduling, it use the control region from the second carrier (CC2) to schedule users on both carriers. The same thing implies in the pico node, but with opposite carriers, where it mutes control channel transmission on CC2, and used CC1 for scheduling. By using this way, we will not have interference in the control region for the cell-edge users [16].
### 3.6.2 Time Domain Techniques

In time domain, eICIC support resource partitioning by creating protected sub-frames for the victim users by muting or reducing transmission power of the aggressor nodes. It is the latest concept of interference coordination that is currently investigated for further development in LTE release-11 [12].

In Macro-Pico deployment with range expansion implementation, the aggressor nodes are the macrocells. By implementing the ABS sub-frames at the macro cells, see figure 3.12, no control or data signals will be transmitted just only reference signals. The users in the RE area will be scheduled within the sub-frames overlapping with ABS of the macrocells, which significantly mitigates cross-tier interference. In case of Macro-Femto deployment, the ABS will be implemented in the Femto cells.

![Figure 3.12: Time domain eICIC](image)

As we can see in this figure, the macro-cell actually lose half of its capacity in the cell-edge, so this way even it eliminate the interference efficiently, but it has more work to do for the lose capacity.

### 3.6.3 Power Control based solution

Power control based techniques are the basic form of interference management for Macro-Femto deployment. Those techniques automatically adapt transmit power of Femto cells and users connected to them based on the observed interference conditions, deployments, cell load, etc. main goal is to protect any potential interference victims. Note that we cannot apply power reduction in macro cell, as it will reduce the macro cells coverage [12].
3.7 Comparison with Wi-Fi

Heterogeneous networks meant to improve the coverage, capacity and performance for the wireless mobile networks so they can satisfy the users’ needs and the traffic demands that the new technologies add. By complementing the macrocells with low power nodes, network operators can also do the same by using 802.11n Wi-Fi access points (AP) since most of the smart phones and tablets today have built-in Wi-Fi access, network operators can offload traffic from macrocells to Wi-Fi networks at residence, offices and public hotspots. In [16], a comparison have been done for system performance of complementing LTE macrocells with low power picocells and with Wi-Fi in unlicensed spectrum using different types of user distribution, different network layout, and different carrier frequency. In figure 3.13, it results shows that the picocells offers a superior performance than Wi-Fi APs due to the different techniques that LTE latest releases introduced like eICIC, advanced terminal receivers with interference cancellation (IC), and the ability to extend the coverage using RE approach. In the other hand, the limited association range for Wi-Fi APs within the large macrocells coverage plays the big difference between them where the Wi-Fi APs transmit at power of 18 dBm, which limit the number of offloaded users.

![Figure 3.13: Picocells throughputs comparing with WI-FI throughputs](image)

In addition to this, other deployment consideration shows the advantages of picocells deployment over Wi-Fi deployment:
3.7.1 WiFi Coexistence with LTE

For picocells deployment, the handover between macrocells and picocells is well defined, where the advanced UEs have the ability to detect, measure, report and handover even in weak signal presence. In the other hand, 3GPP standard consider Wi-Fi as a non-trusted system, where it require a new network entity called Home Agent that anchors the IP flows. So that the LTE networks are not aware of the current radio characteristics of Wi-Fi APs makes the handover more challenging than picocells. In the Wi-Fi networks, clients are not always connected to the strongest APs, since they start searching for new APs only when the signal with the current APs become too weak. Therefore, Wi-Fi does not guarantee connectivity to the strongest APs, thereby limiting the potential capacity and throughputs improvement.

3.7.2 Quality of Service (QoS)

LTE picocells support QoS as an integrated part of heterogeneous networks. Regardless of the serving cell, the UE will have the same QoS since they are coordinated with each other. In the Wi-Fi networks, it is difficult to predict the interference and traffic load due to non-operator deployed APs.

3.7.3 Security

Since the picocells are that same as macrocells except in the power level, there is no security issue for deploying them.

Wi-Fi networks are operated by different operators; there is no predefined authentication between them. When the UE want to be offloaded to a Wi-Fi network, seamless authentication required without losing connection or users experience. There is no standardization work done in Wi-Fi to enable this kind of authentication, which enables 3GPP credentials (SIM) to authenticate the user over Wi-Fi. However, it will require all providers to adhere to a common standard.
4 Indoor Models Deployment and Investigation

4.1 Introduction

Low power nodes of the LTE heterogeneous networks considered a promising way to meet the future traffic demands. Pico nodes are one type of the low power nodes that have low power and shorter antenna height comparing with macro nodes. They are easy to deploy, need less or no network planning and costs effective. They can be deployed outdoor or indoor in selected areas to increase the capacity, coverage area and improve overall system performance.

This chapter describes the:

- Indoor pico models as specified in the 3GPP TR36.814 [18].
- Implementation of the models in LTE MATLAB simulator provided from Ericsson Research AP.
- Investigation using two different Inter-Site Distance (ISD) systems and four deployment scenarios to understand the impacts of macro nodes on indoor pico nodes at different positions, hotspot density and hotspot size and how they will affect their coverage areas and performance.

This chapter is organized as follow: Section 4.2 describes indoor pico models. Section 4.3 shows simulator parameters. Section 4.4 describes pathloss analysis for pico coverage area. Section 4.5 shows and describes results of reference deployment case. Section 4.6 shows and describes results of varying building position of the reference case. Section 4.7 shows and describes results of varying hotspot density of the reference case. Section 4.8 shows and describes results of varying hotspot size of the reference case.
Models Description

The models we implemented and investigated in this report are as specified in the 3GPP TR36.814 [18] for indoor pico deployment in heterogeneous networks. There are two models; models-2 is a simplified channel model that assumes all the users are located within buildings, and model-1, which is more general where the users can be located inside and outside the building. All the simulations in this report based on model-1.

The model consists of single floor, see figure 4.1. The height of the floor is 6 meters. The floor contains 16 rooms of 15m x 15m each with a long hall of 120m x 20m. Two pico nodes are placed in the middle of hall at 30m and 90m with respect to the down side of the building.

![Figure 4.1: Sketch of indoor hotspot environment](image)

The model specifies the channel model values of distance dependent pathloss, shadowing standard deviation, penetration-loss, and fast fading, see table 4.1. The values are differ depends on base-station type (macro or pico), link type (LOS or NLOS), and user location (outside the building, inside the same building, or inside a different building).

<table>
<thead>
<tr>
<th>Cases</th>
<th>Path Loss (dB)</th>
<th>Shadow sta. dev</th>
<th>Pent. Loss</th>
<th>Fast Fading</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE to macro BS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| (1) UE is outside            | $P_{L_{LOS}}(R) = 103.4 + 24.2 \log_{10}(R)$  
$P_{L_{NLOS}}(R) = 131.1 + 42.8 \log_{10}(R)$ | 10dB             | 0dB        | ITU UMa     |
| (2) UE is inside             | $P_L(\text{dB}) = \max(131.1 + 42.8 \log_{10}(R), 147.4 + 43.3 \log_{10}(R))$ |                  |            |             |
| UE to RRH/Hotzone            |                                                                 |                  |            |             |
| (1) UE is inside a different building as the indoor hotzone | $P_{L_{LOS}} = 89.5 + 16.9 \log_{10}(R)$  
$P_{L_{NLOS}} = 147.4 + 43.3 \log_{10}(R)$ | 10dB             | 40dB       | ITU InH (NLOS) |
| (2) UE is outside            | $P_L(\text{dB}) = \max(131.1 + 42.8 \log_{10}(R), 147.4 + 43.3 \log_{10}(R))$ |                  |            |             |
| (3) UE is inside the same building as the indoor hotzone | $P_{L_{LOS}} = 89.5 + 16.9 \log_{10}(R)$  
$P_{L_{NLOS}} = 147.4 + 43.3 \log_{10}(R)$ |                  |            |             |

<table>
<thead>
<tr>
<th>LOS: 3dB</th>
<th>NLOS: 4dB</th>
<th>ITU InH</th>
</tr>
</thead>
</table>
| $\text{Prob}(R)$ =  
$1 \quad R \leq 0.018$  
$\exp(-(R - 0.018)/0.027), \quad 0.018 < R < 0.037$  
$0.5 \quad R \geq 0.037$ | 0dB |         |

Table 4.1. Channel model 1 of indoor pico nodes
4.2 Deployment Parameters

All the simulations done using MATLAB based simulator. In table 4.2, important system deployments parameters used are presented. Some other parameters will be shown for each deployment scenario later in this chapter like, deployment position, hotspot density, and hotspot size.

| Deployment systems | ISD: 500m with carrier freq 2GHz  
| ISD: 1732m with carrier freq 700MHz |
| --- | --- |
| `. Macro Cells | 9 cells (3-site wrap-around) |
| Antenna configuration | MIMO 2Tx-2Rx  
| Macro: 3GPP scm / Picocell: Omni-directional |
| Antenna gain | Macro: 14 dBi; Pico: 5 dBi |
| Bandwidth | 10 MHz |
| Traffic Model | Full buffer |
| `. UEs/macro cell | 25 UEs (Total: 225 UEs) |
| Macro Tx power | 46 dBm |
| Pico Tx power | 30 dBm |
| UE Tx power | 23 dBm |
| Uplink power control | 3GPP LTE |

Table 4.2: System deployment parameters

Important definitions:

- **Cell selection**: In this report, the two cell selections are used; the optimal cell selection for downlink (RSRP) and the optimal cell selection for uplink (minimal PL). The bias value added to compensate for the minimal pathloss cell selection is the difference between macro power and pico power, which is equal to 16 dBm.

- **Hotspots**: Is a fraction number of total users used in the simulation, to be clustered in selected area. The fraction number vary for each scenario, the remaining users are uniformly distributed over the whole cell.

- **Deployment position**: Two deployment positions are investigated, 0.5, 1.5 times Macro\(_{\text{radius}}\), where Macro\(_{\text{radius}} = \text{ISD}/3\) for three sector sites, ISD = 500m or 1732m.
4.3 Pathloss Analysis for Pico Coverage

Macro nodes have a power range from 40 dbm to 46 dbm, where the pico nodes have a power range from 23 dbm to 30 dbm. Complementing macrocells with low power nodes, the downlink coverage area for these low power nodes will be limited by the macro nodes power. Indoor low power nodes also have limited coverage due wall penetration. It is well known that the transmitted power decrease with square of distance; thereby the power difference between macro nodes and pico nodes will vary with distance. Moving the pico nodes away from the macro nodes will reduce the power difference and this means that the pico downlink coverage will increase. To illustrate this relation, figure 4.2 shows a pathloss analysis for one macro node pathloss and one pico node pathloss excluding the fading. The wall penetration-loss and the antennas-gain difference between macro node antenna and pico node antenna are considered. In this analysis, the macro antenna faces the long side of the building.

Figure 4.2: Pathloss analysis for pico coverage area at different positions with two ISD systems

In figure 4.2, the pathloss analysis for indoor pico coverage areas for two deployment positions and ISD systems (500m and 1732m) are shown. The green lines represent the pico node signal strength at different positions related to the macro radius (0.5, 1.5 times Macro\textsubscript{radius}, where Macro\textsubscript{radius} = ISD/3 for three sector sites). The red lines represent the macro node RSRP, and the blue lines represent the macro node pathloss. The pico coverage area can be seen between the two points where the green lines intersect with the red and blue lines.
Due to macro node power, higher macro antenna gain, and building wall penetration, pico coverage area is limited to indoor where the transition zone area are hidden within the building wall. Pico node has better power difference indoor. Power difference improves as we move to the cell edge, and with an ISD of 1732m @ 1.5 is the maximum. That means, as the building with the indoor pico node moves further from the macro node, the pico users get better SINR level thus better performance. The coverage area increase as we move away from the macro node because of power difference between nodes outdoor decreased.

Pico node coverage area using minimal pathloss cell selection is larger than the coverage area using RSRP cell selection as the power difference between nodes is smaller, which means more users will be offloaded and served by the pico node. However, the new offloaded users using pathloss cell selection could have very low SINR in downlink (could be less than zero) due high interference from macro node, and this affect their downlink throughputs.
4.4 Simulation Results: Reference case

Heterogeneous networks deployment is meant to offload macrocell users in selected areas. The gain of such deployment can be seen at both cell types; macrocells and picocells. For macrocell, offloading some users toward pico nodes freeing up some resources that can be used for the remaining macrocell users. On the other hand, the offloaded users will have better experience and improve channel conditions for both links; downlink and uplink.

Deployment parameters

For the reference case, table 4.3 shows the deployment parameters.

<table>
<thead>
<tr>
<th>System</th>
<th>Position</th>
<th>Hotspot Size</th>
<th>Hotspot Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISD 500m</td>
<td>@ 0.5 times macro radius</td>
<td>As building size</td>
<td>50%</td>
</tr>
</tbody>
</table>

Table 4.3: Deployment parameters for the reference case

Figure 4.3 illustrates the deployment scenario.

Users distribution results

To understand the load balance of such deployment, Figure 4.4 shows the users distribution for this deployment scenario.
Figure 4.4: Users distribution for the reference case.

From Figure 4.4, we can note that:

- Hotspot share is 50% of total users, but we have 2.53% (52.53% - 50.0%) from macro share happened to be indexed inside the building when we uniformly distribute the macro users in each macrocell, since the building is a part of macrocell area. Moreover, this is hold for all the coming scenarios.

- Pico nodes offload more users with minimal pathloss cell selection since the coverage area is larger.

- Both pico nodes are unable to offload all the indoor users with both cell selections. The macro nodes RSRP is relatively strong compared to the pico nodes RSRP in this deployment scenario thus 7.38% of indoor users are macro users using RSRP cell selection and 0.89% using minimal pathloss cell selection.

- Due high macro power and wall penetrations, pico nodes are unable to offload any user from outdoor using RSRP cell selection, even with minimal pathloss cell selection; offloaded users are still very small.

- Around 7% (51.96% - 45.16%) of all users are in the transition zone area offloaded using minimal pathloss cell selection, 0.31% of them are from outside the building.

**Separated results**

The performance gain of such deployment can be seen from user throughputs. Figure 4.5 shows the downlink bit rates for pico users and macro users comparing with macro only system deployment.
From figure 4.5, macro users and pico users got improved downlink bit rates in macro-pico system deployment comparing with macro-only system. Indoor users where most of them are offloaded toward pico nodes got better channel conditions thus higher downlink bit rates. Pico nodes are less loaded with RSRP cell selection thereby higher data rates, which is the opposite for macro nodes. Macro users in macro-pico system also got improved downlink bit rates since macro nodes are less loaded and have more resources per user comparing with macro nodes in macro-only system. In summary, due to less loaded nodes, close and protected users, pico users’ improvements are larger than macro users’ improvements.

In the user distribution, we have ~7% of all users are in the transition zone area offloaded with minimal pathloss cell selection where 0.31% of them are outside the building. Those users have low SINR that affects their downlink performance. This can be seen from the 5th percentile of users downlink bit rates, see figure 4.6 (enlarged part of figure 4.5). Outdoor pico users have low performance even lower than macro-only system.

Figure 4.5: Downlink bit rates for the reference case.
From figure 4.6, users in the transition zone area had degraded in downlink performance; the rate depends on user position either he is inside the building or outside. Most of the transition zone area users have an acceptable performance since they are inside the building so they don’t have severe degrade in SINR, also the load balance for this users distribution is consider unfair (macro nodes share is 50%, where two pico nodes share is 50%, thus 25% each), where pico nodes are less loaded.

The corresponding downlink average SINR is shown in figure 4.7. Pico users have better SINR level than macro users since they are closer and protected where most of them are indoor, but with minimal pathloss cell selection, we have low SINR for pico users offloaded from transition zone area, they have high interference thus low SINR level.
Figure 4.7: Downlink average SINR curves for the reference case.

The corresponding uplink bit rates for macro users and pico users comparing with macro-only system are shown in figure 4.8. The same results hold. The indoor users where most of them are offloaded toward pico nodes got reduced distance to their serving node thus higher uplink bit rates. Macro users also gained from less loaded macro nodes. There are no drawbacks for outdoor offloaded pico users with minimal pathloss cell selection, since they are connected with the optimal node for uplink.

Figure 4.8: Uplink bit rates for the reference case.
The uplink average SINR shown in figure 4.9.

![Uplink Average SINR for the reference case.](image)

**Figure 4.9: Uplink Average SINR for the reference case.**

In figure 4.9, pico users have better uplink SINR level than macro users since most of them are inside the building and have quite close distance to the serving node comparing with macro users where most of them are outside.

**Overall system results**

In the last discussion, we have seen the gain of complementing macrocell with pico nodes, both user types gained from such deployment. To look at the overall system, figure 4.10 shows the downlink bit rates for macro-pico system compared with downlink bit rates for macro-only system.
Figure 4.10: Macro-Pico downlink bit rates compared with Macro-Only downlink bit rates for the reference case

Figure 4.11 shows the overall macro-pico system downlink average SINR compared with downlink average SINR for macro-only system.

Figure 4.11: Macro-Pico downlink average SINR compared with Macro-Only downlink average SINR for the reference case

Figure 4.12 shows the uplink bit rates for macro-pico system compared with uplink bit rates for macro-only system. With minimal path-loss cell selection, users are offloaded to the optimal cell thereby minimal pathloss provides better uplink throughputs.
Figure 4.12: Macro-Pico uplink bit rates compared with Macro-Only uplink bit rates for the reference case

Figure 3.13 shows the overall macro-pico system uplink average SINR compared with average uplink SINR for macro-only system.

Figure 4.13 Macro-Pico uplink average SINR compared with Macro-Only uplink average SINR for the reference case
4.5 Simulation Results: Varying building position

In the pathloss analysis early in this chapter, we have shown that pico coverage area and the power difference inside the building increase as we move further from the macro node, so that offloaded users toward pico nodes will increase and the indoor pico users will maintain higher SINR level.

**Deployment parameters**

To understand the relation between building position related to the macro nodes with the pico coverage area and system performance, we deployed the same previous scenario but @ 1.5 times the macro radius. Table 4.4 shows the deployment parameters.

<table>
<thead>
<tr>
<th></th>
<th>System</th>
<th>Position</th>
<th>Hotspot Size</th>
<th>Hotspot Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Case</td>
<td>ISD 500m</td>
<td>@ 0.5 times macro radius</td>
<td>As building size</td>
<td>50%</td>
</tr>
<tr>
<td>Comparison Case</td>
<td>ISD 500m</td>
<td>@ 1.5 times macro radius</td>
<td>As building size</td>
<td>50%</td>
</tr>
</tbody>
</table>

Table 4.4: Deployment parameters for varying building position

Figure 4.14 illustrates the deployment scenario.

![Deployment scenario for varying building position](image)

**Users distribution**

To understand the impact of deployment position on pico coverage area, figure 4.15 shows the users distribution for both deployment positions @ 0.5 and @ 1.5.
From Figure 4.15, we can note that:

- 1.87% (51.87 – 50.0%) of macro users are indexed inside the buildings.
- Pico users increased with both cell selections as the power difference increased indoor. Hence, indoor macro users reduced.
- Using minimal pathloss cell selection, number of pico users offloaded from outdoor increased @ 1.5, but due macro power and wall penetrations, this number is still very small ~ 1%.

**Separated results**

The impact of deployment position on system performance can be seen from downlink bit rates, see figure 4.16. Both positions are compared.
In figure 4.16, we can see an improvement in the comparison case comparing with reference case for both user types; macro users and pico users. Macro users got improved as more few users offloaded to the pico nodes comparing with the first position. User distribution also got changed where now macro cell-edge users are indexed inside and offloaded toward pico nodes. Pico users got improved downlink bit rates. Most of the indoor users are offloaded toward pico nodes using both cell selections. The power difference indoor between macro nodes and pico nodes got increased, thus all the indoor users got better SINR thus better downlink bit rates. Also we can see that the Macro-Only system (the dashed magenta line) got degraded in performance which is a consequence of indoor users are being further away from the macro nodes, thereby lower SINR which affect their downlink bit rates.

The corresponding downlink average SINR comparing both results from comparison case and reference case as shown in figure 4.17.

![Figure 4.17: Downlink average SINR for varying building position](image)

In figure 4.17, we can see improvements in Pico users SINR in the comparison case comparing with reference case as the power difference indoor increased. Macro users got improved due user distribution change at the comparison case macro cell edge users got offloaded. Macro Only system got reduced SINR as the indoor users got further away from the macro nodes.

The corresponding uplink bit rates shown in figure 4.18.
In uplink and since the user maintain the same distance to the serving nodes (most of them are inside the buildings in the both cases) pico users almost maintain the same performance in the both cases with slightly degrade in comparison case. Pico nodes are more loaded in the comparison case than reference case. As a result, macro nodes thus they are less loaded in the comparison case. On the other hand, macro only system got degraded in performance in the comparison case as the indoor users got further away thus higher pathloss which affect their uplink performance.

Figure 4.19 shows the uplink average SINR for both deployment positions.
In figure 4.19, offloading indoor macro users reduce the uplink interference thus improve uplink SINR for pico users. For macro users, offloading bad users toward pico nodes improve their uplink SINR.

**Overall system results**

In the last discussion in this section, we have seen the gain of moving the pico nodes further away from macro nodes to cell-edges, both user types got improved. To look at the overall system, figure 4.20 shows the downlink bit rates for macro-pico systems for both positions compared with downlink bit rates for macro-only system also for both positions.

**Figure 4.20: Macro-Pico downlink bit rates compared with Macro-Only downlink bit rates for varying building position**

**Figure 4.21: Macro-Pico downlink average SINR compared with Macro-Only downlink average SINR for varying building position**
Figure 4.22: Overall systems uplink bit rates for varying building position.

Figure 4.23: Overall systems uplink average SINR for varying building position
4.6 Simulation Results: Varying hotspot density

Heterogeneous networks can be deployed anywhere, but most of the gain of such deployments comes in areas that have much users, so we gain from offloading these users. Selected areas could be indoor or outdoor, near or far the macro nodes at the cell edges. Indoor deployments like offices, malls, or airports; where these areas are time variant. Offices loaded during the day hours normally, malls could be anytime mostly in weekends, airports most probably high loaded in holydays. The number of offloaded users depends also when and where the pico node is being deployed.

4.6.1 Case-1: Comparison with Lower hotspot density

*Simulation parameters (Case-1)*

In the reference case, we have shown the results for indoor deployment @ 0.5 related to the macro radius and we compared it with different position @ 1.5. In both cases, we assumed that 50% of users are considered in hotspots where the hotspot size as the building size. In order to understand the effects of different load balances between macro nodes and pico nodes, we have done several simulations for different hotspot densities. The results hold for different positions thus results from position @ 0.5 is shown only. Table 4.5 shows the deployment parameters.

<table>
<thead>
<tr>
<th>System</th>
<th>Position</th>
<th>Hotspot Size</th>
<th>Hotspot Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Case</td>
<td>ISD 500m @ 0.5 times macro radius</td>
<td>As building size</td>
<td>50%</td>
</tr>
<tr>
<td>Comparison Case</td>
<td>ISD 500m @ 0.5 times macro radius</td>
<td>As building size</td>
<td>25%</td>
</tr>
</tbody>
</table>

Table 4.5: Deployment parameters for varying hotspot density with smaller

*Users distribution (Case-1)*

Both deployment scenarios are at the same position, thus, the power difference and coverage area are the same; the only difference is the hotspot density. Figure 4.24 shows the users distribution for both cases.

Figure 4.24: Users distribution for varying hotspot density with lower density
From figure 4.24, we can note that:

- Number of pico users got reduced as indoor users got reduced.
- Indoor macro users using RSRP cell selection got reduced as hotspot users got reduced.
- Pico users offloaded from outdoor more or less remain the same with few more users offloaded with minimal pathloss cell selection.

**Separated results (Case-1)**

To understand the impact of load balance on performance, figure 4.25 shows the downlink bit rates for both system cases.

![Figure 4.25: Downlink bit rates for varying hotspot density with lower density](image)

In figure 4.25, in the comparison case, macro users downlink bit rates got degraded as macro nodes got overloaded. On the other hand, pico users had better performance with comparison case since pico nodes are less loaded and have more resources per pico user. Macro only system has slightly degraded in performance as more users has to be in the cell-edges with comparison case. Since we have more users outdoor (non-hotspot users) which gives worse SINR level to those users comparing when they were indoor; the buildings are very close to the macro nodes and we got high probability of line of sight (LOS) links with indoor users than cell-edge users.

Figure 4.26 shows the corresponding downlink average SINR.
In figure 4.26, both cases are in the same position, thus macro and pico users maintain the same downlink SINR level. For macro only, users got degraded as we got more users outside and in the cell-edges.

Figure 4.27 shows the uplink bit rates for both system densities. As we can see, the same results hold also in uplink.

Figure 4.28 shows the uplink average SINR for both system densities.
In figure 4.28, pico users got improved in uplink average SINR as indoor macro users reduced, thus lower interference. Some pico users offloaded with minimal pathloss had worse SINR level, since we had few more users offloaded from outdoor. Macro users slightly degraded as we got more users to be in the macro cell-edges having high pathloss, and for the same reason, macro only system got degraded.

4.6.2 Case-2: Comparison with Higher hotspot density

**Simulation parameters (Case-2)**

In case-2, the system as case-1 deployed but with 75% of users considered hotspots. Table 4.6 shows the deployment parameters.

<table>
<thead>
<tr>
<th></th>
<th>System</th>
<th>Position</th>
<th>Hotspot Size</th>
<th>Hotspot Density</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reference Case</strong></td>
<td>ISD 500m</td>
<td>@ 0.5 times macro radius</td>
<td>As building size</td>
<td>50%</td>
</tr>
<tr>
<td><strong>Comparison Case</strong></td>
<td>ISD 500m</td>
<td>@ 0.5 times macro radius</td>
<td>As building size</td>
<td>75%</td>
</tr>
</tbody>
</table>

Table 4.6: Deployment parameters for Varying hotspot density with larger
Users’ distribution (Case-2)

Figure 4.29 shows the users distribution for both cases.

From figure 4.29, we can note that:

- Number of pico users got increased as indoor users increased
- Macro users offloaded from indoor got increased as indoor users increased.
- Pico users offloaded form outdoor slightly decreased as outdoor users decreased.

Separated results (Case-2)

In Case-2, we can see that the situation is reversed. Now pico nodes got more users than macro nodes [~25% are macro users and ~75% are pico users, for two pico nodes thus ~37.5% per pico node]. Macro users improved in performance where pico users degraded in comparison case comparing with the reference case, see figure 4.30. On the other hand, macro only system slightly improved in performance as more users got inside thus reduces the macro cell-edge affects.
From figure 4.30, pico users still have better performance comparing with macro users even when pico nodes are more loaded, that’s because pico users have better SINR level comparing with macro users, this can be seen from downlink average SINR both system densities in Figure 4.31.

In figure 4.31, Pico users and macro users maintains the same downlink SINR level since they are in the same deployment position. Macro only system improved since we got more indoor having better SINR comparing when they were in the cell-edges since the building is very close to macro nodes.
Figure 4.32 shows the uplink bit rates for both system densities, the same results hold.

![Figure 4.32: Uplink bit rates for varying hotspot density with higher density](image)

The uplink average SINR shows after in figure 4.33.

![Figure 4.33: Uplink average SINR for varying hotspot density with higher density](image)
In figure 4.33, as the indoor macro users offloaded with RSRP increased (7.38% to 10.8%), higher interference added to the pico nodes in uplink, thus pico users offloaded with RSRP got degrade in uplink average SINR. The opposite happened to pico users offloaded with minimal pathloss, since indoor macro users offloaded with minimal pathloss more or less the same, reducing the number of outdoor users reduce the macro users thus we got fewer interference. For macro users, they maintain the same uplink SINR with minimal pathloss cell selection, but for users offloaded with RSRP cell selection they got improved since we had more indoor users offloaded toward macro nodes, and since the buildings are very close, those users have high probability of LOS links thus better SINR. The same result hold for macro-only system, more indoor users more LOS links, and they have better performance than cell-edges users.

**Overall system results**

Improving the load balance between nodes leads to improve the overall system performance. For the first case, we have seen that reducing the hotspot density will reduce the offloaded number of users toward pico nodes since the pico coverage area in limited to inside the building. Increasing the hotspot density will increase the number of offloaded users thereby improving the load balance and overall system performance. Figure 4.34 shows the 50th percentile downlink bit rates for the overall systems with different hotspot densities.

![Figure 4.34: 50th percentile Downlink bit rates for different systems with different hotspot density](chart)

In figure 4.34, as the hotspot density increases as the overall 50th percentile system improves since the load balance between nodes improves. System improvement slows down as it reaches the optimal load balance between nodes. Macro only system 50th percentile also improves where the buildings with the hotspots inside it are close to the macro nodes thus increasing the hotspot density reduce the macro cell-edge effects on the system.
The same results hold for uplink, see figure 4.36. The 50th percentile uplink bit rates are shown for different system hotspot density.

In figure 4.36, 50th percentile uplink bit rates of overall system improves as the load balance improves. Pico nodes always offload fewer users using RSRP cell selection thus higher interference from close macro users. Keep increasing the hotspot density, the system improvements slows down and then it will get worse after the optimal system load balance. At this deployment position, increasing the hotspot density, the indoor macro users’ increase thus pico nodes get more interference from those users that degrade average uplink SINR and system throughputs.
Figure 4.37: Uplink bit rates for different systems with different hotspot density
4.7 Simulation Results: Varying hotspots size

In all the simulations before we assumed that the building size is fixed (120m x 50m) and the hotspot is always having the same size as the building size. Hotspot size could be less or larger than the building size. To understand the relation between the hotspot size, building size, and pico coverage area, we have done several simulations with different hotspot size. The results hold for all positions, so that results from deployment position @ 0.5 will be shown only. Figure 4.39 illustrate the three deployment scenarios, where hotspot size in the reference case varied to be smaller, and larger than the building size.

![Figure 4.38: Sketch of indoor deployment with different hotspot size](image)

4.7.1 Case-1: Comparison with smaller hotspot size

*Simulation parameters (Case-1)*

Pico users performance varies depend on how close or far they are from the serving node, or if they are offloaded from indoor or outdoor where the closer and indoor ones have better performance. To understand this relation, we deployed a system with hotspot size smaller than the building size, and compare the results when the hotspot size equals to the building size. Table 4.7 shows the deployment parameters.

<table>
<thead>
<tr>
<th></th>
<th>System</th>
<th>Position</th>
<th>Hotspot Size</th>
<th>Hotspot Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Case</td>
<td>ISD 500m</td>
<td>@ 0.5 times macro radius</td>
<td>As building size</td>
<td>50%</td>
</tr>
<tr>
<td>Comparison Case</td>
<td>ISD 500m</td>
<td>@ 0.5 times macro radius</td>
<td>Smaller with 10m (5m from each side)</td>
<td>50%</td>
</tr>
</tbody>
</table>

Table 4.7: Deployment parameters for varying hotspot size with smaller size
**Users distribution (Case-1)**

Figure 4.39 shows the users distribution.

From figure 4.39, we can note that we have almost the same user distribution in both deployment scenarios, but when the hotspot size is smaller than the building size, hotspot users got closer to pico nodes thus we have few more indoor users offloaded toward pico nodes, and as a consequence, indoor macro users got slightly decrease.

**Separated results (Case-1)**

When pico users get closer to serving node, they will maintain better SINR level that improves their performance. This can be seen in the downlink bit rates in figure 4.40.
From figure 4.40, we can see that when hotspot size got smaller, pico users got improved downlink bit rates since they got closer to the serving node thus better channel conditions and this reduce the cell edge effect of pico nodes and improve their performance. Macro users maintain the same performance since changing hotspot size for this scenario does not change anything for them. For macro-only system, the users maintain the same performance level in this deployment scenario.

The corresponding downlink SINR curves shown in figure 4.41

Figure 4.41: Downlink SINR for varying hotspot size with smaller size

In figure 4.41, macro users as long the macro only system maintain the same SINR level, where pico users got a slightly improvement as they become closer to the serving nodes. In the uplink, the same results hold, where indoor users got even minimal pathloss to the serving nodes thus higher performance, see figure 4.42.

Figure 4.42: Uplink bit rates for varying hotspot size with smaller size
The corresponding uplink average SINR shows in figure 4.43

Figure 4.43: Uplink average SINR for varying hotspot size with smaller size

4.7.2 Case-2: Compression with larger hotspot size

*Simulation parameters (Case-2)*

In case-2, the same system as in case-1 deployed but with hotspot size larger than the building size, table 4.8 shows the deployment parameters.

<table>
<thead>
<tr>
<th></th>
<th>System</th>
<th>Position</th>
<th>Hotspot Size</th>
<th>Hotspot Density</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reference Case</strong></td>
<td>ISD 500m</td>
<td>@ 0.5 times macro radius</td>
<td>As building size</td>
<td>50%</td>
</tr>
<tr>
<td><strong>Comparison Case</strong></td>
<td>ISD 500m</td>
<td>@ 0.5 times macro radius</td>
<td>Larger with 30m (15m from each side)</td>
<td>50%</td>
</tr>
</tbody>
</table>

Table 4.8: Deployment parameters for varying hotspot size with larger

*Users distribution (Case-2)*

The hotspot size is considered larger than building size with 30m, thus some of the hotspot users became outdoor and close to the building and in pico nodes coverage area, so that more users will be offloaded toward pico nodes from outside. To understand the difference, figure 4.45 shows the users distribution for both systems with hotspots equal and larger the building size.
From Figure 4.44, we can note that:

- Number of pico users decreased as the indoor users decreased.
- Number of indoor macro users decreased as indoor users decreased.
- As the number of close users to the building increased, number of pico users offloaded from outdoor using minimal pathloss cell selection increased.

**Separated results (Case-2)**

Load balance between nodes in heterogeneous networks has much affect in the overall system performance. In this users distribution, we can see that the load balance considered unfair since ~60% - ~70% of users are macro users, and this makes the macro nodes over loaded where the pico nodes is less loaded. Figure 4.45 shows the downlink bit rates for both systems with different hotspot size.
In figure 4.45, macro users got degraded in performance in the comparison case since they are more loaded comparing with reference case which is the opposite case for pico nodes thus pico users got improved in performance.

Figure 4.46 shows the corresponding downlink SINR curves comparing both deployment scenarios.

![Figure 4.45: Downlink bit rates for varying hotspot size with larger size.](image1)

![Figure 4.46: Downlink SINR for varying hotspot size with larger size](image2)
In figure 4.46, pico users offloaded with minimal pathloss cell selection got degraded in comparison case since we got more users offloaded from outdoor (i.e. from transition zone area), those users have lower downlink SINR. However, with RSRP cell selection, pico users almost maintain the same downlink SINR level. For macro users, they got improved as we had less macro users indoor and the outside hotspot users (~ 15%) they are macro users and close to macro nodes, thus they got better SINR level.

In uplink, the same results hold. Pico users improved as pico nodes are less loaded, which is the opposite case for macro users where they got degrade in performance as macro nodes got over loaded, see figure 4.47. In addition, we can note that there is not such low performance for pico users offloaded from outdoor.

Figure 4.47: Uplink bit rates for varying hotspot size with larger size

Uplink average SINR shown in figure 4.48
Figure 4.48: Uplink average SINR for varying hotspot size with larger size

In figure 4.48, pico users got improved in uplink SINR in the comparison case since indoor macro users got reduced (7.38% to 4.31% with RSRP and 0.89% to 0.71% with PL), thus less interference to pico nodes. On the other hand, since we have 15% of hotspot users are outside and close to the buildings, outdoor pico users offloaded with minimal pathloss got increased (0.31% to 1.16%), those users got affected from wall penetration. Macro users got improved as less users offloaded from indoor, and the outside hotspot users are very close to macro nodes thus they got better SINR.

**Overall system results (Case-2)**

Indoor and close users have better performance than outdoor and far users. As the users get closer to the serving node as the average SINR for both link types improve thus better throughputs. Figure 4.49 shown the 50th percentile downlink bit rates for different hotspot size.
In Figure 4.49, the 50th percentile downlink bit rates for the overall system improve when the hotspot size gets smaller (-10m), most of the indoor users get better channel conditions and the load balance improves as cell-edge indoor users will be offloaded toward pico nodes. Increasing the hotspot size (+30m) will decrease the indoor users thus the offloaded pico users’ decrease, and for this user’s distribution, it affects the load balance where macro nodes become overloaded.

Figure 4.50: Downlink bit rates for different systems with different hotspot size

In Figure 4.50, the downlink bit rates for different systems with different hotspot sizes are shown. The figure illustrates how the bit rates change with varying hotspot sizes for different system configurations.
The same results hold for uplink. Figure 4.51 shows the 50th percentile uplink bit rates for difference hotspot size.

![Figure 4.51: 50th percentile uplink bit rates for different systems with different hotspot size](image1)

In figure 4.51, when the hotspot size got smaller (-10m), the indoor cell-edge pico users got reduce distance to the serving node thus better SINR and better system load balance since some indoor macro users offloaded toward pico nodes, and this improve the load balance for this users distribution. On the other hand, increasing the hotspot size, decrease the indoor users thereby fewer users offloaded toward pico nodes, which makes the macro nodes overloaded. Decreasing the indoor users decrease the indoor macro users, thus less interference in uplink.

![Figure 4.52: Uplink bit rates for different systems with different hotspot size](image2)
5 Discussions, Conclusions and Future Works

Heterogeneous networks deployment is considered a promising way for system improvements. Complementing macrocell with low power nodes add many advantages where it is easy, fast, and cost effective comparing with the traditional ways. Picocells, Femtocells, and Relays are the main heterogeneous network nodes. They have low transmitting power and lower antenna heights comparing to macro nodes, thus they have less coverage area. Deploying low power nodes in selected areas will increase the system capacity, coverage area, and the users’ throughputs. Introducing such deployment raises new challenges; interference and imbalanced load between nodes are considered the main issues. Many reasons behind such issues mainly, power difference, unplanned deployments, and different access methods.

In this thesis, the indoor models for pico nodes as specified in the 3GPP TR36.814 [18] are implemented and investigated by means of simulation. The simulator is MATLAB based provided from Ericsson Research AP. Different deployment scenarios are investigated to better understand the impacts of deployment position, interference, and load balance on system performance.

For indoor pico deployment, other factors that control the pico coverage area are added. Generally, macrocell power and deployment position controls the picocell coverage area. For indoor scenario, building size and wall penetration also have a big role. Due to wall penetration attenuation, the pico nodes coverage area is limited to inside the building. The transition zone area, i.e. where the optimal cell selection differs between downlink and uplink, is to a large extent covered by the building walls in most of the cases.

Wall penetration protect the indoor users from macro power, thus indoor users maintain better channel conditions comparing with outdoor users. Moving the building as long the indoor pico nodes further away from macro nodes will increase the pico coverage area and improve the pico users SINR inside the building, thus they will maintain better performance. Load balance between nodes has a big effect on system performance. Pico nodes have better channel conditions indoor, thereby pico nodes can handle larger load share than macro nodes.

Users distribution have impacts on the system performance. Closer and indoor users have better performance than far and outdoor users. Since the pico nodes coverage area is limited to indoor, capturing the indoor load traffic so that pico nodes being closer to the most of the users improve the system performance and load balance between nodes. The interference in indoor deployment is minimized due to wall penetration but it is not canceled, so that resources coordination between nodes is beneficial to mitigate and handle the interference scenarios.
To extend the works carried out at this thesis, some future works will be interesting like, implement the enhanced resource coordination (eICIC) to understand the gains on system coverage and performance. Analyze the handover procedure between picocells and macrocells to understand the impacts of handover on performance. In addition, it will be interesting to find out the advantages of complements the work with CoMP techniques as one solution to enhance the transition zone area users performance.

6 References


