Addis Ababa University

Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Performance Evaluation of 6-Sector Site and Small Cell for Addis Ababa UMTS Deployment Scenario

By

Tirufire Aberra

Advisor

Dr. Beneyam Berehanu Haile

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Telecom Network Engineering

November 2018

Addis Ababa, Ethiopia

Addis Ababa University

Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Performance Evaluation of 6-Sector Site and Small Cell for Addis Ababa UMTS Deployment Scenario

By

Tirufire Aberra

Approval by Board of Examiners

________________ ____________________

Dean, School of Electrical and

Computer Engineering Signature

Dr. Beneyam Berehanu Haile (Phd) ______________

Advisor Signature

_________________________________ ______________

Examiner Signature

_________________________________ ______________

Examiner Signature

_________________________________ ______________

Examiner Signature

Declaration

I declare that the work contained is my own, has not been summited for a degree in any other university or professional qualification, and all sources of materials used for the thesis have been fully acknowledged.

Tirufire Aberra ___________________

Name Signature

Place: Addis Ababa

Date of Submission: ________________

This thesis has been submitted for examination with my approval as a university advisor.

Dr. Beneyam Berehanu Haile ___________________

Advisor's Name Signature

ABSTRACT

The demand for high data rate has been increasing due to various innovative data services that improve human life. To accommodate the increasing demand with satisfactory Quality of Service (QoS), operators must continuously improve their network capacity. To that end, besides deploying a Fourth-Generation (4G) network, already operational Third-Generation (3G) network capacity can be improved by applying various capacity improving techniques including six sectorization, adding small cells, macro site densification, Multiple Input Multiple Output (MIMO) and using multiple carrier.

In this thesis, capacity challenges of Addis Ababa Universal Mobile Telecommunications System (UMTS) network are analyzed using real data from network management system. Further, performance evaluation and comparison of six-sector sites, small cell deployment and their hybrid deployments are presented in the context of addressing the capacity challenges. The evaluation is performed using carrier to interference plus noise ratio (CINR) and throughput metrics and WinProp based propagation computation and network simulation by applying dominant path pathloss model over building map of selected deployment area of Addis Ababa.

Results show that full deployment of six-sector has performance improvement compared to full 3-sector with 2.9 dB CINR and 284.23% DL throughput gains. In addition, 6-sector with 3-sector (hybrid) has 2.2 dB and 231.05% gain in CINR and DL throughput compared to full 3-sector deployment respectively. Furthermore, femto with 5% penetration has 0.3 dB CINR gain over full 3-sector. Based on the results, deployment of 6 sector site (both full and hybrid) can enhance capacity of UMTS network significantly and can elevate the capacity challenges faced. Furthermore, femto also has improved the capacity and with an increase in penetration ratio, the gain can be further increased.

Keywords— UMTS Capacity Challenges, Capacity Enhancement Techniques, Six Sectorization, Small Cell, Addis Ababa UMTS Network

ACKNOWLEDGEMENTS

First of all, I am thankful to Almighty God for giving me everything I need throughout my work and Virgin Mary for her prayers and giving me strength.

Secondly, I would like to express my sincere gratitude and strongest thanks to my Advisor, Dr Beneyam Berehanu Haile, for giving me the opportunity to work under his supervision, for guiding me in every step, giving his valuable and constructive feedbacks starting from planning to the completion of this research work. This thesis would not be possible without his support.

In addition, my genuine thanks and gratefulness goes to my Mother-in-law for her support, encouragements and also to my sister-in-laws. I wish to acknowledge the support provided by my husband encouraging me in every step of the way and my son provide unending inspiration. Strongest thanks to my parents, brothers and sister for their continuous support and encouragement at every step of my work.

Finally, I am grateful to my friend Banchiamlak G/Tsadik for her enormous support and encouragements on my working and being by my side always. And my special thanks are extended to the service management center staffs and management for their assistance with the collection of data and for their encouragement. Last but not least I would like to thank my classmates, ethiotelecom staffs and management for their support.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

1-SC	One Single Carrier
3G	Third-Generation
3GPP	Third-Generation Partnership Project
4-SC	Four Single Carrier
4G	Fourth-Generation
ACK	Acknowledgment
AICH	Acquisition Indicator Channel
AMC	Adaptive Modulation and Coding
ARQ	Automatic Repeat Request
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BLER	Block Error Rate
BMC	Broadcast/Multicast Control
CCCH	Common Control Channel
CCH	Control Channels
CDMA	Code Division Multiple Access
CE	Channel Element
CINR	Carrier to Interference plus Noise Ratio
CN	Core Network
CPICH	Common Pilot Channel
CQI	Channel Quality Indicator
CRC	Cyclic Redundancy Check
CS	Circuit Switched
CTCH	Common Traffic Channel

DCCH	Dedicated Control Channel
DCH	Dedicated Channel
DC-HSDPA	Dual Carrier HSDPA
DL	Downlink
DS-CDMA	Direct Sequence Code Division Multiple Access
DSCH	Downlink Shared Channel
DSSS	Direct Sequence Spread-Spectrum
DTCH	Dedicated Traffic Channel
D-TxAA	Dual-stream Transmit Adaptive Antenna
Eb	Energy per bit
Ec	Energy per chip
E-DCH	Enhanced Dedicated Channel
FACH	Forward Access Channel
FDD	Frequency Division Duplex
FEC	Forward Error Correction
GGSN	Gateway GPRS Support Node
GGSN	Gateway GPRS Support Node
GMSC	Gateway Mobile Switching Center
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
GSMC	Gateway Mobile Switching Center
HARQ	Hybrid Automatic Repeat Request
HetNet	Heterogeneous Network
HLR	Home Location Register
HMS	Home Node B Management System
HNB	Home Node B

HNB-GW	Home Node B Gateway
HSDPA	High-Speed Downlink Packet Access
HS-DSCH	High-speed Downlink Shared Channel
HSPA	High-Speed Packet Access
HS-SCCH	High-Speed Shared Control Channel
HSUPA	High-Speed Uplink Packet Access
IP	Internet Protocol
ITU	International Telecommunication Union
Kbps	Kilobits per second
KPI	Key Performance Indicator
L1	Layer One
L2	Layer Two
L3	Layer Three
L-GW	Local Gateway
LTE	Long Term Evolution
MAC	Medium Access Control
Mbps	Megabits per second
MC	Multi-Carrier
MCS	Modulation and Coding Schemes
MIMO	Multiple Input Multiple Output
MSC	Mobile Switching Center
MT	Mobile Terminal
No	Noise
OVSF	Orthogonal Variable Spreading Factor
PCCH	Paging Control Channel
P-CCPCH	Primary Common Control Physical Channel

PCH	Paging Channel
P-CPICH	Primary Common Pilot Channel
PDCP	Packet Data Convergence protocol
PDSCH	Physical Downlink Shared Channel
PICH	Paging Indicator Channel
PLMN	Public Land Mobile Network
PMS	Performance Monitoring System
PN	Pseudo-Noise
PRACH	Physical Random Access Channel
PRS	Performance Report System
PS	Packet Switched
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
R99	Release 99
RAB	Radio Access Bearer
RACH	Random Access Channel
RAN	Radio Access Network
RAT	Radio Access Technology
RB	Radio Bearer
RF	Radio Frequency
RLC	Radio Link Control
RNC	Radio Network Controller
RRC	Radio Resource Control
RRM	Radio Resource Management
S-CCPCH	Secondary Common Control Physical Channel

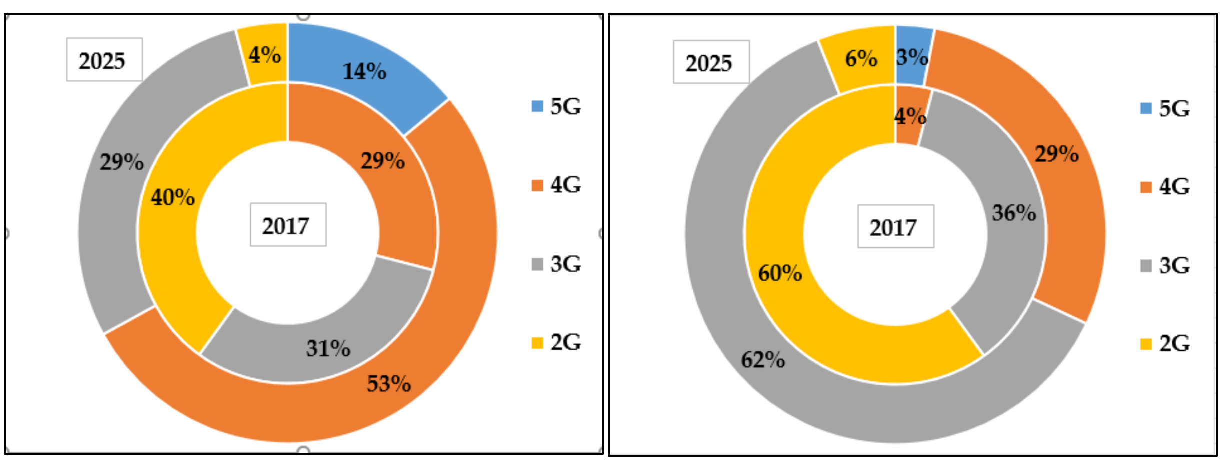
SCH	Synchronization Channel
S-CPICH	Secondary Common Pilot Channel
SeGW	Security Gateway
SEQ	Service and Experience Quality
SF	Spreading Factor
SGSN	Serving GPRS Support Node
SGSN	Serving GPRS Support Node
SINR	Signal to Interference plus Noise Ratio
TCH	Traffic Channel
TDD	Time Division Duplex
TE	Terminal Equipment
TxAA	Transmit Adaptive Antennas
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
USIM	UMTS Subscriber Identity Module
UTRA	UMTS Terrestrial Radio Access
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
WCDMA	Wideband Code Division Multiple Access

1 INTRODUCTION

1.1 Background

UMTS is a 3G cellular system which presents a range of data, voice, text, and multimedia-based services [1]. To improve quality of data services the first UMTS standard Release 99 (R99) packet domain has been evolved to High-Speed Packet Access (HSPA) and HSPA+ including mainly multiple carriers, higher order modulation, higher order MIMO and other features in the consecutive Third-Generation Partnership Project (3GPP) releases.

Most mobile operators have deployed HSPA/HSPA+ network and the incumbent ethio telecom has also deployed them in almost all cities and other parts of Ethiopia [2]. The 3G share in 2017 and forecasted 3G share in 2025 both across the globe and in Sub-Saharan countries is shown in *Figure 1.1* [3]. As can be seen from the figure, 3G has been and will be significantly contributing to accommodating mobile services. Its role is more significant in Sub-Sahara countries including Ethiopia.



a) *b)*

Figure 1.1 Technology share in the a) world and b) Sub-Saharan Africa [3]

Therefore, besides preparing and deploying a 4G network, mobile operators shall continuously optimize their 3G network to meet the increasing data demand with higher QoS requirement. The network needs to have sufficient network capacity to ensure required user QoS for the various innovative data services. If there is limited network capacity either users' data rates are decreased or users are not admitted to the network. These results in unsatisfactory network users who might strongly complain or churn to operators. The work towards satisfactory QoS requires identifying and understanding the causes of network capacity challenges. To understand the causes of network capacity challenges, network traffic and connection failures from network management system are analyzed.

To address the capacity challenges caused by limited resources, six sectorization and small cell technologies are selected from available popular technologies based on relevance and practicability. The performance analysis of these technologies and their hybrid is done using WinProp based system level simulation. The performance results show that 6-sector has significant gain compared to 3-sector.

1.2 Statement of the Problem

Currently, there is a growing demand for data services and the adoption of mobile data service is increasing rapidly [4]. Human lifestyle is changing in terms of how people do business, educate and communicate. Expanding mobile network to support these increasing data demand and introducing new relevant technologies is an important work for mobile operators.

In Addis Ababa, users have experienced difficulties in getting the desired QoS of the Wideband Code Division Multiple Access (WCDMA) network and there are capacity challenges [5]. Moreover, the failure increase is very much related to the traffic increase over the 24-hours period which indicates high traffic caused the capacity challenges.

There has been some progress in recent years to meet the increasing data demand in Addis Ababa [6]. Nonetheless, several challenges remain in terms of how to enhance and expand these networks to meet the growing demands of an increasingly digital economy and society. To improve capacity of UMTS network without rework (within a short period of time), proper selection, study and evaluation of capacity improvement techniques is important. However, if there is no criteria for selecting capacity improvement techniques by analyzing their performance, there will be frequent network capacity challenges.

1.3 Related work

To improve user QoS due to lack of network capacity, operators need to increase network capacity to the level of meeting required data demand. Real wireless [7], presented techniques for increasing the capacity of wireless broadband networks for the UK on behalf of Ofcom, the UK regulator. It evaluates options that are better suited for the UK for the year 2012 to 2030. Capacity-enhancing techniques considered in the study subcategorized as Spectrum, topology, and technology are shown in *Figure 1.2*. These techniques are evaluated based on performance gains, cost and cost to the society. The study also considers a combination of technologies specifically HSPA+ and LTE.

The papers presented in [7] and [8] show that before the deployment of a network or before expansion work, different options should be evaluated using different metrics. Based on observations on [7], traffic is never equally distributed between sites and is also not equally distributed over a 24-hour period which is also true for Addis Ababa case. The paper presents option like adding macro sites in hot spots, deploying six sector sites, implementing QoS differentiation and also femtocells which can provide a significant capacity offload if marketed with appropriate use pattern.

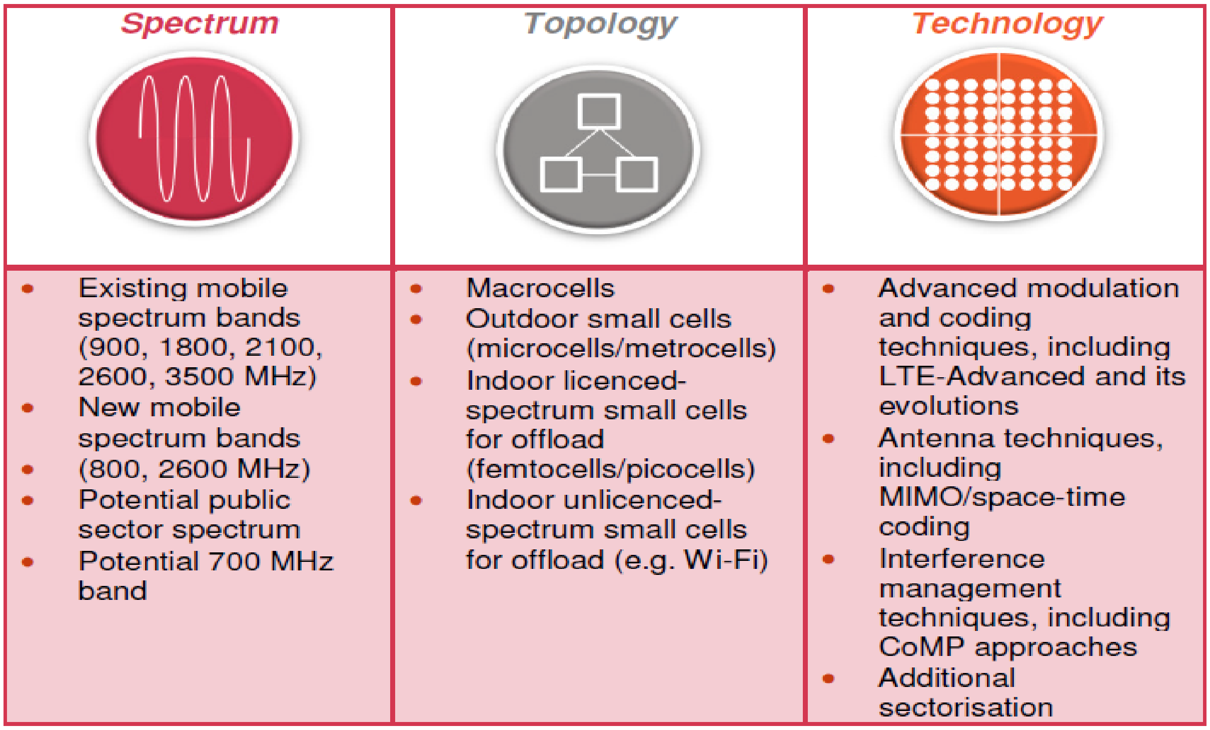


Figure 1.2 Techniques considered [7]

6-sector was among techniques that are used to improve capacity, coverage, and quality [9] [10] [11]. Especially in [9], a case study of a real installed WCDMA 6-sector deployment for UMTS-Frequency Division Duplex (FDD) in Stuttgart is presented which tested 3 deployments scenarios.

- All sites are 3-sectored
- Hotspots are 6-sectored with maximum DL power of 20 W for each cell
- Hotspots are 6-sectored with maximum DL power of 10 W for each cell

With the second scenario, they observed that there was a 23% increase in coverage and 1.8x capacity increase. In [10], further demonstrated simultaneous users increase when the number of sectors increases for 384kbps. For example, for bit energy to noise ratio (Eb/No) value of 4 dB, 88 users are simultaneously connected in 6-sectors but for 3-sectors, 45 users are simultaneously connected.

Currently, six sectorization is based on the new advanced antenna technology called twin beam. In [11], CommScope showed sectorization using twin beam technology and advantages in contrast to using two narrowband antenna. The benefit of six-sector compared to three-sector configuration regarding capacity is also shown. Six-sector has less overlap area compared to three-sector, as a result, the soft handover overhead decreases. From the challenges stated in the paper, using two narrow band antenna doubles the cost and creates load on the tower. The overlap area for both 3 and 6-sectored antenna is a shown in *Figure 1.3*.

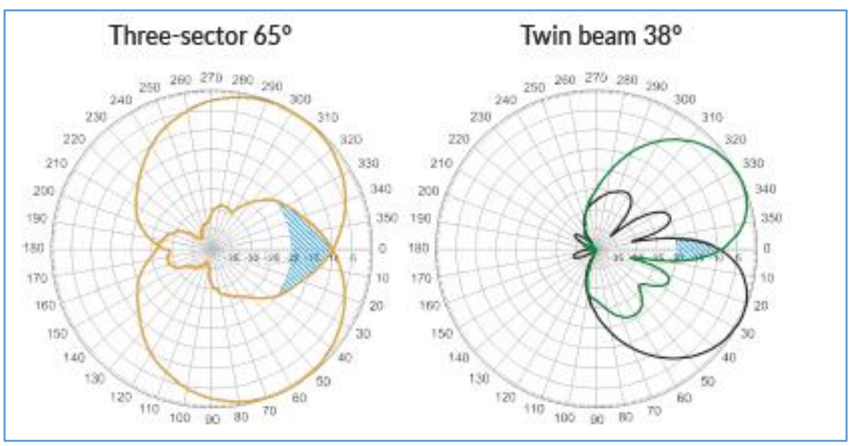


Figure 1.3: Three sector vs six sector [11]

CommScope's white paper also showed wireless operators strategies for increasing capacity and sectorization history (from Omni to 3-sector to twin beam). *Figure 1.4* explores strategies for the search of more capacity that is presented in [11]. The paper concludes as "the bottom line is higher QoS and increasing the QoS means ramping up capacity."

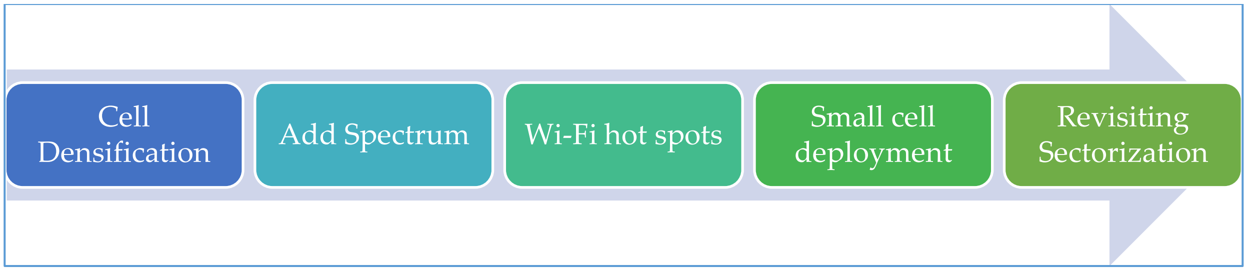


Figure 1.4: Quest for more capacity [11]

A study in [12] showed that not only higher order sectorization but also the beam width of the antenna affects capacity and coverage. It is shown that interference leakage into neighboring sectors reduces the capacity of the network due to the overlap in the antenna radiation patterns as well as the influence of the environment on the shape of the patterns. The effect can be kept small by careful selection of the antenna beam width. The sectorization gain can vary from 1 for Omni to 5.07 for 6-sector with 33-degree orientation in DL. The increase of the soft handover areas can be kept at an acceptable level so that the additional overhead due to soft handover connections is small enough.

In [13] [14] the future of HSPA+ has been put forward. The growth of users of UMTS service was predicted to grow in the future and physical capacity of the system may not be able to support the demand. So, to bring the performance of HSPA+ to the next level new techniques like carrier aggregation, MIMO and Heterogeneous Network (HetNet) have been introduced to enhance the capacity and improve cell edge experience. Multi-Carrier (MC) in HSDPA is further studied in [15]. The simulation results showed that for the same offered load MC HSDPA achieved better user throughput and double the data rate. In addition, it is shown that MC HSDPA will increase the user throughput by a factor N throughout the system coverage area where N is the number of carriers used.

1.4 Objective

1.4.1 General objective

The ultimate objective of this thesis is selecting and evaluating capacity enhancements techniques for UMTS data service in the context of Addis Ababa.

1.4.2 Specific objectives

The specific aims of the thesis are to:

- Identify and analyze existing capacity challenges for UMTS network
- Select relevant and practicable capacity improvement techniques for UMTS network
- Analyze and evaluate the selected techniques
- Undertake a performance comparison of the selected techniques

1.5 Methodology

The research plan has five phases. In the first phase, identification and analysis of existing capacity challenges of Addis Ababa UMTS network by using the data from the network performance system is carried out.

In the second phase, capacity improvement techniques are studied. The collection and study of these techniques are conducted by digging out information from literature, currently available global telecom operators, standards and other available data.

The third phase of the research is studying of capacity enhancement techniques based on performance results and the capacity gain added. Here the performance of the capacity improvement techniques are studied in details from performance results of related works.

The selection of capacity improvement techniques using device penetration data from Service and Experience Quality (SEQ) analyst is in the fourth phase of the research. Finally, the performance of the capacity enhancement techniques are compared in the given Addis Ababa UMTS network. In this phase, network simulation system (WinProp) is used to test the performance of capacity enhancement techniques and Matlab is used for comparison of results.

1.6 Scope

The scope of this thesis work is:

- Considered UMTS packet switched (PS) service for both challenge analysis and techniques selection but does not mean techniques cannot be applied for circuit switched (CS) services.
- Addis Ababa network is used for analysis of capacity challenges and Bole area is used for the simulation.
- The measurement data is obtained from the Performance Monitoring System (PMS) of the operator namely Performance Report System (PRS) and SEQ analyst.
- The input parameters are based on the configuration obtained at the start of the simulation. There may be some changes afterward.
- Used uniform (location independent) traffic for the simulation.

1.7 Thesis outline

Chapter 2 discusses UMTS technology from the network architecture to HSPA/HSPA+ main feature. Chapter 3 describes capacity challenges in Addis Ababa network including some performance output from PRS. In chapter 4, six capacity improvement techniques for WCDMA/HSPA/HSPA+ will be discussed including network architecture of 3G femtocell.

In Chapter 5, selection of capacity enhancement techniques and scenario description are presented and Chapter 6 discusses system modeling, and assumptions for simulation with selected experimental area details, description of the tools and parameter for the simulation. Chapter 7 describes the detailed result of the experiment and compared the gains between different deployment strategies. Finally, Chapter 8 concludes the thesis by bringing up future research possibilities related to this study.

2 UMTS TECHNOLOGY

2.1 UMTS architecture

UMTS consists of three main parts [1]: the User Equipment (UE), the Radio Access Network (RAN), and the Core Network (CN), as shown in *Figure 2.1.*

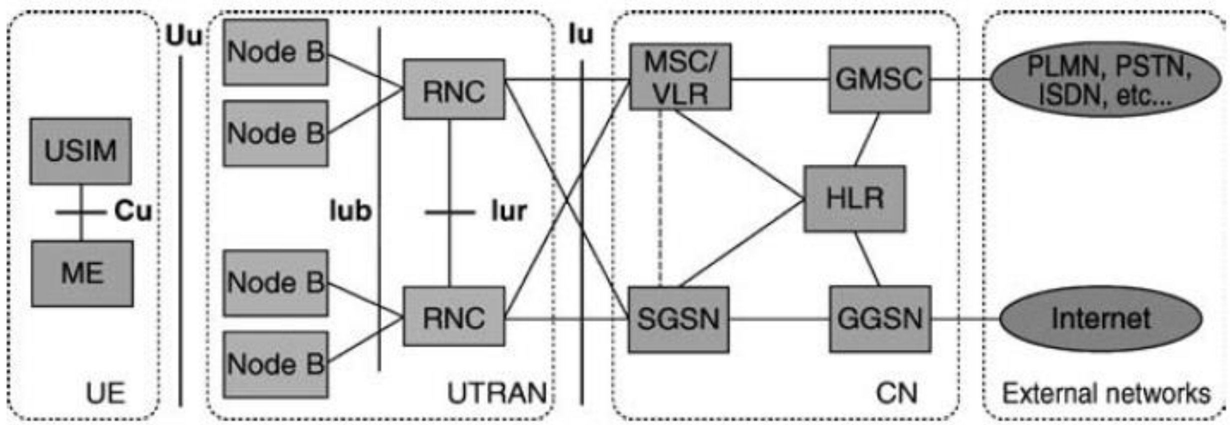


Figure 2.1 Network Elements [1]

The functions of each network element is described below

UE consists of the radio terminal used for radio communication over the Uu interface named Mobile Equipment (ME) and a smart card that holds the subscriber identity which is called UMTS Subscriber Identity Module (USIM). It performs authentication algorithms, and stores authentication and encryption keys and some subscription information that is needed at the terminal.

Universal terrestrial radio access network (UTRAN) consists of:

- **Node B** converts the data flow between the Iub and Uu interfaces and some radio resource management.
- **Radio Network Controller (RNC)** control of the radio resources and is the access point for all services that UTRAN provides for the CN.

CN consist of:

Gateway Mobile Switching Center (GMSC) connects the mobile network, and the external CS networks in Circuit Switched (CS) domain.

Mobile Switching Center (MSC) is responsible for establishing and controlling circuit switched connections.

Visitor Location Register (VLR) stores information on visiting area of subscribers.

Home Location Register (HLR) is a database that stores master copy of user's profile.

Serving GPRS Support Node (SGSN) is mainly responsible for mobility management like registration and update of the UE, paging related activities, and security issues for PS domain.

Gateway GPRS Support Node (GGSN) has a similar function like GMSC which is interfacing the 3G network to the external PS networks.

Interfaces

- **Cu interface:** is an interface between the USIM and the ME.
- **Uu interface:** an interface between UE and the fixed part of the system also known as air Interface.
- **Iub interface:** is an interface between a Node B and an RNC.
- **Iu interface:** is an interface between UTRAN to the CN.
- **Iur interface:** is an interface that connects two different RNCs.

2.2 Code Division Multiple Access (CDMA)

CDMA is a multiple access technique where a number of transmitters simultaneously communicate over a single communication channel (frequency) with the assignment of unique CDMA code for each sender-receiver pair. Before sending, the sender multiplies the bit sequence by the code, in turn, the receiver multiplies the received sequence with the code then obtain the original sequence of bits. Synchronization between a sender and a receiver is necessary for decoding the information correctly [20].

Principles of Spread Spectrum

The spread-spectrum technology was developed for military and navigation purposes due to it has an efficient anti-jamming properties and low probability of interception. This is because of its low power spectral density since it uses wider transmitted bandwidth.

The fundamental idea of WCDMA spreading is to spread a certain lower bandwidth information over a wider transmission bandwidth. WCDMA uses Direct Sequence Spread-Spectrum (DSSS). In DSSS, if an information sequence has N modulation symbols and M-chip-long spreading sequence it results in N×M chips sequence. The M is called the spreading factor [23] [36].

WCDMA uses a two-level code system: orthogonal spreading codes and pseudo-random scrambling codes. In order to support variable data rates, the WCDMA air interface allows per-channel selectable spreading factors, and this family of spreading codes is called Orthogonal Variable Spreading Factor (OVSF) which is in the form a hierarchical tree structure as shown in *Figure 2.2*. The use of OVSF and scrambling codes are different in the downlink and uplink directions. In the downlink direction, the OVSF codes are used to multiplex different channels transmitted in the same cell [1] [23]. While in the uplink direction, the OVSF codes are used to separate data and control channels from a specific user. Cross-correlation between the sequence from one part of the tree and with another sequence from a different branch of the tree is zero.

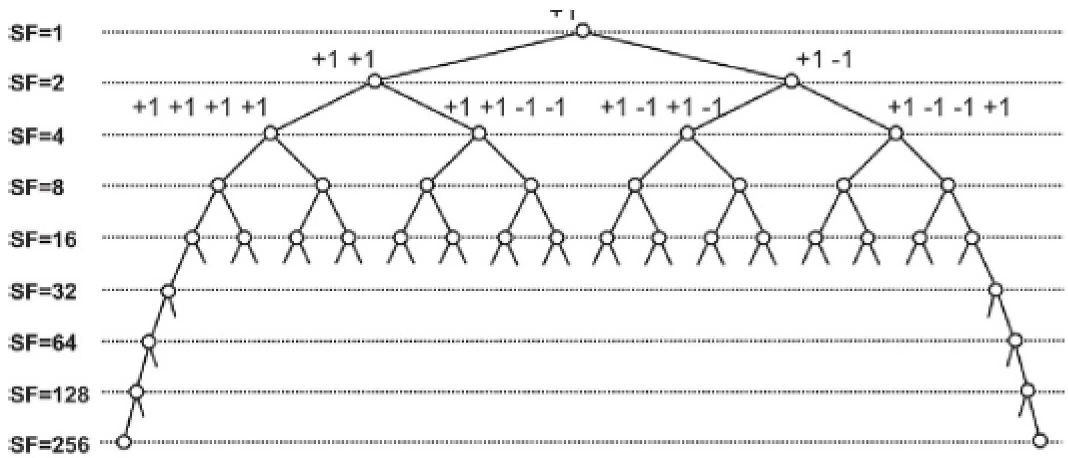


Figure 2.2 Channelization codes [22]

Scrambling, using pseudo-random sequences, is used in addition to spreading. In the downlink direction, different scrambling codes separate different cells, and in the uplink direction, they separate different users.

2.3 UMTS radio interface protocol architecture

The radio interface is layered into three protocol layers as shown in *Figure 2.3* and the functions of each layer is discussed.

Physical layer (L1) main functions includes Forward Error Correction (FEC), encoding/decoding of transport channel, macro-diversity combining and softer handover execution, modulation/demodulation, spreading/despreading of physical channels, and frequency and time synchronization [16].

Data link layer (L2) is subdivided into Medium Access Control (MAC), Radio Link Control (RLC), Packet Data Convergence Protocol (PDCP), and Broadcast/Multicast Control (BMC). RLC sublayer is divided into Control (C-Plane) and User plane (U-Plane) whereas PDCP and BMC exist in user plane only. MAC layer offers services to the RLC layer in the form of Logical Channels [15] [21]. MAC offers services to L1 by transport channels in which data are transferred in the form of transport blocks.

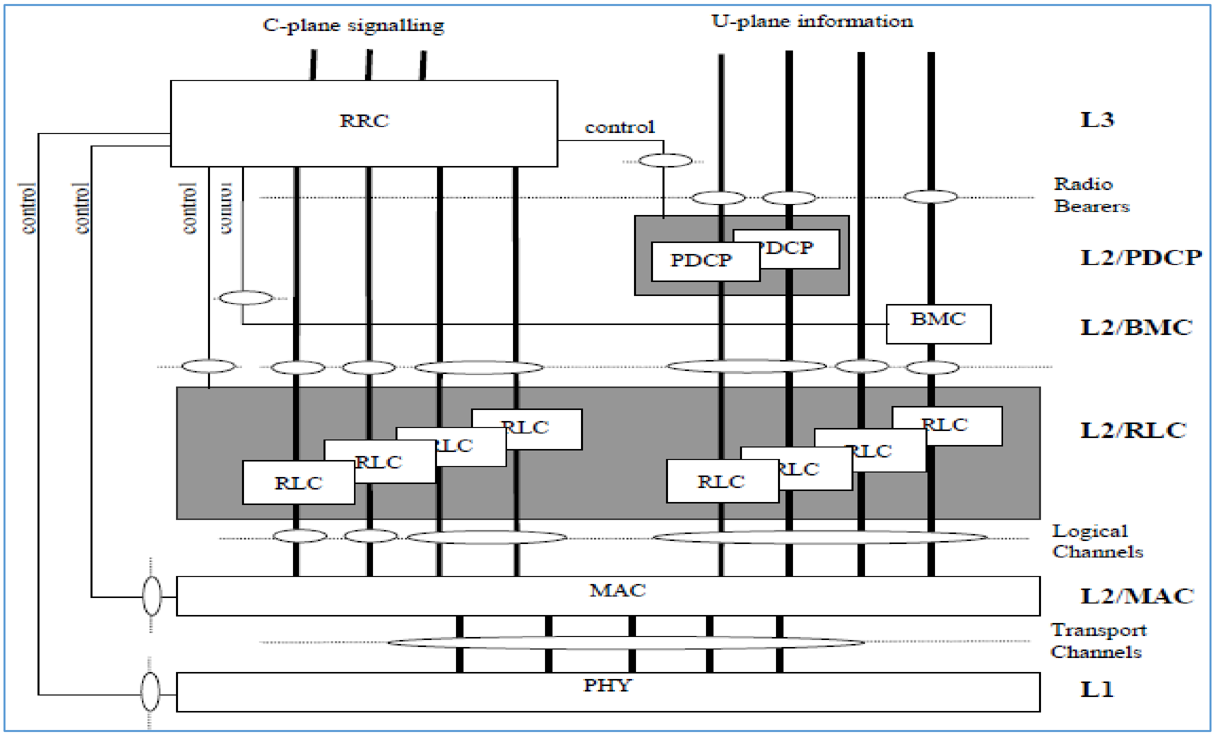


Figure 2.3 UMTS radio interface protocol architecture [16]

RLC sublayer functions include segmentation/reassembly, concatenation/padding, transfer of user data, error correction, in-sequence delivery, flow control, and ciphering.

MAC sublayer function includes mapping between logical and transport channels, selects appropriate transport format for each transport channel, multiplexing/demultiplexing, segmentation/reassembly, in-sequence delivery of upper layer protocol data units, traffic volume measurement, ciphering, and Hybrid Automatic Repeat Request (HARQ).

RRC: is responsible for handling of control plane signaling and used to control the mobility of the UE in connected-mode, reconfigure and release Radio Bearers (RBs). The

RRC protocol is also used for setting up, controlling UE measurement-reporting criteria and downlink outer-loop power control. Initial cell selection and cell reselection are also part of RRC connection management procedures. RRC messages carry all parameters required to set up, modify and release L2 and L1 protocol entities [18].

The main functions of PDCP sublayer are header compression/decompression and transfer of user data. BMC provides broadcast/multicast transmission in the user plane and main functions include storage of cell broadcast message, traffic volume monitoring, scheduling of BMC messages, transmission of BMC message to UE and delivery of cell broadcast messages to the upper layer.

2.4 UMTS QoS

2.4.1 Definition of QoS

International Telecommunication Union (ITU) has defined QoS as a determining factor of user satisfaction for a service delivered that is the collective effect of the performances [37]. In [38], QoS is defined as the network ability to provide a service at a guaranteed service level.

2.4.2 Management functions in UMTS

Network service are end-to-end and the traffic pass through different bearer services [38]. The entities involved in the UMTS packet data architecture which provide QoS services are discussed in section 2.1 here only mention additional entity which is Core Network Edge Node (CN Edge Node). It provides the interface between the RAN and the PS core for assuring session and mobility management. R99 QoS architecture encompasses different functionalities and end-to-end QoS architecture are shown in *Figure 2.4*.

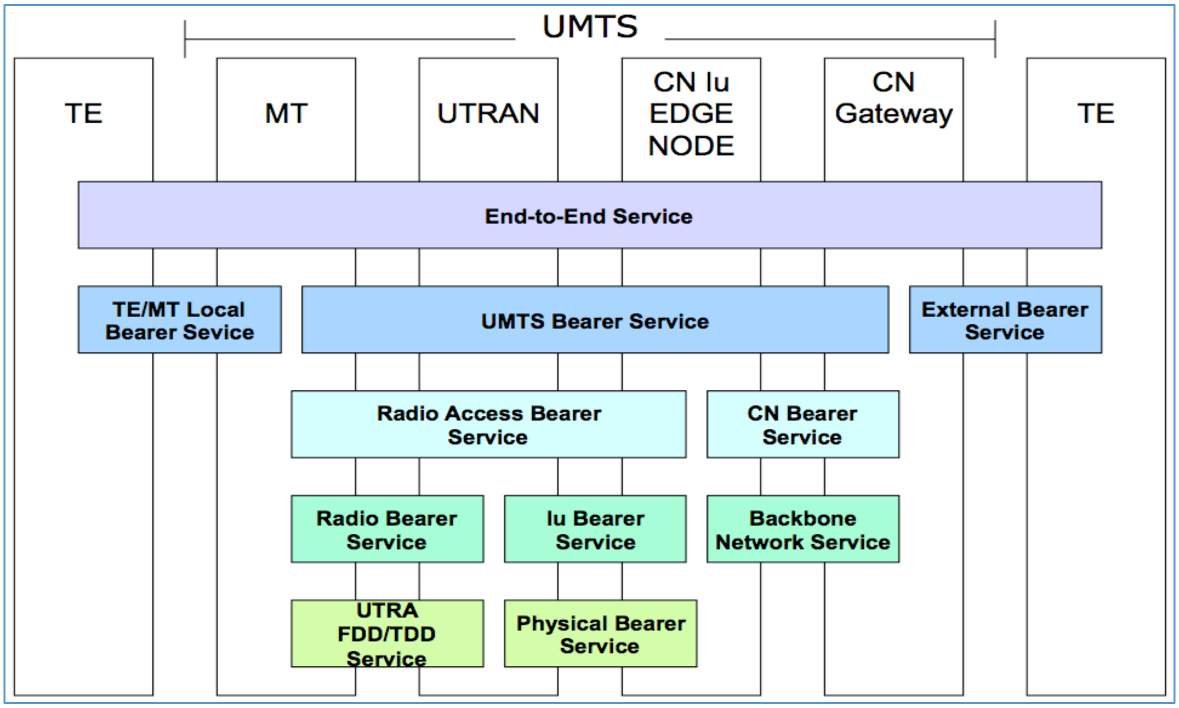


Figure 2.4 R99 End-to-End QoS Architecture [38]

- **Terminal equipment (TE) /mobile termination (MT) local bearer service:** is responsible for the local QoS between the TE and MT.
- **UMTS Bearer Service** consists of radio access bearer service and CN bearer service.
- **Radio access bearer service** provides confidential transport of signaling and user data between MT and CN Edge Node. The Radio Bearer Service (RAB) service is composed by a radio bearer service and an Iu-bearer service.
- **RAB** is used to cover all the aspects of the radio interface transport. This bearer service uses the UTRAN FDD/Time Division Duplex (TDD).
- **UTRA FDD/TDD service** provides the transport between the radio access network and the UE through the radio bearer service.
- **The Iu-Bearer service** provides the transport between UTRAN and CN together with the physical bearer service.

- **CN bearer service** connects the UMTS CN Edge Node with the CN gateway to the external network.
- **The backbone network service** is selected to fulfill the QoS requirements of the core network bearer service and covers the L1/L2 functionality
- **Physical bearer service** provides the transport between the RAN and the CN.
- **End-to-end service** includes all bearers' service.

2.5 UMTS Channels

UMTS uses channels for transmission and reception of information (signaling and user data) which are categorized as logical, transport and physical.

2.5.1 Logical channels

The logical channel provides data transfer services at the MAC layer and are classified as Control Channels (CCHs) and Traffic Channels (TCHs). CCHs are used for transfer of control-plane (signaling) information and TCHs are used for the transfer of user-plane (user data) information only [17]. Common channels are briefly described as follows:

Broadcast Control Channel (BCCH): used for broadcasting system control information in the downlink direction.

Paging Control Channel (PCCH): used for transferring paging information in the downlink direction.

Common Control Channel (CCCH): used for transmitting control information in both directions.

Dedicated Control Channel (DCCH): a point-to-point bi-directional channel for transmitting dedicated control information between the network and a UE.

Traffic channels are described as:

Dedicated Traffic Channel (DTCH): is a point-to-point channel dedicated to one UE for transfer of user information and can exist in both uplink and downlink directions.

Common Traffic Channel (CTCH): a point-to-multipoint unidirectional channel for transfer of dedicated user information for all UEs or a group of specified UEs.

2.5.2 Transport channels

In 3GPP, all transport channels are defined as unidirectional that is either in the uplink or downlink directions. One or several transport channels, depending on services and state, can be simultaneously assigned to UE. Transport channels are categorized as dedicated and common transport channels. The common transport channel are divided between all users or a group of users in a cell [1] [23] [42]. Common transport channels are described below:

Broadcast Channel (BCH): is used to transmit information specific to the UTRA network or to a given cell including random access codes and cell access slots.

Forward Access Channel (FACH): carries downlink control information to terminals located in the given cell and also used to transmit a small amount of downlink packet data.

Paging Channel (PCH): carries data relevant to the paging procedure. The paging message can be transmitted in a single cell or several cells according to the system configuration.

Random Access Channel (RACH): carries uplink control information such as a request to set up an RRC connection and also used to send small amounts of uplink packet data.

Downlink Shared Channel (DSCH): introduced in release 5, carries dedicated user data that is shared between users in time.

High-speed Downlink Shared Channel (HS-DSCH): is introduced in HSPA+ that has similar functions as DSCH.

2.5.2.1 RRC states

Idle mode: the UE does not have an RRC connection. Its receiver is switched off for most of the time and will wake up during paging occasions to listen to paging messages. Mobility is based on reselection [23].

CELL_PCH: is a state where the UE has an RRC connection but cannot send or receive data. The location of the UE is based on the last cell in which the UE was in CELL_FACH state. Mobility is based on UE cell reselection. The UE is accessed through the paging channel.

URA_PCH: is similar to CELL_PCH, except that the UE's location is only known within a paging area.

CELL_FACH: can send and receive small amounts of data on FACH and RACH. But UE does not have dedicated channels allocated. Mobility is through cell reselections.

CELL_DCH (dedicated mode): UE is allocated a dedicated channel. Mobility is managed by the network by means of handover.

2.5.3 Physical channels

Physical channels are grouped as common and dedicated [18]. Common physical channels ,in the downlink direction, carry cell broadcast data used for L1 handshaking, synchronization, channel estimation, Layer 3 (L3) information transmission and non-connection oriented user data [18] [41].

Physical Random Access Channel (PRACH): uplink direction, RACH is mapped onto the PRACH.

Common Pilot Channel (CPICH): used for measuring signal quality using matrixes like Received Signal Code Power (RSCP). There are two types of CPICH, the Primary and the Secondary. The Primary CPICH (P-CPICH) is the phase reference for most of the common and dedicated channels [39]. The Secondary CPICH (S-CPICH) provide an additional phase reference. Each S-CPICH may be transmitted over the entire cell or over only a part of the cell.

Common Control Physical Channel (CCPCH) consists of a Primary CCPCH (P-CCPCH) that carries BCH and Secondary CCPCH (S-CCPCH) is used to carry the FACH and PCH.

Synchronization Channel (SCH): used in the cell search procedure. It consists of two sub-channels that are transmitted in parallel, Primary SCH for downlink slot synchronization in the cell and the secondary SCH for downlink frame synchronization.

Physical Downlink Shared Channel (PDSCH): carries the DSCH transport channel.

Acquisition Indicator Channel (AICH) carriers the response of RACH message.

Paging Indicator Channel (PICH): carries paging indicators.

2.6 Radio Resource Management (RRM)

RRM is responsible for air interface resources efficient utilization. It guarantees QoS, maintain the planned coverage area and optimize the radio resource usage in the network

[1]. RRM function can be implemented in different network elements as shown in *Figure 2.5*.

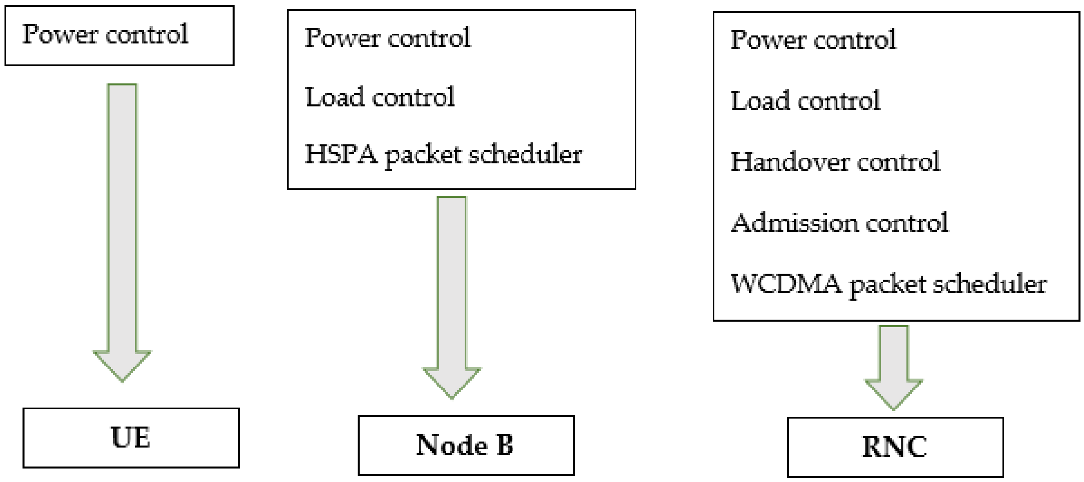


Figure 2.5 Locations of RRM algorithms in a WCDMA/HSPA network

2.6.1 Power control

Both the uplink and the downlink direction capacity of CDMA systems is generally interference limited. In the downlink direction, there is interference between different users, as well as between the different propagation paths of the same user. Tight and fast power control is perhaps the most important aspect in WCDMA, in particular on the uplink direction. Without it, a single overpowered mobile could block a whole cell which is known as *Near-far Problem* [1] [17]. To ensure common channels coverage and on the dedicated channels to provide an agreed quality of connection in terms of Block Error Rate (BLER), power control is needed and are configured for each type of services [19] [40].

Open-loop power control: is used for initial power setting prior to initiating RACH transmission. It is not very accurate due to the fact that it is difficult to measure large power dynamics.

Closed-loop power control starts when UE enters a dedicated mode. There are two layers in the closed loop operation: an outer loop and an inner loop [40].

An outer loop power control is needed in both uplink and downlink to keep bearer service quality requirement while keeping power as low as possible. In the uplink direction, it is located in RNC and in the downlink direction it is located in the UE.

An inner-loop power control, also known as fast closed loop power control, is used for keeping the received uplink signal-to-interference ratio at a given target. It is the ability of the UE to adjust its power in accordance with one or more transmit power control commands which is received in the downlink.

2.6.2 Handover

Handover is a process of transferring a user form one cell to another due to the mobility of users. Handovers types that are related to WCDMA are described below [1].

Intra-frequency handover is a handover performed within one WCDMA frequency which includes soft/softer and hard handover.

> **Soft handover:** is handing a mobile over from one Node B to another. In this case, UE is connected to two or more cells belonging to different Node B of the same RNC or to different RNC.
>
> **Softer handover:** is handing a mobile over from one cell to another. In this case, UE has connected two cells under one base station.
>
> **Hard handover:** In this situation, UE's all the old radio links are released before the new radio links are established.

Inter-frequency hard handover is handing a mobile over from one WCDMA frequency carrier to another.

Inter-system hard handover can take place between the WCDMA FDD and another technology, such as Global System for Mobile Communication (GSM).

2.6.3 Admission control

The admission control is executed when a bearer is set up or modified. The admission control algorithm estimates the load increase that is created by the establishment of the bearer in the radio network. The uplink and downlink directions admission control are estimated separately. The requesting bearer can be admitted only if both uplink and downlink admission control admit it [1]. Admission control strategy in the uplink can be wideband power-based and throughput-based.

Load estimation based on wideband received power in uplink: the received wideband interference power (I_{total}), can be divided into the powers of own cell (intra-cell) interference (I_{own}), other-cell (inter-cell) interference (I_{oth}), and background receiver noise, (P_N).

$I_{total} = I_{own} + I_{oth} + P_N$	(2.1)
$Noise\ rise = {I_{total}}/{P_N} = \frac{1}{1 - \eta_{UL}}$	(2.2)

Uplink load factor (η_{UL}) can be calculated:

$\eta_{UL} = 1 - \frac{P_N}{I_{total}} = \frac{Noise\ rise - 1}{Noise\ rise}$	(2.3)

Power-based load estimation in downlink: The downlink load of the cell can be determined by the total downlink transmission power, (P_{total}). The downlink load factor can be defined as:

$$\eta_{DL} = \frac{P_{total}}{P_{max}} \tag{2.4}$$

Where P_{max}: the maximum Node B transmission power

η_{DL}: Downlink load factor

2.6.4 Load control

Another important RRM function is ensuring the stability of the system by controlling overload. Overload situations should be exceptional if the system is properly planned, and the admission control and packets scheduler work sufficiently well. If overload is encountered, however, the load control returns the system quickly and controllably back to the targeted load that is defined by the radio network planning [1].

The possible load control actions are listed below:

- Deny downlink power-up commands received from the UE.
- Reduce the uplink Eb/N0 target used by the uplink fast power control.
- Reduce the throughput of packet data traffic.
- Handover to another WCDMA carrier.
- Handover to GSM.
- Decrease bit rates of real-time UEs.
- Drop low priority calls in a controlled fashion.

2.6.5 Packet scheduling

Packet scheduler determines the available radio resources for non-real time radio bearers, share the available radio resources and monitors the system loading. In addition to load target and overload threshold, the maximum allowed load increase and decrease margins are important parameters, to avoid peaks in interference and to maintain system stability.

2.7 HSPA/HSPA+ Technology

2.7.1 HSPA

3GPP Releases 5 and 6 are the baseline for mobile broadband access which is HSPA. HSPA consists of High-Speed Downlink Packet Access (HSDPA) and High-Speed Uplink Packet Access (HSUPA) [1].

2.7.1.1 HSDPA

Few major changes brought by HSDPA includes packet scheduling and retransmissions moving from RNC to the Node B which made the architecture became flatter, the peak bit rates increased to 1.8–3.6 Mbps and later to 7.2–14.4Mbps, the latency decreased from 200 ms to below 100 ms, the spectral efficiency and network efficiency considerably increased [20] [23].

The need for variable SF which is the basic idea of the R99, are disabled and substituted by means of adaptive modulation and coding (AMC) with multi-code operation. Higher-order modulation introduced are 16-Quadrature Amplitude Modulation (16-QAM) and 64QAM. The transport channel carrying the user data with HSDPA operation is named DSCH [1] [23].

With the introduction of DSCH, HSDPA MAC layer is installed in Node B so that retransmissions can be controlled by the Node B which leads to faster retransmission thus shorter delay.

2.7.1.2 HSUPA

HSUPA is Release 6 specifications that improved uplink packet data performance by means of fast physical layer (L1) retransmission and combining, as well as fast Node B controlled scheduling. The Node B estimates the data rate transmission needs of each active HSUPA user based on the device-specific feedback. Further, the retransmissions are initiated by the Node B feedback. HSUPA retains the uplink power control which was also in WCDMA Release 99, Unlike HSDPA. The main change, which is introduced in HSUPA channel, is the uses of Multi-code operation, fast L1 HARQ and Fast Node B scheduler [1].

2.7.2 HSPA+

3GPP brings a number of further substantial enhancements to the end-user performance, network capacity and to the network architecture [1] [21] [22] [23]. To implement the HSDPA feature, new channels are introduced in addition to HS-DSCH:

- High-Speed Shared Control Channel (HS-SCCH) carries the necessary physical layer control information to enable decoding of the data on HS-DSCH and to perform the possible physical layer combining of the data sent on HS-DSCH in case of retransmission or an erroneous packet.

2.7.2.1 *Release 7*

Higher order modulation and coding

Higher-order modulation is introduced in both downlink and uplink direction. 16QAM can double the bit rate compared with Quadrature Phase Shift Keying (QPSK) by transmitting 4 bits instead of 2 bits per symbol and 64QAM can increase the peak bit rate by 50% compared with 16QAM, since 64QAM transmits 6 bits with a single symbol [1].

The peak bit rate with 64QAM reached 21.1Mbps and HSUPA with 16QAM capability made the peak rate to 11.5Mbps. UE category for HSUPA are shown in *Figure 2.7.*

Category	TTI (ms)	Modulation	Coding rate	Peak bit rate (Mbps)	3GPP release
3	10	QPSK	¾	1.4	Release 6
5	10	QPSK	¾	2.0	Release 6
6	2	QPSK	1/1	5.7	Release 6
7	2	16QAM	1/1	11.5	Release 7

Figure 2.6 Selected HSUPA terminal categories [1]

Continuous packet connectivity

Release 7 introduced two type of discontinuous transmission [40]:

Discontinuous uplink transmission: the mobile terminal cuts off the control channel transmission when there is no user-plane data to be sent. These features not only reduces the power consumption but also reduces the interference transmitted by the terminal. As a result, a higher system capacity can be achieved.

Downlink discontinuous reception: enable the UE to turn off its receiver at times. The terminal will be informed in downlink about the possible times where there may be scheduled data.

Flat architecture

Both in the packet core and in the radio network release 7 introduced flat architecture using direct tunnel and flat radio. The direct tunnel allowed the user plane to bypass SGSN and the flat radio network architecture integrated RNC functionality into the Node B and removed the need for RNC. When the flat radio architecture and the direct tunnel are combined, there are only two network elements are required in the user plane.

In addition to the above improvements, setup time reduction, terminal enhancement to support multiple antennas, end-to-end QoS negotiation, charging and QoS enforcement with multi-technology networks and better integration with external networks are enhanced [40].

2.7.2.2 Release 8 and beyond

Multi-carrier operation

Dual-cell downlink was included in Release 8 specifications of HSPA. The basic dual cell HSDPA capability enables a single UE to receive two adjacent downlink 5 MHz carriers simultaneously and to decode HSDPA data on both if scheduled so by the Node B scheduler [20]. Release 8 restricted the two cells to belong to the same Node B, be mapped to adjacent 5 MHz carriers in the same frequency band and tightly time synchronized. Furthermore, for complexity reasons, DC-HSDPA in release 8 was a separate capability from MIMO and the two could not be configured simultaneously. Only dual-carrier in the downlink was standardized thus, a single uplink carrier carries physical layer signaling for both downlink carriers [23]. In release 9, the capability of DC-HSDPA was extended by combining it with MIMO where MIMO operating on either of the carriers or both carriers and also added the ability to configure the carriers in different frequency bands.

The release 10 HSPA supports four-carrier HSDPA, which enables the Node B scheduler to select dynamically from four different 5-MHz carriers, thus covering a total of 20 MHz of bandwidth. In release 10, the four carriers can be configured in one band or two bands. In a single band, the carriers need to be configured to be contiguous. four-carrier HSDPA functionality was extended in release 11 to enable non-contiguous carriers to be allocated and also eight-carrier HSDPA was defined where up to eight simultaneous carriers can be configured for a UE from the same Node B [23].

Downlink MIMO

MIMO enables a double peak data rate in downlink but also increases the feedback required in uplink by doubling the number of HS-DSCH. For 2x2 MIMO both the hybrid-ARQ with Acknowledgment (HARQ/ACK) and the Channel Quality Indicator (CQI) have to be transmitted for both streams. In 4x4 MIMO, Node B can transmit up to four parallel streams which double the peak data rate per carrier. However, HSDPA peak data rate remains at 336 Mbit/s due to the fact that 4-branch MIMO only supports up to four carriers [23].

HetNet

HetNet is joint deployment of different cell layers and/or technologies. Small cells can provide more capacity and coverage when required. They can be outdoor or indoor, or home or enterprise small.

3 UMTS NETWORK CAPACITY CHALLENGE OF ADDIS ABABA

In the deployed UMTS network of Addis Ababa, there are 726 sites in 21 clusters with one, two, three, and four single carriers per cell. The sites are distributed in 5 RNC with different location area codes.

3.1 Capacity challenges

The main causes of RRC and RAB failure are limited resources (congestion) and no reply which is related to timers, coverage, etc. The type failures due to limited capacity in Addis Ababa network are discussed in the next section starting from descriptions of network resources.

3.1.1 Radio resources and failure causes description

The resources are shown in *Figure 3.1* with their location and the description of the resources is defined below.

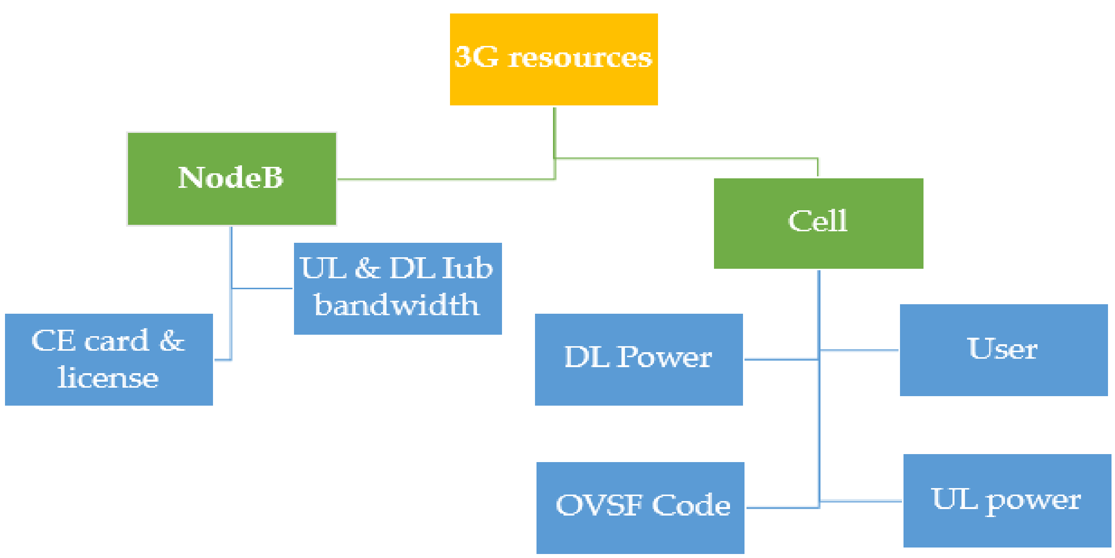


Figure 3.1 Resource location

CE is resource pool at Node B which is shared between all cells connected to a Node B. CE is both hardware and software resource. Hardware CE is card and software CE is license and 1 license will be equal to 16 CEs. Number of UL/DL license can be assigned independently and monitor can be done separately for UL and DL [49].

OVSF Code: is a hierarchical tree structure code and different service uses different braches. For example in the downlink PS R99 uses SF8 – SF128 and HSDPA uses SF16.

UL Power: is the noise raise measured in terms of RTWP. As stated in section 2.6.3 admission control can be based on RTWP. Rejection related to this may indicate interference due to increase number of UE in a given cell. This failure causes re-establishment of the link, so disconnection of service may occur.

DL Power: is the total power of a cell. Typical use of power depends on the number of carriers. The power consumption of each service is depend on the radio condition of UE. As stated in section 2.6.3 , admission control in the downlink is based on power.

HSDPA/HSUPA user: is the number of simultaneous users configured for each cell depends on the equipment's (Node B) capability. For instance, one cell can be configured with 5 simultaneous HSDPA users others can support up to 15 users.

UL and DL Iub bandwidth: is the pool resource at the baseband unit which is shared between cells. The failure related to this resource is zero in the current network.

3.1.2 Capacity challenges analysis

3.1.2.1 Temporal capacity challenge analysis

In *Figure 3.2,* RRC failures trend for the last 6 months (from March 2018 to August 2018) is presented and shows that at 21:00 (9PM at night) is the peak hour for RRC failures.

Moreover, the peak R99 traffic occurs at this time which indicates that the failures is related with the increase in traffic. The majority of RRC failures at peak hour occurred due to CE (uplink and downlink) limitation.

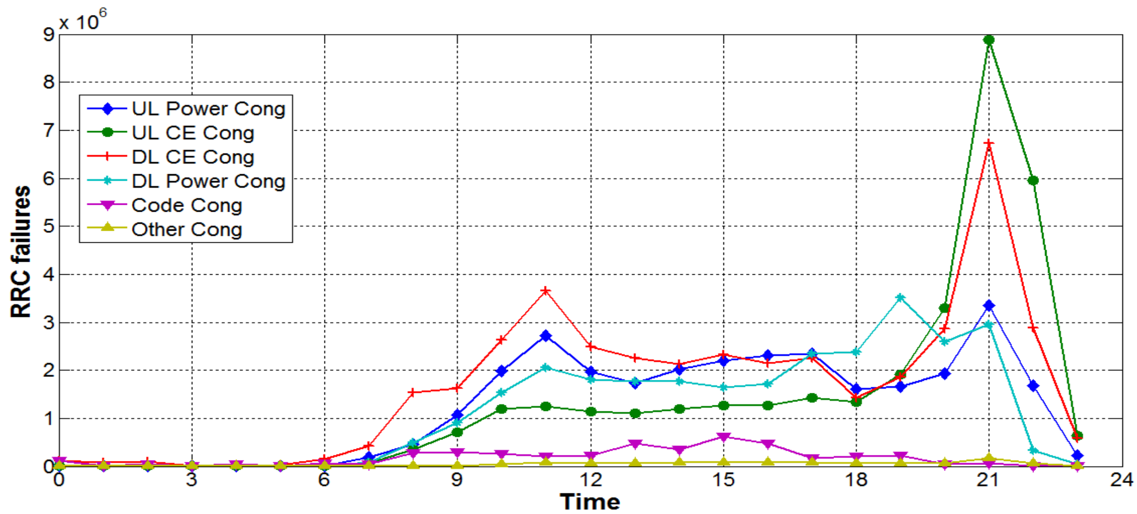


Figure 3.2 RRC failures for the duration of March-August 2018 [46]

RAB failures causes are shown in *Figure 3.3.* Similar to RRC failures, the peak failure occurred at 9 PM however, the main cause was UL power. The other main causes were DL power and UL CE limitation.

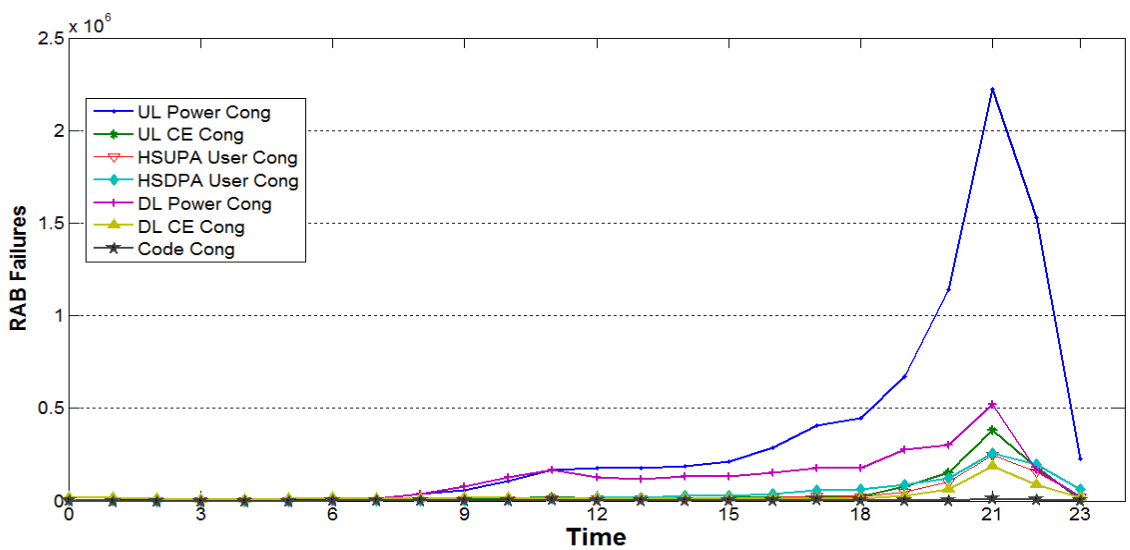


Figure 3.3 RAB failures from March-August 2018 [46]

HSPA traffic trend for the 24-hours is presented in *Figure 3.4*. The increase in the traffic starts mainly at 10 AM which is similar to failures and the peak is at 4 PM.

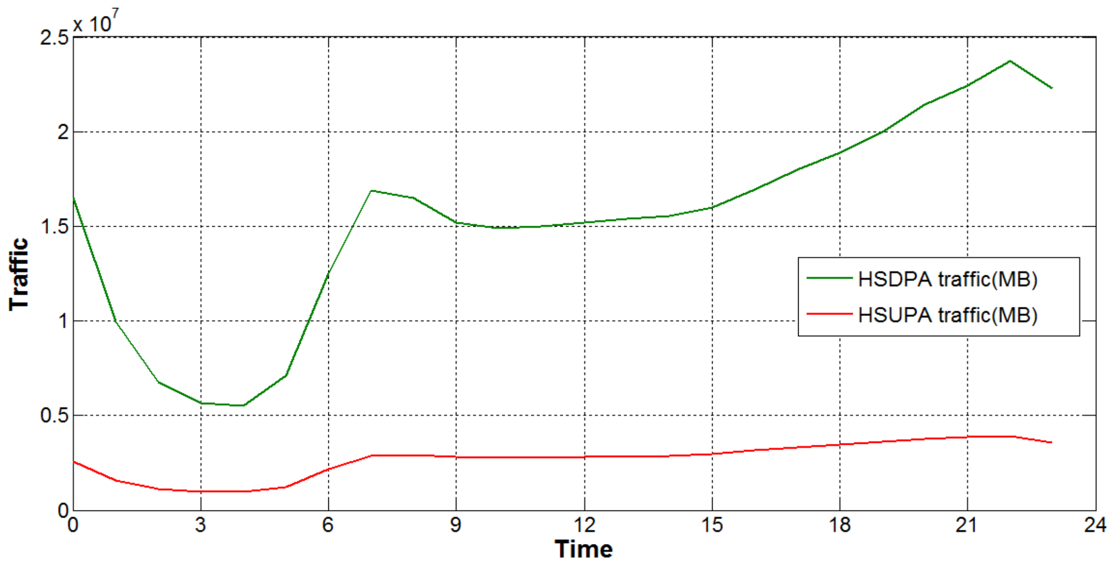


Figure 3.4 HSPA traffic trend [46]

As shown *Figure 3.5*, R99 traffic increases starting from at 10 AM which is similar to failures and the peak is at 9 PM.

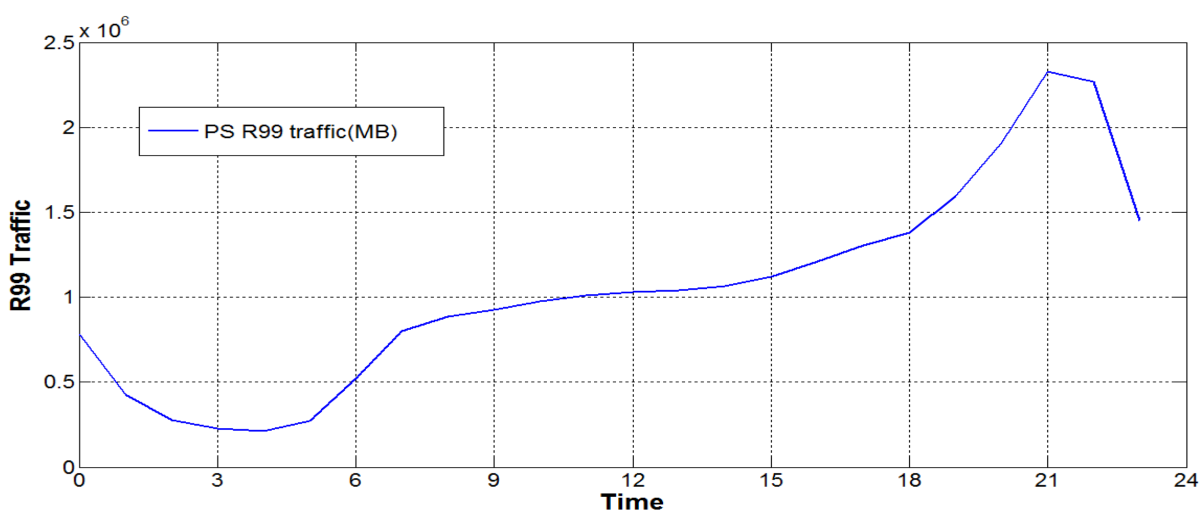


Figure 3.5 R99 traffic load trend [46]

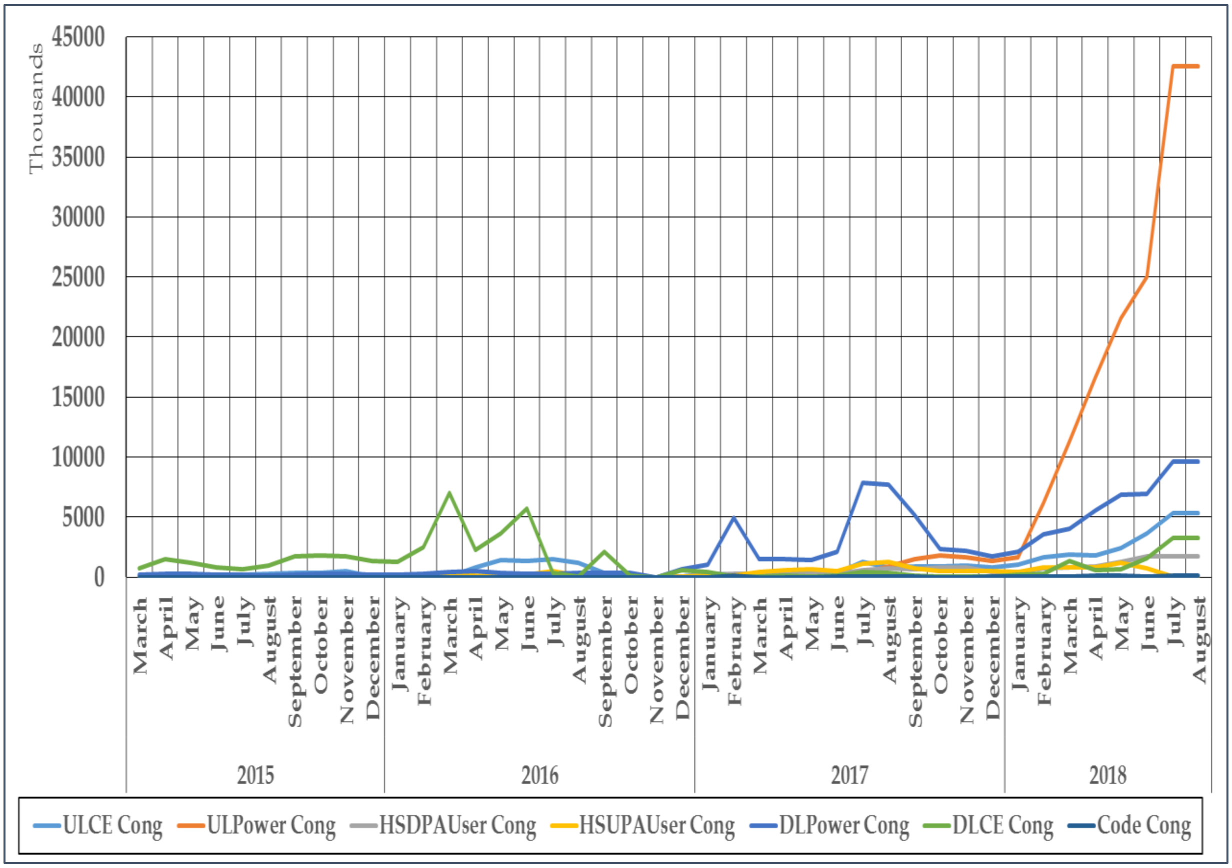


Figure 3.6 RAB failures from March 2015 to August 2018 [46]

The above figure (*Figure 3.6)* shows the trend of RAB failures from March 2015 to August 2018. For the year 2015 and 2016, the main cause was limited DL CE while in 2017 DL power limitation was the main reason. In 2018, failures caused by limited resources has raised significantly and the main cause was UL and DL power.

3.1.2.2 Spatial and temporal capacity challenge analysis

For spatial and temporal analysis, 6 areas are selected which consists of both commercial and residential areas. The data presented is average PS RAB failures per hour for each area.

Summit, Abado and Jemo are residential area. As can be seen from the figures (*Figure 3.7*, *Figure 3.8*, *Figure 3.9*), UL power congestion is the number one failure reason and the peak occurs at 21:00 or 9 PM.

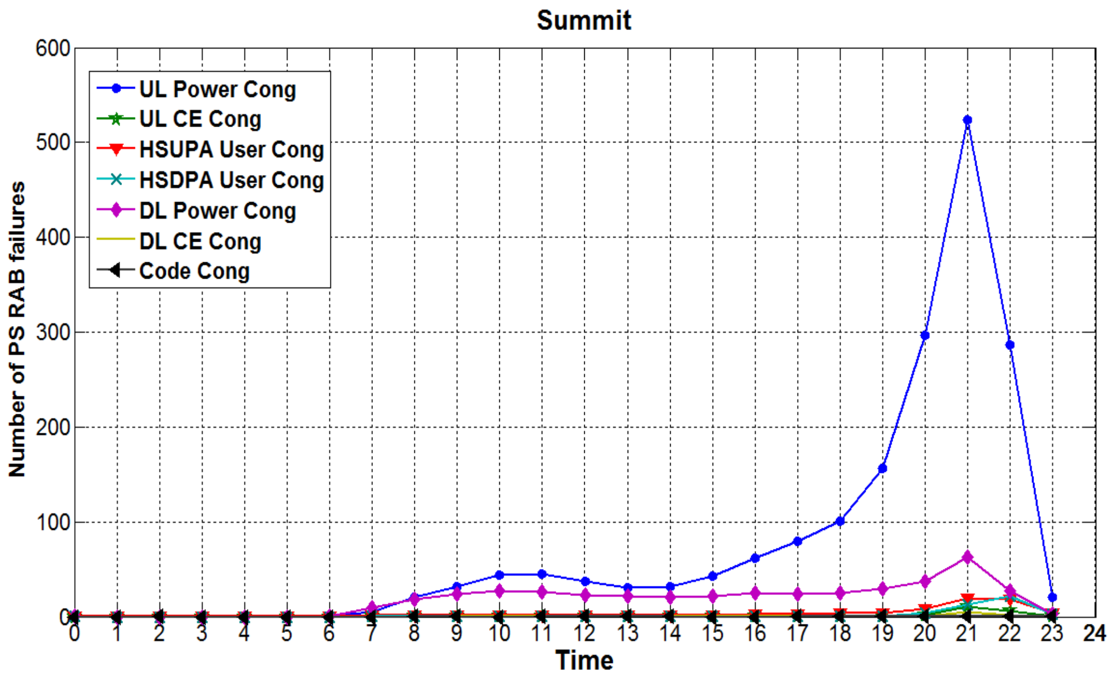


Figure 3.7 Average PS RAB failures per hour [46]

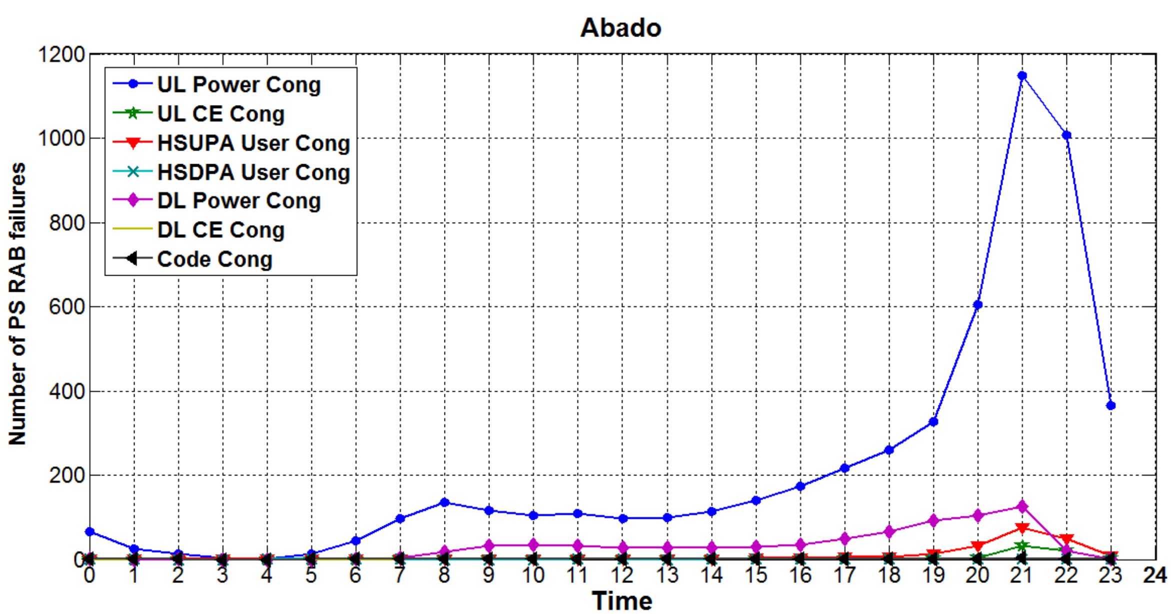


Figure 3.8 Average PS RAB failures per hour [46]

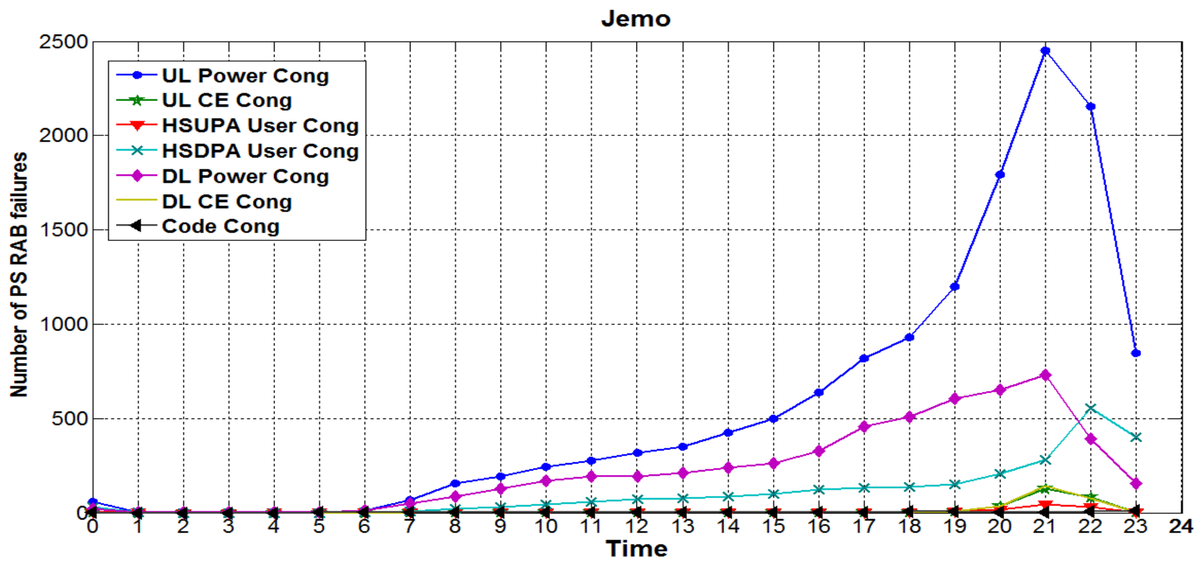


Figure 3.9 Average PS RAB failures per hour [46]

Bole Medhanealem, Megenagna and Merkato are commercial areas. As can be seen from the figures (*Figure 3.10*, *Figure 3.11* and *Figure 3.12* respectively), UL power congestion is the number one failure cause and the peak occurs at 17:00 (11 PM) for Bole Medhanealem and Megenagna areas and 10:00 (10 AM) for Merkato area. The number of failures is larger between 9:00 (9 AM) and 18:00 (12 PM).

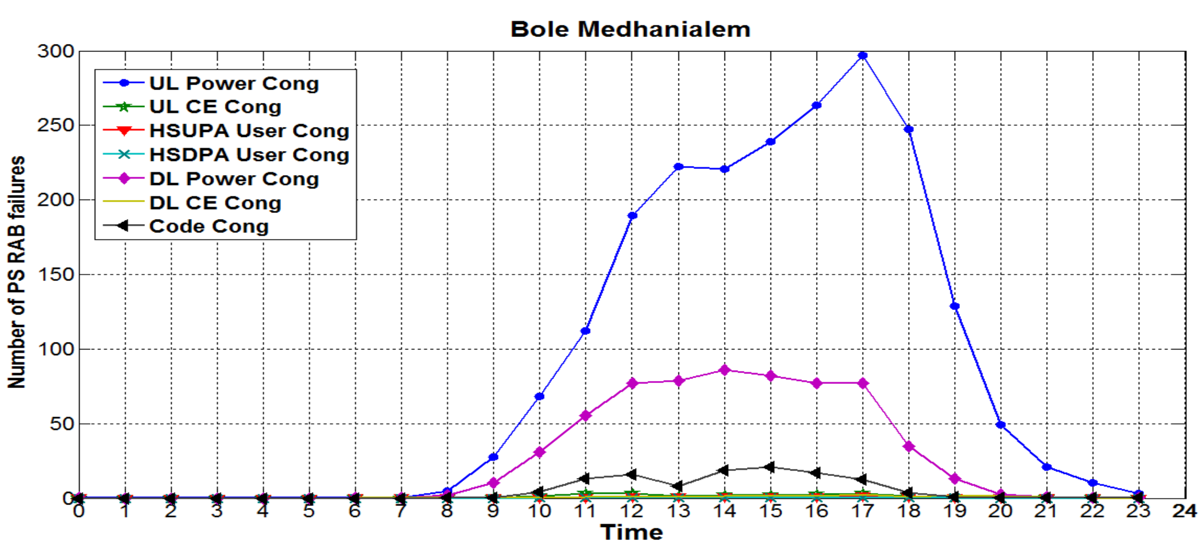


Figure 3.10 Average PS RAB failures per hour [46]

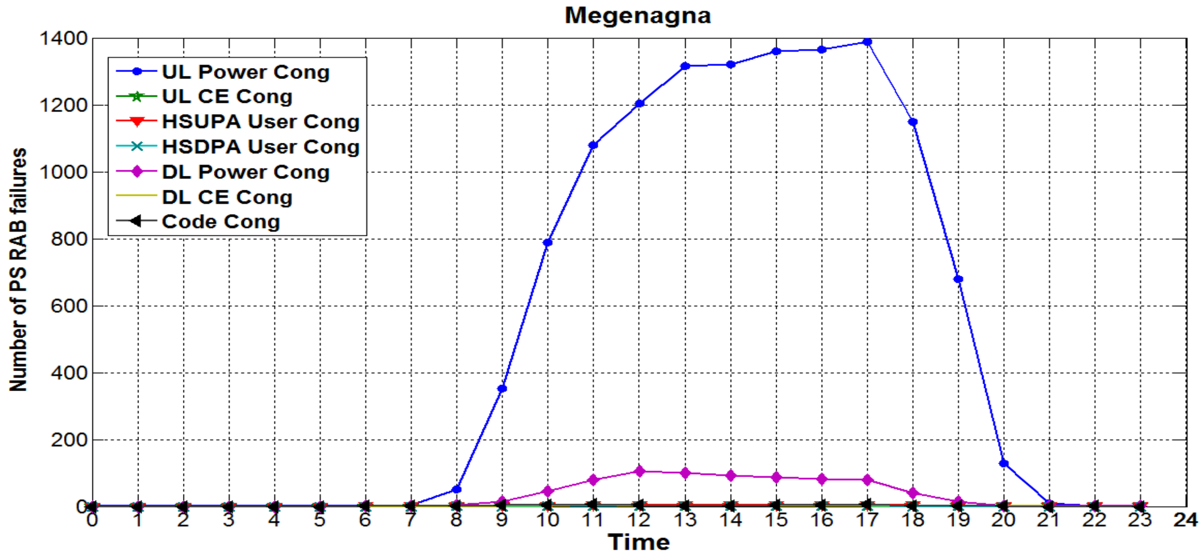


Figure 3.11 Average PS RAB failures per hour [46]

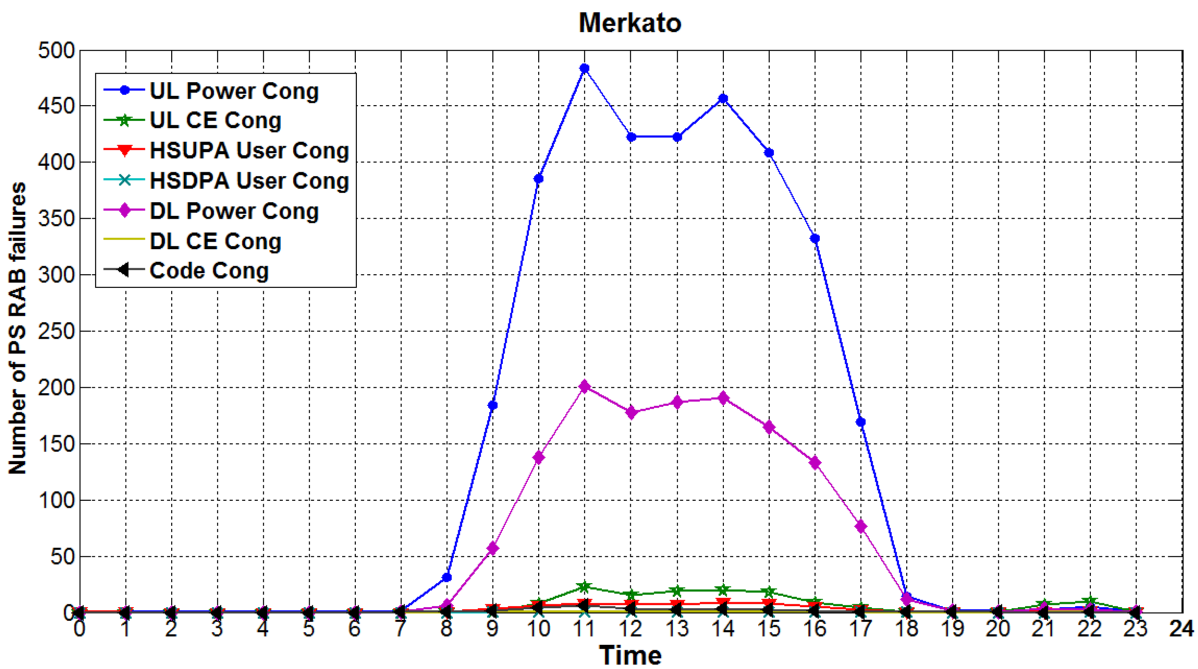


Figure 3.12 Average PS RAB failures per hour [46]

From the above data, it has been shown that for commercial areas the failure is high between 9:00 to 17:00 whereas for residential areas failure is high between 18:00 to 23:00.

The main reason behind this variation is the movement of users between the two area types i.e. commercial and residential.

3.2 Categorization of capacity challenges

As it has been shown in section 3.1.2, the main causes of failures are CE (DL and UL) and power (DL and UL) congestion. In addition, high HSDPA and HSUPA users causes RAB failures. The categorization of the capacity challenge is based on the location of the resource i.e. located at the cell or Node B. The capacity improvement techniques differ for each category. In table 3.1, the capacity challenges with improvement techniques are presented. The mapping is done based on where the techniques are applied (cell or NodeB).

Table 3.1 Challenges with improvement techniques

Capacity challenge	Improvement techniques
DL CE Cong	Expansions (card and software) and site densification
UL CE Cong	
DL Power Cong	6-sectorization, MIMO, adding another band, small cell, carrier aggregation and site densification
UL Power Cong	
Code Cong	
HSDPA User Cong	
HSUPA User Cong	

4 UMTS CAPACITY IMPROVEMENT TECHNIQUES

There are different capacity improvement techniques for WCDMA/HSPA/HSPA+ that can be used to overcome the capacity limitations. From these techniques, six are presented here which are selected based on literature and operators experience.

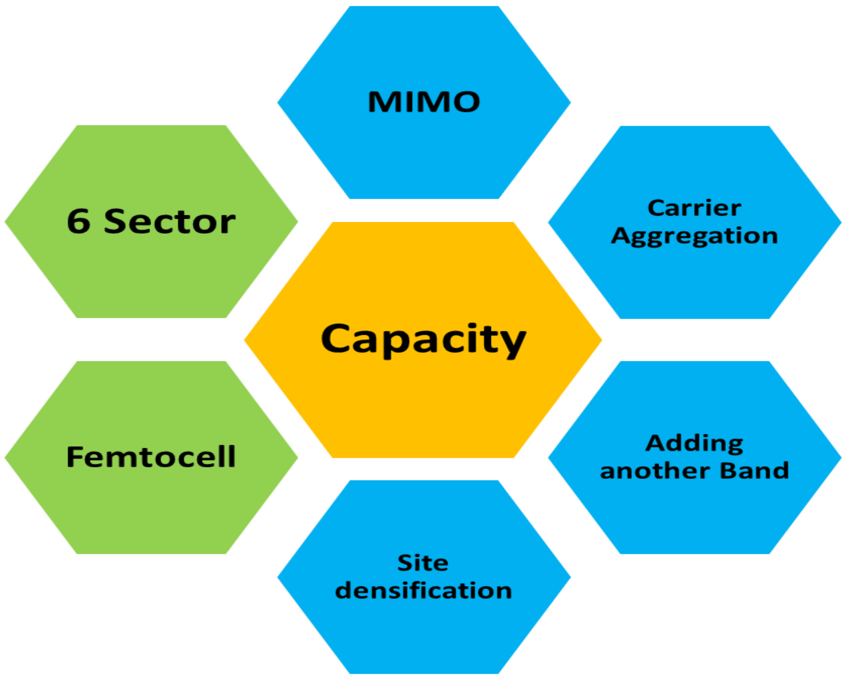


Figure 4.1 Capacity enhancement techniques considered

4.1 Site densification (Macrocell densification)

Capacity requirements exceeded the maximum capacity provided by existing sites due to the increase in the number of users and traffic volume. In this situation, new sites must be added to maintain user experience. Adding sites in densely populated areas raises many issues such as insufficient space for installing antennas and cabinets, high space rental fees, and even it may be harder to find suitable new sites. In a dense urban environment, deploying macrocells is becoming harder [11].

4.2 MIMO

MIMO allows multiple antennas to transmit and receive data simultaneously, thereby increasing channel reliability and improving network capacity. MIMO increases network capacity by several times without adding frequency spectrums or sites which significantly improves spectral efficiency. The gains generated by MIMO can be categorized into diversity gain which is provided by multiple transmit and/or receive antennas transmitting the same signal for reliability and multiplexing gains provided by data transmitted over multiple channels [21] [23].

Both transmit diversity and spatial multiplexing have been incorporated by 3GPP as standard in the form of closed loop transmit diversity technique called Transmit Adaptive Antennas (TxAA) and its dual-stream counterpart D-TxAA for MIMO HSDPA [20]. One challenge of MIMO arises from the requirement of high SINR. If this conditions does not occur, then benefits will be low [23].

In dual-stream, the HS-DSCH is modified to support up to two transport blocks per transmission time interval which each are mapped to one stream. Each transport block is individually coded and CRC is attached to each of the transport blocks. The physical-layer processing for each stream is identical to the release 5, including spreading and scrambling.

The paper in [43] made measurements in several cell location and showed that MIMO delivered maximum peak rate of 27.16Mbps which are near to the theoretical limit and average single-user throughput increase by 18.43%. In addition, from the several tests performed in live network 25% gain in average cell throughput was shown. However, at the time the availability of devices was the main bottleneck for the operator and any other operator wishing to deploy the HSPA+ features.

4.3 New spectrum bands

The addition of a new spectrum band can be introduced either by adding part of an existing band or a band with the same frequency, but a different technology such as adding 2.1GHz TDD to 2.1GHz FDD network. The frequency bands that can be used for WCDMA/HSPA/HSPA+ specified by 3GPP are presented in *Figure 4.2* [21] [48].

Operating Band	TX-RX frequency separation	UL Frequencies UE transmit, Node B receive	DL frequencies UE receive, Node B transmit	Total Spectrum
I	190 MHz	1920-1980 MHz	2110-2170 MHz	2X 60 MHz
II	80 MHz	1850-1910 MHz	1930-1990 MHz	2X 60 MHz
III	95 MHz	1710-1785 MHz	1805-1880 MHz	2X 75 MHz
IV	400 MHz	1710-1755 MHz	2110-2155 MHz	2X 45 MHz
V	45 MHz	824-849 MHz	869-894 MHz	2X 25 MHz
VI	45 MHz	830-840 MHz	875-885 MHz	2X 10 MHz
VII	120 MHz	2500-2570 MHz	2620-2690 MHz	2X 70 MHz
VIII	45 MHz	1749.9-1784.9 MHz	1844.9-1879.9 MHz	2X 35 MHz
IX	95 MHz	1710-1755 MHz	2110-2155 MHz	2X 45 MHz
X	400 MHz	1710-1770 MHz	2110-2170 MHz	2X 60 MHz
XI	48 MHz	1427.9-1447.9 MHz	1475.9-1495.9 MHz	2X 20 MHz
XII	30 MHz	699-716 MHz	729-746 MHz	2X 17 MHz
XIII	31 MHz	777-787 MHz	746-756 MHz	2X 10 MHz
XIV	30 MHz	788-798 MHz	758-768 MHz	2X 10 MHz
XIX	45 MHz	788-798 MHz	758-768 MHz	2X 10 MHz
XX	41 MHz	832-862 MHz	791-821 MHz	2X 30 MHz
XXI	48 MHz	1447.9-1462.9 MHz	1495.9-1510.9 MHz	2X 15 MHz
XXII	100 MHz	3410-3490 MHz	3510-3590 MHz	2X 80 MHz
XXV	80 MHz	1850-1915 MHz	1930-1995 MHz	2X 65 MHz
XXVI	45 MHz	814-849 MHz	859-894 MHz	2X 35 MHz

Figure 4.2 WCDMA frequency bands in 3GPP [48]

Yet, when a new band is added to an existing macrocells, operators will incur the costs of deploying a new antenna if a multi-band antenna is not used else only a software upgrade cost.

4.4 Carrier aggregation

One way to increase the overall transmission bandwidth is the use of multi-carrier transmission or carrier aggregation. Multi-carrier is introduced into HSPA across multiple releases [20] [21] [23]. The band configurations supported for each release including single/dual band and contiguous/non-contiguous band is shown in *Figure 4.3*.

	Aggregation Type	Band Combination	Release 8	Release 9	Release 10	Release 11
DC-HSDPA	Single band	Bands 1–14	X	X	X	X
	Single band	Bands 15–21		X	X	X
	Single band	Bands 22–25			X	X
	Single band	Band 26				X
	Dual band	Bands 1 + 8, 2 + 4, 1 + 5		X	X	X
	Dual band	Bands 2 + 11, 2 + 5			X	X
4C-HSDPA	Dual band	Band 1 (3 carrier) + band 8 (1 carrier)			X	X
	Dual band	Bands 2 + 4, 1 + 5[1]			X	X
	Single band, contiguous	Band 2 (3 or 4 contiguous carriers)				X
	Dual band	Band 2 (1 carrier) + band 5 (2 contiguous)				X
	Single band, non-contiguous	Band 1[2] Band 5[3]				X
8C-HSDPA	Single band, contiguous	Band 1				X

Figure 4.3 Band combinations for multi-carrier HSDPA [23]

In a study presented in [15] average user throughput as a function of offered load [Mbit/s/sector] have been shown for single-carrier HSDPA and a multi-Carrier HSDPA. The results show that, multi-carrier HSDPA has remarkable performance over single carrier even though as the number of single carrier's increase, performance slightly improved. For example, for an offered load of 6.4 Mbit/s/sector, the user throughput increased from 300 kbps in two single-carrier to 600 kbps dual-carrier HSDPA.

However, there are several critical issues related to the use of wider transmission bandwidths such as spectrum availability [23].

4.5 Six sectorization

As a general rule, network capacity is proportional to the number of transmitters. However, capacity enhancement techniques such as adding a new site or spectrum are challenging for operators since new site acquisition is becoming difficult and a spectrum is scarce resources. As a result, upgrading to 6-sector is a better option with significantly lower cost than new build sites because much less equipment and civil works are required [8] [10]. To that end, paper [10] presented results that shows relative to the 3-sectored scenario the capacity has increased by +77% and +65% for 6-sectored cells with 20W and 10W transmit powers respectively.

Further, a study conducted in central London area of Telefonica UK's network with 51 sites presented in [44]. It investigated HSPA+ homogenous network's optimal horizontal beam widths for 6, 9, 12 and 15-sectored sites and compared their performances. For inter-site distances of 500 m, 6-sector with 34-degree has 1.82x capacity gain over 3-sector at 62-degree beamwidth. In addition, when inter-site distances of 1732 m is used, 6-sector has 1.85x capacity gain over 3-sector. Furthermore, the stand-alone results show that the coverage area increased by 14% for 6-sector compared to 3-sector. Additionally, the gains increases as the number of users increases. For example, network simulation showed that 6-sector has 1.41x, 1.71x, 1.85x and 1.87x capacity gain over 3-sector with 500, 1000, 2000 and uniform traffic. This study considered higher order sectorization for a network-wide capacity upgrade than hotspot deployments unlike paper [10].

Currently, six sectorization with a well-designed dual-beam antenna has simplified deployment and installation compared with traditional 33-degree horizontal beamwidth antenna. Dual-beam has easy control of the soft handover ratio due to less overlapping areas between sectors and reduces interference between the two sectors [11].

Six-sectorization with dual-beam increases site capacity by 50% to 85% and improves the coverage performance by 3 dB [35]. Operators like Philippines Globe and AIS could be a real example that deployed 6-sector network. AIS has progressively used different method to improve the service but it is 6-sector cell with dual beam technology that showed remarkable performance up to 70 % capacity gain. Further, Globe's 2100 MHz UMTS network downlink data traffic increase by 50%, uplink data traffic by 74.73% and voice traffic by 31.69% [31] [42].

4.6 SMALL CELL

Small cells are low-power radio access nodes which can be used in densely populated areas and indoor hotspots where adding spectrums or macro base stations may not visible. In addition, site acquisition becomes extremely difficult. Small cell have easy site acquisition and flexible deployment to improve the user experience. Small cells can be divided into 3 type depending on range and power used [24].

Femtocell: Also known as Home Node B (HNB) in 3GPP, is a cellular network access point that has low power. Femtocell can use residential DSL, cable broadband connections, optical fibers or wireless last-mile technologies to connect standard mobile devices to a mobile operator's network [24].

Picocell: is typical low power base station used in an enterprise or public indoor areas. Sometimes the term picocell implies outdoor small cell as well.

Microcell: are short ranged outdoor base stations to enhance insufficient coverage. Sometimes it can be installed indoor also if the area is out of the scope of picocells.

Depending on the access method, femtocell can be open, closed and hybrid. In open access any user can connect to the access point whereas in closed access only listed or registered users can connect and the list is defined by the owner of a femtocell [25]. The hybrid access method gives priority to the listed users, but still allows open access to anyone for the remaining capacity.

4.6.1 Femtocell

3GPP started femtocell feasibility study in March 2007. On May 2008, members of femto forum, now known as small cell forum, came to a single architecture. 3GPP release 8 described the feasibility of femtocell and basic network architecture.

4.6.1.1 Network Architecture for 3G femtocell

Figure 4.4 shows 3G femtocell network architecture. The network entities and interfaces are described [27].

Home Node B (HNB) (Femtocell): is a small-scale Node B connected to the mobile network over the Iuh interface.

Home Node B Gateway (HNB-GW): aggregates many HNBs and is uniquely identified towards the RNC on a particular Iur interface by the RNC ID. It appears to the CN as an RNC and appears to other RNCs as an RNC. It is presented as a single IuCS/PS interface to the CN [27].

Local Gateway (L-GW) may be present only when the HNB operates in local IP access mode. HNB may be assigned the same inner IP address for the Gn/S5 interfaces as for the Iuh interface, or a different IP address.

Home Node B Management System (HMS): handles the remote management HNBs. It facilitates HNB-GW discovery, provides configuration data to the HNB and performs location verification of HNB and assigns appropriate serving elements.

Security Gateway (SeGW): terminates secure tunneling for TR-069 as well as Iuh, Iurh, and Gn/S5 for certain deployment options, authenticates HNBs, and provides the HNB with access to the HMS and HNB-GW.

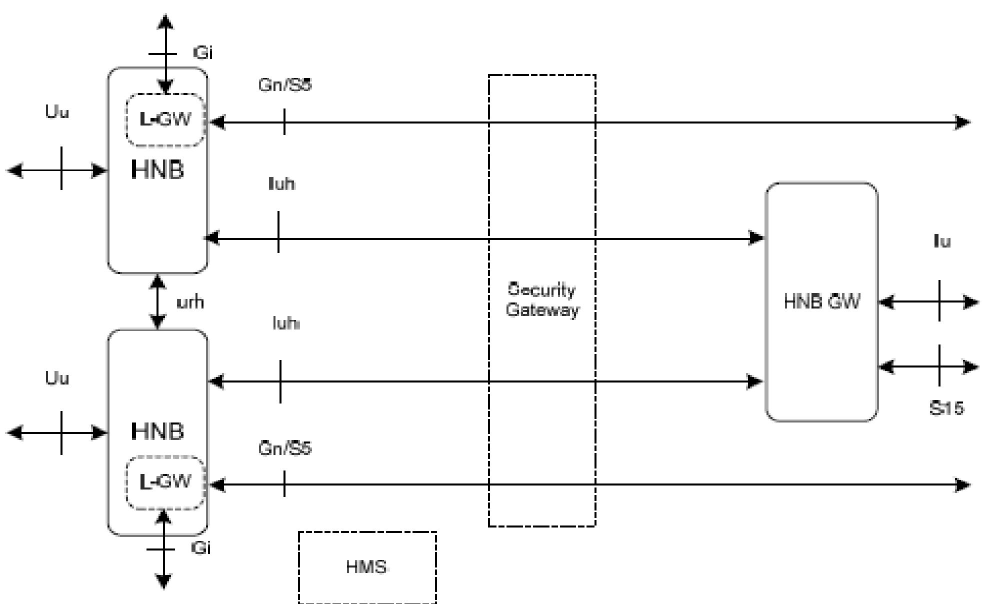


Figure 4.4 HNB access network reference model [27]

Deploying Small cells have challenges like ensuring self-deployment and optimization work on a large scale, managing interference between femtocells and macrocell layers, and ensuring sufficient QoS over DSL backhaul.

Some femtocell deployment challenges have been overcome. For example, the interference issues have now been resolved by introducing interference mitigation techniques which enable co-channel operation between the femtocell and macrocell [29]. Real-world deployments have now demonstrated femtocells working on the same carrier as macros without interference issues.

Femtocells bring benefits such as increasing cell density at realistic costs, enhancing indoors coverage, improving spectrum usage efficiency, reducing the load from the macro layer, improving service for outdoor users and giving a better SINR distribution and better SINR mean MIMO works better.

4.6.1.2 Backhaul

Backhaul network provides connectivity between the core network, and the small cells to deliver the service with the desired QoS level [25] [26] [29]. There are different backhaul option which are categorized as wired and wireless. As their names suggest a wired backhaul provides connectivity through cables like fiber and copper while a wireless backhaul uses electromagnetic wave propagations such as microwave. These options have their own benefits and challenges, from wired backhauls for example, fiber increases the capacity of the link but it is expensive. Similarly, microwave may benefit the operator since it does not need to install cables but finding line-of-sight connection between the small cell and the macrocell may be difficult. So for different locations and site positions, one can choose different backhauls and the backhaul availability may define the location where the small cells are placed.

5 TECHNIQUE SELECTION AND SCENARIO DESCRIPTION

5.1 Capacity improvement technique selection criteria

The method used to select capacity improvement techniques is presented in *Figure 5.1*.

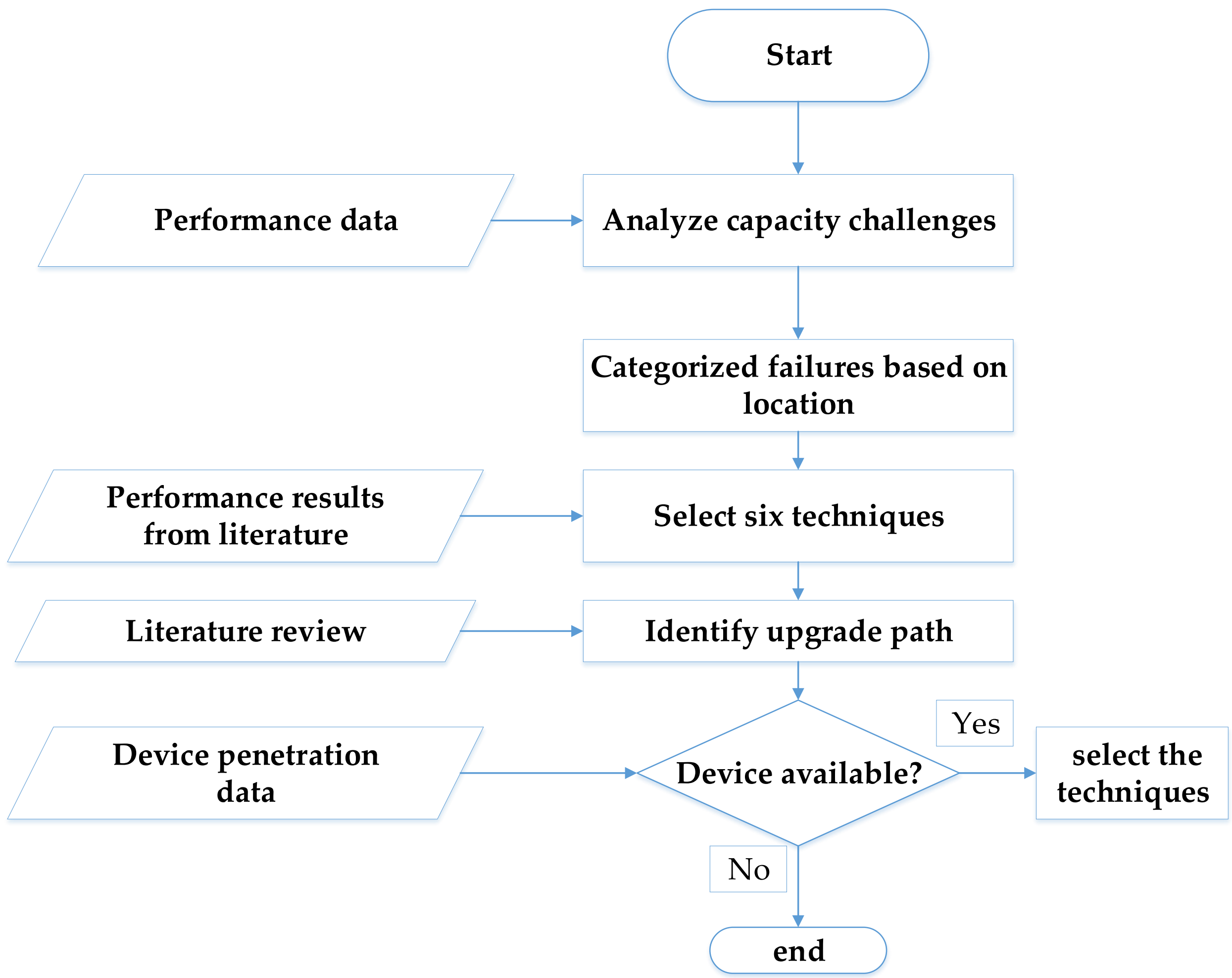


Figure 5.1 Method for selecting capacity improvement techniques

To select practicable techniques, first, extracted RRC and PS RAB failures from performance management system and analyzed the failure causes related to limited resources. Then categorized the failures based on where the resources are set i.e. Node B or cell. This due to the fact that the technique used can vary based on the location of the resource. For example, transmit power is resource that is configured per cell whereas CE is configured and placed at Node B level. So, CE congestion, which is Node B resource, requires expansion only if the network architecture does not allow sharing of CE between locations outside a given RNC or whole network sharing especially software CE.

After categorizing the techniques, extracted device penetration data and analyzed the distribution and capabilities of user devices. Finally, selected two practicable and relevant techniques.

5.1.1 Upgrade path

The six techniques are selected based on literature and the upgrade path for the six capacity improvement techniques is summarized below.

Table 5.1 Upgrade path

Technique	Upgrade path
Site densification (Macrocell densification)	Installation of new site which requires obtaining new location and whole new equipment is needed.
MIMO	Mostly now day's only software upgrades may be needed, but for older types changing the antennas is needed.
New spectrum	Similarly this depends on the frequency range the current antenna supports. If not supported installing of multi frequency antenna.

Carrier aggregation	In the current scenarios only software upgrades may be needed, but for older types changing the antennas is needed.
Six sectorization	Only software upgrades may be needed if supported by the current equipment (dual beam antenna), but for older types changing the antennas is needed.
Small cells	Installation of small cells when needed.

5.1.2 Device availability

The device availability or penetration help to identify

- What type of user equipment are available?
- What is their distribution?

The knowledge of user devices is important to identify which techniques are practicable to the customer or which techniques are possible? According to the data obtained from SEQ Analyst, the share are described in pie chart to see their shares. As it can be seen form *Figure 5.2* in the downlink, 56% of the UE support 21Mbps which means that only support higher order modulation (64QAM) while 20% of the UE support 42Mbps which means can support MIMO or DC-HSDPA [28] [48].

In terms of spectrum other than 2100MHz, most of the UE support lower bands like 900MHz and 850MHz. As a result, six-sectorization and small cells are selected.

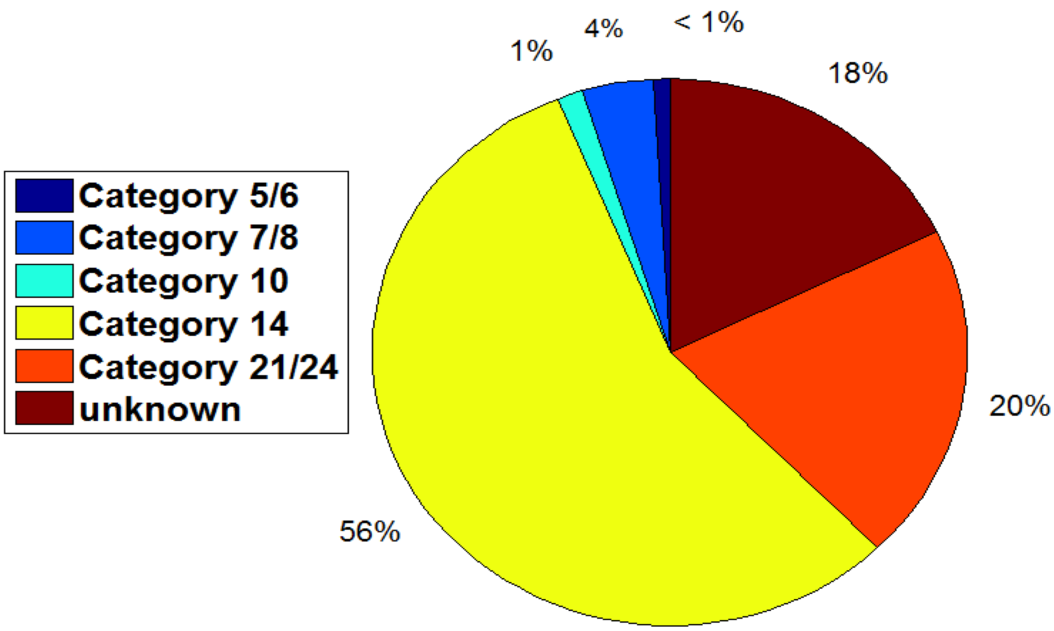


Figure 5.2 DL device penetration [47]

In the uplink, *Figure 5.3* shows that 77% of UE support 5.7Mbps and 4% of UE support 11Mbps [20] [48].

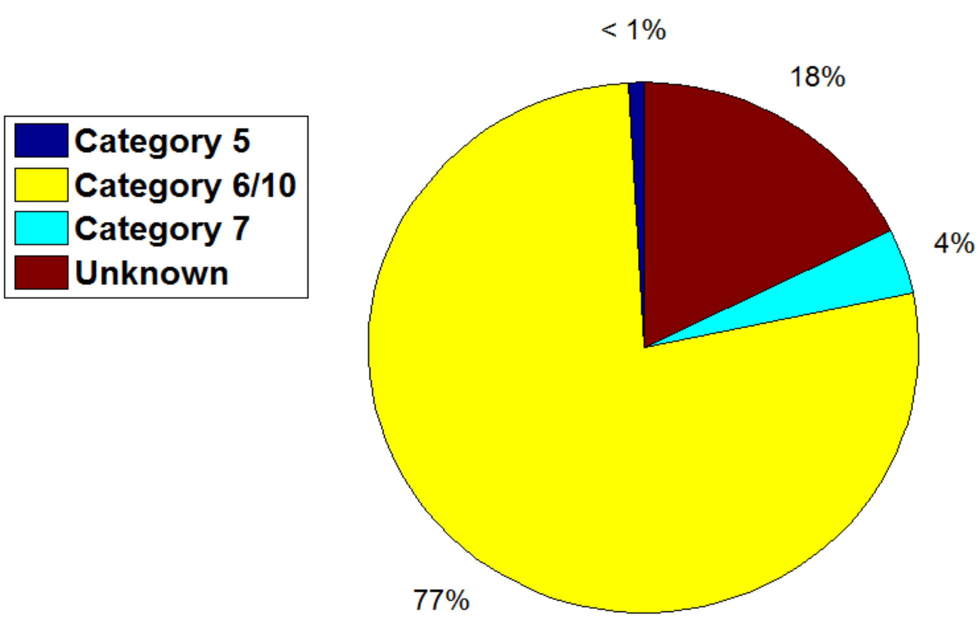


Figure 5.3 UL device penetration [47]

In *Figure 5.4*, device type penetration is shown, in which it is shown that 85% the device are smart Phone; wireless module and feature phone being the least from all device type.

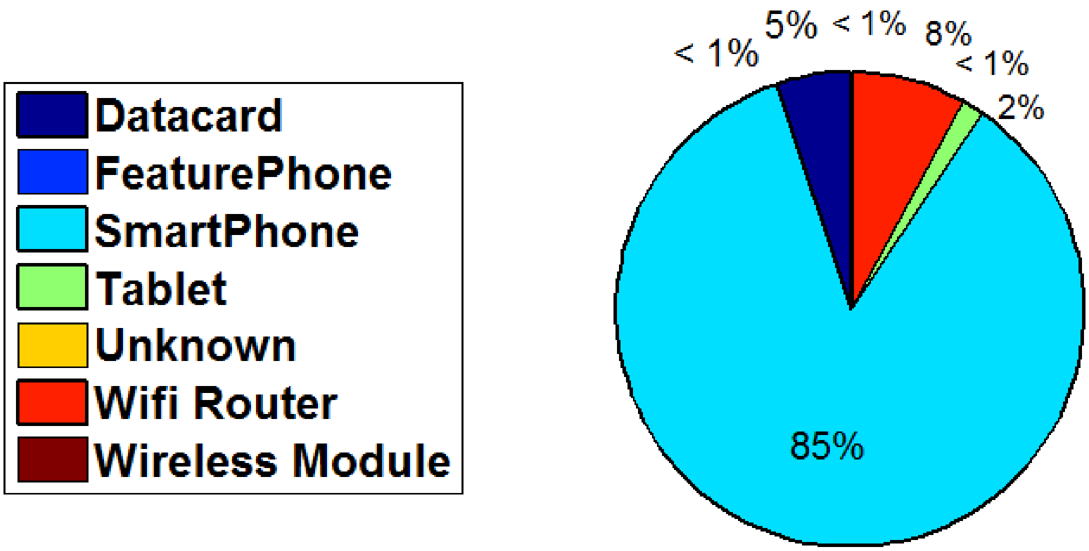


Figure 5.4 Device type penetration [47]

5.2 Scenario description

Description of the scenario used to perform performance evaluations are presented in this section and *Figure 5.6* – 5.13 presents downlink data rate view for all deployment scenarios.

The first scenario has 33 Node Bs (99 macrocells) that are fully 3-sectored (Full 3-sector). Their position can be identified from the data rate plot of *Figure 5.5*. In this scenario, macrocells have been deployed according to real network configured positions, antenna azimuths and tilt. One carrier per cell is used therefore named as one carrier per cell full 3-sector (1-SC full 3-sector) and four carriers are reused.

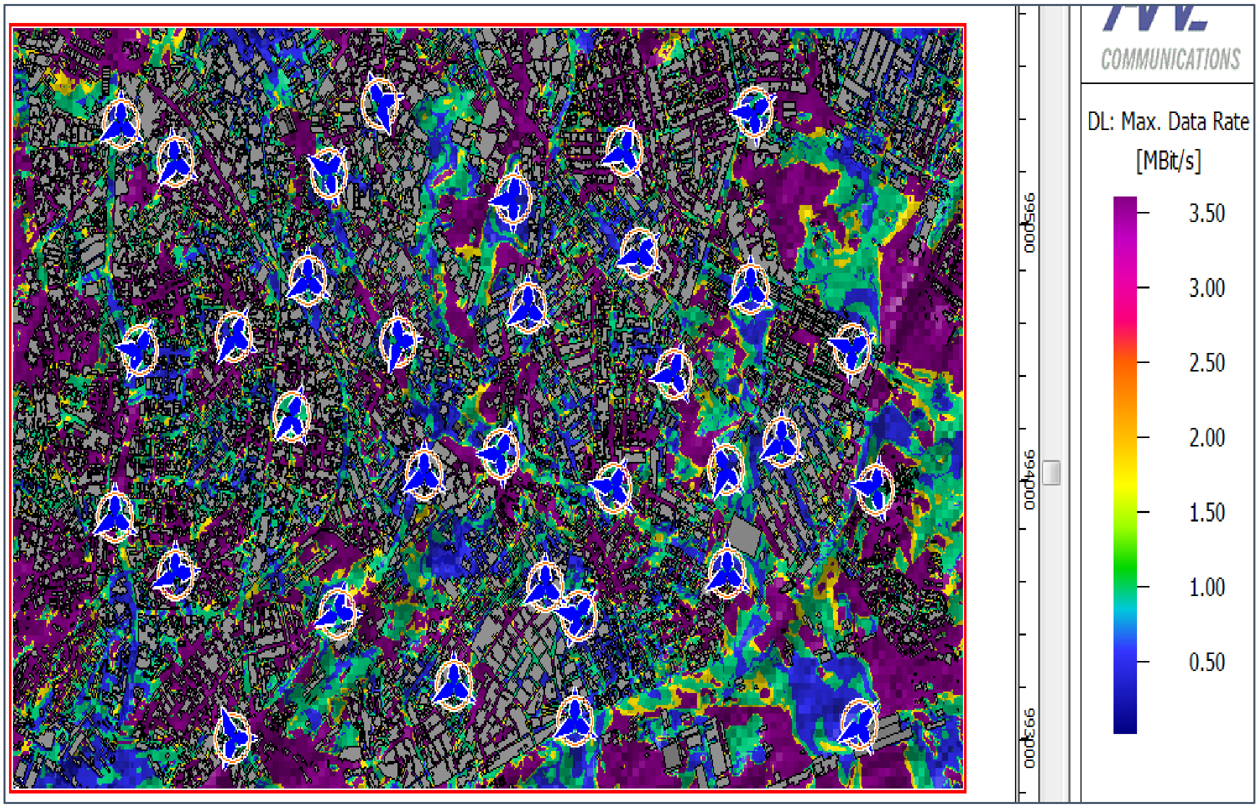


Figure 5.5 Data rate plot of Full 3-sector with one single carriers per cell

In the second scenario, all Node Bs are 6-sector with same positions as the previous scenario but with different antenna azimuth and tilt (5-degree) and named as Full 6-sector. In this experiment, 198 macrocells or 33 Node Bs were used. Their position can be identified from the data rate plot of the *Figure 5.6*. One carrier per cell is used and a total of 4 carriers are reused.

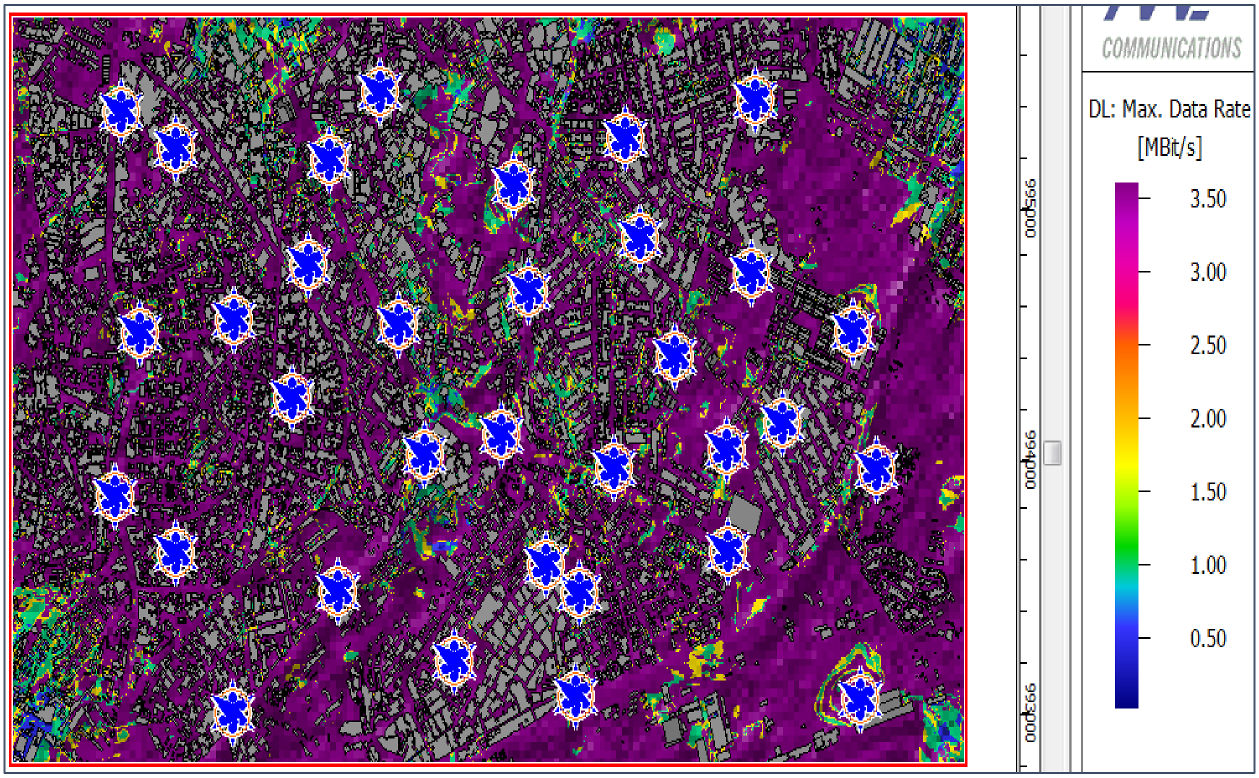


Figure 5.6 Data rate plot of full 6-sector

In the third scenario, hybrid, containing both 3 and 6-sectored Node Bs with same site positions as the first scenario but with different antenna azimuth and tilt. In this experiment, 165 macrocells or 33 Node Bs are used. Their position can be identified from the data rate plot of *Figure 5.7*. The placement of 6-sector Node Bs is based on data rate from previous two experiments. 3-sector Node Bs are upgraded to 6-sectored if have low data rate otherwise the upgrade is based on their position (if within a layer of worst cells). In this scenario again, one carrier per cell is used and a total of 4 carriers are reused.

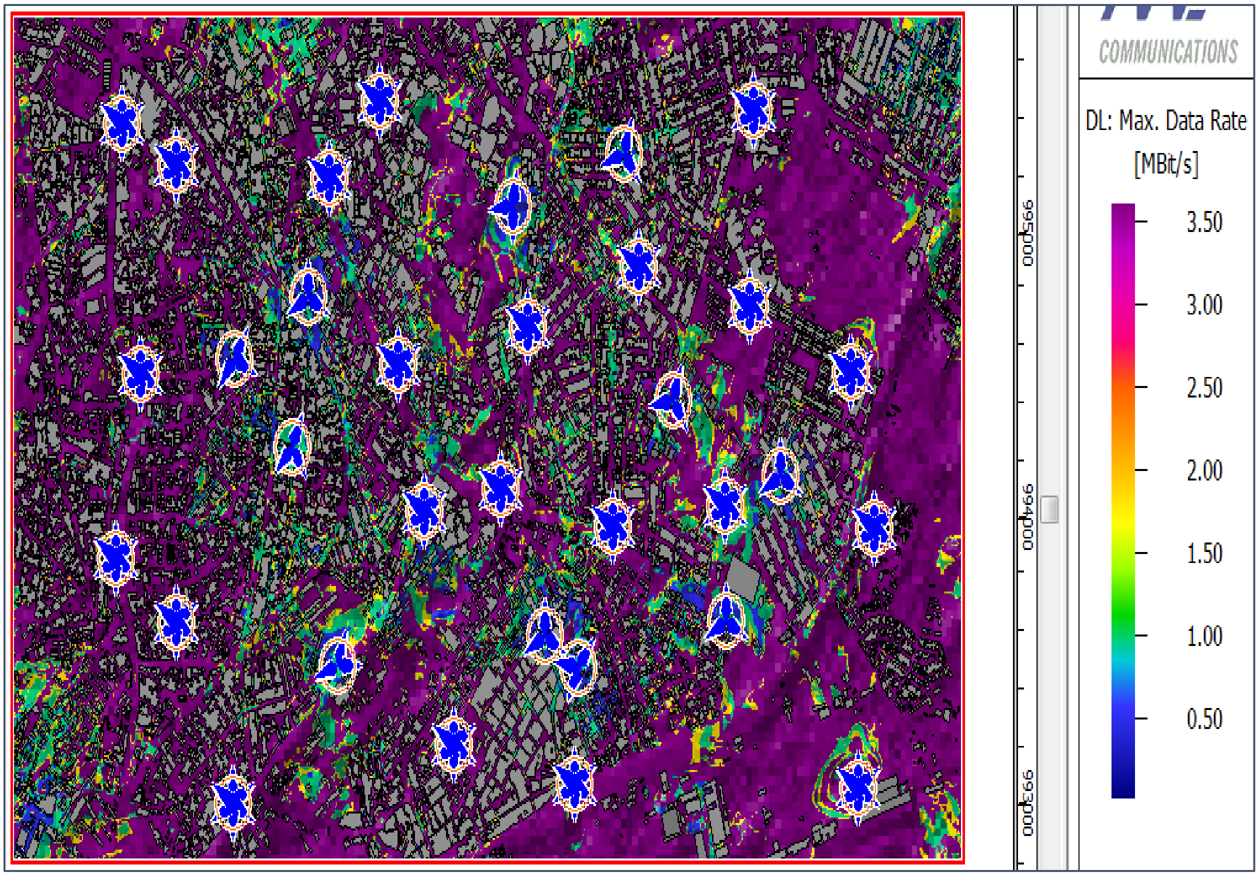


Figure 5.7 Data rate plot of hybrid

The fourth scenario is 3-sector with 0.01 femto penetration where femtocells operating in a separate frequency band (orthogonal deployment). Orthogonal deployment is to avoid interference between macrocells and femtocells layers. The positions can be identified from the data rate plot of *Figure 5.8*. The placement of femtocell is based on data rate values from the first experiment. This means femtocells are placed if have low data rate. In this experiment, 33 three-sectored Node Bs or 99 macrocells and 63 femtocells were used.

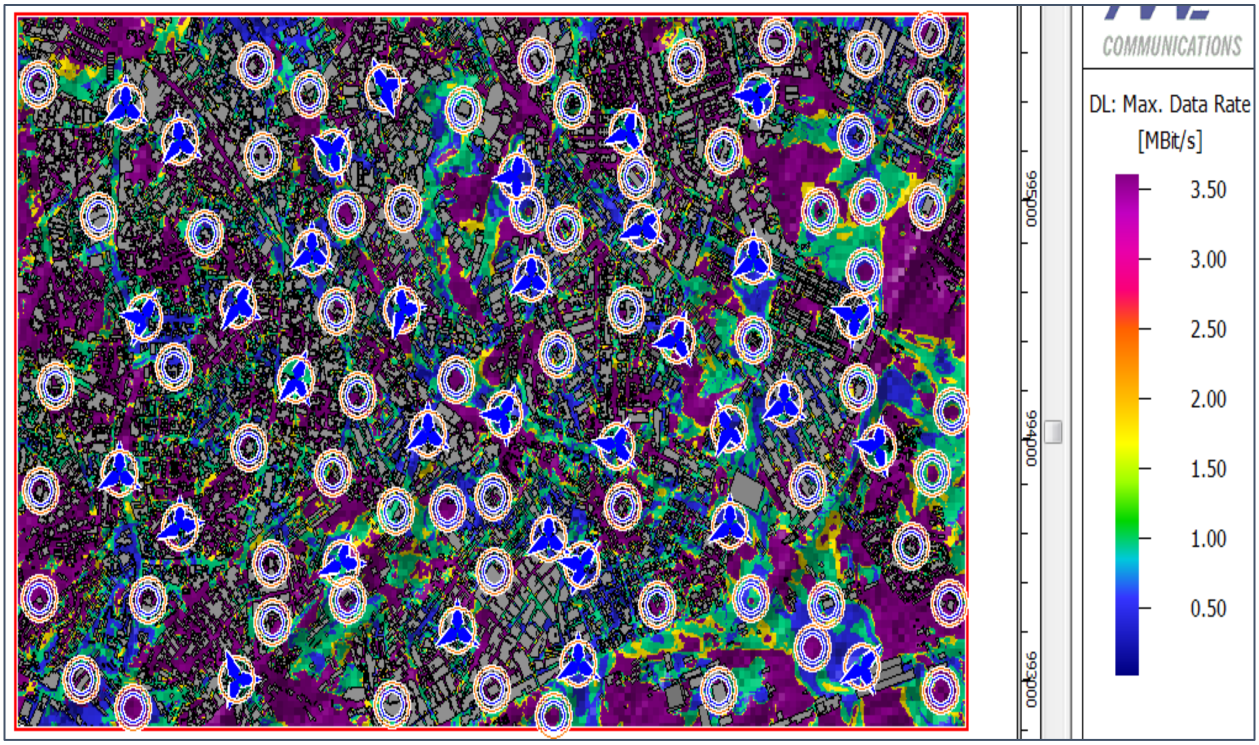


Figure 5.8 Data rate plot of 3-sector with 0.01 (1%) Femto penetration

The fifth scenario is three-sector with 0.03 femto penetration using orthogonal deployment similar to the fourth scenario. Their position can be identified from the data rate plot of *Figure 5.9*. The placement of femtocell is based on data rate values from the first experiment. This means femtocells are placed if have low data rate in the area. In this experiment, 33 three-sectored Node Bs or 99 macrocells and 185 femtocells were used.

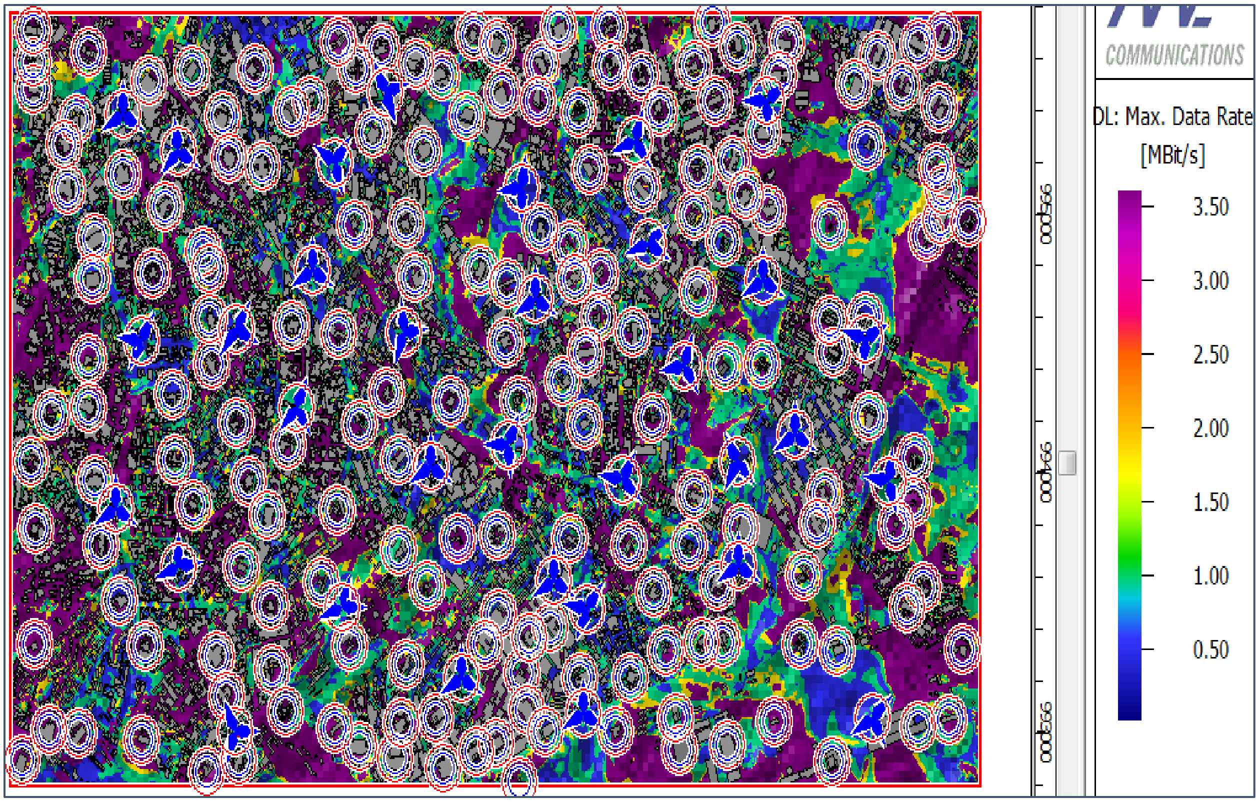


Figure 5.9 Data rate plot of 3-sector with 0.03(3%) Femto penetration

The sixth scenario is three sector with 0.05 femto penetration using orthogonal deployment between macrocells and femtocells. Their position can be identified from the data rate plot of *Figure 5.10*. The placement of femtocell is similar to fifth scenario. In this experiment, 33 three-sectored Node Bs or 99 macrocells and 308 femtocells were used.

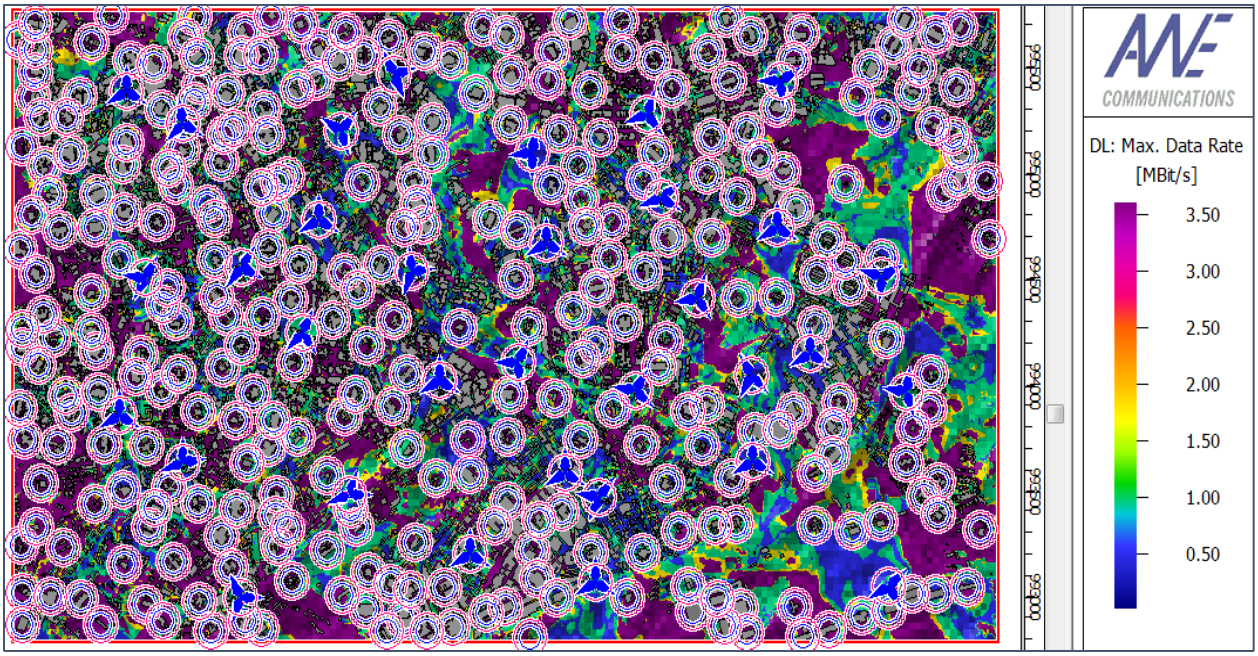


Figure 5.10 Data rate plot of 3-sector with 0.05(5%) femto penetration

The seventh scenario is hybrid with 0.005 femto penetration with orthogonal deployment. Their position can be identified from the data rate plot of *Figure 5.11*. The placement of femtocell is based on data rate values from the third experiment. This means femtocells are placed if they have low data rate. In this experiment, 11 three-sectored Node Bs and 22 six-sectored Node Bs (165 macrocells) and 31 femtocells were used.

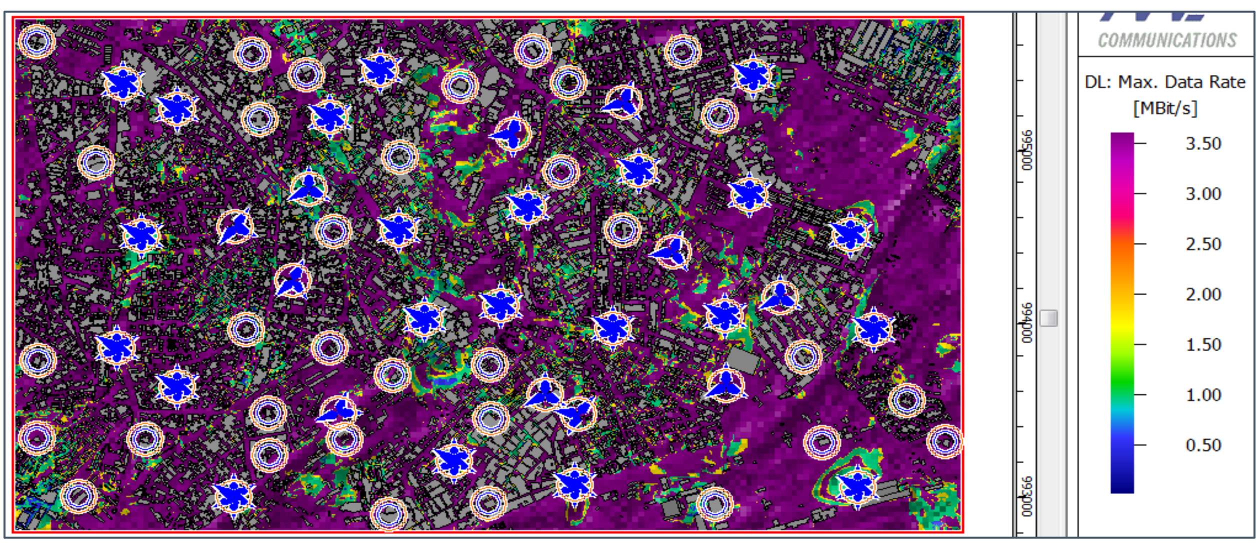


Figure 5.11 Data rate plot of hybrid with 0.0055 (0.55%) femto penetration

The eight scenario has 33 Node Bs (99 macrocells) and their position can be identified from the coverage plot of *Figure 5.12*. In this scenario, macrocells have been deployed according to real network configure position, antenna azimuths, tilt and a total of 4 carriers are used. Most of the parameters used are the same as the first scenario except the number of carrier per cell and named as four carrier per cell full 3-sector (4-SC full 3-sector). From the 33 Node Bs used, 31 Node Bs uses 4 carriers per cell, 1 Node B three carriers per cell, and 1 Node B two carrier per cell.

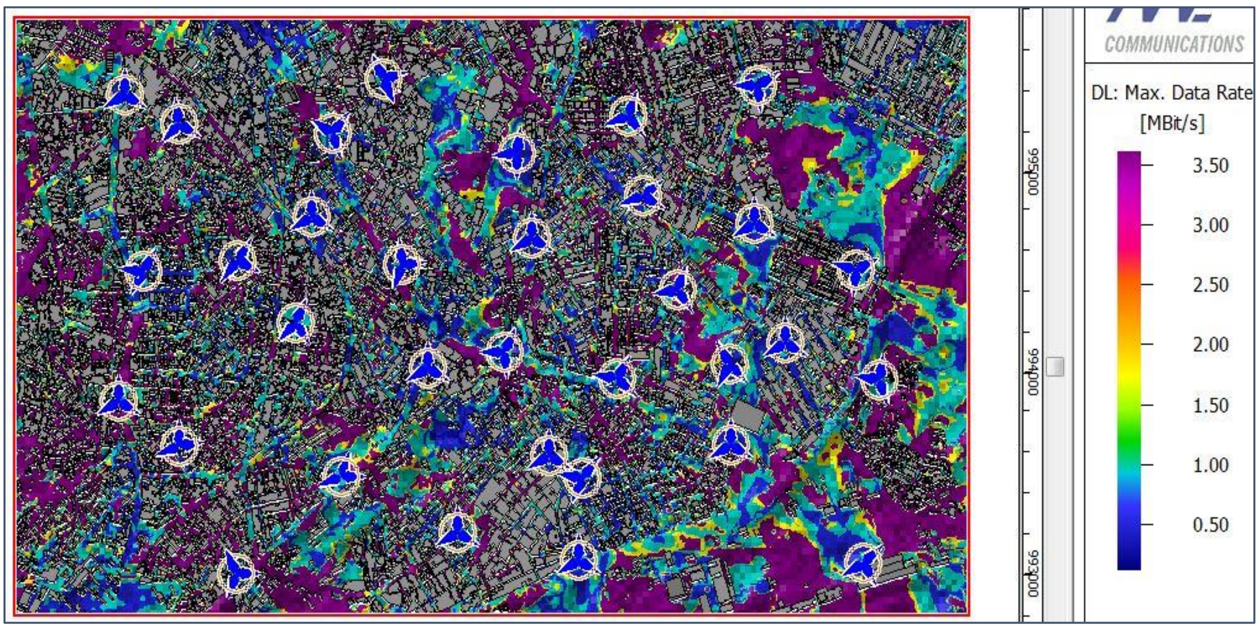


Figure 5.12 Data rate plot of full 3-sector with four single carriers per cell

Femto location selection criteria

1. Set the penetration rate for femto deployment
2. Select cells that has low data rate performance in full 3-sector simulation results and from real network performance reports
3. Share the number of femto between the cells
4. Select the points with worst data rates
5. Place the femto

6 SYSTEM MODELING AND ASSUMPTIONS

6.1 System Modeling

6.1.1 Tools

To do the antenna pattern, propagation and network simulation WinProp is used and for performance comparison Matlab. In 2016 Altair Engineering, Inc. acquired 100% of the shares of AWE Communications together with all WinProp related Products and Services. In this section, the details of the tool are described [30].

WinProp is used for propagation modeling of different scenarios (rural, urban, indoor, tunnels, etc...) and for network planning of different air interfaces (LTE, 3G, 2G, etc...) using propagation models like dominant path model. Depending on the scenario, predictions are based on topographical, clutter, urban building, and/or 3D planar objects/walls (vector) databases. It has 6 components ProMan, WallMan, AMan, TuMan, CoMan, and OptMan [32]. For the study 3 components of WinProp have been used.

ProMan does the wave propagation models, radio network planning and network simulation using static, Monte-Carlo and location dependent simulations. For capacity planning, WinProp computes throughput, maximum data rate etc. *Figure 6.1* presents a graphical user interface of ProMan and different parameters like MCS are shown.

WallMan: used to define building database and converts the different format to ProMan supported formats including building databases, topographic and clutter databases.

AMan: handles antenna patterns, converts commercially available antenna file formats (*.xml, *.msi, *.pln,…), converts from a 2x2D pattern (horizontal & vertical) to 3D pattern and to define manually vertical and horizontal antenna patterns.

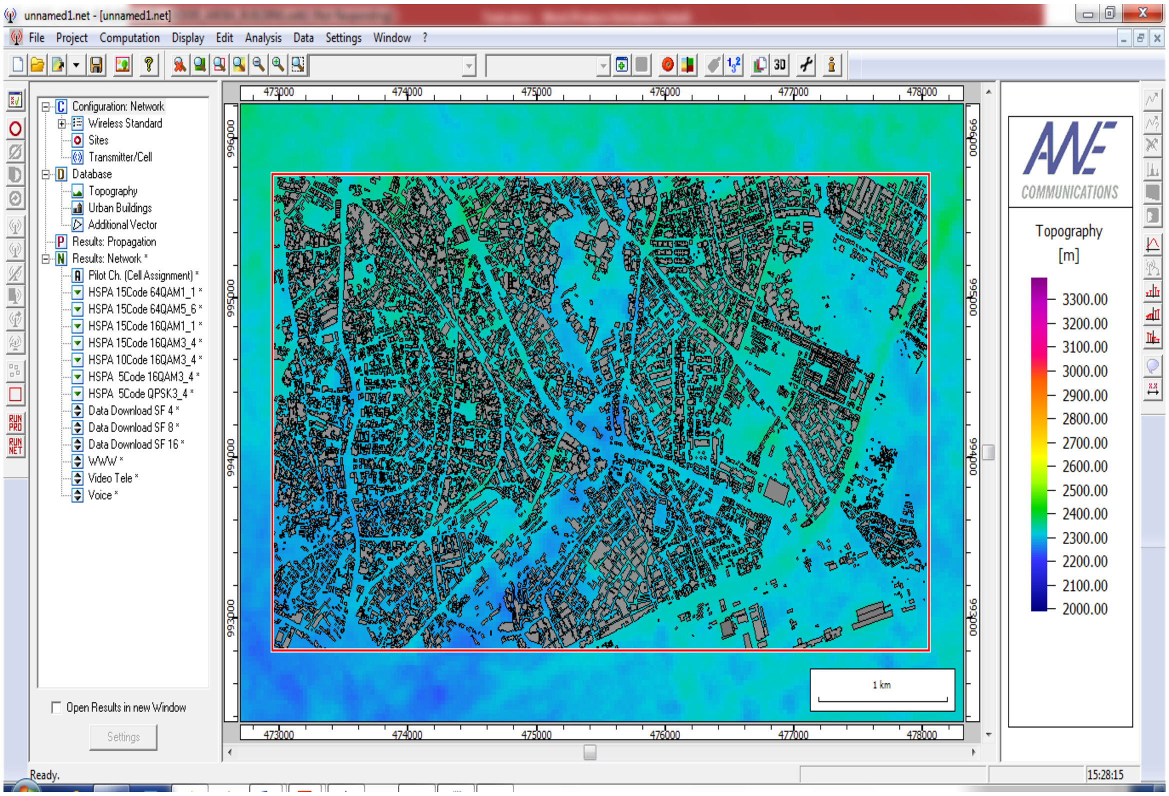


Figure 6.1 ProMan GUI

6.1.2 Propagation model

A dominant path model, determines the dominant path and predicts the path loss along those dominant paths by using criteria like, a small number of interactions, short paths, and a small number of transmission. By adjusting weight more than one path can be calculated for each pixel and one path per pixels is determined which is the most dominant one [39].

6.1.3 Selected area

Addis Ababa is the capital city of Ethiopia that shares most urban population [33]. Recently in Addis Ababa, an urban settlement is growing. World Bank study shows, in Ethiopia, an increase in urban population as % of total population from 18.6% in 2013 to 20.4% in 2017.

For this study, 15Sq Km is used in bole area that consists of Bole Medhanealem, Bole Dembel, and Bole airport that are located in Bole and kirkos sub-cities. Bole is one of a higher potential area that has densely populated buildings. Bole sub-city has 328,900 with 2,694.1 population density per sq. m [34]. The population of the area is estimated at about 40000 – 45000. The building database shows 6156 buildings with heights between 3 and 56 meters, 3-meter height can be assumed mostly one-storied building. *Figure 6.2* topographic with building databases. In this regard, network deployment in this area will have higher propagation losses which presents the worst case scenario. Currently, 33 macro sites with 3 cells are deployed in the specified location.

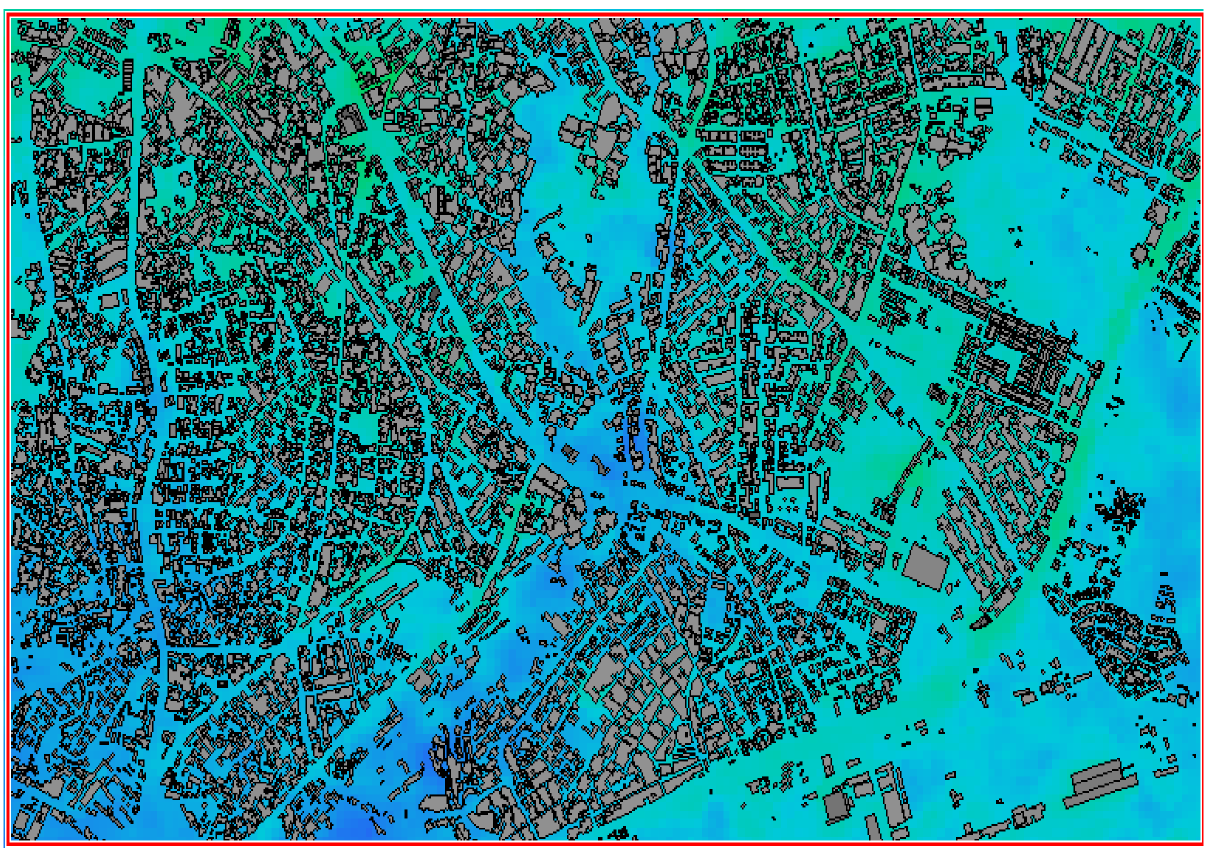


Figure 6.2 Topographic database with building data on it

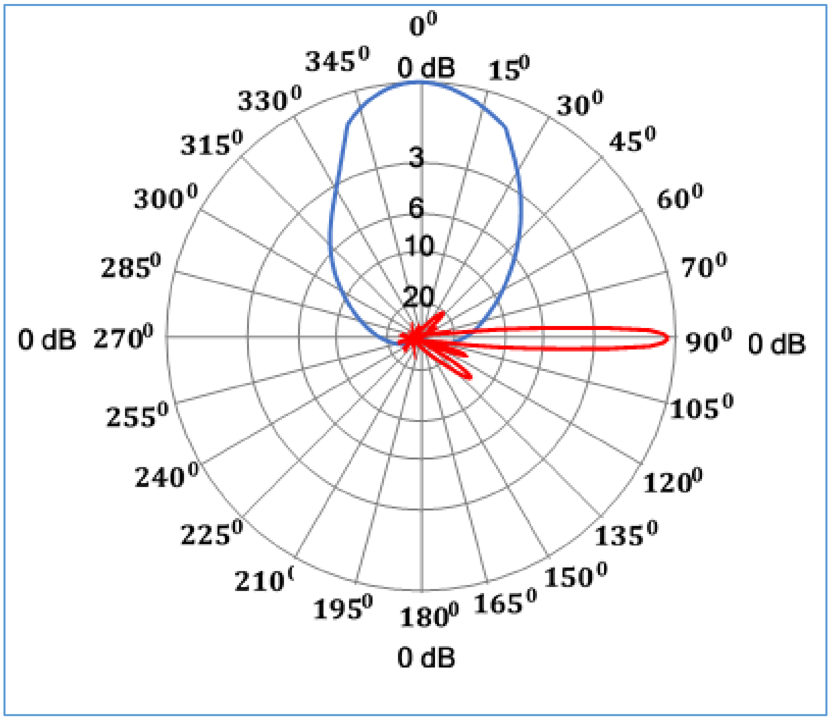
6.2 Assumptions and parameters

General simulation assumptions and parameters are shown in *Table 6.1*.

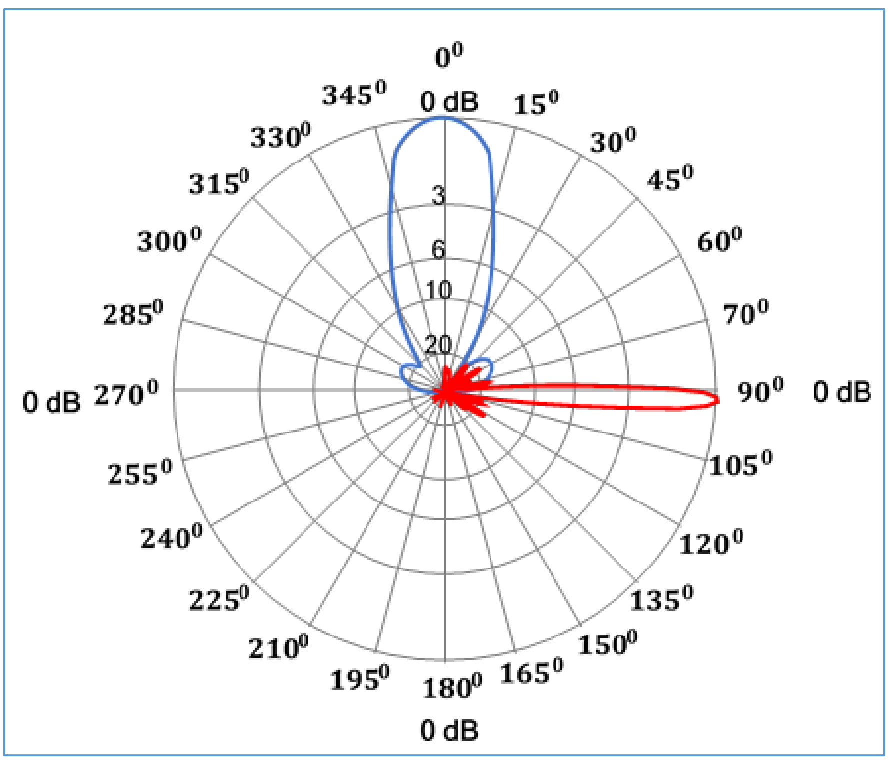
Table 6.1 General simulation assumptions and parameters

Parameter	**Values/ Assumptions**
Air interface	Five 5 MHz carrier (DL/UL frequency 2112.5/1922.5 MHz, 2117.5/1927.5, 2122.5/1932.5, 2127.5/1937.5, and 2142.5/1952.5), 3.84 Mchips/s, Duplexing scheme FDD
Prediction height	1.5 m
Propagation modeling	Dominant Path Model
Macro Node B (MNB)	Different for each deployment scenario but have power 43 dBm, antenna gain 17.5 dBi, 4 dB noise figure, cable loss 2 dB/100m, Coupling loss 10, Radiating cable loss 2 dB
Antenna	Aggison ADU451819 60° HPBW 17.5 dBi antenna gain for 3-sector MNB
Femto	Omnidirectional antenna with a power of 23 dBm
UE	Omnidirectional 1 dB body losses, 6 dB noise figure
Femtocell height	From 2-7 meters
Orthogonality Factor	0.75
Indoor coverage model	Exponential decrease
User distribution	uniform

The directional antenna used for 3-sector is "Aggison ADU451819" model with 60° Half-Power BeamWidth (HPBW) and 17.5 dBi antenna gain. *Figure 6.3* shows the horizontal and vertical pattern of the antenna [45]. For 6-sector 32° HPBW and 17.5 dBi antenna gain is used.



a)



b)

Figure 6.3 antenna pattern for a) 3-sector [45] and b) 6-sector (log scale)

7 SIMULATION RESULTS AND PERFORMANCE EVALUATION

Different deployment scenarios performance gain are compared. Several issues affected the total network performance and created the mentionable differences between different deployments. The key issues in femto deployment are interference, position, and penetration of femto in the network. For the performance comparison, three matrixes are used to measure the gain which are maximum achievable DL CINR, UL maximum throughput, and DL maximum throughput.

7.1 Result for all deployment scenarios

7.1.1 CINR results

The CDF of different deployment scenarios is presented in *Figure 7.1*. It shows that all deployment scenarios have improved the CINR compare to 1-SC and 4-SC full 3-sector. Full six sector increases the CINR from -15.4 dB in three sector case to -12.5dB while femto with 0.05 penetration increases the CINR to -15.1 dB from 1-SC at 10-percentile.

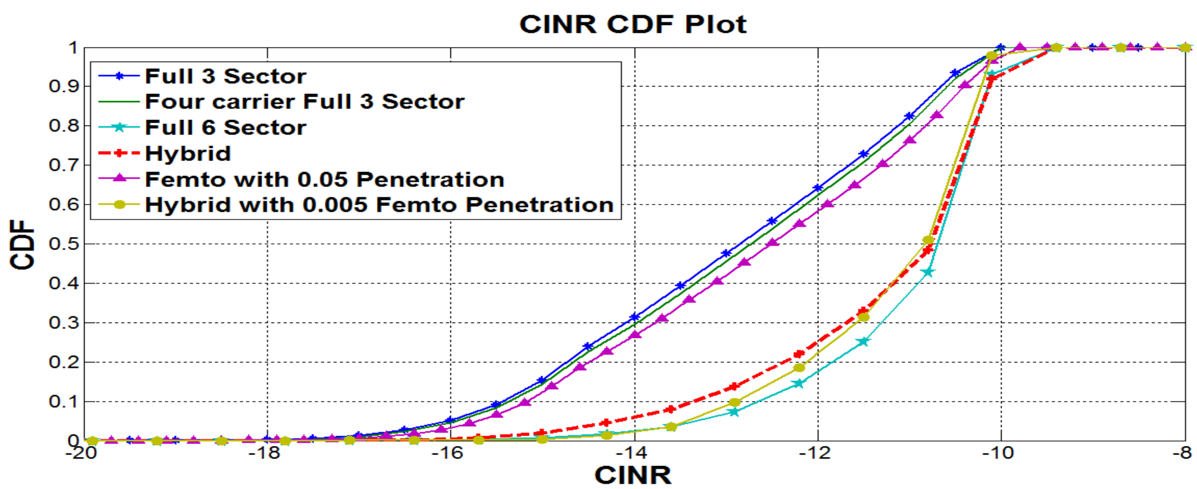


Figure 7.1 CINR plot

The performance of different deployments at 10, 50 and 90-percentiles are shown in *Figure 7.2*. As it can be seen, full 6-sectored deployment significantly improves the CINR by delivering 2.9 dB, 2.2 dB and 0.5 dB gains at 10, 50 and 90-percentile respectively compared to 1-SC full 3-sector. Further, full 6-sector deployment gives 2.8 dB, 2.1 dB and 0.4 dB gains compared to 4-SC full 3-sector at 10, 50 and 90-percentiles respectively. Hybrid deployment has also shown remarkable performances at 10, 50 and 90-percentiles with 2.2 dB, 2.1 dB, and 0.5dB gains correspondingly. With the addition of femto at 0.55% penetration to hybrid, the CINR increases by 0.4 dB at 10-percentile compared to hybrid. Femto with 5% penetration improved the performance by 0.3 dB, 0.3 dB and 0.2 dB relative to 1-SC 3-sector case at 10, 50 and 90-percentile. At 90-percentile, all the different scenarios result difference are small compared to values at 10 and 50-percentiles.

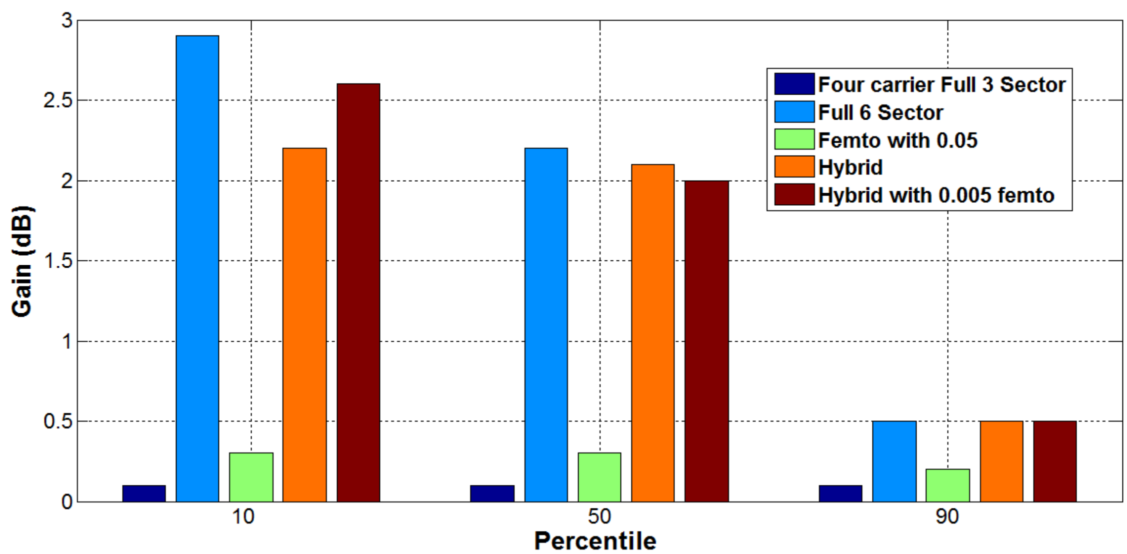
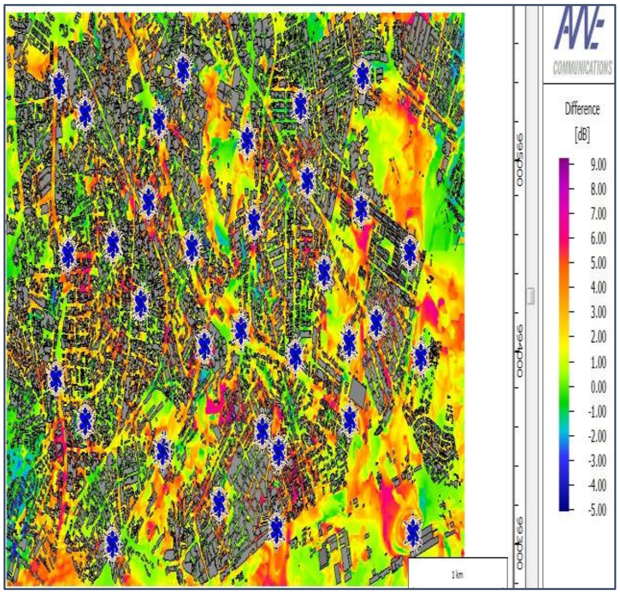
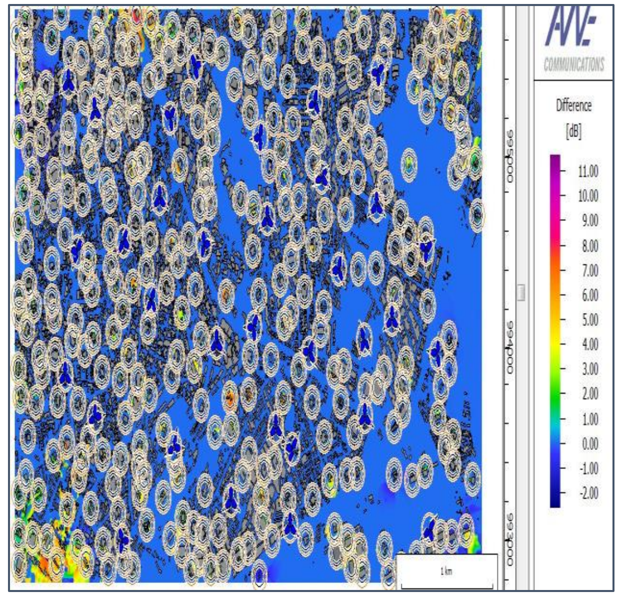


Figure 7.2 CINR percentile comparison

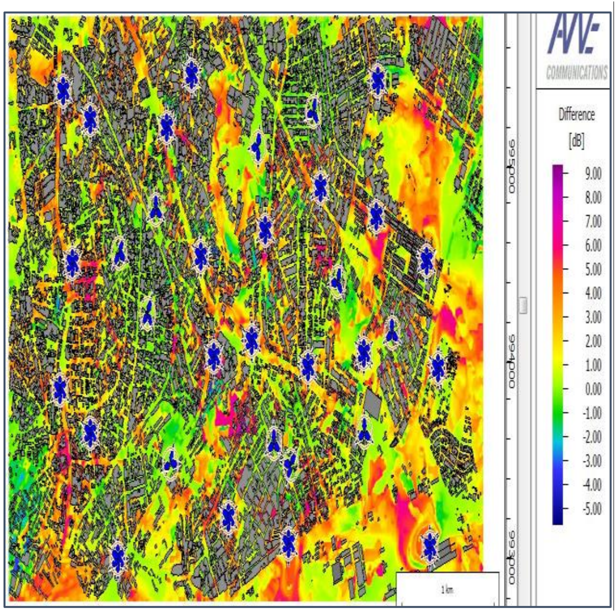
The difference between different deployment scenarios with full 3 sector is shown in *Figure 7.3*. The legend with different colors shows the gains at each pixel. For instance, purple color indicates a gain of 9dB which means pixels with purple color have a 9dB gain compared to 3-sector. As presented in *Figure 7.3* a, 6-sector gains are distributed across the area.



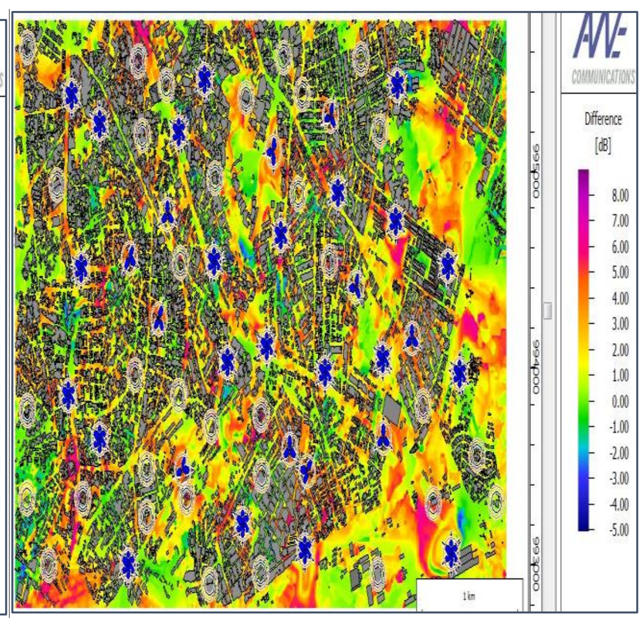
a)



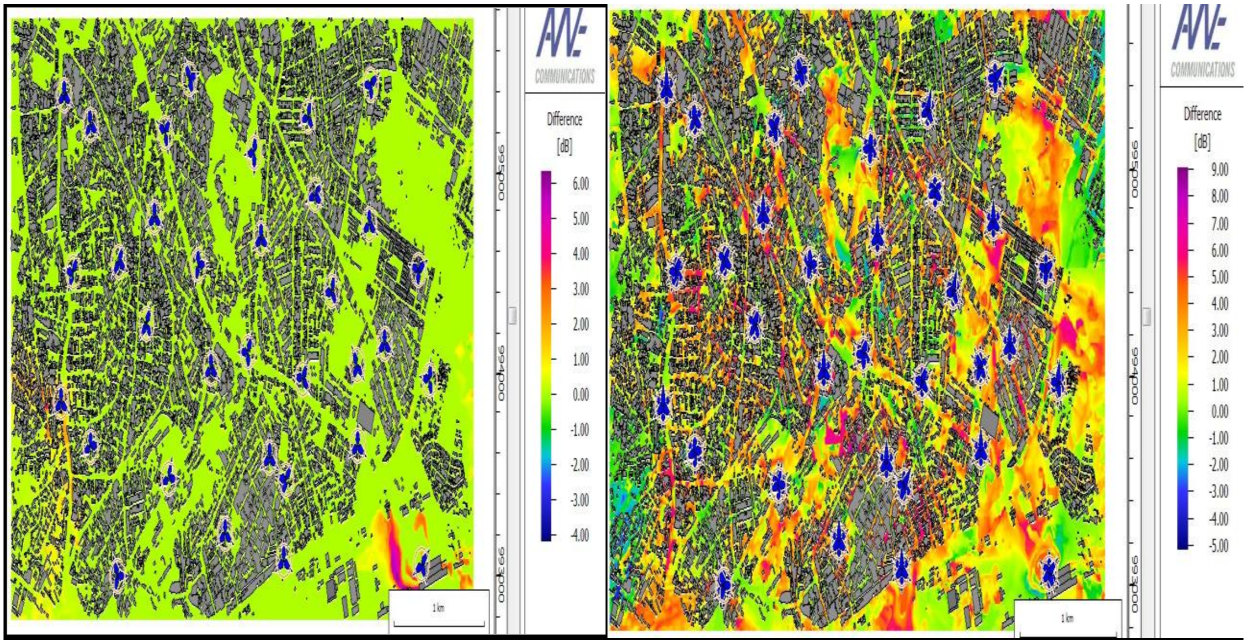
b)



c)



d)



e) *f)*

Figure 7.3 CINR difference plot for a) full 6-sector, b) femto with 0.05 penetration, c) hybrid and d) hybrid with 0.005 penetration e) four carrier full 3-sector compared to full 3-sector deployment f) full 6-sector compared to four carrier full 3-sector respectively

7.1.2 DL throughput results

CDF of DL maximum throughputs are presented in *Figure 7.4* performance gains when compared to full 3-sector deployments at 10, 50 and 90-percentiles are shown in *Figure 7.5*. CDF looks staircase because WinProp uses discrete value while calculating DL throughput values, like 480kbps, 960 kbps, 1.8Mbps and 3.6Mbps. The results shows that 6-sector and femto have improved the throughput compare to 1-SC and 4-SC full 3-sector. Full 6-sectored deployment delivers 284.23%, 280.00%, and 118.81% gain at 10, 50 and 90-percentile respectively when compared to 1-SC full three-sector. Moreover, full 6-sector when compared with 4-SC Full 3-sector, improves the throughput by 2.44x, 2.72x and 1.17x at 10, 50 and 90-percentile respectively. In addition, femto 0.05 penetration, hybrid, and hybrid with 0.005 femto improved the DL throughput by 114.67%, 231.05%, and 278.73% compared to 1-SC full 3-sector respectively at 10-percentile. Similar to CINR results, hybrid with 0.005 femto penetration results have higher gains compared to hybrid deployment at 10-percentile. While in at 50-percentile hybrid, femto with 0.05 penetration and hybrid with 0.005 femto deliver 232.26%, 104.86%, and 230.02% gains compared to 1-SC full 3-sector.

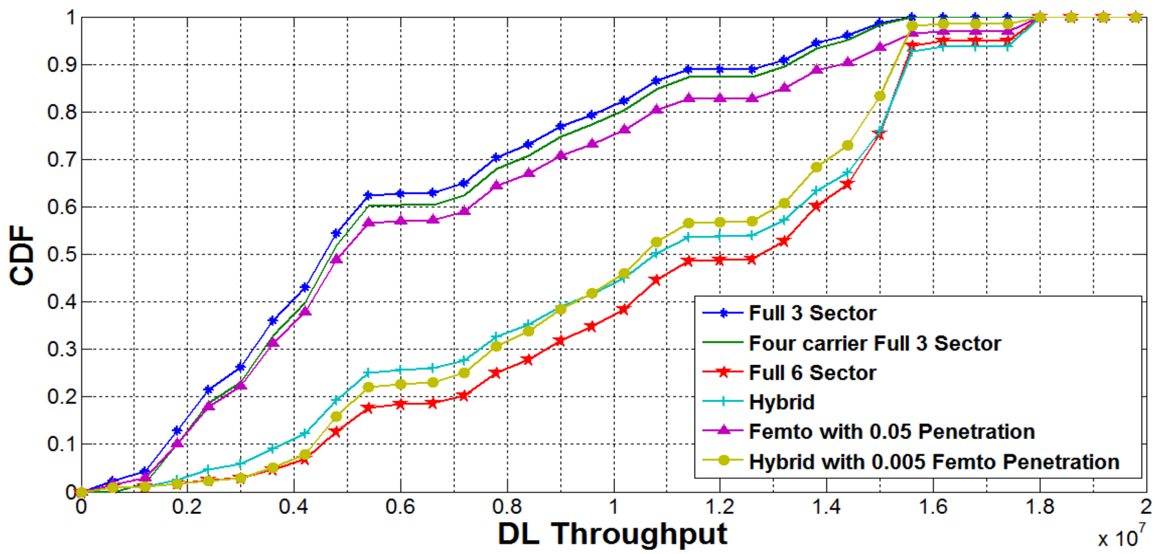


Figure 7.4 CDF of DL throughput (Mbps)

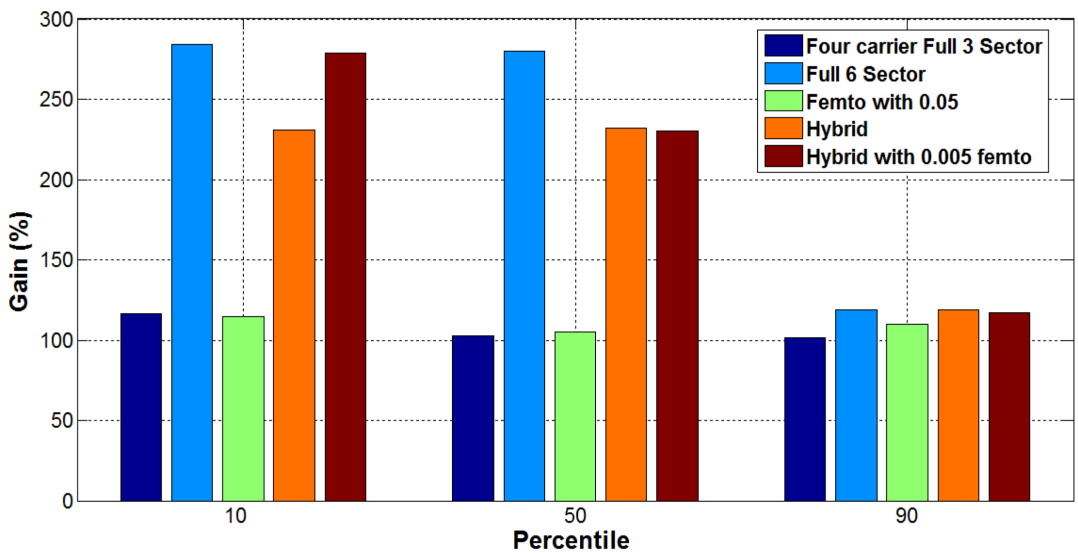


Figure 7.5 DL throughput Percentile compared to 3 sector

7.1.3 UL throughput results

CDF of UL maximum throughputs for all the cases are plotted in *Figure 7.6*. CDF looks staircase because WinProp uses some discrete value while calculating UL throughput values, like 120kbps, 240 kbps, and 480Kbps. As shown in *Figure 7.6*, all deployment scenarios have improved the throughput compare to 1-SC and 4-SC full 3-sector. Full 6-sectored deployment significantly improves the UL throughput by providing 283.33%, 267.03%, 129.44% gains at 10, 50 and 90-percentile respectively compared to 1-SC 3-sector. Further, full 6-sector deployment gives 2.41x, 2.53x, and 1.25x throughput gains at 10, 50 and 90-percentile respectively compared to 4-SC full 3-sector deployment. At 10-percentile, femto with 0.05 penetration, hybrid and the hybrid with 0.005 femto penetration deliver 1.06x, 2.11x, and 2.27x UL throughput gain compared to full 3-sector respectively. Like DL throughput results, hybrid with 0.005 femto penetration have higher gains compared to hybrid deployment at 10-percentile.

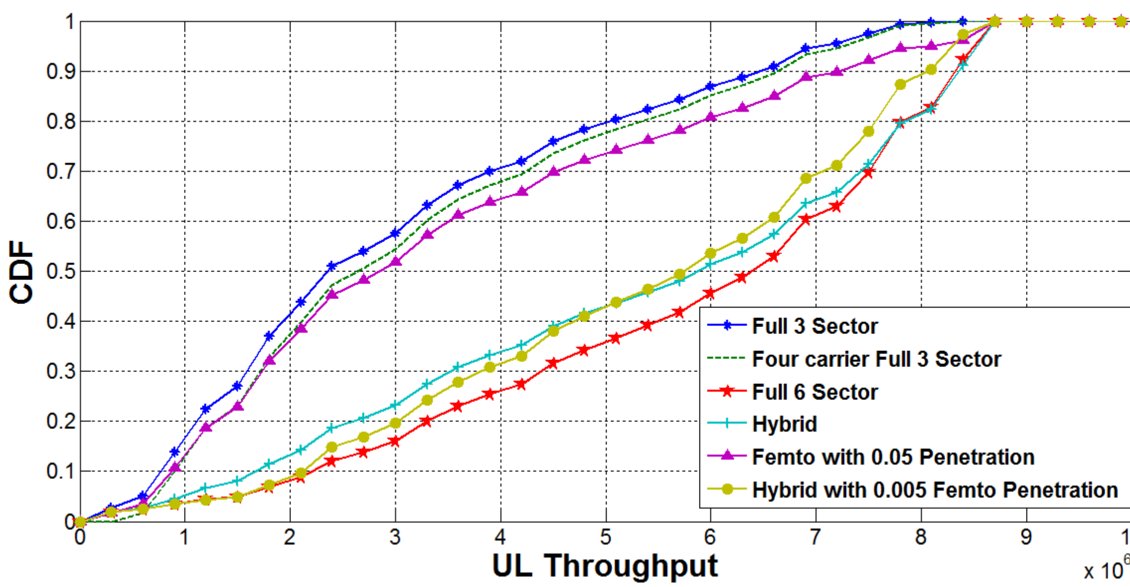


Figure 7.6 UL throughput

The performance improvement of different deployments at 10, 50 and 90-percentiles relative to 1-SC full 3 sector is presented in *Figure 7.7*. Additionally, hybrid, femto 0.05 penetration and hybrid with 0.005 femto penetration gives UL throughput of 243.21%, 118.76% and 238.82% at 50-percentile respectively.

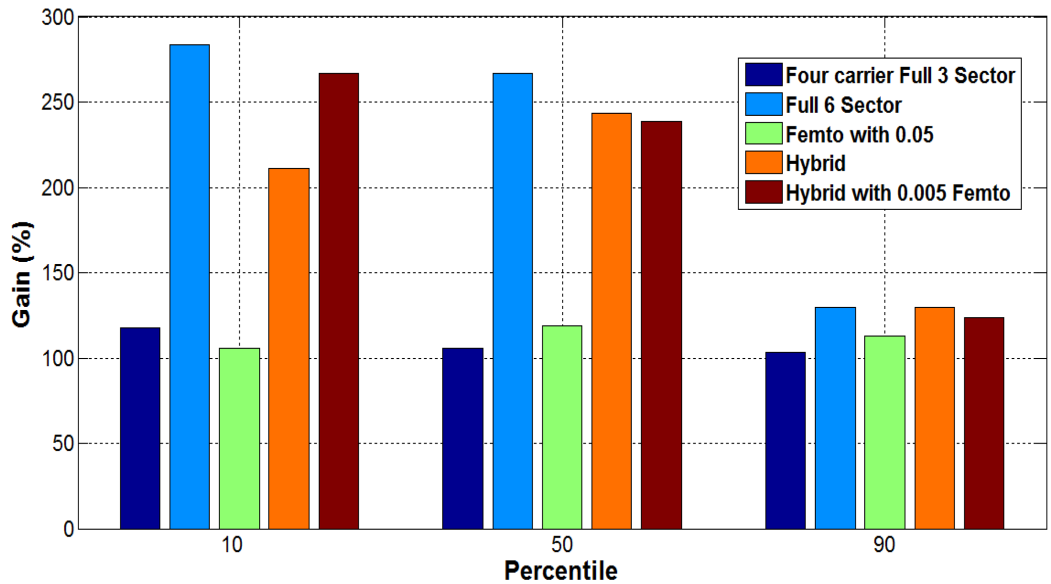


Figure 7.7 UL throughput Percentile comparison

7.2 Results related to femto penetrations

The performance improvement between different femto deployments are shown *Figure 7.8*. Femto with 0.05 penetration and femto with 0.03 penetration increases the CINR by 0.3 dB and 0.2dB compared to 1-SC full three-sector.

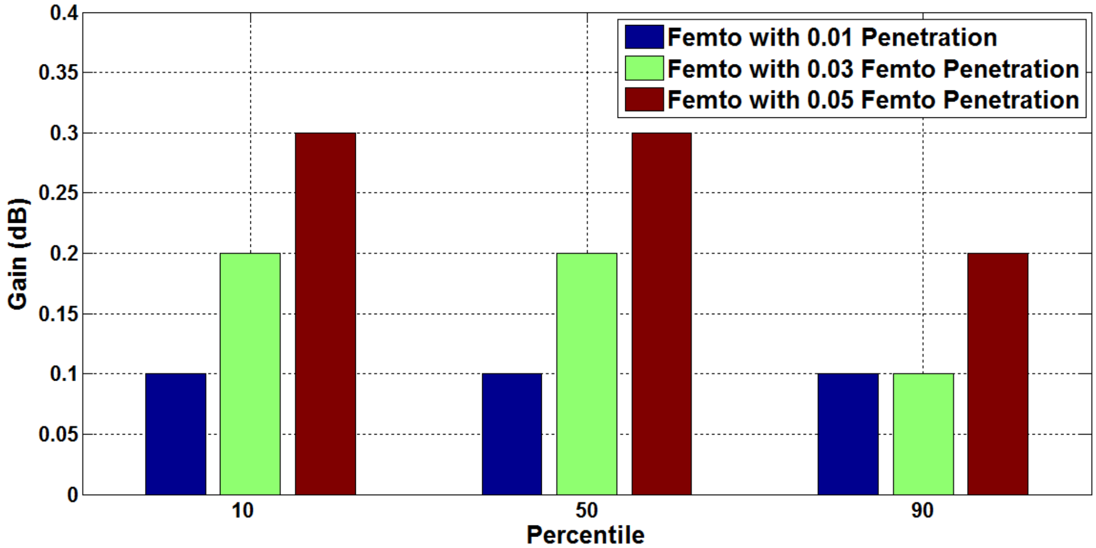


Figure 7.8 CINR for different femto penetration ratio

As can be seen from *Figure 7.9* at 10-percentile, femto with 0.03 penetration and femto with 0.05 penetration deliver 103.67% and 114.67% increase over 1-SC 3- sector.

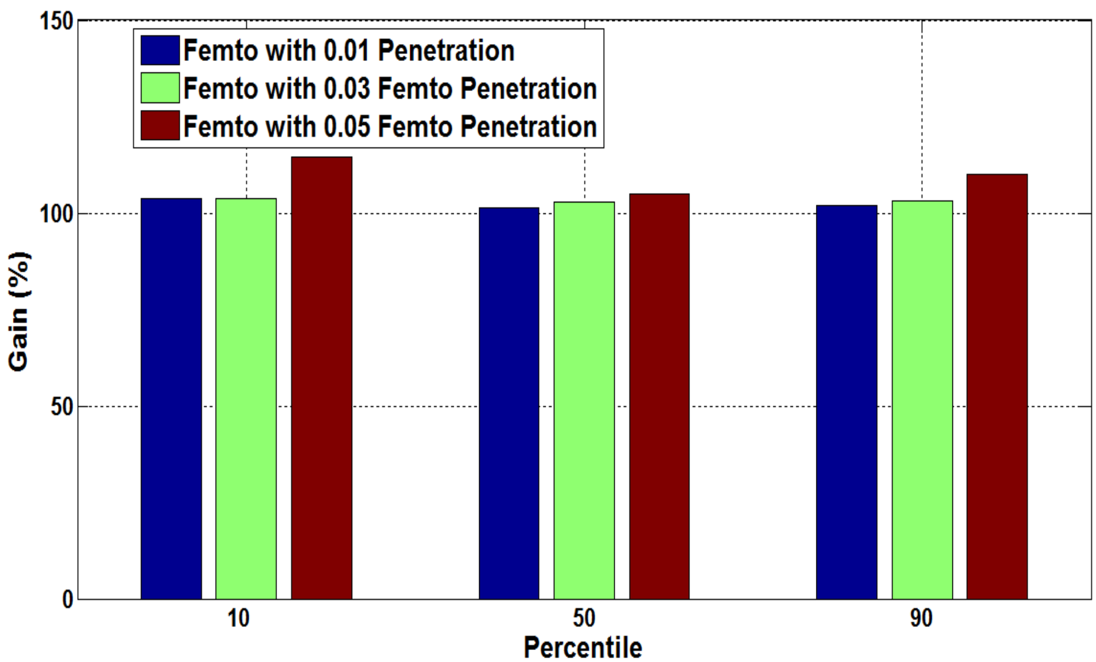


Figure 7.9 DL throughput for different femto penetration ratio

8 CONCLUSION AND FUTURE WORK

8.1 Conclusion

An important step in the study of capacity improvement techniques is analyzing capacity challenges that are caused by limited network resources. As a result, this thesis first studied the network challenges and their causes based on RRC and RAB failures data from network management system which is first contribution of this work. The performance data shows that, there is significant amount of network failures due to limited channel element and power resources and the failures are related to the traffic increase. Further, spatial and temporal variations are studied categorized as residential and commercial areas. In both residential and commercial areas, UL power congestion is main capacity challenge. In residential areas, the peak occurs at 21:00 whereas in commercial areas the peak occurs at 10:00 and 17:00. These shows the variation of the capacity challenges between the areas in time.

To overcome these resource challenges, different improvement techniques namely MIMO, carrier aggregation, adding another band, macro densification, six sector cell and small cell are evaluated based on literature. Then, based on their practicability and relevance, which is measured in terms of device penetration, six sector site and small cell technologies are selected. The data showed that 56% of the devices support higher order modulation only which means techniques like MIMO and carrier aggregation are not supported.

Afterwards, performance evaluation and comparison of six-sector sites, small cell deployment and their hybrid deployments is done through network simulation. The simulation study highlighted the potential benefits of using 6-sector and femtocells. Two different deployment strategies for 6-sector, full and hybrid have been studied.

The simulation results showed that 0.1 dB, 2.2 dB, 0.3 dB, 2.1 dB and 2 dB CINR gains at 50-percentile for four-carrier full 3-sector, full 6-sector, femto 0.05 penetration, hybrid and hybrid with 0.005 femto respectively. In addition, DL throughput also has increased by 116.50%, 284.23%, 114.67% , 231.05% and 278.73% for the above deployment scenarios respectively at 50-percentile.

To conclude, full 6-sector has a remarkable performance improvements compared to all studied scenarios and femto performance gain increase as the penetration increases. Further, hybrid deployment improved the performance compared to 3-sector. Both six-sector and femto can enhance the capacity of UMTS network. Additionally, hybrid can be an option for enhancing capacity of hotspot areas based on the performance gain needed if full deployment is not required.

8.2 Contributions

The main contribution of this work are:

- The failure analysis: related studies on capacity enhancement techniques start to form the need to increase capacity based on the growth of traffic demand and do not study the resources that will be limited due to the rise. Yet in this thesis, the study starts from analyzing network failures that are caused by limited resource and relate it to the traffic patterns.
- Adding device availability as a criterion for selecting techniques: for operators, it is important to know which techniques can be important for users and which segment of their customer can benefit from the network they build.
- The use of a combination of techniques in the performance evaluation: for example using three and six-sector with Femto.

- Studying and comparing more than one single carrier per cell 3-sector with 6-sector has not been studied.

8.3 Future work

In this study backhaul was assumed to be perfect with proper availability, capacity and quality but it might not be the real scenario and the main focus was on the access part only. The femto and macro layer deployment was orthogonal deployment the future may not allow these when multi operator network is introduced.

Potential future works include:

- Adaptive sectorization: sectorization could be adaptive to the network situation using different algorithms.
- Performance of reconfigurable beam antennas in improving coverage, capacity, quality and interference.
- Backhaul options and their performance
- Using LTE system for backhaul connectivity
- Traffic engineering related to small cells
- Interference mitigation techniques when femto and macro layer use the same frequency or co-channel deployment is used
- Self-Organized Network for both 6-sectorization and small cells to minimize interference.
- Economical perspective of the different deployment option could be studied since telecom operators must balance profit and the gains.

REFERENCES

[1] H. Holma and A. Toskala, *WCDMA FOR UMTS HSPA Evolution and LTE,* 5th ed. John Wiley & Sons, Ltd., 2010.

[2] Ethiopian Telecommunications Corporation (ETC), "click to the Ethiopian Millennium: special issue", September 2009.

[3] GSM Association (GSMA), "The Mobile Economy 2018", 2018.

[4] B. B. Haile, D. A. Bulti, and B. M. Zerihun, "On the Relevance of Capacity Enhancing 5G Technologies for Ethiopia," in *10th Ethiopian ICT Annual Conference (EICTC-2017)*, 2017.

[5] A. Jiso, "Quality of Service Evaluation of Voice over UMTS Network: The case of Addis Ababa," MSc. dissertation, Dept. Elect. And. Comp. Eng., Addis Ababa Univ., Addis Ababa, 2017.

[6] Ministry of Finance and Economic Development, " Growth and Transformation Plan Annual Progress Report for F.Y. 2012/13," Ministry of Finance and Economic Development, Addis Ababa, February 2014.

[7] Real wireless, "Techniques for increasing the capacity of wireless broadband networks: UK, 2012-2030", April 2012.

[8] Nokia-Siemens networks, "Mobile broadband with HSPA and LTE – capacity and cost aspects", May 2010.

[9] Bo. Hagerman, D. Imbeni, J. Barta, A. Pollard, R. Wohlmuth and P. Cosimini, "WCDMA 6-sector Deployment-Case Study of a Real Installed UMTS-FDD Network," in *IEEE 63rd Vehicular Technology*, Melbourne, Australia, 2006.

[10] A. Fazlul, M. Mohammad, M. Baitul, M. Ka and M. Fokhray, "Performance Analysis of UMTS Cellular Network using Sectorization Based on Capacity and Coverage," *International Journal of Advanced Computer Science and Applications*, vol. 2, no. 6, 2011.

[11] P. Sorrells, "Twin beam technology adds immediate capacity without additional antennas," White Paper, CommScope, 2013.

[12] A. Wacker, J. Laiho-Steffens, K. Sipila and K. Heiska, "The impact of the base station sectorization on WCDMA radio network performance," in *IEEE 50th Vehicular Technology*, Amsterdam, Netherlands, 1999.

[13] Nokia Networks, "Taking HSPA to the next level with Release 12 and beyond", 2013

[14] QUALCOMM, "HSPA+ Advanced – Taking HSPA+ to the Next Level", 2012

[15] K. Johansson, J. Bergman, D. Gerstenberger, M. Blomgren, and A. Wallen, "Multi-Carrier HSPA Evolution," *VTC Spring 2009 - IEEE 69th Vehicular Technology Conference*, Barcelona, Spain, 2009.

[16] *Radio Interface Protocol Architecture*, 3GPP TS 25.301 V6.4.0 (2005-09), 2005.

[17] J. Laiho, A. Wacker, and T. Novosad, *Radio Network Planning and Optimization for UMTS*, 2nd ed., John Wiley & Sons, Ltd, 2006.

[18] R. Tanner and J. Woodard, *WCDMA–Requirements and Practical Design*, UbiNetics Ltd, 2004.

[19] C. Kappler, *UMTS NETWORKS AND BEYOND* , John Wiley & Sons, 2009

[20] H. Holma, A. Toskala, and P. Tapia, *HSPA+ EVOLUTION TO RELEASE 12 PERFORMANCE AND OPTIMIZATION* , John Wiley & Sons, 2014

[21] H. Holma and A. Toskala, *HSDPA/HSUPA for UMTS*, 5th ed. John Wiley & Sons, Ltd., 2010.

[22] E. Dahlman, S. Parkvall, Sköld Johan, and P. Beming, *3G EVOLUTION: HSPA AND LTE FOR MOBILE BROADBAND*, Elsevier Ltd, 2008.

[23] T. Chapman, E. Larsson, P. von Wrycza, E. Dahlman, S. Parkvall, and J. Skold, HSPA Evolution the Fundamentals for Mobile Broadband, Elsevier Ltd, 2015.

[24] Small Cell Forum, "Small cells - what's the big idea?," White Paper, UK, February 2012.

[25] J. Zhang and G. D. la Roche, *FEMTOCELLS: TECHNOLOGIES AND DEPLOYMENT*, John Wiley & Sons, 2010.

[26] Next Generation Mobile Networks (NGMN), "Small Cell Backhaul Requirements, White Paper", NGMN Alliance, June 2012.

[27] *UTRAN architecture for 3G Home Node B Stage 2*, 3GPP TS 25.467 V11.1.0 (2012-12), 2012.

[28] *UMTS: UE Radio Access capabilities*, 3GPP TS 125 306 V12.9.0 (2017-07), 2017

[29] Ericson, “It all comes back to Backhaul,” White Paper, February 2012.

[30] Altair, About. [online] Available at: https://altair.com/about/ [Accessed 5 Aug. 2018].

[31] P. Ashish, “HOW TO OPERATE: Philippines Globe: New network configuration, new MBB gains,” ISSUE 80, Globe, October, 2016

[32] Altair, WinProp - Propagation Modeling, [online] Available at: https://altairhyperworks.com/product/FEKO/WinProp-Propagation-Modeling, [Accessed 29 August, 2018]

[33] The World Bank, World Development Indicators, [online] Available at: http://databank.worldbank.org/data/reports.aspx?source=2&series=SP.URB.TOTL.IN.ZS&country=#selectedDimension_WDI_Ctry [Accessed 03 march, 2018]

[34] Addis Ababa city government, population , [online] Available at: http://www.addisababa.gov.et/es/web/guest/bole-sub-city [Accessed 03 march, 2018]

[35] Huawei Technologies Co., Ltd , “xMbps Anytime Anywhere,” White Paper, Huawei, 2014

[36] H-H. Chen, *The Next Generation CDMA Technologies*, John Wiley & Sons, Ltd, 2007.

[37] *QUALITY OF SERVICE AND DEPENDABILITY VOCABULARY*, ITU E.800, 2007.

[38] D. Soldani, M. Li, and R. Cuny, *QoS and QoE Management in UMTS Cellular Systems*, John Wiley & Sons, Ltd, 2006.

[39] A. Richardson, *WCDMA Design Handbook*, Cambridge University Press, 2005

[40] P. Tapia, J. Liu, Y. Karimli, and M. J. Feuerstein, *HSPA Performance and Evolution: A Practical Perspective*, John Wiley & Sons, Ltd, 2009.

[41] *Physical channels and mapping of transport channels onto physical channels (FDD)*, 3GPP TS 25.211 V15.0.0, release 15, 2018

[42] Huawei, Thailand AIS: A Shift from Embarrassing to Wonderful, [online] Available at: http://carrier.huawei.com/en/success-stories/wireless-network/03-ubiquitious-mbb/thailand%20ais, [Accessed 14 July, 2018]

[43] GSMA, "MIMO in HSPA: the Real-World Impact", 2012

[44] R. Joyce, D. Morris, S. Brown, D. Vyas, and L. Zhang, "Higher Order Horizontal Sectorization Gains for 6, 9, 12 and 15 Sectored Cell Sites in a 3GPP/HSPA+ Network," in *IEEE Transactions on Vehicular Technology*, vol. 65, no. 5, pp. 3440–3449, 2016.

[45] Huawei Technologies Co., Ltd., "Antenna Specification," ADU451819 datasheet, 2014

[46] Huawei, *Performance report system*. Computer software. Huawei Technologies Co., Ltd.

[47] Huawei, *Service & experience quality analyst*. Computer software. Huawei Technologies Co., Ltd.

[48] *Universal Mobile Telecommunications System (UMTS); Base Station radio transmission and reception (FDD)*, 3GPP TS 25.104 V15.4.0 (2018-10), 2018.

[49] Huawei, *RAN20.1 Capacity Monitoring Guide (2018-03-31)*, ISSUE 01, 2018