Addis Ababa University

Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Optimization of Soft Handover for Addis Ababa UMTS Radio Access Network

By

Nigussie Beyene

Advisor

Dr. Beneyam Berehanu Haile

A thesis is submitted to the School of Electrical and Computer Engineering in Fulfillment of the Requirements for the degree of Master of Science in Telecom Network Engineering

February 2020

Addis Ababa, Ethiopia

Addis Ababa University

Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Optimization of Soft Handover for Addis Ababa UMTS Radio Access Network

By

Nigussie Beyene

Approved by Board of Examiners

Dr. Yalemzewd Negash	______________________	24/02/2020
Dean, School of Electrical and Computer Engineering	Signature	Date
Dr. Beneyam Berhanu Haile	______________________	24/02/2020
Advisor	Signature	Date
Dr. Ing. Dereje Hailemariam	______________________	24/02/2020
Examiner	Signature	Date
Dr. Ing. Yihenew Wondie	______________________	24/02/2020
Examiner	Signature	Date

Declaration

I declare that this thesis was composed by myself. The work contained herein is my own except where explicitly stated otherwise in the text. No one submitted this work for any other degree or professional qualification except as specified.

Nigussie Beyene Haile ______________________

Name Signature

Place: Addis Ababa, Ethiopia

Date of Submission: February 24, 2020

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

Dr. Beneyam Berhanu Haile ______________________

Advisor's Name Signature

Abstract

Handover is an essential radio management technique of mobile communication to enable seamless communication while users move from one cell to another one. To mitigate impacts of interference on cell-edge users, third Generation (3G) supports soft handover where users can be simultaneously served by two or more cells, in addition to hard handover, where a user is served by only one cell. The number of soft handover users and their active cells determine the degree of soft handover overhead. The soft handover overhead data for the year 2018 of Addis Ababa 3G network is 87% average overhead, which is considerably beyond the maximum recommended value. This figure indicates the requirement to optimize the soft handover overhead using the soft handover related network parameters' configurations.

In this thesis, soft handover overhead performance of the Addis Ababa 3G network is analyzed. The spatial distribution of the overhead is visualized using data collected from the network management system. Furthermore, optimization of soft handover overhead is done through fine-tuning window add, pilot power, and electrical antenna down tilt. We apply a heuristic algorithm for the optimization considering potential sets of values for the optimization variables. Moreover, obtained results are compared with a result obtained using existing default network configuration parameters. For the sample 3G sites network simulation, we use WinProp while we also use MATLAB and Google Earth for soft handover performance analysis and visualization.

Soft handover overhead performance analysis of 5 Radio Network controllers (RNCs) shows that the Addis Ababa network is within the range of 111 to 115% for the 90^{th} percentile. Sites in RNC4 using carrier three are selected for the simulation and optimization as 5 to 21 more number of radio links used comparing with the other three carriers. After optimization, results show that soft handover overhead and network capacity are considerably improved by fine-tuning the window add, pilot power, and antenna tilt parameters. For instance, soft handover overhead is reduced from 85.4 % to 57.7% and network capacity gain by 3.76% when using window add of 2 dB, pilot power of 7.5%, and electrical antenna down tilt by 2 degrees. Soft handover overhead is reduced from 85.4 % to 46.6% and network capacity gain by 5.72% when using window add of 1.5 dB, pilot power of 5% and electrical antenna down tilt by 3 degrees.

Keywords – Soft handover, pilot power, antenna down tilt, window add, soft handover overhead, 3G, Addis Ababa, optimization

Acknowledgment

First and foremost, I would like to thank God Almighty for giving me the strength, knowledge, ability, and opportunity to undertake this thesis study and to persevere and complete it satisfactorily. Without his blessings, this achievement would not have been possible. I am also thankful for ethio telecom for providing me the opportunity to study this industry-tailored master's program.

In my journey towards this master's program, I have found a role model and a pillar of support in my guide, Dr. Beneyam Berehanu, assistant Professor, Addis Ababa Institute of Technology, Addis Ababa, Ethiopia. He has always been there providing his heartfelt support and guidance and has given me precious advice, inspiration, and suggestions in my quest for knowledge. He has given me all the freedom to pursue my research, while silently and non-obtrusively ensuring that I stay on course and do not deviate from the core of my research. Without his able guidance, this thesis would not have been possible, and I shall eternally be grateful to him for his assistance.

I want to thank the members of my thesis examiner committee Dr. Ing. Dereje Hailemariam, director for academic affairs and Dr. Ing. Yihenew Wondie, assistant Professor, Addis Ababa Institute of Technology, Addis Ababa, Ethiopia for who gave detailed insightful comments about my thesis work. The comments have helped me greatly in preparing this final version of my thesis.

Sincere thanks to radio network planning group, optimization staff, and network operation center for providing me the necessary support in my work. I acknowledge my dearest brother in Christ Senai Asefa, who facilitated the Grammarly application that helped me to identify the mistakes and suggestions for correction.

Finally, I must express my very profound gratitude to my beloved wife and to my children for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

Table of contents

List of Figures

List of Tables

Acronyms

2.5G	Second and half Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
B3G	Beyond Third Generation
BLER	Block Error Rate
BS	Base Station
BTS	Base Transceiver Station
CCCH	Common Control Channel
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CPICH	Common Pilot Channel
CS	Circuit Switched
CTCH	Common Traffic Channel
DCCH	Dedicated Control Channel
DL	Down Link
DPM	The Dominant Path Model
DS-CDMA	Direct Sequence Code Division Multiple Access
Eb/Io	Energy per bit per Interference ratio
Ec/Io	Energy per chip per Interference ratio
FACH	Forward Access Channel
FDD	Frequency Division Duplex

GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
GUI	Graphical User Interface
HLR	Home Location Register
HS-DSCH	High Speed Downlink Shared Channel
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LLD	Low Level Design
MCS	Modulation and Coding Scheme
ME	Mobile Equipment
MSC	Mobile Services Switching Centre
NP-hard	Non-deterministic Polynomial-time hardness
PCCH	Paging Control Channel
P-CPICH	Primary Common Pilot Channel
PLMN	Public Land Mobile Network
PRS	Performance Recording System
PS	Packet Switched
PSTN	Public Switched Telephone Network
QoS	Quality of Service
RAB	Radio Access Bearer
RAN	Radio Access Network
RLC	Radio Link Control
RNC	Radio Network Controller

RRC	Radio Resource Control
RRM	Radio Resource Management
SGSN	Serving GPRS Support Node
SHO	Soft Handover Overhead
SINR	Signal to Interference plus Noise ratio
TCH	Traffic Channel
TDD	Time Division Duplex
U2000	UMTS 2000
UE	User Equipment
UL	UP Link
UMTS	Universal Mobile Telecommunication Service
USIM	User Service Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
WAP	Wireless Application Protocol
WCCS	Wireless Cellular Communication System
WCDMA	Wide Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

1 Introduction

1.1 Motivation and background

Telecommunication has been in existence for ages and has undergone numerous changes in recent years, especially due to mobile communication systems. Starting from the first generation of a mobile system that supports only analog voice communication, mobile technologies have been significantly evolved to the current fifth generation (5G) system that supports full Internet Protocol (IP) advanced and diverse digital services.

UMTS (Universal Mobile Telecommunications Service) is a 3G broadband, packet-based transmission of text, digitized voice, video, and multimedia at data rates up to 2 megabits per second [28]. UMTS offers a consistent set of services to users, no matter where they are in the world [30]. UMTS network was introduced in Ethiopia in 2008, and expansion for the network was performed in 2015 [35]. The latest number of 3G's RBS (Radio Base Station) in Addis Ababa is 738 that are macros and three sectored with 7091 carriers as per the data retrieved on November 11, 2018, from the network management system.

Radio network planning and optimization has a significant impact on coverage and capacity. Optimization includes network performance measurements, analysis of the measurement results, and updates in the network configuration and parameters. It is beneficial to define those measurement results that are considered the most important ones, Key Performance Indicators (KPIs). Base station transmission power, soft handover overhead, drop call rate, and packet data delay are few of the KPIs. As described in [7], the comparison of KPIs and desired target values indicates the problem areas in the network where the network tuning can be focused.

The soft handover overhead is a common metric that is often used to quantify the soft handover activity in a network. It may also be regarded as a measure of the additional hardware/transmission resources required in 3G for the implementation of soft handover where users can be connected to two or more cells simultaneously. For instance, if there are 100 users in a 3G network where 60 of them used a link (connected to one cell), 20 of them used two links (connected to two cells) and remaining used three links (connected to three cells), the average number of links used by a user will be 1.6. Thus, users in the network are using 0.6 additional links (resources) for the implementation of the soft handover. We can say that the soft handover overhead of this network is 60%. Radio network planning is responsible for the proper handover parameter setting. The soft handover overhead is planned to be about 20–40% for a standard hexagonal cell grid with three sector sites [17].

Monitoring performance of Radio Access Bearer (RAB), which is used for information transfer and Radio Resource Control (RRC) for signaling is crucial for a telecom operator. The RAB and RRC's failure rate are the two KPIs that are being evaluated weekly by ethio telecom. The RAB's failure rate is increasing weekly as a whole and is above 2%, which is a baseline for ethio telecom for three of Radio Network Controllers (RNCs) as shown in Figure 1.1 (below). RRC's failure rate is also above the benchmark 2% except for an RNC 5 as shown in Figure 1.2.

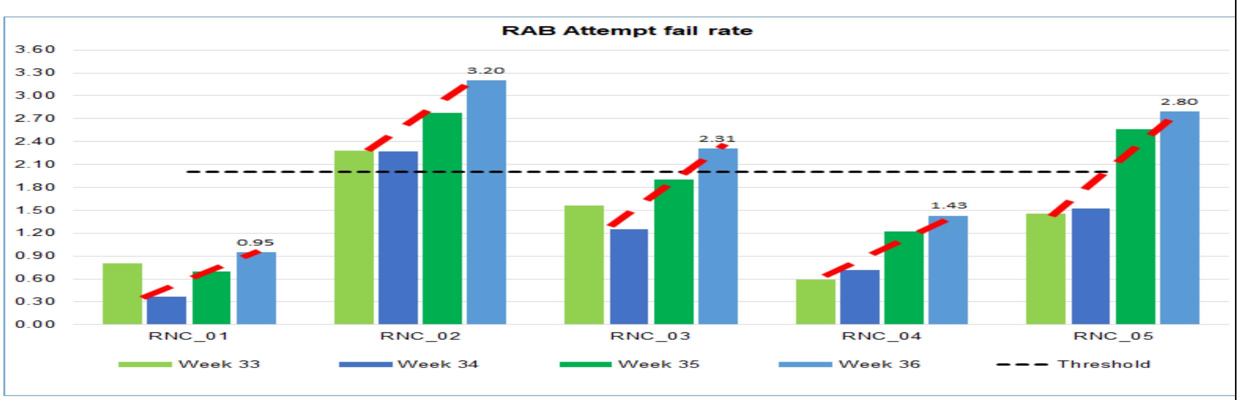

Figure 1.1 RAB attempt failure of RNCs for four weeks

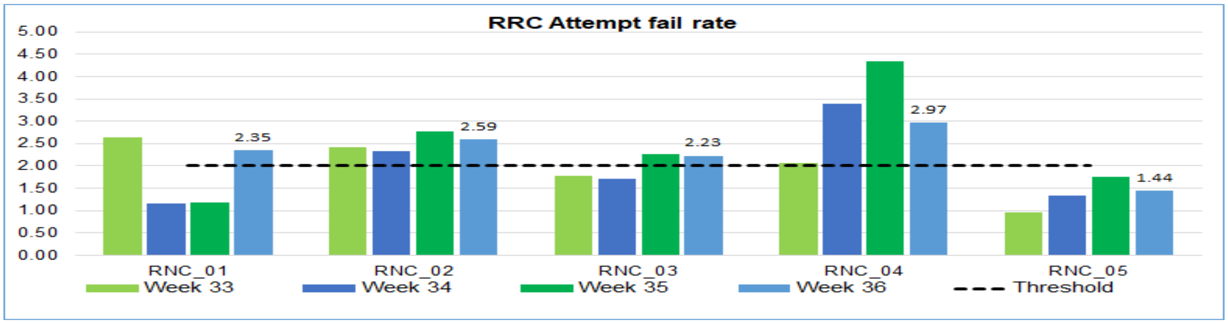

Figure 1.2 RRC attempt failure of RNCs for four weeks

1.2 Statement of the Problem

The soft handover overhead per hour for one week from Nov 19 to 25, 2018, is retrieved from network management of the operator, namely the Performance Recording System (PRS) for 15 UMTS sites. As shown in Figure 1.3, the average soft handover overhead is between 80 to 90%, and the cumulative average is 87% that is beyond the standard 20 to 40%. The monthly soft handover overhead of the 3G network in Addis Ababa for the year 2018 also confirmed the same. The RRC's and RAB 's failure rate are above the target as mentioned in section 1.1 while the additional resources allocated for soft handover 87%. Thus, Addis Ababa UMTS network has a very high soft handover overhead that significantly reduces network capacity.

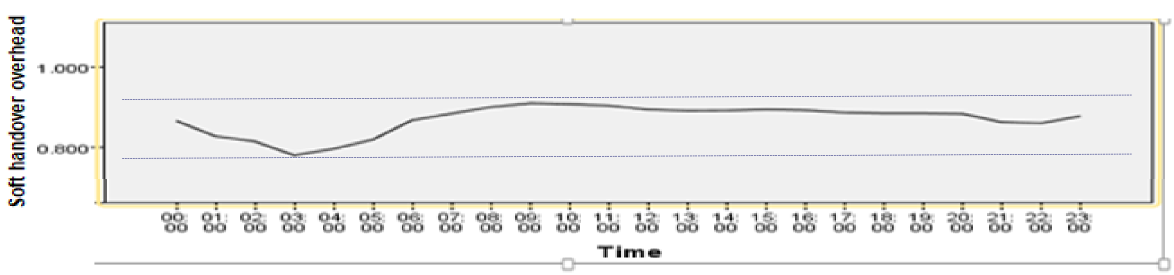

Figure 1.3 Average soft handover overhead for all sites an hourly bases

In soft handover, a User Equipment (UE) connection consists of at least two radio links established with cells belonging to different or same RBSs. Soft handover acts as macro diversity since UE is connected to more than one radio link at any given point, adds redundancy, and reduces interference. However, there is a tradeoff between soft handover and system capacity. A UE involved in soft handover uses several radio links, more Down Link (DL) channelization codes, and more DL power than a single-link connection. Consequently, if all the UEs connected to a particular RNC are considered, more resources are needed in the RBSs, over the air interfaces, and in the RNC, which contribute to network capacity reduction. For this reason, the number of radio links involved in the soft handover must be limited.

1.3 Related Works

In the Radio Access Networks (RAN), guaranteed service levels and performance management are crucial factors because of limited licensed spectrum support of cognitive mesh mobility and multimedia services. Ways to enhance the performance of RAN is by selecting appropriate network parameters and parameter optimization. In the papers reviewed, the analysis is focused on the downlink as it is seen more crucial from the soft handover point of view due to the additional link required in the downlink.

The performance of soft handover is evaluated by checking the link level indicators in [2] and [8]. In [2], enhanced search and optimization based genetic algorithm is used to optimize UMTS soft handover overhead network parameters. The authors used the proposed window add and window drop to increase capacity and control downlink transmission power. The authors set default random network parameters (window add, window drop), and they monitored performance through KPIs from the UMTS network. They compared DL transmission power, Signal to Noise Ratio (SNR), and Common Pilot Channel (CPICH) KPI's with target business service levels. Whenever UMTS network performance gets degrading, Genetic Algorithm (GA) runs to optimize soft handover and tunes the optimized predicted network parameters to the UMTS network. The authors concluded that downlink **transmission** power gets reduced with optimized simulations and results in minimization of interference with neighbor cells and an increase in the capacity of a radio access network. But the capacity gain due to reduced power is not specified.

While [8] proposed and analyzed a new finger assignment technique that is applicable for RAKE receivers when they operate in the soft handover region. This scheme employs a new version of Generalized Selection Combining (GSC). By investigating the tradeoff among the error performance, the path estimation load, and the soft handover overhead, the authors showed that the new scheme offers comparable performance while requiring a smaller estimation load and soft handover overhead. The authors focused on the receiver operation when the mobile unit is moving from the coverage area of its serving Base Station (BS) to that of a target BS. The receiver compares the received SNR with a particular target SNR, and if it is greater than or equal to target SNR, no finger reassignment is needed. Otherwise, the rake reassigns receiver fingers to the most energetic paths among the available resolvable paths. They concluded that soft handover overhead is reduced from 80% to 55% by their proposed scheme maintaining the same error rate as GSC.

Investigation of soft handover based on the resource efficiency indicators, such as the mean active set number, active set update rate, and handover delay time, is the area of research. In [3], the authors have shown the effect of soft handover parameters on the performance of Wide Code Division Multiple Access (WCDMA) cellular networks. They considered the time to trigger event1a, time to trigger event 1b, time to trigger event 1c, and maximum active cell size as the soft handover parameters. They showed through numerical results that the above settings have a decisive effect on High Speed Uplink

Packet (HSUPA). They got the uplink throughput gain of 14% with a triggering time of 2 milliseconds by reducing the maximum active set size from 3 to 2. Thus, tuning and setting appropriate values for the active set size enabled the authors to achieve higher system performance.

System level indicators are also used to evaluate the performance of soft handover. The possible indicators could be related to the quality of service, such as outage probability, call blocking probability, and handover failure rate for a given load. [14] used system and link level indicators to evaluate the soft handover performance. [14] presented the impact of different soft handover overhead parameters on UMTS network performance in an indoor environment. The measurement results indicate those relatively high thresholds for window add and drop events simultaneously with a long time to trigger for drop events are the most suitable for UMTS indoor environment due to the lack of multipath diversity, and to combat fast deep fluctuations of the indoor radio channel. The measurements were conducted for the combination of various soft handover static and dynamic parameters. The authors concluded that with [6dB 9dB] thresholds for window add and drop events and with [160ms 1280ms] the time to trigger values, the smallest signal to interference ratio (SIR) target, and downlink transmission powers is achieved.

Resource efficiency, system, and link level indicators to evaluate the soft handover performance can be used. In WCDMA networks, CPICH signals are used by mobile terminals for channel quality estimation, cell selection, and handover. The strength of the CPICH signal determines the coverage area of the cell, impacts on the network capacity, and the quality of service. The more power spent on pilot signals, the better the coverage obtained. On the other hand, a higher value of the pilot power level in a cell means higher pilot pollution in the network and less power available to serve user traffic in the cell.

[15] presented a model for pilot power optimization that allows them to study the effect of various soft handover probability and coverage degree levels. The authors used a WCDMA network based on a planning scenario for the city of Berlin. In the authors' model, two control parameters considered, which are the minimum required traffic coverage degree and the soft handover probability. They used a heuristic algorithm to find a feasible solution due to the problem is NP-hard. They could reduce pilot power consumption by a slight decrease in the degree of coverage. On the other hand, ensuring a certain degree of soft handover probability affected strongly the coverage, which increased the cell overlapping areas in the network. Finally, the author concluded that the higher the soft handover probability in the system is, the less is the power saving effect of weakening the coverage constraint.

[6] used resource efficiency and system level indicators to evaluate soft handover performance. The authors showed the performance of a cellular network could be increased with the proposed adaptive soft handoff algorithm. The algorithm dynamically calculated the soft handover margin based on the received signal strength and distance. The performance was evaluated in terms of active set update rate, active cell set size, soft handover region, and the probability of outage. The authors could decrease the active set update rate by increasing the soft handover margin and concluded that the proposed algorithm is effective.

Most of the researches focused on optimizing either of the network capacity or soft handover related parameters without using the real network configurations. In most of the telecom operators, tuning of the pilot power and antenna tilting are used in case of pilot pollution occurrence, which contributed to interference and for coverage improvement.

1.4 Objective

1.4.1 General Objective

The ultimate goal of this thesis work is to analyze and improve soft handover overhead performance of a UMTS network.

1.4.2 Specific Objectives

The thesis addresses the following specific objectives:

- ✓ Collecting soft handover performance data from the network management system.
- ✓ Identifying relevant metrics to analyze the performance of UMTS soft handover.
- ✓ Show soft handover overhead performance of all 3G sites in Addis Ababa using Google earth.
- ✓ Selecting sample 3G sites to work on the improvement of soft handover overhead and network capacity.
- ✓ Analyzing and presenting obtained results of soft handover overhead and network capacity by tuning soft handover related parameters that are window add, pilot power and electrical antenna down tilt.

1.5 Methodology

There are five phases to comprehend the completion of this thesis, as shown in Figure 1.4. In the first phase, related works to soft handover overhead are reviewed. In the second phase, the necessary performance data and configuration parameters are collected from the network management system. In the third phase, the analysis and selection of the sample sites for simulation using WinProp.

Validation of the performance of soft handover overhead and finding near optimal solutions for soft handover overhead and capacity is done in phase four. The conclusion and recommendation will be the last. WinProp network simulation software is used for simulation of the selected sites. WinProp is a software suite ideally suited for propagation modeling in different environments (rural, urban, indoor) and with outstanding features for Second Generation (2G)/Second and half Generation (2.5G), 3G, LTE, WLAN, and WiMAX radio network planning [23]. MATLAB is also used for plotting figures and result presentations.

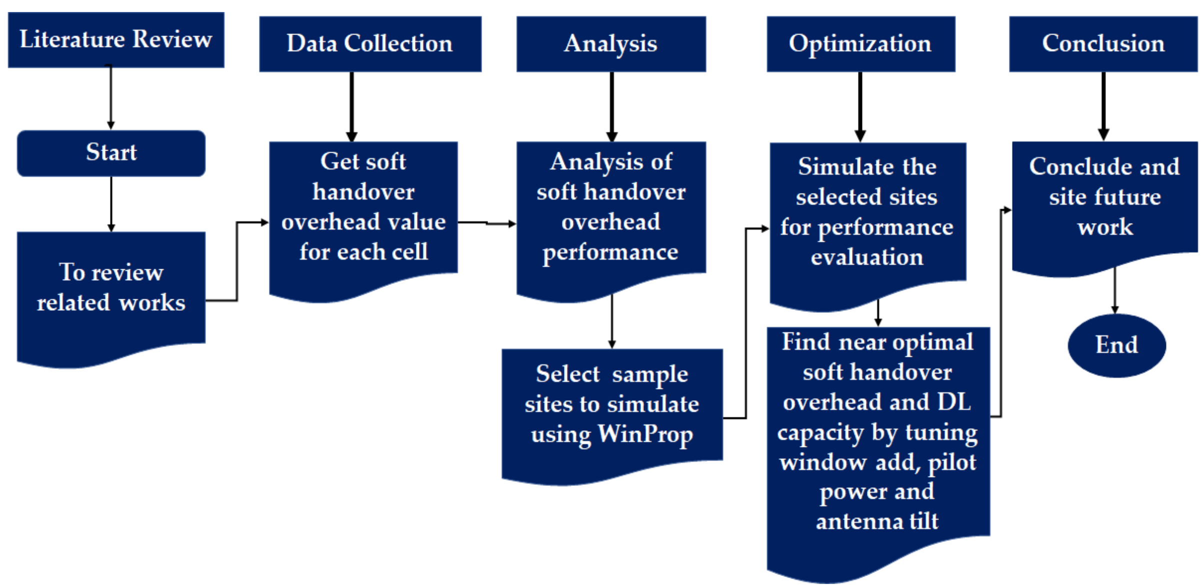

Figure 1.4 Methodology

1.6 Scope and limitation

1.6.1 Scope

The thesis is focused on UMTS technology. 3G sites in Addis Ababa are used to analyze soft handover overhead performance. Three soft handover tuning parameters window add, pilot power, and electrical antenna down tilt are used to find near optimal solutions of soft handover overhead and downlink network capacity.

1.6.2 Limitation

As with most studies, the design of the current study is subject to limitations. The flexibility of simulation work has been limited due to the WinProp simulation software is mainly used for planning of radio network. Furthermore, the generalizability of the results is limited by the number of simulations run to find near optimal solutions.

1.7 Contributions

Network parameter selection and optimization techniques are key in improving the performances of a mobile network so that due attention should be given. These techniques are very important as an operator without requiring additional investment. Soft handover overhead performance evaluation and analysis is one of the contributions in this work. This thesis work also contributes by providing insight method of optimizing soft handover overhead and network capacity simultaneously using window add, pilot power, and electrical antenna tilt parameters. In general, soft handover overhead is reduced from 85.4 % to 46.6% and network capacity gain by 5.72% when using window add of 1.5 dB, pilot power of 5% and electrical antenna down tilt by 3 degrees.

1.8 Thesis outline

The remaining part of the thesis is organized into six chapters. The handover in UMTS technology, which includes background on UMTS is presented in Chapter 2. Analysis and distribution of the soft handover overhead for the Addis Ababa UMTS network are described in Chapter 3. In Chapter 4, the soft handover overhead trade off, optimization parameters, and optimization approach are discussed.

System modeling, assumptions, scenarios for selected area details, description of the tools, and parameters for the simulation are discussed in Chapter 5. In Chapter 6, the detailed result of the simulation and compared the near optimal solutions for soft handover overhead and capacity gains between different scenarios are described. Finally, Chapter 7 concludes and gives insight into future works.

2 Handover in UMTS

2.1 Background on UMTS

2G systems like Global System for Mobile Communication (GSM) were initially designed for efficient delivery of voice services. UMTS networks are, on the contrary, designed from the beginning for flexible delivery of any service. In addition to the flexibility, the WCDMA radio solution brings advanced capabilities that enable new services [17]. Such capabilities are:

- ✓ Practical bit rates are up to 384 kbps initially, and beyond 2 Mbps with Release 5;
- ✓ Low delays with packet round trip times below 200 milliseconds;
- ✓ Seamless mobility also for packet data applications;
- ✓ Quality of Service (QoS) differentiation for high efficiency of service delivery;
- ✓ Simultaneous voice and data transmission capability; and
- ✓ Interworking with existing GSM/ General Packet Radio Service (GPRS) networks.

WCDMA is a wideband Direct-Sequence Code Division Multiple Access (DS-CDMA) system where UE's information bits are spread over a wide bandwidth by multiplying the user data with quasi-random bits (called chips) derived from CDMA spreading codes [5]. The use of a variable spreading factor and multi connections are supported to provide very high bit rates (up to 2 Mbps). The chip rate of 3.84 Mega chips per second leads to a carrier bandwidth of approximately 5 MHz. Subject to his operating license, a network operator can deploy multiple 5 MHz carriers to increase capacity, in the form of hierarchical cell layers.

WCDMA supports variable user data rates, which enables the concept of obtaining Bandwidth on Demand (BoD) is well supported [17]. The user data rate is kept constant during every ten milliseconds frame. However, the data capacity among users can change from frame to frame. This fast radio capacity allocation will typically be controlled by the network to achieve optimum throughput for packet data services.

WCDMA supports two basic modes of operation [31] that are Frequency Division Duplex (FDD) and Time Division Duplex (TDD). In the FDD mode, separate 5 MHz bandwidth carrier frequencies are used for the uplink and downlink. Whereas in TDD, only one 5 MHz is shared between the uplink and downlink.

2.1.1 UMTS Architecture

UMTS network composed of three main parts UE, Radio Access Network (RAN), and Core Network (CN) as shown in Figure 2.1. UE is composed of Mobile Equipment (ME) and USIM (User Service Identity Module). RAN is composed of NodeB and RNC. CN is comprised of circuit switched (CS) and packet switched (PS) functional modules. For CS operations Mobile Services Switching Centre (MSC) and Gate way Mobile Services Switching Centre (GMSC) along with database modules such as Visitor Location Register (VLR), Home Location Register (HLR) will be available. For PS operations, Serving GPRS Support Node (SGSN) and Gate way Serving GPRS Support Node (GGSN) will serve the purpose. GMSC is connected to Public Switched Telephone Network (PSTN)/Integrated Services Digital Network (ISDN) in the CS case, while GGSN is connected to a Packet Data Network (PDN) for PS cases.

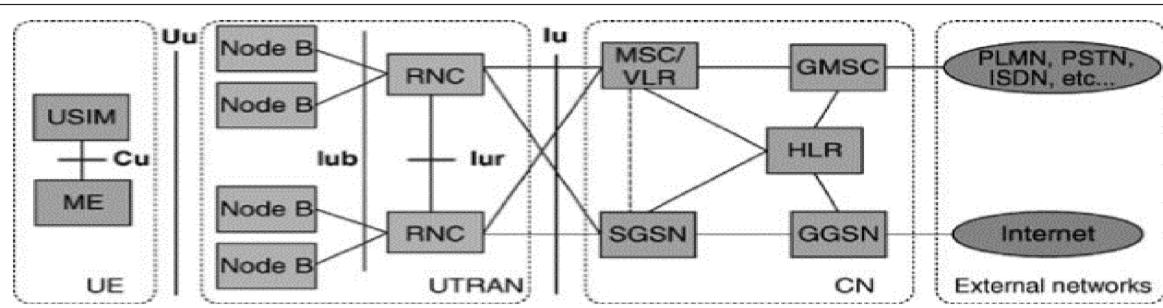

Figure 2.1 Network Elements in PLMN [17]

The function of USIM is to hold the subscriber identity, perform authentication algorithms, and store authentication and encryption keys and some subscription information that is needed at the terminal. ME is used for radio communication over the Uu interface. Node B converts the data flow between the Iub and Uu interfaces and participates in radio resource management. RNC owns and controls the radio resources of Node Bs connected to it and access point for all services that UMTS Terrestrial Radio Access Network (UTRAN) provides for the CN.

HLR is a database located in the user's home system that stores the master copy of the user's service profile. The UE is served for the circuit switched through MSC and VLR, which holds a copy of the visiting user's service profile. If there is a need to connect a UE to external CS networks, GMSC is used as a gateway. SGSN's functionality is similar to that of MSC/VLR but is typically used for PS services. And GGSN**'s** feature is close to that of GMSC but is concerning PS services.

There are primary open interfaces in UMTS which are Cu, Uu, Iu, Iur and Iub. Cu is the electrical interface between the USIM smartcard and the ME, and Uu the interface through which the UE accesses the fixed part of the system. Iu connects UTRAN to the CN, and Iur is the interface that allows soft handover between RNCs. Iub connects Node B and an RNC.

2.1.2 UMTS radio interface protocol and channels

The radio interface is layered into three protocol layers as shown in Figure 2.2. The main functions of a physical layer (L1) are 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 [33].

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.

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 an 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).

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, the transmission of BMC message to UE and delivery of cell broadcast messages to the upper layer

Layer 3 consists of RRC that is responsible for the 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 [34].

The physical layer structures naturally relate directly to the achievable performance issues when observing a single link between a mobile and a base station. Usually, it is essential to have low SIR requirements for sufficient link performance with various coding and diversity solutions in the physical layer as the physical layer defines the fundamental capacity limits. The 3G systems are wideband from the service point of view as well. The physical layer offers services to the MAC layer via transport channels that were characterized by how and with what characteristics data is transferred. The MAC layer, in turn, provides services to the RLC layer using logical channels.

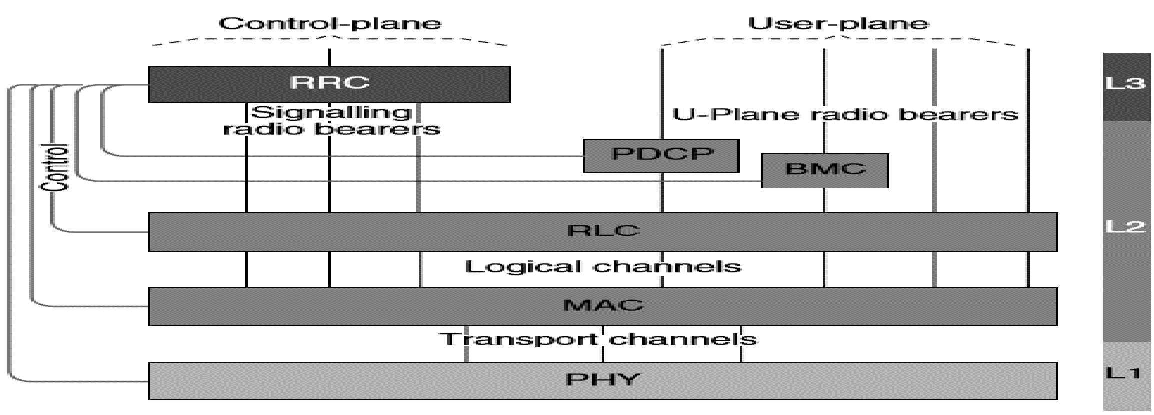

Figure 2.2 UTRA FDD Radio Interface protocol architecture [17]

The logical channels are characterized by what type of data is transmitted. The logical channel offers data transfer services at the MAC layer and is classified as Control Channels (CCHs) and Traffic Channels (TCHs). CCHs are used for the transfer of signaling information, and TCHs are used for the transfer of user data.

CCHs are:

- ✓ **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)**: transmits dedicated control information between the network and a UE.

TCHs are categorized 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): used for the transfer of dedicated user information for all UEs or a group of specified UEs.

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. Common transport channels are:

- ✓ **Broadcast Channel (BCH)**: is used to transmit information specific to the UTRA network or 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.

2.1.3 Radio Resource Management

Radio Resource Management (RRM) is responsible for the efficient utilization of air interface resources. RRM is needed to guarantee QoS, to maintain the planned coverage area, and to offer high capacity [17]. The family of RRM algorithms can be divided into handover, power, admission, load control, and packet scheduling functionality.

- ✓ Power control: is needed to keep the interference levels at a minimum in the air interface and to provide the required quality of service.
- ✓ Handovers: are needed in cellular systems to handle the mobility of the UEs across cell boundaries.
- ✓ Admission control: Before admitting a new UE, admission control needs to check that the admittance will not sacrifice the planned coverage area or the quality of the existing connections.
- ✓ Load control: If the overload is encountered, the load control functionality returns the system quickly and controllably back to the targeted load, which is defined by the radio network planning
- ✓ Packet scheduling: The radio access algorithms for supporting packet switched services and analyses their performance. Such services are, for example, messaging, email, WAP/web browsing, streaming video or Voice over IP.

Typical locations of the RRM algorithms in a WCDMA network are shown in Figure 2.3.

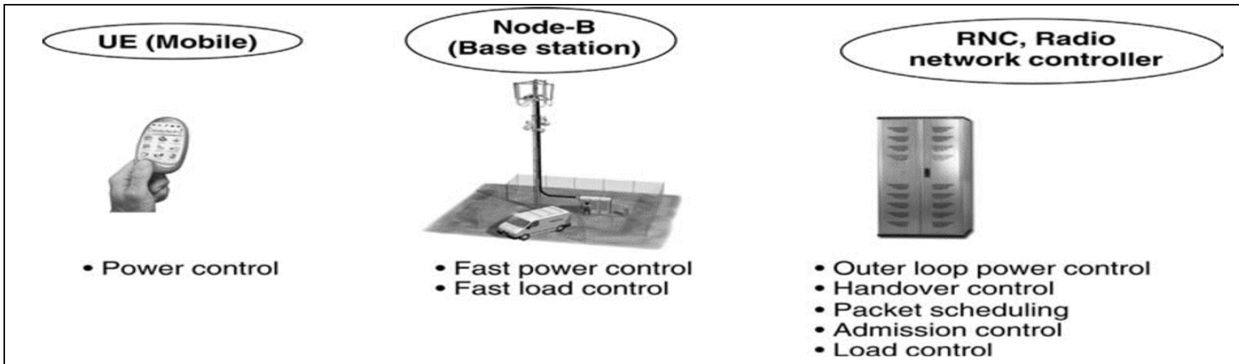

Figure 2.3 Locations of RRM algorithms in a WCDMA network [17]

2.2 Handover

One of the major characteristics that made wireless cellular communication system (WCCS) essential is mobility. Handover is the process of achieving continuous service as a user moves between cells. Handover is needed during cell crossing or/and signal quality degradation in the current cell. Phases of handover are discovery, decision, and execution. Network discovery finds an appropriate network that satisfies user desired QoS. The decision phase is the phase when the handover should take place (also known as a handover initiation phase). The execution phase corresponding to the mobile connection to the target cell. These phases determine the seamlessness of the handover. Wrong time of initiation leads to unnecessary handover or call drop rate is increased and thereby result in poor QoS. Different factors are considered to classify the handover as described in [1]:

- ✓ Access technology: Handover is classified as horizontal, and vertical handover, which is a handover between BS’s of the same and different network technology respectively.

- ✓ Type of technology that the system supports: Handover is classified as hard and soft handover. Hard handover where the serving station is released before new resources can be committed. Soft handover where a connection is established before breaking away from the old cell.
- ✓ Initiating and assisting entities: The handover is classified depending on either a user or network initiates and controls the handover process.

Some of the commonly used parameters to execute handover are Received Signal Strength Indicator (RSSI), SNR, distance, velocity, network coverage, delay of transmitting data, the power consumption of a user, etc. The effect of handover in mobile communication is enormous. An ineffective handover leads to problems such as poor utilization of bandwidth, system overload, call blocking, call termination, packet loss, and poor QoS. We focus on soft handover whose classification is from referring to the type of technology that is UMTS.

2.3 Soft/softer handover

During softer handover, a mobile station is in the overlapping cell coverage area of two adjacent sectors of a base station as shown in Figure 2.4. The communications between the mobile station and base station take place concurrently via two air interface channels, one for each sector separately. These air interface channels require the use of two separate codes in the downlink direction so that the mobile station can distinguish the signals. The two messages are received in the mobile station using rake processing, very similar to multipath reception. But the fingers need to generate the respective code for each sector for the appropriate despreading operation [17].

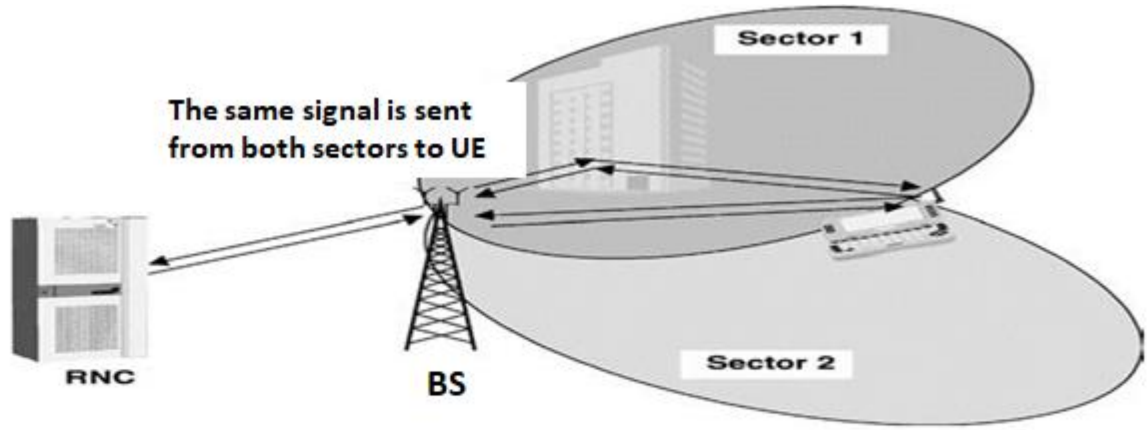

Figure 2.4 Softer handover [17]

In the uplink direction, a similar process takes place at the base station. The code channel of the mobile station is received in each sector, then routed to the same baseband rake receiver, and the maximal ratio combined. During softer handover, only one power control loop per connection is active. Softer handover typically occurs in about 5–15% of links [17].

During soft handover, a mobile station is in the overlapping cell coverage area of two sectors belonging to different base stations as shown in Figure 2.5. As in softer handover, the communications between mobile station and base station take place concurrently via two air interface channels from each base station separately. As in softer handover, both channels (signals) are received at the mobile station by maximal ratio combining rake processing. Seen from the mobile station, there are very few differences between softer and soft handover [17].

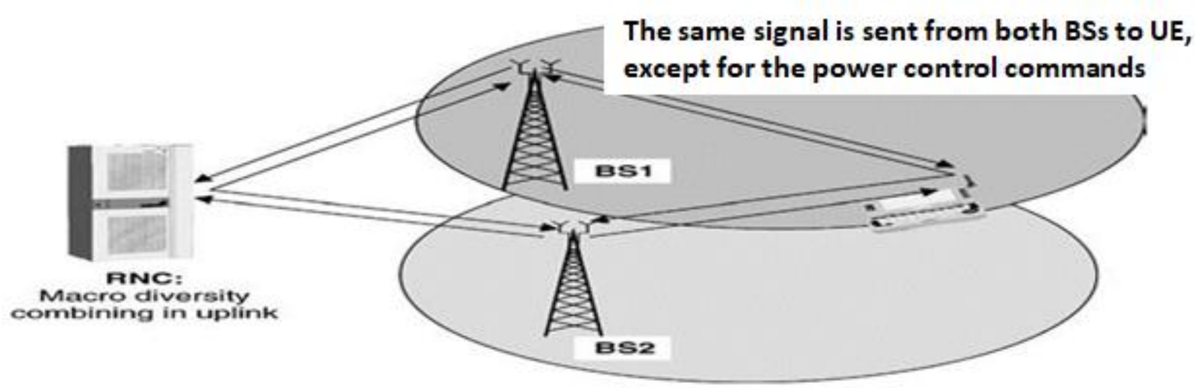

Figure 2.5 Soft handover [17]

However, in the uplink direction, soft handover differs significantly from softer handover. The code channel of the mobile station is received from both base stations, but the collected data is then routed to the RNC for combining. The same frame reliability indicator such as Cyclic Redundancy Check (CRC) as provided for outer loop power control is used to select the better frame between the two possible candidates within the RNC. Note that during soft handover, two power control loops per connection are active, one for each base station. Soft handover occurs in about 20–40% of connections [17]. To cater for soft handover connections, additional resources are needed. These are additional rake receiver channels in BSs, transmission links between BS and RNC, and rake fingers in UE.

2.3.1 Soft Handover Algorithm

The soft handover uses CPICH Energy per chip to Interference power ratio (Ec/Io) typically as the handover measurement quantity, which is signaled to RNC. The active and monitored set is used in the handover description. The active set is the cells in the active set form a soft handover connection to the UE. The monitored set is the list of cells that the UE continuously measures, but whose CPICH Ec/I0 are not strong enough to be added to the active set.

The soft handover algorithm is shown in Figure 2.6 and is described as follows:

- ✓ If Pilot_Ec /I0 > Best_ Pilot_Ec/I0 - Reporting range + Hysteresis_event1A for a period of ΔT and the active set is not full, the cell is added to the active set. This event is called Event 1A or Radio Link Addition
- ✓ If Pilot_Ec /I0 < Best_ Pilot_Ec/I0 - Reporting_range - Hysteresis_event1B for a period of ΔT, then the cell is removed from the active set. This event is called Event 1B or Radio Link Removal.

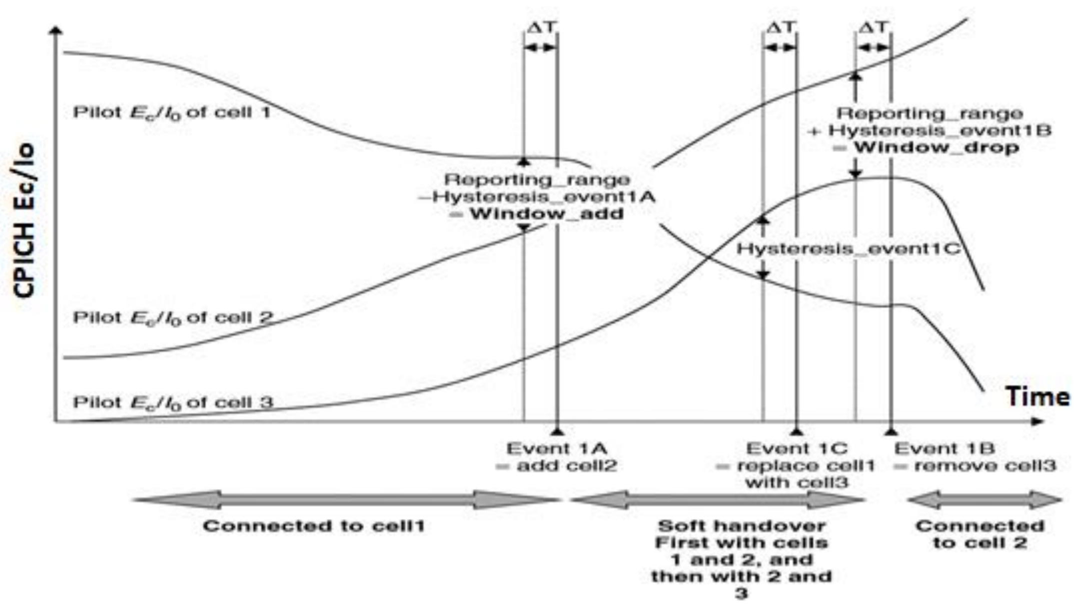

Figure 2.6 WCDMA soft handover algorithm [17]

- ✓ If Best_candidate_Pilot_Ec /I0 > Worst_Old_Pilot_Ec /I0 + Hysteresis_event1C for a period of ΔT and active set is full and, then the weakest cell in the active set is replaced by the most reliable candidate cell in the monitored set. This event is called Event 1C or combined radio link addition and removal. The maximum size of the active set depends on the vendor's technology.

- ❖ Reporting_range is the threshold for soft handover.
- ❖ Hysteresis_event1A, event1B, and event1C are the addition, removal, and replacement hysteresis respectively.
- ❖ Reporting_range - Hysteresis_event1A is also called Window add.
- ❖ Reporting_range + Hysteresis_event1B is also called Window drop.
- ❖ ΔT is the time to trigger
- ❖ Best_ Pilot_Ec/I0 is the strongest measured cell in the active set.
- ❖ Worst_Old_Pilot_Ec/I0 is the weakest measured cell in the active set.
- ❖ Best_candidate_Pilot_Ec/I0 is the most robust measured cell in the monitored set.
- ❖ Pilot_Ec /I0 is the measured and filtered quantity.

2.3.2 Soft handover gain

The primary purpose of soft handover is to provide seamless handover and added robustness to the system. Soft handover is mainly achieved via three types of gain provided by the soft handover mechanism:

- ✓ Macro diversity gain: A diversity gain over slow fading and sudden drops in signal strength due to, e.g., UE movement around a corner.
- ✓ Micro diversity gain: A diversity gain over fast fading.
- ✓ Downlink load sharing: A UE in soft handover receives power from multiple Node Bs.

2.3.3 Soft handover overhead

The soft handover overhead is a standard metric, which often is used to quantify the soft handover activity in a network. Equation (2.1) is used to define soft handover overhead in [17] while Equation (2.2) in [26].

$$\sum_{n=1}^{M_{active}} nP_n - 1 = \frac{\sum_{i=1}^{X} P_{1i} + \sum_{i=1}^{X} 2.P_{2i} + \sum_{i=1}^{X} 3.P_{3i}}{X} - 1 \tag{2.1}$$

$$\left(\sum_{n=1}^{M_{active}} nAn \Big/ \sum_{n=1}^{M_{active}} An \right) - 1 \tag{2.2}$$

Where

- ✓ M_{active} is the number of maximum active set size.
- ✓ P_{1i} ,P_{2i} and P_{3i} is the probability of a UE being connected to one cell, two cells and three cells respectively.
- ✓ An is the number of UEs who are being in n way soft handover. Thus, n is 1, 2, and 3 if the UE is being connected with one cell, two cells, and three cells respectively.
- ✓ X, is the total number of UEs in one way, two way, and three-way soft handover respectively.

Each connection between a UE and Node B requires logical baseband resources, reservation of transmission capacity over the Iub, and RNC resources. Thus, the soft handover overhead may also be regarded as a measure of the additional hardware/transmission resources required for the implementation of soft handover.

The formulas are elaborated below by considering a network that supports 100 users with below assumptions:

- ✓ The probability of a user's connection to one cell, two cells and three cells is 0.5, 0.25 and 0.25 respectively.
- ✓ A maximum active set size (Possible number of connections in a network by a user) is 3.

The soft handover overhead of the network is calculated as follows using Equation 2.1:

$$=\frac{\sum_{i=1}^{100} 0.5+\sum_{i=1}^{100} 2.0.25+\sum_{i=1}^{100} 3.0.25}{100} - 1 = \frac{(100*0.5)+(100*2*0.25)+(100*3*0.25)}{100} - 1 = \frac{(50)+(50)+(75)}{100} - 1 = 0.75$$

Thus, the soft handover overhead of the network will be 75%.

Let us assume that 50, 25 and 25 users are connected to one cell, two cells and three cells respectively. Then the soft handover overhead is calculated as follows:

$$\left(\sum_{n=1}^{3} nAn / \sum_{n=1}^{3} An \right) - 1 = (((1*50) + (2*25) + (3*25))/(50+25+25)) - 1 = 0.75$$

Thus, the soft handover overhead of the network will be 75%. In other words, on average, the number of radio links assigned to a user in the network is 1.75.

As per [17], the soft handover overhead can be controlled by:

- ✓ Proper selection of the parameters Window add, Window drop, pilot power, and the maximum active set size.
- ✓ The network topology (site location relative to each other, number of sectors per site).
- ✓ Node B antenna radiation patterns.
- ✓ The path loss and shadow fading characteristics.

As an example, the soft handover overhead versus window add from [17] is shown in Figure 2.7 for a standard hexagonal cell grid with three sector sites and a maximum active set size of three. It is observed that the soft handover overhead increases approximately linearly when Window add and Window drop are increased. For the same soft handover parameter settings, the soft handover overhead is typically more significant for the scenario with small cells, compared to large cells.

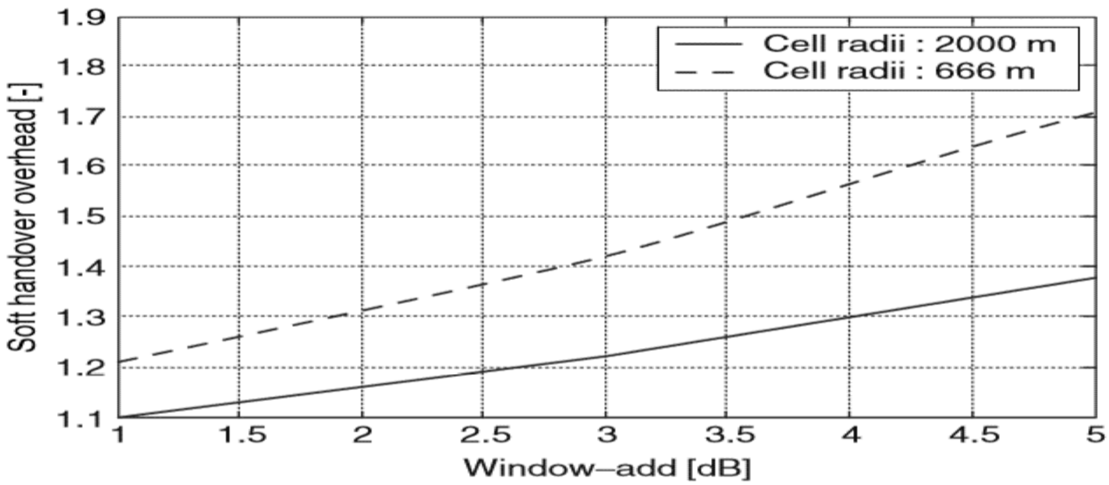

Figure 2.7 The soft handover overhead versus the Window add

3 Soft handover overhead performance

In the deployed UMTS network of Addis Ababa, there are 5 RNCs which controls 735 sites with one, two, three, and four carriers per cell. Recently up to five carriers are used for 3G sites in Addis Ababa. Each site is three sectored, and there are a total of 2205 cells in the network with overall carriers of 7088. The soft handover overhead is obtained for each carrier using Equation (2.2). The performance of the soft handover overhead is evaluated for all carriers under each cell. The details of the carriers are shown in Table 3.1.

Table 3.1 Carriers detail

Carrier	Carrier ID	Frequency (MHz)	
		DL	UL
1	10588	2117.5	1927.5
2	10613	2122.5	1932.5
3	10663	2132.5	1942.5
4	10688	2137.5	1947.5

3.1 A spatial plot of soft handover overhead

The 3G sites are divided into five areas, and each area is controlled by one RNC as shown in Figure 3.1.

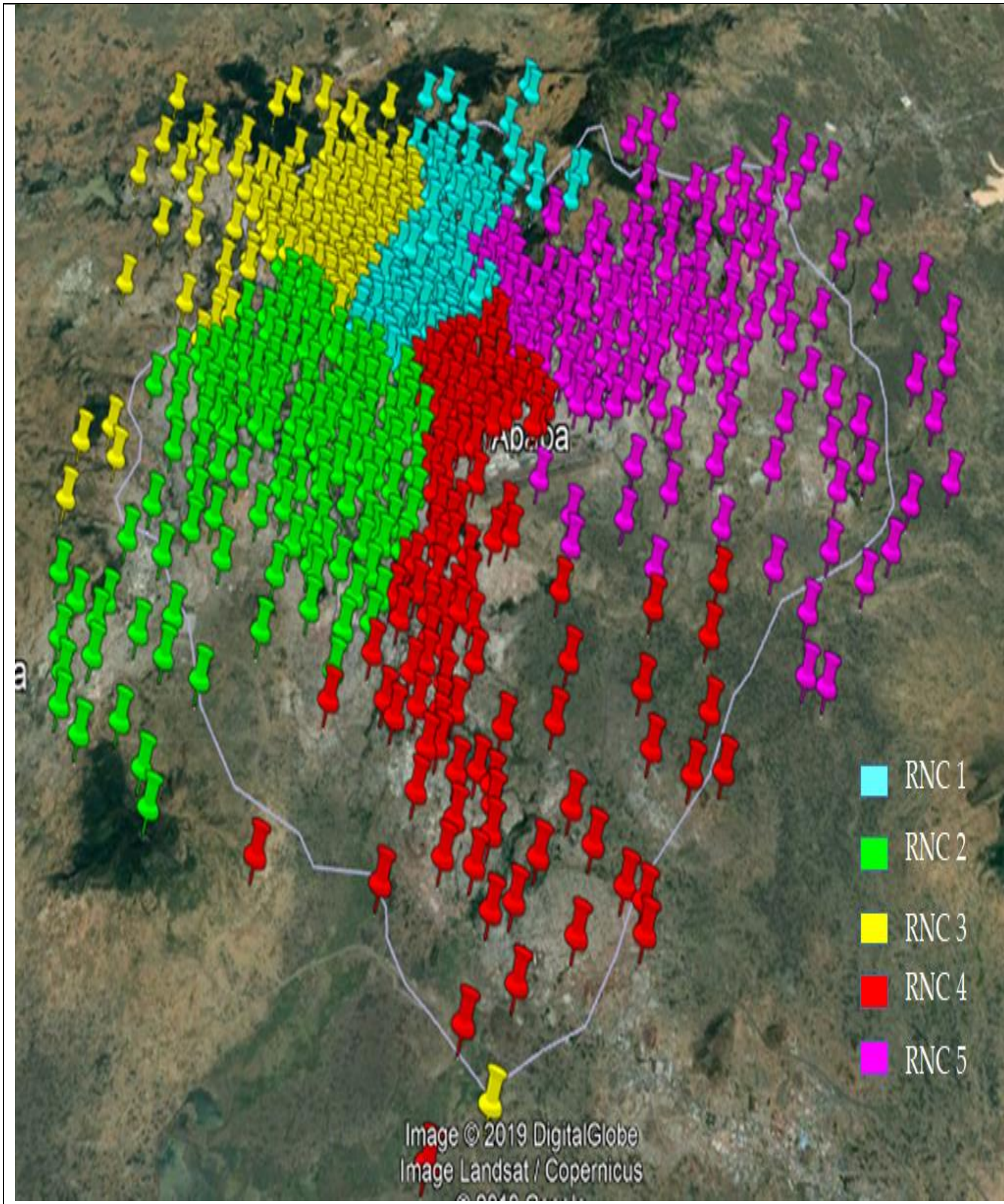

Figure 3.1 3G sites in Addis Ababa

Sites which are within the range of recommended soft handover overhead value (20 to 40%) is only 1.83%. Almost 97% of the sites' soft handover overhead is beyond the recommended value. Thus, most of the UEs are using the extra resources, which contributes to the inefficient usage of the network capacity.

Soft handover overhead values spatial plot are shown across 3G sites in Addis Ababa using Google earth. The spatial plot for the sites under RNC1 is shown here in Figure 3.2, while the others are found in the Appendix. Soft handover overhead of about 88% of sites under RNC1 is above 60%.

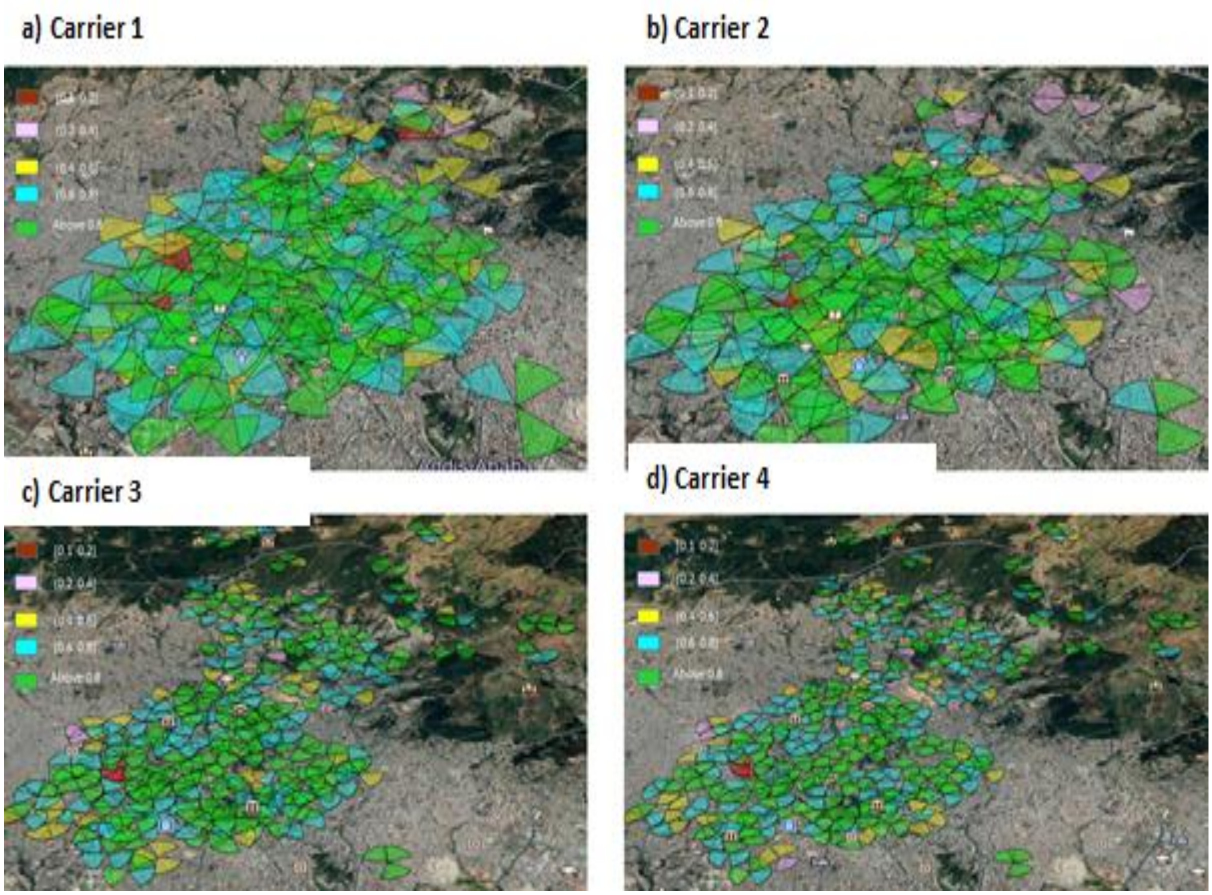

Figure 3.2 Soft handover overhead spatial plot for sites under RNC 1

3.2 Analysis of the Soft handover overhead

A certain number of places to be selected depending on the performance of the soft handover overhead (SHO). Cumulative Distribution Function (CDF) is used to evaluate the performance and selection of sample sites. Sites in RNC 3 and 5 are with soft handover overhead of 114 and 115% for the 90th percentile respectively. However, RNC 4 with 112% is considered for further analysis as configuration parameters of the sites under RNC 3 and 5 could not be found. The details are shown in Figure 3.3.

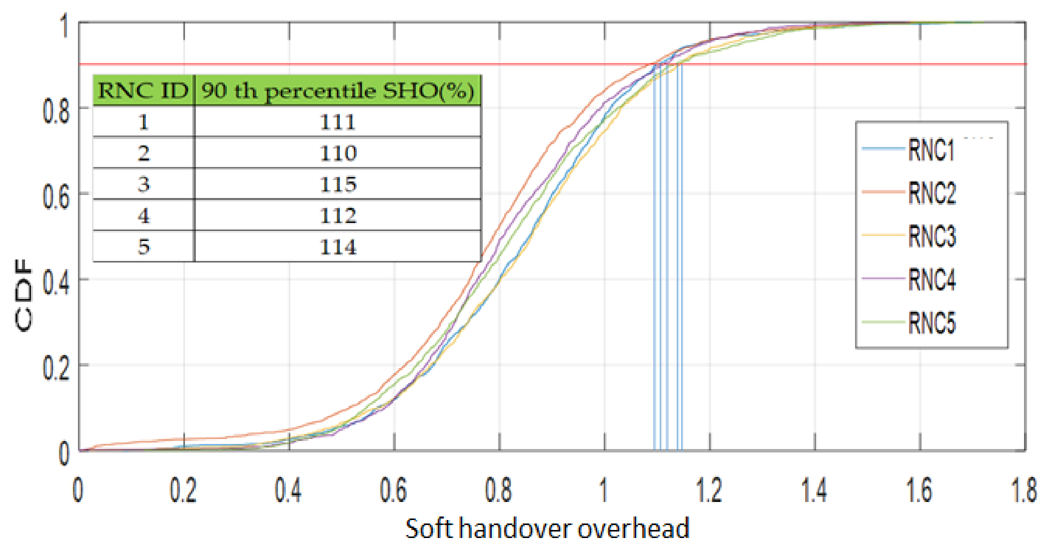

Figure 3.3 CDF for soft handover overhead of the 5 RNCs

One hundred twenty nine sites are controlled by RNC 4 and used 1335 carriers in total. Soft handover overhead for the two carriers (1 and 2) is 113% for the 90th percentile while 110% for the remaining two carriers as shown in Figure 3.4.

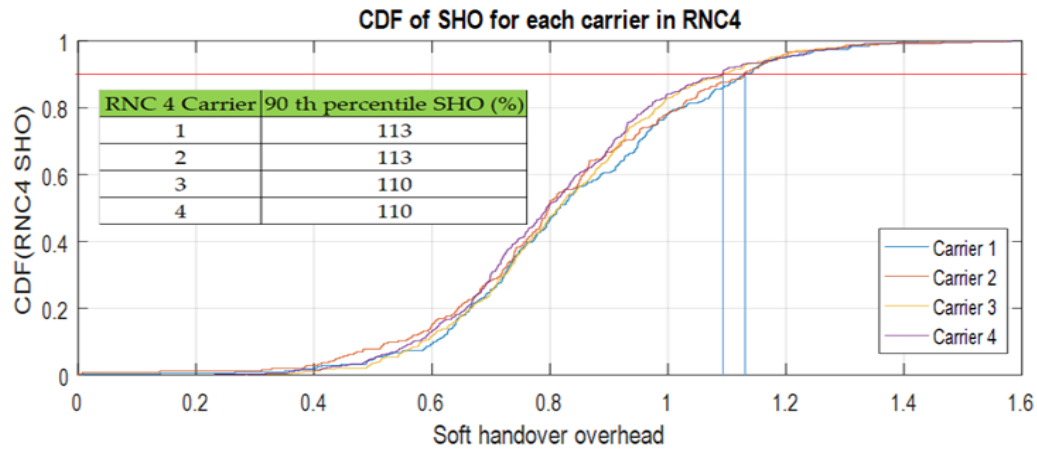

Figure 3.4 CDF for soft handover overhead of carriers in RNC4

The number of radio links that are used per cell for each carrier is also considered for the selection of the carrier to be used during the simulation. 90th percentile of the radio links is 51 for carrier 3, and the others used a smaller number of links as shown in Figure 3.5. So, the sample area of sites in RNC4, which are using carrier three is selected for the simulation and work on optimization.

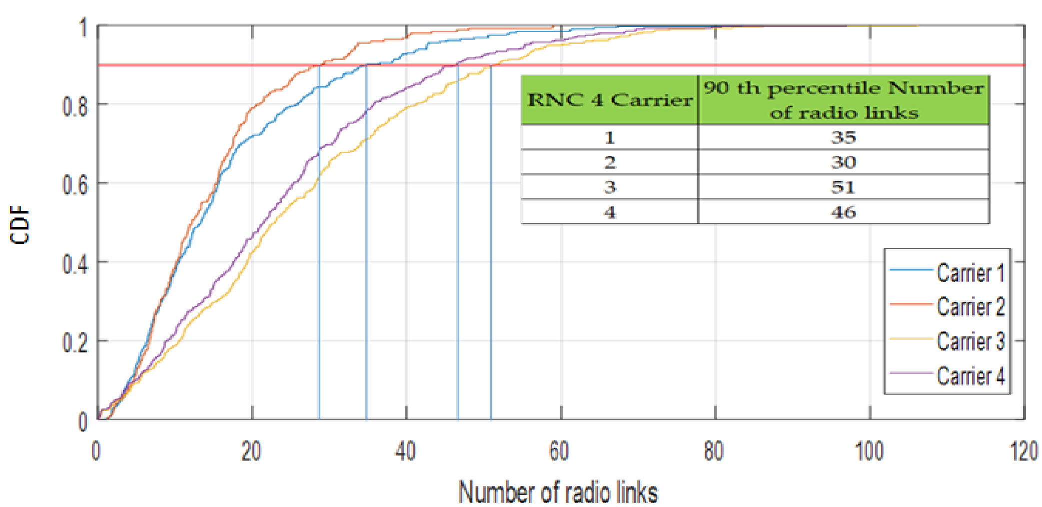

Figure 3.5 CDF for radio links of carriers in RNC4

4 Soft handover overhead optimization

Soft handover overhead should be kept within reasonable limits to save the downlink traffic capacity of the cell [17]. The usual fair or maximum acceptable soft handover overhead value in WCDMA is 20–40%. Thus an average of 1.2 to 1.4 radio links is recommended to be used per a UE connection. This target is a value for a mature network. The target value is partly based on hardware requirements [17] like to prevent running out of codes. Besides, it is essential to optimize the hand over performance for high and effective utilization of radio resources. High overhead is generally not such a big problem for the uplink [18]. In the uplink direction, the power from the UE can be slightly increased owing to non-optimal handover conditions. For the downlink, however, reaching an optimal overhead value is more important [18].

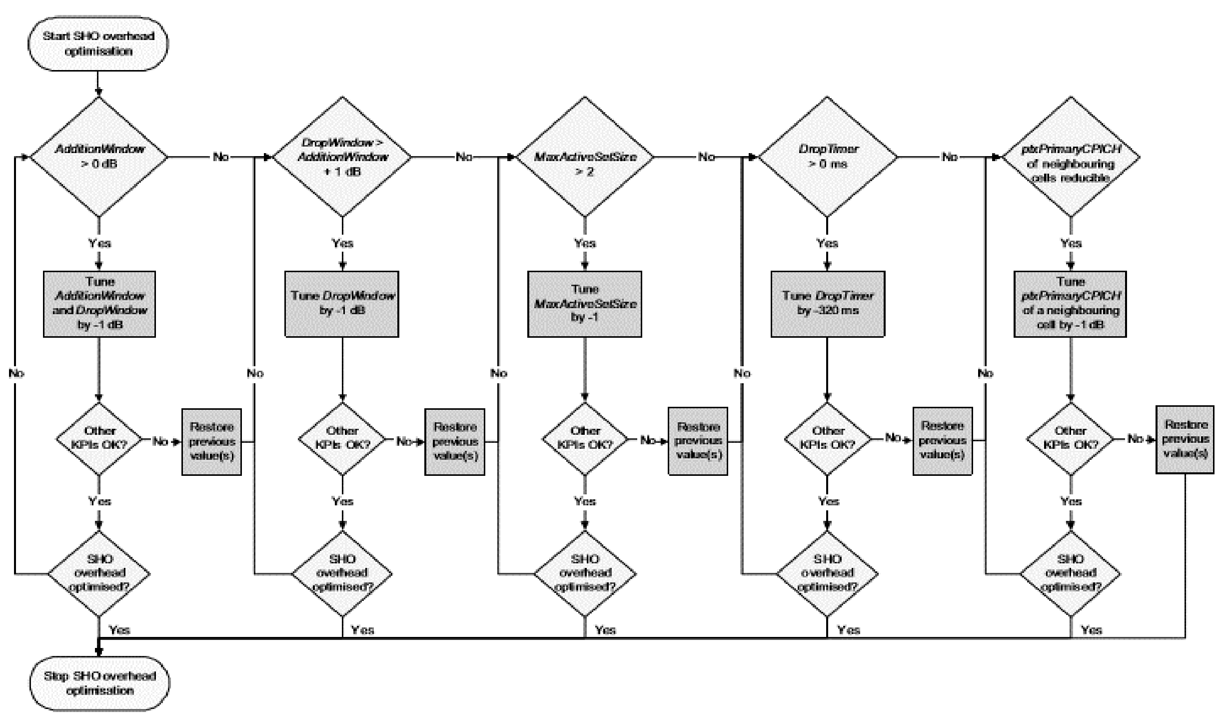

Figure 4.1 Optimization of soft handover overhead [18]

The most critical parameters for optimizing the soft handover overhead are window add, window drop, maximum active set size, antenna tilt, and P-CPICH transmission power (pilot power) [21]. The flow chart of optimizing the soft handover overhead is as shown in Figure 4.1 using the tuning parameters mentioned above. However, trade off to be considered in optimizing the soft handover overhead like capacity, coverage, and required SINR for the services to be used by a UE.

4.1 Soft handover overhead optimization parameters

The window add determines the relative difference of the cells CPICH Ec/Io at the UE end that are to be included in the active set. The window add must be optimized so that only the relevant cells are in the active set. A window add that is either too large or too small will result in a reduced capacity. To high window add will result in reduced downlink capacity and increase of soft handover overhead while reduced uplink capacity in case of low window add.

Window drop is set relative to the window add. The hysteresis is a couple of decibels, meaning that the drop window is slightly larger than the window add. If the drop window is too large, the wrong cells stay in the active set, resulting in reduced uplink and downlink capacity. If the drop window is too small, a frequent handover that degrades the capacity, and the hand over related signaling is increased.

The impact of a too sizeable active set is in a reduced capacity in both the uplink and downlink. On the other hand, if it is set too low, it will result in frequent branch replacements, with delayed handovers degrading the performance in both the uplink and downlink. The reduced Block Error rate (BLER) performance will cause the transmit powers to go up. Increased transmission powers in an interference limited environment mean diminished capacity.

P-CPICH is one of the essential common channels in the network. If set too high, the sum of all common channels' power can easily eat up in the order of 50% of the cell's power resources [13]. Thus, leaving not enough power for the traffic channels (dedicated as well as shared ones), which creates a shortage in cell capacity. The power of the P-CPICH also defines the cell coverage area and, if set too small, coverage holes will be the result. Furthermore, the power of the P-CPICH is one of the main determining factors in mobility management, as its reception is responsible where and to which cells soft handover is performed.

In [21] a study is conducted based on the Shinjuku area of Tokyo and assumed all users to be indoors. For the multi-path channel profile, the ITU Vehicular A channel was assumed. Ten sites covered the 13.5km2 area is considered for his study. The selected antenna installation height was 50m, and the propagation loss was calculated with the Okumura–Hata model. The simulations used four different sector configurations and the site locations were kept fixed. The gain of all antennas was set to 15dBi and window add with a value of 4dB was used. A service mix of voice users (8kbps), circuit switched data users (64kbps), and packet switched data users (144kbps) was assumed. In the study, electrical down tilting was applied, and the results show that an optimum tilt angle can be found considering both capacity and coverage probability. The trend that can be seen from Table 4.1 which is taken from [18] shows that by tilting the antenna, the other-to-own-cell-interference ratio decreases as the tilting is increased. Because the main antenna beam is delivering less power towards the other BSs. Therefore, most of the radiated power is going to the area that is intended to be served by this particular BS. At the same time, the network could also serve more users than if the antennas were not tilted. There is always some optimum value for tilting, which depends on the environment, site and user locations, and the antenna radiation pattern. If the tilting angle is too big, the service area could decrease, and the BS would be unable to serve such a large area.

Table 4.1 Examples of the impact of antenna tilt on network capacity [18]

Antenna tilt	Other-to-own-cell-interference ratio, i	Served users	Soft handover overhead	Uplink coverage probability (outdoor to indoor) for 8/64/144 kbps
Omni case				
0°	0.79	239	28%	70/32/40%
Three-sector case, 65° antenna				
0°	0.88	575	40%	86/59/62%
4°	0.75	624	39%	91/71/72%
7°	0.59	697	36%	92/76/76%
10°	0.37	856	30%	90/75/74%
14°	0.38	787	32%	81/62/61%
Four-sector case, 65° antenna				
0°	1.09	604	41%	92/70/71%
4°	0.94	707	30%	95/81/81%
7°	0.72	833	26%	96/84/83%
10°	0.47	959	21%	94/82/81%
14°	0.50	886	26%	86/69/68%
Six-sector case, 33° antenna				
0°	1.15	880	48%	93/76/76%
4°	1.03	946	49%	96/83/83%
7°	0.88	1037	45%	96/85/84%
10°	0.73	1054	41%	95/83/82%
14°	0.58	930	33%	86/70/69%

Reproduced by permission of IEEE.

4.2 Soft handover overhead trade off

The primary purpose of soft handover is to provide seamless handover and added robustness to the system. This soft handover is mainly achieved via three types of gain provided by the soft handover mechanism, which is macro/micro diversity and downlink load sharing. Macro diversity gain is a gain over slow fading and sudden drops in signal strength, while micro diversity gain is a gain over fast fading. Downlink load sharing means a UE in soft handover receives power from multiple Node Bs [17]. Thus, the maximum transmission power to a UE in n-way soft handover, which indirectly improves coverage. On the other hand, UE using several radio links requires more channelization codes, which reduce network capacity.

Soft handover overhead and its trade off for a cellular network to be formulated for multi objective optimization purposes. Consider a UMTS network consisting of M cells and a service area represented by a grid of N pixels. A pixel is assumed as a UE and UEs uniformly distributed across the selected network area. For a cell, P_{Tx} is the total available transmit power, and Pilot power to denote the percentage of power allocated to the common channel P-CPICH. P_{Tx} is assumed to be similar for all cells in the network.

The total number of radio links in a network is the sum of radio links assigned to a user that is N(1+SHO). The transmission power of a radio link P_T including a cell antenna gain G, antenna down tilt gain G_d can be found as:

$$P_T = \frac{(1-\text{Pilot power}\%).P_{Tx}}{N(1+SHO)}.Ga.Gd \tag{4.1}$$

Using the parameters in [21] and the curve fitting function in MATLAB, the antenna down tilt gain G_d approximated by a Gaussian function as:

$$G_d = 6.208.\, e^{\left[-\frac{(\theta-\theta_{tilt})^2}{116.64}\right]} + 0.4142 \tag{4.2}$$

Where

- ✓ θ_{tilt} the electrical antenna down tilt;
- ✓ θ the angle from the cell to the UE

Received power by a user P_{useri} in a network is formulated in [16] ignoring thermal noise:

- ✓ No soft hand over

$$P_s = \frac{vR}{W}\left[\frac{E_b}{I_0}\right]_t \left[\frac{1}{X_1}\right].P_T = b_1.P_T \tag{4.3}$$

Inserting Equation (4.1) in (4.3)

$$P_s = \frac{vR}{W}\left[\frac{E_b}{I_0}\right]_t \left[\frac{1}{X_1}\right] . \frac{(1 - \text{Pilot power\%}). G_a. G_d. \text{P}_{\text{Tx}}}{\text{N}(1 + \text{SHO})} \tag{4.4}$$

✓

Two-way soft handover

$$P_{s1} + P_{s2} = \frac{2\frac{vR}{W}\left[\frac{E_b}{I_0}\right]_t . P_T}{X_1 + X_2} = b_2. PT \tag{4.5}$$

Inserting Equation (4.1) in (4.5)

$$P_{s1} + P_{s2} = \frac{2\frac{vR}{W}\left[\frac{E_b}{I_0}\right]_t . \frac{(1 - \text{Pilot power\%}). G_a. G_d. \text{P}_{\text{Tx}}}{\text{N}(1 + \text{SHO})}}{X_1 + X_2} \tag{4.6}$$

✓ Three-way soft handover

$$P_{s1} + P_{s2} + P_{s3} = \frac{3\frac{vR}{W}\left[\frac{E_b}{I_0}\right]_t . P_T}{X_1 + X_2 + X_3} = b_3. PT \tag{4.7}$$

Inserting Equation (4.1) in (4.7)

$$P_{s1} + P_{s2} + P_{s3} = \frac{3\frac{vR}{W}\left[\frac{E_b}{I_0}\right]_t . \frac{(1 - \text{Pilot power\%}). G_a. G_d. \text{P}_{\text{Tx}}}{\text{N}(1 + \text{SHO})}}{X_1 + X_2 + X_3} \tag{4.8}$$

Where

- ✓ $X_1 = \frac{1}{1-\alpha+\sum_{i=2}^{19}\left[\frac{r_i}{r_1}\right]^{-a} 10^{(z_i - z_1)/10}}$; $X_2 = \frac{1}{1-\alpha+\sum_{j=1,\neq 2}^{19}\left[\frac{r_j}{r_2}\right]^{-a} 10^{(z_i - z_2)/10}}$;
- ✓ $X_3 = \frac{1}{1-\alpha+\sum_{k=1,\neq 3}^{19}\left[\frac{r_k}{r_3}\right]^{-a} 10^{(z_k - z_3)/10}}$;
- ✓ P_{si} is the power received by a UE from a radio link of a cell;
- ✓ W is the chip rate; R is the service bit rate; v is the activity factor; α is the orthogonal factor;
- ✓ $\left[\frac{E_b}{I_0}\right]_t$ is the Required SINR to provide the service with a data rate of R;

- ✓ Z is shadow fading margin; a is path loss exponent; i, j, k are the index of serving and neighbor cells; r_i the distance from UE to a cell; Factor bi shows the relative strength of the required power for the UE

It is shown in [16] that the relative strength of the required power for the UE in case of soft handover is greater than without soft handover that is b3 > b2 > b1 in case of without considering shadowing. While it is in reverse in case of the cell border when shadowing is considered as shown in Figure 4.2.

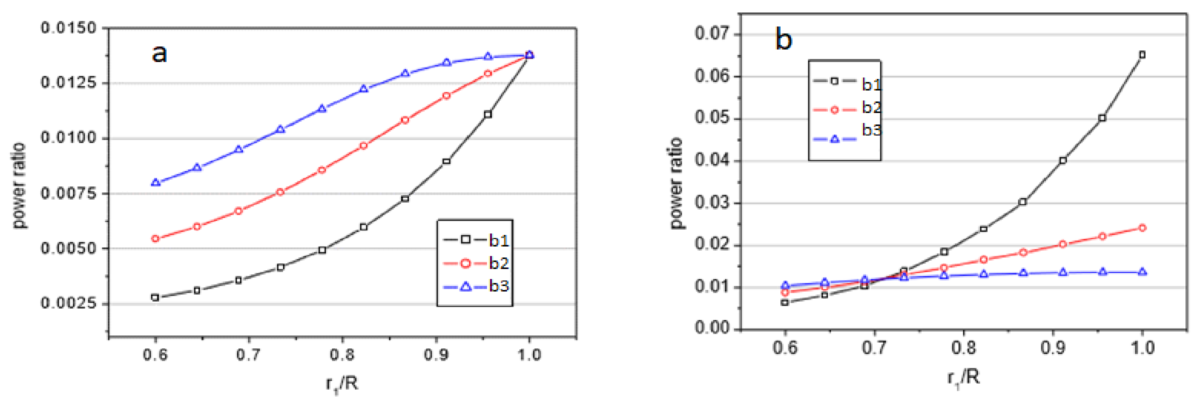

Figure 4.2 Mean b1, b2, b3 vs. mobile location [16]

a) Without shadowing b) shadowing is considered

During connected mode, the UE continuously monitors the P-CPICH Ec/I0 of the cells defined by the intra-frequency neighbor cell list and evaluates the reporting criteria. If one of the reporting events is fulfilled, the UE sends an event-triggered measurement report. Before the P-CPICH Ec/I0 of a cell is used by the handover algorithm in the UE, an arithmetic mean of a certain number of the latest measured values is taken. The average is taken over the linear values of Ec/I0, not the dB values. For intra-frequency measurement criteria, radio link addition (event 1A) are triggered when Equation (4.9) is fulfilled as defined in [18]:

$$10.log_{10}M_{New} + CIO_{New} \geq W.10.log_{10}\left(\sum_{i=1}^{N_A} M_i\right) + (1-W).10log_{10}M_{Best} - \left({(R_{1a} - H_{1a})}/{2}\right) \quad (4.9)$$

where

- ✓ M_{New} is the P-CPICH Ec/I0 measurement result of the cell entering the reporting range;
- ✓ CIO_{New} is the cell-individual offset of the cell entering the reporting range;
- ✓ Mi is a P-CPICH Ec/I0 measurement result of a cell in the active set;
- ✓ N_A is the number of cells in the active set;
- ✓ M_{Best} is the P-CPICH Ec/I0 measurement result of the most reliable cell in the active set;
- ✓ W is a weighting parameter sent from the RNC to the UE;
- ✓ R_{1a} is the reporting range constant for event 1A sent from the RNC to the UE;
- ✓ H_{1a} is the hysteresis parameter for event 1A. The hysteresis parameter, together with the reporting range constant, is usually called the addition window (window add).

The probability of adding radio links or triggering event 1A is increasing as the window add is rising, which can be seen from the Equation. Thus, if Equation (4.9) is not fulfilled, no soft handover and power received by a UE will be the one in Equation (4.4) and either Equation (4.6) or (4.8) if it is fulfilled.

The SINR of a user is the ratio of a received signal to noise and interference. It is defined as:

$$SINR_i = \frac{P_{useri}}{I + N_0} \quad (4.10)$$

Where

- ✓ I is the own and other interference power signals in the network;
- ✓ N_0 is thermal Noise

As shown in the Equation above, received power P_{useri} by a UE depends on the pilot power, antenna down tilt gain and window add. Thus, we can say that P_{useri} is a function of pilot power, window add (W_{add}), and electrical antenna down tilt. Soft handover overhead of UMTS network is formulated as follows customizing the one in Equation (2.1) as:

$$\frac{\sum_{i=1}^{N} \sum_{n=1}^{M_{active}} nPni\{P_{useri}(Wadd, Pilot\ power, Antenna\ tilt)\}}{N} - 1 \quad (4.11)$$

The probability of a user P_{ni} to be one way, two way, or three-way soft handover depends on the three parameters described. Thus, received power P_{useri} by a UE indirectly can be used to predict the probability of a UE being connected to one, two, or three radio links.

The capacity of the network is formulated as:

$$B \sum_{i=1}^{N} log_2(1 + SINR_i(P_{useri})) \quad (4.12)$$

Where N is the total number of users, and B is bandwidth, which is 5 Mhz in the case of WCDMA.

4.3 Optimization approaches

A multi objective optimization problem is considered subject to the coverage constraint, which is described in terms of the received power within the receiver sensitivity threshold and the SINR requirement for the services used by a UE. Thus, the function f in Equation (4.13) represents the objective function:

$$f: min\ (\frac{\sum_{i=1}^{N}\sum_{n=1}^{M_{active}} nPni\{P_{useri}(Wadd, Pilot\ power, Antenna\ tilt)\}}{N} - 1) \text{ and}$$
$$\max B \sum_{i=1}^{N} log_2(1 + SINR_i(P_{useri})) \quad (4.13)$$

Subject to:

$1dB \leq Wadd \leq 3dB;$ (i)

$0.025 \leq Pilotpower \leq 0.1;$ (ii)

$20\% \leq SHO \leq 40\%$ (iii)

$(Percentile \text{ of } power\ recived \leq -100\ dBm) \leq 5\%;$ (iv)

$P_{Tx} \leq 43dBm$ (v)

From the perspective of giving information about mobile coverage, National Regulatory Authorities (NRAs) are recommended to choose the criteria based on the strength of the signal received [22]. A given area is declared in coverage if the average received signal power in that area is greater than a pre-specified minimum. The range of received signal power thresholds of UMTS reported by the NRAs in Europe are shown in Figure 4.3. In this thesis, -100 dBm is taken as a threshold because 83% of the NRAs in Europe using 100dBm and less.

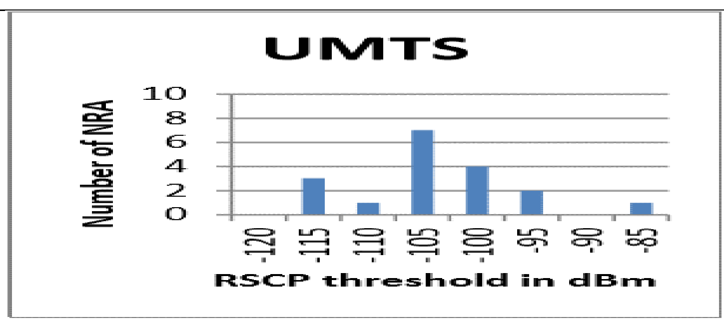

Figure 4.3 Number of NRA using given thresholds for UMTS [22]

The problem is not straight forward to find the optimal solution of the problem which needs a practical configuration of the sites using simulation. An educated guess, which is one of the metaheuristic algorithms, is used to select near optimal solutions. The tuning parameters are variables of the function which will be used to find the optimal solutions. The approach is to simulate by varying tuning parameters individually and in combination. The methodology used is shown in Figure 4.4.

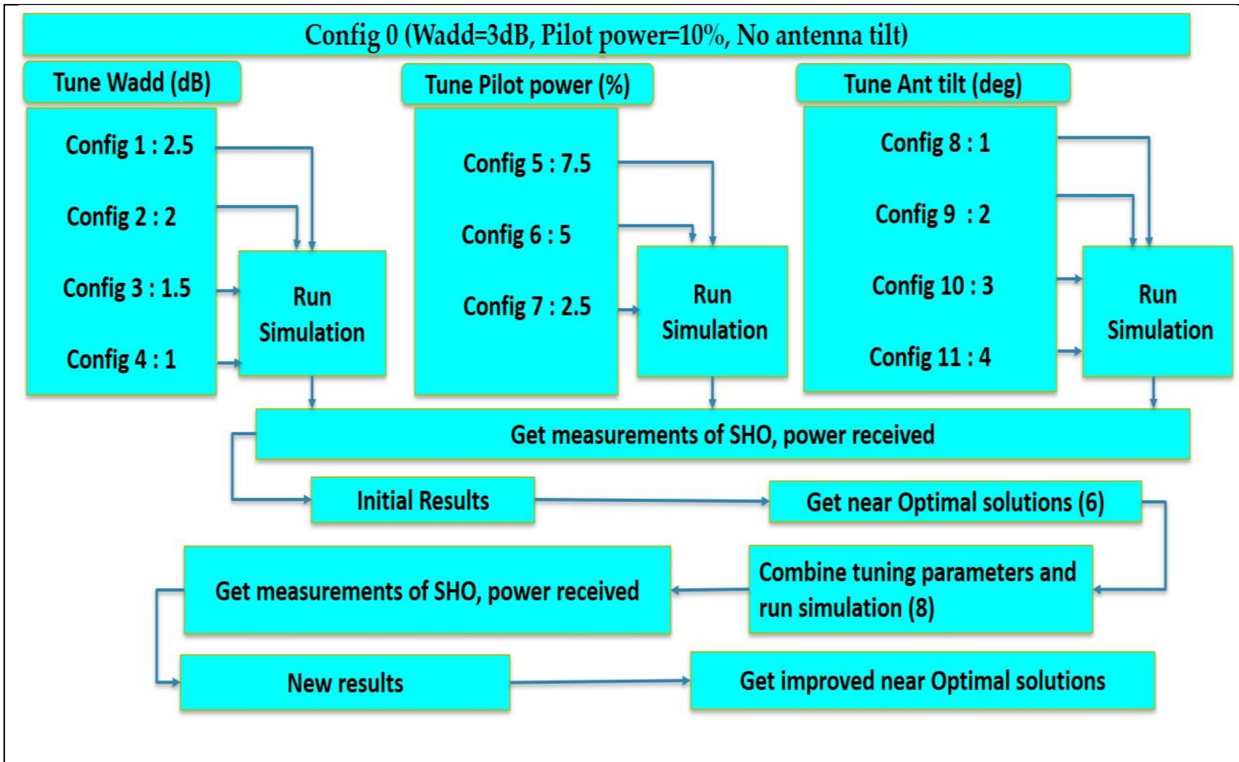

Figure 4.4 Soft handover overhead and capacity optimization methodology

Tuning starts with the widow add with a range of 0.5 dB and run a simulation for each of them and take measurements related to objectives and constraints. In this case, a total of 4 simulations are run, keeping the existing configured values for the two remaining tuning parameters, which are pilot power and electrical antenna down tilt. Then tuning of pilot power will proceed with a range of 2.5%, three simulations are run, and measurements are taken. Still, the existing configuration of the window add and electrical antenna down tilt are kept. The tuning of the electrical antenna down tilt from its current configuration is the third step to run four simulations.

Two near optimal solutions are selected from each tuning parameter. The values of tuning parameters that bring the near optimal solutions are used in combination for the better improvement. Accordingly, eight simulations are run.

5 System Modeling, Scenarios and Assumptions

5.1 System modeling

5.1.1 Tools

WinProp and MATLAB are used for the network simulation and analysis respectively. WinProp is highly accurate and very fast empirical and deterministic propagation models that are available for a wide range of scenarios like rural, urban, indoor, tunnel and vehicular. It supports arbitrary transmitters, including cellular and broadcasting sites, satellites, repeaters, and leaky feeder cables. WinProp is a leading software in the domain of wireless propagation and radio network planning, and details of the WinProp is described in [29, 23].

WinProp computes the capacity that is throughput, maximum data rates, packet delays, QoS of the different radio links of cells in the network. The computation is based on coverage analysis and traffic assumptions. Capacity limitations and overloaded cells can be detected quickly, and systems can be optimized to provide both high capacity and throughput.

There are six WinProp software suites which are ProMan, Aman, WallMan, CoMan, TuMan, and CompoMan. Three of them have been used for the network simulation (ProMan, Aman and Wallman)

ProMan is the software package that is designed to predict the path loss accurately between transmitter and receiver, including all essential parameters of the mobile radio channel. It offers network planning modules for 2G/2.5G, 3G/B3G, WLAN, WiMAX networks.

Radio network planning tools rely on accurate wave propagation models to predict the path loss between two arbitrary points. Besides the shielding of objects and multipath propagation, the antenna pattern of the antennas used for the communication link influence the actual path loss. For this purpose, AMan is developed to handle antenna patterns with a convenient Windows GUI.

WallMan provides a powerful graphical user interface that allows for editing types of building databases conveniently. All calculations performed in WinProp concerning the wave propagation modeling in urban and indoor scenarios rely on databases.

5.1.2 Propagation Model

WinProp offers various wave propagation models, and the dominant path model is among these models. The Dominant Path Model (DPM) is not based on all power rays between the transmitter and the receiver, which contributes with similar energy to the total power received. Only a few propagation paths are dominant in terms of energy input [19]. The DPM can be applied in indoor, urban and rural scenarios. It concentrates only on the dominant paths and does not calculate the routes with small energy contribution.

5.1.3 Selected sites/area

Sample UMTS sites are chosen for the network simulation and to work on the optimization of the soft handover overhead and network capacity. For this study, an 18 square kilometer, which consists of Saris and Bole bulbula in Yeka and Bole sub cities is selected. Currently, 26 3G sites with three sectored cells are deployed in the specified location.

5.2 Assumptions and parameters

Simulation assumptions and parameters used for the specified area are as per the existing configuration and shown in Table 5.1.

Table 5.1 Assumptions and parameters in the simulation

Parameters	Assumptions
Air Interface	One 5 MHz carrier (DL/UL frequency 2132.5/1942.5 MHz), 3.84 Mchips/s, Duplexing scheme FDD
Prediction height	1.5m
Propagation modeling	Dominant Path Model
Node B	Transmit power 43 dBm, antenna gain 17.9 dBi, 5 dB noise figure, cable loss 0 dB
Antenna	Kathrein_742212
UE	Omnidirectional 1 dB body losses, 6 dB noise figure, Antenna Gain 1dBi, Transmit Power 23dBm
Orthogonality factor	0.63
Resolution of prediction results	15mx15m
Simulation	Static simulation which is homogenous traffic per cell

5.3 Scenario description

Description of the scenarios used to perform performance evaluations is presented in this section and shows the network capacity and soft handover overhead for all the parameters considered for optimization. In all scenarios, the assumptions and parameters in network simulation are the same except the changes of Window add, Pilot power, and electrical antenna down tilt.

In the first scenario, window add with values of 2.5dB, 2dB, 1.5dB and 1dB are used. In this scenario, the pilot power and electrical antenna down tilt of the cells are kept as they are configured in the existing network. In the second scenario, Pilot power with values of 7.5%, 5%, and 2.5% are used. In this scenario, window add and electrical antenna down tilt of the cells are kept as they are configured in the existing network.

In the third scenario, electrical antenna down tilt by 1, 2, 3 and 4 degrees are used. In this scenario, window add and Pilot power of the cells are kept as they are configured in the existing network.

In the fourth scenario, the combinations of the three parameters are selected by choosing the two near optimal solutions from each of them. Thus window add (2dB and 1.5 dB), pilot power (7.5 and 5%), and electrical antenna down (2 and 3 degrees) results in eight combinations as shown in Table 5.2.

Table 5.2 Combined parameters

Configuration	Wadd(dB)	Pilot(%)	Antenna tilt (Degree)
Config 12	2	7.5	2
Config 13	2	7.5	3
Config 14	2	5	2
Config 15	2	5	3
Config 16	1.5	7.5	2
Config 17	1.5	7.5	3
Config 18	1.5	5	2

6 Results and Discussion

This chapter presents the study results using WinProp radio network simulation tool for system level network simulation and MATLAB for plotting results.

6.1 Results

The current existing configuration parameters of 3G sites in Addis Ababa are used to simulate the four scenarios mentioned in the previous chapter. In the first simulation, the default configuration parameters of the Window add (3dB), Pilot power (10%), and electrical antenna down tilt were used. The results from this simulation were used as a reference for the optimization of the two network performance indicators that are capacity and soft handover overhead of the network. One of the constraints is the received power by UE should be within the acceptable range as per the target defined. The received power also indicates an acceptable range of the coverage hole which is allowed in the network. In this simulation, the mean network capacity of the selected sites is 5.616 Mb/s, with 85.4% of the mean soft handover overhead. The downlink received power below the threshold is 2% as shown in Figure 6.1.

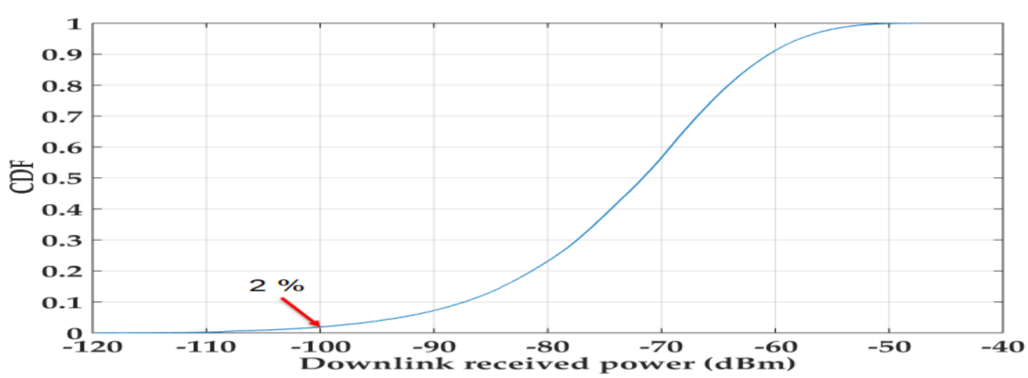

Figure 6.1 CDF for the received power of the existing sites with default configuration (Config 0)

In the first scenario, the window add was used as a tuning parameter, and the results for the capacity and soft handover overhead is shown in Figure 6.2. The soft handover overhead is decreasing as window add is decreasing while the capacity is almost the same for all. Their respective received power using CDF is shown in Figure 6.3. The downlink received power below the threshold is 2% for all configuration.

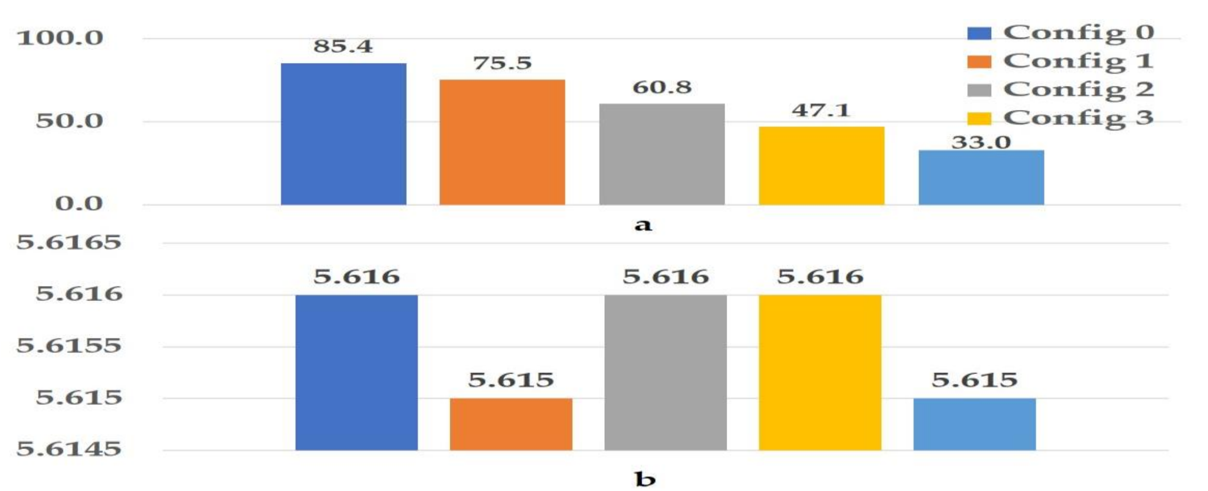

Figure 6.2 a) Mean overhead (%) and b) Capacity (Mb/s) for different window add

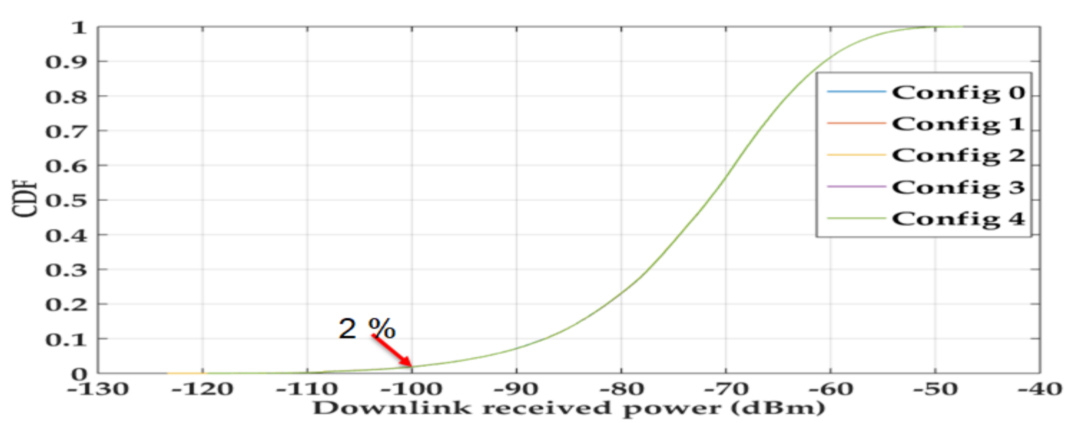

Figure 6.3 CDF for the received power using different window add values

In the second scenario, the pilot power was used as a tuning parameter, and the results for the capacity and soft handover overhead is shown in Figure 6.4. Both soft handover overhead and network capacity are increasing as pilot power is decreasing except the soft handover overhead in case of pilot power of 7.5%. Their respective received power using CDF is shown in Figure 6.5. The downlink received power below the threshold is increasing as the pilot power is decreasing.

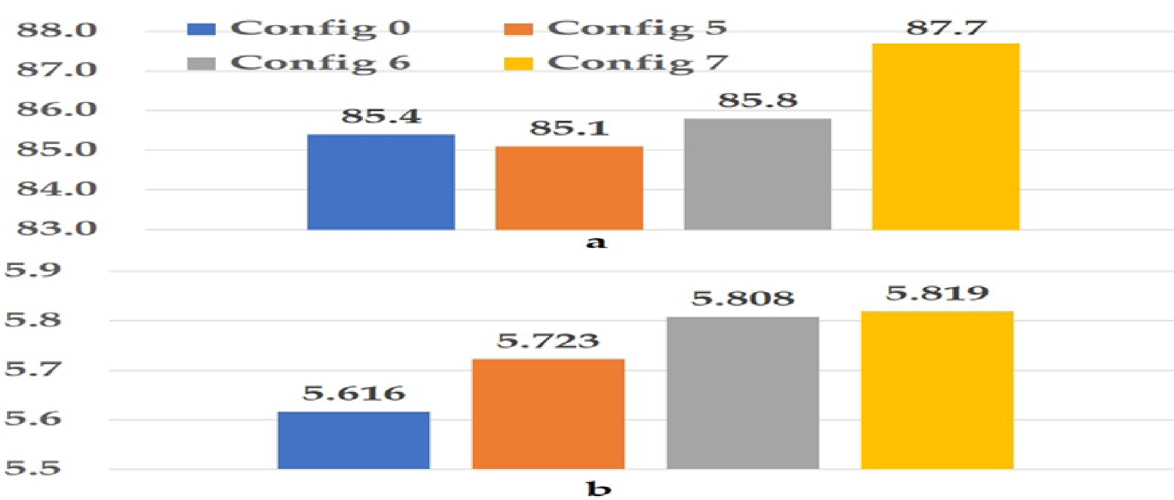

Figure 6.4 a) Mean overhead (%) and b) Capacity (Mb/s) for different pilot power

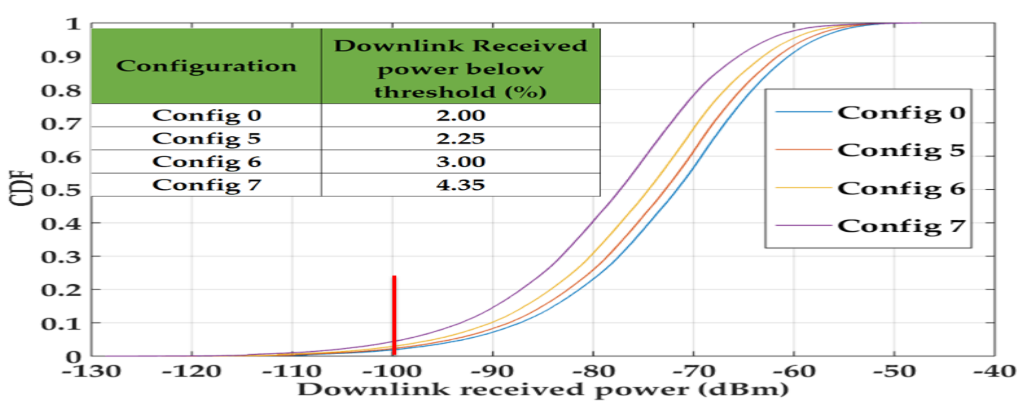

Figure 6.5 CDF for the received power using different pilot power

In the third scenario, the electrical antenna down tilt was used as a tuning parameter, and the results for the capacity and soft handover overhead is shown in Figure 6.6. Soft handover overhead is decreasing as electrical antenna down tilt is increasing. The capacity is increasing until the down tilt degree is two and falling while increasing for the down tilt degree. Their respective received power using CDF is shown in Figure 6.7. The downlink received power below the threshold is increasing as the tilting antenna is decreasing.

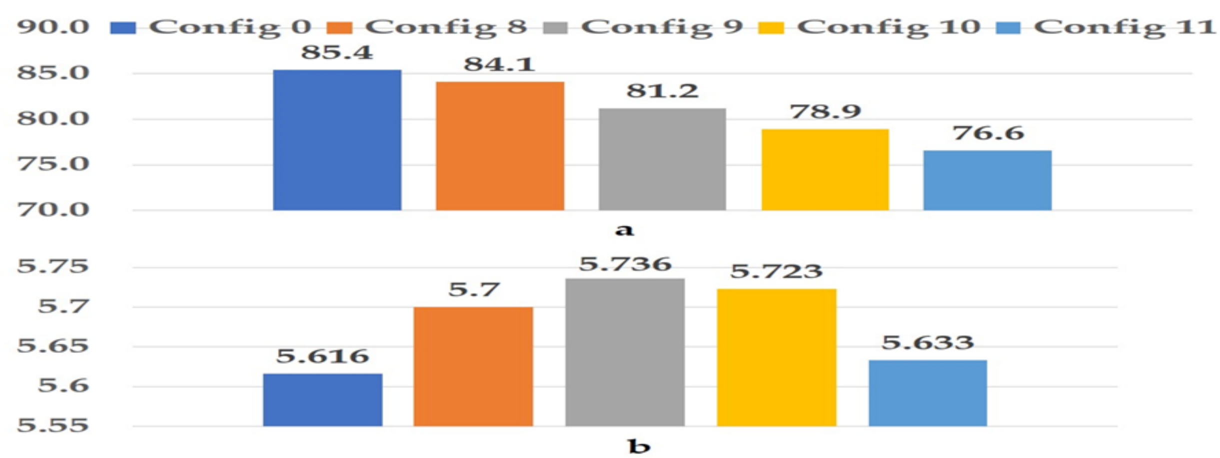

Figure 6.6 a) Mean overhead (%) and b) Capacity(Mb/s) for different antenna tilt

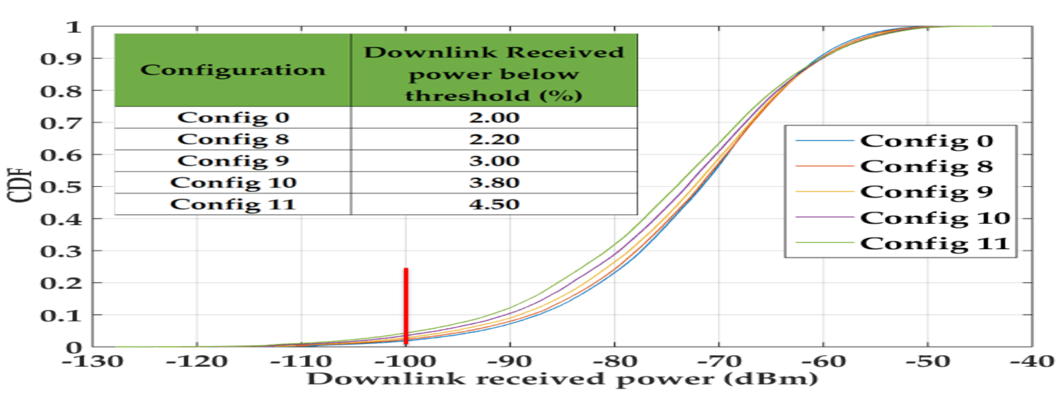

Figure 6.7 CDF for the received power using different electrical antenna down tilt

In the fourth scenario, the combinations of the three tuning parameters were used, and the results for the capacity and soft handover overhead is shown in Figure 6.8. Comparing with the three scenarios, here improvements are observed in both the reduction of soft handover overhead and increment of network capacity. Their respective received power using CDF is shown in Figure 6.9. The downlink received power below the threshold is between 4 and 5% which is still within the acceptable range.

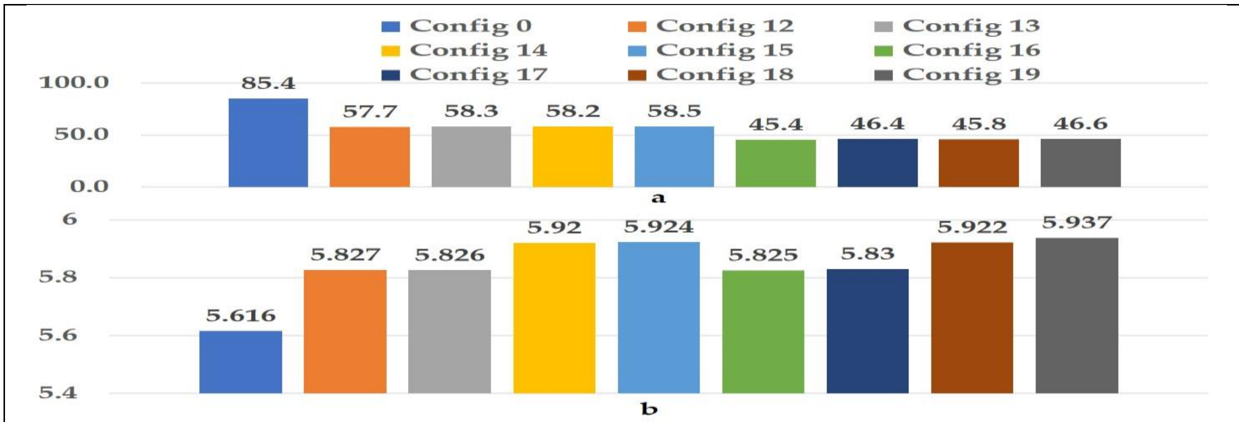

Figure 6.8 a) Mean overhead (%) and b) Capacity(Mb/s) for combinations parameters

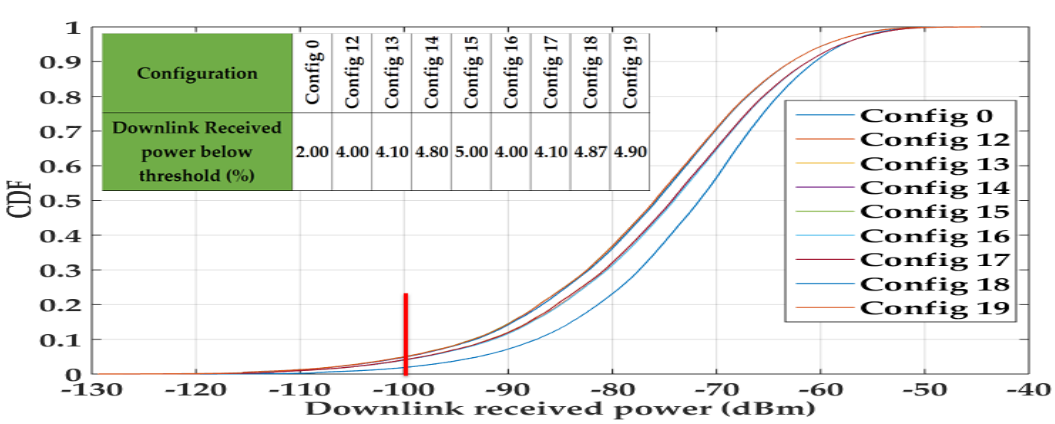

Figure 6.9 CDF for the received power using combined tuning parameters

6.2 Discussions

The results show that the soft handover overhead could be reduced, and the capacity could be increased by tuning the three parameters fulfilling the constraints defined. In the first scenario, two near optimal solutions were chosen using an educated guess, which is one of the heuristic algorithms. A plot of Network capacity versus soft handover overhead is used to select near optimal solutions. Window value of 2 dB (Config 2) and 1.5 dB (config 3) were taken as near optimal solutions as soft handover overhead is minimized in keeping the capacity of default configuration as you can see in Figure 6.10. The soft handover overhead could be reduced by 24.6 and 38.3% from the default configuration in case of using window add values of 2 and 1.5 dB respectively. These two windows add values that were used for the better optimization of the network capacity and soft handover overhead.

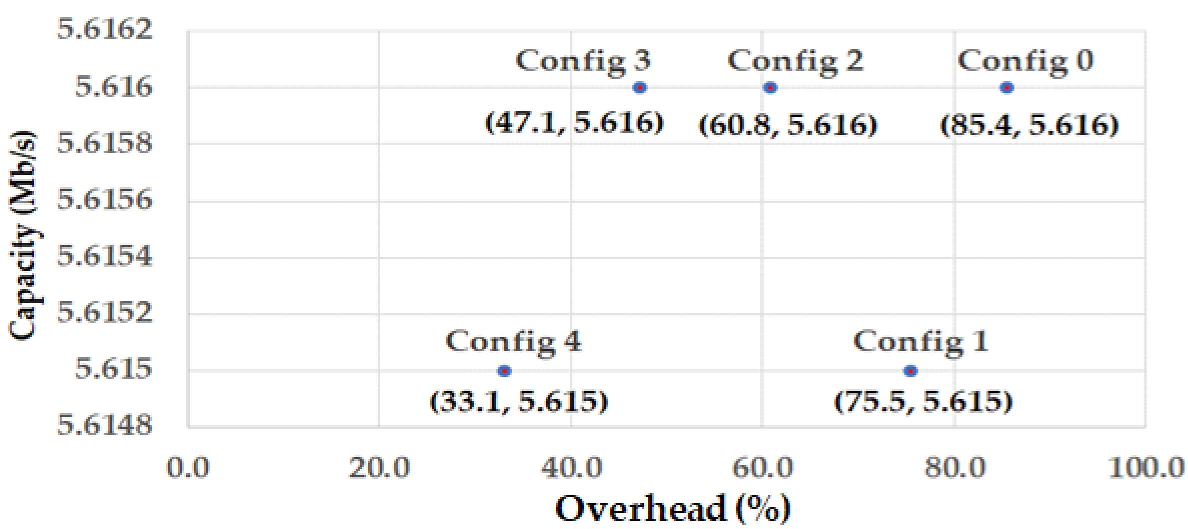

Figure 6.10 Capacity versus overhead for different window add values

In the second scenario, pilot power of 7.5% (Config 5) and pilot power of 5% (config 6) were taken as near optimal solutions as capacity is maximized with a small difference of the soft handover overhead compared with the default configuration as you can see in Figure 6.11. The capacity could be increased by 1.91 and 3.42% from the default configuration in case of using pilot power values of 7.5 and 5% respectively. These two pilot power values were used in combination with the remaining two parameters for the better optimization of the capacity and soft handover overhead.

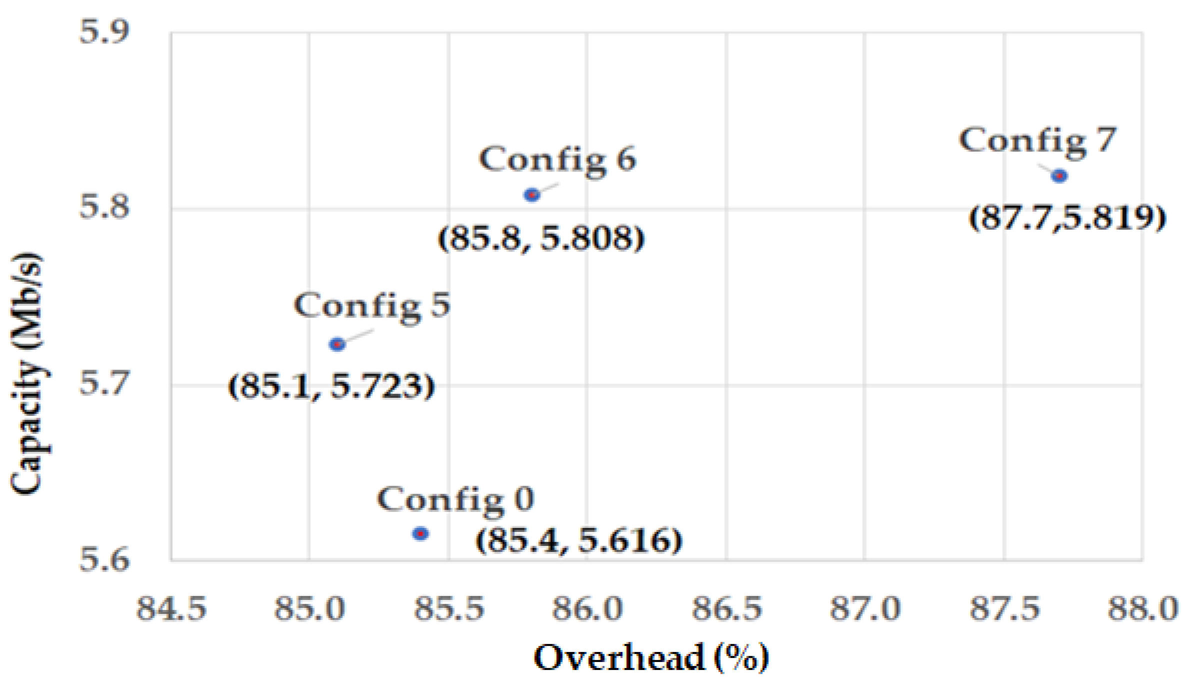

Figure 6.11 Capacity versus overhead for different Pilot power values

In the third scenario, there was a reduction of soft handover overhead and increment of network capacity for all electrical antenna down tilt cases comparing with the default configuration. Electrical antenna down tilt from existing 2 degree (Config 9) and 3 degree (config 10) were taken as near optimal solutions as the main target is to maximize capacity in the reduction of the soft handover overhead. The capacity could be increased by 2.14 and 1.91% from the default configuration in case of using electrical antenna down tilt by 2 and 3 degrees from default antenna configuration respectively. The soft handover overhead could be reduced by 4.2 and 6.5% case of using electrical antenna down tilt by 2 and 3 degrees from default antenna configuration respectively. Electrical antenna down tilt by 2 and 3 degrees was used in combination with the remaining two parameters for the better optimization of the capacity and soft handover overhead.

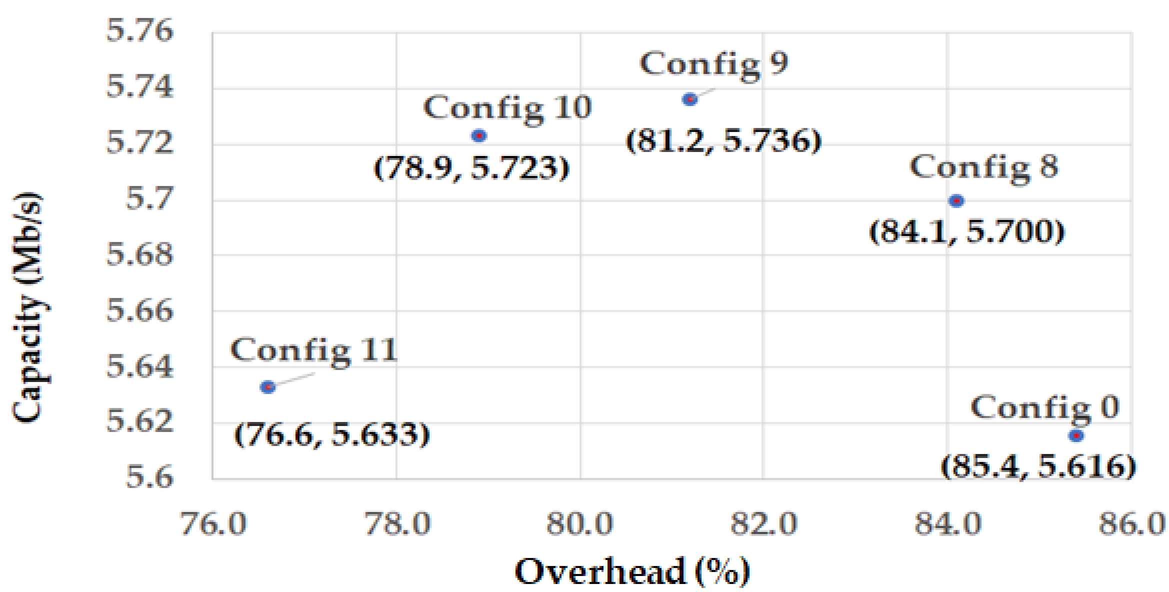

Figure 6.12 Capacity versus overhead for different electrical antenna down tilt

In the fourth scenario, there was a reduction of soft handover overhead and increment of network capacity for all combined cases comparing with the default configuration as shown in Figure 6.13. The network capacity could be increased within the range of 3.72 to 5.72%, and the soft handover overhead could be reduced within the range of 26.9 and 40% from the default configuration in all cases as shown in Table 6.1.

In this scenario, the capacity gain was increased by 2.6 and 3.6% compared with the second and third scenarios respectively. Besides, the soft handover overhead was reduced by 40 and 33.5%, contrasting with the second and third scenarios respectively. Thus, using combined parameters brought improvement rather than using a single setting in optimizing soft handover overhead and network capacity.

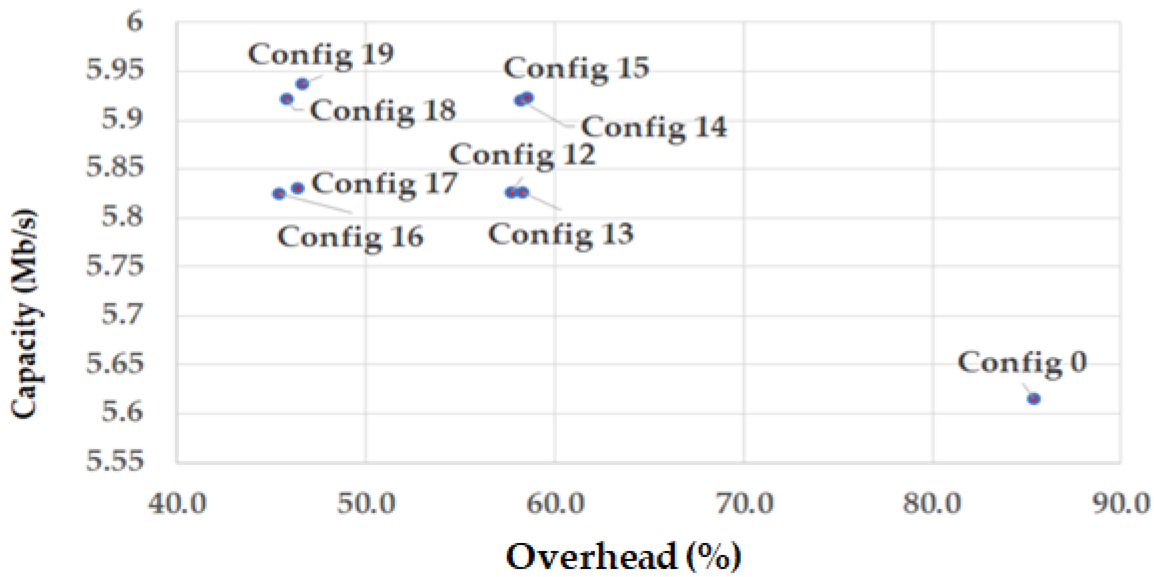

Figure 6.13 Capacity versus overhead for different combinations of the three parameters

Table 6.1 Overhead reduction and capacity gain

Configuration	SHO (%)	Capacity (Mb/s)	SHO reduction (%)	Capacity gain (%)
Config 0	85.4	5.616		
Config 12	57.7	5.827	27.7	3.76%
Config 13	58.3	5.826	27.1	3.74%
Config 14	58.2	5.92	27.2	5.41%
Config 15	58.5	5.924	26.9	5.48%
Config 16	45.4	5.825	40.0	3.72%
Config 17	46.4	5.83	39.0	3.81%
Config 18	45.8	5.922	39.6	5.45%
Config 19	46.6	5.937	38.8	5.72%

Previous researches focused on optimizing either of the network capacity or soft handover related parameters. Enhanced search and optimization based genetic algorithm is used in [2] to maximize window add and window drop to increase network capacity. But the specific gain is not specified. By [8], soft handover overhead could be reduced from 85% to 55% using the new finger assignment for the UE in the region of the soft handover. However, network capacity improvement is not considered. Optimization of the pilot power was presented by [14] and concluded that the higher soft handover overhead contributed to the less power saving which is generic and obvious.

My thesis relied on configuration parameters of the real network and optimized both the soft handover overhead and network capacity, considering the constraints defined. Thus, the network capacity could be increased by 5.72%, and soft handover overhead could be reduced by 38.8% when using window add of 1.5 dB, pilot power of 5% and electrical antenna down tilt by 3 degrees.

7 Conclusion and future work

7.1 Conclusion

This thesis aimed to analyze the performance and optimization of soft handover overhead for the 3G network. Based on the measurement counters from the network management system of the operator namely Performance Report system (PRS), soft handover overhead 2018 performance data of Addis Ababa 3G network shows 87% average, which is considerably beyond the maximum recommended value. Thus 47% of additional radio links (resources) are allocated to the UE taking 40% of soft handover overhead as a maximum recommended value.

Window add, pilot power and electrical down tilt were used to optimize both the soft handover overhead and capacity of the 3G network. Decreasing the window add and pilot power value contributed to the reduction of the soft handover overhead and increment of network capacity respectively. While in the tuning of electrical antenna down tilt, both soft handover overhead and capacity were optimized. Using the three parameters in combination enabled more improvements in both reduction of soft handover overhead and network capacity gain comparing with the tuning parameter individually. Accordingly, soft handover overhead could be minimized to 46.6% with network capacity gain of 5.72% fulfilling the required SINR and received power threshold when using window add of 1.5 dB, pilot power of 5% and electrical antenna down tilt by 3 degrees.

7.2 Future work

In this thesis, a total of 20 simulations have been run and near optimal solutions were found. So further researches are needed to further optimize the soft handover overhead and capacity of 3G networks. These future works include:

- ✓ A new study on the optimization of the network capacity and soft handover overhead by using a combination of the three parameters from start. In this case, a dynamic simulator is required as the number of simulations will be 80 and tiresome to run them manually one by one.
- ✓ Study the optimization considering window drop, triggering period for window add and window drop on top of the three parameters.
- ✓ Study the optimization of soft handover overhead and network capacity gain varying of the maximum active set size.

Appendix

The Soft handover overhead spatial plot for all RNCs controlling 3G sites in Addis Ababa is shown in figures for all carriers (a-carrier 1, b-carrier 2, c-carrier 3 and d-carrier 4) used in each RNC.

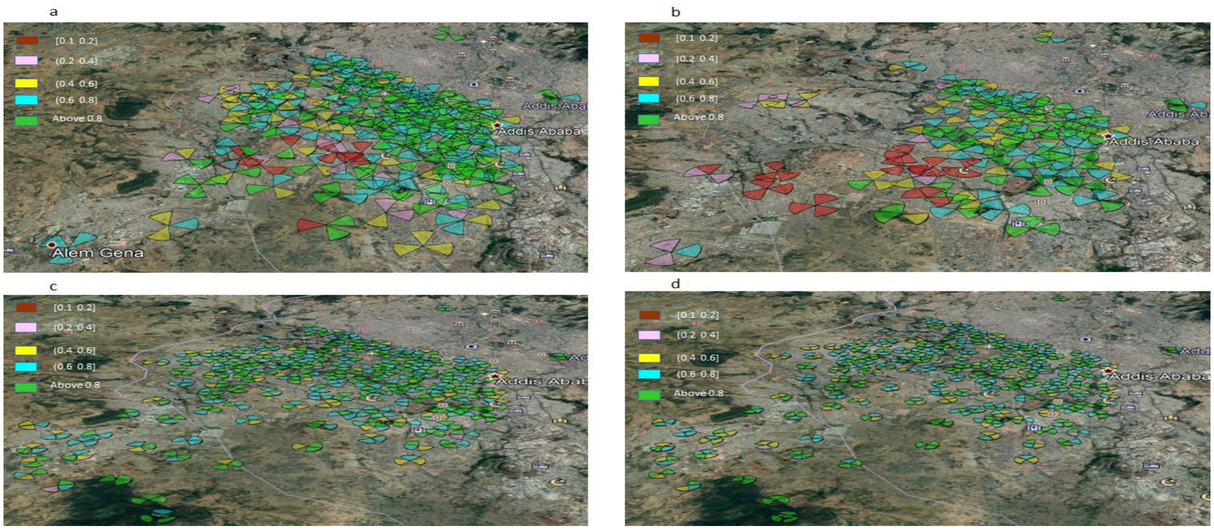

Figure 7.1 Soft handover overhead spatial plot for sites under RNC 2

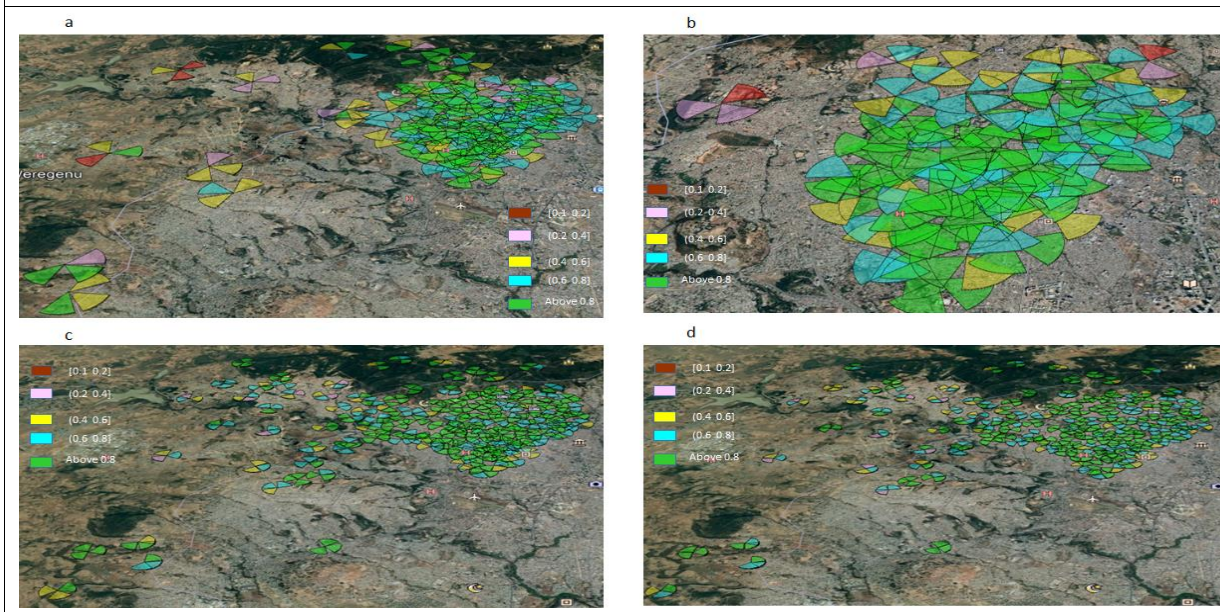

Figure 7.2 Soft handover overhead spatial plot for sites under RNC 3

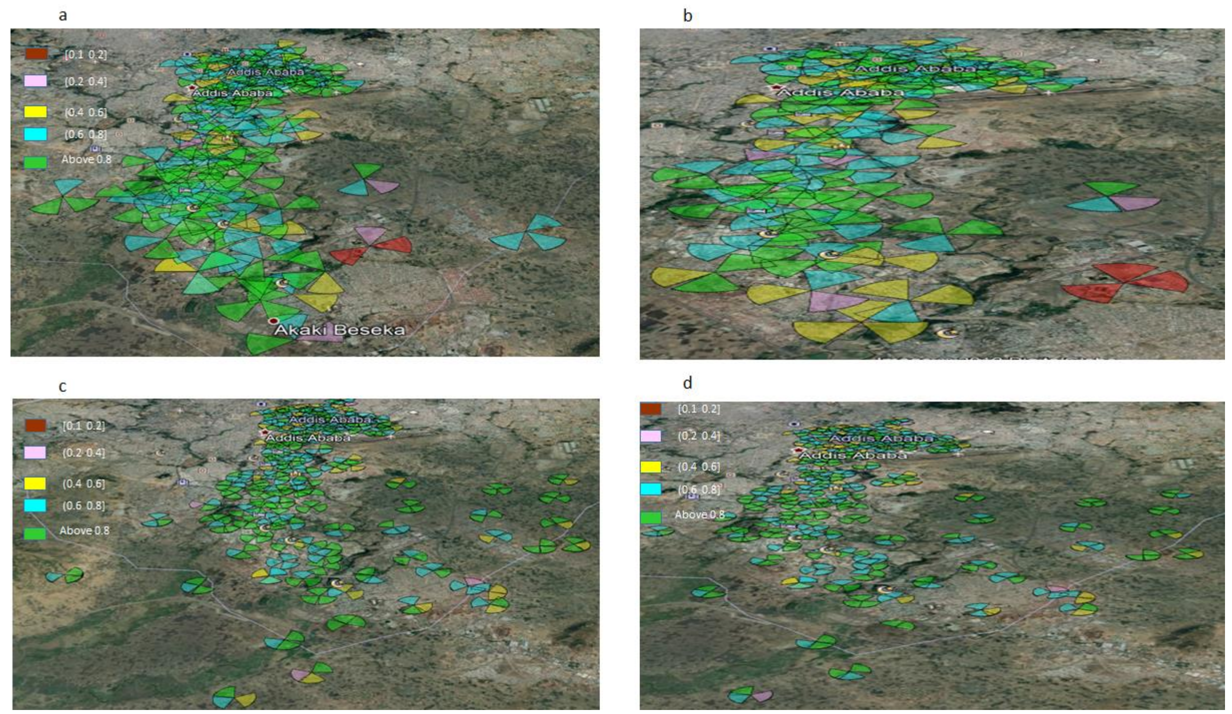

Figure 7.3 Soft handover overhead spatial plot for sites under RNC 4

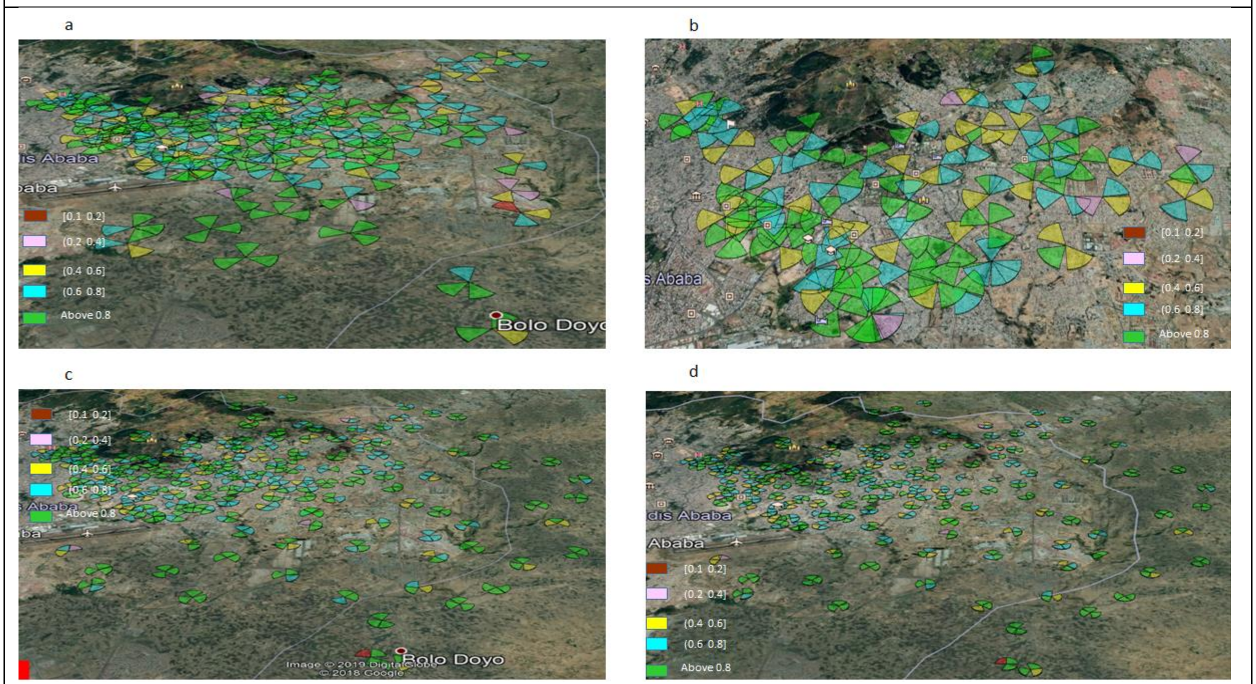

Figure 7.4 Soft handover overhead spatial plot for sites under RNC 5

Reference

[1] J. O. Abolade, O. A. Fakolujo, and A. Orimogunje, "Handover in Mobile Wireless Communication Network - A Review", ***Advanced Engineering, management and Science***, vol. 3, no. 9, pp. 934–940, 2017.

[2] Minhas, X. Ning, and S. Anamalamudi, "An enhanced genetic algorithm to optimize network parameters for soft handover in universal mobile telecommunications systems", ***Simulation System Science Technology***, vol. 17, no. 44, pp.1–8, 2016.

[3] I. Soy, A. Safak, and H. Bakiler, "Active Set Size Effects at HSUPA in WCDMA Systems", ***Applied Mathematics, Electronics and Computers***, vol. 3, no. 3, p. 146-149, 2015.

[4] A. G. Markoc and G. Sisul, "Self-optimizing uplink outer loop power control for WCDMA network," ***Radio engineering***, vol. 24, no. 2, pp. 499–506, 2015.

[5] Sarita, Dipesh, and Naresh, "Comparative Analysis of Maximum Ratio Combining and Equal Gain Combining Diversity Technique for WCDMA: A Survey", ***Engineering Inventions***, vol. 3, no. e-ISSN: 2278-7461, pp.72 – 77, 2013.

[6] N. P. Singh and B. Singh, "Performance enhancement of cellular network using adaptive soft handover algorithm," ***Wireless Pers Communication***, vol. 62, no. 1, pp. 41–53, 2012.

[7] K. I. Lakhtaria, "Enhancing QoS and QoE in IMS Enabled Next Generation Networks", ***Applications of graph theory in wireless ad hoc networks and sensor networks***, vol. 2, no. 2, 2010.

[8] S. Choi, M. Alouini, K. Qaraqe, and H. Yang, "Soft handover overhead reduction by RAKE reception with finger reassignment", ***IEEE Transaction Communication***, vol. 56, no. 2, pp. 213–221, 2008.

[9] A. Anpalagan, R. Vannithamby, W. Zhuang, and S. Aissa, "Radio resource management in 3G+ systems", ***Eurasip Journal Wireless Communication Network***, vol. 1, pp. 1–3, 2006.

[10] R.R. Yager, "Multiple Objective Decision Making using Fuzzy Sets", ***International Journal of Man-Machine Studies***, vol. 9, no. 4, pp. 375-382, 1977.

[11] D. Soldani and J. Laiho, "An Enhanced Radio Resource Management with Service and User Differentiation for UMTS Networks", ***IEEE 58th Vehicular Technology Conference***, FL USA, Oct. 2003, pp. 3473–3477.

[12] J.M. Mendel, "Fuzzy Logic Systems for Engineering: A Tutorial", ***Proceedings of the IEEE,*** Nj USA, March 1995, pp. 345-377.

[13] Buot, T. Zhu, H. Schreuder, H. Moon, and S. Song, "Soft handover optimization for WCDMA", ***4th International Symposium on Wireless Personal Multimedia Communications***, Aalborg, Denmark, September 2001.

[14] J. Lacki, J. Niemela, and J. Lempiainen, "Optimization of Soft Handover Parameters for UMTS Network in Indoor Environment", Msc thesis, Institute of Communications Engineering, Tampere University of Technology, Finland, 2005.

[15] I. Siomina and Di Yuan, "Soft Handover Overhead Control in Pilot Power Management in WCDMA Networks", MSC thesis, Department of Science and Technology, Linkoping University, Norrkoping, Sweden, 2005.

[16] Yue Chen., "Soft Handover Issues in Radio Resource Management for 3G WCDMA Networks." Doctor of Philosophy, Department of Electronic Engineering Queen Mary, University of London, London, 2003.

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

[18] J. Laio and A. Wacker, ***Radio Network Planning and Optimization for UMTS***, 2nd ed., England, John Wiley & Sons Ltd, 2006.

[19] A. Richardson, ***WCDMA Design Handbook***, 1st ed. England, Cambridge University Press, 2005

[20] T. Rappaport, ***Wireless Communications: Principles and Practice***, 2nd ed. NJ USA, Prentice Hall, 2001.

[21] J. Yang, M. Ding, G. Mao, Z. Lin, D. Zhang, and T.H Luan, "Optimal Base Station Antenna Down tilt in Downlink Cellular Networks", Computing Research Repository, arXiv:1802.07479v1, Feb. 2018.

[22] Body of European regulators for Electronic Communication, "Common Position on monitoring mobile coverage", Riga Latvia, 2018.

[23] AWE Communications GmbH, Gartringen, Germany. *ProMan user manual, 4th ed.* 2014

[24] *Further advancements for E-UTRA physical layer aspects (Release 9)*, TR 36.814, 3GPP mobile competence center, Sophia Antipolis Cedex, France, 2010.

[25] *Technical Specification Group Services and System Aspects; End-to-end Quality of Service (QoS) concept and architecture*, TS 23.207 v6.1.0., 3GPP Mobile competence center, Sophia Antipolis Cedex, France, 2008

[26] *WCDMA Performance - Radio Access Network KPI Definition Manual for UMTS6.1*, V1.0. Huawei Technologies Co. Ltd., 2007

[27] *Radio Resource Control (RRC) Protocol Specification,* TS 25.331, v5.11.03, 3GPP mobile competence center, Sophia Antipolis Cedex, France, 2004.

[28] Dialogic, What Is Evolved Packet System (eps)?. Accessed on: Aug. 8, 2019. [online]. Available: https://www.dialogic.com/glossary/eps

[29] Altairhyperworks, WinProp-Propagation-Modeling. Accessed on: Sep. 11, 2019. [online]. Available: https://altairhyperworks.com/product/Feko/WinProp-Propagation-Modeling/

[30] Tech target, What is UMTS (Universal Mobile Telecommunications Service). Accessed on: July 12, 2019. [online]. Available: https://searchmobilecomputing.techtarget.com/definition/UMTS/

[31] Engineers Garage, 3G Technology. Accessed on Jun. 13, 2019. [online]. Available: https://www.engineersgarage.com/article_page/3g-technology/

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

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

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

[35] Addis Fortune, Mobile users surpass 50m. Accessed on May 30, 2017. [online]. Available: https://addisfortune.net/articles/mobile-userssurpasses-50m/