ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY

ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

Optimization of CDMA 2000 Cellular Mobile Radio Network, Case of Ethio Telecom's in Addis Ababa

By

Girma Dereje

Advisor

Dr.Yalemzewd Negash

A Thesis Submitted to the School of Graduate Studies of Addis Ababa

University in Partial Fulfillment of the Requirements for the Degree of

Masters of Science in Electrical Engineering

April, 2016

Addis Ababa, Ethiopia

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY

ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

Optimization of CDMA 2000 Cellular Mobile Radio Network, Case of Ethio Telecom's in Addis Ababa

By

Girma Dereje

Approval by Board of Examiners

Chairman, Dept. Graduate Signature

Committee

Dr.Yalemzewd Negash

Advisor Signature

Internal Examiner Signature

External Examiner Signature

Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

Girma Dereje ____________________

Name Signature

Place: Addis Ababa

Date of Submission: _________________

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

Dr. Yalemzewd Negash _______________

Advisor’s Name Signature

Abstract

This thesis describes the conceptual expressions required for network coverage and capacity limiting factors, examines service quality issues, and presents practical solutions to problems common to sub-optimality of Ethio Telecom cellular Code Division Multiple Access (CDMA) networks. The target of radio network optimization is to simultaneously maximize the system coverage and capacity. This thesis addresses the impact of antenna height, tilt and power on network coverage and system capacity. Moreover, the impacts of the aforementioned elements were investigated using MATLAB simulation tools. Accordingly the goal of the investigation is to have as high signal strength as possible in the area where the cell should be serving traffic.

The paper also exposes the work carried out via drive test on selected sites located at Addis Ababa, and presents optimization done and recommendation given to improve network coverage and capacity of the cited area.

Trade off between several system parameters such as operating frequency, voice activity factor, Uplink threshold, interference factor, data rate and bandwidth are considered to optimize the capacity and coverage of the network. Since, managing system interference by precise power control is a very critical concept for CDMA; reverse link interference analysis, and their effects are also studied.

Key Words - Capacity, CDMA, Coverage, Optimization, Bandwidth, Reverse link

Acknowledgment

The highest praise belongs to the almighty God the Father, whose guidance and care are special for me, for granting me life and health to complete this thesis.

I am deeply grateful to my advisor, Dr Yalemzewd Negash for his guidance and invaluable support during my work. I thank him for his encouragement during the course of this work and for various suggestions improving the quality of this thesis.

I am also very grateful to Melese Fentaye and Gebremedin Woldemariam of Ethio-Telecom, CDMA Optimization Section, for the numerous discussions and their fruitful collaboration. Further I thank them for their continuous technical support and for providing valuable statistical advice and guidance. And also staffs from NNOC RAN Network Activity piloting section were very helpful.

Last, but not least, I would like to thank my parents and family for the tremendous support during my studies. Without their assistance I wouldn't have reached my goals. Finally, with my love and gratitude, I want to dedicate this thesis to my mother, Belayinesh Oljira for her unselfish devotion to me throughout my life and for setting an example to me of living by one's principles.

Table of Contents

List of Tables

List of Figures

Abbreviations

3G	Third Generation
3GPP	Third Generation Partnership Project
BSC	Base Station Controller
BTS	Base Transceiver Station
CDMA	Code Division Multiple Access
CPICH	Common Pilot Channel
DL	Down link
ETC	Ethiopian Telecommunication Corporation
EVDO	Evolution Data Optimized
FER	Frame Error Rate
GSM	Global System for Mobile Communication
HF	High Frequency
HSDPA	High Speed Downlink Packet Access
IEEE	Institute of Electrical and Electronics Engineering
IID	Independent and Identically Distributed
IS	Interim Standard
KPI	Key Parameter Indices
LS	least squares
LCH	lost call held
MSE	Mean Square Error
MMSE	Minimum Mean Square Error
MS	Mobile Station
OVSF	Orthogonal Variable Spreading Factor
PCH	Physical Channel

SCH	Synchronous Channel
P-CPICH	Primary Common Pilot Channel
QoS	Quality of Service
RF	Radio Frequency
RAKE	Radio Activated Key Entry
RBS	Radio Base Station
RSCP	Received Signal Code Power
RSSI	Received Signal Strength Indicator
R-FCH	Reverse Fundamental Channel
R-PICH	Reverse Pilot Channel
RNC	Radio Network Controller
RRM	Radio Resource Management
S-CPICH	Secondary Common Pilot Channel
SHO	Soft Hand Over
UL	Upper Link
UMTS	Universal Mobile Telecommunication System
WLAN	Wireless Local Area Network
ZTE	Zhongxing Telecommunication Equipment

1. Introduction

The increasing use of radio communication throughout Europe and subsequent congestion of frequency spectrum resulted in the introduction of the cellular system of communication for commercial operation in 1992 [1]. The cellular network requires that a coverage area be divided into different cells and sectors using the principle of frequency reuse. The many advantages of the cellular network over its land line both for the subscriber and service providers has led to unprecedented patronage and hence increase in mobile phone users, making cellular telephony the economically most important form of wireless communications world-wide.

Development of the third generation (3G) systems, such as code division multiple access (CDMA) – including 2000 series that utilizes CDMA as an underlying channel access method provided connectivity to packet data networks via cellular systems while increasing voice capacity. As one would expect, many of the rapidly growing internet applications and services are finding their way into the mobile wireless domain and taking advantage of the 3G system. Services such as real time streaming video and music, and online interactive gaming are just a few examples of services whose popularity is growing beyond expectations. Hence, services of this nature have challenged 3G networks standardization capable of providing increase data throughput. The 3G networks may also be referred to as universal mobile telecommunication system (UMTS) [1].

Spectrum and power are a valuable and limited resource. Therefore for an operator, cost effective improvement in capacity is always an important goal. Capacity gain, both for voice and new data services, is crucial for an operator’s competitiveness. It is possible to achieve significant capacity improvements in existing networks without deploying additional carrier and base stations or drafting new standards. By following proper *radio frequency* (RF) network planning and optimization techniques; CDMA operators would see immediate benefits on their network capacity. CDMA is a digital cellular technology that uses spread-spectrum techniques [2]. It does not assign a specific frequency to each user. Rather, every channel uses the full available spectrum. Individual conversations are encoded with a pseudo-random digital sequence.

Optimization of the radio coverage and capacity entails operating the network to its optimum (best) output state. Optimization is the process of adjusting the inputs to or characteristics of a device, mathematical process, or experiment to find the minimum or maximum output or result [2]. It is an established fact that an optimized network performs better and subscribers notice the difference, hence operators have been investing in and upgrading their networks to meet demand, since they realize that their success will be based on a differentiated service quality, attractive services, and a good value proposition [1].

Radio planning and coverage optimization are critical issues for service providers and vendors that are deploying third generation mobile networks and need to control coverage as well as the huge costs involved. Due to the peculiarities of the Code Division Multiple Access (CDMA) scheme used in 3G cellular systems like UMTS and CDMA2000, network planning cannot be based only on signal predictions, and the approach relying on classical set covering formulations adopted for second generation systems is not appropriate.

The objective of network planning and optimization is to maximize the coverage and capacity, and the quality of service. However, in the 3G planning, since all carriers in the network use the same frequency range, frequency planning is not required.

Throughout this thesis I focus on the problem of coverage and capacity optimization in CDMA networks. The goal is to improve the capacity and coverage of the network, measured as served users, only by changing the base station parameters. The focus is on the optimization of design parameters and system configuration parameters. These parameter adjustments improve the CDMA radio network capacity and coverage by means of reducing inter-cell interference, achieve cell load sharing, and optimize base station power resources.

1.1 Radio Network Planning and Optimization

With new wireless communication technologies and the increasing size of radio networks, the tasks of network planning and optimization are becoming more and more challenging. This is firstly because the radio resource is scarce these days due to the increasing number of subscribers and the many different types of networks operating within the limited frequency spectrum. Secondly, deploying and operating a large network is expensive and therefore requires careful network dimensioning to ensure high resource utilization. As a consequence, manual network design and tuning for improving radio resource allocation are most likely to fail in current and future networks. This necessitates developing automated tools and optimization work that are able to tackle the difficult task. Furthermore, radio network planning and resource optimization can clearly benefit from the well-established optimization theory due to similarities in the objective-oriented way of approaching a problem, selecting the best solution from a number of possible solutions and dealing with many restrictions. In fact, many of the network planning and resource optimization problems can be viewed as specific applications of classical optimization problems.

In this thesis, optimization is considered as the main approach to designing and improving performance of wireless networks such as Universal Mobile Telecommunications System (UMTS), Wireless Local Area Networks (WLANs) and ad hoc networks. The goal is to identify relevant problems for each of the technologies, formalize the problems, and find reasonable solution approaches. First, however, we will discuss what radio network planning and optimization are about, the type of problems they typically address and the typical optimization techniques that can be utilized to solve these problems.

1.1.1 Planning, Optimization or Both?

The tremendous popularity of wireless networks has attracted the attention of many researchers into planning and optimization of wireless networks and radio resources. *Network planning* refers to the process of designing a network structure and determining network elements subject to various design requirements. Network planning is associated with *network dimensioning* and *detailed planning*, i.e., two network life phases both of which are very important since an implemented plan imposes further hard constraints on network performance.

Network optimization amounts to finding a network configuration to achieve the best possible performance. *Network optimization* is about maximizing capacity, reducing associated cost, and enhancing service quality.

The applicability of optimization techniques for ensuring good network performance is quite intuitive, both for planning a network and/or radio resources, and for optimizing them during operation and maintenance, provided that a reasonable trade-off between the model complexity and reality can be found. Moreover, due to network complexity, its size, and the necessity of dealing with many factors and control parameters, the planning and optimization tasks are often beyond the reach of a manual approach. As a result, the latest trend is *automated wireless network planning and optimization*, initiated by operators of cellular networks but well spread in industrial and research societies. The trend implies using computer systems to generate network design decisions with the minimum amount of human assistance. Such planning systems can clearly benefit from incorporating different optimization modules implementing optimization algorithms. For automated optimization, optimization algorithms are not just a part of the system but are the core of the system. In addition to making the network design process time-efficient, planning and optimization tools can significantly reduce network deployment, operation and maintenance costs.

1.2 Motivation for this Thesis

Ethiopia is one of the last countries in Africa allowing its national telecom, Ethio Telecom (ETC) a monopoly on all telecom services including fixed, mobile, internet and data communications. This monopolistic control has stifled innovation and retarded expansion. A recently expired management contract with France Telecom dramatically improved performance for ETC though there remain weaknesses in quality of service.

Although there is considerable investment in telecoms services, the sector is heavily facing challenges in providing attractive data and communication services. Most of the technologies deployed have been provided by ZTE and Huawei. Although a number of major contracts have been signed with Chinese vendors since into 2013, the country’s mobile penetration remains one of the lowest in the world. Nevertheless, growth is strong and enormous growth potential remains. Albeit from a low base, mobile penetration is rising and the sector continues to benefit from the poor fixed-line infrastructure which has promoted mobile alternatives as the only viable, or robust, telecoms option in many areas. The country's broadband market is also set for a boom following massive improvements in international bandwidth, national fiber backbone infrastructure and 3G mobile broadband services. After years of low uptake due to prohibitive pricing, retail prices are now comparable to other markets in the region that are already more developed.

1.2.1 Statement of the problem

The scarcity of radio spectrum in wireless network and the ever increase in the network users leaves the communication channels so crowded. This introduces interference in the entire communication system thereby degrading the Quality of Service (QoS) and system capacity. Therefore there is the need to examine the possible options for increasing the capacity of the available radio frequency by reducing interferences that exist in the system. This led to the advent of properly optimizing key radio network configuration and system parameters. These techniques are aimed at maximizing the available radio frequency spectrum and coverage. CDMA came to the lime light as a result of the need to accommodate the requirements of the third generation (3G) wireless system in which high quality data, throughput, multimedia, streaming audio, streaming video and broadcast-type services to users are supported. CDMA, being an interference limited mode of access technology system utilizes its ability to provide the entire available spectrum for communication to its teaming users as an improvement to the existing TDMA system. The interference limited nature of CDMA scheme in the entire cellular system as a result of large number of users accessing the network simultaneously need much to be desired in terms of network capacity improvement.

Slow network response times, low and unreliable connections, call setup failure, poor voice quality, low data rates, dropped data and calls, unable to download software, pictures and videos are just some of the problems often reported from the customers and undesirable characteristics of a network that is strained to its limits.

Complaints most of the time reported from the customer:

- Signal available but cannot originate calls (unable to make outgoing call and receive)
- Calls cut off frequently and voucher card recharging problem
- Difficult to originate Calls during peak time (after 9:00 PM)
- Initially enough signal available but latter reduced
- Echo problem
- Balance lost

Users desire to utilize a high data rate communication and quality of service fully operational indoor and outdoor. Thus, Mobile network has to be planned and optimized in order to reach these requirements. So, cellular network operators must periodically optimize their networks to accommodate traffic growth and performance degradation. Optimization action after service rollout is to correct the expected errors in network planning and to achieve improved network capacity, enhanced coverage and quality of service.

1.2.2 Contribution of this thesis

The main contribution of this thesis is to propose the way to increase capacity and improve coverage in CDMA cellular network.

There had been astronomical increase in the number of mobile users in recent times. Investigation had shown that these increased numbers of mobile users contribute high percentage of interferences that degrades the Quality of Services (QoS) in wireless network. Hence, interference is the most limiting factor of improved capacity in CDMA cellular network and has been one of the problems militating against the high efficiency of any mobile network. In effect, the scarcity of radio frequency spectrum and the ever increasing network users has necessitated the need to adopt some optimization work. This paper therefore analyses interferences in a CDMA with special emphasis placed on Adjacent Channel Interference (ACI). The CDMA system used in this study is Ethio Telecom, one of the leading mobile wireless networks in Ethiopia.

1.3 Objectives of this thesis

The objectives of research in this thesis can be divided as follows:

1.3.1 General Objectives

- The main objective of this study is to present effective method of performing coverage and capacity optimization within a CDMA network of Addis Ababa.
- Analyzing the possible sources and factors that contribute to performance degradation and possible techniques to mitigate their effect and indicate the most important performance measures to be employed.

1.3.2 Specific Objectives

- Investigating traffic growth and area of congestion of Ethio Telecom's CDMA 2000 network.
- Identifying the key system configuration and design parameters and investigating their influence on network capacity.
- Studying inconsistencies or limitations in current overall network design, quality, performance and process, and identifying and characterizing the areas where improvement should be achieved.
- Different issues, findings, trials and improvements will be investigated and finally, observation or recommendations will be given.
- The various ways of ensuring or maintaining radio parameters at their standard thresholds to enhance the network performance and to reach an improvement in capacity of the system in a short time will equally investigated.
- On the other hand, detail analysis of effects of other-cell interference on coverage and capacity will be studied.

1.4 Literature review

Optimization is needed, both in the planning stage to optimize the network configuration for investment saving as well as after the deployment of the network to satisfy growing service demand [7, 8]. There is some published research [1, 4, 5, and 6] regarding various methods and algorithms for the individual control of base station parameters such as CPICH (Common Pilot Channel) power and antenna down tilt settings, which are the two most common optimization parameters that have significant influence on network capacity. In [4] different algorithms are researched and evaluated on two different network scenarios and planning tools. The evaluation of the network is done by looking at the Key Performance Indicators (KPI) [1] of the RAN (Radio Access Network) in the output of the network simulator. Careful configuration of the many network and cell parameters is required and crucial to the network operator, because they determine the capability to provide services, influence the quality of service (QoS), and account for a major portion of the total network deployment and maintenance costs [6]. Love et al. in [5] demonstrated that a rule-based optimization technique for setting pilot power levels significantly outperforms a manually-designed solution in terms of network cost. In [21], Zhu et al. studied by simulations load balancing by controlling CPICH power and proposed a set of key performance indicators (KPIs), among which are network throughput, DL load factor, DL call success rate, and DL bad quality call ratio, which have to be monitored when adjusting CPICH power. In [23], Valkealahti et al. presented a cost minimization approach that was implemented in a network simulation tool and studied by simulations. A CPICH transmit power tuning algorithm for equalizing cell load while ensuring sufficient coverage in an irregular macro cellular system was proposed by Ying et al. in [22]. In [24], Kim et al. presented a problem of pilot power minimization subject to coverage constraints and a heuristic algorithm that adjusts the pilot power for one cell in each iteration. Another approach for load balancing based on the simulated annealing optimization technique was presented by Garcia-Lozano et al. in [25], where the authors aimed at finding a CPICH power setting that minimizes the total UL transmit power and ensures the required coverage degree.

1.5 Scope

CDMA Network Optimization in general is a large and demanding process that involves a trade-off between many factors, such as service coverage, network capacity, quality of service (QoS), equipment costs, and expected revenues from network operation. In order to limit the scope of this thesis, the main focus has been on the actual coverage and capacity optimization analysis, service quality issues, and practical solutions to problems common to sub-optimality of CDMA networks for selected sites.

1.6 Methodology

The process of optimization is a continuous process. It is carried out from time to time until the desired network performance threshold is attained. The performance of a network is expressed by values of some certain parameters called Key Parameter Indices (KPI). Thus, this thesis is entirely based on books on CDMA Network Optimization, 3GPP standardization documents, different IEEE articles and journals, previous studies on this subject and known simulators.

The methodology will have the following distinct steps:

Traffic data collection and analysis

- Traffic data collection, analysis and interpretation based on the measurement statistics. Study the relevant performance parameters from the BSC & BTS of the currently operating CDMA system.

Mat-lab Simulation

- Based on collected data and mathematical expressions, coverage and capacity simulation works are carried out for the selected deployment area or sites.

1.7 Thesis outline

This thesis has the following structure: Chapter one presents the objectives, motivation, methodology and a short introduction with problem explanation. Beside a short overview of technical challenges in CDMA Network Optimization is presented. Chapter 2 presents the CDMA radio network coverage and capacity limiting factors. For the several limiting reasons possible solutions are given. In Chapter 3 the parameters, which are used during this thesis for optimizing the coverage and capacity in a CDMA network, are described in more detail. Further, the influence of these parameters on the capacity in the network is explained. Chapter 4 presents power control in reverse and forward link along power control management in CDMA. In Chapter 5 the developed MATLAB routine for simulation are explained in detail and presents some results achieved with these MATLAB routines. Finally, Chapter 6 summarizes and concludes the thesis and gives a brief outlook on possible future work.

2. Coverage and Capacity limiting Factors

2.1 Introduction

Unlike GSM, the coverage and capacity improvement methods cannot be separated anymore in the CDMA system. There is always a tradeoff between coverage and capacity. Some of the improvement methods enhance the coverage at the cost of capacity, while others improve capacity, but at the same time the coverage decreases.

In CDMA the network coverage and capacity can be either uplink or downlink limited. It is generally accepted that service coverage is uplink limited. However, system capacity may be either uplink or downlink limited depending upon the system configuration and the traffic profile. In rural environments, where the network is normally planned with relatively low uplink load, the scenario is typically capacity limited in the uplink. A downlink capacity limited scenario is more likely in an urban scenario, where the network is planned for higher uplink load to increase the system capacity [4].

When a cell's capacity limitation is reached, additional users cannot be admitted to the system and, therefore, they are put to "outage". Outaged users are within the coverage of the cell, but not able to access the network services. Thus, as the number of users at outage increases, the network capacity decreases. The outage problems can be managed by radio resource management (RRM) and optimization of the base station parameters. Therefore, understanding and identifying the limitations is important for the development of optimization strategies for increasing coverage and capacity effectively.

This chapter provides the basis for understanding the reasons for coverage and capacity limited scenarios both in the uplink and downlink. Further, the corresponding solutions for the enhancement of network coverage and capacity are presented.

2.2 Uplink and Downlink Coverage limited Scenarios

The majority of existing literature makes the assumption that service coverage is uplink limited [4]. In general this is true; though it is fairly easy to identify scenarios where service coverage is downlink limited, for example when the data rate is asymmetric with more data in the downlink combined with a limited base station transmit power capability. The simplest method for studying service coverage performance is using a link budget. For the identification, which parameters need to be improved to enhance service coverage performance, the link budget is also very useful.

Techniques, which require additional investments for improving the service coverage are active antennas, mast head amplifiers, higher order receiver diversity, increased sectorization, repeaters and smart antennas. Some of these techniques improve coverage, but at the cost of capacity. However, other techniques like smart antennas simultaneously improve both coverage and capacity.

Link budgets for a CDMA system follow the same principles as those for GSM. The main differences are the inclusion of processing gain, E_b/N_t requirement, soft handover gain, target uplink cell loading and a headroom to accommodate the fast power control loop. In the link budget the target loading is the main capacity related parameter. A low value for the target loading corresponds to a larger cell range, but a lower cell capacity.

Improving any of the parameters in the link budget will lead to an improvement in service coverage performance. However, improving service coverage leads to a greater average base station transmit power requirement per downlink connection.

If the system capacity is uplink limited, then this is of no consequence. Although, if the system capacity is downlink limited, then improving service coverage will lead to a loss in system capacity. A different approach would be to improve the E_b/N_t performance. Then, it is possible to simultaneously enhance both service coverage and system capacity.

2.3 Uplink Capacity limited Scenarios

In the uplink, there are two possible limiting factors for uplink capacity limited systems. One reason could be that the mobile doesn't have enough transmit power to achieve the required bit energy to interference plus noise density ratio (E_b/N_t) to access the network services. An uplink capacity limited scenario can also occur when the maximum uplink load is reached and therefore no additional users can be accepted in the system. The traffic associated with an uplink capacity limited scenario is generally relatively symmetric.

I) Insufficient Uplink Power

The maximum allowed transmit power of a mobile must be enough to fulfill the E_b/N_t requirement at the base station in order to access the network services. The transmit power $P_{TX,MS}$ needed for the mobile is calculated using Equation (2.1) and compared to the maximum allowed.

$$P_{TX,MS} = \frac{N_O.L_P}{v.(1-\eta_{UL}).(1+\frac{W}{R.\rho.v})} \tag{2.1}$$

Where N_O is the background noise, L_P is the propagation loss between the mobile and the base station, R, ν and ρ are the bit rate, service activity and uplink E_b/N_t requirement of the chosen service respectively, W is the CDMA chip rate and η_{UL} is the uplink loading.

Hence, if the mobile fails to fulfill the required E_b/N_t, the RNC commands the mobile to increase its transmit power through the closed loop power control algorithm, which is based on the received power measured at the base station. If this is not possible, because the maximum transmit power of the mobile is achieved, the mobile is put to outage.

From Equation (2.1) we can see that the required transmit power of a mobile is directly proportional to the path loss. Consequently, this power level could be reduced by decreasing the path loss, e.g. by adjusting the antenna down tilt or the antenna azimuth.

II) Uplink Cell Load Limitation

An uplink capacity limited scenario is likely to occur in environments where the capacity requirements are relatively low and the network has been planned with a low uplink cell load to maximize cell range and thus reduce the requirements for the sites. The maximum permissible level of uplink cell load $\eta_{UL\,threshold}$ determines the interference margin that appears in any link budget calculation. The greater the cell loading, the greater the required number of sites, as well as the higher potential capacity per site. The traffic in an uplink capacity limited scenario is generally relatively symmetric. The uplink load equation is defined as Equation (2.2) [4]

$$\eta_{UL} = \sum_{k=1}^{K_n} \frac{1}{\left(1 + \frac{W}{\rho_k . R_k}\right)} . (1 + i) \qquad (2.2)$$

Where K_n is the number of mobiles connected to base station N. R_k and ρ_k are the bit rate and E_b/N_t requirement from the user k of the chosen service, respectively. W is the CDMA chip rate and i is the other-to-own cell received power ratio.

In an uplink capacity limited system, the capacity per cell is directly proportional to the maximum permissible level of uplink cell load [4]. Each mobile which establishes a connection with the same E_b/N_t requirement and activity factor, increases the cell load by the same amount. Doubling the maximum cell load $\eta_{UL\,threshold}$ results in doubling the cell capacity for an uplink limited scenario. The impact upon cell range is dependent upon the absolute levels of the cell load. The relationship between the cell load and the maximum allowed propagation loss is exponential [4]. In Equation (2.3) the relationship between the uplink cell load η_{UL} and the resulting increase in receiver interference floor L is shown.

$$L = 10 \cdot \log_{10}(1 - \eta_{UL}) \qquad (2.3)$$

As η_{UL} achieves 100 %, the receiver interference floor increases without limit. However, this condition in practice can never occur, because the mobiles have a finite transmit power capability.

When the maximum uplink load of a cell is reached, $\eta_{UL} \geq \eta_{UL\ threshold}$ (where $\eta_{UL\ threshold}$ is the planned maximum permissible level of uplink cell load), any additional users will be set to outage even though the users would have enough transmit power to access the network services.

In the following list, the reasons why the maximum uplink cell load is reached are summarized:

- The network is planned with a too low uplink cell load η_{UL}.
- High base station transmits power capability.
- Relatively symmetric traffic (e.g. speech users).

For a uplink capacity limited scenario, more users can be admitted into the system by shrinking the planned service coverage area of the cells (by the use of down tilting the antenna) so that the mobiles at the cell boundaries handover to adjacent cells that have lower traffic density to achieve load balancing within the network. As a result, the overall network capacity will be improved.

2.4 Downlink Capacity-limited Scenarios

A downlink capacity limited scenario occurs due to several reasons: the maximum transmit power of the base station is reached, OVSF code utilization reaches its limitation, or the requested code power for a mobile is higher than the permitted level.

Downlink capacity limited scenarios are likely to occur in suburban or urban environments, where the network has been planned to a relatively high uplink cell loading [4]. The traffic associated with a downlink capacity limited scenario is generally asymmetric, with a greater amount of traffic in the downlink.

I) Cell Power Limitation

Downlink capacity limited scenarios due to maximum cell power are likely to occur where the network has been configured with low base station transmit power capability, which may have been done in some circumstances to reduce the requirement for power amplifier modules. In Equation (2.4) the total required transmit power from the serving base station is shown.

$$P_T = \sum_{k=1}^{K_n} P_{TX,n} + P_{common} \tag{2.4}$$

In Equation (2.4) $P_{TX,n}$ is the required code power for the connected user n, and P_{common} is the overall transmit power of the common channels. In general, approximately 20% of the maximum cell power $P_{TX,max}$ is assigned to the pilot and common control channels. The remaining 80% is available to support traffic channel capacity.

When the base station reaches its maximum transmit power level, $P_T = P_{TX,max}$ (where $P_{TX,max}$ is the maximum base station transmitting power capability), it cannot allocate extra power to an additional user even if the cell is not highly loaded. In this case, additional users cannot be added without modifying the base station configuration.

All active users belonging to a cell, including those mobiles connected by soft handover share the total transmit power P_T. Hence, a lower average code power requirement $\bar{P}_{TX}$ ($\bar{P}_{TX} = \frac{1}{n}\sum_{t=1}^{n} P_{TX,n}$) results in a higher cell capacity. Furthermore, it is possible to increase the number of served users by reducing the soft handover overhead. Soft handover links only occur at the cell border, which experience maximum path loss and therefore require higher code power.

The capacity offered by each transmit power configuration $P_{TX,max}$ is a function of the traffic profile as well as the maximum propagation loss defining the cell range. The greater the propagation loss, the greater the average code power P_{TX} and the lower the cell capacity. In other words, we can say that the smaller the cell size the lower P_{TX} and the higher the cell capacity.

As we can see from Equation (2.4), a part of the total transmit power of the base station is assigned to the common pilot channel (CPICH) and the other common channels. Consequently, by reducing the CPICH power and the powers of the other common channels, more power will be available to support the traffic channel capacity.

In the following list the reasons, why the maximum transmit power $P_{TX,max}$ of a base station is reached, are summarized:

- The network is planned with a too high uplink cell load η_{UL}.
- Low base station transmits power capability.
- Greater traffic on the downlink (asymmetric traffic, e.g. data users).

II) Orthogonal Variable Spreading Factor (OVSF) Code Limitation

In CDMA spreading and scrambling operations are performed in two steps. The user signal is first spread by the channelization code, called orthogonal variable spreading factor (OVSF) code, and then randomized by the scrambling code. In the downlink, scrambling codes are used for the separation of the individual cells, which have maximum 512 available codes. The separation of the individual downlink connections for different users within one cell is done by the OVSF codes.

Channelization codes become the limiting factor under relatively high throughput scenarios [4]. This is likely to occur in either microcell or indoor scenarios, the cell range is limited and code orthogonality is high.

One possible solution to avoid OVSF code limitation is to reduce SHO links. Hence, the number of available OVSF codes for serving links increases. This is because SHO connections require independent channels from several base stations at the same time and therefore are reducing the available OVSF codes.

Another possibility when the channelization codes become the limiting factor would be to use a second scrambling code to introduce a second channelization code tree. The two code trees will not be orthogonal to another and so this will cause higher intra-cell interference.

III) Code Power Limitation

In the downlink, each dedicated link needs a certain transmit power to reach the E_b/N_t requirement for a sufficient connection to the mobile. In Equation (2.5) the required transmit power for a certain link is presented.

$$P_T \geq \frac{\rho \cdot \frac{R}{W}}{\sum_K \frac{\beta_k}{L_{P_k} \cdot (I_{tot} - \alpha_k \cdot I_k + N_{MS})}} \tag{2.5}$$

Where N_{MS} is the background noise level at the mobile station, I_{tot} is the total wideband interference power received at the mobile station, I_k is the total wideband power received at the mobile station from base station k, L_{P_k} is the link loss from base station k to the mobile station,

α_k is the orthogonality factor of cell k and β_k is the scaling factor (relative maximum link powers) for different base stations in the active set. This code power P_{TX} is limited per single traffic link. This limitation is defined as the maximum transmitted power $P_{TX,max}$ on one channelization code on a given carrier. If the code power P_{TX} requested by a mobile is higher than the permitted level ($P_{TX} > P_{TX,max}$), the mobile will not be admitted.

3. Key Optimization Parameters

3.1 Introduction

In this chapter the parameters, which are used in this thesis for optimizing the capacity and coverage in a CDMA network, are described in more detail. Careful configuration of the many network and cell parameters is required and crucial to the network operator, because they determine the capability to provide services, influence the quality of service (QoS), and account for a major portion of the total network deployment and maintenance costs. However, there are numerous configurable base station parameters which are multidimensional and interdependent, and their influence on the network is highly non-linear.

The following list shows the most important parameters:

- Antenna settings
    - Antenna azimuth
    - Antenna tilt
    - Height
    - Antenna pattern
- Transmit power level share
- Soft handover parameters
    - Active set size
    - Active set window

A CDMA system must be also optimized from a system point of view, so that the system can tolerate the maximum interference level. These system configuration parameters include user mobility, data rate, Band width, imperfect power control coefficient and other-cell interference factor.

All these parameters have a strong influence on the interference in the system and therefore on the amount of served mobile terminals (capacity of the network). The optimization investigations described in this section focus on optimizing transmit power as well as antenna height, antenna tilt and antenna azimuth. So, in the following a description of these four parameters is presented. Furthermore, the influence of these key optimization parameters on the network, especially on system capacity and coverage will be explained.

3.2 Antenna Parameters

The antenna parameters are the most important ones related to the interference situation in the network. Besides the height of the antenna and the used pattern, the azimuth angle and the elevation angle can be tuned. The height of the antenna as well as the antenna azimuth can only changed with a higher operating expense. However, changing antenna tilt and antenna pattern is associated with less effort.

3.2.1 Antenna Height

The antenna height is the basis of base station coverage area. If the antenna height is increased, path loss is lessened and on decreasing the antenna height path loss increases [6].

3.2.2 Antenna Azimuth

When adjusting the antenna azimuth, all three antennas are turned in the same direction at the same time, so that the spacing between them will be kept constant at 120^0, as shown in figure 3.1. The arrows symbolize the directions of the main beams of the antennas.

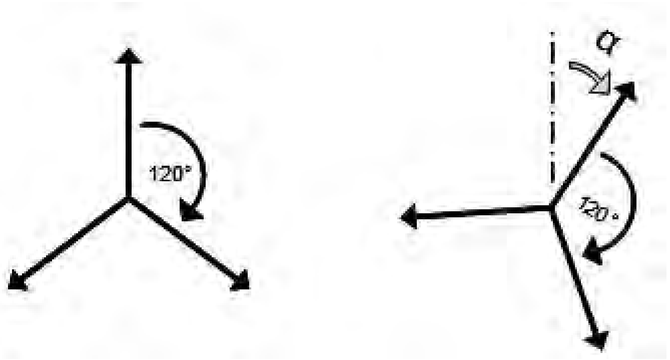


Figure 3.1: Adjustment of base station azimuth

For finding the optimum azimuth settings in a network, the interference has to be taken into account. The goal of the azimuth optimization in this work is to reduce the intra- and inter-cell interference. As a result the capacity of the network will be increased.

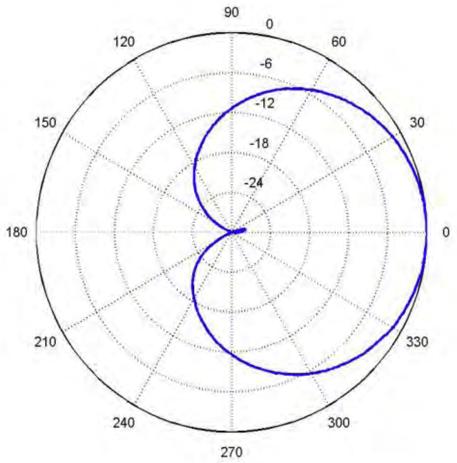


Figure 3.2: Horizontal pattern of base station antenna (in dB)

In Figure 3.2, the horizontal pattern of the used KATHREIN 739707 antenna is shown. The pattern shows a difference in antenna gain of about 6 dB between the main direction of the antenna (0^0) compared to an angle of $\pm 60^0$ (at this angle the adjacent sectors of this base station begin, and there the mobile stations will initiate a handover to the neighboring cell). Due to that difference of 6 dB, the direction of the main beam of the antenna is quite significant and thus it is important to adjust the azimuth of the antennas in order to reach the highest antenna gain for the users in the own cell, as well as the lowest gain (or highest attenuation) for the mobile stations located in neighboring cells. This way, less power is needed for covering the area, and therefore less interference is generated.

3.2.3 Antenna Tilt

The antenna tilt is defined as the elevation angle of the main beam of the antenna relative to the azimuth plane. Since the tilt is usually set in the direction down to the ground, the term down tilt is often used. A positive down tilt is defined as the negative elevation angle of the main beam of the antenna relative to the horizontal plane (see figure 3.3). The service area in figure 3.3 is the own cell and the far-end interference area is the area of the adjacent cells.

The antenna down tilt can be implemented in a mechanical way as well as by electrical tilting. These two tilting mechanisms have different effect: When using mechanical tilting, the antenna pattern itself stays constant and is only tilted, while with electrical tilting the antenna pattern changes when adjusting the tilt. Figure 3.4 shows the used vertical antenna pattern.

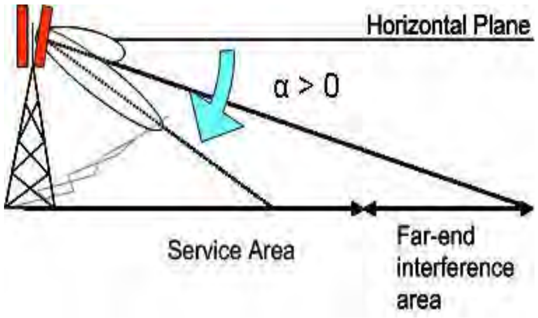


Figure 3.3: Adjustment of base station downtilt

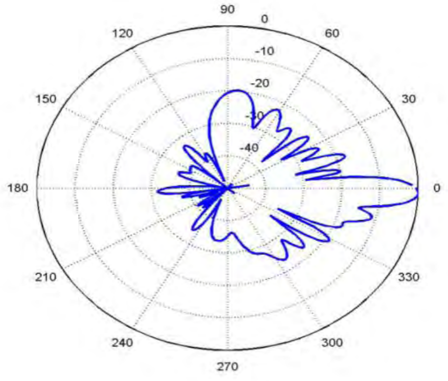


Figure 3.4: Vertical pattern of base station antenna (in dB)

Antenna downtilt is often used in mobile wireless systems, particularly in the CDMA network, where traffic in all cells is simultaneously supported using the same carrier frequency. The desired effect is a reduction of the other-to-own cell interference ratio $\imath$, which is defined according to [5] in Equation (3.1)

$$\imath = \frac{I_{oth}}{I_{own}} \tag{3.1}$$

In Equation (3.1) I_{oth} denotes the inter-cell interference (interference from the other cells) and I_{own} is the intra-cell interference (interference from the own cell).

By down-tilting the antennas, the other-to-own-cell interference ratio $\imath$ can be reduced: The antenna main beam delivers less power towards the neighboring base stations, and therefore most of the radiated power goes to the area that is intended to be served by this particular base station [14]. Due to the fact that the interference in the system is decreasing, the capacity increases and more users can be served in the network. However, down-tilting the antenna will also reduce the sectorization efficiency, which will decrease the cell capacity.

Both, other-to-own-cell interference ratio $\imath$ and sectorization efficiency affect the overall network capacity. According to [14], for small and moderate antenna downtilt angles, the improvement provided through inter-cell interference rejection dominates, and a net increase in capacity can be achieved. For larger downtilt values, the reduction of sectorization efficiency dominates, and the result is a net decrease in capacity.

Additionally, antenna tilt adjustment also affects the cell coverage area. Too much down-tilting causes that the service area could become too small and also holes in the coverage of the network can occur. Furthermore, if the down-tilting reaches a certain value, the interference in the neighboring cells increases again due to the side lobes of the vertical antenna pattern. In [16] it is shown that, for smaller inter-cell site separation, higher downtilt is required to mitigate the inter-cell interference. As the inter-cell site separation increases, smaller downtilt is advantageous, offering higher gains to distant users. Hence, the impact on the cell coverage area limits the tilt to reasonable values.

The simulation analysis of [15] shows that the optimum value for the antenna tilting depends on the propagation environment, the cell site, user locations, and the antenna radiation pattern. Furthermore, in order to achieve the highest number of served users, it is very crucial to effectively control the inter-cell interference and soft handover overhead. It also stated that due to the antenna radiation pattern side lobes and nulls, there could be some variations of i and coverage probability can occur as a function of the antenna tilting angle. In [17] it is demonstrated that antenna tilt tuning can also help to relieve congestion in hot-spot sectors and maintain the blocking probability at an acceptable level.

3. 3 Transmit Power Level

Controlling the transmit power of the mobile and base station reduces the system interference and thus can be used to reduce the cluster size if implemented properly. In practical cellular radio and personal communication systems the power levels transmitted by every subscriber unit are under constant control by the serving base stations. This is done to ensure that each mobile transmits the smallest power necessary to maintain a good quality link on the reverse channel. Power control not only helps prolong battery life for the subscriber unit but also dramatically reduces the reverse channel *C/I* in the system.

4. Power Control in CDMA Networks

This section presents the basic characteristics of a CDMA network which have direct effects on the network performance.

In CDMA, since all mobiles transmit at the same frequency, the internal interference of the network plays a critical role in determining the capacity of the network. The transmit powers of each mobile must be controlled to limit the interference.

Power control is basically needed to solve near-far problem. In order to reduce the near-far problem, the main idea is to achieve same received power level from all mobiles at the base station. Each received power should be at the minimum level that still allows the link to meet the system requirements such as E_b/ N_t. In order to receive the same power level at the base station, the mobiles that are closer to the base station should transmit less power than the mobiles far from the base station. In Figure 4.1, there are two mobiles of the cell A, A_1 which is closer to the base station and A_2which is far from the base station. P_r is the minimum signal level for required system performance. Therefore, the mobile A_2 should transmit more power than A_1 to achieve same P_r at the base station, $\mathrm{P}_{\mathrm{A}_2} > \mathrm{P}_{\mathrm{A}_1}$. If there was no power control, in other words their transmit power were the same, the received signal from A_1 would be much larger than A_2. Therefore, S/I would be low for A_2 and A_1 would not allow A_2 to have a reliable communication since they share the same spectrum band.

4.1 Reverse Link Power Control

Beside the near far effect described above, the immediate problem is to determine the mobile's transmit power when it first establishes a connection. Before the mobile has contact with the base station, it has no idea about the amount of interference in the system. Therefore, the mobile is in suspense about its initial transmit power. If the mobile attempts to transmit high power to guarantee the contact, it may introduce too much interference. On the other hand, if mobile transmits at lower power not to disturb other mobiles' connections, its power may not meet the required E_b/ N_t. As specified in IS-95 standards, the mobile acts as follows; when it wants to get in the system, it first sends signal called *access probe* with low power.

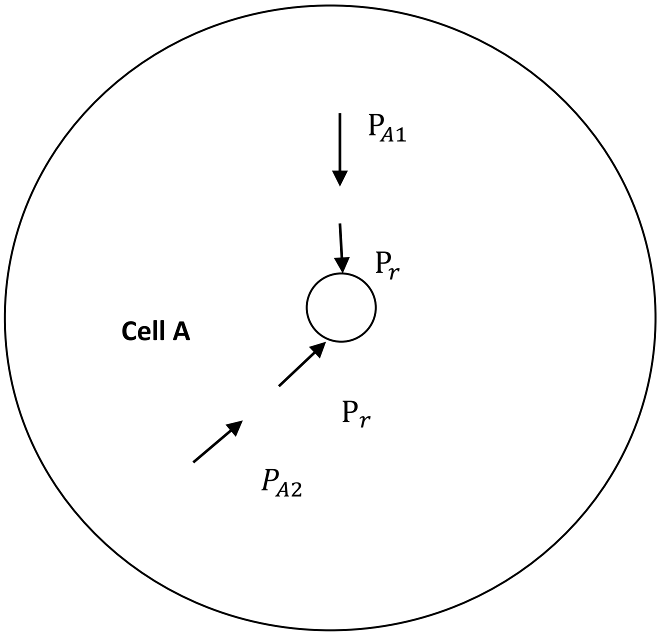


Figure 4.1: In CDMA, each users' transmit power is assigned by power control to achieve the same received power P_r at base station.

The mobile sends its first access probe, and then it waits for a response from base station for a time, if it does not receive any response, then second access probe is sent with higher power. The process is repeated until the base station responds. If the responded signal by base station is high, mobile understands that base station is closer and enters the network with low transmit power. Likewise, if the responded signal is low, mobile knows the path loss is large and transmits high power. In this operation, base station does not tell mobile its transmit power, but mobile estimates its own transmit power.

The process described above is called *open loop power control* since it is controlled by only mobile itself. Open loop power control starts when mobile first attempts to communicate with base station and continues during the connection. This power control is used to compensate for the slow varying shadowing effects. However, since the reverse and forward links are on different frequencies, estimating the transmit power due to the forward path loss of base station will not give the precise solution to power control. This power control will fail or be too slow for fast Rayleigh fading channels.

The *closed loop power control* is used to compensate for the fast Rayleigh fading. This time, mobile's transmit power is controlled by the base station. For this purpose, base station continuously monitors the reverse link signal quality and if the link quality is bad, it tells the mobile to power up, similarly if the link quality is very high, the base station command the mobile to power down.

4.2 Forward Link Power Control

Similar to reverse link power control, forward link power control is also needed to keep the forward link quality at a specified level. This time, mobile monitors the forward link quality and tells base station to power up or power down. This power control has no effect on near-far problem, since all signals fade together to the same power level when they arrive to the mobile. Briefly, there is no near-far problem in forward link. Figure 4.2 illustrates this.

IS-95 based CDMA networks have different link structures in forward and reverse links. The forward link consists of four different channels; pilot, synchronization, traffic and paging channels.

$$\mathrm{P}_{pilot} = 15\% - 20\%\ \mathrm{P}_{total}$$

$$\mathrm{P}_{sync} = 1.5\% - 2\%\ \mathrm{P}_{total}$$

$$\mathrm{P}_{paging} = 7\%\ \mathrm{P}_{total}$$

$$\mathrm{P}_{traffic} = 71\%\ \mathrm{P}_{total}$$

$$\mathrm{P}_{traffic/mobile} = \mathrm{P}_{traffic}/total\ number\ of\ mobiles \qquad (4.1)$$

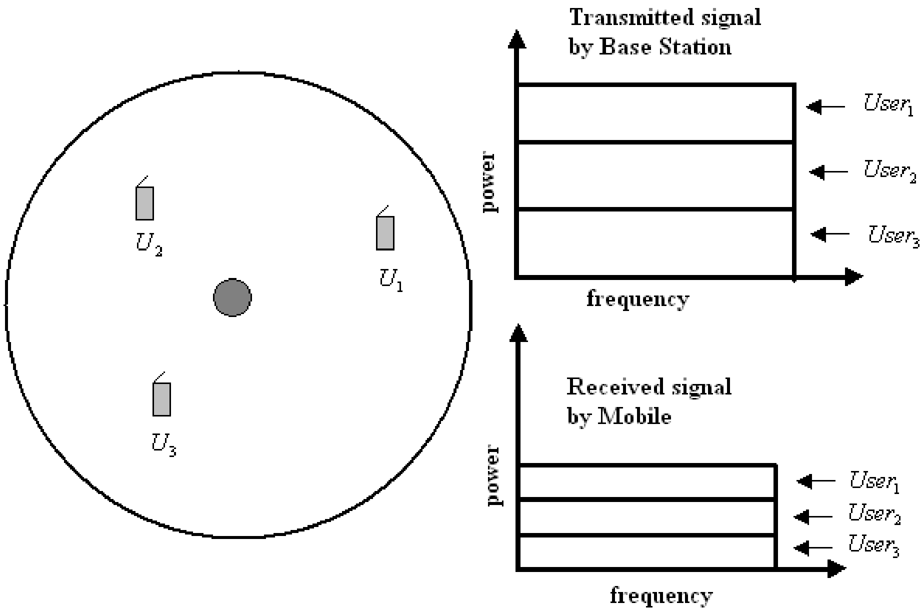


Figure 4.2: All signals from base station fade together to the same power level when they arrive to the mobile.

There is one pilot channel, one synchronization channel, seven paging channels and several traffic channels. Each of these forward link channels is spread orthogonally to form a composite spread spectrum signal to be transmitted by the base station. In Figure 4.3, the power ratios allocated to these different channels are shown.

In reverse link, there are two channels, one is access channel and other is traffic channel. There is no need to transmit a pilot signal from the mobile.

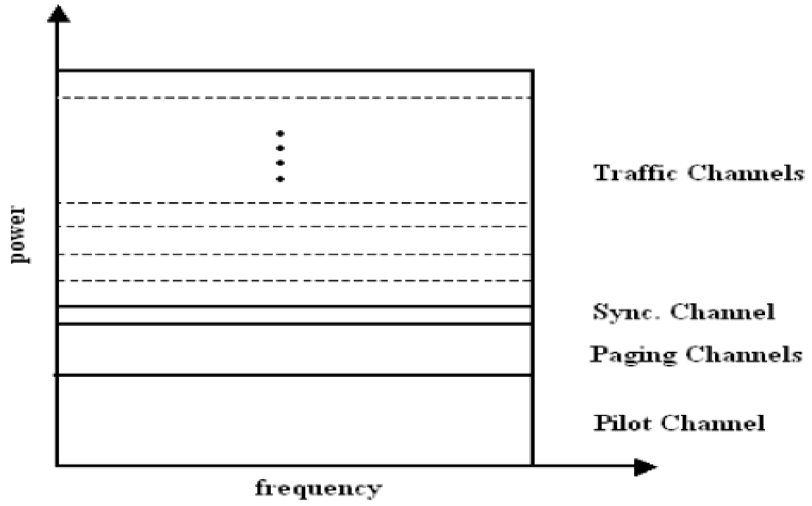


Figure 4.3: Forward link channels

4.3 Power Management in CDMA Networks

Each channel in a CDMA signal is spread by one of 64 orthogonal codes called Walsh codes, as shown in Figure 4.4.

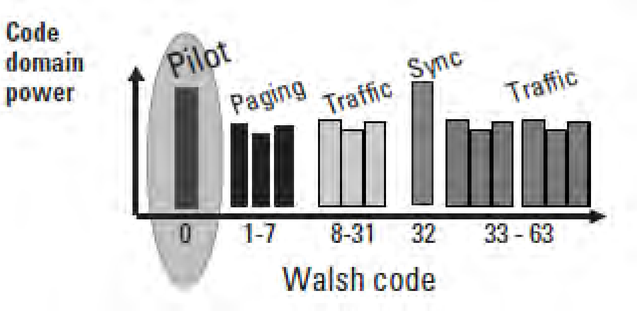


Figure 4.4: Walsh codes comprising CDMA signal

The Walsh codes spread the signal over a bandwidth range of approximately 1.25 MHz. Most of the Walsh codes are used for data and voice traffic channels. The other codes are dedicated to pilot, paging and sync channels. The paging channels (Walsh codes 1 through 7) are used by the base station to alert the phone. In most networks, only Walsh code 1 is used for paging, making codes 2 through 7 available for traffic use. The sync channel (Walsh code 32) is used to provide timing to the phone.

To understand how the pilot signal works, it is necessary to understand short codes. The last step in generating the CDMA signal in the base station is modulation of the data by a pseudo-random sequence called a short code. The short code is identical for all base stations, with one exception. Each base station has a different phase delayed version of the same short code. This is usually represented as a time shift measured in chips (A chip is approximately 0.8 microseconds). This time offset in the short code is what uniquely identifies each base station. The time offset essentially acts as a color code. The pilot channel (Walsh code 0) is an unmodified version of the short code just described. Therefore, it is identical for every base station, with the exception of the timing of its short code generator. It is this pilot channel timing offset that is used by a mobile phone to identify a particular base station, distinguish it from the others, and thereby communicate with the proper base station.

4.3.1 Common Pilot Channels (CPICH)

The Common Pilot Channel, or CPICH, is a fixed rate (30 Kbps) downlink physical channel that carries a continuously transmitted pre-defined bit/symbol sequence [31]. The CPICH is an unmodulated code channel, which is scrambled with the cell-specific primary scrambling code. The function of the CPICH is to aid the channel estimation at the terminal for the dedicated channel and to provide the channel estimation reference for the common channels when they are not associated with the dedicated channels or not involved in the adaptive antenna techniques. Figure 4.5 shows the frame structure of a CPICH. The CPICH uses the spreading factor of 256 (which is the number of chips per symbol), and there are 10 pilot symbols in one slot. This gives 2560 chips per slot and thus 38400 chips per radio frame of 10 ms.

The common pilot channel in CDMA consists of two sub-channels, the primary CPICH (P CPICH) and the secondary CPICH (S-CPICH), both have the same frame structure shown in Figure 4.5.

The difference is that the P-CPICH is always under the primary scrambling code with a fixed channelization code (code zero) allocation and there is only one such channel in a cell. Since there are 512 different primary scrambling codes available, typically it is possible to ensure that a single primary scrambling code is used only once in a particular area. S-CPICH may have any channelization code of length 256 and may be under a secondary scrambling code as well.

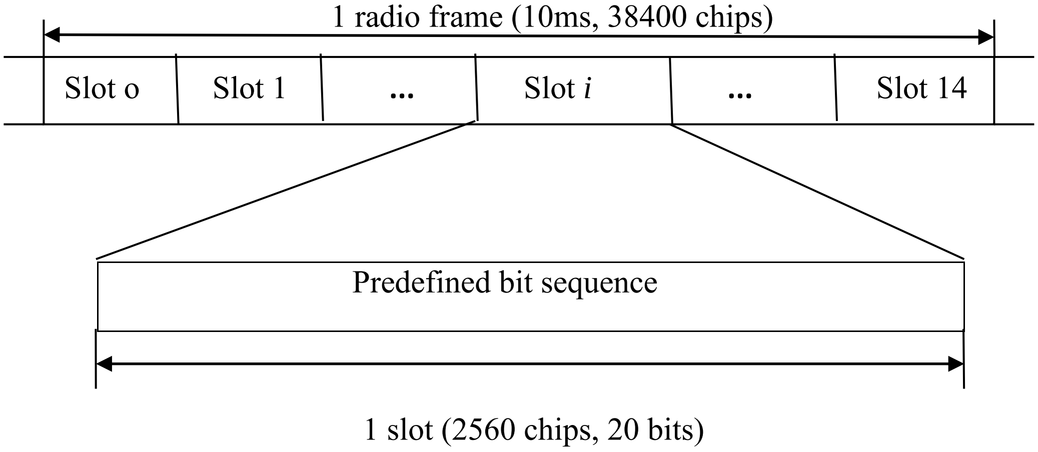


Figure 4.5: CPICH frame structure

Normally, each cell has only one CPICH, P-CPICH, and it is used for broadcasting the pilot signal over the cell. In some cases, a cell may have also several additional CPICHs, S-CPICHs. Similar to P-CPICH, a secondary CPICH provides a coherent reference for demodulation of other channels, but it is typically not broadcasted over the entire cell and is mainly used to support coverage in dedicated hot-spot areas that are served by narrow beam antennas. In this case, a dedicated area uses the S-CPICH, whereas the P-CPICH broadcasts the pilot signal over the entire cell. This is because the CPICH intended as a phase reference for another channel and the channel itself must use the same antenna.

The CPICH does not carry any higher layer information; neither is there any transport channel mapped to it. It may be sent from two antennas in case transmission diversity methods are used in the RBS. In this case, the transmissions from the two antennas are separated by a simple modulation pattern on the CPICH signal transmitted from the diversity antenna, called diversity CPICH. The diversity pilot is used with both open loop and closed loop transmit diversity schemes.

4.3.2 Common Pilot Power Management in CDMA Networks

Because of the potential downlink limitations in CDMA based networks and utilization of downlink pilots for cell synchronization and handover control, tuning of downlink related radio network configuration parameters are of critical importance. CPICH power optimization is used not only as a control parameter in the presented models but also as a measure of the amount of interference in the network when configuring RBS antennas.

The CPICH is very important for handover, cell selection and cell reselection. After turning on the power of the mobile station and while roaming in the network, the mobile measures and reports the received level of chip energy to interference plus noise density ratio (E_b/N_t) on the CPICH to the base station for the cell selection procedures. E_b is the average energy per pseudo noise (PN) chip, and N_t denotes the total received power density, including signal and interference, as measured at the mobile station antenna connector.

This E_b/N_t ratio is given by Equation (4.2),

$$\frac{E_b}{N_t} = \frac{RSCP_{CPICH}}{RSSI} \tag{4.2}$$

Where the received signal code power ($RSCP_{CPICH}$) is the received power of the CPICH measured at the mobile station. It can be used to estimate the path loss, since the transmission power of the CPICH is either known or can be read from the system information. The received signal strength indicator (RSSI) is the wideband received power within the relevant channel bandwidth in the downlink.

The cell with the highest received CPICH level at the mobile station is selected as the serving cell. As a consequence, by adjusting the CPICH power level, the cell load can be balanced between neighboring cells, which reduces the inter-cell interference, stabilizes network operation and facilitates radio resource management [19]. Reducing the CPICH power of one cell causes part of the terminals to hand over to adjacent cells, while increasing it invites more terminals to hand over to the own cell, as well as to make their initial access to the network in that cell.

During the radio network planning process, the CPICH transmit power of the base stations should be set as low as possible, while ensuring that the serving cells and neighboring cells can be measured and synchronized to and the CPICH can be used as a phase reference for all other downlink physical channels. Too high values of CPICH power will cause the cells to overlap and therefore create interference to the neighboring cells, called ’pilot pollution’, which will decrease the network capacity. Furthermore, the CPICH power is part of the total transmit power of the base station, which is generally limited. Thus, less CPICH power would provide more power for the traffic channels, and therefore increase the capacity. On the other hand, the mobile stations are only able to receive the CPICH down to a certain threshold level of E_b/ N_t , which determines the coverage area. Due to that fact, setting the CPICH power too low will cause uncovered areas between the cells. In an uncovered area, CPICH power is too weak for the mobile to decode the signal, and call setup is impossible. According to the specifications of the Third Generation Partnership Project (3GPP), the mobile must be able to decode the pilot from a signal with E_b/ N_t of -20 dB [18].

To make Equation (4.2) better understandable, the E_b/ N_t ratio can also be described with Equation (4.3).

$$CPICH_{E_b/ N_t} = \frac{\frac{P_{CPICH}}{L_P}}{\sum_{i=1}^{numBS_S} \frac{P_{TX,i}}{L_{Pi}} + I_{ACI} + N_O} \qquad 4.3$$

Where P_{CPICH} is the CPICH power of the best server, L_P is the link loss to the best server, $P_{TX,i}$ is the total transmit power of $BS\ i$, L_{Pi} is the link loss to base station i, I_{ACI} is adjacent channel interference, N_O is the thermal noise of the mobile and $numBS_s$ is the number of base stations in the network.

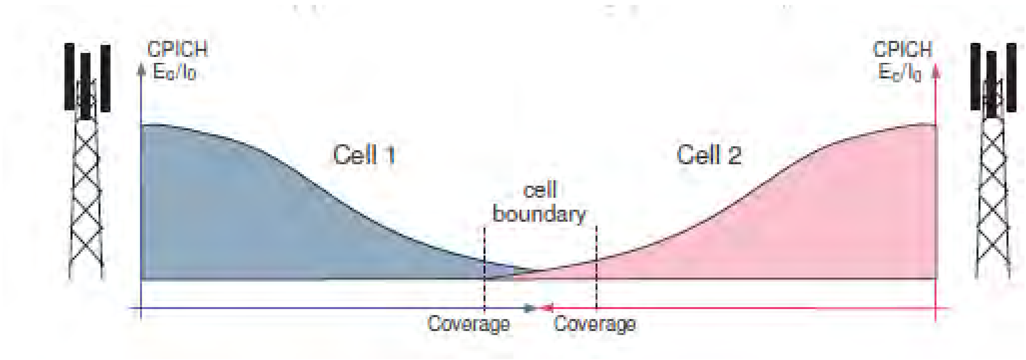
In general, a mobile terminal makes two types of measurements on CPICH. The first is CPICH Received Signal Code Power (RSCP) which is used for handover evaluation, downlink (DL) open loop power control, uplink (UL) open loop power control, and for estimating the path loss (because the transmit power of the CPICH is either known or can be read from the system information). The second measurement is the $CPICH_{E_b/ N_t}$, the ratio of the received energy per chip for the CPICH to the total received power spectral density at the antenna connector of the mobile terminal. The ratio is also often referred to as *carrier-to-interference ratio*, or CIR. This measurement is used for cell selection/re-selection [21, 20] and for handover evaluation [20], and it is the most important mobile terminal measurement in CDMA for the purpose of network planning since it typically has a good accuracy [22] and is used as the basic coverage indicator.

Cell selection is a procedure of choosing a cell for the mobile to camp on after a mobile terminal has switched on and has found a suitable network. The selection decision is made based on the measured E_b/ N_t values of the CPICH signals. Cell selection is preceded by *initial cell search* during which the mobile terminal tries to find a cell and determine the cell's downlink scrambling code. The scrambling code information is needed to be able to receive system information.

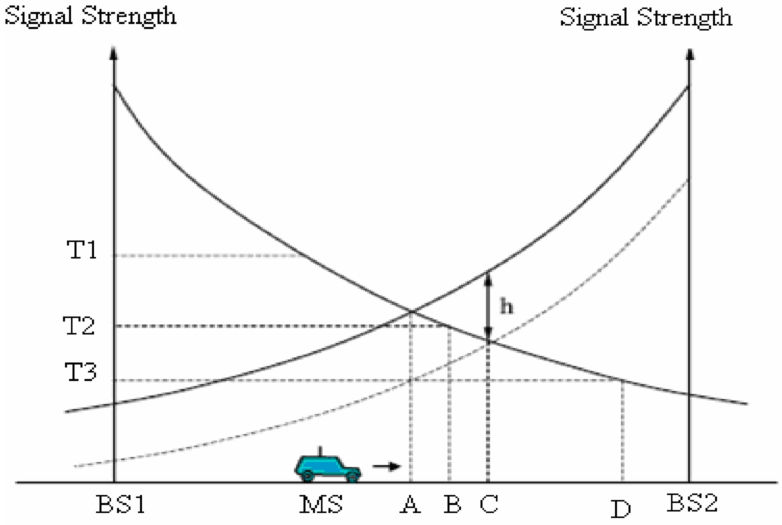
Cell search is also performed when a mobile terminal is in the active or idle modes (*target cell search*). Target cell search is used to determine handover candidate cells and is triggered when the network requests the mobile terminal to report *detected set* cells. On this request the mobile terminal shall search for cells outside the monitored and active sets that together contain cells continuously measured by the terminal. Moreover, the RNC sends a set of thresholds that are used when the mobile terminal measures the cells and decides whether the measurements should be reported to the RNC. Based on the reported measurements, the RNC decides whether to update the list of cells to be measured or not. *Cell reselection* procedure is responsible for guaranteeing the required QoS by always keeping the mobile camped on a cell with good enough quality. Based on measurements of the monitored and active sets, the mobile terminal ranks the cells by the cell-ranking criterion and reselects the best cell if the reselection criteria are fulfilled during a certain time interval. The quality of cells is determined based on $CPICH_{E_b/ N_t}$ measurements.

Soft/softer handover is a function in which the mobile terminal is connected to several RBSs at the same time. The decisions about triggering soft/softer handover (SHO) are based on the received signal strength or comparison of the $CPICH_{E_b/ N_t}$ values between RBSs as shown in figure below. The soft handover (SHO) area can also be controlled by the strength of the CPICH power. By reducing the CPICH power, the SHO areas will decrease. However, a certain amount of overlapping cell boundaries is necessary for mobiles near the cell border to perform SHO and to counteract fluctuations of receiving signal power.

We have discussed how the CPICH measurements are used in different procedures and have observed that the measurements play an important role for cell coverage. This also suggests that the CPICH measurements have a great impact on cell sizes and therefore can be utilized for controlling the load of a cell and load balancing among neighboring cells



(a) Two overlapping cells (smooth handover)



(b) Signal strength and hysteresis between two adjacent BSs for potential handoff

Figure 4.6: Handover operation and cell selection

Let us now examine the factors that define the CPICH quality. According to the definition of CPICH RSCP and $CPICH_{E_b/N_t}$ the list of the factors is as follows,

- CPICH transmit power,
- Attenuation between the antenna and user terminal,
- Interference on the same channel (total received signal power from own and other cells),
- Noise and adjacent channel interference.

Attenuation and the amount of received noise and adjacent channel interference depend on the environment and hardware. Downlink attenuation is also dependent on antenna configuration which, however, can be considered fixed in short-term planning. Interference on the same channel is mostly dependent on the amount of traffic since user traffic signals contribute to the total received signal power more than control channels. As a result, the CPICH transmit power can be viewed as an efficient and the only relatively autonomous factor for controlling the received CPICH signal strength, especially in highly loaded networks with constantly high interference. In a long run, antenna configuration can also be viewed as an effective source of improving the quality of the received CPICH signals due to interference reduction. Therefore, one of the extensions of the pilot power optimization problem studied in the thesis addresses joint optimization of CPICH power and RBS antenna configuration. Note, however, that finding an optimal (non-uniform) CPICH power setting in a network, even without considering antenna configuration, is not simple since this involves resolving a trade-off between power consumption and coverage. Challenges arising in pilot power control are discussed in the next section.

As conclusion, the level of the CPICH power is very important to reach high capacity in the system. Therefore, the CPICH power level is a key optimization parameter and included in the optimization strategies for the increase of the capacity in this thesis. The power levels of the other common channels (PCH, SCH ...) are typically set with respect to the CPICH power level.

4.3.3 Pilot Power Control Challenges

Pilot power control in CDMA networks is a crucial engineering issue which has been attracting the attention of researchers in industry and academia during the last several years. In CDMA network, adjusting the P-CPICH power levels allows us to control cell sizes, the number of connected users to a cell and to balance the traffic among the neighboring cells, which in turn allows us to regulate the network load. The goal of pilot power control is to ensure that all RBSs use just enough transmit power to guarantee the required coverage and QoS in the entire network.

Pilot power control always involves a *trade-off between the pilot power consumption and coverage*. The transmit powers of the downlink common channels are determined by the network. In general, the relation between the transmit powers between different downlink common channels is not specified by the 3GPP standard and may even change dynamically. Usually, as a rule of thumb, for the P-CPICH a transmit power of about 30-33 dBm, or 5-10% of the total cell transmit power capability, is allocated [23, 25]. In addition to P-CPICH, a cell uses a number of other common channels, and the transmit power of these channels is typically set in proportion to that of P-CPICH.

The total downlink transmit power is shared between the control and traffic channels. Obviously, the more power is spent for control signaling, the less power is left to serve the user traffic. Excessive pilot power can easily take too large proportion of the total available transmit power, so that not enough power is left for traffic channels although more mobile terminals may be willing to handover to the cell if the cell size increases. Also, with introducing HSDPA, the amount of high-speed data traffic depends on the power left in the cell after allocating the necessary power to dedicated channel traffic. This makes efficient power allocation for common channels particularly important. Although the amount of power allocated to other DL common channels does not exceed that of P-CPICH (is about 80% of the P-CPICH power), the total amount of power consumed by all DL common channels, including P-CPICH, is almost 20% of the maximum power of the cell. Reducing this amount to 10–15% would have a significant impact on network capacity. Decreasing the CPICH power leaves more power available for user traffic and therefore increases the cell capacity, but may also cause coverage problems. On the other hand, increasing the pilot power yields better coverage, but this is at a cost of less power available for user traffic.

There is another factor that needs to be considered in the trade-off between coverage and pilot power consumption – *soft and softer handovers*, which depends on coverage and affects power consumption and network performance. SHO improves the performance due to the macro diversity principle allowing to reduce the transmit powers both in uplink and downlink. On the other hand, in SHO, a mobile terminal is simultaneously linked to two or more cells which increases the traffic amount (SHO overhead). The SHO overhead must be kept within reasonable limits to save the traffic capacity of the cell, otherwise, the network capacity gain from macro diversity can vanish due to high SHO overhead or even turn into a network capacity loss.

Another goal of pilot power management is to control the amount of *interference* in the network. The strength of the CPICH signal affects the total interference in several ways. First, their transmit power adds to the total downlink interference in the network. Second, higher CPICH transmit power increases cell overlap areas and the number of users in SHO. The latter may lead to higher interference in case SHO link gain is smaller than SHO overhead. Third, special distribution of both UL and DL interference depends on coverage areas of different cells that, in turn, depend on CPICH power.

CPICH signals provide cell–specific signals for RRM procedures, such as handover and cell selection/reselection. Detecting CPICH signals of approximately equal strengths or multiple strong CPICH signals at the same time may cause *pilot pollution*, i.e., pilot pollution can be observed in areas where a mobile terminal does not have enough RAKE fingers for processing all the received pilot signals or there is no dominant pilot signal at all [26, 27]. Pilot pollution cannot be totally avoided with traditional radio network planning methods due to inhomogeneous propagation environment and overlapping cells, but it can be reduced, for example, by optimizing the pilot powers in such a manner that required coverage thresholds are still exceeded [27]. The result is clear in cell dominance areas. Among the other instruments of reducing pilot pollution are optimizing antenna configurations [24, 28] and implementation of repeaters [29]. Repeaters can make the dominance area of a donor cell clearer, but, if not carefully planned, they can also shift pilot pollution interference and create pilot polluted areas in another location.

The use of CPICH reception level at the terminal for handover measurements has the consequence that by adjusting the CPICH power level, the cell load can be balanced between different cells, which also allow to control the load of hot spot cells, i.e. the cells that serve hot spot areas, and to improve network capacity. Reducing the CPICH power causes part of the terminals to hand over to other cells, while increasing it invites more terminals to handover to the cell as well as to make their initial access to the network in that cell. In CDMA networks, load balancing is always associated with the effect of cell breathing which occurs when the cell load changes. The increasing cell load leads to the increased total received power which decreases the CIR and makes the cell shrinking. The dynamic cell breathing is the power management process, in which a base station automatically adjusts pilot power level as the cell load increases to ensure the balance between the uplink and the downlink handover boundary [30].

From the discussion in this section it follows that the pilot power assignment is a challenging task in planning and optimization for CDMA networks. The problem of pilot power optimization is a multi-objective problem with many parameters. This kind of problem is very difficult to formulate and even more difficult to solve, especially for large real-life networks. Therefore, there is no standard approach for solving this problem. In most cases, pilot power assignment is based on a combination of professional experience and solutions to simplified optimization problems with different objectives.

4.4 Capacity and Coverage Optimization

In capacity and coverage optimization process, propagation data for the base stations is essentially needed. For this purpose, first target area is subdivided into grid points, and at each grid point the path losses for each base station is calculated. This process is shown clearly with three sample base stations in Figure 4.7. These path losses include only the losses due to the terrain profile and distance from the transmitter. Effects of fading and mobile speed will be included in E_b/N_t calculations.

Then, one by one at each grid point, the forward and reverse link analysis are performed for each base station. Note that grid points do not indicate the mobiles' locations. The service area is represented by a grid of *bins* (small square or rectangular areas) with a certain resolution, assuming the same signal propagation conditions across every bin. Number of mobiles is a parameter to calculate base station sensitivity, interference level etc.

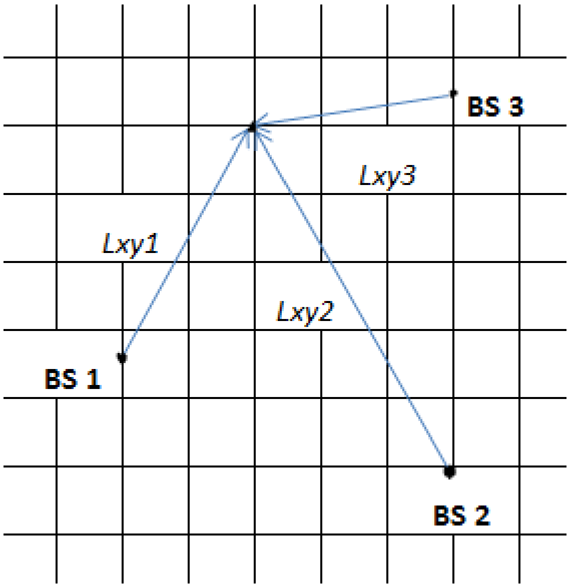


Figure 4.7: Path losses, L_{XY}, are calculated at each grid point(X, Y) for each base station.

Thus, for a given number of mobiles in cells, the grid points are tested whether they meet the required E_b/N_t for both forward and reverse links. Area, formed by points in which the required E_b/N_t is satisfied, is said to be coverage area. Following two subsections explain the calculations in detail.

4.4.1 Forward Link Analysis

In forward link, any point in target region receives signals from all base stations, especially from nearer base stations. If one of the base stations exceeds the required E_b/N_t, that base station will set up a reliable communication with that point.

In Figure 4.8, there is a mobile and three neighboring base stations. L_1, L_2 and L_3 show the path losses to the mobile from the base stations 1, 2 and 3, respectively.

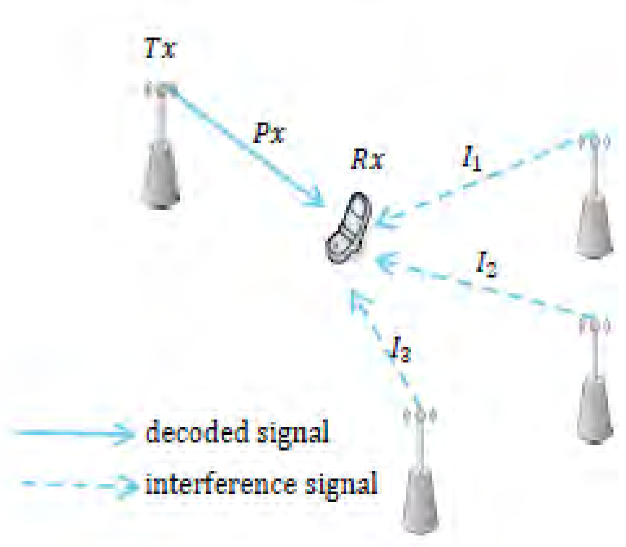


Figure 4.8: A mobile receives 3 signals from 3 base stations, signal from BS_1 is taken as the desired signal, and other signals are as interferers.

Aim is to check whether that point can have service from BS_1 or not. For this purpose, let P_1, P_2 and P_3 be the total transmit powers of the base stations. $P_{rtraff1}$ is the received traffic channel power from BS_1 at the target grid point,

$$P_{rtraff1} = \frac{(P_1 L_1 \emptyset)}{M_1} \tag{4.4}$$

Where;

$\emptyset$: fraction of total power assigned to traffic channels (typically 0.7)

M_n : number of active mobiles in BS_n

The other two base stations, BS_2 and BS_3, act like interferer for the BS_1 since they use same spectrum band. They interfere with their traffic powers. Therefore the total interference by BS_2 and BS_3 at that point is simply the power sum of the received signals,

$$P_{other} = \sum_{i=1}^{N} \frac{(P_i L_i \emptyset)}{M_i} \tag{4.5}$$

Where; N : number of interferer base stations (2, in this example)

The thermal noise density and total thermal noise in the band are,

$$N_0 = T_e k N_f \tag{4.6}$$

$$N = (T_e k N_f) BW \tag{4.7}$$

where;
N_f : noise factor of the mobile unit
BW : bandwidth of the system
T_e : receiver temperature
k : Boltzmann constant

Total interference plus thermal noise power as total noise is,

$$N_T = P_{other} + N \tag{4.8}$$

Therefore, the received E_b/N_t from BS_1 becomes

$$\frac{E_b}{N_t} = \frac{P_{rtraff1}}{N_T} G_p \tag{4.9}$$

Where;
G_p : processing gain (BW/datarate)

If the calculated E_b/N_t is greater or equal to the required E_b/N_t, that mobile can take service from BS_1.

The required E_b/N_t depends on the mobile speed and the approximate E_b/N_t values based on field trials are given in [28]. Table 4.1 shows the results. Note that at very high speeds, the required

E*b*/N*t* is lower because in that case the fade duration is smaller than chip length. Thus, only burst errors result on the link, they are corrected by interleaving and Viterbi decoding, therefore required E_b/N_t is lower.

Table 4.1: Required E*b*/N*t* on the downlink as a function of mobile speed

Required Eb/Nt	Mobile Speed
5dB	< 8km/hr
7dB	=48 km/hr
6dB	>96km/hr

To sum up the forward link analysis, consider the single cell network in Figure 4.9. Let's say total transmit power of BS_1 is 10 W. If the traffic power fraction is 70%, total traffic power becomes 7 W. For instance, we want to obtain the coverage area for 40 mobiles. Therefore, transmitted traffic power per mobile is 7W/40 = 175 mW. Since we know the path losses to each grid point, received signal at all points can be calculated easily with base station power of 175 mW. We know the thermal noise and processing gain, so at each point received E_b/N_t can be calculated as given in Equation 4.9. The final step is to check if these E_b/N_t's meet the required E_b/N_t, say 7 dB (mobiles are moving with speed of 48kmph). Succeeded points are the forward link coverage area of BS_1 for 40 mobiles.

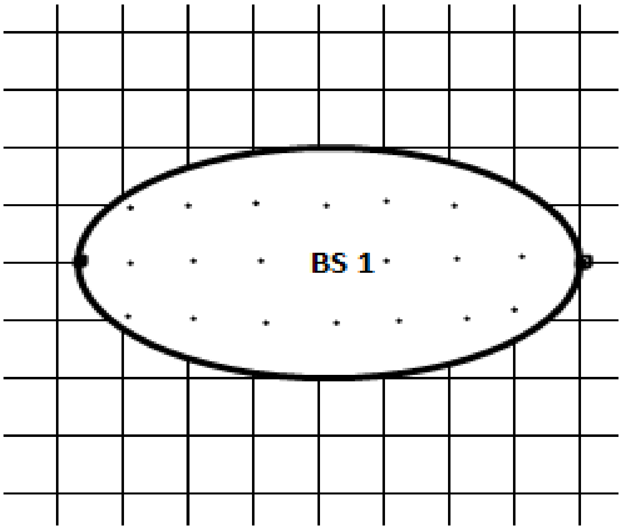


Figure 4.9: Sample Forward Link analysis. Grid points are tested for required E_b/N_t and area formed by succeeded points is the forward link coverage area.

4.4.2 Reverse Link Analysis

In reverse link, this time the link is said to be reliable if the mobile can reach the base station with sufficient E_b/N_t. For that, maximum power that mobile can transmit, total interference at the base station and the base station sensitivity level should be known. Base station sensitivity level is shown in Equation 4.10.

$$S = \frac{(E_b/N_t)\ N_0}{\frac{1}{R} - \frac{(M-1)\upsilon_f(1+f)(E_b/N_t)}{W\eta_p}} \tag{4.10}$$

where;

E_b/N_t : required E_b/N_t

R : bit rate

W : band width

N_0 : thermal noise density

f : other-cell interference factor

M : actual capacity (number of users)

η_p: Imperfect power control effect

After obtaining the base station sensitivity level for required E_b/N_t, the grid points are also checked whether mobiles could exceed the base station sensitivity level from that point. For example, if there are 40 users to be served by the base station, the base station sensitivity level becomes -117.6 dBm (for a single cell) and if maximum mobile transmit power (typically -6 dBW) and path loss are known, each grid point can be tested if they can reach the base station.

Any point that satisfies both forward and reverse link E_b/N_t, is said to be covered by the base station. If these processes are repeated for all base stations at each grid point for a given number of mobiles for each base station, coverage areas of the base stations can be obtained. Same points can be covered by different base stations, those regions are said to be hand off regions. As seen in Equation 4.3 and 4.10, the number of mobiles in cell is a parameter to calculate received E_b/N_t, for both forward and reverse links.

5. Simulation Analysis and Results

Simulation is the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviors/functions of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time. In this thesis, MATLAB tool was chosen as a universal and widely spread tool to formulate and solve an optimization problem. The tool provides a method for checking and analyzing results for coverage and capacity improvement of CDMA network. The code is meant to be simple and easy to use. In some cases, simple mathematical calculation and analysis was simply be done by using EXCEL for its simplicity.

5.1 Network Overview

Currently, the numbers of voice and data subscribers are increasing very rapidly, but the network development is very slow. The subscribers are suffering from poor coverage and compete with more users, hence the average user throughput becomes lower and lower. In order to improve the network performance and user experience, optimization of the network is most important in parts of the Addis Ababa city.

As report of Ericson mobility June 2015, Mobile voice was overtaken by mobile data at the end of 2009. Data was the number 1 service category at the beginning of 2010 in terms of traffic generated on mobile networks. Mobile voice traffic growth should remain limited compared to the explosive growth in data traffic from 2010 to 2020.

5.1.1 Network Basic Information

Up to now, there are totally 731 BTSs available and are already launched.

Table 5.1: Network basic information

BSC	1X		DO	
	CELL	*Carrier*	*CELL*	*Carrier*
Addis	360	924	360	540
Bahirdar	104	230	77	77
Dessie	76	127	60	60
Dire Dawa	97	149	75	75
Jimma	115	160	76	76
Mekelle	77	146	72	72
Shashemene	177	357	151	151
Total	989	2062	845	934

5.1.2 Packet User Growth Trend and Forecast

In order to forecast the future user growth trend, we collect all the user growth since August 2009. The DO user increases more than by 1220 users per month in recent six months, and now total number of subscriber is 17567.

Figure 5.1: EVDO user growth trend

The 1X packet user increases on average by 3757 users per month in recent six months, and now total number of subscriber is 102846.3

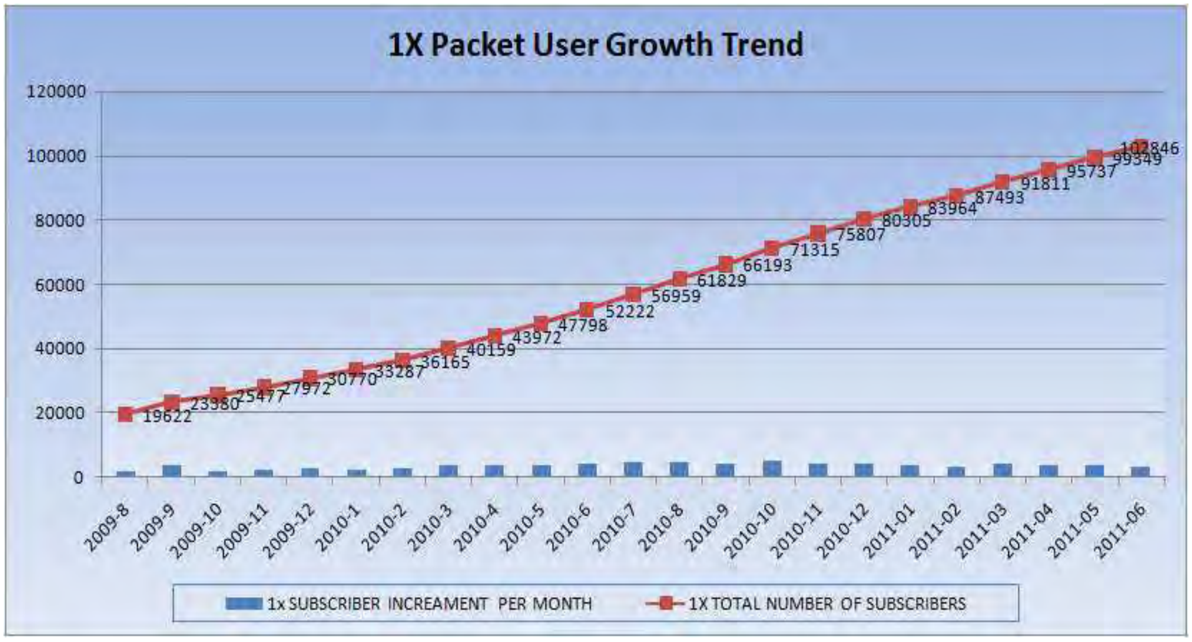


Figure 5.2: 1X CDMA user growth trend

The number of mobile phone subscribers in the country has reached 37 million, just three million subscribers short of the GTP objective in the sector.

Hence we must either expand or optimize the network to increase the amount of resources available by adding more carriers, more sites and more transmission links.

5.2 A Short Investigation and Optimization Practice of Ethio Telecom CDMA Optimization Section

This study was carried out following the need for higher capacity and improved coverage for selected busy sites. This covered a total of five cluster areas. The investigation was done for EVDO sites in Addis Ababa.

5.2.1 Base Station Layout

The figure below shows the base station layout of the sites in Addis Ababa.

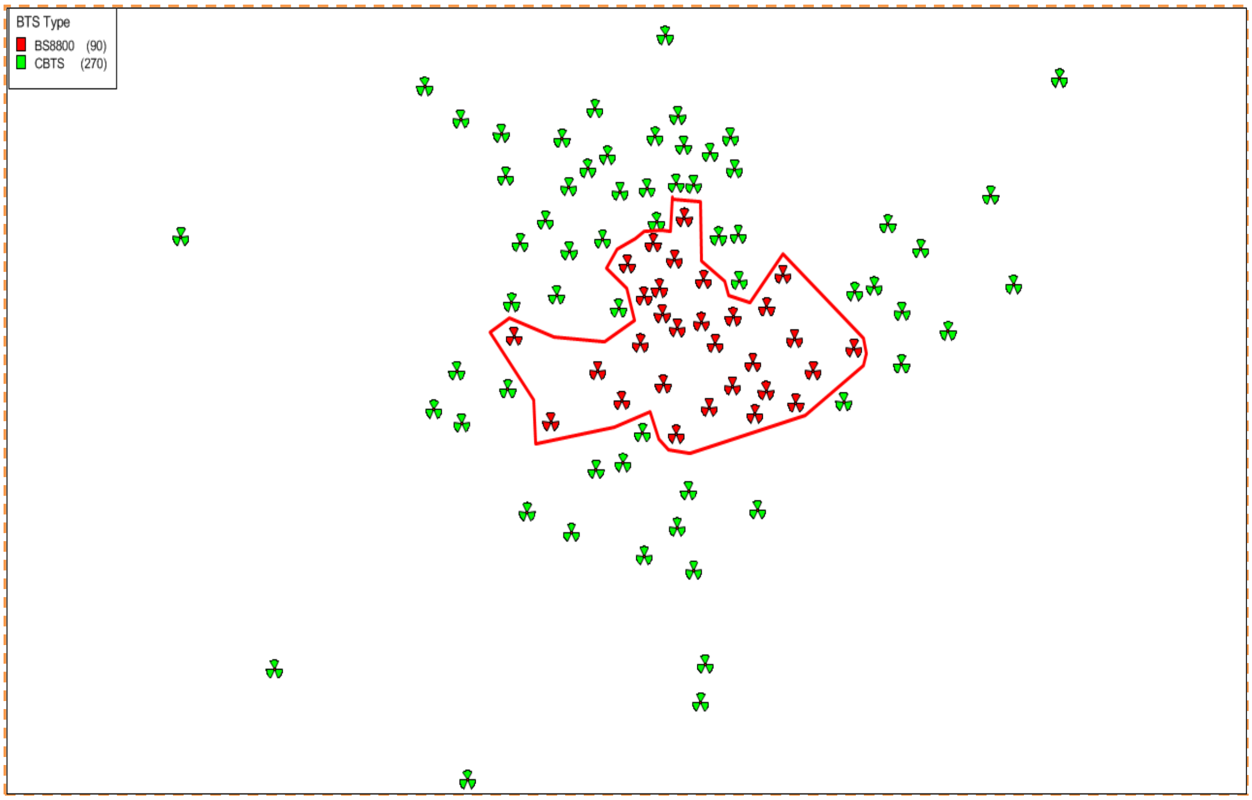
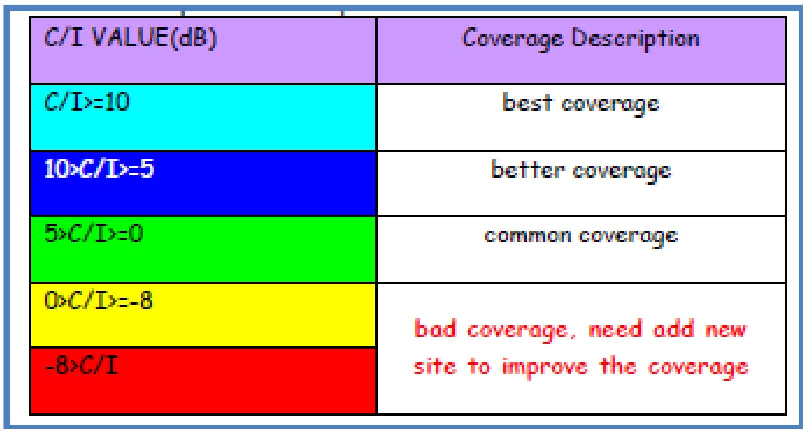


Figure 5.3: Map info plot of BTS layout of the Network in Addis Ababa

5.2.2 Problem Areas

C/I is the most important parameter for EVDO network, it indicates the coverage quality. C/I value description and expansion standard is given in below table.



C/I VALUE(dB)	Coverage Description
C/I>=10	best coverage
10>C/I>=5	better coverage
5>C/I>=0	common coverage
0>C/I>=-8	bad coverage, need add new site to improve the coverage
-8>C/I	

The picture below is a pictorial representation of the data as viewed from the Mentum Planet Data collection interface.

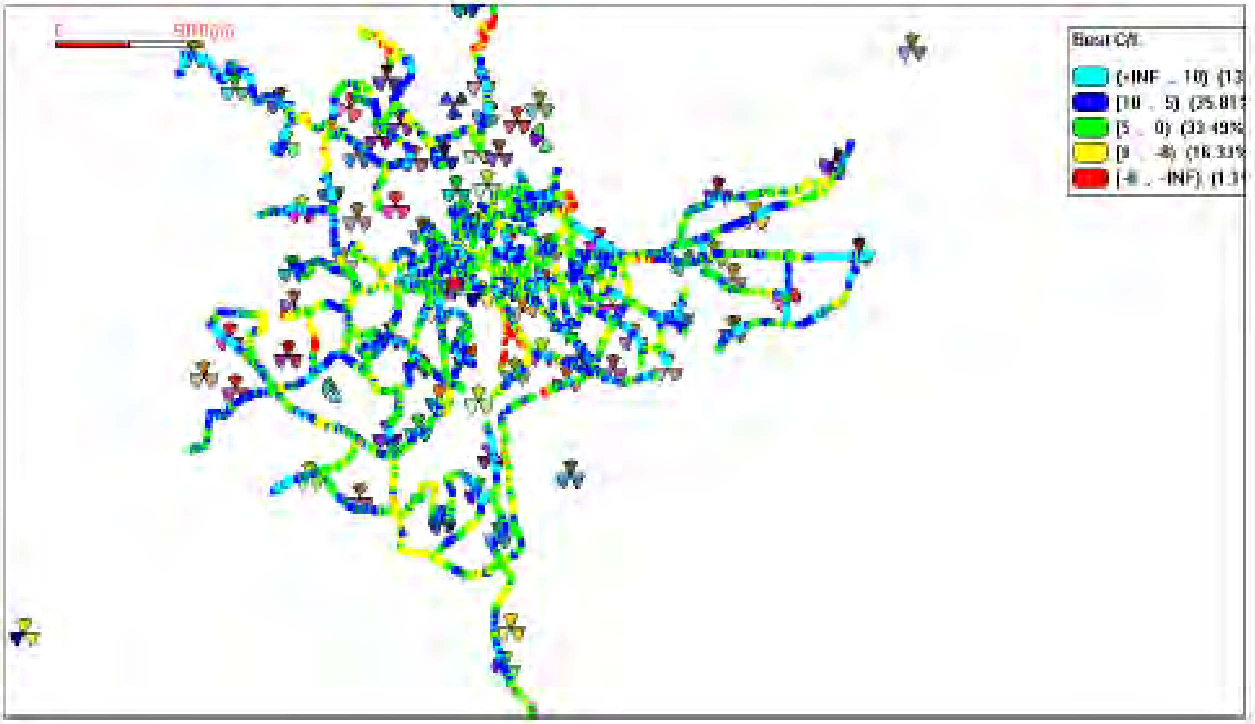


Figure 5.4: A log-file recorded during the drive test exercise

Best C/I in some areas are not very good due to coverage issues, and these areas need new additional sites or optimization work to improve the coverage.

A set of devices called drive test kit is used for this purpose. This setup system is placed in a vehicle while the vehicle moves around predefined route called test route. The data obtained in this process called log-file gives the real behavior of the network at the time of collection.

After collection, the log-file was analyzed. Possible problems are identified within the network. Proper recommendations are then made to improve the network performance.

Implementation of recommendation involves changing the antenna height or tilt, performing parameter audit or simply changing transceivers within one or two base transceiver stations within the network of operation. After implementing the recommended changes, another drive test exercise is performed to ascertain the effect of the changes in the network parameters. Post optimization is a continuous process as it will go on until the desired threshold of network performance is attained. After each optimization exercise, the KPIs obtained are checked against the desired threshold. This is called benchmarking. Below are sample of optimization work done by CDMA Optimization Section of Ethio Telecom. After possible problem are identified, proper recommendation have been given and expected to solve the cited network problem in the area.

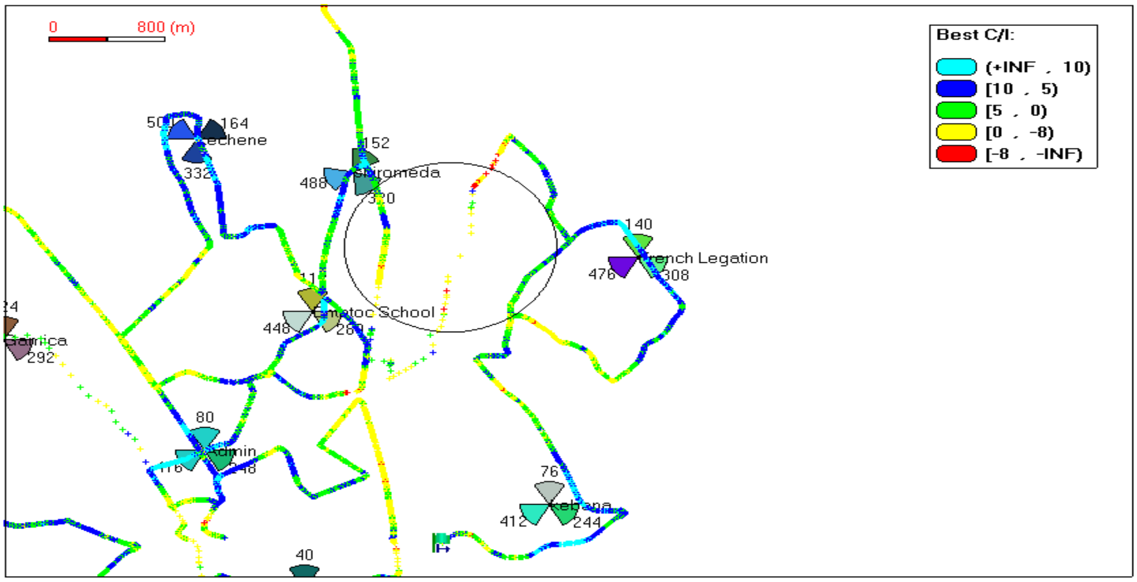


Figure 5.5: Between French Legation and Shiromeda

As shown in above figure, the circled area has poor coverage. This problem can be solved by relocating the Shiromeda site.

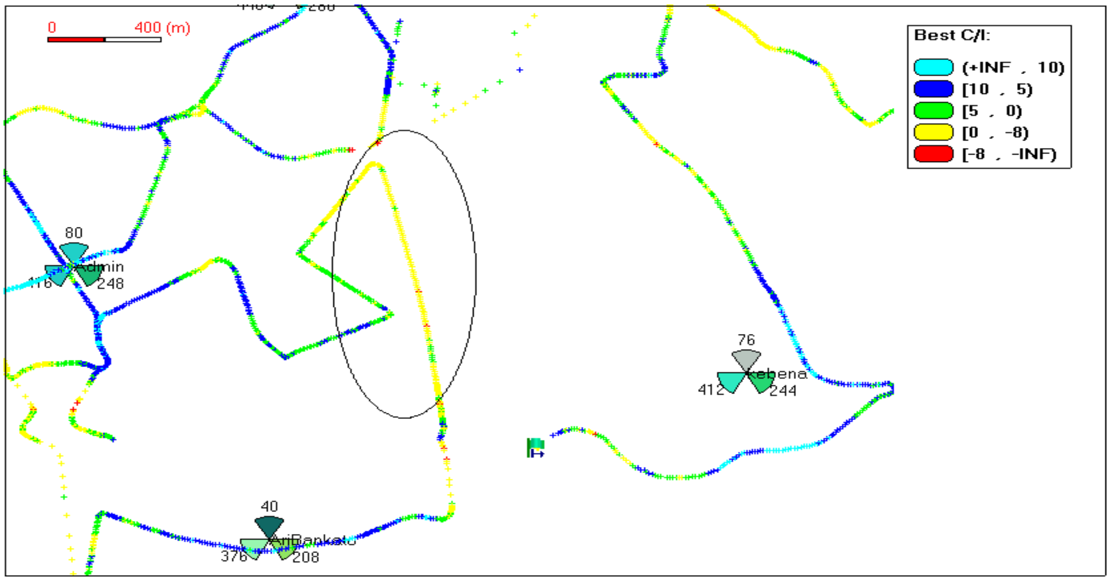


Figure 5.6: Between Arat Kilo and Sidist Kilo

As shown in above figure, the circled area has big problem. The problem is caused by poor coverage and high user overload. The recommended solution is adding new BTS.

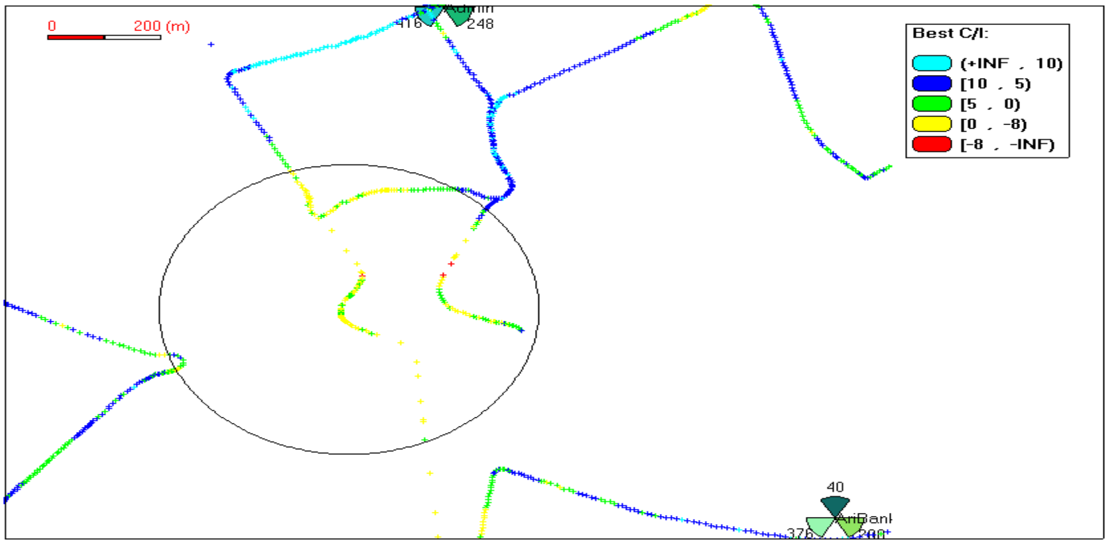


Figure 5.7: Piazza Area

As shown from the figure, the circled area has big problem. The problem is caused by poor coverage and high user overload. The recommended solution is adding new BTS.

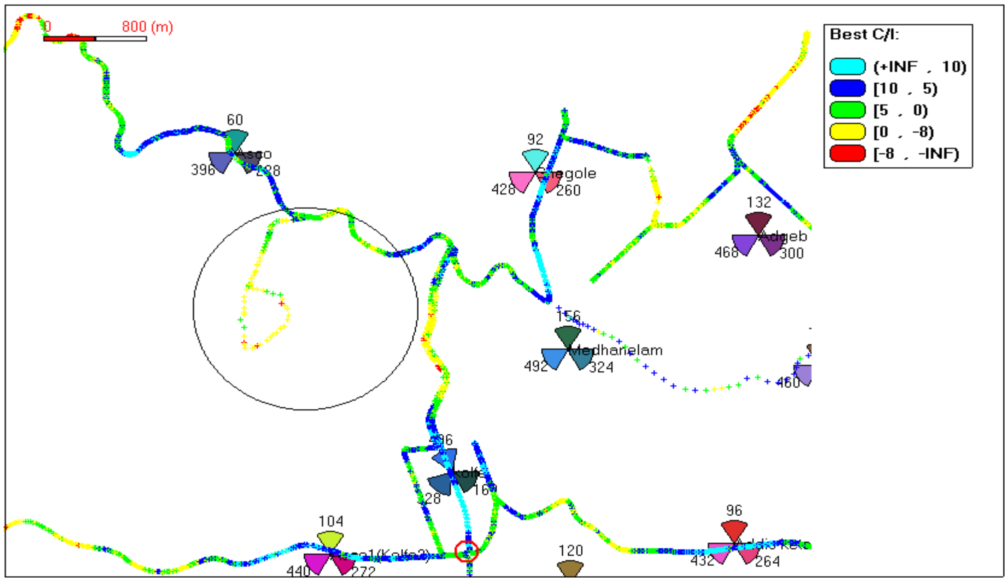


Figure 5.8: Asco Condominium Area

The circled area has poor coverage problem. The recommended solution is adding new BTS.

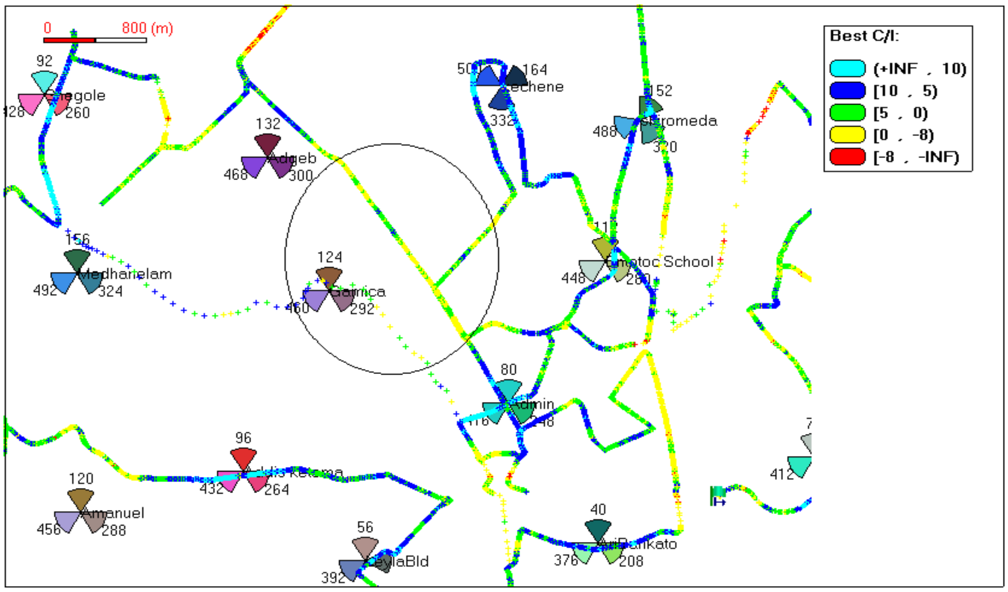


Figure 5.9: Addisu Gebeya Area

From the above figure, the circled area has big problem. The recommended solution is adding new BTS.

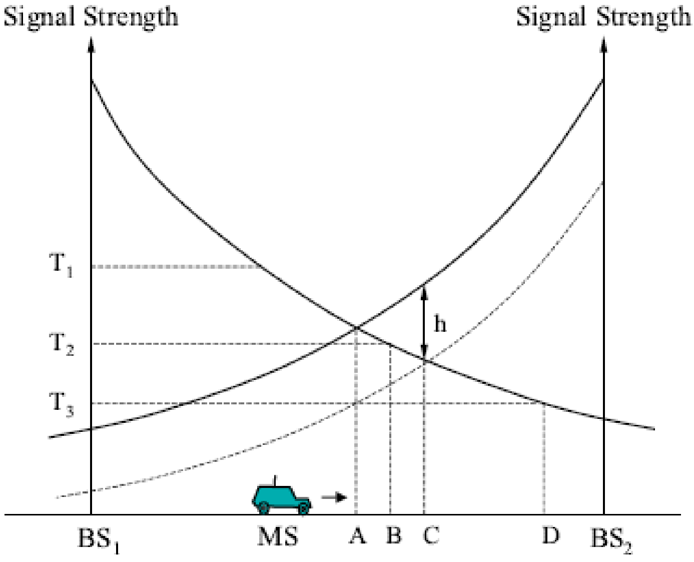
5.3 Analysis of Coverage and Handoff in CDMA Cellular Systems

The analysis is done for a model with two base stations separated by a distance d and a mobile moving from one base station to another along a straight line. Figure 5.10 shows a MS moving from one BS (BS1) to another (BS2). The mean signal strength of BS1 decreases as the MS moves away from it. Similarly, the mean signal strength of BS2 increases as the MS approaches it.

5.3.1 Implementation

The analysis and implementation is based upon various factors affecting the handoff procedure. The decision to initiate a handoff can be made by measuring several quantities such as received signal level from the communicating and neighboring base stations, received signal strength to interference ratio, and the bit error rate.

The simplest and the most commonly used method are based on received signal strength of the transmitted power. The received signal strength in land mobile communication has three kinds of variations i.e. path loss, shadowing and Rayleigh fading. Here we are considering the effects of the received signal strength due to path loss only.



.

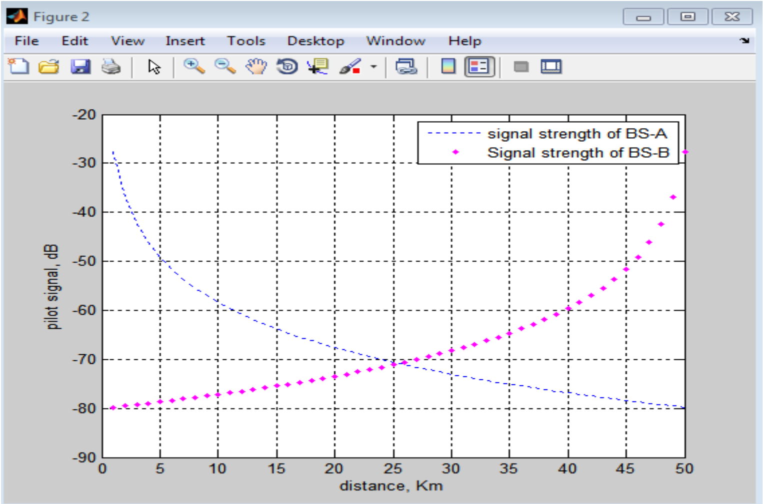
Figure 5.10: Signal strength and hysteresis between two adjacent BSs for potential handoff

For path loss in a macro cell environment, we have used the Hata-Okumura model (which considers the propagation loss between isotropic antennas, quasi smooth terrain and using the (standard) empirical formula for urban area propagation loss) due to simplicity of the formula in relating the distance with path loss.

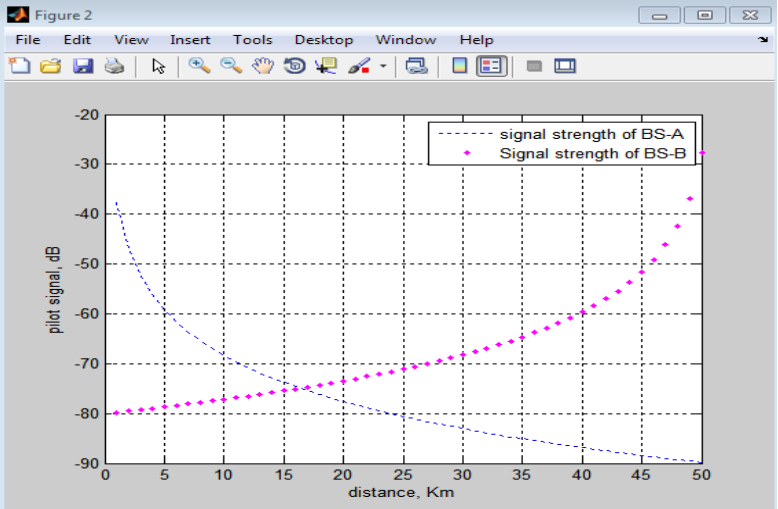
Controlling the transmit power of the mobile and base station reduces the system interference and thus can be used to reduce the cluster size if implemented properly. In practical cellular radio and personal communication systems the power levels transmitted by every subscriber unit are under constant control by the serving base stations. This is done to ensure that each mobile transmits the smallest power necessary to maintain a good quality link on the reverse channel [6, 7]. Power control not only helps prolong battery life for the subscriber unit but also dramatically reduces the reverse channel *C/I* in the system.

When selecting the optimum transmit power, the goal is to have as high signal strength as possible in the area where the cell should be serving traffic. Beyond the serving area of the cell, the signal strength should be as low as possible so as to combat the problem of fluctuation in received signal strength by the mobile users in a cell. As the BTS power increases received power also increases; so the signal from the BTS will cover more distance. In fig 5.11a and 5.11b the impact of transmit power on received signal level (coverage area) and its effect on handoff initiation is shown. Figure 5.11a shows the received signal strength from base station A decreases from the base station *A* toward base station *B*, while the received from base station *B* increases. In the middle between these base stations, there is an ideal boundary where the received signal strength is equal. This is handover region where conventional handoff takes place to keep the connection. With the conventional handoff algorithm MS cannot handoff from base station *A* to *B* unless it is up to the ideal boundary, even if the base station is fully congested and base station *B* has no users on the entire coverage area.

However, with the application of proper algorithm it is possible to handoff from base station *A* to base station *B* when the load of the serving base station is high load and the neighboring base stations are medium load or low load. For example from Figure 5.11a, when a MS receives signal strength of-70dB from base station *A,* it will receive-70dB from base station *B* at a distance of 25km from both base station. From base station *A* toward base station *B* up to 25 km the signal strength of base station *A* is better, so that it covers the area. Beyond that base station *B* covers the area. Suppose we want base station *B* to cover more distance and reduce cluster size of base station *A* as shown in fig 5.11b. By proper optimization and control of transmit power of mobile and base station we can reduce cluster size and coverage area of mobile network. As observed from the figure cluster size of base station *A* is reduced where as coverage area of base station *B* is increased.



(a)



(b)

Figure 5.11: Received signal strength from base station *A* and *B* without noise

The communication quality should be maximized through minimizing the number of handoffs [1, 8]. Excessive handoffs lead to heavy handoff processing loads and poor communication quality. The more attempts at handoff, the more chances that a call will be denied access to a channel, resulting in a higher handoff call dropping probability.

5.4 A Short Investigation of impacts of Antenna Height, Antenna Tilt and Transmit power on Network Coverage

I. Impact of Antenna Height on Coverage

The relationship between path loss and antenna height can be establish through the models proposed by Hata, Okumura, Electronic and communication committee(ECC-33) and European cooperative for scientific and technical research(Cost-231)[7].

The core of the signal coverage calculation for any environment is a path loss model which relates the loss of signal strength to distance between the base stations to the mobile station [8].

A. Free Space

Free-space attenuation is defined as the transmission loss caused by the dispersion of the energy of the wave that would occurs were the antennas to be replaced by isotropic radiators placed inside a perfectly dielectric, homogeneous, isotropic and unlimited environment where there are no obstacles between the transmitter and the receiver [9,10].

The equation for free-space attenuation (A_0) is:

$$A_0 = \left(\frac{4\pi d}{\lambda}\right)^2 \qquad (5.1)$$

This equation can be rewritten in logarithmic form, and become:

$$A_0 = 32.4 + 20\log_{10}(f) + 20\log_{10}(d) \qquad (5.2)$$

Where d is the distance in kilometers between the transmitter and the receiver, λ is the wavelength in kilometers and f is the frequency in MHz

B. Hata Model

A number of research groups have carried out measurements in outdoor environments of which the most extensive set of measurements was carried out by Okumura, et al., in the city of Tokyo.

The range of dependence was presented as curves of median received field strength for various parameters. Subsequently, Hata expressed these results in terms of path loss between isotropic antennas and developed curve fitted formulas which have proven to be very useful in system planning [11].

The standard formula for median path loss in urban areas under the Hata model is [1, 12]:

$$L_{urban} = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_{re}) - \alpha(h_{re}) + 44.9 - 6.55\log_{10}(h_{te}))\log_{10}(d) \quad (5.3)$$

The parameters in this model are the same as under the Okumura model, and $\alpha(h_{re})$ is a correction factor for the mobile antenna height based on the size of the coverage area. For small to medium sized cities, this factor is given by:

$$\alpha(h_{re}) = (1.1\log_{10}(f_c) - 0.7)\,h_{re} - (1.56\log_{10}(f_c) - 0.8)\,dB \qquad (5.4)$$

and for larger cities at frequencies $f_c > 300$ MHz it is given by:

$$\alpha(h_{re}) = 3.2\left(\log_{10}(11.75\,h_{re})\right)^2 - 4.97dB \qquad (5.5)$$

Where;

h_{te} is the base station height in meters, h_{te}: 30–200m
h_{re} Receiver (mobile) effective antenna height (m), h_{re}: 1–10m
f_c range of frequencies, 150-1500 MHz
d is the link distance in km

C. Lee Model

The Lee model is a power law model, with parameters taken from measurements in a number of locations, together with a procedure for calculating an effective base station antenna height which takes account of the variations in the terrain [13]. The simplified formula of the Lee model at the cellular frequency is given by [5.6]:

$$L_p = 1.14 * 10^{-13}\,\frac{h^2}{d^{3.84}} \qquad (5.6)$$

Where *d* is the distance (in kilometers) between the base station and the mobile user and *h* is the height (in meters) of the base station antenna. Note that in this case, the path loss varies as an inverse power of 3.84 compared to an inverse power of 2 in free space. In other words, the path loss encountered in terrestrial mobile communication systems is worse than that seen in free space. Converting (5.6) into decibel form yields

$$L_p = -129.45 - 38.4\log_{10}(d) + 20\log_{10}(h) \tag{5.7}$$

Where, again, d is in kilometers and h is in meters.

D. COST 231 model

The path loss using COST 231 model for urban area is given as:

$$P_L(dB) = 46.33 + 33.9\log(f) - 13.82\log\ (h_{te}) - \alpha(\ h_{re}) + [44.9\ - 6.55\ \log\ (h_{re})]\log(d) \tag{5.8}$$

Where;

$\alpha(\ h_{re})$ = [1.1log$(f) - 0.7$] h_{re} – [1.56log$(f) - 0.8$]

E. ECC-33 model

Whereas the path loss using ECC-33 model is given as:

$$P_L(dB) = A_{fs} + A_{bm} - G_t - G_r \tag{5.9}$$

Where;

A_{fs} = free space attenuation,

A_{bm}= basic median path loss,

G_t = BS height gain factor and

G_r= received antenna gain factor

They are individually defined as:

A_{fs} = 92.4 + 20 log (d) + log (f)

A_{bm}= 20.41 + 9.83 log (d) + 7.894 log (f) + 9.56 [log (f)] ^{2}

G_t = log (h_{te} / 200) [13.958 + 5.8 log (d)] ^{2}

G_r= [42.57+ 13.7 log (f)] [log(h_{re}) $-$ 0.585], Where,

f = operating frequency in GHz

Table 5.2: Simulation parameters and their specification

Parameter	**Values**
Operating Frequency	850 MHz
BTS transmit power	43dBm
MS transmit power	30dBm
Antenna Gain	17.5 dB
Log-normal fade margin(dB)	54 dB
BTS height	38m
MS height	1.5 m
Distance between transmitter and receiver	1-10(km)
Cable losses (dB)	1.5 dB
Connector losses (dB)	2 dB

The simulation parameters found in Table 5.2 are gotten through some measurements; with the measured values used as our simulation parameters. One can effectively use equation (5.3), equation (5.8) and equation (5.9) to develop a MATLAB script that will calculate the path loss for hata, cost 231 and ECC-33 at antenna height(20m-38m) respectively.

The various calculated path losses for Hata, COST 231 and ECC-33 are presented in Table 5.3

Table 5.3: Effect of varying BS antenna height on path loss

BS Antenna height(m)	**Hata Lp (dB)**	**COST231 Lp (dB)**	**ECC-33 Lp (dB)**
20	165.4	164.5	238.3
22	164.5	163.7	238.2
24	163.7	162.9	238.1
26	163	162.2	238
28	162.4	161.5	237.9
30	161.8	160.9	237.9
32	161.2	160.4	237.8
34	160.7	159.8	237.7
36	160.2	159.3	237.7
38	159.7	158.8	237.6

Also path loss has a relationship with received power using equation (5.10) [4, 5].

$$\mathrm{Rxd\ (dBm)} = \mathrm{EiRPT_x} - \mathrm{L_{MASK}} - \mathrm{L_P} \tag{5.10}$$

Where R_{xd} (dBm) is received power in dBm.

$\mathrm{EiRPT_x}$ is maximum Effective Isotropic Radiated Power of the cell in dBm (that is, at the peak gain point of the antenna). $\mathrm{L_{MASK}}$ is antenna mask loss value for azimuth and elevation angles respectively in the direction of the path being calculated in dB. When the received signal is directly on the main beam of the antenna, this value will be zero. $\mathrm{L_P}$ is the path loss in dB.

$$\mathrm{EiRP} = \mathrm{P_A}\ \mathrm{Power} + \mathrm{antenna\ G} \tag{5.11}$$

Where: Antenna G = antenna Gain + 2.14 (if the gain is in dB). In effect, if path loss increases then received power will decrease. If path loss decreases then received power will increase so the signal from the BTS will cover more distance.

Having known the values for the path losses for Hata, cost 231 and ECC-33 at BS antenna height, one can also determine their various values for the received power (R_{xd}) by developing a MATLAB script using equation (5.10).This will give rise to Table 5.4.

Table 5.4: Effect on received signal strength by varying BS antenna height.

BS Antenna height(m)	Hata R_{xd} (dBm)	COST231 R_{xd} (dBm)	ECC-33 R_{xd} (dBm)
20	-105.4	-104.5	-178.3
22	-104.5	-103.7	-178.2
24	-103.7	-102.9	-178.1
26	-103	-102.2	-178
28	-102.4	-101.5	-177.9
30	-101.8	-100.9	-177.9
32	-101.2	-100.4	-177.8
34	-100.7	-99.82	-177.7
36	-100.2	-99.31	-177.7
38	-99.67	-98.84	-177.6

The results of the effect of varying BS antenna height on path loss is depicted by fig. 5.12, while the result of the effect of varying BS antenna height in received signal strength is depicted by fig. 5.13.

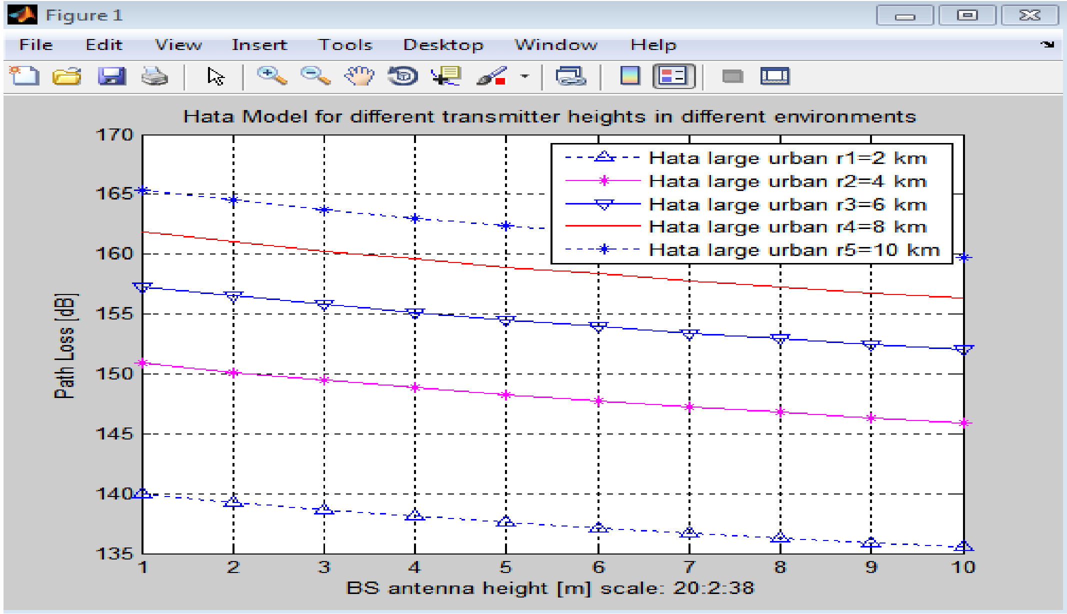


Figure 5.12: Figure showing path loss against BS Antenna height for the various distances

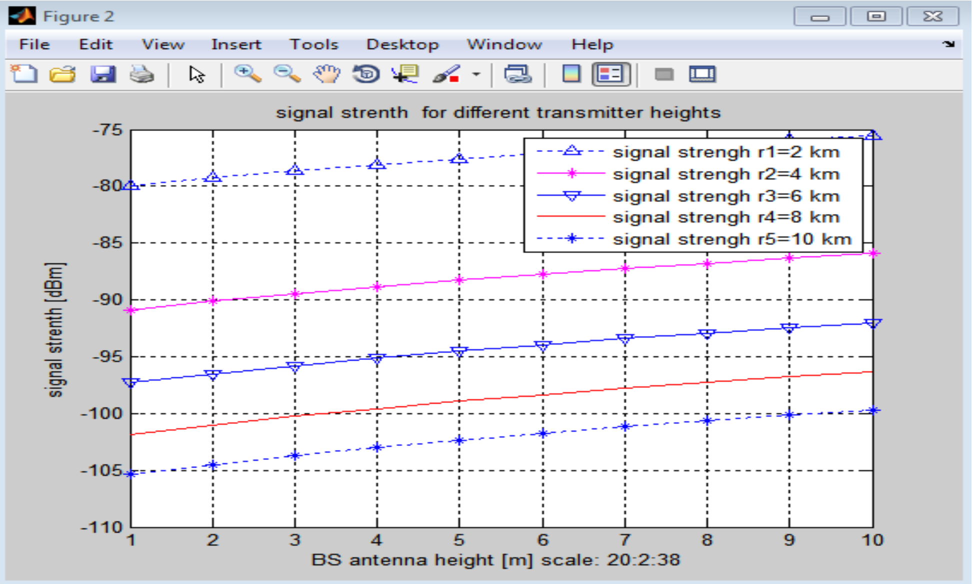


Figure 5.13: Plot showing received signal strength against BS antenna height for the various distances

II. Impact of Antenna Tilt on Coverage

Total tilt effect is the sum of both electrical tilt and mechanical tilt. Electrical tilt is constant at 2° as it is manufacturer specific whereas mechanical tilt is varied from 0° to 5°. So the total tilt is usually varied from 0° to 7° roughly, but that can be used in practice. The tilt angles can be estimated through simple calculation of the vertical angle between the antenna and the area of interest. In other words, we chose a tilt angle in such a way that the desired coverage areas are in the direction of vertical diagram.

Using the basic formula of Pythagoras; we have tan ϴ = Opposite / Adjacent;

$$\text{Angle}=\arctan(\text{Height}/\text{Distance}) \tag{5.12}$$

Where; opposite = Height

Adjacent=Distance

Note: the height and distance must be in the same measurement units.

Figure 5.14: Relationship between antenna height, tilt and T-R distance

Using measurement, one can always obtain the value of the antenna tilt angle, T-R distance or antenna height. So at ϴ = 0° - 5°, values were obtained for the antenna height respectively; which were used together with equations (5.10) to develop another MATLAB script for computing the received signal strength for hata, cost 231 and ECC-33 respectively. The values obtained were presented in Table 5.5. Table 5.5 summarizes the impact on received signal level (coverage area) by varying the Antenna Tilt.

Table 5.5: Effect on received signal strength by varying the BS antenna tilt

Tilt angle (degree)	0	1	2	3	4	5
Hata Okumara Rxd (dBm)	-248.1	-249	-225.1	-301.13	-205	-228
COST 231 Rxd (dBm)	-249	-249.2	-225.2	-302.03	-250.5	-229
ECC 33 Rxd (dBm)	-350.7	-340.3	-302	-441.15	-350	-290

Furthermore, figure 5.15 shows the effects of varying the BS antenna tilt on received signal strength level.

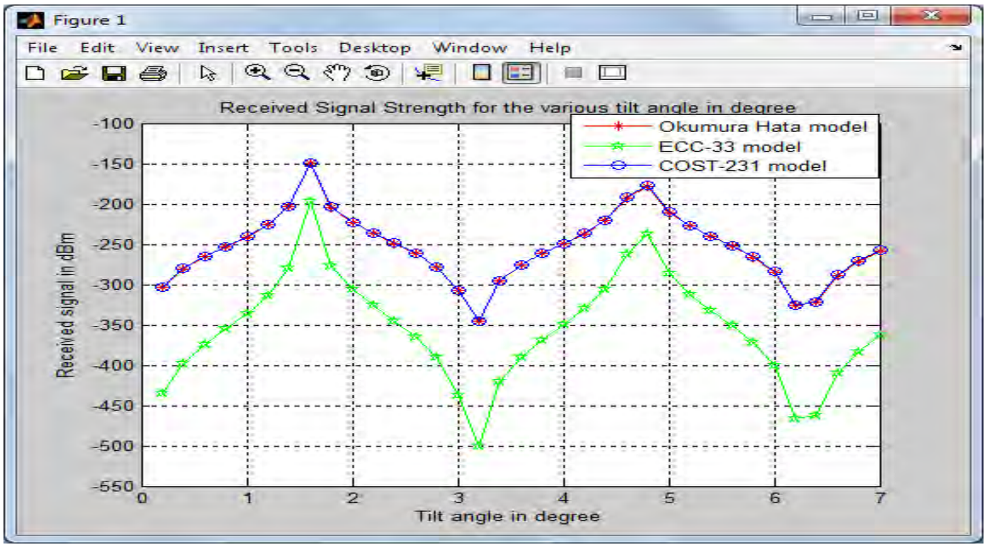


Figure 5.15: Plot showing the effect of tilt on Received signal level

III. Impact of Transmitter Power on Coverage

The impact on received signal level (coverage area) by varying the transmitted power from 30 dBm to 46 dBm is shown in table 5.6. It should be noted that the received signal strength for various path loss models like Hata okumura model, cost 231model and ECC-33 model are calculated using equation (5.13).

$$Pr = Pt + Gt + Gr - PL - A \qquad (5.13)$$

Where Pr is Received Power, Pt is Transmitted Power, Gt is Transmitted antenna gain, Gr is Received antenna gain, PL is Path loss, A is Connector and cable loss

The power received (Rxd) for Hata, Cost 231 and ECC-33 models when transmitted power vary at a step size of 2dBm, from 30dBm to 46dBm can easily be calculated by developing a MATLAB script using equation 5.13, having known the values for other parameters in that equation(see Table 5.2); this actually gave rise to Table 5.6.

Coverage and capacity of CDMA network is investigated and evaluated on the basis of received signal level and its impact on network coverage and capacity is studied by varying the BS antenna height, antenna tilt, antenna azimuth and transmit power.

Table 5.6: Effects on received signal strength by varying transmitted power

T_{xd} power (dBm)	Hata R_{xd} (dBm)	COST231 R_{xd} (dBm)	ECC-33 R_{xd} (dBm)
30	-119.9	-119	-192.8
32	-117	-116.2	-190.7
34	-114.2	-113.4	-188.6
36	-111.5	-110.7	-186.5
38	-108.9	-108	-184.4
40	-106.3	-105.4	-182.4
42	-103.7	-120.9	-180.3
44	-101.2	-100.3	-178.2
46	-98.65	-97.81	-176.2
48	-96.17	-95.34	-174.1

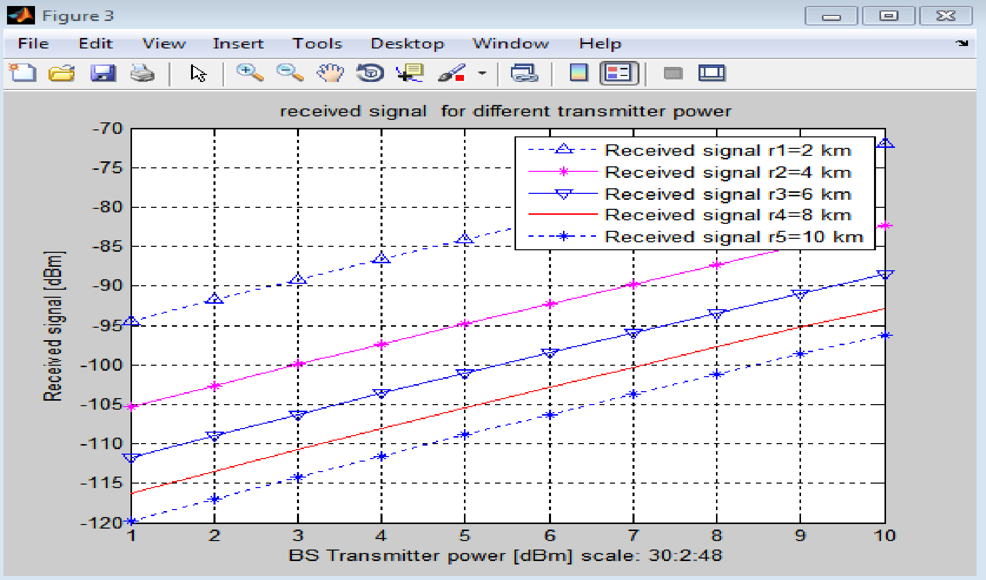


Figure 5.16: Coverage Prediction Plot showing the impact of transmitted power on coverage area (received signal strength)

5.5 Optimizing Reverse Link Capacity of CDMA Network

In essence, the capacity of a CDMA network is interference limited. Maximum number of mobiles that can be supported by the network is called *pole capacity* and this quantity is the basic measure of capacity of a CDMA network. In order to formulate the capacity, the amount of interference introduced by the system users need to be determined. Following calculations are given for reverse link which is the limiting direction. And also the simulation parameters used in our study are presented in table 5.7. For this study; the data was collected through drive test in three CDMA sites located in Addis Ababa (see Table 5.8).

The investigation was carried out in NAAZ, sadist kilo area in certain selected grid areas with geographical coordinate of 9^o 01’29’’ North, 38^o 44’ 48’’ East.

The measurements of the received signal strength were collected through drive test with the aid of test mobile system (TMS). This was conducted around three base station of a mobile communication network at 850 MHZ frequency band. The TMS gives the received signal level at a spherical distance; the height of the mobile station is about 1.5 m while the base station consists of heights of 32 m and 34 m. The peak transmitter power is approximately 47 dbm for all base station. The result of this analysis will be used to check whether mobile could exceed base station sensitivity level from that point.

Table 5.7 : Capacity Simulation Parameters

Parameter	**Value**
Frequency Band	850 MHz
Mobile transmit power	-6 dBW
Number of users	20-50
Spread Rate (W)	1228800 Hz
Data Rate (R)	9600
Required Eb/Nt	6.5 dB
Percentage of base station power allocated (x)	0.75-0.99
Noise over the full bandwidth (NoW)	4.90E-12
Voice activity factor	0.5
UL threshold	0.85

Table 5.8 : Field Measurement Data

Grid	**Site Name(Rx value dBm)**			**Sub city**
	AA_TEP068	AA_TEP090	AA_TEP370	
1	-45	-44	-160	Arada
2	-168	-129	-131	Arada
3	-64	-158	-46	Arada
4	-69	-63	-67	Arada
5	-78	-71	-70	Arada
6	-79	-72	-74	Arada
7	-71	-65	-75	Arada
8	-75	-68	-77	Arada
9	-86	-79	-79	Arada
10	-83	-76	-81	Arada

In digital communications, the metric $E_b/\ N_t$, or energy per bit per noise power density, is primarily used in link calculations. Here, the term N_t indicates the total interference power density due to other mobiles plus thermal noise power density.

If S is the signal power and R is the data rate, the bit energy E_b is,

$$E_b = \frac{S}{R} \tag{5.14}$$

In reverse link, because of the power control, all mobiles reach at the base station with same power of S, then N_t is

$$N_t = I_o + N_o = \frac{(M-1)\,v_f S}{W} + N_o \tag{5.15}$$

Where M is the number of mobiles, W is the bandwidth and v_f is voice activity factor. $E_b/\ N_t$ becomes, equation 5.14 divided by equation 5.15;

$$\frac{E_b}{N_t} = \left(\frac{W}{R}\right)\frac{S}{N_o W + (M-1)\,v_f S} \tag{5.16}$$

Equation 5.16 relates the energy per bit ($E_b/\ N_t$) to two factors; the signal to interference ratio S/N of the link and the ratio of transmitted bandwidth W to bit rate R. The ratio W/R is also known as the *processing gain* of the system, G_p. Solving Equation 5.16 for M we get;

$$M = 1 + G_p \frac{1}{(E_b/\ N_t)v_f} - \frac{N_o W}{S\,v_f} \tag{5.17}$$

As seen in Equation 5.17, maximum number of mobiles can be reached as S goes to infinity. This is theoretical limit and can not be reached in real life since transmit powers of mobiles are limited. This asymptotic cell capacity M_{max} is called *pole capacity* and given in Equation 5.18.

$$M_{max} = 1 + G_p \frac{1}{(E_b/\ N_t)v_f} \tag{5.18}$$

We can add imperfect power control effect as a coefficient η_p. For instance if it is 0.85, that means approximately 15 percent of its capacity is lost due to the imperfect power control. Equation 5.18 becomes;

$$M_{max} = 1 + G_p \frac{\eta_p}{(E_b/ N_t)\upsilon_f} \tag{5.19}$$

Equation 5.19 is given for a single cell network, however in an actual multi-cell CDMA network, the mobiles in neighboring cells also introduce interference and this interference can not be power controlled since those mobiles are controlled by their own base stations. Figure 5.17 shows the effect of other cells' mobiles. Total number of other-cell mobiles is generally much larger than the number of own cell mobiles. However, their average received power at the base station is said to be some fraction (*f*) of own cell received power. Therefore, total interference can be written as $S\, \upsilon_f (M-1)(1+f)$. Equations 5.17 and 5.19 can be modified to include the other cell effect as,

$$M = 1 + G_p \frac{\eta_p}{(E_b/ N_t)\upsilon_f(1+f)} - \frac{N_o W}{S\, \upsilon_f(1+f)} \tag{5.20}$$

$$M_{max} = 1 + G_p \frac{\eta_p}{(E_b/ N_t)\upsilon_f(1+f)} \tag{5.21}$$

Where,

f is other-cell interference factor and given as,

$$f = \frac{P_{other}}{P_{incell}} \tag{5.22}$$

P_{other} is total other cell received power; P_{incell} is total own cell received power; f is a very critical parameter to obtain the maximum number of mobiles in a cell.

For a single cell system, f is zero and if the required E_b/ N_t is 6.5 dB and processing gain is 128 (bandwidth is 1.23 MHz, data rate is 9.6 kbps), if we neglect 1, the Equation 5.21 returns 48 users for voice activity of 0.5 and imperfect power control coefficient of 0.85. However, for multi-cell networks, f would not be zero and Figure 5.18 shows how the pole capacity changes with respect to interference factor f.

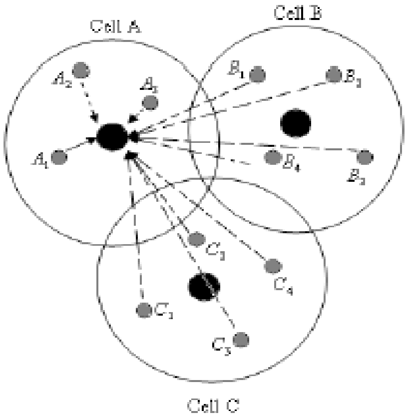


Figure 5.17: Mobiles of neighboring cells also affect the interference at the base station.

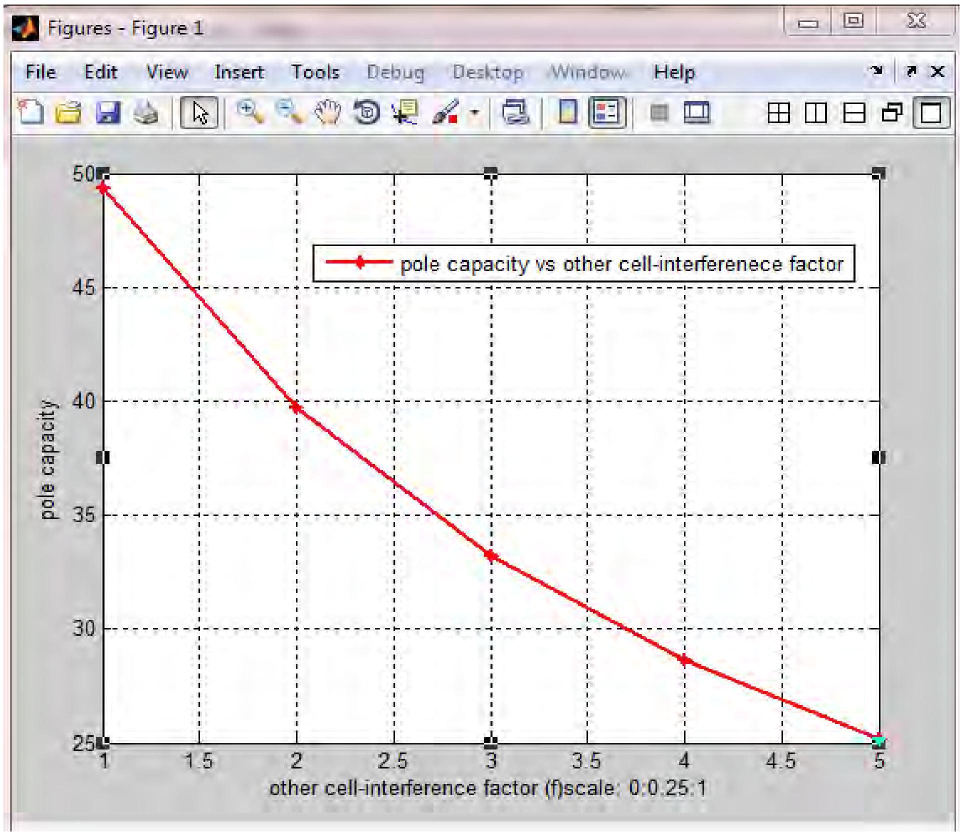


Figure 5.18: Pole capacity decreases as other-cell interference factor *f* increases.

Also, if we solve Equation 5.20 for S, we would find the minimum required received power by the base station to satisfy the given E_b/ N_t for a given number of mobiles M;

$$S = \frac{(E_b/N_t)\ N_o}{\frac{1}{R} - \frac{(M-1)\upsilon_f(1+f)(E_b/N_t)}{W\eta_p}} \tag{5.23}$$

This S value is the base station sensitivity, so any mobile who wants to have a reliable communication should exceed this value to tolerate other mobiles' interference. Figure 5.19 shows the relationship between sensitivity and number of mobiles for different *f* values. This also explains the dependence of cell size on number of mobiles and other-cell interference factor. Also in Figure 5.19, note that as received power S increases, system reaches its pole capacity. The results show that there is capacity degradation, due to imperfect power control.

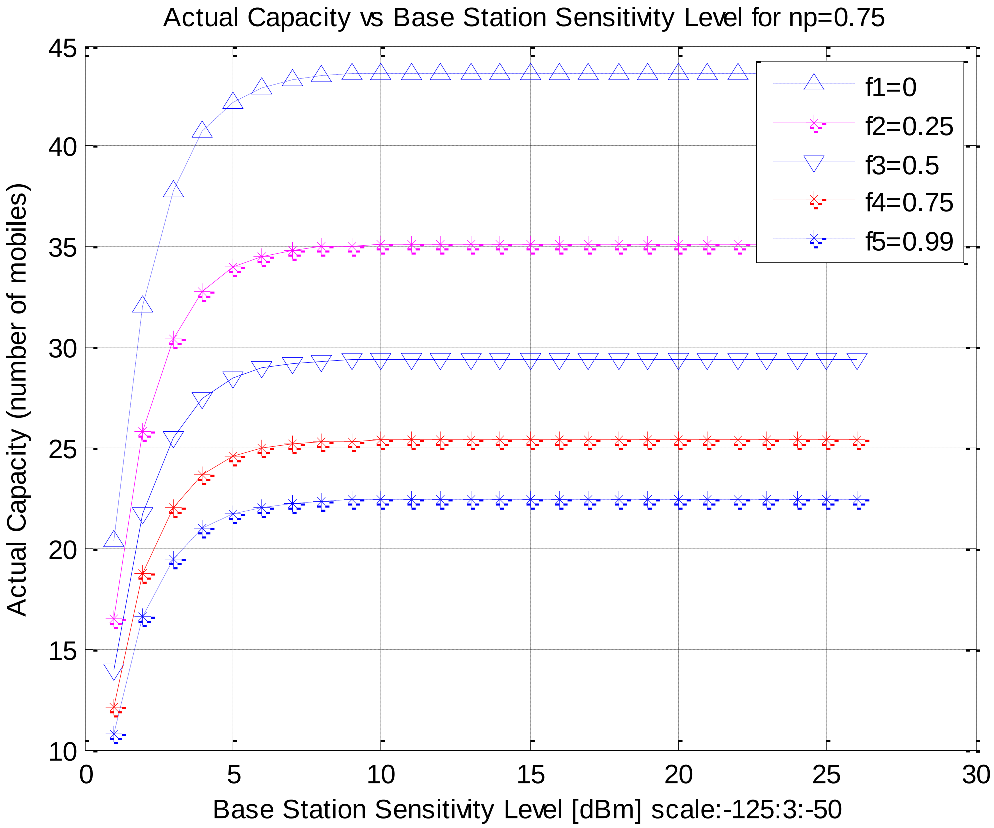


Figure 5.19: Base Station sensitivity decreases as number of mobiles increases.

In addition to other-cell interference factor *f*, there are other parameters like *cell loading* and *noise rise* to evaluate the system performance.

Cell loading, ρ, is the ratio of actual capacity to the pole capacity, M/M_{max}. If we divide Equation 5.20 by Equation 5.21, we get ρ;

$$\rho = \frac{M}{M_{max}} = \frac{M}{M+\frac{N_o W \eta_p}{S\,\upsilon_f(1+f)}} = \frac{S\,\upsilon_f(1+f)M}{N_o W + S\,\upsilon_f(1+f)M} \qquad (5.24)$$

Noise rise, η_r, is defined as the rise of the interference level above the thermal noise level;

$$\eta_r = \frac{N_o W + S\,\upsilon_f(1+f)M}{N_o W} = \frac{1}{1-\rho} \qquad (5.25)$$

Note that when ρ approaches 1, η_r approaches infinity and the system reaches its pole capacity. Figure 5.20 illustrates the relationship between ρ and η_r. Cell loading and noise rise concepts can be easily related to the cell size. As stated before, S is the received signal power from one mobile by the base station. If S is very high, cell loading approaches 100%. S is high when mobiles are very close to the base station, in other words when the cell size is small. Similarly, if the received powers from mobiles are as low as the thermal noise level, η_r is very small and cell loading is close to zero percent. In that case, cell size would be very large.

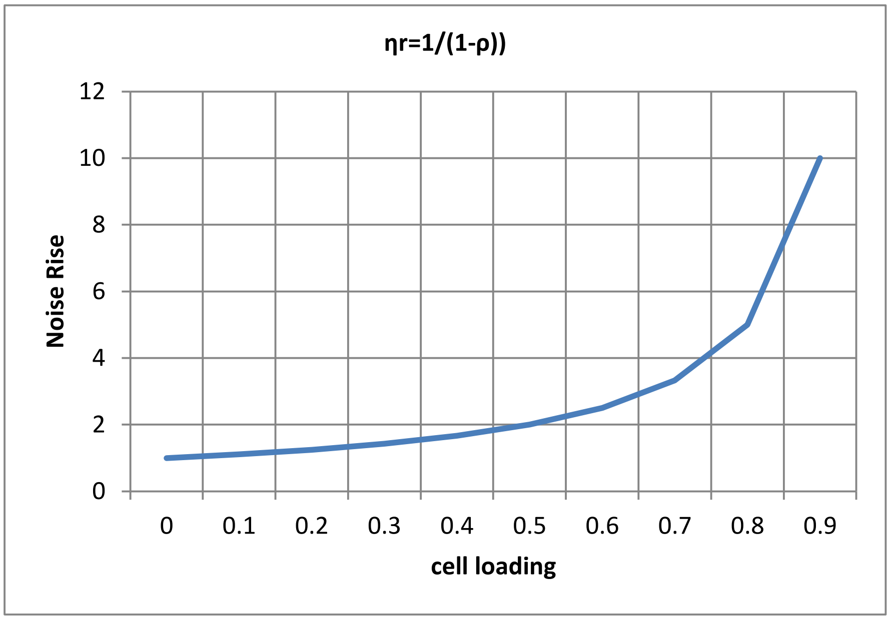


Figure 5.20: Noise rise approaches infinity as cell loading approaches 1.

When the maximum uplink load of a cell is reached, any additional users will be set to outage even though the users would have enough transmit power to access the network services. Figure 5.21 illustrates the greater the cell loading, the greater number of sites, as well as the higher potential capacity per site. Since the maximum permissible level of uplink cell load of the three base stations is 0.85, only 31 to 32 users could be admitted for other-cell interference factor of

0.99 based on estimation. For other-cell interference factor of 0.75, only 31 to 32 users could be admitted. For other-cell interference factor of 0.5, about 32 users could only get access to the network. For other-cell interference factor of 0.25 and 0, only 32 to 33 users could access network services. Referring to table 5.8 and figure 5.19, in grid 1, mobiles in base station AA_TEP370 could not exceed the base station sensitivity level from that point. So the link is not reliable and the mobile cannot reach the base station with sufficient E_b/N_t. In grid 2, all users in three BTS can not establish reliable communication since the mobile cannot reach the base station with sufficient E_b/N_t. Also users in grid 3 can not access the network from BTS AA_TEP090 for similar case mentioned. Generally we can observe from figure 5.21, only users in the range of 31 to 33 can access the network for selected three BTS. Additional users can not admitted to the system since the maximum cell loading of the three BTS is 0.85; therefore, they are put to "outage".

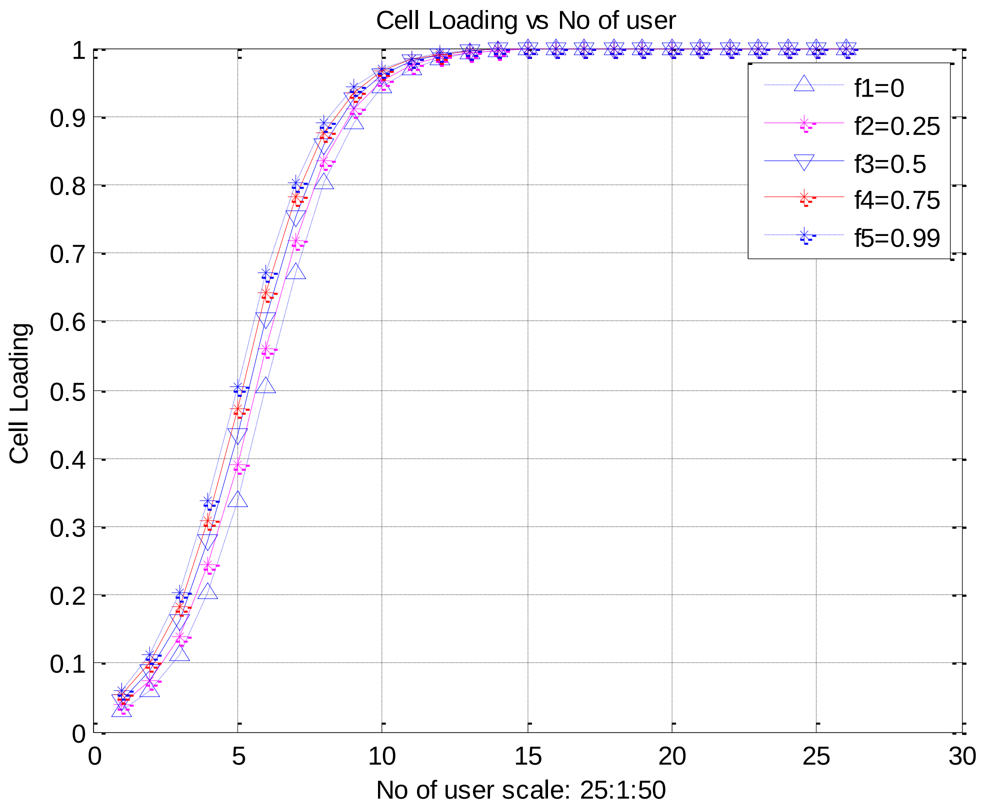


Figure 5.21: Cell loading for different interference margin

6. Conclusion and Recommendation

6.1 Conclusion

Efficient planning and optimization of mobile networks is a key to guaranteeing superior quality of service and user experience. This paper has developed expressions that can be used for detailed analysis of the criterion of optimization. CDMA network operators have various solutions, both short term and long term, to enhance their system capacity. Abnormalities such as forward/reverse link imbalance, excessive soft handoff areas, and improper RF parameter settings could lead to under utilization of system capacity.

This paper has also explained that with proper network planning and network optimization of the installed CDMA network, operators can quickly and efficiently utilize their network resources to achieve optimum system capacity.

Understanding the limitation mechanisms for service coverage and system capacity forms an essential part of being able to develop effective capacity optimization strategies for CDMA radio networks.

This thesis focuses on possible ways of increasing the network capacity on system level optimization corresponding to base station configuration. There are several possible ways to increase the network capacity without additional infrastructure and cost investment, for instance:

- Minimizing the intra- and inter-cell interference
- Shrinking the service coverage area
- Optimizing power allocation
- Optimizing SHO links
- Improving imperfect power control coefficient

RF parameter settings should be fine tuned according to the traffic loading distribution in order to improve the overall network performance. RF parameter adjustments could be considered after the RF environment has been optimized and the network has reached a stable stage.

In CDMA cellular systems with interference based admission control, the interference level resulting from the connected users in the cell affects the capacity and coverage of the cell and any reduction in interference converts directly into an increase in capacity. Also, it is well known for CDMA systems with non orthogonal users and single user detection that the coverage of a cell has an inverse relationship with the user capacity of the cell. Since all users share the same spectrum, power control is exercised in the reverse and forward links.

Other-cell interference factor and cell loading are very critical parameters for a CDMA network. f has a direct effect on the pole capacity. As f decreases, pole capacity increases. On the other hand, cell loading (ρ) is also very important for coverage area. As loading increases, cell approaches its pole capacity and cell size gets smaller. On the other hand, if priority is given to coverage area and pole capacity is not cared, cell loadings would decrease, cells enlarge and intersection area increases. This time, other cell interference effect increases, pole capacity decreases and in their wide coverage areas cells could only serve limited number of mobiles.

Desired case is when ρ is low enough to allow cell boundaries to overlap and f is low enough to serve reasonable number of mobiles.

6.2 Recommendation

The state monopoly Ethio Telecom (ET) targets to boost mobile network access to 113 million in the second Growth and Transformation Plan (GTP II). The telecom giant currently provides mobile telephone service to approximately 50 million subscribers. The telecom enterprise aims to provide mobile telephone service to a total of 91 million subscribers, which is nearly double the number of current mobile users. The rest 22 million will be open to avoid network congestion. In the coming five years, the telecom provider will enhance its capacity. Broadband internet data subscription will grow to 39 million from the current 1.46 million subscribers. Mobile internet data coverage will also grow from 8 million to 16.9 million users, while overall internet data coverage will grow to 10 percent from the current 3.3 percentage. The telecom enterprise will not engage in significant infrastructural expansion in the coming five years. Rather, the enterprise plans to upgrade current infrastructure to accommodate the anticipated rise in subscription.

The company has fulfilled 90% of the sector's objective in the first phase of the Growth and Transformation Period (GTP). In GTP I, the telecom firm had targeted to reach 50 million mobile subscriptions. To attain the target, the telecom giant had undertaken massive infrastructural expansion and optimization work throughout the country.

Mobile communication systems have seen rapid development in recent years with the number of operators still increasing as well as the number of subscribers. In a cluttered environment, the link quality is a challenge to the service provider of serious concern especially in Code Division Multiple Access (CDMA) systems because it determines the ultimate capacity. To increase the capacity of CDMA cellular network, the design parameters must be optimized prior but a system optimization is dependent on the system configuration (site location, antenna type, orientation, down-tilt and the propagation model employed) at deployment presenting a dichotomy.

The load on the system increases with time and thus affecting the network performance, hence the need to periodically monitor the carrier loads, and expand the network if necessary. Interference affects network capacity and the overall performance and quality of end user experience (call setup, call drop rate, etc) and these are considered key issues that need to be resolved.

Ethio Telecom should explore capacity analysis of cellular CDMA systems and the coverage capacity tradeoff along with some methods to increase the capacity and coverage of such systems.

In this thesis, several methods to analyze the capacity of CDMA systems in simulation session were presented and they all showed that such systems are interference limited and any reduction in interference results in an increase in capacity. Therefore, using methods such as voice monitoring, sectorization, and soft handoff will increase the capacity by reducing the amount of interference seen by the BS.

Finally, in CDMA systems, there is a tradeoff between coverage and capacity due to the limited power available for the user. So, as the interference increases, the user has to increase his signal's power to keep the SNR at the desired value and since the power is limited, the user will experience degradation in service unless he gets closer to his BS.

Ethio Telecom must periodically optimize their networks to accommodate traffic growth and performance degradation. For example for selected BTS site improving maximum cell load, re-optimizing key BTS configuration parameters and system parameters will improve network performance and quality of service. Optimization action after service rollout is to correct the expected errors in network planning and to achieve improved network capacity, enhanced coverage and quality of service.

Additionally, Ethio Telecom must use the optimized propagation model that takes in to account nature of network condition to achieve an optimal quality of service and network performance.

APPENDIX

```
%ADDIS ABABA UNIVERSITY [AAiT]
%SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING
%COMMUNICATION ENGINEERING STREAM (M.Sc)
%GIRMA DEREJE
%MATLAB CODE FOR ACTUAL CAPACITY VS BASE STATION SENSITIVITY LEVEL
%***************************************************************
clc
SdB= -125:3:-50;
%SdB=[-83,-86, -75 , -71 , -79 , -78 , -69 , -64 , -48,  -45];
S=10.^(SdB/10);
Gp=128;
EbNt=4.5;
NoW=4.89779*10^-12;
for Vf=0.5; f1=0;f2=0.25;f3=0.5;f4=0.75;f5=0.99;np=0.75 ;
K1=Gp*(np./(EbNt*Vf*(1+f1)));
K2=Gp*(np./(EbNt*Vf*(1+f2)));
K3=Gp*(np./(EbNt*Vf*(1+f3)));
K4=Gp*(np./(EbNt*Vf*(1+f4)));
K5=Gp*(np./(EbNt*Vf*(1+f5)));
N1=(NoW*np)./(S*Vf*(1+f1));
N2=(NoW*np)./(S*Vf*(1+f2));
N3=(NoW*np)./(S*Vf*(1+f3));
N4=(NoW*np)./(S*Vf*(1+f4));
N5=(NoW*np)./(S*Vf*(1+f5));
end
M1=1+K1-N1;
M2=1+K2-N2;
M3=1+K3-N3;
M4=1+K4-N4;
M5=1+K5-N5;
plot (M1,'b:^');
```

```
hold on
plot (M2,'m-*');
hold on
plot (M3,'v-');
hold on
plot (M4,'r-*');
hold on
plot (M5,'b*:');
%axis[50 60:20 100]
xlabel('Base Station Sensitivity Level [dBm] scale:-125:3:-50')
%[-83,-86,-75,-71,-79,-78,-69,-64,-48, -45]')-125:3:-50');
ylabel('Actual Capacity (number of mobiles)');
legend('f1=0','f2=0.25','f3=0.5','f4=0.75','f5=0.99')
title('Actual Capacity vs Base Station Sensitivity Level for np=0.75 ')
grid;

%MATLAB CODE FOR POLE CAPACITY VS OTHER CELL-INTERFERENECE FACTOR
%****************************************************************
clc
f=[0,0.25,0.5, 0.75,1];
EbNt=4.5;
Gp=128;
Vf= 0.5;
Np=0.85;
num=[Gp*Np,Gp*Np,Gp*Np,Gp*Np,Gp*Np];
denom=EbNt*Vf*([1,1,1,1,1]+f);
polecap=[1,1,1,1,1]+(num./denom);
figure(1)
plot(polecap, 'r:*');
hold on
xlabel('other cell-interference factor (f)scale: 0:0.25:1');
ylabel('pole capacity');
```

```
legend('pole capacity vs other cell-interferenece factor')
grid;

%MATLAB CODE FOR CELL LOADING VS NO OF USER
%***************************************************************
clc
SdB= -125:3:-50;
%M=[25, 29, 30, 33, 40, 49, 50, 52, 55 , 60];
M=25:1:50;
%SdB=[-83,-86, -75 , -71 , -79 , -78 , -69 , -64 , -48,  -45];
S=10.^(SdB/10);
EbNt=4.5;
NoW=4.89779*10^-12;
 for Vf=0.5; f1=0;f2=0.25;f3=0.5;f4=0.75;f5=0.99 ;
 N1=(S*Vf*(1+f1)).*M;
N1max=(NoW+S*Vf*(1+f1)).*M;
N2=(S*Vf*(1+f2)).*M;
N2max=(NoW+S*Vf*(1+f2)).*M;
N3=(S*Vf*(1+f3)).*M;
N3max=(NoW+S*Vf*(1+f3)).*M;
N4=(S*Vf*(1+f4)).*M;
N4max=(NoW+S*Vf*(1+f4)).*M;

N5=(S*Vf*(1+f5)).*M;
N5max=(NoW+S*Vf*(1+f5)).*M;
end
Cload1 = N1./N1max;
Cload2 = N2./N2max;
Cload3 = N3./N3max;
Cload4 = N4./N4max;
Cload5 = N5./N5max;
plot (Cload1,'b:^');
hold on
```

```
plot (Cload2,'m-*');
hold on
plot (Cload3,'v-');
hold on
plot (Cload4,'r-*');
hold on
plot (Cload5,'b*:')
 %axis([25 50 0 1]);
xlabel('No of user scale: 25:1:50 ')
%-125:3:-50');
ylabel('Cell Loading');
legend('f1=0','f2=0.25','f3=0.5','f4=0.75','f5=0.99')
title('Cell Loading vs No of user')
grid;


%MATLAB CODE to study effect of key optimization parameters
%*************************************************************
clc
t1=20:2:38;
Pt=30:2:48;
Gt=17;
Gr=2;
A=3.5;
%Hata height dependence
m=1.5; r1=2;r2=4;r3=6;r4=8;r5=10; f=900;
amurb=3.2*(log10(11.75*m)).^2-4.97;%hata large urban
LHurbt1 = 69.55+26.2*log10(f)-13.82*log10(t1)-amurb+(44.9-
6.55*log10(t1))*log10(r1);
LHurbt2 = 69.55+26.2*log10(f)-13.82*log10(t1)-amurb+(44.9-
6.55*log10(t1))*log10(r2);
LHurbt3 = 69.55+26.2*log10(f)-13.82*log10(t1)-amurb+(44.9-
6.55*log10(t1))*log10(r3);
LHurbt4 = 69.55+26.2*log10(f)-13.82*log10(t1)-amurb+(44.9-
6.55*log10(t1))*log10(r4);
LHurbt5 = 69.55+26.2*log10(f)-13.82*log10(t1)-amurb+(44.9-
6.55*log10(t1))*log10(r5);
%Received power without noise
Srt1=60-LHurbt1;
Srt2=60-LHurbt2;
Srt3=60-LHurbt3;
Srt4=60-LHurbt4;
```

```
Srt5=60-LHurbt5;
%Power coverage
Prt1=Pt + Gr + Gt - LHurbt1 - A;
Prt2=Pt + Gr + Gt - LHurbt2 - A;
Prt3=Pt + Gr + Gt - LHurbt3 - A;
Prt4=Pt + Gr + Gt - LHurbt4 - A;
Prt5=Pt + Gr + Gt - LHurbt5 - A;
%Impact of tilt
tilt1 = atand (t1./r1);
tilt2 = atand (t1./r2);
tilt3 = atand (t1./r3);
tilt4 = atand (t1./r4);
tilt5 = atand (t1./r5);
figure(1)
%subplot(2,1,1);
plot (LHurbt1,'b:^');
hold on
plot (LHurbt2,'m-*');
hold on
plot (LHurbt3,'v-');
hold on
plot (LHurbt4,'r-');
hold on
plot (LHurbt5,'b*:');
xlabel('BS antenna height [m] scale: 20:2:38');
ylabel('Path Loss [dB]');
legend('Hata large urban r1=2 km','Hata large urban r2=4
km','Hata large urban r3=6 km','Hata large urban r4=8 km','Hata
large urban r5=10 km')
title('Hata Model for different transmitter heights in different
environments')
grid
figure(2)
plot (Srt1,'b:^');
hold on
plot (Srt2,'m-*');
hold on
plot (Srt3,'v-');
hold on
plot (Srt4,'r-');
hold on
plot (Srt5,'b*:');
xlabel('BS antenna height [m] scale: 20:2:38 ');
ylabel('signal strenth [dBm]');
legend('signal strengh r1=2 km','signal strengh r2=4 km','signal
strengh r3=6 km','signal strengh r4=8 km','signal strengh r5=10
km')
title('signal strenth  for different transmitter heights')
grid
```

```
figure(3)
plot (Prt1,'b:^');
hold on
plot (Prt2,'m-*');
hold on
plot (Prt3,'v-');
hold on
plot (Prt4,'r-');
hold on
plot (Prt5,'b*:');
xlabel('BS Transmitter power [dBm] scale: 30:2:48');
ylabel('Received signal [dBm]');
legend('Received signal r1=2 km','Received signal r2=4
km','Received signal r3=6 km','Received signal r4=8
km','Received signal r5=10 km')
title('received signal  for different transmitter power')
grid
figure(4)
plot (tilt1,'b:^');
hold on
plot (tilt2,'m-*');
hold on
plot (tilt3,'v-');
hold on
plot (tilt4,'r-');
hold on
plot (tilt5,'b*:');
legend('tilt r1=2 km','tilt r2=4 km','tilt r3=6 km','tilt r4=8
km','tilt r5=10 km',4);
grid on;xlabel('tilt [degree]');ylabel('pilot signal
[dB]');title('tilt for different transmitter heights in
different environments')
```

REFERENCES

1. J. Laiho, A. Wacker, and T. Novosad, Radio Network Planning and Optimization for UMTS, John Wiley & Sons, Chichester, UK, 2002.
2. T. Baumgartner, Smart Antenna Strategies for the UMTS FDD Downlink, PhD Thesis, Technische Universit¨at Wien, Austria, August 2003.
3. J. Fuhl, Smart Antennas for Second and Third Generation Mobile Communications Systems, PhD Thesis, Technische Universit¨at Wien, Austria, 1997.
4. A. Gerdenitsch, S. Jakl, M. Toeltsch and T. Neubauer,"Intelligent Algorithms for System Capacity Optimization of UMTS FDD Networks", 4th International Conference on 3G Mobile Communication Technologies, London, United Kongdom, 2003.
5. R.T. Love, K.A. Beshir, D. Schaeffer, R.S. Nikides,"A Pilot Opimization Technique for CDMA Cellular Systems", Vehicular Technology Conference, 1999. VTC 1999 - Fall. IEEE VTS 50th, pp.2238-2242, vol.4, 1999.
6. Y.Y. Chong,"Local Algorithm for UMTS Radio Network Capacity Optimisation", Master Thesis, Helsinki University of Technology, Helsinki, June 2003.
7. R. M. Mathar and T. Niessen. "Optimum positioning of base stations for cellular radio networks", Wireless Networks, vol. 6, pp. 421-428, 2000.
8. R. M. Whitaker and S. Hurley,"Evolution of Planning for Wireless Communication Systems", Proceedings of the 36th Hawaii International Conference on System Sciences (HICSS'03), pp. 295-305, 2003.
9. H. Hata "Empirical formula for propagation loss in land mobile radio resources", *IEEE Trans. on vehicular technology*, VT-29(3), 1980.
10. S. R. Saunders, *Antennas and Propagation for Wireless Communication Systems*, 2 nd ed., England: John Wiley & Sons Ltd, 2007, pp. 89- 92,170-178.

11. S. C. Bundy,”Antenna Downtilt Effects on CDMA Cell-Site Capacity”, *Proceedings of Radio and Wireless Conference*, RAWCON 99, pp. 99-102, August 1-4, 1999.

12. J. Laiho-Steffens, A. Wacker and P. Aikio, ”The impact of the radio network planning and site configuration on theWCDMA network capacity and quality of service”, *Proceedings of 51th IEEE Vehicular Technology Conference*, VTC 2000-Spring, vol. 2, pp. 1006-1010, Tokyo, Japan, May 15-18, 2000.

13. S. Plimmer, M. Feeney, D. Barker and T. Normann, ”Adjusting antenna downtilt boosts UMTS optimization”, Wireless Europe, pp. 34-35, November 2002.

14. 3GPP,”Requirements for support of radio resource management (FDD), TS25.133”, v6.0.0, September 2002, http://www.3gpp.org.

15. K. Valkealathi, A. H¨oglund, J. Parkkinen and A. H¨am¨al¨ainen, ”WCDMA Common Pilot Power Control for Load and Coverage Balancing”, *Proceedings of 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, vol. 3, pp. 1412-1416, 2002.

16. T. Isotalo, J. Niemel¨a, J. Borkowski, and J. Lempi¨ainen. Impact of pilot pollution on SHO performance. In *Proc. of the 8th IEEE International Symposium on Wireless Personal Multimedia Communications (WPMC’05)*, Sep. 2005.

17. H. Holma and A. Toskala, editors. *WCDMA for UMTS: Radio Access for Third Generation Mobile Communications*. John Wiley & Sons, third edition, 2004. J. Lempi¨ainen and M. Manninen, editors. *UMTS Radio Network Planning, Optimization and QoS Management for Practical Engineering Tasks*. Springer, 2004.

18. J. Niemel¨a and J. Lempi¨ainen. Mitigation of pilot pollution through base station antenna configuration in WCDMA. In *Proc. of the 60th IEEE Vehicular Technology Conference (VTC2004-Fall)*, pages 4270–4274, Sep. 2004.

19. J. Yang and J. Lin. Optimization of power management in a CDMA radio network. In *Proc. of the 52nd IEEE Vehicular Technology Conference (VTC2000-Fall)*, pages 2642–2647, Sep. 2000.

20. D. Lister, S. Dehghan, R. Owen, and P. Jones "UMTS capacity and planning issues." *IEE International Conference on 3G Mobile Communication Technologies* p. 218 -223, 2000.

21. H. Zhu, T. Buot, R. Nagaike, and S. Harmen. Load balancing in WCDMA systems by adjusting pilot power. In *Proc. of the 5th Intl. Symposium on Wireless Personal Multimedia Communications*, pages 936–940, Sep. 2002.

22. S. Ying, F. Gunnarsson, and K. Hiltunen. CPICH power settings in irregular WCDMA macro cellular networks. In *Proc. of the 14th IEEE Intl. Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2003)*, pages 1176–1180, Sep. 2003.

23. K. Valkealahti, A. H¨oglund, J. Pakkinen, and A. Flanagan. WCDMA common pilot power control with cost function minimization. In *Proc. of the 56th IEEE Vehicular Technology Conference (VTC2002-Fall)*, pages 2244–2247, 2002.

24. D. Kim, Y. Chang, and J. W. Lee. Pilot power control and service coverage support in CDMA mobile systems. In *Proc. of the 49th IEEE Vehicular Technology Conference (VTC1999-Spring)*, July 1999.

25. M. Garcia-Lozano, S. Ruiz, and J. Olmos. CPICH power optimisation by means of simulated annealing in an UTRA-FDD environment. *Electronics Letters*, 23(39):2244– 2247, Nov. 2003.