ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

FACULTY OF TECHNOLOGY

ELECTRICAL AND COMPUTER ENGINEERING

DEPARTMENT

Performance analysis of CDMA based Wireless Local Loop (WLL) Communication, Case of ETC's implementation in Addis Ababa

by

Getu Zeleke

A thesis submitted to the school of Graduate studies of Addis Ababa University in partial fulfillment of the requirements for the degree of

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Abbreviations and Acronyms

ACI – Adjacent Channel interference
ACK – Acknowledgment
A/D – Analogue to Digital converter
AGC –Automatic Gain Control
AMPS –Advanced Mobile Phone Service
AWGN –Additive White Gaussian Noise
BER –Bit Error Rate
BPSK –Binary Phase Shift Keying
bps –bits per second
BSC –Base Station Controller
BSS –Base Station system
BTS –Base Transceiver Station
BW –Bandwidth
C – System Capacity
CCI –Co Channel Interference
CDG –CDMA Development Group
CDMA –Code Division Multiple Access
CH –Telephone Channel
CRC –Cyclic Redundancy Check
DCPC –Distributed Constrained Power Control
DS-CDMA –Direct Spread CDMA
D/R – Distance b/n co channel cell section , R cell radius
DPC –Destination Point Code / Distributed Power Control
EIB –Erasure Indication Bit
ERL –Earlang, Unit for Telephone traffic per subscriber
ETC –Ethiopian Telecommunications Corporation
FCH –Forward Channel
FDMA –Frequency Division Multiple Access
FEC –Forward Error Correction
FER –Frame Error Rate
FH –Frequency Hopping
FSU –Fixed Subscriber Unit
FPC –Full Period Correlation
FLPC – Forward Loop PC
IF –Intermediate Frequency
INIT-PWR – Initial Power Adjustment(dB)
LE –Local Exchange
LFSR – Linear Feed Back shift Register
MAI –Multi Access Interference
MMS –Multi Message Service
NOM-PWR –EXT –Nominal Power Extended
NOM-PWR –Nominal Power
PC –Power Control
PCG –Power Control Group

PDSN –Packet Data Switched Network
PSTN –Public Switched Telephone Network
PPC –Partial Period Correlation
QoS –Quality of Service
RAC –Radio Access Controller
RAKE –Multi access signal Receiver
RF –Radio Frequency
RLL –Radio Local loop
RSSI –Reverse Signal strength indicator
RT –Random Time
Rx –Receiver
SIR –Signal to Interference Ratio
SINR –Signal to Interference plus Noise Ratio
SMS –Short Message System
SNR –Signal to Noise Ratio
Tx –Transmitter
VAD –Voice Activity Detection
WLL –Wireless Local Loop

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Abstract

The demand for CDMA –WLL, Wireless Local Loop, Communication system is higher than wired network. The CDMA–WLL system in Addis Ababa is providing voice and data communication services. Because of its fast and reliable service, many customers are looking forward to be connected to the system.

As CDMA's nature, each CDMA –WLL user generates interference on the other users (Self jamming). The increasing number of users is going to cause system capacity limitation, unsatisfactory and degraded service quality , QoS.

Addis Ababa CDMA-WLL system has started service provision with about 31,000 voice and 960 data communication users. As indicated above when the number of users increases, the service quality started degradation by dropping and blocking calls from the system with limited capacity allocation.

These problems are results of improper planning and implementation work so that the system needs more technical solutions to provide better service quality, QoS and higher system capacity.

To reduce the effect of the mentioned system problems, this thesis explores different techniques and methodologies. Cell sectoring and power controlling techniques pointed as the main performance enhancement methods3.
. Using Power control as the main solution, WLL system's major problems would be enhanced both in service quality and capacity.

This thesis proposes efficient power control technique based on centralized SIR balancing algorithm. Performance characteristics, enhanced service quality and system capacity of the proposed technique are presented.

The study also explains related advantages of signal to interference, SIR, based power control algorithm which are used to increase network capacity, extend battery life and improve quality of service.

Chapter-1 Introduction

1.1. Background

Code Division Multiple Access (DS-CDMA), based on spread spectrum techniques used extensively in defense applications for over twenty years, this technique enables definition of near-orthogonal channels in code-space. CDMA enables multiple channels to use the same frequency and time slots.

Each bit to be transmitted by or for a user is uniquely coded by spreading the bit into 64 or 256 or even 1024 chips. The receiver separates the data of a user by a decoder which correlates the receive signal with the code vector associated with that user. On correlation, the interference from other users would become nearly zero and add only a small amount of noise, where as the desired signal will be enhanced considerably. The technique is useful in exploiting the inherent time-diversity from multipath delay-spread, especially if the spreading is significant (Chip time of 0.1 μ sec to 1 μ sec).

Code Division Multiple Access (CDMA) is a radically new concept in wireless communications. It is a direct sequence spread–spectrum (DS/SS) technology, allowing many users to occupy at the same time a frequency allocation in a given band/space. It assigns a unique code to each user that differentiates him/her from others in the same spectrum. In a world of finite spectrum resources, CDMA enables many more people to share the airwave at the same time than do alternative technologies.

CDMA WLL system fully integrated with the PSTN, offers fixed line carrier and new telecom carrier a powerful weapon to fight market share. It enables quality voice and value added mobile services including SMS, MMS, customized ring back tones and high speed data. The system has many technical and economical advantages, including large capacity, wide coverage, high spectrum efficiency, fast deployment, low cost, fast service provisioning and limited mobility. [1]

CDMA offers an answer to the capacity problem. The key to its high capacity is the use of noise carrier waves, as was first suggested decades ago by Claude Shannon.
Instead of partitioning either spectrum or time into disjoint slots each user is assigned a different instance of the noise carrier. While those waveforms are not rigorously orthogonal, they are designed as orthogonal but lose their orthgonality during Tx. Practical application of this principle has always used digitally generated Pseudo-noise, rather true thermal noise.

The basic benefits are preserved, and the transmitters and receivers are simplified because large portions can be implemented using high density digital devices.
The major benefit of noise-like carrier is that the system sensitivity to interference is fundamentally altered. Traditional time or frequency slotted systems must be designed with a reuse ratio that satisfies the worst case interference scenario, but only a small fraction of the users actually experience that worst case.

Use of noise carriers, with all users occupying the same spectrum, makes the effective noise the sum of all other user signals.

The receiver correlates its input with the desired noise carrier, enhancing the signal to noise ratio at the detector. The enhancement overcomes the summed noise enough to provide an adequate SNR at the detector because the interference is summed; the system is no longer sensitive to worst case interference, but rather to average interference. Frequency reuse is universal, that is multiple users utilize each CDMA carrier frequency. The reuse pattern is now near-far problem.

CDMA was assumed unworkable in the mobile radio environment because of what was called the near-far-problem. It was always assumed that all the stations transmitted constant power. In the mobile radio environment some users may be located near the base station, others may be located far away. The propagation path loss different between those extreme users can be many tens of dB. Suppose, for example that only two users are present, and that both are transmitting with enough power that the thermal noise is negligible.[1]

$$\text{SNR in dB is } \left(\frac{E_b}{I_b}\right)_{dB} = W / R + (P_j - P_i) \qquad (1.1)$$

If there is say 30 dB difference between the largest and smallest path loss, then there is a 60dB difference the SNR of the closest user and the farthest user, because these are the received powers. To accommodate the farthest users, the spreading bandwidth would have to be perhaps 40dB. Or 10,000 times the data rate. if the data rate were 10,000 b/s, then W = 100Mhz. the spectral efficiency is very low, far worst than even the most inefficient FDMA or TDMA systems. Conversely, if a more reasonable bandwidth is chosen, then remote users receive no service. [1]

The only problem with the technique is that as completely orthogonal codes are not possible, especially on the uplink, the total bit-rate supportable from all users using this technique is significantly less than the total bit-rate supportable with TDMA and FDMA technique using the same frequency spectrum.

This disadvantage in the CDMA system is made up by better reuse efficiency, as the same spectrum with different set of codes can almost totally be reused in every cell. The theoretical reuse efficiency could be as high as 1, but in practice less. With sectored antennas, it is possible to reuse the spectrum in each sector, with a 3-sector cell site resulting in a reuse efficiency of nearly 0.5 per sector.

$$F = \frac{\text{No. of channels in a group}}{\text{No. of total available channels in the system}}$$

Spread spectrum system generally fall in to one of the following categories, frequency hopping (FH) or direct sequence (DS). A DSSS system provides a carrier modulated by a digital code in which the code bit rate is much larger than the information rate.

Whereas in the FH system the carrier frequency is shifted in discrete increments in a pattern generated by a code sequence.
In both cases synchronization of transmitter and receiver is required. Both forms can be regarded as using a pseudo-random carrier, but they create the carrier in different ways.

1.2 Multiple Access Techniques

In today's digital cellular systems, numerous users transmit to and receive from the same base station simultaneously through three major types of multiple-access techniques namely, frequency division multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA). In FDMA, the frequency spectrum is divided into segments and assigned to different users. Thus, users' signals are orthogonal in frequency.

In TDMA, each user transmits for a fraction of time over the whole spectrum. Since users' signals are transmitted at different time, they are orthogonal in time. Finally, in the CDMA technique users' digital signals are spread over the entire frequency spectrum with different spreading codes that ideally should have very low correlation among each other. At the base station, different users' signals are then recovered by correlating the received signals with the assigned spreading codes. The process is known as dispreading.

Ideally, in a single cell system, the performance of the three multiple-access techniques is the same for systems using the same modulation scheme. That is the number of users that can be accommodated is equal to the total available spectrum, W, divided by the required date rate, R, assuming that al1 systems use BPSK modulation and Nyquist pulse shape with no excess bandwidth. However, this ideal performance can never be achieved in practice due to interference caused by the adjacent channels in both FDMA and TDMA system.

Therefore, guard bands and guard times are always required to minimize the adjacent channel interference. For CDMA spread signal transmissions among users and the existence of multipath cause high interference to al1 users, called multiple access interference (MAI).
In a multiple cell environment, a fair comparison for the performance of the three different multiple-access schemes becomes very difficult. The result depends on the availability of technologies, the environment of operations, and the assumptions made. However, CDMA does own some advantages that cannot be found in FDMA and TDMA.

The two major issues that cause degradation in system capacity in a terrestrial mobile wireless network are the multi-user interference and the multipath propagation. The first problem is solved in the CDMA system by spreading each user's signal such that the multi-user interference can be modeled by Additive White Gaussian Noise (AWGN).[1]

In an environment with multipath propagation, different replicas of the signal arrive with different delays. For TDMA and FDMA systems with narrow-band signals, these replicas cannot be resolved and they are combined constructively or destructively causing fading. For a CDMA system the replicas of the wide band spread spectrum signal with different delays that are greater than one chip period can be resolved and combined constructively using a RAKE receiver.

Another economic benefit of CDMA is its potential to provide higher ce11 capacity over FDMA or TDMA. This is due to its feature of universal frequency reuse. Thus, in CDMA, the entire frequency band is shared by every user in al1 cells, which not only relieves the need for frequency planning, it also increases the ce11 capacity. Due to these superior features, CDMA has been adopted widely in wireless communication system.

A traditional narrow band system based on FDMA and on TDMA is a dimension limited system. The number of dimensions is determined by the number of non-overlapping frequencies for FDMA or by the number of time slots for TDMA.
Spread spectrum systems can tolerate some interference, so the introduction of each additional active radio increases the overall level of interference to the cell-site receivers receiving CDMA signals from mobile station transmitters.

Each base station introduces a unique level of interference that depends on the received power level at the cell site, its timing synchronization relative to other signals at the cell site, and its specific cross-correlation with other CDMA signals.

The number of CDMA channels in the network depends on the level of total interference that can be tolerated in the system. Thus the CDMA system is limited by interference, and the quality of system design i.e. load distribution, coverage allocation and BTS capacity limitations play an important role in its overall capacity. A well designed system will have a required bit error probability with a higher level of interference than a poorly designed system. Forward error correction (FEC) coding techniques improve tolerance to interference and increase overall CDMA system capacity.[2]

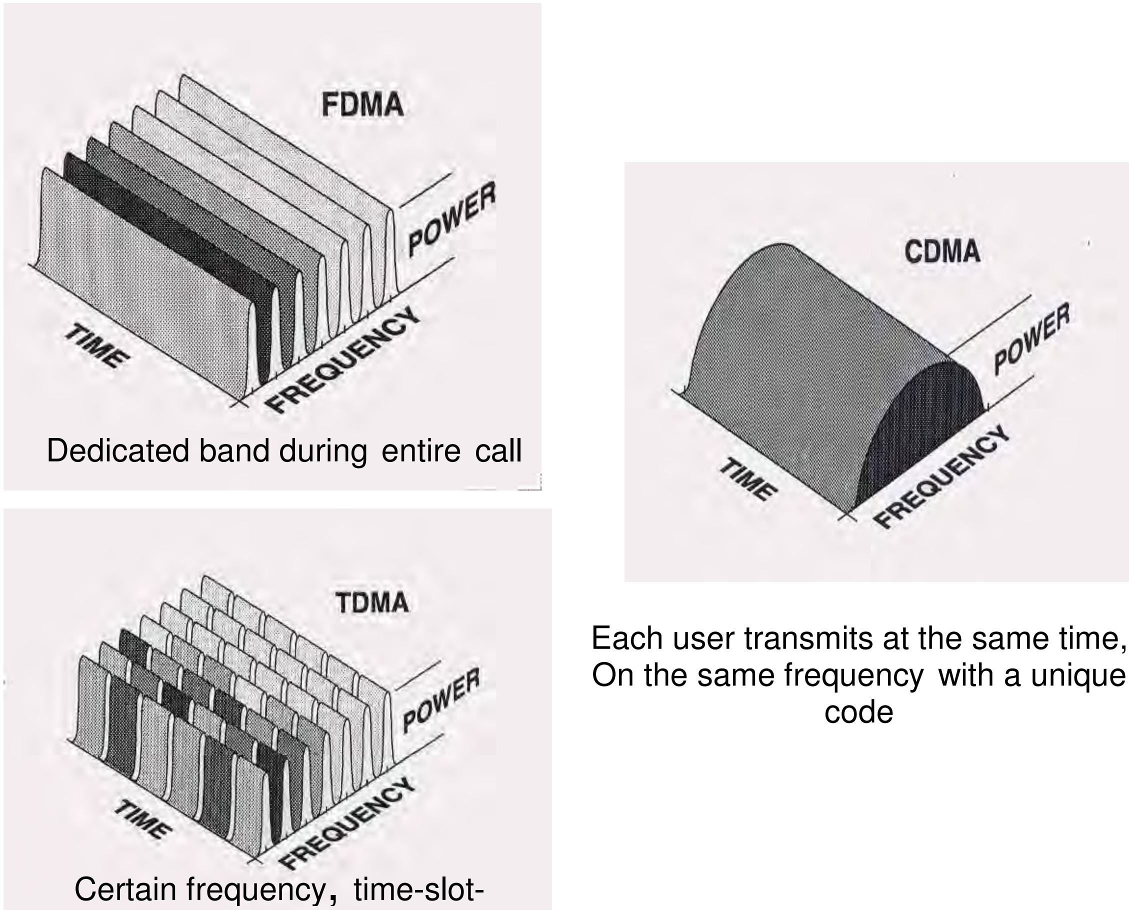


Figure 1.1 FDMA, TDMA and CDMA access techniques

1.3 Thesis Objective

The motivation for this thesis is to study and propose different techniques used to achieve higher capacity and provide better QoS for the wireless local loop system.
The two most important factors that cause performance degradation in a DS-CDMA system are known to be the effect of multipath fading and the multiple-access interference.

Detailed analysis of ETC's CDMA WLL system in terms of system capacity, interference, call blocking & dropping probabilities, and desired service quality will be performed and provide technical proposal to improve these problems.

The effect of multipath fading in a WLL system will be easily compensated with power control technique. As most users are fixed (FSU),multipath fading has negligible effect in the existing WLL system. As a result, we will focus on techniques that are efficient in combating multiple-access interference (MAI).

The use of orthogonal spreading codes during signal transmission has been shown to be very effective in alleviating the effect of intra-ce11 interference and it has been adopted in the forward link of DS-CDMA. To further increase ce11 capacity, we have to reduce also the inter-ce11 interference. Although sectorization is already used to achieve higher capacity, the sector size is limited in order to have high trunking efficiency.

1.4 Methodology

- Literature review

    - Study and analyze the standard CDMA based WLL technology regarding system capacity, coverage, frequency diversity, multipath resistance and provisioning of better quality of service for respective users.

    - 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.

    - Investigate performance enhancing methods using power control algorithm and other related techniques, i.e.

        - Improving receiver sensitivity

        - Cell splitting and sectoring

        - Better usage of soft/softer handover techniques in ensuring the desired quality of service.

- 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 WLL system.

- Matlab simulation

    - Based on the proposed power control algorithm system performance enhancement will be demonstrated.
      (Plots of system capacity, C Mc/s Vs Signal interference ratio, SIR/ SINR in dB)

1.5 Thesis Organization

The thesis is organized as follows:-

In chapter 1 introduction to CDMA system ,its performance and application analysis has been discussed. Multiple access techniques i.e. FDMA,TDMA and CDMA are introduced and compared .Thesis objective has been introduced.

In chapter 2 CDMA-WLL wireless local loop system stated with its configuration and application. Multiple access interferences (MAI) has been explained and interference reduction techniques in relation to system capacity and QoS are discussed. Multiple fading channels and its characteristic, the use of directional antenna in WLL system and capacity and spectral efficiency analysis have been explained with respect to the CDMA WLL system application.

In chapter 3 Addis Ababa CDMA WLL systems has been explained with its system capacity, network configuration and encountered problems.
Different base transceiver stations (BTS) and Base station controller (BSC) Traffic data analysis performed and presented as graphs.
Basic CDMA WLL traffic analysis systems and mathematical approach discussed.

In chapter 4 CDMA WLL system capacity and QoS enhancement techniques and algorithms are explained. Cell splitting Cell sectoring and power control algorithms are discussed in accordance to meet the thesis objective. Different power control algorithms and technique have been discussed.

In chapter 5 the Proposed power control technique and its algorithm are analyzed and provided as a network solution to resolve capacity and QoS problems.

In chapter 6 Conclusion and future work
Further analysis and experimental works has been indicated in WLL data communication applications.
References also included.
-Annexes
- Traffic measurement data

Chapter-2 Wireless Local Loop System

Radio becomes ideal for use in the local loop. The generic term used to describe telephone systems where the final link to a fixed location is made using radio is known as radio in the local loop (RLL) or wire-less local loop (WLL). The use of radio instead of copper wire to connect telephone subscribers has a number of advantages: it provides quick deployment of telephone services to developing countries where the need for telecommunications far exceeds the ability to install wire line infrastructure in a timely manner, it has a low initial installation cost, its maintenance costs are also far lower than the costs for wired networks. The radio infrastructure can easily be dismantled and re-installed in another area.

Radio not only provides a convenient medium for mobile communications, it also has many advantages in providing fixed network access. Currently due to the cost consideration of redesigning a WLL system, many operators and manufacturers are using the existing mobile cellular equipment to provide the local loop services. Because of the difference in service requirements and channel characteristics, the mobile cellular architecture should be modified to gain more capacity for use in fixed wireless systems.

Wireless in Local Loop (WLL), on the other hand, is meant to serve subscribers at homes or offices as fixed subscriber unit (FSU). The telephone provided must be at least as good as wired phone. Its voice quality must be high a subscriber carrying out long conversation must not be irritated with quality; one must be able to use speakerphones, cordless phones and parallel phones. The telephone must support fax and modem communications and should be connectable to a Public Call Office.[2]

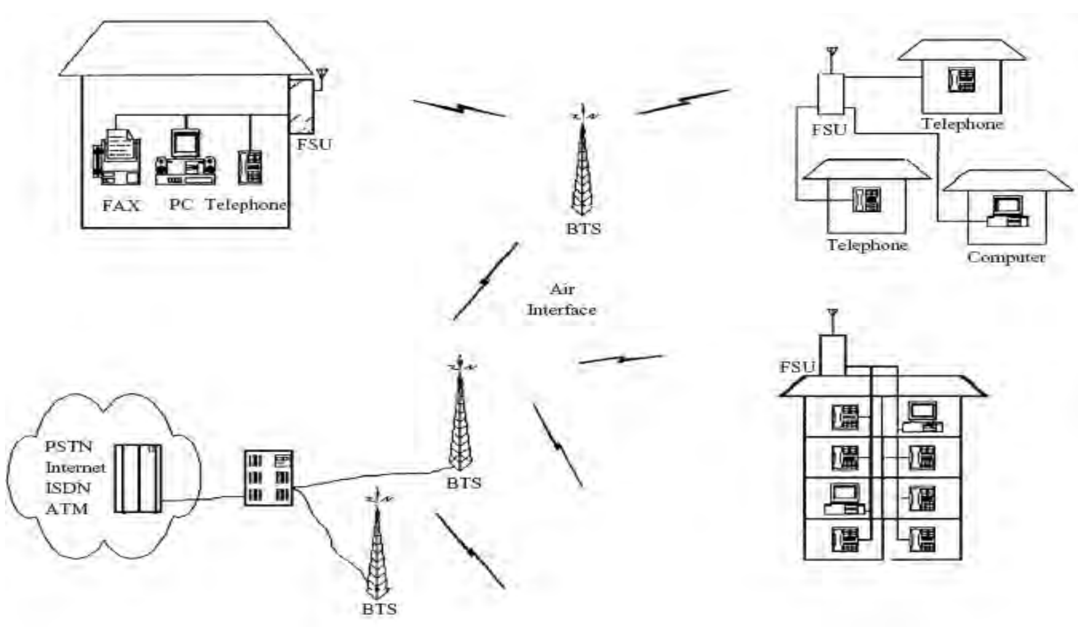


Figure 2.1 Generic WLL architecture (Networking)

Ability to provide medium rate Internet access is a must. Further, the traffic supported should be reasonably high at least as high as 0.1E per subscriber. Besides, ability to support a large number of subscribers in an urban area (large teledensity) with a limited frequency spectrum is required. For the systems to be of use in developing countries, the cost of providing this wireless access should be less than that required for wired telephone. Airtime charges are totally unacceptable.

Therefore, even though the mobile communication systems and wireless in local loop systems may appear to be similar, and sometimes even used interchanging, the requirements are quite distinct.

2.1 WLL System Capacity

There are several factors, which determine the efficient use of a radio spectrum in a wireless in local loop system. In this section, we will attempt to determine an expression for the capacity, *C*, of a WLL system. The capacity expression will be in terms of the number of subscribers per sqkm that can be served given an available spectrum, Erlang traffic used, cell radius and number of sectors used and the payload that has to be provided to each subscriber. Some of the popular access techniques will be compared using Capacity C, equals Numbers of subscribers served per sq km expression.

Multi access and modulation efficiency and overheads = *M* bps/hz: This factor combines modulation efficiency, effect of overhead and multi-access efficiency and gives the number of bits of payload delivered per Hz of spectrum.

Therefore, total number of channels of *x* bps available is total spectrum available ,S multiplied by multi-access and modulation efficiency then divided by payload required per subscriber or *(SM/x).*

Since *R* fraction of these channels can be utilized in each sector, the number *x* bps channels available per sector will be *(SMR/x).*

Since traffic per subscriber is *e* Erlang, if the number of channels available in each sector is large, the total number of subscribers in each sector would have simply been the number of channels available divided by *e*. However, if the number of channels per sector is not large, the trunking efficiency, T_e, will reduce the number of subscribers that can be served in each sector.[2]

Therefore, number of subscribers in each sector $= \left(\frac{SMR}{x}\right) \cdot \left(\frac{Te}{e}\right)$ (2.1)

Since there are n_s non-overlapping sectors per cell, and r is the radius of the cell, the capacity or subscriber density C that can be served is

$$C=\left(\frac{SMR}{x}\right).\left(\frac{Te}{e}\right).\left(\frac{\eta s}{\pi r^2}\right) \quad \text{Subscribers/sq.km} \qquad (2.2)$$

Where

r = radius in km for each cell
n_s = number of non-overlapping sectors used per cell
R = reuse efficiency (depends on access technique and n_s, and governs fraction of total spectrum that can be effectively used in each cell and each sector)
M= Multi access and modulation efficiency and overheads, bps/hz
e = Erlang traffic per subscriber
T_e = trunking efficiency (a factor which depends on the Erlang traffic per subscriber, e, and number of channels available in each sector/cell)
S = total spectrum available in Hz
x = payload in bps required per subscriber.

Note that not all variables on the right hand side of the equation are independent as R is a function of access technique and n_s, whereas T_e is a factor depending on *(SMR/x)* as well as to some extent on the non-ideality of the sectored antennas.

2.2 Multiple Access Interference (MAI)

Multiple accesses refer to the simultaneous transmissions by numerous users to a common receiving point. In a CDMA system, al1 users share the whole spectrum in al1 cells. Therefore, a spreading sequence having noise-like auto-correlation and uniformly low cross-correlations with *any* other spreading sequences is assigned to each user.

A commonly used pseudo-noise (PN) sequence is generated by a set of linear feedback shift registers (LFSR) which has a maximum period of $2^n - 1$, where n is the number of stages of the feedback shift registers. The long code and short code are generated by a LFSR with maximum period called m-sequence; the long code has a period of $2^{42} - 1$ and the period of the short code is equal to 2^{15}.

The noise-like correlation property of m-sequences is realized only when full period correlation (FPC) is employed at the receiver. Full period correlation is impractical when the PN sequence used has a long period such as those used in IS-95. This is because long acquisition time in most communications systems is intolerable. Also to support a given data rate in the available spectrum, the correlation period is usually limited. In this case, most receivers use partial period correlation (PPC). In a system that adopts partial segments are masked onto the coded bit before transmission.[4]

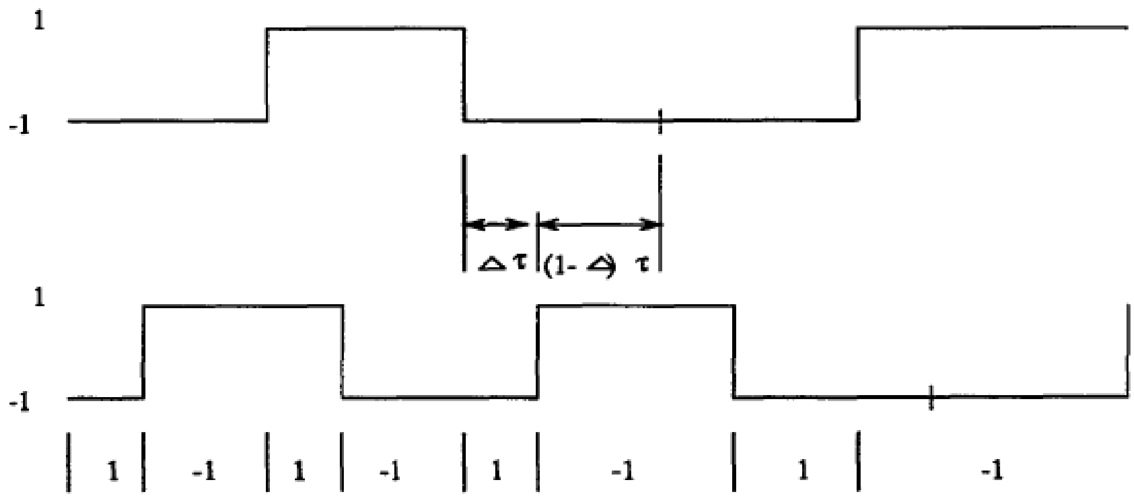


Figure 2.2 Partial sequence correlation with different spreading codes,r1 & r2

Analyzing the partial correlation property of PN sequences involves finding the correlation for al1 PN sequences with different code phase offsets. Even for PN sequences with moderate length, it becomes an intractable task. One approach is to find a set of sequences in which each sequence has good randomness properties. When the period of the spreading code is much longer than the observation period, the small segment of the m-sequences can be approximated by a random sequence.

Figure 2.2 describes the partial sequence correlation for a sequence of rectangular chip pulses. If we assume the use of rectangular chip pulse, for observation period of M chips, we can express the correlation function as a summation of two random variables:-

$$r_1 = \Delta c^1{}_i c^2{}_{i+D} \quad \text{and}$$
$$r_2 = (1 - \Delta) c^1{}_i c^2{}_{i+D} \qquad (2.3)$$

where c^1 and c^2 are independent random sequence with $c^1{}_i$ and $c^2{}_{i+D}$ equal to 1 or -1 and D is the chip offset between the sequences. r_1 and r_2 then take one value +/- Δ and $+/-(1 - \Delta)$ respectively. We denote Ec be the chip energy for the rectangular pulse and Tc be the chip period.

Then the correlation between two spreading codes for D > 1 is given as

$$R = \sum_{i=1}^{M} Ec(r_1 + r_2) \qquad (2.4)$$

For M>>1, we apply Central Limit Theorem and the correlation R, becomes Gaussian.

$$\sigma^2 = Ec\,(1 - 2\Delta + 2\,\Delta^2\,)\,M \qquad (2.5)$$

Multiple access interference (MAI) is then a result of the non-zero cross-correlation among spreading codes.
The above analysis of MAI assumes the use of random spreading sequence. It has been shown that after dispreading, the interference power is approximately reduced by the processing gain. The multiple access interference increases as the number of users in the system increases. This accounts for the lower ce11 capacity for using CDMA in a single ce11 system as compared to TDMA and FDMA. We can improve the capacity of a CDMA system by assigning orthogonal spreading codes to the user in the same cell. This is done in the forward link (the transmissions from the base station to the mobiles). In a point to multipoint transmission, the base station is able to coordinate al1 the transmissions of the orthogonal signals.

As a result, interference only arises from other cells (inter-ce11 interference). However, for a systems operating in a multipath environment, interference caused by users of the same ce11 (intra-ce11 interference) and interference coming from the delayed version of the desired signal (inter-path interference) still exist and cause performance degradation to CDMA systems.

In the reverse link (transmissions from mobiles to the base station), the coordination of users' transmission becomes impossible as rapid movement of users causes problem in maintaining synchronization. As a result, users are usually assigned long period PN spreading codes instead.

2.2.1. Interference Reduction Techniques

The target Signal to Interference Ratio (SIR) determines the re-use distance(D) primarily. The target SIR is based on the minimum sensitivity required at the receiver input in order to obtain a particular Bit Error Rate (BER). The required BER is typically 10^{-3} for voice applications (and 10^{-6} or higher for data applications by using error control coding).

Depending on the choice of multiple access, the modulation scheme and the particular application (mobile or fixed wireless), the target SIR set point will differ.
Interference reduction techniques are widely used in wireless systems to increase re-use efficiency while retaining the target SIR requirement.
These techniques include: Sectorisation, Voice Activity Detection, Power Control, Rate Control and Frequency Hopping.

In continuously transmitting wireless systems like DS-CDMA, Voice Activity Detection (VAD) is very useful to reduce power consumption, and also increase user capacity. In VAD, not only is the presence or absence of speech energy monitored, but also the regions corresponding to unvoiced speech and the transition regions between voiced to/from unvoiced speech. DS-CDMA exploits VAD to reduce its bit-rate from 8kbps to 4/2/1kbps corresponding to unvoiced speech, transition regions, and comfort noise regions. [4]

VAD information can be used to define rate control and/or power control operations. For example, in DS-CDMA, when VAD returns a no-speech activity flag, the bit-rate for that user can be dropped from 8kbps to 1kbps (rate control) by lengthening the bit period by a factor of eight (from T_b to $8T_b$).
Simultaneously, the transmit power of the user can be reduced by a factor of $8^2 = 64$. Now, the integrator in the receiver will integrate over $8T_b$ which will give back the same energy per bit for that signal. Therefore, rate and power control do not charge the effective energy-per-bit or SNR for that signal.

Of course, sophisticated power control is also done (both on the base and mobile stations) in DS-CDMA to mitigate the near-far problem of direct sequence spectrum communications. Even TDMA/FDMA systems can employ rather simple power-control mechanisms to reduce co-channel and adjacent channel interference. For example, all low range (near base station) duplex channels can lower their peak powers and still meet the target SIR.

2.3 Multipath Fading Channel

The complex low-pass equivalent impulse response of the multipath channel for the k^{th} user is written as

$$h_k(t) = \sum_{l=1}^{L} \alpha_{k,l} \, \delta(t - \tau_{k,l}) \, e^{-j\theta_{k,l}} \qquad (2.6)$$

Where αk,l, τk,l and θ_k ,l are the signal amplitude received from the l^{th} path the time delay of the l^{th} path relative to the first path and the random phase shift, respectively.
The average number of resolvable paths, L, is then given by

$$L = \left[\frac{T_D}{T_C} \right] + 1, \qquad (2.7)$$

Where T_D is the RMS delay spread, T_c is the chip duration, and the function [x] equals the largest integer smaller than or equal to x. Since the receiver cannot resolve paths that arrive with relative delays less than Tc, the signal amplitude q, r consists of paths that are combined constructively or destructively. The amplitude variation due to the multipath characteristics of the channel is named channel fading.

In dense urban environments, the fading amplitudes $\alpha_{k,l}$ for l= 1,2, - - - , L are usually modeled as identically distributed independent Rayleigh random variables.
In a multipath fading environment, fading amplitudes are correlated in both time and in frequency. The degree of correlation depends on the coherence bandwidth Δf_c and coherence time Δt_c of the channel. [6]

The coherence bandwidth of the channel is measured as the inverse of the delay spread, i.e, $\Delta f_c = 1/T_D$. The fading amplitude of two sinusoidal signals with frequency separation larger than Δf_c will have correlation less than 0.5.

When the coherence bandwidth is small in comparison with the bandwidth of the transmitted signal, the channel is said to be frequency-selective; otherwise, the channel is said to be frequency-non-selective or flat fading channel .The coherence time, Δt_c is inversely proportional to the Doppler spread (B_d)

$$B_d = \frac{V}{C} fc \qquad (2.8)$$

where v is the velocity of the telephone terminal (mobile) unit, c is the speed of light, and f_c is the carrier frequency. The signals received with time separation longer than Δt_c, are assumed to experience independent fading.

As mentioned in the above section, multipath fading causes large variation in the received signal strength. In order to guarantee a satisfactory quality of service at most times, the system always operates in a higher signal to interference plus noise ratio (SINR) than the minimum required SINR. The difference between the minimum required transmit power and the actual operating power in the fading environment is known as the fading margin.[6]
Multipath fading is mainly occurs in the mobile (GSM) application. Its effect in WLL system, especially for fixed user's application (FSU) using directional antennas would not be considered.

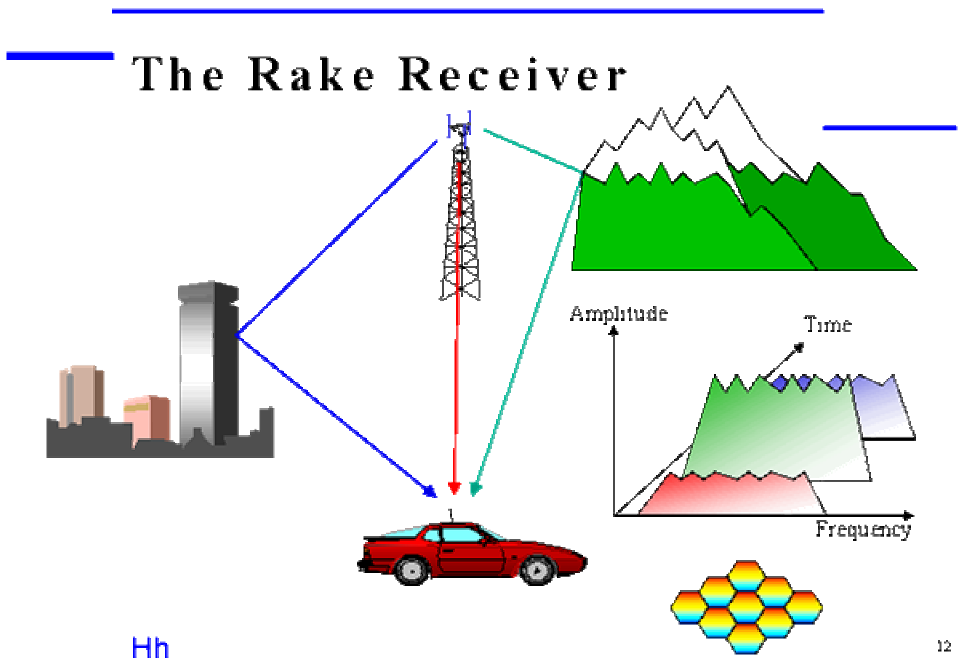


Figure 2.3 Multipath fading channel

2.3.1 Directional Transmitter Antenna

The use of directional antenna is an effective way to reduce inter-ce11 interference. In a CDMA system, most inter-ce11 interference is caused by transmitters located close to the ce11 boundary. One way to solve the problem is to lower the transmit power for users at the boundary; however, this is not possible for a CDMA system due to the near-far effect (i.e. signal transmitted at distant location is overwhelmed by signals coming from near the base station).

The use of directional transmitter antenna is most suitable for the WLL system since the transmitter knows the direction of the base station. By pointing the beam to its own base station, the transmitter does not create interference to the neighboring cells.

Due to the complexity of antenna structure and the radiation of signal power at radio frequency, the beam width of around 60" is considered reasonable. In addition, the use of antenna diversity in the base station also prevents the use of very narrow beam transmitter antenna.

CDMA takes advantage of multiple fading to enhance communication and voice quality. Using RAKE receivers and other improved signal processing techniques each base station (BTS) select the three strongest multipath signals and coherently combines them to produce an enhanced signal.

The multipath fading of the radio channel is used to an advantage in CDMA where as, in narrowband systems fading causes a substantial degradation of signal quality. By using soft handover, CDMA eliminates the ping pong effect that occurs when the mobile telephone is near a border between cells and the call is rapidly switched between the two cells.[6]

2.4 Capacity and Spectral Efficiency

The interconnection of a WLL system to the PSTN and the requirements that a WLL system has to fulfill governs the choice of a WLL technology. A wireless communication system has to recognize that the frequency spectrum available will always be limited. Obviously, since the telephone as well as an Internet connection is not used continuously, the channels must be assigned to a subscriber on demand. But this is not enough. The key focus has to be efficient use and reuse of the spectrum.[6]

What governs use and reuse of spectrum?

The use and reuse of spectrum is governed by multiple factors including:

Channel pay load (bit rate) :- higher bite rate payload will require larger frequency sources as compared to a lower bit rate payload. Therefore for voice communication on wireless systems, it may be desirable to have efficient voice compression and lower bit rate voice coders.

Signaling overhead :-As signaling is key to setting up, monitoring and tearing down of a call, signaling communications need to be carried out on air between subscriber equipment ad the base stations. The signaling equipment may be dedicated for each user or may be shared. usually ,more sophisticated the system, more is the signaling requirement. The signaling becomes an overhead that takes away certain frequency resources and play a role in overall efficiency of spectrum usage

Modulation efficiency :-The modulation techniques employed has a direct bearing on efficient use of spectrum. More efficient techniques (16-QAM ,8-QAM, QPSK , MSK) are usually expensive to implement and may sometimes require large power margins. For WLL ,one would require the technique to be implemented in each subscriber's equipment. Therefore QPSK,MSK or even BFSK techniques are often used even though their spectral efficiency is moderate

Cell-radius (range) :-Cell radius is perhaps the most important factor governing the spectrum utilization in a wireless system. Subscriber density is inversely proportional to the square of cell radius . $SD \sim N / e \times \prod r^2$

Choice of multiple access (FDMA,TDMA,CDMA):- A key parameter determining the efficient reuse of spectrum is governed by multiple access technique used .The access technique define s how the frequency spectrum is divided into channels and affects reuse of the channels.

Interference reduction techniques :-The target signal to interference ratio (SIR) determines the reuse distance primarily. The target SIR is based on the minimum sensitivity required at the receiver input in order to obtain a particular bit error rate (BER). The required BER is typically 10-3 for voice application. Interference reduction techniques are widely used in wireless system to increase reuse efficiency while retaining the target SIR requirement.

Spatial diversity and space-time processing:-Use of multiple antennas at a (Fixed) subscriber terminal as well as at the base station allows one to spatially multiplex different data streams on the same carrier by transmitting the streams through different antennas.. Use of L antennas can give (nearly) an L-fold increase in data rate. This technique is also called MIMO (Multi input multi output) processing, one particular version of spatial multiplexing, called V-Blast gives spectral efficiencies as high as 30 bits/sec/Hz in short range , fixed wireless application.

Chapter-3 Addis Ababa CDMA based WLL Network

CDMA based wireless local loop technology has been deployed in different part of the country in the past few years. A CDMA -WLL system operating at 800 MHz with 16 BTS sites has been introduced to cover Addis Ababa and its outskirts.

The design capacity of the system was to accommodate 36,000 voice subscribers and 2% of them were considered to use data service at the maximum rate of 48kbps.
Main operation and Maintenance center of the system is located in the Bole area in East Addis Ababa Zone (EAAZ).

Because of strong customer demand about 31,000 voice and 960 data subscribers are connected to the system. Initially the quality of service from the network was good but as soon as more users began to be connected, service quality started declining and degraded.

Call setup failure, call drop, poor voice quality, and poor radio coverage are some of the problems often reported from the customers.

The stated problems are reported to be due to BTS capacity limitation, poor coverage and reverse link interferences that were encountered.

To enhance the performance of CDMA based WLL system Cell Splitting, Cell Sectoring and Power Controlling techniques are used for combating interference, increasing system capacity and improving of coverage planning & quality of services, QoS.[3]

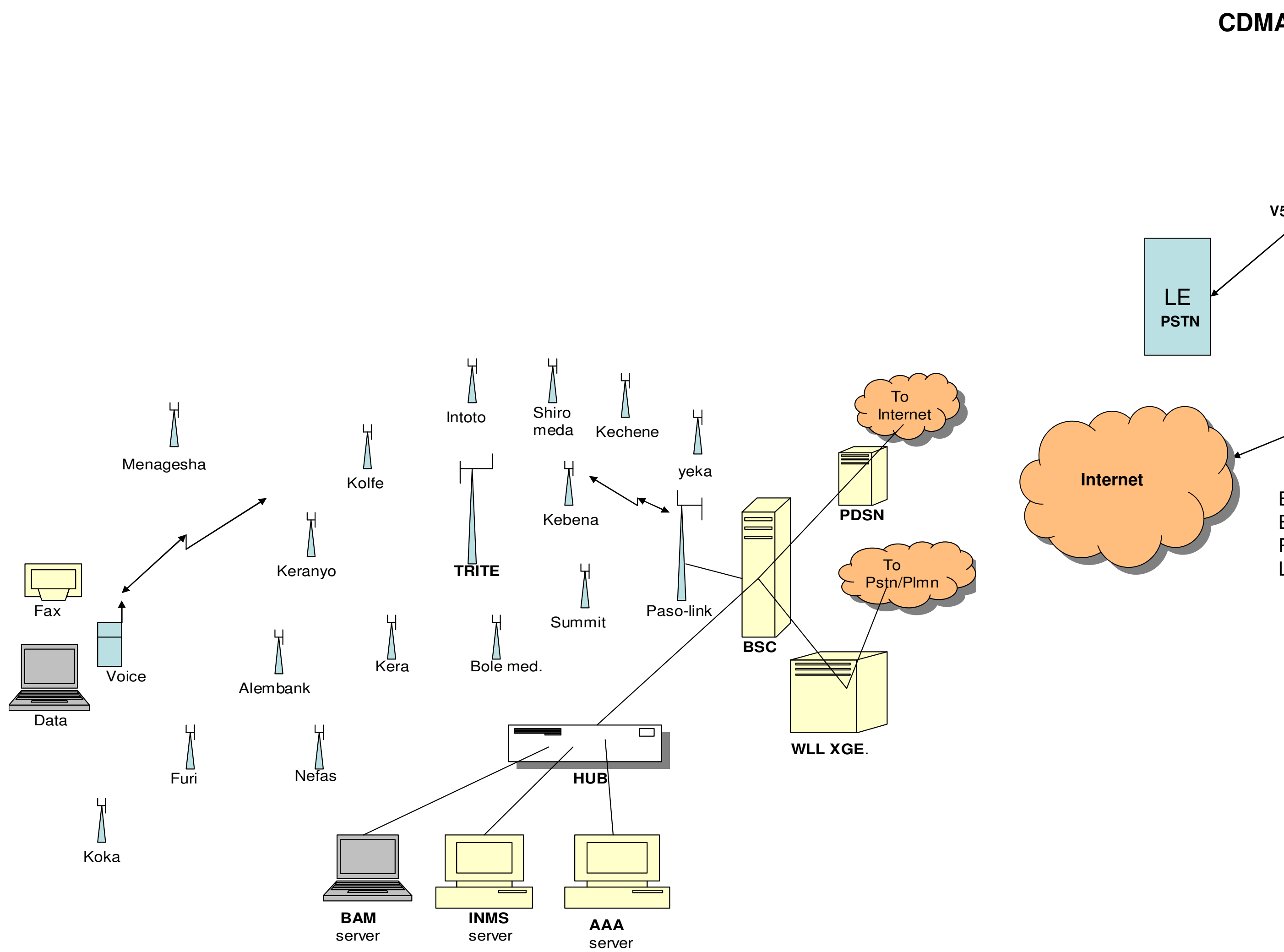
Addis Ababa Wireless local loop, WLL Radio network types, system configuration and service areas are presented below :-

Radio Network type used

- The WLL system uses one BSC controller located at Bole area (EAAZ) office and has 16 BTSs with 88 transmitters.

  The 16 BTS are categorized as:-

- 14 BTS configured with two directive antennas in each sector (S222 type), one BTS configured with one directive antenna in each sector (S111 type) and one BTS at KOKA uses (type101) configuration.



Addis Ababa CDMA WLL existing system configuration

Figure 3.1 (a) & (b) Addis Ababa CDMA WLL system

Table 3.1 CDMA based WLL network utilization in Addis Ababa zonal offices as of 06/07/2005

Zone offices / Services	CAAZ	EAAZ	NAAZ	SAAZ	SWAAZ	WAAZ	Total users Per Service
Voice	2819	7238	4122	5136	4648	6232	30195
Internet	66	372	73	192	64	146	913
Fax	12	225	15	105	29	93	479
Total/Zone	2897	7835	4210	5433	4741	6371	31487

3.1 Coverage Performance (A.A)

To overcome customer complaints, additional sites were introduced ; antenna adjustment & neighbor list updating and optimization work have been done. These actions were expected to provide the maximum coverage from the existing BTS sites.

The status of coverage is determined by E_c/I_o, handset received power and handset transmits power.
E_c/I_o is the ratio of the strength of certain pilot signal energy to the total RF signal received at the user's terminal. It indicates the cleanness of pilot, foretells the readability of the associated traffic channels and guides soft handover decisions.[3]

The following are the main identified reasons for the degradation of quality of service in the network.

1. The number of subscriber sold in some of the zone office is not in proportion to the designed capacity of the corresponding BTS.
2. The mobility of subscribers is not restricted. All subscribers are allowed to move to any location they want in the city resulting in concentrating service demands to limited number of BTS sites.
3. In few areas, poor coverage is observed due to the shadowing effect of the small hills blocking signals from the nearby CDMA site.
4. Experiencing reverse link interference on more than 5 BTS's sites from the existing transmission system.
5. CDMA-800Mhz often claims a range of up to 20Km. However as CDMA is an interference limited system, not a propagation limited system, the 20Km claimed range is observed to be true only under very light loading conditions.
6. Intoto and Furi BTS sites cover the whole city, needs swap or replacing them by normal few BTs, this reduces over cover network interference across the cells.

Traffic data analysis

The following figures show Traffic measurement data as obtained from the operational CDMA WLL system. The figures show the BSC RAC voice and data traffic density, call set up success and call drop ratios, average transmitter power, traffic density and call success ratios attempted during the indicated days for 24 hrs.

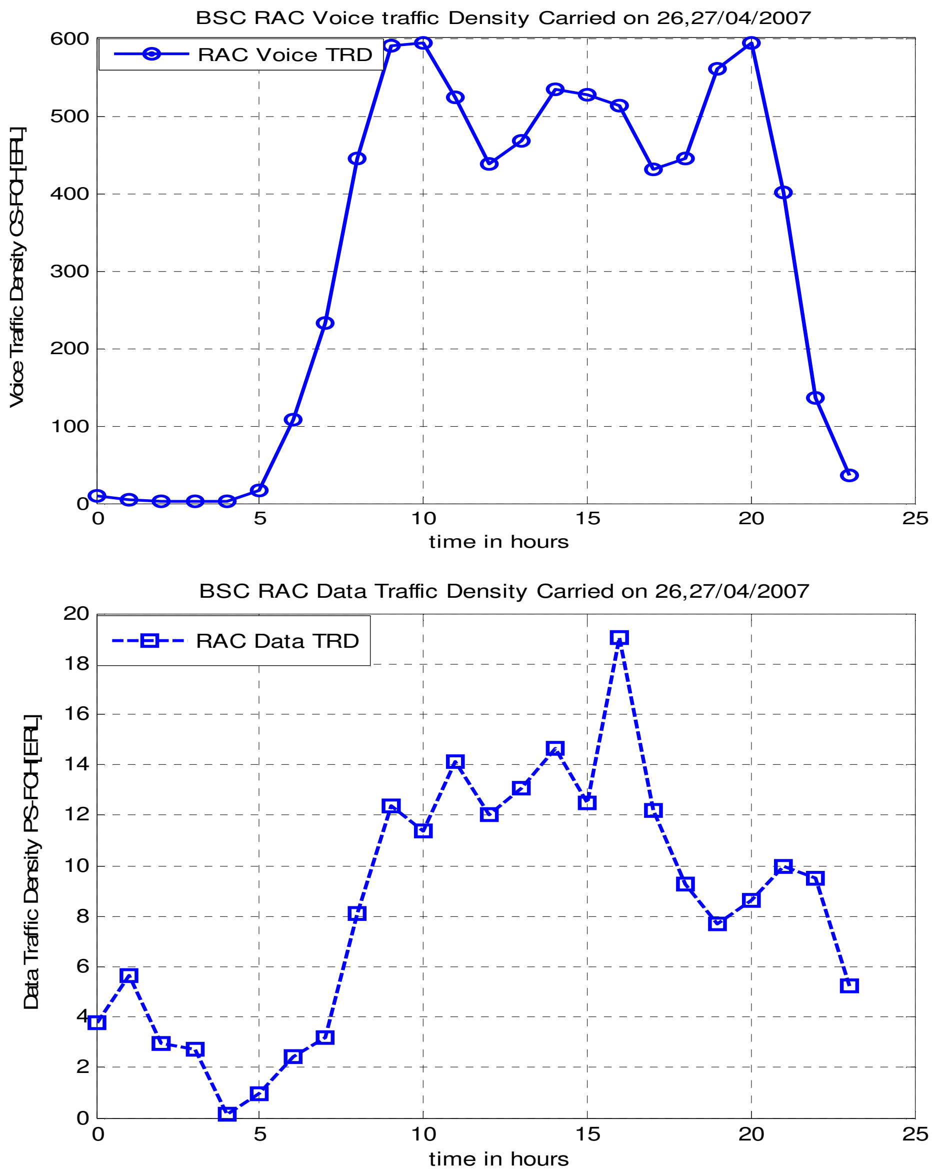


Figure 3.2 (a,b) Voice(a) & Data(b) traffic density measurement representation Of CDMA WLL main control switch (BSC RAC)

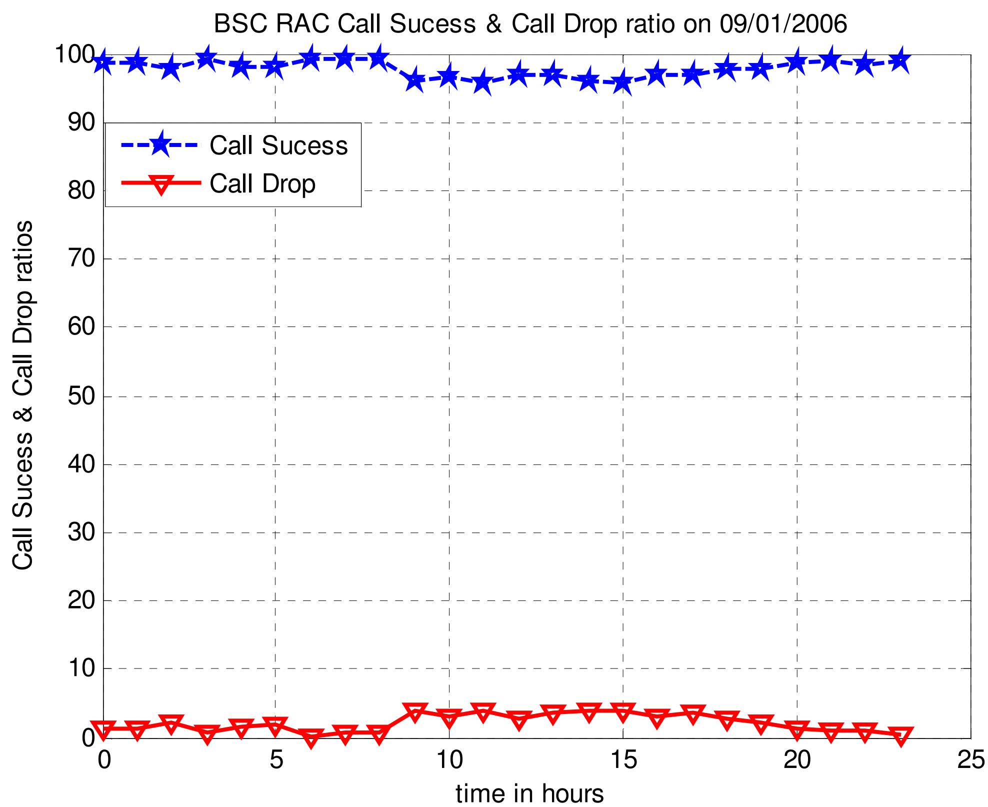


Figure 3.2(c) Call set up success and call drop ratio of CDMA WLL main control switch
(BSC RAC)

The BSC RAC Traffic performance indicates that voice traffic has higher service provision in the network. Comparably less amount of Data traffic with internet and fax transmission is observed.

Data communication requirement shows a growing trend. From figure 3.2(c) Call attempt success ratio is higher, call drops & call blocking conditions also have been observed because of internal and external interferences.
Call success and Call dropping ratios showed a better performance after system parameter adjustment and expansion works.

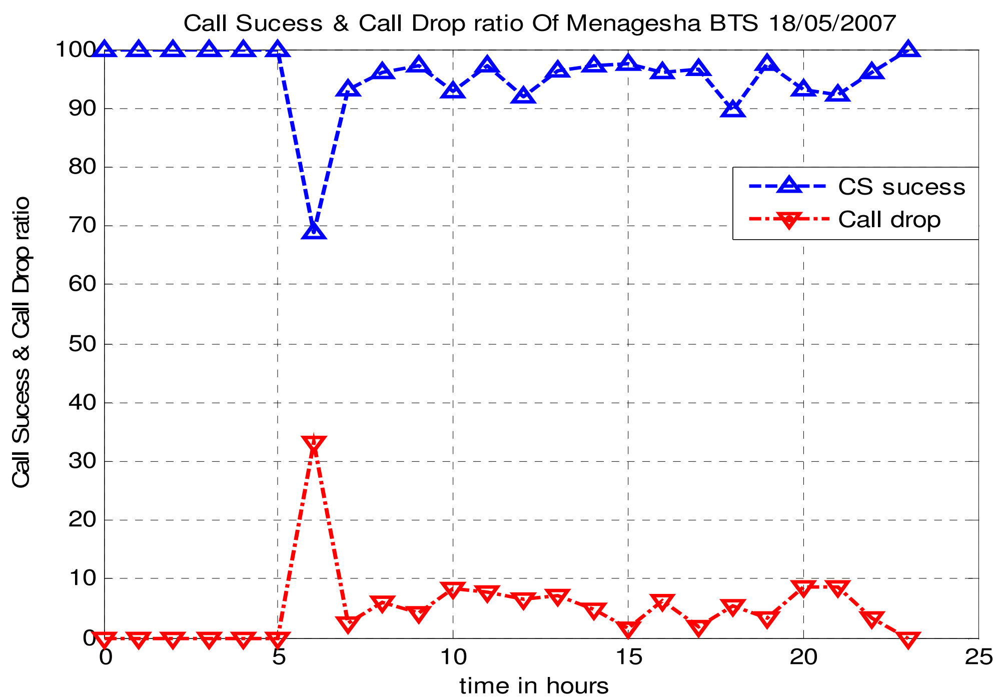


Figure 3.3 Call set up success ratio and Call drop ratio of Menagesha BTS

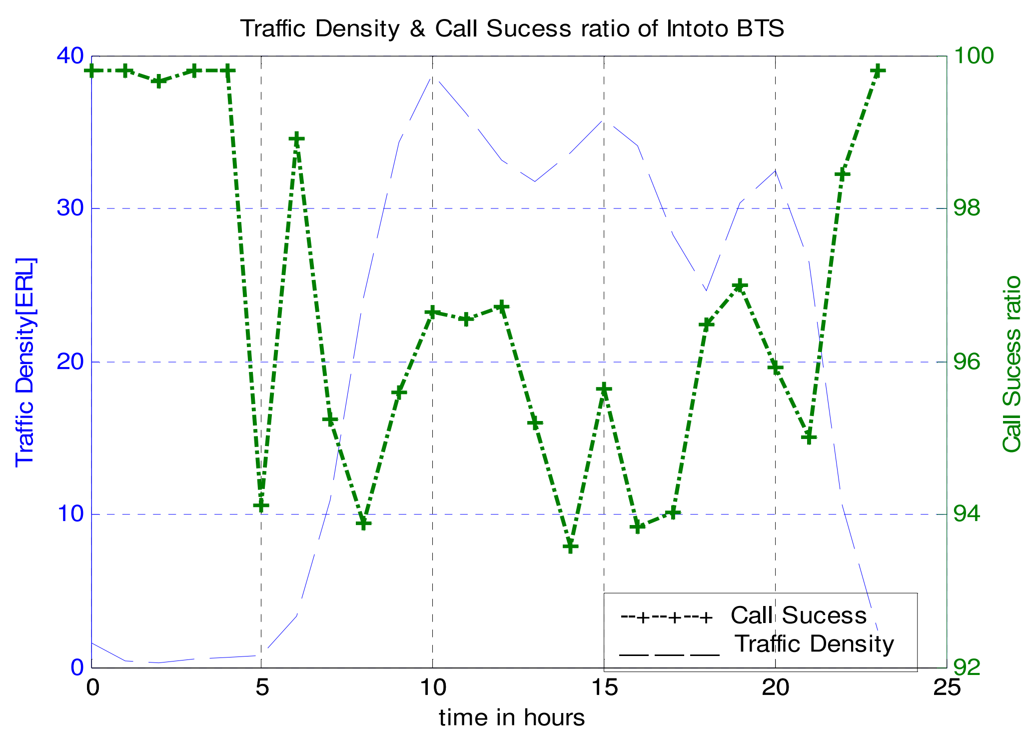


Figure 3.4 Traffic density and call success ratio of Intoto BTS

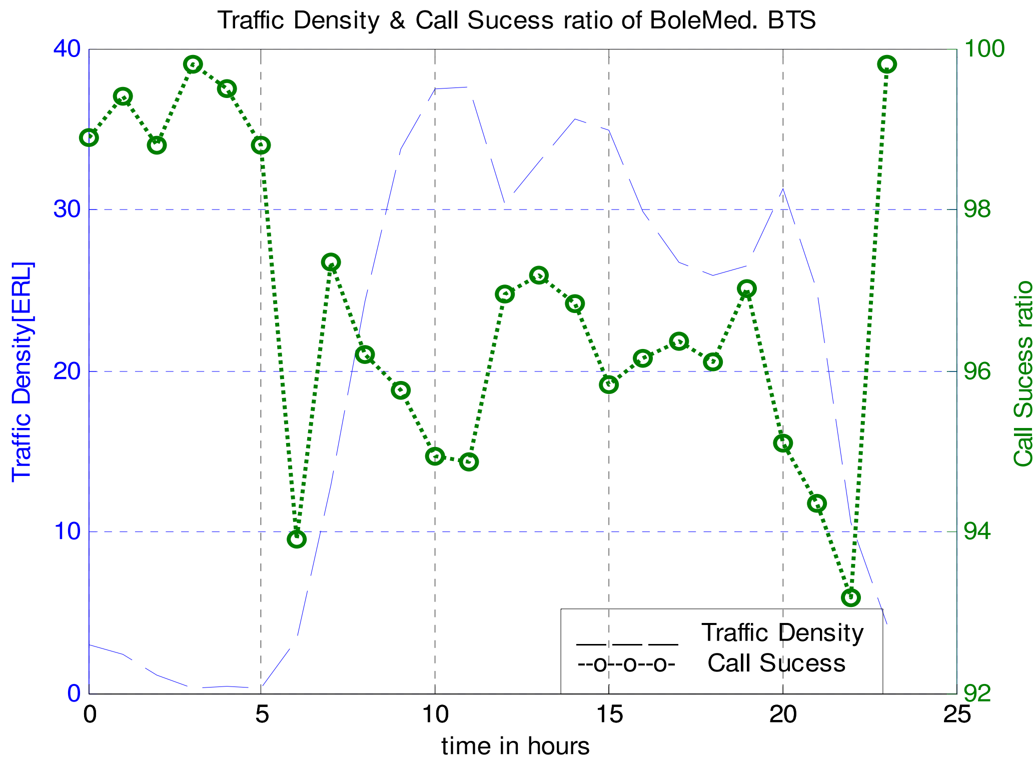


Figure 3.5 Traffic density and call success ratio of BoleMed BTS

Figures 3.3, 3.4, 3.5 show sample Voice Traffic measurements, Traffic density, Success call attempts and Call drop ratios of Menagesha , Intoto and BoleMed.BTs.

Relative performances with the traffic density are indicated. When the telephone traffic volume increases, the respective call success ratios show increasing pattern with respect to the traffic situation at particular instant.

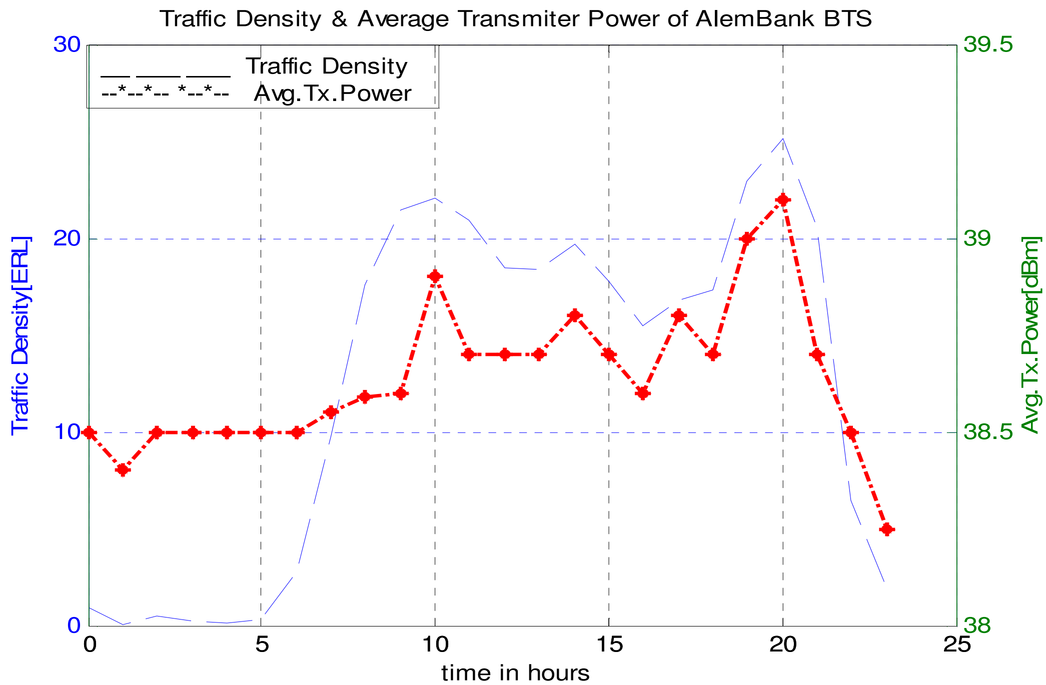


Figure 3.6 Average Transmitted power Vs Traffic density of Alem Bank BTSs

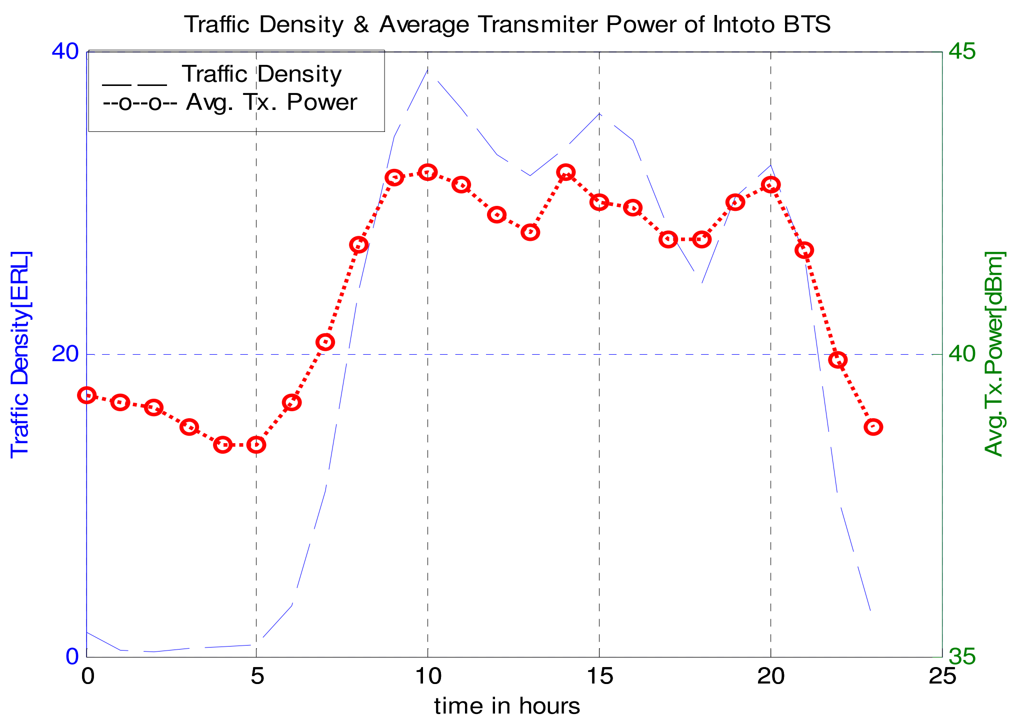


Figure 3.7 Average Transmitted power Vs Traffic density of Intoto BTSs

The average transmitter power requirements in the BTS follow the traffic condition. When more users are trying to be connected to the system, the particular BTS uses its maximum transmitter power to reach to the user.

Each BTs in the network uses a maximum about 44dBm and minimum of 38dBm as transmission power. When more users are trying to be connected to the network, more interferences are generated causing system deterioration, call set up failure and call blockings.

To prevent the system from such situations power controlling method is required to regulate transmission power of the BTS and enhance system performance as proposed in this thesis work. Each BTS has to radiate the maximum power confined to its localized cell size and desired direction.

3.3 Traffic based capacity Analysis

The number of available channels at every access point is a rough but useful capacity measure. It describes the capability to serve users from an operator perspective, but it does not reflect the user satisfaction. For this purpose we start by introducing the assignment failure rate V_p as the user performance constraint. The capacity is determined as given by $w * V_p$ for the hypothetical static channel allocation. In this allocation scheme, the channel in each cell can be freely allocated to any terminal in the cell, independently of what is going on in other cells. The worst case interference assumption will guarantee that the SIR condition is fulfilled for any of these channel allocation. Therefore, considering the allocation of channel in one particular cell and assuming that the number of terminals in this cell is Mc, the number of assignment failures can be computed as : [9]

$$Z = \max(0, Mc-\eta) \quad , \quad \eta = [C/K] \text{ - Channels/cell} \qquad (3.1)$$

the assignment failure rate can be found as :

$$Vp = \frac{E[Z]}{E[Mc]} = \frac{E[\max(o, Mc-\eta]}{wAc} = \sum_{k=\eta}^{\infty}(k-\eta)\frac{(wAc)^{k-1}}{k!}e^{-wAc} \qquad (3.2)$$

Where the fact that Mc is Poisson distributed with expected value wA_c has been used. Further [9]

$$A_c = \frac{3\sqrt{3}}{2}R^2 \quad \text{, denotes the area of the cell} \qquad (3.3)$$

with R as the cell radius.

The figure below shows the assignment failure rate Vp as a function of traffic load, Some typical values of η as function of the relative traffic load w_η defined as:

$$w_\eta = \frac{wA_c}{\eta} \tag{3.4}$$

An alternative measure of the traffic load is the expected number of terminals per cell per the total number of channels in the entire system, C

$$w_c = \frac{wAc}{C} = \frac{w_\eta}{K} \tag{3.5}$$

As evidenced from the figure, the assignment failure rate is an increasing function of w and decreasing in η .Less obvious is the fact that the assignment failure rate is decreasing in η when we increase w with the same amount, i.e. keeping w_η constant. A well known result from traffic theory is that a system with many channels is more efficient than a system with fewer channels (i.e. the bigger the better, trunking gain).

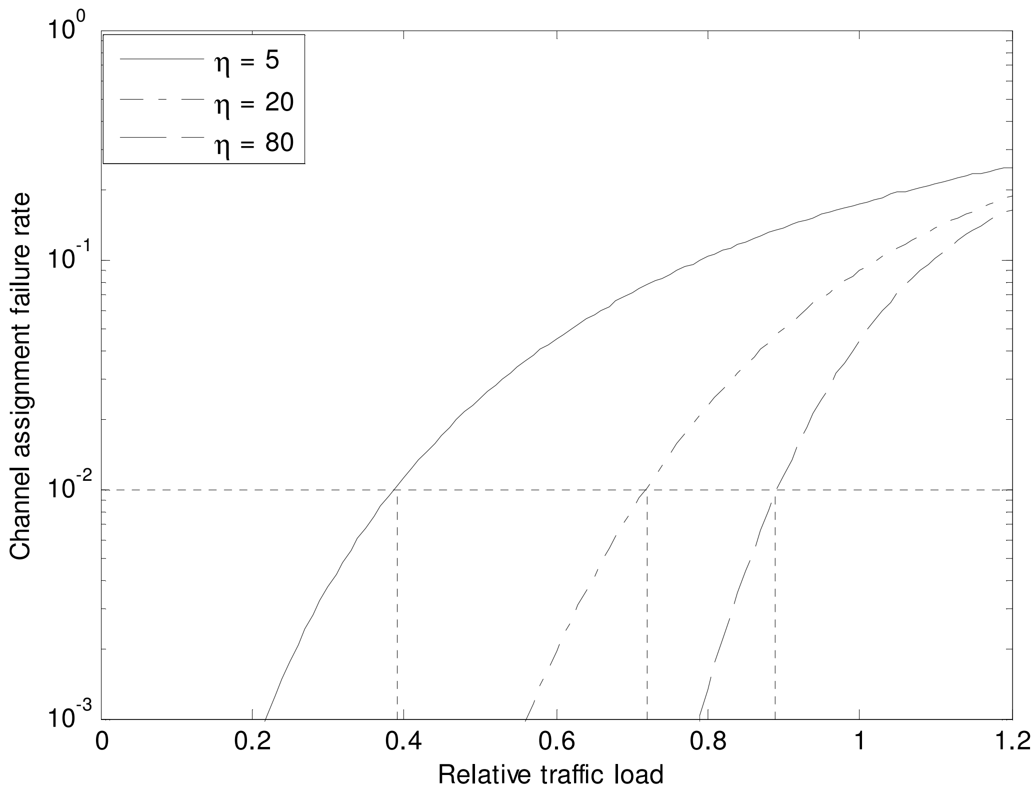


Figure 3.8 Relative traffic load(w_η) Vs Channel assignment failure rate (Vp)

Re writing $w_\eta = \frac{wA_c}{\eta}$, yields, (3.6)

$$w = \frac{w_\eta \eta}{A_c} = \frac{Cw_\eta}{KA_c} \quad (3.7)$$

The following reuse channel group K, approximation can be made

$$K = \frac{\Delta^2}{3} = c(\alpha)\, \gamma_0^{\,2/\alpha} \quad (3.8)$$

Where c(α) is a constant and γ_0 is the minimum required SIR (target). Inserting this result in to [w] expression we get the following approximation result:

Using the relation, c'(α) = 1/ c (α)

$$w = c'(\alpha) \frac{Cw_n}{\gamma_0^{\,2/\alpha} A_c} \quad (3.9)$$

Where

- M_c – Number of terminals
- K – Reuse channel group (K=3,7,..)
- Δ – Normalized reuse distance (D/R)
- η – Channels per cell
- k – Wave form
- α – Free space propagation
- w – System capacity in calls/Km^2
- w_η – Relative traffic load
- Vp – Channel assignment failure rate

From this expression, there are in principle three ways to increase the capacity of a wireless communication system:

- **Increasing C**: This is fairly obvious. The drawback is the increased Bandwidth (increasing proportionally to C) since new spectrum resources may be hard to come by this could be difficult.

- **Balancing (Balancing) γ_0**: Employing more interference resistance modulation per detection and coding schemes. Since these results in decreased K, and thus increased η, the gain is twofold since the factor w_η is also increased. Net gain in capacity can usually be achieved.

- **Reducing A_c**: By decreasing the size of the cells, A_c will improve propagation (i.e. to line of sight conditions α = 2) which will reduce the constant c' somewhat. If Ac reduces , access ports /unit area will increase , call attempt will be sucessfulThe penalty is the increasing number of cells (access ports) per unit area, since the number of access port is inversely proportional to A_c. The capacity will be roughly proportional to the total number of access ports in the system.[9]

3.4. Erlang Capacity of DS-CDMA Systems

The capacity of a DS-CDMA system, because of its frequency reusing and unique coding techniques could be more than ten times larger than that of other types of wireless communication systems. So far this proportion has been examined through a simple capacity calculation. The capacity derivation can be refined in to a more advanced form.

The refinement will start with the uplink in a single cell. Assume that users will arrive at the cell according to the Poisson process with rate λ and each user's service time will follow the exponential distribution with mean $1/\mu$.Under this setting , it can easily be seen that the number of users per cell, say k_u, will follow the Poisson distribution with mean λ / μ in the steady state.

$$P_m = \frac{(\lambda / \mu)^{k_u}}{k_u\,!} e^{-\lambda / \mu} \qquad (3.10)$$

At a given instance of time, each user may be active or not, which is assumed to have the following probabilistic relation.

$$\rho = P_r\,(V_i = 1) = 1 - P_r\,(V_i = 0) \qquad (3.11)$$

Where V_i denotes the user activity status with one being active, zero being non active. Further more a constant received power is assumed. Then the total received power at the base station is described by:

$$\sum_{i=1}^{K_u} V_i E_b R + N_o W \qquad (3.12)$$

Where N_o is the density of noise power at the receiver, W is spreading bandwidth (Chip rate), R is data rate.
Now focusing on the user with index 1, interference plus noise power for this user can be described by:

(Total interference for each user from remaining other users)

$$I_o W = \sum_{i=2}^{K_u} V_i E_b R + N_o W \quad , \qquad (3.13)$$

In the power controlled DS-CDMA system, as the number of users is increasing, the interference will also increase. However if the interference amount is above a certain threshold, then power value for each user will have to increase very rapidly to cope with the large interference. Therefore, the system becomes extremely unstable even though, in principle, the DS-CDMA system has no limitation in accepting new users.

However, if the system becomes congested, none of the users can communicate properly due to increased interference.

Therefore, a system stability threshold, S_t can be defined in a way that the relative value of the total interference power compared to receive noise should satisfy:

$$\frac{I_o W}{N_o W} \leq \frac{1}{S_t} \quad (3.14)$$

For instance, when S_t is 0.1, the system is said to be congested. The total interference power experienced by single user is ten times larger than the receiver noise.
If the interference situation does not satisfy the above condition, then the system becomes unstable. Rewriting this condition will give:-[9]

$$\sum_{i=2}^{K_u} V_i \leq \frac{(W/R)(1-S_t)}{E_b/I_o} \quad (3.15)$$

Therefore the important question at hand is the probability given by

$$P_{unstable}=\Pr\left(\sum_{i=2}^{K_u} V_i > \frac{(W/R)(1-S_t)}{E_b/I_o}\right) \quad (3.16)$$

$$=\Pr\left(\sum_{i=1}^{K_u} V_i > \frac{(W/R)(1-S_t}{E_b/I_o}\right)$$

$$=\Pr\left((Z > \frac{(W/R)(1-S_t)}{E_b/I_o}\right)$$

The maximum load λ / μ can be derived, for a given system instability probability, when the user activity factor ρ is fixed, i.e., it can be proved that the random variable Z is Poisson distributed with mean ρ (λ / μ) when k_u follows the Poisson distribution with mean λ / μ ,thus the probability of system instability can be calculated for a given ρ and
λ / μ.

This is very similar to the conventional Erlang capacity calculation where the maximum load λ / μ that will give the blocking probability less than a certain value is derived ,when the number of channels per cell is given by Ko.[9]

$$P_b = P_{Ko} = \frac{(\lambda/\mu)^{Ko} / Ko!}{\sum_{j=0}^{K_o} (\lambda/\mu)^j / j!} \quad (3.17)$$

Capacity derivation in the multi-rate cell DS-CDMA system can now be easily extended from the single cell case by considering the multiple cells as an arranged single cell. The only change is to replace the mean of Z in $P_{unstable}$ by ρ (1+f) λ / μ, where the number f is the fraction of interference coming from the other cells compared to the own cell. Therefore using $P_{unstable}$, the system instability probability in the multiple-cell case can be expressed as follows.[9]

$$P_{unstable} \sim = e^{-\rho(1+f)\lambda/\mu} \sum_{k=K_o}^{\infty} \frac{(\rho(1+f)(\lambda/\mu))^k}{k!} \quad (3.18)$$

Where

$$K_o = \left(\frac{(W/R)(1-S_t)}{E_b/I_o} \right) \text{ is the largest integer that does not exceed } \frac{(W/R)(1-S_t)}{E_b/I_0} \quad (3.19)$$

f = fraction of interference coming from the other cells
Z = Number of assignment failure /Poisson distributed rv.)
ρ = User activity factor
λ / μ = Maximum load, with the blocking probability
S_t = System stability threshold
Vi = User activity statues
Ko = No. channels per cell

As the number of users increased, interference and noise level also increases. When the interference threshold is exceeded, the power level has to be increased to over come the strength of the interference. This action introduces other interferences causing unstable system.

Therefore because of these actions quality of service delivery is degraded causing higher probability for call drop and call blocking situations. System capacity also decreases so that no more users can be connected to the system unless appropriate adjustment action or technical solution provided, such as Cell sectoring and transmitter power controlling.

Chapter-4 CDMA based WLL system capacity enhancement techniques

As the demand for wireless service increases, the number of channels assigned to a cell eventually becomes inefficient to support the required number of users. At this point, cellular design techniques are needed to provide more channel per unit coverage area, some of the techniques used are discussed in this chapter.

4.1 Cell Splitting

Cell splitting is the process of subdividing a congested cell into smaller cells, each with its own base station and a corresponding reduction in antenna height and transmitter power. Cell splitting increases the capacity of a cellular system since it increase the number of times that channels are used. By installing new cells called microcells, between the existing cells, capacity increases due to the additional number of channels per unit area.**[2]**

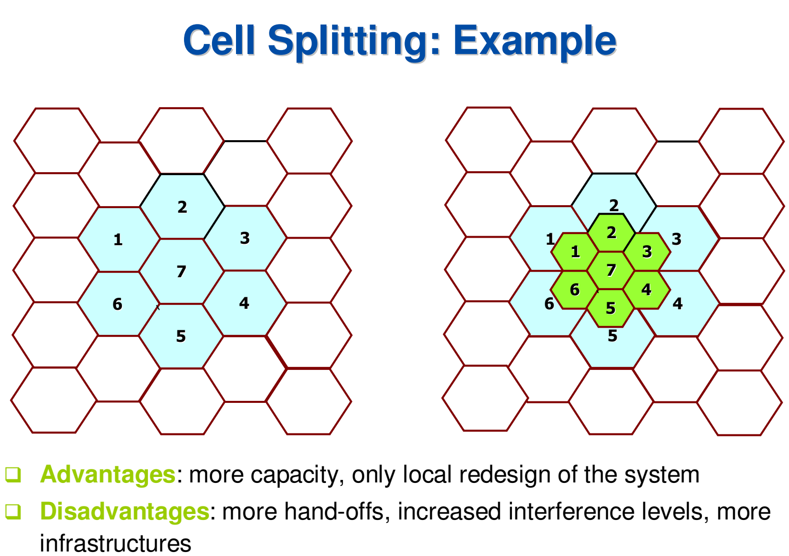


Figure 4.1 Cell Splitting

For the new cells to be smaller in size, the transmit power must be reduced. The transmit power of the new cells with radius half of the original cells can be found by examining the received power Pr at the new and old cell boundaries and setting them equal to each other. This is necessary to insure that the frequency reuse plan for the new micro cell behaves exactly as for the original cells.

Power at old cell boundary - $P_{r1} \alpha R^{-n}$

And power at new cell boundary - $P_{r2} \alpha (R/2)^{-n}$ (4.1)

Where Pr1 and Pr2 are the received power of the larger and the smaller base stations respectively and n is the path loss exponent. If we take n=4 and set the received powers equal to each others, then $P_{r2} = P_{r1}/16$.

In practice not all cell are split at the same time. It is often difficult for the service providers to find the real estate that is perfectly situated for cell splitting. Therefore different cell sizes will exist simultaneously. In such situations special care needs to be taken to keep the distance between co-channel cells at required minimum, and hence channel assignments become more complicated.

When there are two cell sizes in the same region, we cannot simply use the original transmit power for all new cells or the new transmit power for all original cells.
If the larger transmit power is used for all cells some channels used by the smaller cells would not be sufficiently separated from the co-channel cells. On the other hand, if the smaller transmit power is used for all cells; there would be parts of the larger cell left un served. For this reason channels in the old cell must be broken into two channel groups, one that correspond to the smaller cell use requirements and the other corresponding to the larger cells. [2]

4.2 Cell Sectoring

The technique for decreasing co-channel interference and thus increasing system performance by using directional antennas is called sectoring. The factor by which the co-channel interference is reduced depends on the amount of sectoring used.

It is possible to sectorise a cell by using base stations with directional antennas, such that the base station serves subscribers only in a given sector. Such non overlapping sectors can not only reduce the interference power, but also increase range. It is also possible to use overlapping sectors in order to improve trunking efficiency, and thereby, support more users in an area. Overlapping sectors are more suitable for fixed wireless applications.

Directional antennas providing 60^0 sectors have been used in wireless systems deployments to increase the re-use ratio from 1/7 to 1/4 and even 1/3 (i.e. an increase from 7-cell reuse to 4-cell and 3-cell reuse). A capacity increase of nearly 4.5 times over omni cell capacity has been obtained using 60^0 sectoring deployments. The reuse is better if the antenna at the base station has very low gain outside the sector(s) that it is supposed to serve.[2]

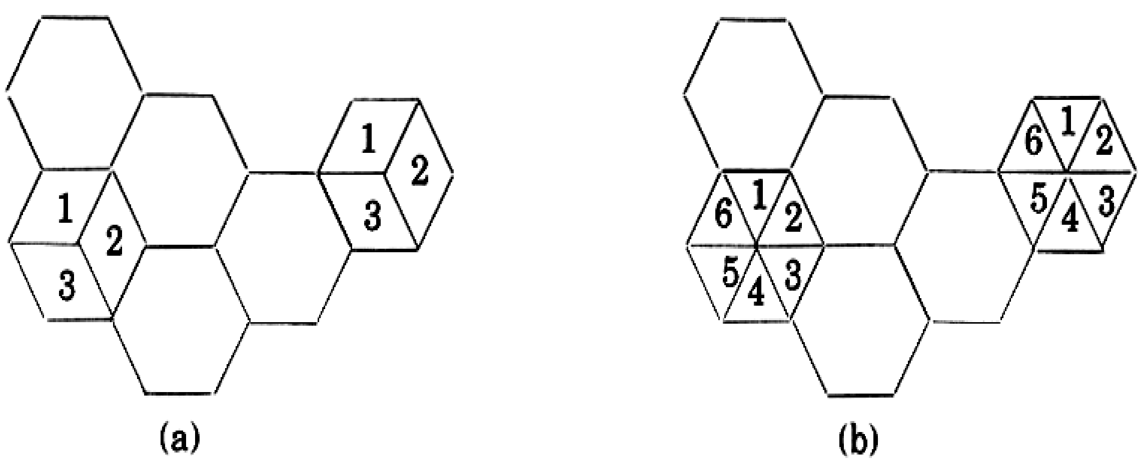
Cell Sectoring is a very effective technique to reduce multiple-access interference and is widely used in the terrestrial mobile wireless networks to increase cell capacity. Theoretically, a CDMA system with n sectors per ce11 has cell capacity n times better than the non-sectorized system.

However, in practice, the improvement in cell capacity is always less than n because a receiver antenna with infinite attenuation outside the main lobe is impractical to build. So, signals received from other sectors still interfere with the desired user's signal, but even if at much reduced level.

In the cell sectoring method, the cell radius is kept unchanged and we seek methods to increase the D/R ratio,(D = Distance between Co-channel cell sectors and R= Cell radius). Sectoring increases SIR such that the cluster size may be reduced. In this approach, first the SIR is improved using directional antennas, and then capacity improvement is achieved by reducing the number of cells in a cluster, thus increasing the frequency reuse.

In order to do this successfully, it is necessary to reduce the relative interference without decreasing the transmit power. The co-channel interference in a cellular system may be decreased by replacing a single omni-directional antenna at the base station by several directional antennas, each radiating within specified sector. By using directional antenna, a given cell will receive interference and transmit with only a fraction of the available co-channel cell. Compared to its advantages to the communication system, Cell sectoring requires less expense to add more antennas in the system.

A cell is normally partitioned in to 120 degree sectors or six 60 degree sectors as shown in the figure below.



(a) 120° sectoring; (b) 60° sectoring.

Figure 4.2 Cell sectoring

4.3 CDMA Power Control

The CDMA network capacity significantly depends on the so-called near-far effect and control of MAI. Theory and practice of CDMA were aware of this fact. All practical systems use power control (PC) to reduce this effect. PC is more efficient in system optimization for speech.

Power control is used to alleviate the problem, by controlling the signal powers to be the lowest necessary and at the same time minimizing the total level of interference such that more users can be served with acceptable quality. In addition, power control is also essential to combat the near-far problem in which the received power from users near the base station causes undue level of interference to far-out users.

CDMA power levels have to be equal for each call, each PN code, with absolute certainty. However, some calls are much closer to the serving antenna than others and have much higher radio path gains. We call this the near far problem. Signal paths gains vary considerably, reaching as high as 80dB if one such subscriber is 100 times closer to the base station than another. We use power control in CDMA to adjust transmitters so that the received power levels are balanced.[8]

A CDMA channel running at 85 percent of its full call capacity will overwhelm a call received at just 1dB below optimal power, because CDMA requires each user to have a prescribed fraction of the signal, safety margins are not going to solve problems of inaccurate power control.
Adding a 1.5dB safety margin to the power control algorithm only serves to reduce system capacity by 30 percent. CDMA relies heavily on the power control algorithm doing an effective job of managing power levels.[8]

When the mobile telephone starts a call, it sets its transmit power based on measurements it makes of the forward channel. This initial choice of transmit power is done without base station participation, so we call it open-loop power control. Once the call radio link is established, within the two-way data stream is a flow of power control messages going in both directions, power-up and power-down messages. This feedback driven process is called closed-loop power control.

In CDMA we determine the need for power-level adjustment by looking at the signal quality as measured by the error rate. How do we measure signal quality in CDMA? The Forward Error-Correction (FEC) systems provide bit error rate (BER) estimate. The error correction figures out which bits are wrong and corrects them. It also can tell the power-control system how often it had to do this.

If the error correction figure is higher than an optimal level, then the power-control system tells the transmitter to turn up the power and conversely, when this is lower than the optimal level, it tells the transmitter to turn down the power. The radio link is therefore in a constant state of small corrections in its quest to maintain optimal power.

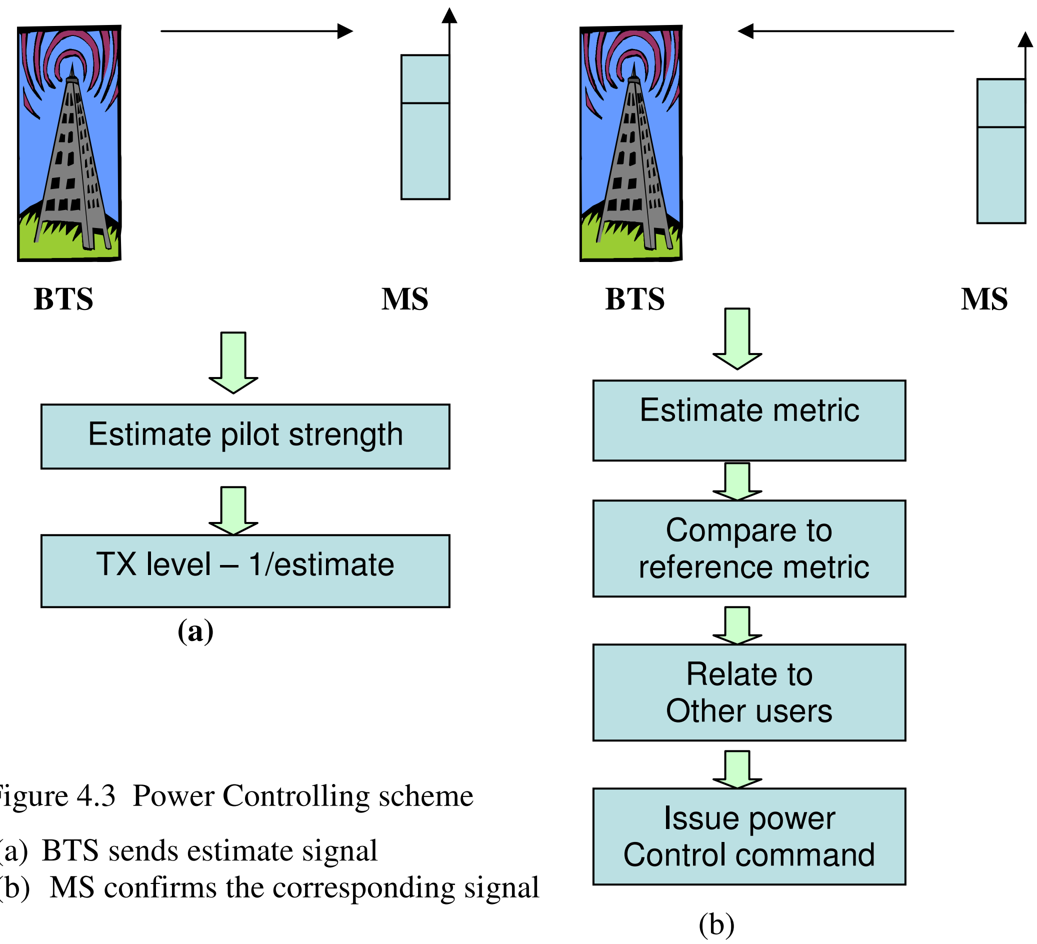


Figure 4.3 Power Controlling scheme

(a) BTS sends estimate signal
(b) MS confirms the corresponding signal

It may seem odd that we reduce power in order to increase the number of errors to an ideal level. However, in CDMA, a low error rate is an indicator that this signal is using more than its allotted percentage of the entire signal power. This call is clear, but a cost of greater interference for all the other calls on the cell. Reducing the power on this one call will bring all the calls on the one cell closer to equal in received power.

Sometimes the raw bit stream has too many errors to resolve, which usually happens when the signal is really weak. When it does happen, there is no dispute that a power-up message is called for.

Another approach in closed loop power control method is to measure the Eb/No directly rather than using the BER. For each bit, we take the total amplitude of all its chips-just adds them all up. Then we do the PN-code manipulations and recompute the total amplitude of all the chips.[8]

The transmission level estimates the signal pulse interference, and the metric estimates signal after processing gain. If the second is divided by the first is low, then we increase transmitter power. When the ratio is high, we decrease power.

Both these techniques rely on statistical averaging for their success. Under normal conditions, they point in the right direction just over half the time.
It might take a hundred measurements and messages to get power levels reliably within 1.0 dB of optimal. In CDMA system almost 1000 power-control messages are sent each second. Even at this high rate, a moving user terminal in a fading environment poses a power-control challenge.

CDMA is an interference limited system. Since all mobiles transmit at the same frequency, interference generated within the system plays a critical role in dimensioning system capacity and voice quality. The transmit power from each mobile must be controlled to limit interference. However, the power level should be adequate for satisfactory voice quality.
As the mobile moves around, the RF environment changes continuously due to fast and slow fading, shadowing, external interference, and other factors. The objective of power control is to limit transmitted power on the forward and reverse links while maintaining link quality under all conditions. Due to noncoherent detection at the base station, interference on the reverse link is more critical than it would be on the forward link. Reverse link power control is therefore essential for a CDMA system stability and better performance.[8]

The target value for the received power level must be the minimum level possible that allows the link to meet user defined performance objectives (BER, FER, Capacity, dropped call rate, and coverage). In order to implement such a strategy, the mobiles closer to the base station must transmit less power than those far away.

Voice quality is related to frame error rate (FER) on both the forward and reverse link. The FERs are largely correlated to Eb/It. The FER also depends on the vehicle speed, local propagation conditions and distribution of other co-channel mobiles. Since the FER is a direct measure of signal quality, the voice quality performance in a CDMA system is measured in terms of FERs rather than Eb/It. Thus, to assure good quality, it is not sufficient to maintain a target Eb/It, it is also necessary to respond to specific FERs as they occur. The recommended performance bounds are:-

- A typical recommended range for FER – 0.2% to 3% (Optimum power level is achieved when FER $\leq$ 1%).
- A maximum length of burst error – 3 to 4 frames (Optimum value of burst error ~ 2 frames) [8]

NB. To achieve better QoS, the FER has to be in the specified limit.

4.3.1. Reverse link power control

The reverse link power control affects the access and reverses traffic channels. It is used for establishing the link while originating a call and reacting to large path loss fluctuations. The reverse link power control includes the open loop power control (also known as autonomous power control) and the closed loop power control.

4.3.1.1. Reverse link open loop power control

The open loop power control is based on the principle that a mobile closer to the base station needs to transmit less power as compared to the mobile that is farther away from the base station or is in fade. The mobile adjusts its transmit power based on total power received in the 1.25Mhz band (i.e. power in pilot, paging, sync, and traffic channels). This includes power received from all base stations on the forward link channels. If the received power is high, the mobile reduces it's transmit power. On the other hand, if the power received is low, the mobile increases it's transmit power.(Tx = 1/Rx)

In open loop power control the base station is not involved. The mobile determines the initial power transmitted on the access channel and traffic channel through open loop power control. A large dynamic range of 80dB is allowed to provide an ability to guard against deep fades.[9]

Figure 4.4 Open loop power controls depends on the mobile state (receiving of high/low power)

The mobile links itself to the CDMA system by receiving and processing the pilot, synch., and paging channels. The paging channel provides the access parameter message which contains the parameters to be used by the mobile when transmitting to the base station on an access channel. The access parameters are:

- The access channel number
- The nominal power offset (NOM_PWR)
- The initial power offset step size

- The incremental power step size
- The number of access probes per access probe sequence
- The time out window between access probes
- The randomization time between access probe sequences

Based on the access parameters received on the pilot, sync, and paging channels the mobile attempts to access the system via one of several available access channels. During the access state, the mobile has not yet been assigned a forward link traffic channel(which contains power control bit), Since the reverse link closed loop power control is not active, the mobile initiates, on its own , any power adjustment required for the suitable operation.

The prime goal in CDMA systems is to transmit just enough power to meet the required performance objectives. If more power is transmitted than necessary, the mobile becomes a jammer to another mobile. Therefore, the mobile tries to get the base station's attention first by transmitting at very low power. The key rule is that the mobile transmits in inverse proportion to what it receives.

When receiving a strong pilot from the base station, the mobile transmits a weak signal back to the base station. A strong signal at the mobile implies a small propagation loss on the forward link. Assuming the same path loss on the reverse link, only a low transmit power is required from the mobile in order to compensate for the path loss.

When receiving a weak pilot from the base station, the mobile transmits back a strong signal. A weak received signal at the mobile indicates a high propagation loss on the forward link, consequently a high transmit power level is required from the mobile.

The mobile transmits the first access probe at a mean power level defined by.[9]

T_x = -R_x – K + (NOM_PWR – 16 x NOM-PWR-EXT) + INIT –PWR (dBm) (4.2)

Where

T_x	-	Mean output transmit power(dBm)
R_x	-	mean input receive power (dBm)
NOM-PWR	-	Nominal power (dB)
NOM-PWR-EXT	-	nominal power for extended handover (dB)
INIT-PWR	-	initial adjustment (dB)
K	-	73 for cellular (Band class 0), and
K	-	76 for PCs (Band class 1)

The INIT -PWR were 0, then NOM-PWR – 16 x NOM –PWR-EXT would be the correction that should provide the correct received power at the base station.
NOM-PWR -16 X NOM-PWR –EXT allows the open loop estimation process to be adjusted for different operating environment.

The major flaw with this criterion is that reverse propagation statistics are estimated based on forward link propagation statistics. But since the two links are not correlated, a significant error may result from this procedure. However, these errors will be corrected once the closed loop power control mechanism becomes active as the mobile seizes a forward traffic channel and begins to process power control bits.[8]

After the acknowledgment time window (Ta) has expired, the mobile waits for an additional random time (RT) and increases it's transmit power by a steps size. The mobile tries again. The process is repeated until the mobile gets a response from the base station. However, there are a maximum number of probes per probe sequence and a maximum number of probe sequences per access attempt.

The entire process to send one message and receive an acknowledgment for the message is called an access attempt. Each transmission in access attempt is referred to an access probe. The mobile transmits the same message in each access probe in an access attempt. Each access probe contains an access channel preamble and an access channel capsule. Within an access attempt, access probes are grouped in to access probe sequences .Each access probe sequence consists of up to 16 access probes. All transmitted on the same access channel.

There are two reasons that could prevent the mobile from getting an acknowledgment after the transmission of the probe.

1. The transmit power level might be insufficient. In this case, the incremental step power strategy helps to resolve the problem.
2. There might be a collision due to the random contention of the access channel by several mobiles. In this case, the random waiting time minimizes the probability of future collision.

The transmitted power is defined by

$$T_x = - R_x - K + (\text{NOM-PWR} - 16 \text{ X NOM-PWR-EXT}) + \text{Sum of incremental Step power} \quad (4.3)$$

Where the access probe correction is the sum of the appropriate incremental power steps prior to receiving an acknowledgment at the mobile.

For every access probe sequence, a back-off delay is generated Pseudo randomly. Timing between accesses probes of an access probe sequence is also generated Pseudo randomly. After transmitting each access probe, the mobile waits for Ta. If an acknowledgment is received, the access attempt ends. If no acknowledgment is received, the next access probe is transmitted after an additional random time.

If the mobile does not receive an acknowledgment within an access attempt, the attempt is considered as a failure and the mobile tries to access the system at another time. If the mobile receives an acknowledgment from the base station, it proceeds with the registration and traffic channel assignment procedures. The initial transmission on the reverse traffic channel shall be at a mean out put power defined by Tx .[8]

The source of error in the open loop power control are :-

- Assumption of reciprocity on the forward and reverse links
- Use of total received power including power from other stations.
- Slow response time ~ 30 ms to counteract fast fading due to multipath

4.3.1.2. Reverse link closed loop power control

Fading sources in multipath require a much faster power control than the open loop power control. The additional power adjustment required to compensate for fading losses are handled by the reverse link closed loop power control mechanism, which has a response time of 1.25ms for 1dB steps.

The quicker response time gives the closed loop power control mechanism the ability to override the open loop power control mechanism in practical applications. The closed loop power control provides correction to the open loop power control. Once on the traffic channel, the mobile and base stations engage in closed loop power control.

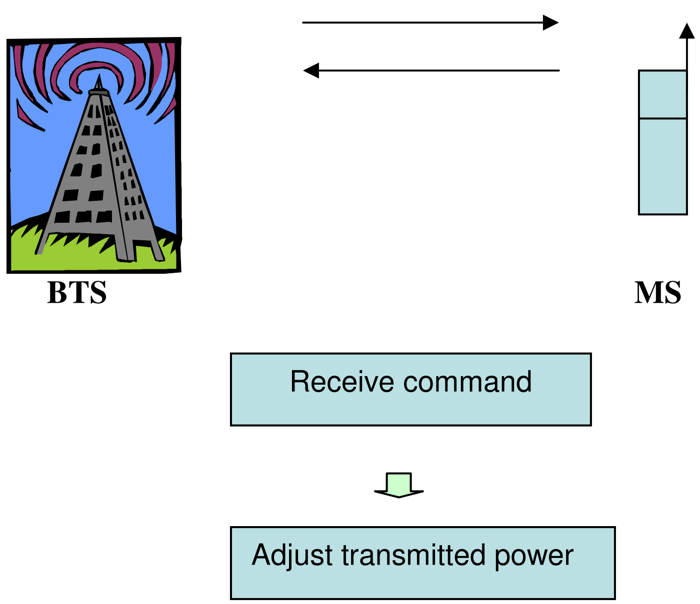


Figure 4.5 Closed loop power control depends on the base station

The reverse link closed loop power control mechanism consists of two parts: inner loop power control and outer loop power control. The inner loop power control keeps the mobile as close to its target ($Eb/It)_{set\ point}$ as possible. Whereas the outer loop power control adjusts the base station target ($Eb/It)_{set\ point}$ for a given mobile.[9]

The energy efficiency of power control has a significant effect on total signal capacity. The power-control messages have to travel between the system and user terminal somehow, and this takes more power and costs CDMA capacity. We can send nearly perfect power-control messages by devoting a lot of power to power control. Or we can economize on power-control.

If the measurement part is perfect i.e., if the receiver always makes the right power change determination, then a high rate of power-control messages is supposed to be more energy efficient. We could send a small number of large-change messages with enough energy per power-control bit to ensure a highly accurate power-control process. Or we could send a large number of small-change messages with less energy per bit. The power-control process would be less accurate bit by bit, but the larger number of attempts more than makes up the difference.

It is tempting to visualize a system with a thousand power-control messages per second maintaining exact power level and tracking the small boosts and fades of a telephone moving at 60mi/h (100 km/h). The power control in CDMA does keep control of power. There are significant capacity losses due to power-control errors in CDMA. If we find that power control were not a problem, then we would reduce the power allotment for power control and increases the capacity of the system in this way

4.3.2. Forward Link Power Control

Forward link power control (FLPC) aims to reduce interference on the forward link. The FLPC not only limits the in cell interference, but it is especially effective in reducing other cell / sector interference. The forward link power control attempts to set each traffic channel transmit power to the minimum required to maintain the desired FER at the mobile. The mobile continuously measures forward traffic channel FER. It reports this measurement to the base station on a periodic basis.

After receiving the measurement report, the base station takes the appropriate action to increase or decrease power on the measured logical channel. The base station also restricts the power dynamic range so that the transmitter power never exceeds a maximum value that would cause excessive interference or so that it never falls below the minimum value required for adequate voice quality. Since FERs are measured (not as Eb/It as in closed loop strategy), this process is a direct reflection of voice quality. However, it is a much slower process. Because orthogonal Walsh codes are employed for the forward link instead of long PN codes. Therefore, slow measurements do not add much degradation to system performance.

A 20 ms frame is organized into 16 time intervals of equal duration. These time intervals, each of 1.25 ms are called power control groups (PCGs). Thus, a frame has 16 PCGs. Prior to transmission, the reverse traffic channel interleaver output data stream is gated with a time filter. The time filter allows transmission of some symbols and deletion of others.

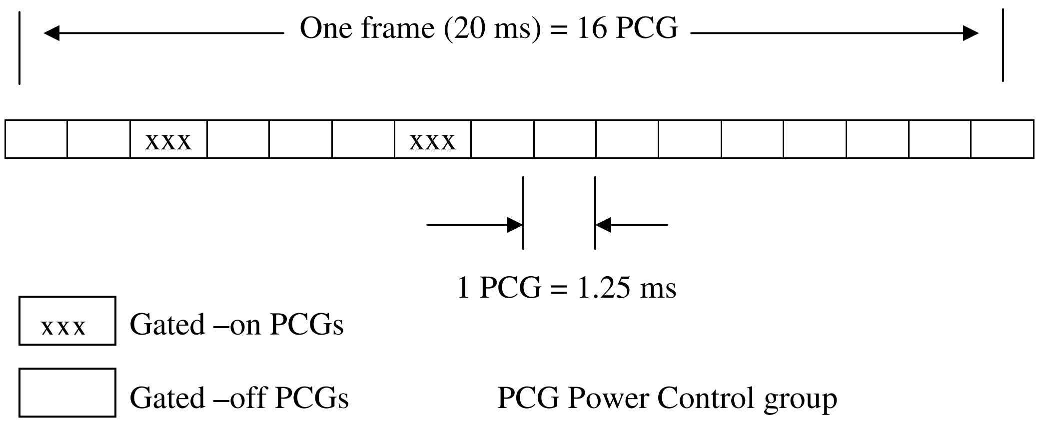


Figure 4.6 Power control groups

Similar to the reverse link transmission, the forward link transmission are organized in 20 ms frames. Each frame is subdivided in to 16 PCGs. The transmission of a power control bit occurs on the forward traffic channel in the second PCG following the corresponding reverse link PCG in which the signal strength was estimated.
Once the mobile receives and processes the forward link channel, it extracts the power control bits from the forward traffic channel. The power control bit then allow the mobile to fine-tune it's transmit power on the reverse link.[7]

Table .4.1 Power Control Groups Vs Frame Rate

Frame Rate	Rate(kbps)	No. of PCGs Sent
Full	9.6	16
1/2	4.8	8
1/4	2.4	4
1/8	1.2	2

The relationship between Eb/It and the corresponding FER is nonlinear and varies with vehicle speed and RF environment .Performance deteriorates with increasing vehicle speed. The best performance corresponds to a stationary vehicle where additive white Gaussian noise dominates. Thus, a single value of Eb/It is not satisfactory for all conditions. The use of a single, fixed value for Eb/It could reduce channel capacity by 30% or more by transmitting excessive, unneeded power.

Since FER is a direct measure of link quality, the system is controlled using the measured FERs rather than Eb/It. FER is the key parameter in controlling and assuring a satisfactory voice quality. It is not sufficient to maintain a target Eb/It, but it is necessary to control FERs as they occur. The objective of the reverse outer loop power control (ROLPC) is to balance the desired FER on the reverse link and system capacity.[7]

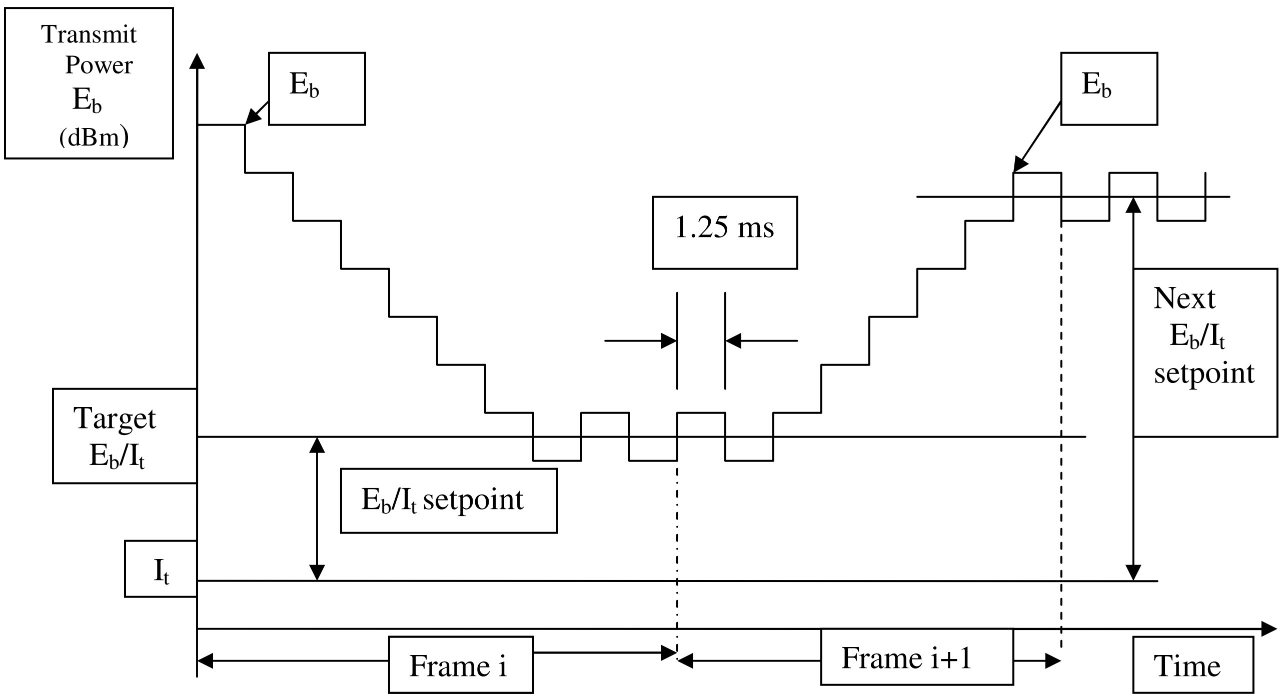


Figure. 4.7. Target E_b/I_t

4.4. Reference power level

Since the measurement of the average received power in practice is very difficult, power control based on SIR (the effect of noise is assumed to be negligible) is preferred. In addition, SIR, not the received power, determines the bit error probability of the user. Utilizing SIR, both the near -far problem and the control of multiple access interference (MAI) is addressed.

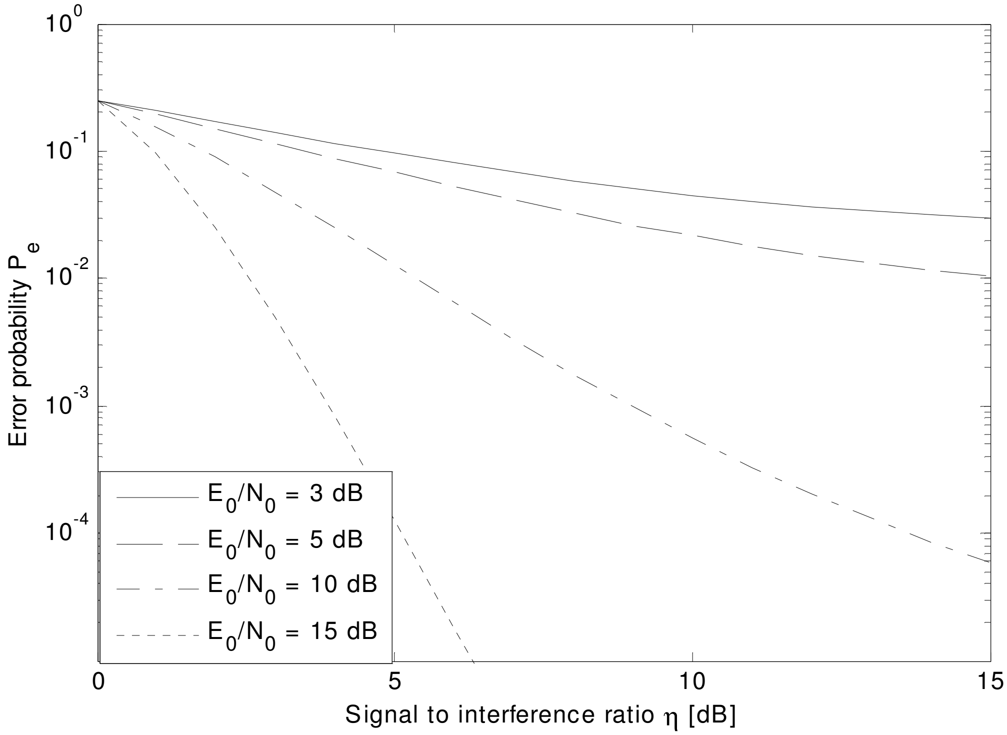


Figure 4.8 Error probability Vs SIR,η [dB]

Methods for estimating SIR are proposed in which a BER value, instead of the SIR, was estimated as a quality measure. PC schemes in which transmitters adapt their power to meet at the receiver some signal quality target, instead of received power target, are called quality based PC. If the variations of the interference levels are not fast compared to the signal changes, the performance of power control methods based on average power or SIR measurement are quite similar. This is also the case when the number of simultaneous users in a system is small. [7]

In such cases, all the users reduce their transmission power, and thermal noise dominates over MAI. It is usually assumed that when there are a large number of simultaneous users, Power Control of a single user does not affect the total interference power much. The performance of the power control methods based on average power or SIR measurement should also be similar. However, showed remarkable changes in the interference level, even though there were several tens of simultaneous active mobile stations in the base station service area.

Since CDMA is interference limited, the system capacity is maximized by minimizing each mobile interference. By capacity we mean here the maximum number of simultaneous active users per cell. Interference is minimized when mobile station transmit with the minimum possible power by which good quality communication is achieved, thus power controlling , significantly affects the capacity of the CDMA system.

Imperfect PC reduces the CDMA system capacity; Even a smaller error in PC reduces the capacity considerably. The effect of imperfect PC on the capacity was analyzed in both a single cell and the cellular CDMA systems. In the case of single cell the influence of both voice activity detection and processing gain were also taken in to account. The capacity was determined as the maximum number of users in a cell with which each received signal's SIR at the base stations, is at least (with 99% probability) larger than 7dB.When PC error was σ = 1dB, the capacity of the cellular system was observed to decrease about 50 to 60% compared to the capacity of the system using ideal σ = 0dB.[8]

4.5 Power Control Algorithms

4.5.1 Transmitter Power Control

The transmitter power affects the link signal quality and the interference environment in the wireless system. However, adjusting the transmitter power to improve the link performance is not a trivial problem. If a terminal with a low SIR increases its transmit power, the SIR is momentarily increased.

The increase in transmitter power will on the other hand also increase the interference in the other links in the system, causing these terminals to increase their power competition.
Lowering the transmission power will decrease the interference to the other links, but could of course, jeopardize its own link. To resolve this problem, assumes an orthogonal and static channel allocation and consider the communication links that are established on an arbitrary channel, say C_0.

For the uplink case the transmitters are terminals and the receivers are the corresponding access port .for the downlink case, their role are reversed. Consider an instant of time in which the link gains between every receiver i and every transmitter j is stationary and is given by g_{ij}. Without loss of generality, the links are numbered such that transmitter j is the one communicating with receiver i. In a DS-CDMA system, many terminals will communicate with the same access port through a common frequency channel. In this situation, access ports i and j may denote the same physical one if the terminals i and j are assigned to the same access port.[5]

Furthermore, assume that there are Q transmitters assigned to the channel Co, where transmitter j uses power P_j. let us use the following vector notation to describe all transmission powers of the transmitters:

$$P = (p1, p2, ...pQ)^T \tag{4.4}$$

In the uplink case, the value p_j means the transmission power of terminal j. however , in the down link , it denotes the transmission power dedicated to terminal j by the access port to which terminal j is connected .
The interference summation is taken over all transmitters on channel Co. If the transmitter power and the receiver noise (mostly thermal noise) taken into account. The following expression for the SIR in the receiver i on the channel can be derived.[9]

$$SIR=\Gamma_i=\frac{g_{ii}p_i}{\sum_{j=1,j\neq 1}^{Q} g_{ii}p_j+n_i.} \qquad (4.5)$$

Where n_i denotes the receiver noise at the receiver i.

Definition 1:-

The transmitter i is said to be supported if it has the SIR satisfying

$\Gamma_i \geq \gamma_o$, where γ_o is a target threshold , then

$$P_j \geq \gamma_o \left(\sum_{j=1,j\neq 1}^{Q} \frac{g_{ii}}{g_{ii}} p_j + \frac{n_j}{g_{ii}} \right) \qquad (4.6)$$

This expresses the minimal power that the transmitter i should use to achieve the target SIR, assuming the other transmitter's power is fixed.

Definition 2:-

The target SIR γ_o is said to be achievable if there exists a non-negative power vector p such that $\Gamma_i \geq \gamma_o$ for all i.

In other word, if the system of linear inequality has a non negative power solution, the target SIR γ_o is achievable. For this, the following proposition can be derived from the well known linear algebra properties.

Proposition 1:-

The target SIR γ_o is achievable if the dominant (largest) eigenvalue of the matrix H, denoted by $\rho(H)$, is less than or equal to one. The case of $\rho(H)$ =1 will make γ_o achievable only when the receiver noise is zero.[9]

Normalized link gain matrix; $H_{ij} = \gamma_o \frac{g_{ij}}{g_{ii}} = \gamma_o A$ for $i \neq j$

Normalized noise vector; $\eta = (\eta_i) = \gamma_o \underline{n_i}$

g_{ii}

4.5.2. SIR Balancing

Consider a power control that maximizes the minimum SIR in all links. It can be proved that such a power control is achieved by making every transmitter's received SIR balanced (equalized) while keeping the balanced SIR as high as possible. To investigate this further, consider the noiseless, $\eta = 0$. Then from $(I- H)p \geq \eta$ the following linear inequality system can be formulated for a given target SIR γ_o : [9]

$$(I- H)p \geq 0 \qquad (4.7)$$

Then the question is to find the maximum achievable γ_o . Introducing a matrix A such that $H = \gamma_o A$

Proposition2:-

The inequality $(I- \gamma_o A)P \geq 0$ has solution in $P \geq 0$ if and only if $\gamma_o \leq \frac{1}{\rho(A)} = \gamma^*$

Where $\rho(A)$ is the dominant eigenvalue of the matrix A. the power vector satisfying the expression $(I- \gamma_o A)P \geq 0$ with equality and achieving the largest SIR γ^* for all links, is P^*, that is , the eigenvector corresponding to the eigenvalue $\rho(A)$.

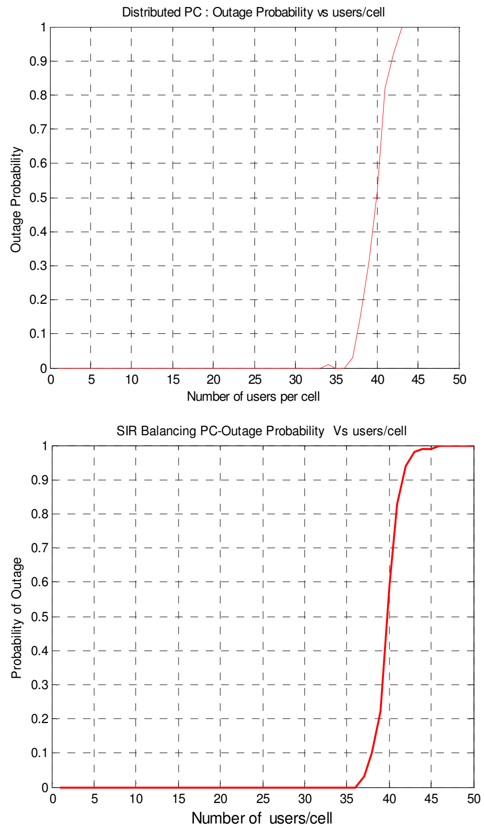


Figure 4.9 SIR balancing power control, Outage probability Vs users/cell

Power control problem and its relation to the call admission problem is time varying as the number of active users in the cell changes over time.
Outage probability is the probability that some randomly chosen user has SIR below a prescribed /target value.
By minimizing the outage probability, i.e. keeping all received SIR values maximized with respect to the target value, results improved QoS and enhances system capacity.

4.5.3 Distributed Power control (DPC) / Iterative method /

One assumption used so far is that randomly generated link gain matrix G is known. This assumption, however, is impractical since it requires a centralized measurement mechanism for the system, which in turn will require very heavy signaling between access ports and terminals. In this section, focus is on how to avoid such a centralized control and how to design distributed power control algorithms.

Consider the power control problem in $(I-H)p \geq \eta$. Since the ideal situation is to make connection with the minimal transmission power, the following equality constraint on SIR can be considered [9]

$$(I-H)p = \eta \qquad (4.8)$$

It is assumed that the receiver noise is not negligible and that there exists a unique and non negative power vector P* that solves the $(I-H)p = \eta$ problem . In other words, $\rho(H) < 1$ so that the matrix $(I-H)$ is nonsingular and $P^* = (I-H)^{-1}\eta \geq 0$.

Since every element in the matrix H is hardly available in practical systems, efficient methods, i.e., Gaussian elimination for solving the linear equation system $(I-H)p = \eta$ cannot be utilized. Only those iterative methods that can be executed with local measurement and signaling have drawn much attention.
The theoretical roots of many iterative power control algorithms can be found in numerical linear algebra. Consider the following general iterative method for solving $(I-H)p = \eta$: [9]

$$P^{(n+1)} = M^{-1}NP^{(n)} + M^{-1}\eta , \qquad n = 0,1,..... \qquad (4.9)$$

Where M and N are Matrixes of appropriate sizes such that

$$P^* = M^{-1}NP^{(n)} + M^{-1}\eta \qquad (4.10)$$

The vector $P^{(n)}$ denotes the power level at the n^{th} iteration . Approximately selecting M and N , the above iterative method can converge , that is

$$\lim_{n \to \infty} P^{(n)} = P^* = (I-H)^{-1}\eta \qquad (4.11)$$

By defining M = I and N=H , a power control algorithm can be constructed from

$$P^{(n+1)} = HP^{(n)} + \eta , \; n = 0,1,..... \qquad (4.12)$$

It is easy to see that, for each transmitter i, the method becomes

$$p_i^{(n+1} = \frac{\gamma_o}{g_{ii}}(\sum_{j=1, j\neq 1}^{Q} g_{ij} p^{(n)}{}_j + n_i) = \frac{\gamma_{oP9n)}}{\gamma_i^{(n)}} P^{(\eta)}, \qquad n= 0,1,2 \ldots\ldots \qquad (4.13)$$

Where $\gamma_i^{(n)}$ and $p_i^{(n)}$ denote the received SIR and transmission power of transmitter i at iteration n , respectively. This algorithm is denoted by DPC (Distributed Power Control).
DPC requires only local signaling and measurement on SIR at the receivers. This distributed measurement results in errors causing lower QoS.

4.5.4. Constrained power control

It has been assumed that the transmitter power can be adjusted without limitations. This is not realistic, since the maximum output power of a transmitter is upper-bounded in any implementation, In particular for hand held terminals, this constraint is critical ,mainly due to the battery capacity. To consider this limitation in power control, let's introduce a constraint given by:

$$0 \leq P \leq p \qquad (4.14)$$

Where p = ($p_1, p_2, p_3, \ldots\ldots\ldots p_Q$) denotes the maximum transmission power of each transmitter. If the required power is greater than the transmitter's maximum peak power level, some action has to be executed to constrain the power value within the power range for example; DPC can be modified in to the power constrained version.

$$p_i^{(n+1)} = \min \left\{ \frac{\gamma_o}{\gamma_i^{(n)}} p_i^{(n)},\ p_i \right\}, \qquad n = 0,1,2\ldots\ldots \qquad (4.15)$$

This algorithm is called Distributed Constrained Power Control (DCPC). In this algorithm, when the required power from DPC power update is greater than the maximum power, the transmitter uses the maximum power.

DCPC has a property that the power may reach the maximum level when a user is experiencing low channel quality. Unfortunately, even if that maximum power is used, this may not necessary lead to sufficient improvement on channel quality in particular when the user is located in the unfavorable position. The impact will be high power consumption and sever interference, hitting other users.

With this in mind (making DCPC a special case) a more general scheme can be described by ;

$$\text{Pi}^{(n+1)} = \begin{cases} \frac{\gamma_i}{\gamma_i^{(n)}} P_i^{(n)} \text{ if } \frac{\gamma_i}{\gamma_i^{(n)}} P_i^{(n)} \leq p_i \\ p_i \text{ if } \frac{\gamma_i}{\gamma_i^{(n)}} P_i^{(n)} > p_i \end{cases} \qquad (4.16)$$

Where $0 \leq p_i \leq P_i$

<u>Proposition 3:-</u>

The constrained power control algorithm (4.16) will converge to the solution of (I- H)p = η starting with any non negative power vector, when the system (I- H)p = η has the unique solution P* within the power range.

$$0 \leq P \leq p$$

When the channel quality is poor, it is not necessary to use the maximum power. Under poor conditions, the power may even be lowered to the minimum level. In that case the user stays on the same channel and transmission will be resumed, if the interference situation becomes favorable. The main motivation of this power control is to save energy consumption by not transmitting the maximum power when the transmitter cannot be supported within the power range.[9]

Because of low channel quality, DCPC uses maximum power level to overcome the bad situation. This results higher power consumption and generates sever interference causing lower QoS.

4.5.5. Distributed SIR Balancing

The SIR balancing technique discussed in section (4.5.2) is a centralized scheme, requiring full knowledge of the link gain matrix. A distributed SIR balancing algorithm which is given by:

$$p_i^{(n+1)} = \beta .\, p_i^{(n)} \left\{ 1 + \frac{1}{\gamma_i^{(n)}} \right\}, \qquad n = 0,1,2,\ldots\ldots\ldots \qquad (4.17)$$

where β is any positive constant.

$$\lim_{n \to \infty} p_i^{(n)} = p^* \quad \text{and} \quad \lim_{n \to \infty} \gamma^{(n)} = \gamma^* \qquad (4.18)$$

Starting with an arbitrary positive power vector, where γ* is the maximum achievable SIR level and p* is the corresponding power vector as defined above.

A practical problem is that the transmitter powers in the Distributed SIR Balancing algorithms are increasing unless parameter β is chosen properly. In SIR balancing the transmission power ratio among the terminals is more important than the actual power values, selecting;

$$\beta = \beta^{(n)} = \frac{1}{\sum_{i=1}^{Q} p_i^{(n)}} \qquad n = 0, 1, 2, \ldots\ldots.. \qquad (4.19)$$

where

$$P_i^{(n)} = M^{-1}NP^* + M^{-1}\eta \quad [\text{ Min transmitter power of Tx (i) }]$$

$$\rightarrow \quad ß = \frac{1}{M^{-1}NP^* + M^{-1}\eta}$$

Would ensure a constant sum of powers of all terminals, however, calculating this quantity may not be possible in a completely distributed way causing.

- Transmission power incremental.
- Since it is distributed balancing causes inconsistence to over all system performance

Chapter 5. Proposed Power Control Algorithm

Efficient power controls are needed in practical CDMA systems to cope with the near far problem and fading phenomenon. This is one of the critical issues in using CDMA techniques to support simultaneous users, not a single signal level communication. Therefore, the question at hand is if it is possible to implement any perfect power control in a real CDMA system.

Implementing the power control algorithms in real system however, requires some modifications. The reason has been explained by the DPC algorithm.

$$p_i^{(n+1)} = \frac{\gamma_o}{\gamma_i} P^{(n)} \qquad (4.20)$$

In order to implement DPC algorithm,

- Transmission powers should be increased or decreased quickly to track the DPC. However, in real implementation, it is rather difficult to increase or decrease transmission power quickly and in unlimited manner.

- Besides the efforts on measuring $\gamma_i^{(n)}$. There will be some measurement error. Even if the measurement is relatively reliable, delivered information to the transmitter will be a delayed version of the original one due to the distance between the transmitter and the receiver.

- Since the fluctuation in $\gamma_i^{(n)}$ is large, it requires a large signaling bandwidth to deliver the exact information about $\gamma_i^{(n)}$ to the transmitter.

In order to cope with these practical limitations, a slightly different approach is used in the practical CDMA systems. From the two basic power controlling, that is Open loop and Closed loop power control methods. The Open loop power control algorithm does not require any feedback measurement on the transmitter signal quality at the receiver. This kind of power control is needed for the users whose data size is very short and thus it does not have enough time to measure the signal quality at the receiver. It refers to wireless packet access with a small packet size, where instantaneous initial power calculation is needed. For this purpose the transmitter will usually measure the signal strength of the other direction's radio link.

For example, the terminal will measure the signal strength from the access port side. This is accomplished by utilizing the automatic gain control (AGC) circuit of the receiver. The AGC circuits operate on the receiver's IF frequency amplifiers so that the input to the receiver's analogue to digital (A/D) converters is held constant. The AGC control is used to control the gain of the transmitter IF amplifiers exactly in step with the receiver's IF gain.
Thus, if the mobile terminal moves closer to the base station, increasing the received signal level, the receiver AGC will reduce the receiver IF amplifier gain, and the transmitter IF gain. Due to the luck of reciprocity in radio channels, however, this kind of power control may not be accurate.

Due to the frequency separations, uplink and downlink channels will experience completely different radio propagation conditions. In particular when the uncorrelated Rayleigh fading results in sharp decreases in the received signal, the open loop power control can make things worse by increasing / decreasing transmission power rapidly. To take care of this undesirable phenomenon, the closed loop power control is considered.

Closed loop power control algorithm requires feedback measurements as in DPC to adjust transmitter powers. However, due to limitation cited above, a simplified version is used in practical systems. That is, using SIR balancing algorithm the receiver measures the signal quality (SIR) of the transmitter and compares it with a target threshold. If the received quality is less than the target, the receiver will send a binary power up command to the transmitters. Other wise, a power down command will be delivered to the transmitter.

If the measurement occurs N times per second, then it needs the power control channel with the speed of N bps. Upon receiving the power control bits, either up or down, the transmitter will increase or decrease its power by the fixed amount, that is, 1 dB up or 1 dB down.

In the uplink, SIR measurement is made every 1.25ms, giving an 800 bps power control command stream in the down link. The value represented by the closed loop power control is converted to an analogue voltage and then added to the open loop control voltage and applied to the transmitter gain control circuit.[9]

In the down link of DS-CDMA system, however, a slightly different and slow control mechanism is used for the closed loop power control. Increasing the power control speed would improve the power control efficiency. However, at the same time, it will increase the measurement and signaling burden.

In the closed loop power control, the target SIR values are controlled by another loop, called outer loop power control. The outer loop measures the link quality, typically frame error rates, (FER) and adjust the SIR targets accordingly. Ensuring lowest possible SIR target is used at all time to maximize the network capacity.

Soft handovers and power control provides path diversity on the forward and reverse links. Diversity gains are achieved because less and constant power is required on the forward and reverse links. This results in the reduction of total system interference and an increase in system capacity.[9] ,[11]

The SIR balancing algorithm calculates the optimal transmission power assignment for each mobile within the cell, taking into account all the neighboring cells. The scenario consists of a central cell surrounded by six other cells. This power is proportional to the ratio of the total received power of the mobile to the link gain between the base station and that mobile.

SIR balancing algorithm steps

1. Initializing number of iteration

2. Initializing number of mobiles/User's Terminals, UT
3. for I = 1 to number of iteration

. Generate link gain matrix of terminals (MS/UT) from their own base station.
. Generate link gain matrix of terminals (MS/UT) from other base station, gain'.
. Generate thermal noise as random variable , n_i
. Initialize power
. Initialize correction coefficient Cik
. for j = 1 to number of terminals

. Total received power = Sum(power*gain) + 6 * Sum (power * gain')
. Cik = total received power/ gain
. Power(j) = Sum(power)*Cik(j)/SumCik , then
Calculates received **SIR** values

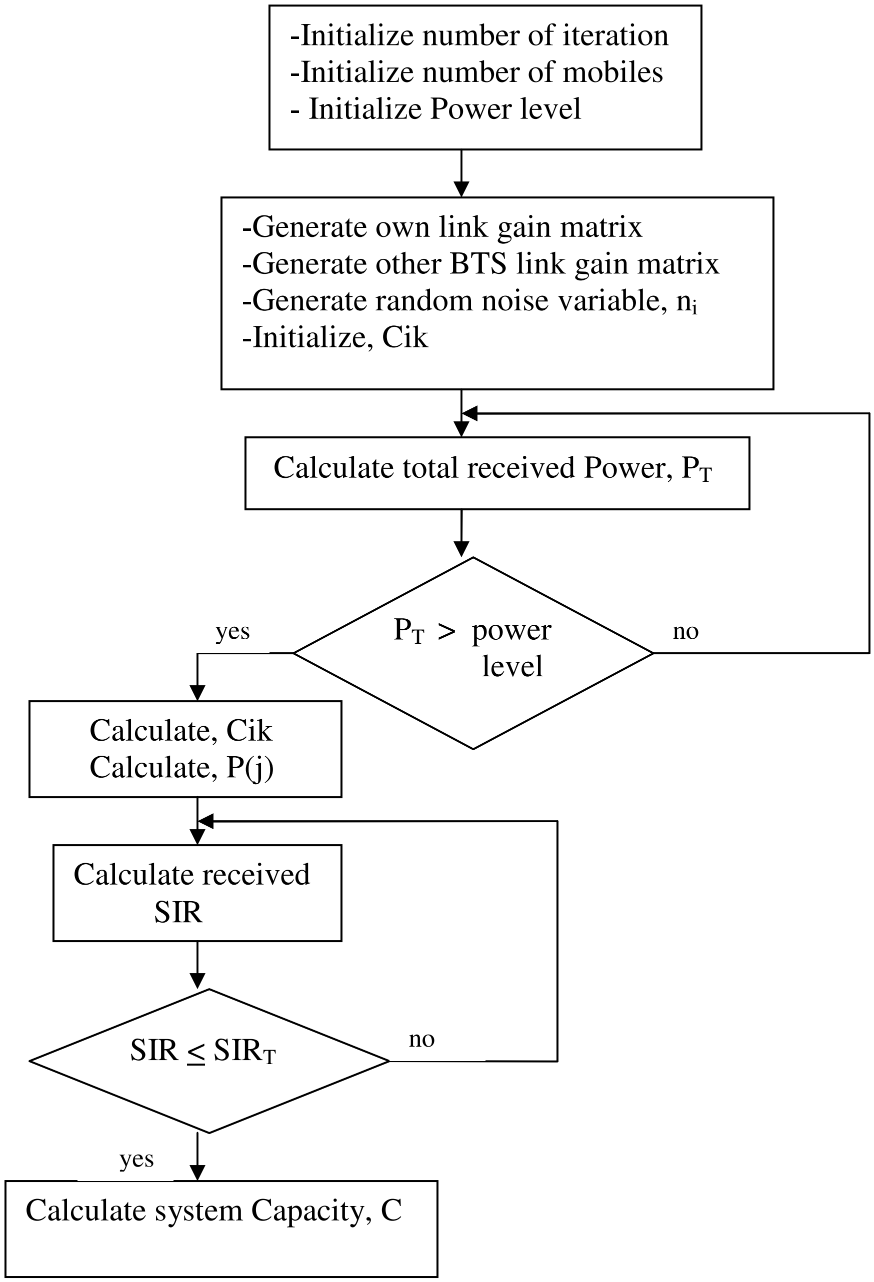


Figure 5.1 Flow chart representing SIR balancing algorithm

Applying Claude Shannon's Capacity equation, with noiseless condition ,$\eta = 0$, and also with Gaussian noise applications,

$$C = Bw \log_2 (1+ SIR),$$

The following plots are obtained by varying SIR target values to 2.0, 2.5 and 3.0(dB). Depending on the received SIR values corresponding system capacity is indicated. As the received SIR increases interference level decreases providing more capacity and better QoS

i) Assumed initial SIR/SINR target =2.0dB. Each received SIR/SINR values are compared with the target and the corresponding system Capacity for N = 2, 4,8,12 users are as shown in fig.5.2(a,b).

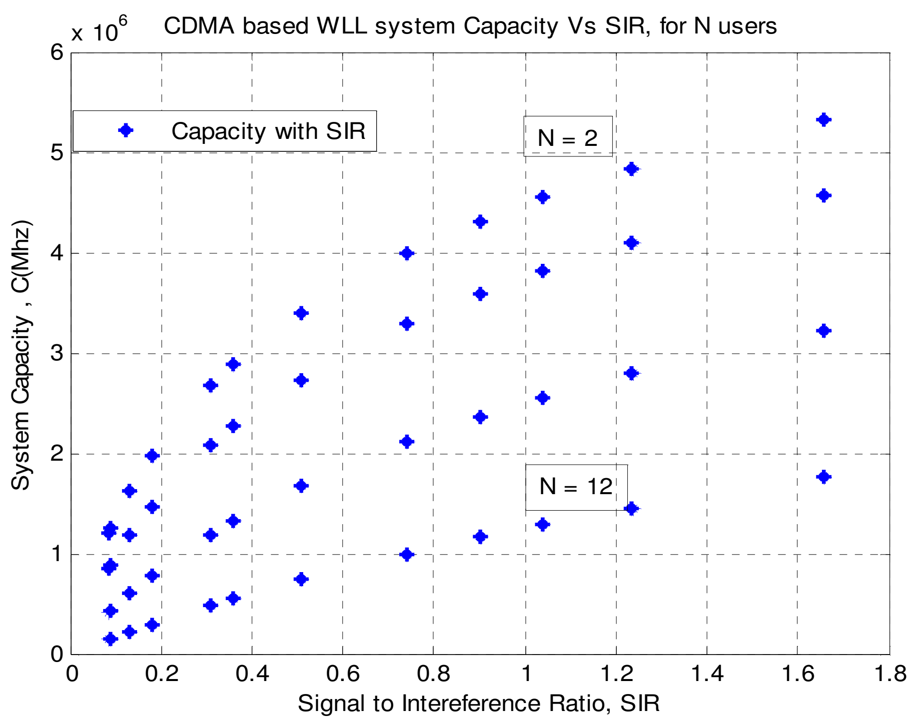


Figure 5.2 (a) SIR Vs System capacity with N = 2, 4,8,12 users

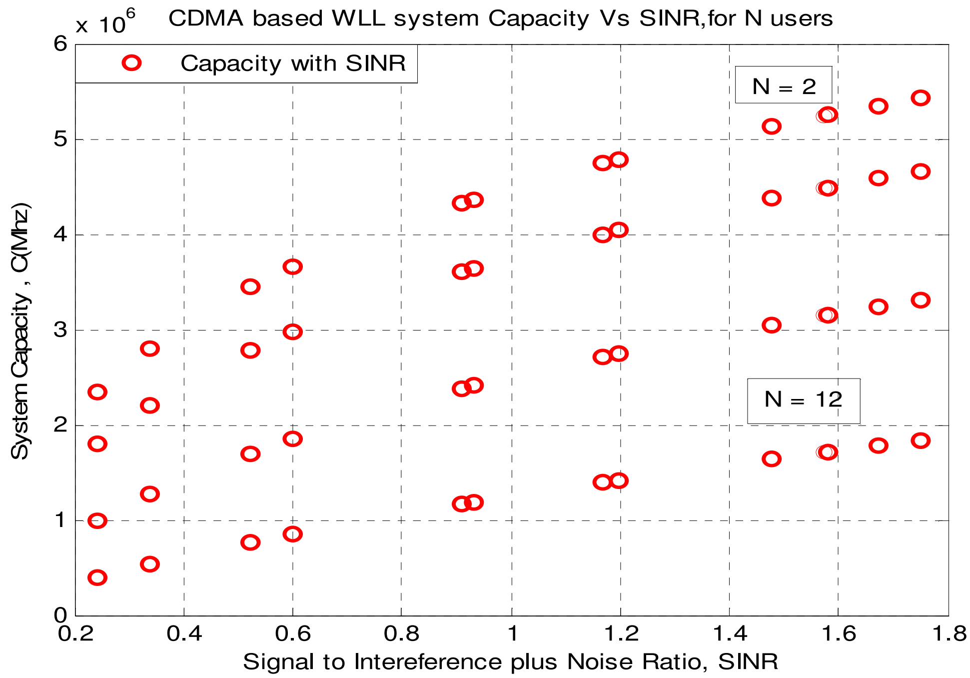


Figure 5.2 (b) SINR Vs System capacity with N = 2, 4,8,12 users

ii) With SIR /SINR = 2.5dB as a target value, the received SIR and the corresponding system Capacity are as shown in fig. 5.3(a, b).

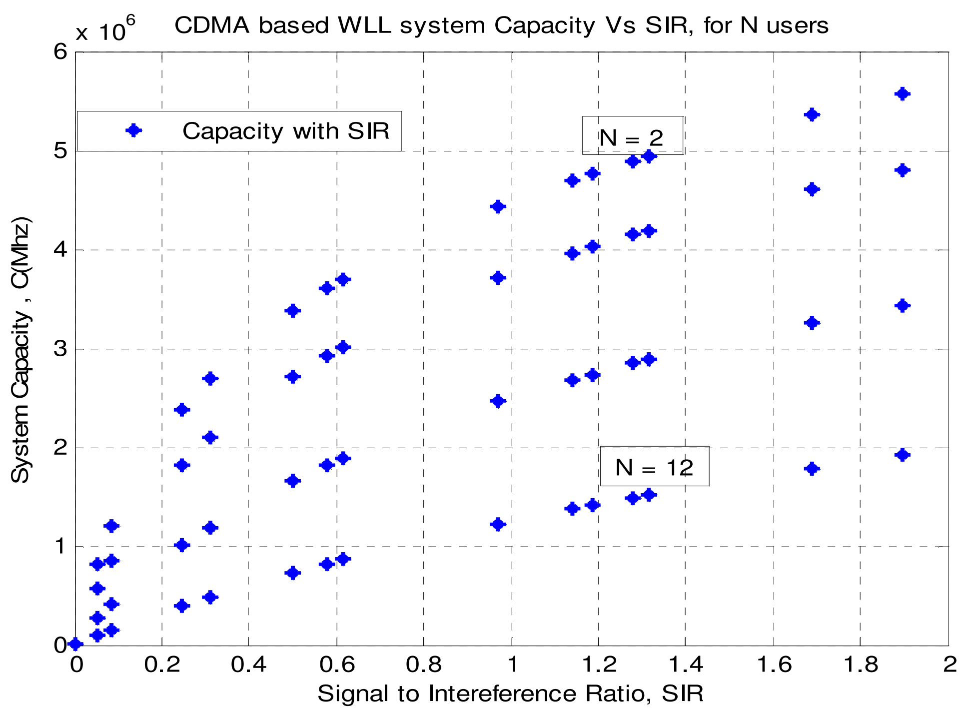


Figure 5.3 (a) SIR Vs System capacity with N = 2, 4,8,12 users

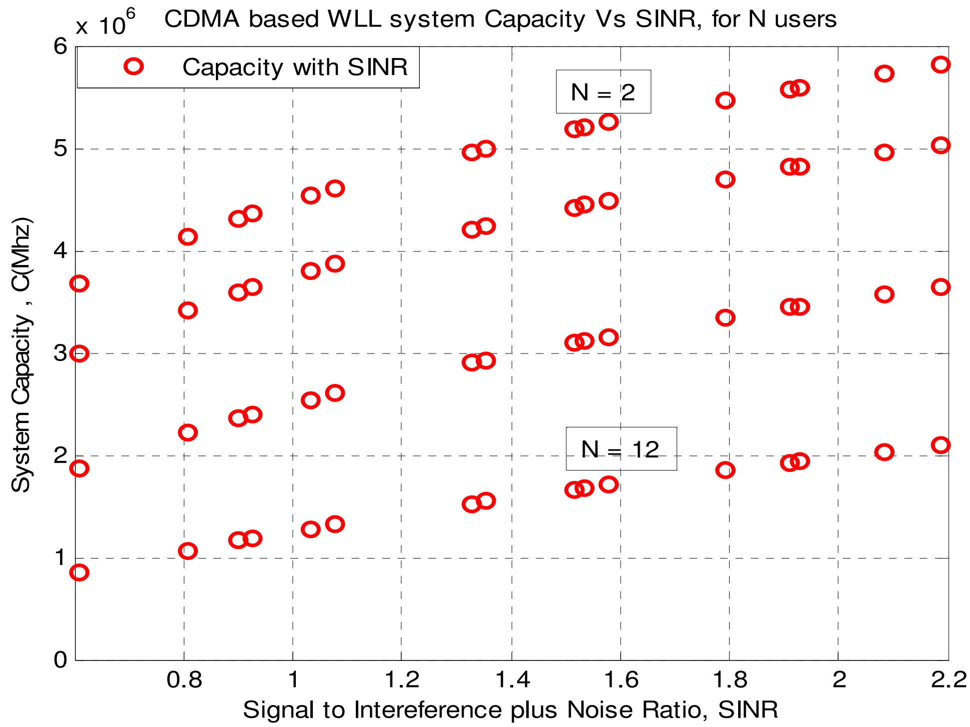


Figure 5.3 (b) SNIR Vs System capacity for N = 2, 4,8,12 users

iii) With SIR /SINR =3.0dB as a target values, the received SIR and the corresponding system Capacity for N= 2, 4,8,12 users are as shown in fig. 5.4(a, b).

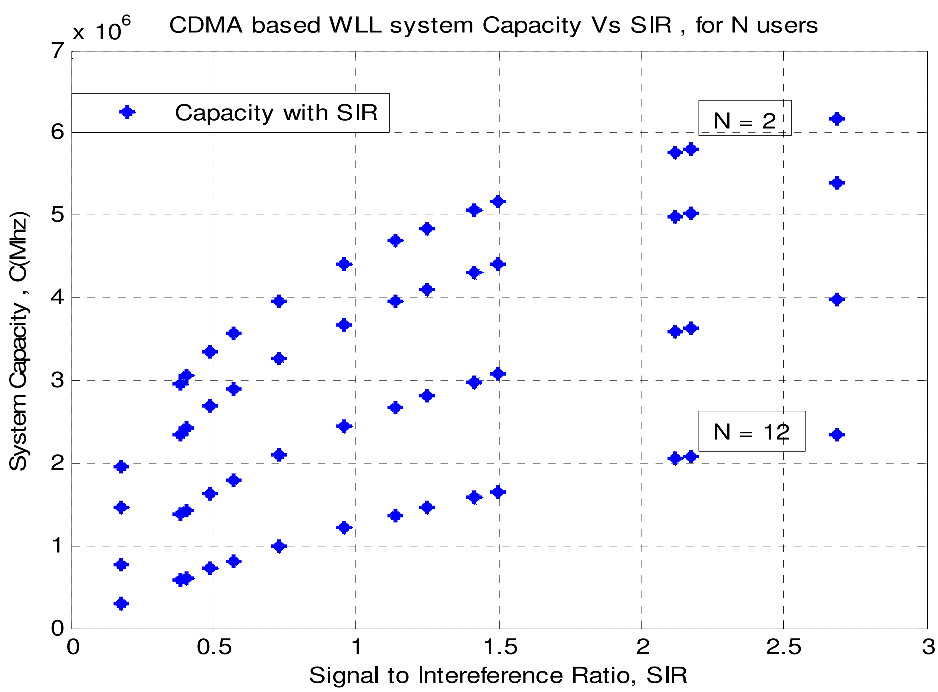


Figure 5.4 (a) SIR Vs system capacity for N = 2,4,8,12 users

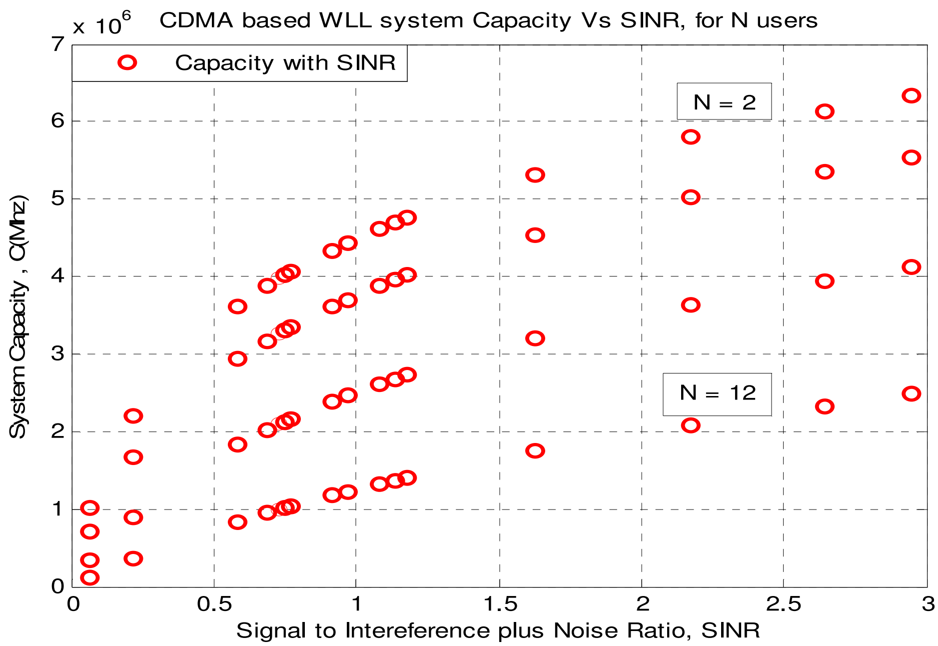


Figure 5.4(b) SINR Vs System capacity for N = 2, 4,8,12 users

Since CDMA WLL mainly interference limited system, the simulation output plots of SIR verses system capacity, C and SINR verses system capacity, C do not show much differences. SINR is signal interference plus noise ratio, noise in CDMA network does not have considerable effect.

So that the generated noise figure contributes very small (negligible) effect to over all determination of SIR/SINR values. Therefore as interference is the main parameter in calculating SIR/SINR, system capacity outputs figures have almost similar data representation.

As the received SIR/SINR value increases system capacity outputs are correspondingly increases .Because of its better performance , the centralized SIR balancing algorithm is preferred to be a proposed algorithm to solve the existed WLL system problem .
The algorithm outperforms better service quality, QoS and enhanced system capacity, C.

iv) Figure 5.5(a, b) Using Maximum Transmission power with SIR/SINR =2dB, and the corresponding system capacities.

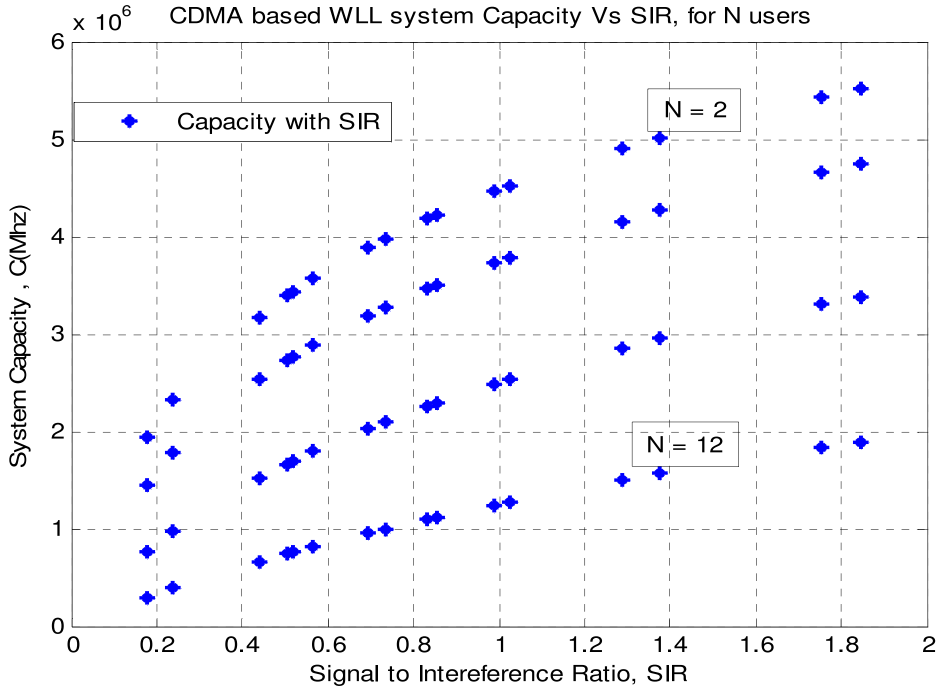


Figure 5.5(a) Using Maximum Power =42dBm, at target SIR = 2dB

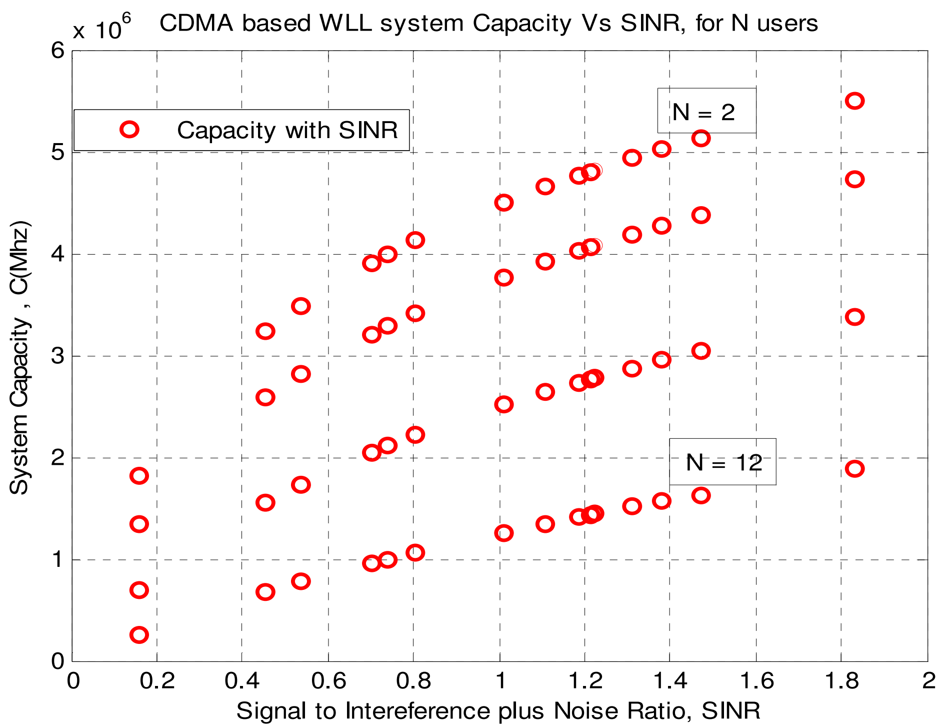


Figure 5.5(b) Using Maximum Power =42dBm, at target SINR = 2dB

v) Figure 5.6(a, b) Using Average Transmission power with SIR/SINR =2dB, and the corresponding system capacities.

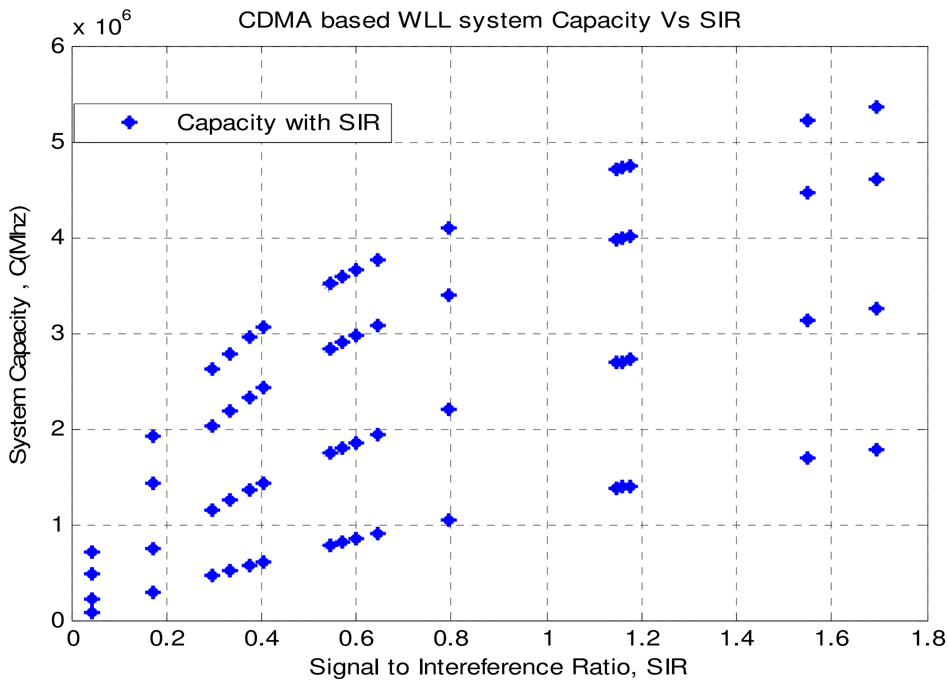


Figure 5.6(a) Using Average Power =40dBm, at target SINR = 2dB

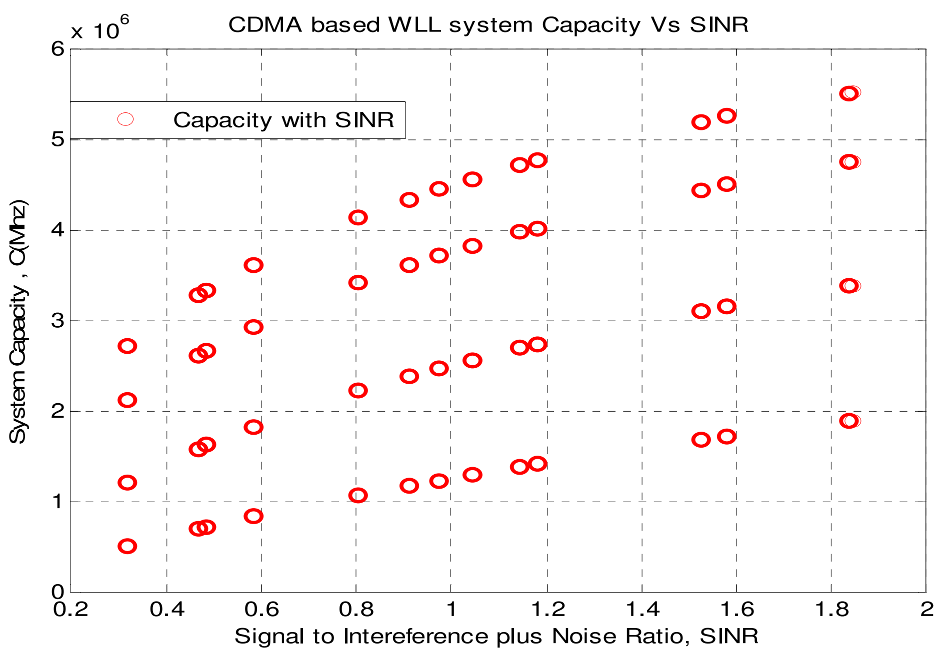


Figure 5.6(b) Using Average Power =40dBm, at target SINR = 2dB

vi) Figure 5.7(a, b) Using Minimum Transmission power with SIR/SINR =2dB, and the corresponding system capacities.

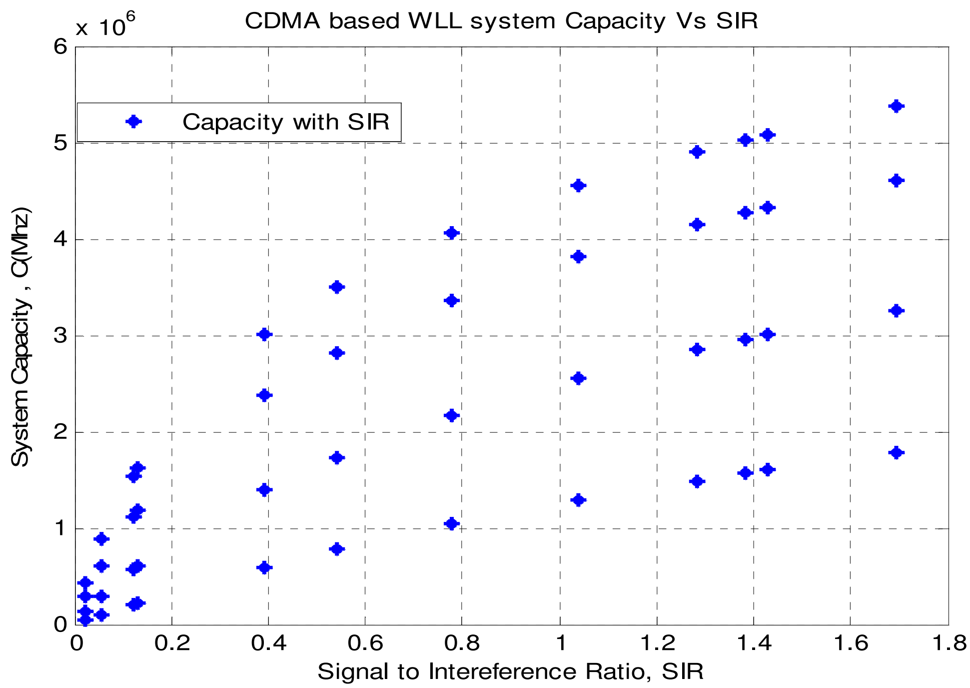


Figure 5.7(a) Using Minimum Power =38dBm, at target SIR = 2dB

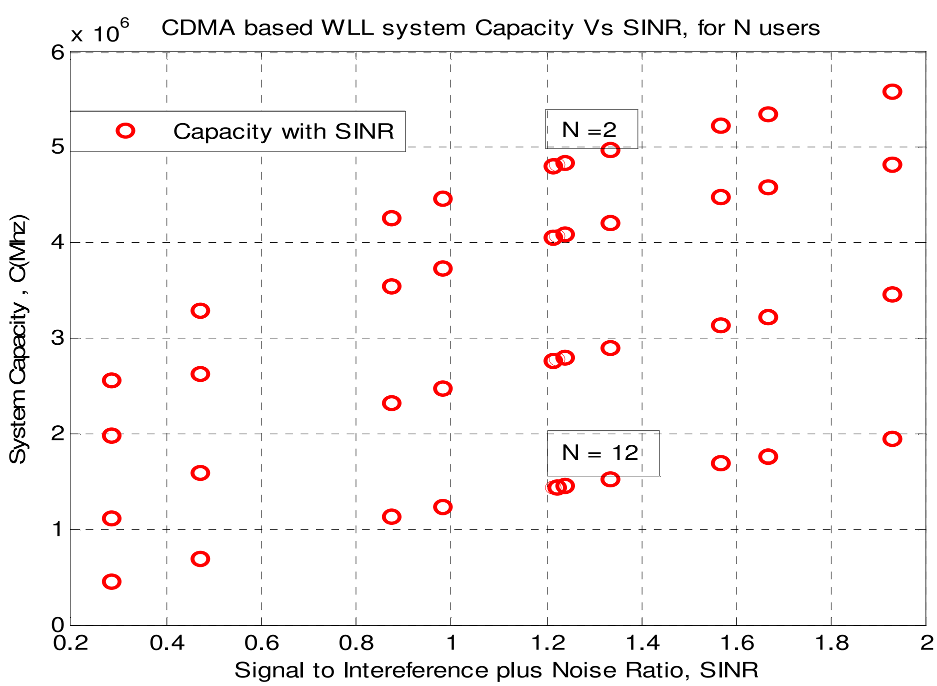


Figure 5.7(b) Using Minimum Power =38dBm, at target SINR = 2dB

Using Maximum, Average and Minimum transmission powers (Pmax.~= 42 dBm, Pavg., ~=40dBm ,Pmin.~= 38dBm) with SIR / SINR = 2dB as a target value for the three cases, and the received SIR / SINR values corresponding to system capacities are shown in figure from 5.5(a, b) to figure 5.7(a, b).

For each case, the SIR Balancing algorithm provides similar capacity enhancing performance for the received SIR / SINR values. The capacity output indicates an increasing performance corresponding to each received SIR values. To reduce power radiation loss and undesired heating, it is required to operate the wireless local loop, WLL, system by using average transmission /radiation power, Pavg., ~=40dBm.

Therefore, to provide better cdma based wireless local loop, CDMA-WLL, system in Addis Ababa, the proposed power control and performance enhancement technique is essential. The transmission power in WLL system has to be controlled and balanced around the indicated average transmission power, Pavg., ~=40dBm.

In addition to the power controlling technique, the cell coverage in Addis Ababa WLL system, must be localized in limited area, the network has to be balanced in load distribution, so that inter cell interference and system over loading will not cause degraded QoS and low system capacity.

<u>Implementation steps</u>

The following steps are required to be followed during implementing of centralized SIR balancing power control algorithm.

1- Service area spectral radius has to be localized in limited range.
2- The BTSs are required to radiate balanced power for all users in the cell.
3- The radiating power has to be controlled dynamically.
4- The receiver's thermal noise effect could be neglected.
5- Maximized SIR has to be received and compared with the target SIR value.
6- Selecting the best target value, the system provides enhanced service quality, QoS and higher system capacity.

Chapter-6. Conclusion and future work

Due to topographic situations there are places in the city where wireless coverage can not be reached by the existing BTS sites. CDMA system must manage two key resources: i.e. Erlang capacity, and power control techniques.

Power control activities both in up link and down link provides better system efficiency by controlling interferences as well as system generating noise. This action results increased system capacity and QoS.

A difficult power management problem arises when the base station attempts to serve a distance subscriber. The base station may assign the entire available power budget to the user, thereby preventing subscribers closer to the base station from accessing the network, even if spare Erlang capacity is available.

Distant subscribers use the entire base station's power budget, drastically reducing the base station's traffic carrying capacity. This is a typical problem observed in the existing network performance. Hence depending on the situations, the only solution of serving isolated distant subscribers is to carry on the Cell splitting and Cell secotorising capacity enhancement methods.

Some base station, BTS sites which are already giving good coverage in the area but working under their maximum load conditions. These site are recommended to carry system expansion work. BTS expansion also requires upgrading the existing BSC for the additional capacity**.**

The CDMA network capacity significantly depends on the so-called near-far effect and control of MAI. All practical systems use power control (PC) to reduce this effect. PC is more efficient in the system optimization and combat the near-far problem in which the received power from users near the base station causes undue level of interference to far-out users. By controlling the signal powers to be the lowest necessary. We minimize the total level of interference such that more users can be served with acceptable quality.

One of the most common approaches to closed loop power control in wireless communication networks is centralized SIR balancing also called power balancing. The SIR balancing solution was originally derived for satellite communication and adapted for wireless communication.

Distributed SIR balancing algorithm is also implemented distributive, but they have the disadvantage that their convergence can be slow and is guaranteed only if every mobile’s target SIR is feasible. There are fundamental limits on the improvements that can be achieved through power control.

Variations on the SIR balancing algorithm have replaced the target SIR by functions incorporating minimum allowable SIR. The variation also been developed to incorporate different user category in order to get access to make a call (call admission), as WLL is primarily used for fixed users , few important terminal can have limited mobility, so that during mobility the appropriate handovers actions has to take place, and base station assignment need attention while SIR balancing technique used.

The performance of any power control algorithm will be limited by update rate, feedback bandwidth, time delays, measurement errors, and filtering effects. These factors may explored in future work activities as shown below

Future works

- Analysis and implementation of efficient network planning and optimization work.

- Resolve major system problems by using the proposed power control performance enhancement technique.

- Examine performances of other power control algorithms based on system parameters requirement.

- System analysis based on multipath mitigation capability, voice activity detection and soft capacity.

- Evaluate Power controlling performances on data communications, analyze its implications on data rate updating, time constraints and encountered error during execution.

References

[1]. CDG Technology, http:// WWW .CDG.org,Sep/2006

[2]. HUAWEI, http:// WWW. huawei.com/news/,Sep/2006

[3]. Assessment on performance and expansion of existing CDMA-WLL in Addis Ababa.(ETC Project Planning offices , Dec.4/2005 ,NP =10)

[4]. SAMPEI, "Application of digital wireless technologies to global wireless Communication", permtice,Vol. No.2, USA

[5]. Jon W. Mark and Weihua zhuang, " Wireless Communications and Networking" John Wiley, V.No.1, 2002 ,PP=134-181

[6]. Power Control for Spread Spectrum Cellular Mobile Radio System, IEEE transaction Communications, April/2005,Vol.53 , No. 4

[7].Rosenberg, " CDMA capacity and Quality optimization" , Wireless Communication, Vol.6,No.3,March 1998

[8]. Vajay K.Garg, "IS-95 CDMA and cdma2000, Cellular / PCS system Implementation" Prentice Hall PTR, 2000,PP=198-206, 388-391

[9].Jens Zander, Seong-Lyun Kim, "Radio Resource Management for Wireless Networks", Prentice Hall, Steve Mann, V.No.1, 2003, Boston,London
.
[10].NIIT , " Basics of wireless communication", Asoke K. Ghosh Prentic-Hall of India,new delhi ,2004,PP =95-159

[11] Glisic, "Adaptive WCDMA", Kluwer A.P., 1994, Boston.

[12]. Proakis J.G, "Digital Communication", fourth edition, New York: McGraw–Hill, 1995

[13]. Potential of CDMA450 for Rural Network Connectivity, IEEE Communication Magazine / January 2007

[14]. J.M.Alin, Power balancing in system employing frequency reuse, COMSAT Technical Review, 3,(1973) 277-299

[15]. Ahlin,L., and J.Zander , 'Principle ofwireless communication', Student literature, 1997

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 .

Name ____________________________

Signature ____________________________

Place ____________________________

Date of submission ____________________

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

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Advisor's Name Signature