ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

FACULTY OF TECHNOLOGY

ELECTRICAL AND COMPUTER ENGINEERING

DEPARTMENT

HANDOFF INITIATION AND PERFORMANCE ANALYSIS IN CDMA CELLULAR SYSTEMS

By

Negassa Sori

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BY

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Declaration

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

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GLOSSARY OF ACRONYMS

3G	Third Generations
4G	Fourth Generations
AMPS	Advanced mobile phone system
AOA	Angle of arrival
BH	Busy hour
BS	Base station
CDMA	Code division multiple access
CPICH	Common pilot channel
CSC	Common signaling channel
DAMPS	Digital advanced mobile phone system
DCA	Dynamic channel assignment
DECT	Digital enhanced cordless telephone
DS	Direct sequence
FCA	Fixed channel assignment
FDMA	Frequency multiple access
GPS	Global positioning system
GSM	Global system for mobile communication
HCM	Handoff completion message
HDM	Handoff direction message
IS-95	Interim standard-95
LOS	Line of sight
MAHO	Mobile assisted handoff
MBPS	Measured based priority scheme
MSC	Mobile station controller
MS	Mobile station
PSMM	Pilot strength measurement message
MTSO	Mobile telephone switching office

NCHO	Network controlled handoff
NLUM	Neighbor list update message
NPS	Non-prioritized scheme
PACS	Personal access communication systems
PCS	Personal communication system
PSTN	Public switching telephone network
PUF	Power up function
QoS	Quality of service
QPS	Queuing priority scheme
RCS	Reserved channel scheme
RNC	Radio network controller
SF	Spreading factor
SIR	Signal to interference ratio
SRS	Sub-rating scheme
SS7	Signaling system 7
TACS	Total Access communication system
TDMA	Time division multiple access
TDOA	Time difference of arrival
TOA	Time of arrival
UHF	Ultra-high frequency
WCDMA	Wideband CDMA

Abstract

Mobile terminals allow users to access services while on the move. This unique feature has driven the rapid growth in the mobile network industry, changing it from a new technology into a massive industry within less than two decades. Handoff is the essential functionality for dealing with the mobility of the mobile users. Compared with the conventional hard handoff employed in the GSM mobile networks, the soft handoff used in IS-95 CDMA and being proposed for 3G has better performance on both link and system level.

In this thesis, an in-depth study of the soft handoff effects on the uplink direction of IS-95 CDMA networks is carried out, leading to optimize soft handoff for capacity under perfect power control approach.

We analyze the performance of different handoff algorithms on the forward link or downlink of a CDMA cellular system. Unlike the reverse link, soft handoffs on the forward link requires additional resources such as CDMA codes and transmit power and also causes additional interference. If handoff requests can be processed and completed instantaneously, transmission from the base station with the best link to the user would achieve a significant fraction of the macro diversity gain without utilizing additional resources. However, in practical systems, there is a nonzero handoff completion delay and soft handoff provides the required robustness to delays, although it comes at the expense of additional network resources. Thus, there is a tradeoff between the extent of soft handoff required and the handoff execution delay. We present an analytical framework to study this tradeoff and also discuss simulation results simulated with the help of Matlab. For this, handoff dropping probability is minimized up to 0.1%.

Markov concept is applied to describe the system's statistic behavior in steady state. System performances such as blocking and dropping probabilities and channel efficiency are also determined.

CHAPTER 1

1.1 Introduction

In a wireless mobile communication system, mobiles moving around the service area require communication services in the form of a wireless connection. In this system, coverage area is divided into smaller regions called cells to allow the reuse of frequency spectrum to increase the network capacity. Each cell is controlled by its own transmitter and receiver (or base station) to serve the mobiles within its range. As the population grows, cells can be added to accommodate that growth. Frequencies used in one cell cluster can be reused in other cells. Conversations can be handed off from cell to cell to maintain constant phone service as the user moves between cells.

The difficulty in the development of the cellular network involved the problem created when a mobile subscriber traveled from one cell to another during a call. As adjacent areas do not use the same radio channels, a call must either be dropped or transferred from one radio channel to another when a user crosses the line between adjacent cells. Because dropping the call is unacceptable, the process of handoff was created. Handoff occurs when the mobile telephone network automatically transfers a call from one radio channel to the other radio channel as a mobile crosses to an adjacent cell.

The process of transferring a mobile station from one channel or base station to another is called a ‘handoff ’, which is an essential element of cellular communication. Since CDMA uses single frequency, it uses a special handoff scheme, so called soft handoff. Soft handoff is a process in which a mobile unit can commence communication with a target station without interrupting the communication with the current serving base station (make before break). The traditional handoff scheme which requires the mobile to break communication with the current base station before establishing a new communication with other base station is called hard handoff (break before make). This scheme has relatively high fade margin (the amount by which a received signal level may be reduced without causing system performance to fall below a specified threshold value), lower uplink capacity (maximum number of mobile stations (MSs) that can be served by a base station (BS)), ping-pong effect and higher hysteresis margin.

Handoffs in wireless mobile networks deal with the mobility of the end users in a mobile network: it guarantees the continuity of the wireless services when the mobile user moves across the cellular boundaries. In first and second-generation mobile networks, hard handoff is employed; in third generation networks, which are predominantly based on the code division multiple access *(*CDMA) technology, the soft handoff concept is introduced. Compared with the conventional hard handoff, soft handoff has the advantages of smoother transmission and less ping-pong effects. Handoffs in wireless mobile networks are mainly used for maintaining service continuity during mobility. It also brings macro diversity gain i.e., more than one BS is used during handoff process (or diversity of BSs) to the system. However, soft handoff has the disadvantages of complexity and extra resource consumption. Therefore, optimization is crucial for guaranteeing the performance of soft handoff.

Until now, several algorithms [6], [7] have been proposed aiming at maximizing the macro diversity gain and minimizing the handoff failure rate and extensive research has been conducted on the optimization of the parameters for these soft handoff algorithms. It has been proved that the individual link quality can be improved by soft handoff and in the uplink soft handoff can increase the capacity and expand the coverage [13],[23]. However, there are no qualified results about the trade-off between the macro diversity gain and the extra resource consumption caused by soft handoff, and the performance to make decision to handoff.

The issue of quality of service (QoS) maintenance is also of great importance during the handoff. In this research work, a selective handoff mechanism for performance analysis and initiation of handoff is proposed. In this mechanism, the handoff by a cell is delayed or hastened with an objective of using the resources available with itself and its neighboring cells effectively. This ultimately results in effective load balancing across the network. As the result of this**,** forced termination probability of a call and handoff blocking probability will be minimized.

The CDMA scheme has been considered as one of the possible choice of future standards in cellular networks because of its various advantages. It is one of the most promising medium access technologies for next generation cellular networks. Recently, there has been an increase in demand for wide-band services such as videophones and videoconferencing over wireless networks. As a result, networks are fast evolving from voice only networks to multi-service networks supporting a heterogeneous mix of services with varying traffic characteristics.

Efficient handoff algorithm can enhance system capacity and service quality cost effectively. Soft handoff is a fascinating technology and has some wellestablished benefits over conventional handoff schemes, such as, higher uplink capacity, reduction/elimination of ping-pong effect and hysteresis margin and imposing fewer time constraints on the network.

Successful and reliable handoffs are major issues for system performance and thus, analysis and implementation in studying some of the factors, which project the advantages of using soft handoff and factors, which enable successful and reliable handoffs, are main target areas of research.

1.2 Objectives

Controlling forced termination of a call and blocking probability in mobile cellular network is a very important issue. Successful and reliable handoffs are major issues for system performance and thus attention would be given to analysis and implementation in studying some of the factors i.e., handoff initiation and channel availability, which project the advantages of soft handoff and enable successful and reliable handoffs. In this thesis, algorithms for handoff initiation and decision to make successful handoff for service continuity would be implemented. Performance criteria of interest here are average number of handoff attempts per call, forced termination probability and blocking probability.

This study will specifically aim at analyzing and initiating handoff schemes that will result in:

- Minimizing ping-pong effect in hard handoff.
- Reduce blocking probability, which is the case for call drop.
- Minimize forced termination probability.

So as to achieve high quality of service with acceptable grade of service by decreasing path loss and call drop.

1.3 Methodology and Scope

The analysis is done for a model with two base stations separated by a distance *d*, and a mobile moving from one base station to another along a straight line. The analysis and implementation is based upon path loss, shadowing and Rayleigh fading. The decision to initiate a handoff can be made by measuring the received signal level from the communicating and neighboring base stations, and received signal strength to interference ratio. The most commonly used method is based on received signal strength. The received signal strength in land mobile communication has three kinds of variations i.e. path loss, shadowing and Rayleigh fading. Here the effect of the received signal strength due to path loss only is considered.

In different literature, several approaches [1], [2], [5], and [8], have been proposed to provide priorities to handoff requests and since it is practically impossible to eliminate handoff drops, the proposed schemes are advocated providing probabilistic QoS guarantee by certain level.

There are a number of advantages of handoffs, particularly, soft handoff which needs to be analyzed and implemented in CDMA cellular systems. Along with so many literature reviews, different schemes have been studied to provide different performance improvement. So, the initiation and performance analysis proposed are compared numerically with the previous results based on the system performance. This can be obtained from different works with the proposed work such as QoS, grade of service, and measuring the received signal strength (pilot signal) to come to decision to initiate handoff through the Hata-Okumara model [9]. The model considers the propagation loss between isotropic antennas using the standard empirical formula for urban area propagation loss due to simplicity of the formula in relating the distance with path loss. A limitation of this model is that it does not consider the structure of buildings and roads.

1.4 Thesis outline

With the objectives of the study stated above, the thesis is organized as follows: Chapter 2 provides a brief overview of multiple access techniques such as: FDMA, TDMA and CDMA. In addition, this chapter reviews some relevant principles of mobile communications, such as locating mobile signal and mobile cellular systems. At the end of this chapter, Erlang and network capacity are briefly discussed. Chapter 3 describes direct sequence CDMA signal spreading and the capacity of CDMA cellular systems. Frequency reuse and cell sectorization for capacity improvement is also discussed under this chapter. It also discusses voice activity, CDMA architecture and its operations in brief. At the end of this chapter, analysis of interference in CDMA is briefly described. Chapter 4 emphasizes on handoff management and handoff initiation techniques. Also in chapter 4, handoff decision algorithms and network performances are discussed in brief. This chapter also discusses principles and operations of soft handoffs. At the end, channel assignment strategies and cellular deployment scenarios are seen in brief. In Chapter 5, system model and analysis of parameters are presented and discussed. Chapter 6 discusses simulation results. The performance is evaluated at the end of this chapter. Finally, Chapter 7 presents conclusions of this study and some feature works.

CHAPTER 2
BACKGROUND IN MOBILE COMMUNICATIONS

2.1 Introduction

Communication has always been an essential part of every kind of human society. So far, many technologies have been developed for this purpose. Among these, mobile communication has been one of the most important technologies that man has ever used. A mobile communication network is a multi-user system, in which a large number of users share a common physical resource to transmit and receive information. The abilities of the second-generation wireless cellular systems, such as Global System for Mobile Communication (GSM), are limited to digital wireless voice traffic. These systems have been designed for voice communications with low-bit-rate data services. Any enhancement or addition of new services also affects the service.

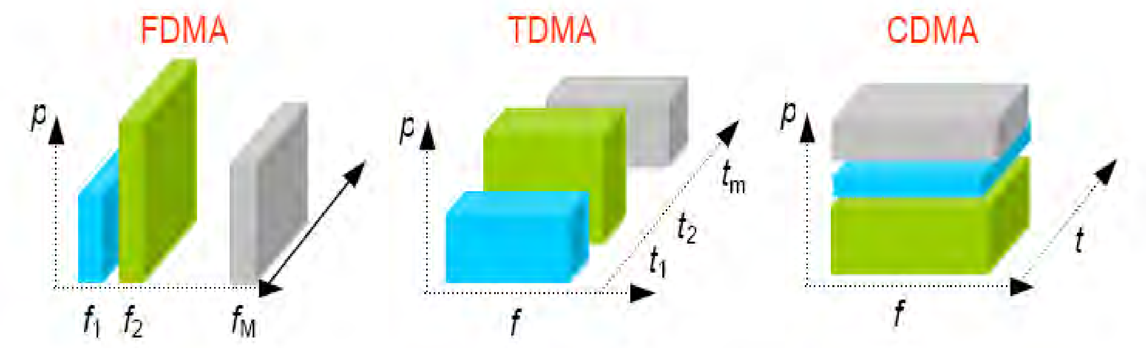
Growing demands for transferring high quality images, video and wireless Internet access with high data rate (up to 2 Mbps) and needs for data-rich, multimedia services accessed instantly over mobile handsets forced the technology to move to Third Generation Cellular Systems (3G) and Fourth Generation cellular Systems (4G). Every wireless cellular system operator, developer or vendor in the world is affected by this technology since mobile cellular systems evolve toward a new generation of networks, services and applications. The third and fourth generations of networks are the new faces of wireless network technologies, which have been significantly improved in terms of system capacity, voice quality, and ease of use.

2.2 Multiple access Techniques

In any communications system with many users, whether it be a fixed line or a wireless scheme, users share some resources. Some mechanism must be employed to enable this resource sharing, and this is referred to as a multiple access scheme. Multiple accesses, or multiplexing, enable multiple signals to occupy a single communication channel. For cellular communications, a change in generation has generally meant a change in the multiple access schemes that is implemented. There are three basic multiple access schemes used in today's cellular networks. These are frequency division multiple access (FDMA), time division multiple access (TDMA) and CDMA. The first generation of cellular systems used FDMA; the majority of second-generation systems use TDMA and most of the third generation schemes use CDMA.

Each of these access schemes uses different methods to allocate calls. FDMA is the basic technology used in the analog Advanced Mobile Phone System (AMPS). FDMA is also used in the Total Access Communication System (TACS). Basically, FDMA places each call on a separate frequency as shown in Figure 2.1a). FDMA partitions the available spectrum into uniform chunks of bandwidth.

The Digital-Advanced Mobile Phone System (D-AMPS) and GSM use TDMA for channel access. TDMA places each call in a certain portion of time in a given frequency as shown in Figure 2.1b). TDMA systems operate in either 800 MHz or the 1900 MHz. The narrow band, 30 kHz wide and 6.7 ms long, is divided into eight time slots which increase the capacity three-fold as compared to an analog system with the same number of channels [15].



(a) FDMA (b) TDMA (c) CDMA

Figure 2.1. Multiple access technologies

CDMA takes a vastly different approach than FDMA and TDMA. This technology is used in ultra-high frequency (UHF) cellular networks in the 800 MHz and 1.9 GHz bands. CDMA is a form of spread spectrum where data is sent in pieces over a number of available frequencies as shown in Figure 2.1c). The pieces of data are spread over the entire spectrum and each call is assigned a unique code sequence. These multiple access technologies are discussed in brief as follows.

2.3 Frequency division multiple access (FDMA)

As previously stated, a wireless system has the resource of frequency to share among many users. The first approach to solving this problem is to split the available frequency into a number of channels, each with a narrow slice of the frequency. This concept is shown in Figure 2.2. Each user in the system that wishes to communicate is allocated a frequency channel, and each channel has a certain gap, known as a guard band, between it and the next channel so that the two do not interfere with each other. Once all the channels are in use, a new user to the system must wait for a channel to become free before communication can commence. Therefore, the system is limited in capacity as it can only support as many simultaneous users as there are channels. This is known as a hard capacity system. Another problem is that if there is any external interference at a particular frequency, then a whole channel may be blocked.

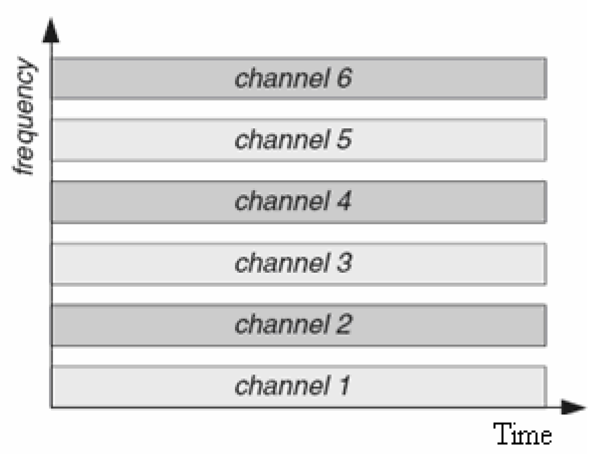


Figure 2.2. FDMA scheme

The concept of FDMA can be considered in the context of radio broadcasting. There is a certain allocation of frequency resources, for example 88 MHz to 108 MHz for FM, and each radio station in a particular region is given one channel within this on which it transmits.

2.4 Time division multiple access (TDMA)

As wireless communications systems are expected to support more and more simultaneous users, there are clearly severe limitations with the FDMA scheme. A more efficient channel usage is required. With TDMA, a frequency channel is divided up into a number of slices of time, as shown in Figure 2.3. Here, a user is allocated a particular time slot, which repeats periodically. In the diagram, the frequency is split into six time slots; a user is allocated one slot in every six. Providing that the time slices are small enough and occur frequently enough, a user is oblivious to the fact that they are only being allocated a discrete, periodic amount of time. In this manner, the capacity can be dramatically increased and hence the efficiency of our system. Again, this is referred to as a hard capacity type network.

As an example, GSM employs both a TDMA and FDMA approach. Within a cell, the frequency being used is further split into time slots using the TDMA principle. If more capacity is required, either more cells, packed closer together, can be introduced, or another frequency channel can be deployed in a cell. This can increase the number of available eight time slots, and hence, the number of simultaneous users.

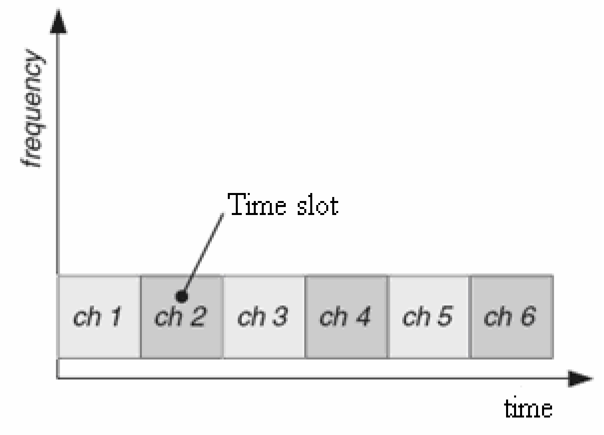


Figure 2.3 TDMA scheme

This does add some complication to the system, since the frequencies being used must be carefully planned so no two frequencies that are the same may border each other. This is the idea of frequency reuse; that is, a frequency can be used more than once in the system as long as there is a sufficient distance between the repeated usage locations. This idea is shown in Figure 2.4, where seven different frequencies, A, B, C, D, E, F and G, are being reused.

Typically in rural areas these cells are of the order of 10 km across but in areas of high usage (such as city centers) this may be reduced considerably to a few hundreds of meters. Another advantage of the smaller cells is that less transmission power is required. This in turn means that the battery of the mobile devices can be smaller and lighter, thus reducing the overall weight of the devices. A single base station can control a number of cells, with each cell using a different frequency. More effective coverage of a highway, for example, can be attained through the use of sectored base stations as illustrated in Figure 2.5. A sectored site is typically used to cover a larger geographical area.

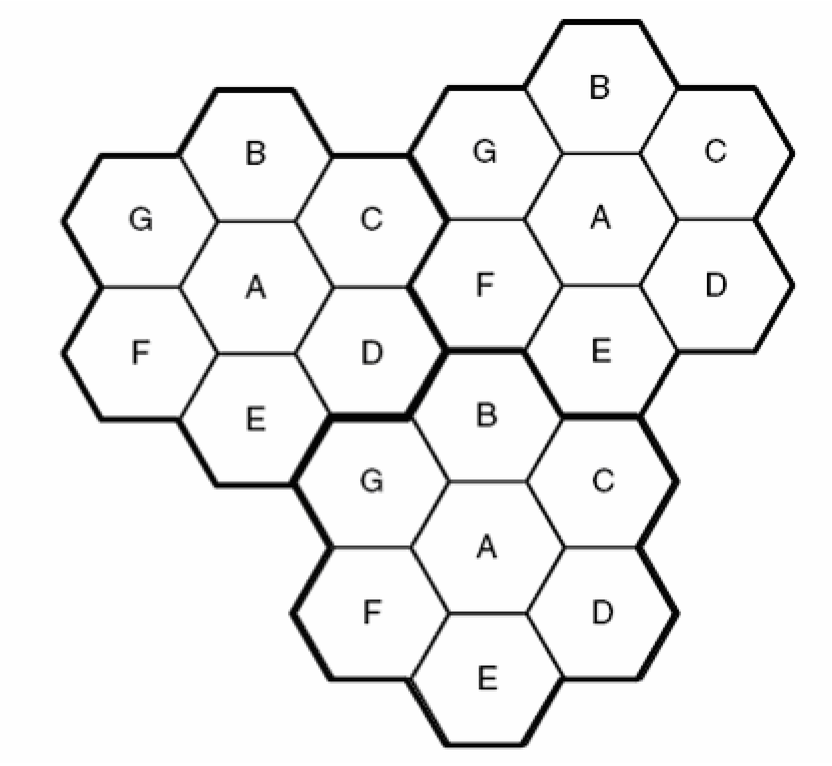


Figure 2.4. Cellular frequency reuse.

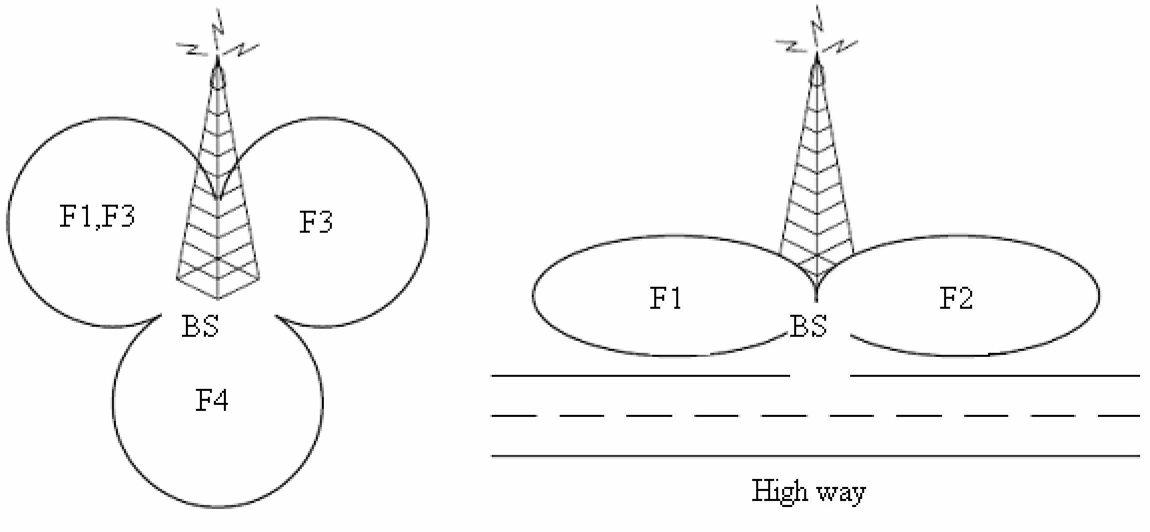


Figure 2.5 Sectoring a BS for efficient coverage.

A cell may also have more than a single frequency allocated to it, as illustrated in figure 2.5. A transceiver unit (TRX) is the physical device located at the base station, which controls each of these separate frequencies. A cell having a number of frequencies will therefore have a number of TRXs. In GSM, a TRX can handle at maximum eight full-rate simultaneous users.

2.5 Code Division Multiple Access (CDMA)

If the previous multiple access schemes are considered in terms of efficiency, each of them involves only one user transmitting on a particular channel at a particular time, which is clearly inefficient. For example, with GSM, in a given cell, only one user is transmitting at any time; all other active users are waiting for their time slot to come around. If a mechanism could allow more than one user to transmit at a time; then the resource usage could be dramatically improved. CDMA is such a scheme, where all users are transmitting at the same frequency at the same time. The effect of interference that users cause to each other is discussed in the next chapter. Having a system that is limited by a noise target rather than specifically allocating resources for the sole use of a particular mobile device is known as a soft capacity system. Evidently, allowing multiple users to transmit simultaneously is not the central issue; providing some system to separate them out again is where the difficulty lies. This is the role of the codes. The great mathematician Andrew J. Viterbi, who is also a cofounder of Qualcomm Inc, accomplished much of the development work associated with CDMA. Thus, many of the patents associated with CDMA are held by Qualcomm, which has resulted in considerable debate with regard to the ownership of CDMA technology.

2.6 Comparison

In FDMA, signals for different users are transmitted in different channels each with a different modulating frequency; in TDMA, signals for different users are transmitted in different time slots. With these two technologies, the maximum number of users who can share the physical channels simultaneously is fixed. However, in CDMA, signals for different users are transmitted in the same frequency band at the same time. Each user’s signal acts as interference to other user’s signals and hence the capacity of the CDMA system is related closely to the interference level: there is no fixed maximum number, so the term soft capacity is used.

The processing gain, together with the wideband nature of the process, gives benefits to CDMA systems, such as high spectral efficiency and soft capacity. However, all these benefits require the use of tight power control and soft handoff to avoid one user’s signal hiding the communication of others. Power control in CDMA and soft handoff will be explained in some detail in chapter 3 and 4 respectively.

2.7 Mobile Signal Location

Most traditional location techniques use some characteristic of the mobile's signal to determine its location. The characteristic used for the location systems in this section is the time-of-arrival (TOA) of the signal. TOA based location was investigated due to its advantages over angle-of-arrival (AOA) and signal strength based location methods.

Signal strength location takes advantage of the fact that the average received power of a radio signal decays in a known fashion with distance. The received signal power of the mobile at several locations can be used to calculate the distance of the mobile from those locations. These distances can then be used to calculate the coordinate position of the mobile. The disadvantage of using this method is the large, random deviations from the mean received signal strength caused by small scale channel effects and shadowing. This can result in received power variation of 10 dB or more from the mean that translates into significant position error.

AOA systems are considerably more accurate than signal strength based ones. However, this technique also has disadvantages. First, determining the AOA of a signal usually requires an antenna array. This increases the amount of modification required on the base stations. AOA based systems also perform slightly worse than TOA based ones in a multi-path environment and the accuracy of AOA systems tends to degrade as the distance to the mobile increases [6]. TOA based schemes have some advantages that make them a good choice for mobile location. First, TOA location systems can be implemented using existing base station antennas. This reduces implementation complexity. The second advantage is that TOA systems are fairly robust in multi-path channels. Multi-path reflections arrive after the first line-of-sight (LOS) component of the signal. This means that as long as the rising edge of the signal is used, the multi-path channel won't cause as much error for a TOA system as it does for the previous two techniques.

One possible disadvantage of the TOA system is that it requires several different reception points to have very good time synchronization. One solution to this problem is to synchronize the different base stations using the time reference from global positioning system (GPS) receivers. Since GPS receivers are already being used in IS-95 CDMA base stations, this can be implemented with very little extra cost.

In order to locate a mobile using TOA, several base stations in the vicinity of the mobile determine the TOA of the mobile's signal at their respective locations. These TOA estimates are then forwarded to a central location and combined with the known base station locations to determine the location of the mobile. While absolute TOA can be used to solve for mobile position, a common technique is to use time difference of arrival (TDOA). In this technique, the difference of the time-of-arrival of the mobile's signal at two different base stations is used to determine its location. The TDOA of a mobile's signal is given by

$$t_i - t_j = \frac{\left(d_i - d_j\right)}{c} \tag{2.1}$$

Where t_i and t_j are the TOA's of the mobile's signal at base stations i and j, respectively. The distance of the mobile from base station i and j is given by d_i and d_j, and the speed of light is denoted by c. These distances can be expressed in terms of the coordinate position of the mobile ($x; y$) and the known positions of base station i and j, given by $\left(x_i, y_i\right)$ and $\left(x_j, y_j\right)$.

The major problem that must be overcome when attempting to locate an IS-95 mobile using TOA is the extremely low signal levels. The first solution to this problem is to simply ask the mobile being located to turn on its transmit power. This can be done using the Power up Function (PUF). This causes the mobile to turn up its power to its maximum level and transmit a known spreading sequence.

2.8 Cellular Systems in mobile network

In this section, the relationship between the reuse ratio (q) and the cluster size (N) for a hexagonal cell will be discussed. Also, a numerical example will be provided to give a better understanding of the equations.

2.8.1 Hexagon structure

In order to allow frequency reuse at much smaller distances in a cellular system, it is important to make efficient use of the available channels. Cellular systems are designed to operate with groups of lower-power base stations spread out over the geographical service area. Each group of base stations serves mobile units, which are located near them. The area served by each base station is called a cell.

The ideal or true shape of a cell is circular. However, in reality, the cell coverage is irregularly shaped. The exact coverage of the cell depends on the terrain and other factors. For design convenience, we assume that the coverage areas are regular polygons. Any regular polygon, such as an equilateral triangle, a square, or a hexagon, can be used. The hexagon is used for two reasons: first, a hexagonal layout requires fewer cells and therefore, fewer transmitter sites and second, a hexagonal cell layout is less expensive compared to square and triangular cells. Fig 2.6 illustrates the concept of frequency reuse distance. There are two sets of 7 cells. The set of frequencies used by cell 1 of one set is reused by the cell 1 of the second set. And the frequency of cell 2 of one set is reused by cell 2 of the second set, and so on. These cells must maintain a minimum geographical distance, which is referred to as the frequency reuse distance and is denoted by *D*.

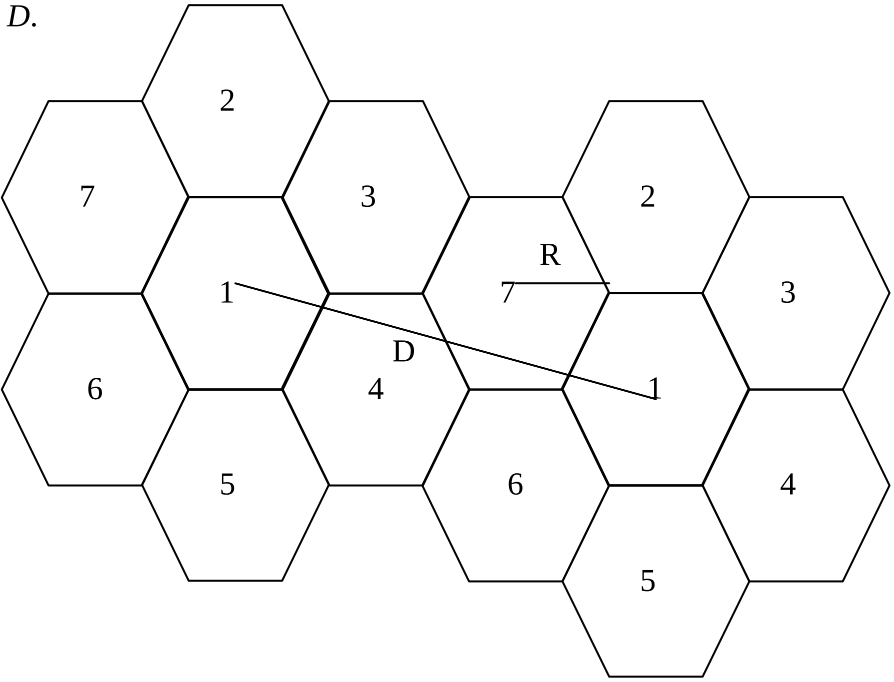


Fig 2.6. Frequency reuse distance *D* and center-to-vertex distance *R*

A cluster is a group of cells that share the total allocated spectrum to the system. Because of the geometry of the hexagon there are only certain cell layouts and cluster sizes that are possible in order to tessellate (without leaving gaps in between the cells). The numbers of cells per cluster, *N*, can only have values, which satisfy the following equation [9].

$$N = i^2 + ij + j^2 \tag{2.2}$$

Where *i* and *j* are integer values. To find the nearest co-channel neighbors of a particular cell, one must do the following:

1. Move *i* cells along any straight chain of hexagons.
2. Turn 60 degrees counter-clockwise and move *j* cells.

Figure 2.7 Illustrates this process with *i*=2, *j*=1 and *N*=7. So in this example, one cluster contains 7 cells. To find the nearest cluster, one should move 2 cells, turn 60 degrees counter-clockwise and then move 1 cell.

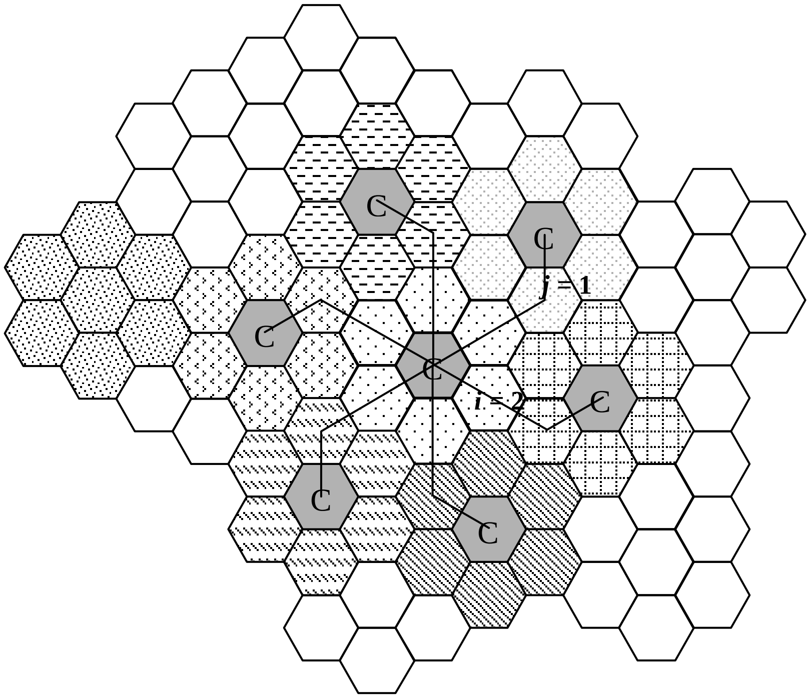


Fig 2.7. Pattern of reuse frequency with N=7 and C=center of cluster

Due to the hexagon structure only some cluster sizes, like 1, 3, 4, 5, 7, are allowed. The co-channel interference is a function of *q* where *q* = *D*/*R*. If there were only two interfering cells, then the signal to interference ratio would be $S/I = q^{-\gamma}$, where γ is the propagation path-loss slope. The relation between *D*, *R* and *N* is given in Eq. (2.3)

$$\frac{D}{R} = q = \sqrt{3N} \tag{2.3}$$

Where D = Direct distance between the cells using the same frequency,

R = Center to vertex distance (cell radius)

N = Cluster size, *q* = Reuse frequency.

In Table 2.1 the values *i* and *j* and the accompanying cluster size and reuse frequency are given.

Table 2.1 Relations between D, R and N

I	*J*	*N*	q=D/R or q= $\sqrt{3N}$
1	0	1	1.73
1	1	3	3.00
2	0	4	3.46
2	1	7	4.58
3	0	9	5.20
4	1	21	7.94

2.8.2 Co-channel interference

Users who transmit in the same frequency channel produce co-channel interference. Signal-to-interference ratio (*S/I*) is defined to express the co-channel interference faced in frequency reuse. This ratio is given by:

$$\frac{S}{I} = \frac{S}{\sum_{k=1}^{6} I_k} \tag{2.4}$$

In a hexagonal-shaped structure, as shown in figure 2.7, there are always six co-channel interfering cells in the first tier. In a small cell system, interference will be the dominating factor and thermal noise can be neglected. Thus, the S/I can also be written as [9]:

$$\frac{S}{I}=\frac{1}{\sum_{k=1}^{6}\left(\frac{D_k}{R}\right)^{-\gamma}} \tag{2.5}$$

Where S/I = Signal to interference ratio at the desired mobile receiver,

S = desired signal power,

I = Interference power,

$2 \le \gamma \le 5$ is the propagation path-loss slope and γ depends on the terrain environment. If we assume, for simplification, that D_k is the same for the six interfering cells, i.e., $D = D_k$, then equation (2.5) becomes:

$$\frac{S}{I}=\frac{1}{6(q)^{-\gamma}}=\frac{q^{\gamma}}{6} \tag{2.6}$$

$$q=\left[6\left(\frac{S}{I}\right)\right]^{\frac{1}{\gamma}} \quad . \tag{2.7}$$

For analog systems using frequency modulation, normal cellular practice is to specify an *S*/*I* ratio to be 18 dB or higher based on subjective tests [9]. An *S*/*I* of 18 dB is the measured value for the accepted voice quality from the present-day cellular mobile receivers. Using an *S*/*I* ratio equal to 18dB ($10^{18/10}=63.1$) and γ =4 in the equation above, then

$$q=[6\times 63.1]^{0.25}=4.41\,. \tag{2.8}$$

Substituting q from Eq. (2.8) into Eq. (2.3) yields

$$N=\frac{(4.41)^2}{3}=6.49\approx 7\,. \tag{2.9}$$

Equation (2.9) indicates that a 7-cell reuse pattern is needed for an *S*/*I* ratio of 18 dB.

Table 2.2 reports all the result regarding different values of *N*.

Table 2.2. Cell reuse factor versus mean *S*/*I* ratio and call capacity

N	*Q*	Voice Channels per cell	Calls per cell per hour	Mean *S*/*I* in dB
4	3.5	99	2610	14.0
7	4.6	56	1376	18.7
21	7.94	19	369	28.2

It is evident from the results in Table 2.2 that, by increasing the cluster size from *N*=4 to *N*=21, the mean *S*/*I* ratio is increased from 14 dB to 28.2 dB (a 101% improvement). However, the call capacity of the cell is reduced from 2610 to 369 calls per hour (a reduction of 86%).

In real life, the frequency reuse depends on the following factors:

1. The power of the transmitted signal,
2. The frequencies used,
3. The type of antenna,
4. The height of the antenna,
5. The weather,
6. The terrain over which the signal is sent.

2.9 Erlang and network capacity

Voice networks use the Erlang as a standard measure of capacity. The Erlang is a measure of total voice traffic in one hour, usually classified as the busy hour (BH), which is the 60-minute interval during a 24-hour period in which the traffic load is at a peak. One Erlang is equivalent to one user talking for one hour on one telephone. Consider that there are 45 calls in a one-hour period, and each call lasts for 3 minutes. This equates to 135 minutes of calls. In hours, this is 135/60 = 2.25 Erlangs. There are some variations in the Erlang model. The most common one is the Erlang-B, which is used to calculate how many lines are required to meet a given minimum call blocking, usually 2–3%, during this BH. For cellular systems, it is used to estimate capacity per cell at base stations. The Erlang B formula assumes that all calls that are blocked are cleared immediately. This means that if a user attempts to connect and cannot, they will not try again. An extended form of Erlang-B factors in that a certain percentage of users who are blocked will immediately try again. This is more applicable to the cellular environment, since if blocked, many users will immediately hit the redial button. The Erlang C model is the most complex since it assumes that a blocked call is placed in a queue until the system can handle it. Thus, for simulation purpose in this thesis we use Elang-B formula and the Markov chain.

CHAPTER 3

CDMA CELLULAR SYSTEM

3.1 Introduction

CDMA is an attractive proposition for increasing cellular system capacity in dense urban areas, due to its many inherent benefits like the ability to mitigate multipath fading and interference, universal frequency reuse, soft handoff capability, and the ability to exploit voice activity detection.

CDMA employs what is known as a wideband spread spectrum technology to carry digitized voice and data transmissions. As each voice is digitized at the mobile phone, it is assigned a unique digital code known as a Walsh code. This code assigned as a pseudorandom noise code that's generated by the digital radio. At this point, the voice transmission has been encoded. This code is then transmitted to the base station, where the voice is decoded, and regular call processing is completed. This process is analogous to each mobile speaking a different language and the base station interpreting its own separate code.

CDMA systems must use reverse channel power control; otherwise, the link performance will suffer from the near-far effect, a condition where the transmissions received from distance MSs experience excessive interference from distant and from nearby MSs. The IS-95 CDMA reverse link employs a fast closed-loop power control algorithm to combat variations in the received signal power due to path loss, shadowing, and fast envelope fading (at low Doppler frequencies). A large number of power control algorithms have been suggested in the literature**.** [3] Proposed a fast signal-to-interference ratio (SIR) based feed back power control algorithm that can mitigate both multi-path fading and shadowing.

Power control is also useful on the forward channel of CDMA systems for combating the corner effect, a condition where a MS experiences a decrease in received signal strength and an increase in multi-access interference as it exists in a cell corner. Various "power balancing" schemes have been proposed to balance the BS transmit power for each MS [8], [12].

3.2 Power Control in CDMA

Power control is a necessary element in all-mobile systems because of the battery life problem and safety reasons, but in CDMA systems, power control is essential because of the interference-limited nature of CDMA. In GSM slow (frequency approximately 2 Hz) power control is employed. In IS-95 fast power control with 800 Hz is supported in the uplink, but in the downlink, a relatively slow (approximately 50 Hz) power control loop controls the transmission power. The reasons for using power control are different in the uplink and downlink.

CDMA base stations control the power of all mobiles for interference reduction purposes. All mobile signals must arrive at the base station at the same power level so that the signals can be properly coded. Power control is a required operational parameter of CDMA digital system operations. For example, if a mobile station that is right next to the base station is transmitting at very high power, and a mobile station 10 mile (16Km) away from the base station is transmitting at very low power, the power of the mobile next to the base station is throttled down to a given level while the power of the mobile 16Km away from the base station is raised to a given level. Power control is necessary to maintain system capacity. Proper control of power in CDMA system results in reducing power costs at the BS, as well as increased battery life in the mobile phone system.

3.3 Types and analysis of CDMA

CDMA is part of a general field of communications known as spread spectrum. Spread spectrum describes any system in which a signal is modulated so that its energy is spread across a frequency range that is greater than that of the original signal. In CDMA, it is the codes that perform this spreading function, and also allow multiple users to be separated at the receiver. The two most common forms of CDMA are:

3.3.1 Frequency hopping (FH): with FH, the transmitted signal on a certain carrier frequency is changed after a certain time interval, known as the hopping rate. This has the effect of ‘hopping’ the signal around different frequencies across a certain wide frequency range. At a particular instant in time, the signal is transmitted on a certain frequency, and the code defines this frequency. This system is used for many communications systems, including the 802.11b wireless LAN standard and Bluetooth. These systems both use the unlicensed 2.4 GHz band, which is inherently subject to interference due to the large number of radio systems sharing that band, not to mention the effects of microwave ovens. By using a large number of frequencies, the effect of interference on the signal is substantially reduced, since the interference will tend to be concentrated in a particular narrow frequency range. FH is also employed in military communications, where the secrecy of the code and the rejection of interference in the form of a jamming signal make it extremely effective.

3.3.2 Direct sequence (DS): with DS, a binary modulated signal is ‘directly’ multiplied by a code. The code is a pseudo-random sequence of ±1, where the bit rate of the code is higher than the rate of the signal, usually considerably higher. This has the effect of spreading the signal to a wideband. At the receiver, the same code is used to extract the original signal from the incoming wideband signal. A bit of the code is referred to as a chip, and the defining parameter for such a system is the chip rate. The chip rate of Is-95 CDMA is 1.2288 M chips/s at bandwidth of 1.25MHz. DS-CDMA is the form used for the air interface in Universal mobile telephone system (UMTS), known as wideband CDMA (WCDMA), with a chip rate of 3.84 M chip/s.

3.3.2.1 DS-CDMA signal spreading

According to information theory, as the frequency spectrum a signal occupies is expanded, the overall power level decreases. In CDMA, the user signals are spread up to a wideband by multiplication by a code. Consider a narrowband signal, say, for example, a voice call. When viewed in the frequency spectrum, it occupies some frequency and has some power level, as illustrated in figure 3.1a). Once the frequency is spread across a wideband, the total power level of this signal is substantially reduced.

Now consider that another user has the same procedure performed on it and is also spread to the same wideband. The total system power is increased by a small amount as the two users are transmitted at the same time. Therefore, each new user entering the system will cause the power of the wideband to increase. The regenerated signal needs to be retrieved with enough power that it can be perceived above the level of the remaining spread signals. That is, it needs to be of a sufficient strength, or margin, above the rest of the signals so that the signal can be accurately interpreted. Considering this as a signal to interference ratio (SIR), or carrier to interference (C/I) ratio, the noise affecting one signal is the remaining spread signals that are transmitting at that frequency. This SIR is classified in CDMA as E_b/N_0. Literally, this means the energy per bit, E_b, divided by the noise spectral density **(**the Noise Power to the Bandwidth of the signal**),** N_0. However, it is really a measure of the minimum required level the signal should be above the noise, which is contributed by the other transmitting users. For mobile device measurements of the quality of the signals from the network, it uses a pilot channel, which is broadcast by each cell. The mobile device measures Ec/I_o, the energy level of this pilot channel, E_c, compared to the total energy received, I_0. Another important characteristic is the rejection of unwanted narrowband noise signals. If a wideband signal is affected by a narrowband noise signal, then, the de-spreading operation while extracting the wanted signal will in turn spread the narrowband noise to the wideband, and reduce its power level.

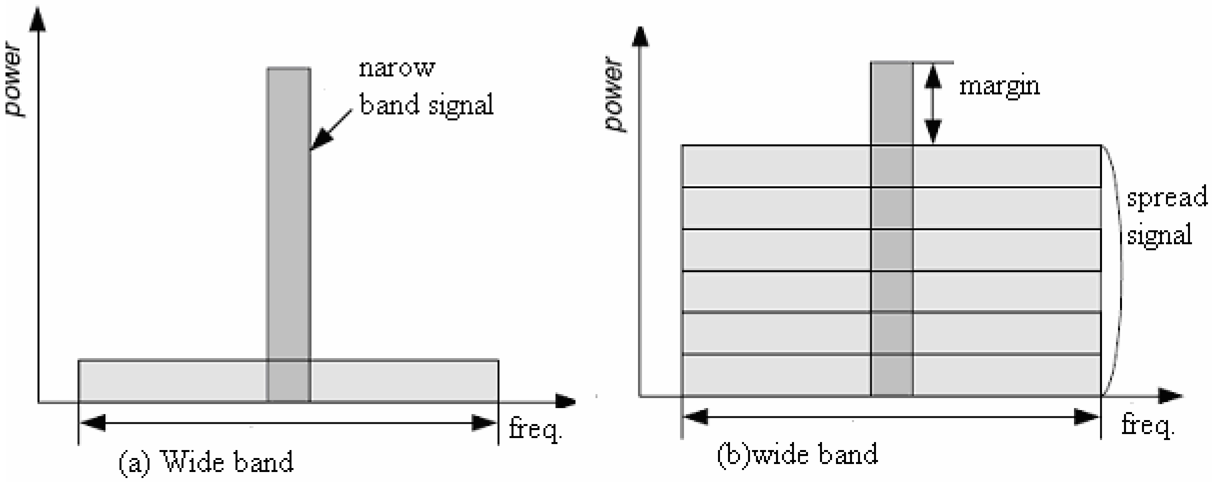


Figure 3.1 Signal spreading

The rejection of the interference effects of wideband noise from other users is the role of convolution coding. This implies that the important factor that will affect how easily signals can be interpreted after they are de-spreading is the power level in the system. The lower the power that the original signals are transmitted with, the lower the noise in the system. It is therefore essential that each user in the system transmit with an optimum power level to reach the receiver with its required power level. If the power level is too high for one user, then that user will generate noise, which in turn affects the performance of all the other users. If there is too little power, then the signal, which reaches the receiver, is too low, and it cannot be accurately 'heard'. An analogy to this idea is a party at which all the guests are talking at the same time at some point, with too many guests, the overall noise level rises to a point where none of the guests' individual conversations can be heard clearly.

There are two solutions to the problem of noise levels. First, an admission control policy is required that monitors the number of users and the noise level, and once it reaches some maximum tolerable level, refuses admission of further users. In a cellular system, such admission control needs to be considered not only for one cell, but also for the effects that noise levels within that cell have on neighboring cells. In the party analogy, the effect on the neighbors should be considered. In conjunction with admission Control, load control should also be implemented to try to encourage some users to leave a cell, which has too many users, and consequently in which the noise level is too high. The second solution is to implement power control. Each user needs to transmit with just enough power to provide a clear signal at the receiver above the noise floor. This should be maintained regardless of where the users are located with respect to the receiver, and how fast they are moving. Power control needs to be performed frequently to ensure that each user is transmitting at an optimum level.

In direct sequence spread spectrum the signal is spread over a large frequency range. For example, a telephone speech conversation, which has a bandwidth of 3.1 kHz, would be spread over 1.25 MHz when transferred over the IS-95 CDMA system. The bandwidth has increased but the information transfer rate has remained constant. This is achieved by using a technique, which introduces a code to represent a symbol of the transmitted message. A code is made up of a number of binary digits (bits), each one of which is referred to as a chip. The whole code consisting of all of the chips representing a symbol takes up the same time span as the original symbol. Thus if a single symbol is represented by a code of 8 chips, the chip rate must be 8 times the symbol rate. For example, if the symbol rate were 16 kbps then the chip rate (assuming 8 chips per symbol) would be 128 kbps. This higher data rate requires a larger frequency range (bandwidth). The ratio of the original (unspread) signal to the spread signal is referred to as the spreading factor and is defined as: Spreading factor (SF) = chip rate/symbol rate

3.4 Capacity of cellular CDMA

CDMA cellular systems typically employ universal frequency reuse, where the bandwidth is shared by all the cells and transmissions are distinguished through the assignment of unique spreading sequences as discussed above section. For such systems, multiple access interference from neighboring cells must be carefully accounted for. The propagation path loss associated with these interfering signals is relatively small compared to those found in narrow-band and mid-band TDMA systems that employ frequency reuse plans.

With cellular CDMA systems, any technique that reduces multiple-access interference translates into capacity gain. Since cellular CDMA systems use speech coding, the multiple-access interference can be reduced by using voice activity detection along with variable rate speech transmission. This technique reduces the rate of speech coder when silent periods are detected in the speech waveform. Voice activity detection has often been cited as an advantage of CDMA systems over TDMA systems. However, TDMA systems can also benefit from voice activity detection, a continuous transmission, through a reduction in the level of co-channel interference.

Cell sectoring is another very effective method for reducing multiple-access interference, where each cell is sectored by using directional antennas. With 120^{o} cell sectors, multiple access interference on the reverse channel will only arise from MSs. Likewise; multiple-access interference on the forward channel is generated by the BSs that are transmitting to MSs. In either case, 120^{0} cell sectoring reduces the multiple-access interference by roughly a factor of three (on average); we say on average because the MSs are assumed to be randomly distributed throughout the plane. Further improvements can be gained by using simple switched beam smart antenna systems with 30^{0} or15^{o} sectors. A straightforward application of these antenna systems reduces the multiple access interference by a factor of 12 and 24, respectively, over a system using omni-directional antennas.

Our analysis of cellular CDMA starts with a cellular layout described by a uniform plane of hexagonal cells of radius R. Each cell contains a centrally located BS with 120^{0} cell sectors. It is further assumed that the MSs are uniformly distributed throughout the system area with a density of K MSs per cell sector. For hexagonal cells of radius R, this yields a subscriber density of $\rho = \frac{2K}{3\sqrt{3R^2}}$ per unit area.

The effects of voice activity detection can be modeled by assuming that each transmitter is independently active with probability p, so that the number of active transmitters in each cell has a (K, p) binomial distribution.

3.5 Basic CDMA uplink capacity

A good starting point for CDMA system capacity analysis is to derive the relation between required E_b/N_0 and the amount of simultaneously transmitting users in a cell [9]. Consider a case of N users simultaneously transmitting, and the receiver demodulation processes a composite signal containing the desired signal having power S and (N-1) interfering signals each also having power S. Thus we assume ideal power control. At each receiver input, the signal-to-noise power ratio can be expressed as

$$SNR = \frac{S}{(N-1)S} = \frac{1}{N-1} \tag{3.1}$$

After dispreading process (processing gain G) signal-to-noise ratio becomes:

$$\frac{E_b}{N_o} = \frac{G}{N-1} \tag{3.2}$$

where $G = \frac{W}{R}$ is the processing gain, W is the total bandwidth of the CDMA signal and R is information bit rate. After including Gaussian noise to equation (3.1), Equation (3.2) changes slightly:

$$\frac{E_b}{N_o} = \frac{G}{(N-1) + \alpha/S} \tag{3.3}$$

Solving Equation 3.3 for N we get:

$$N = 1 + \frac{W/R}{E_b/N_0} - \alpha/S \tag{3.4}$$

Equation 3.4 gives CDMA capacity as [users/carrier], where each user has information bit rate R [b/s]. Carrier bandwidth W is given in hertz [Hz], required $\frac{E_b}{N_o}$ is in linear scale and α and S are given in watts [W]. It is straightforward calculation to give the capacity in [users/MHz] or [kbits/MHz]. It is important to note that several key assumptions are made while equation 3.4 is derived.

1. Isolated cell, no inter cell interference
2. Perfect power control, variation of channel fading are erased by power control
3. No maximum power limit
4. No code limit

Thus equation 3.4 is the upper bound for uplink system capacity.

3.6 Voice activity

Normally during a telephone conversation while one party is speaking the other is listening. This phenomenon can be monitored by the cellular system and the power can be reduced during the silent periods. Here CDMA, e.g. IS-95 has a clear advantage over GSM, because in GSM even if transmitting power is turned off connection occupies same amount of radio resources. This is not the case in CDMA, because there are more codes per carrier than a carrier can use simultaneously. According to measurement active speech ratio of each party is roughly 3/8, thus 25% of time both parties are silent simultaneously. Theoretically, voice activity factor $\varpi = {}^{3}\!/_{8}$ can be easily added to Equation (3.3).

$$\frac{E_b}{N_o} = \frac{G}{(N-1)\varpi + {}^{\alpha}\!/_{S}} \tag{3.5}$$

This would increase the capacity up to 8/3, if system is interference limited, $a << S$. This analysis however requires that N is large, in order to have the ratio of simultaneously active users around 3/8.

3.7 CDMA Architecture and Operations

Each CDMA base station can use the same 1.25MHz bandwidth at the same time. The only change between each block of 1.25MHz spectrum is the pseudorandom Walsh noise code. There are a maximum of 64 allowable pseudorandom Walsh noise codes per 1.25MHz bandwidth in the CDMA modulation scheme.

Prior to the widespread deployment of CDMA systems, which were mainly spurred by the broadband personal communication system (PCS) carriers, there were concerns that CDMA systems could not handle heavy traffic loads. This caused concerns in the industry that CDMA systems couldn’t handle a huge acquisition of customers in a short period of time. Nevertheless, CDMA has many distinct attributes that make it attractive to cellular and PCS providers, as listed in table 3.1.

Table 3.1 Specification for IS-95 CDMA

Uplink frequencies	824-849 MHz (Cellular) 1850-1910 MHz (PCS)
Downlink frequencies	869-894 MHz (Cellular) 1930-1990 MHz (PCS)
Modulation	Quadrature Phase shift keying (OPSK)
Carrier separation	1.25 MHz
Channel data rate	1.2288 Mchips per second
Voice channels per carrier	64

Theoretically, there can be 1.25MHz (41 AMPS channels) plus 18 guard channels (9 below and 9 above) in one IS-95 CDMA channel [6]. Some PCS carriers are successfully using eleven 1.25MHz carriers separation per cell. Today, cellular carriers are using two to four carriers per cell. Theoretically, one carrier frequency of CDMA can handle 22 to 40 voice calls [6]. However, today both PCS and cellular carriers obtain an average 12-14 call per carrier. In contrast to the AMPS standard, which typically employs an N=7 reuse format, CDMA employs an N=1 “reuse” format because identical sets of 1.25MHz bandwidth (spectrum) can be assigned at every base station in a CDMA system. CDMA is a spread spectrum technology because the voice transmissions and the conversations are all spread over the entire broad strip of the 1.25MHz bandwidth.

3.8 CDMA Interference Analysis

CDMA systems are interference-limited and so interference evaluation is one of the fundamental procedures for analyzing the CDMA systems. The total interference experienced by a mobile is composed of two parts: **intra-cell interference** and **inter-cell interference**.

In the uplink, to a certain mobile, the intra-cell interference comes from all the other mobiles served by the same BS. The inter-cell interference is composed of all the signals received from all the mobiles in other cells other than the mobile's serving cell, as shown in Figure 3.2. Therefore, in the uplink, the interference experienced by a certain mobile is related to the load distribution within the network, but not related to the mobile's own location.

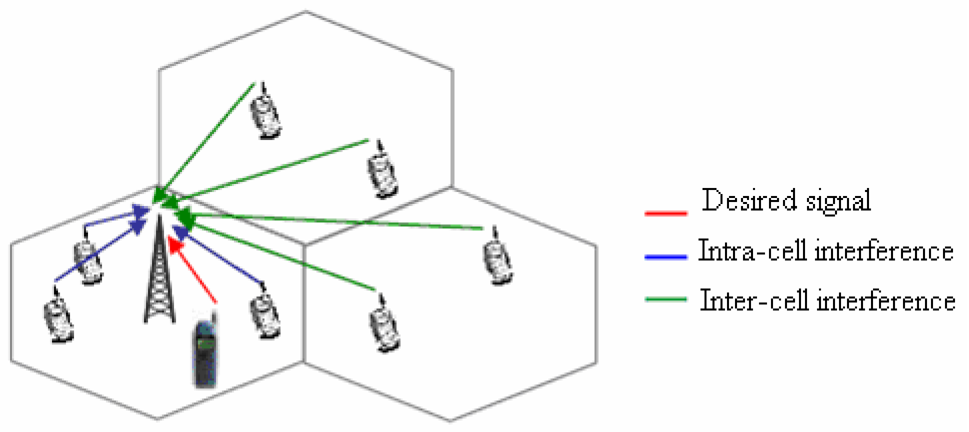


Figure 3.2 Uplink interference

In the downlink, as shown in Figure 3.3, the intra-cell interference to a certain mobile comes from its serving BS: this interference is caused by the partial loss of the orthogonality among the users due to the multi-path effect. The intra-cell interference actually includes part of the power for common control channels and the power for the downlink traffic channels for other users in the same cell. The inter-cell interference is the power received by the mobile from all the other BSs except for its own serving BS.

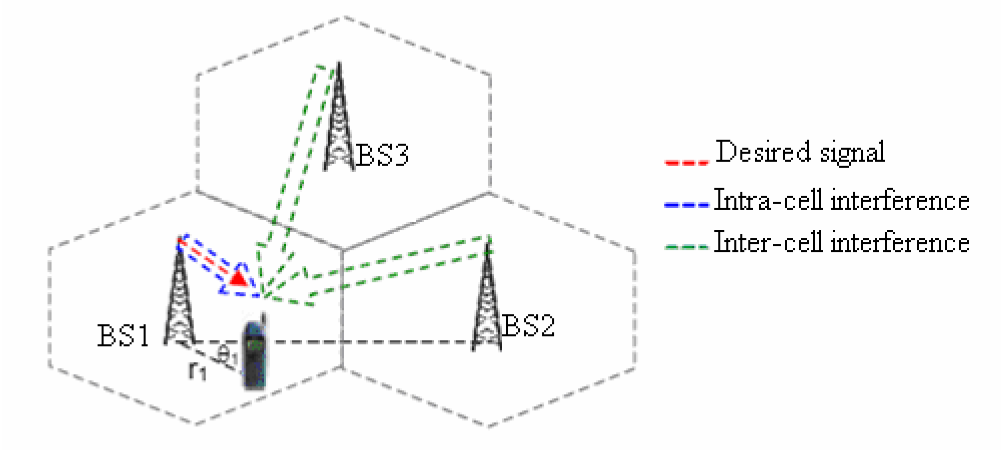


Figure 3.3 Downlink interference

Because the interference sources are fixed BSs in the downlink direction, to a certain mobile, the downlink interference is inevitably linked to the mobile’s location.

CHAPTER 4

HANDOFF PERFORMANCE ANALYSIS

4.1 Introduction

Mobility is the most important feature of a wireless cellular communication system. Usually, continuous service is achieved by supporting handoff (or handover) from one cell to another. Handoff is the process of changing the channel (frequency, time slot, spreading code, or combination of them) associated with the current connection while a call is in progress. It is often initiated either by crossing a cell boundary or by deterioration in quality of the signal in the current channel. Handoff is divided into two broad categories: hard and soft handoffs. They are also characterized by “break before make” and “make before break”, respectively. In hard handoffs, current resources are released before new resources are used; in soft handoffs, both existing and new resources are used during the handoff process. Poorly designed handoff schemes tend to generate very heavy signaling traffic and, thereby, a dramatic decrease in QoS. In this chapter, a handoff is assumed to occur only at the cell boundary. The reason why handoffs are critical in cellular communication systems is that neighboring cells are always using a disjoint subset of frequency bands, so negotiations must take place between the MSs, the current serving BS and the next potential BS. Other related issues, such as decision-making and priority strategies during overloading, might influence the overall performance.

In the next section, we introduce different types of possible handoffs. In Section 4.3 and 4.4**,** principles and operations of soft handoffs are described. Handoff initiation and procedures measurements are briefly described in sections 4.8 and 4.9 respectively. Decision algorithms in handoffs and channel assignment strategies are discussed in this chapter under sections 4.10 and 4.11 respectively. Finally, some cellular system deployment scenarios under section 4.12 are seen in brief.

4.2. Types of Handoffs

Handoffs are broadly classified into two categories: hard and soft handoffs. Usually, the soft handoff can be further divided into three different types: Inter-sector or softer handoff, Inter-cell or soft handoff and Soft-softer handoff.

4.2.1 Hard handoffs

A hard handoff is essentially a "break before make" connection. Under the control of the MSC, the BS hands off the MS's call to another cell and then drop the call. In a hard handoff, the link to the prior BS is terminated before or as the user is transferred to the new cell's BS; the MS is linked to no more than one BS at any given time. Hard handoff is primarily used in FDMA and TDMA, where different frequency ranges are used in adjacent channels in order to minimize channel interference. So when the MS moves from one BS to another BS, it becomes impossible for it to communicate with both BSs (since different frequencies are used). Figure 4.1 illustrates hard handoff between the MS and the BSs.

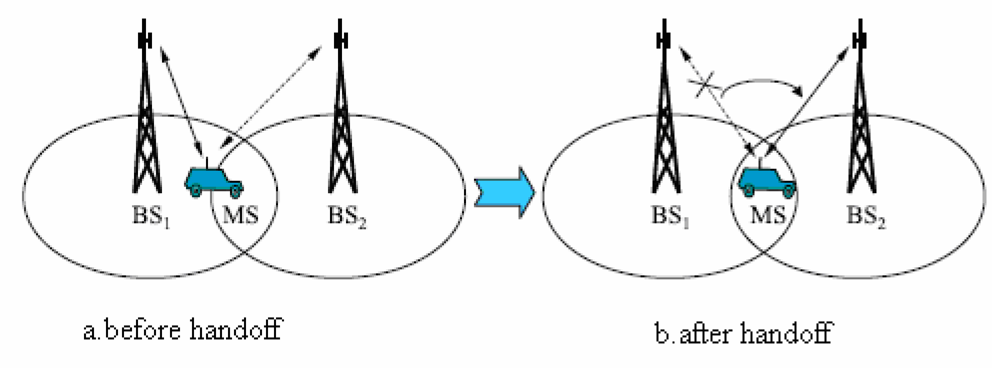


Figure 4.1 Hard handoff between MS and BSs

Scenarios for hard handoff include

- Handoff between base stations or sectors with different CDMA carriers
- Change from one pilot to another pilot without first being in soft handoff with the new pilot (disjoint active sets)
- Handoff from CDMA to analog, and analog to CDMA
- Change of frame offset assignment. CDMA traffic frames are 20 ms long.

The start of frames in a particular traffic channel can be at 0 time in reference to a system or it can be offset by up to 20 ms (allowed in IS-95). This is known as the frame offset. CDMA traffic channels are assigned different frame offset to avoid congestion. The frame offset for a particular traffic channel is communicated to the mobile. Both forward and reverse links use this offset. A change in offset assignment will disrupt the link. During soft handoff the new base station must allocate the same frame offset to the mobile as assigned by the primary base station. If that particular frame offset is not available, a hard handoff may be required. Frame offset is a network resource and can be used up.

4.2.2 Soft Handoff in CDMA

“Soft” call handoffs are different from “hard” call handoffs in that a soft handoff allows both the original cell and new cells to temporarily service a call during the handoff transition. The handoff transition is from the original cell carrying the call to one or more new cells and the final new cell. With soft handoff, the call is actually carried by two or more cells simultaneously. In this regard, the analog system (FDMA), digital system (TDMA) and GSM digital systems as well provides a “break-before-make” switching function in relation to handoff call. In contrast, the CDMA based soft handoff system provides a “make-before break” switching function with relation to call handoff. Not only does soft handoff greatly minimize the probability of a dropped call, but it also makes the handoff virtually undetectable to the user. Soft handoffs are directed by the mobile telephone. Usually, soft handoff can be categorized as follows.

4.2.2.1. Inter-sector or softer handoff.

The mobile communicates with two sectors of the same cell as shown in figure 4.2. A RAKE receiver at the base station combines the best versions of the voice frame from the diversity antennas of the two sectors into a single traffic frame.

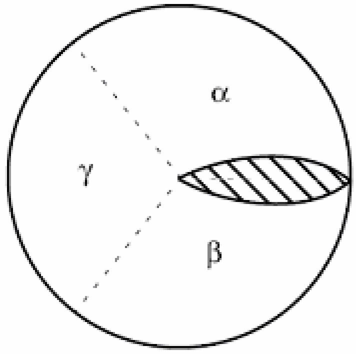


Figure 4.2 Softer handoff

4.2.2.2 Inter-cell or soft handoff.

The mobile communicates with two or three sectors of different cells as in figure 4.3. The base station that has the direct control of call processing during handoff is referred to as the primary BS.

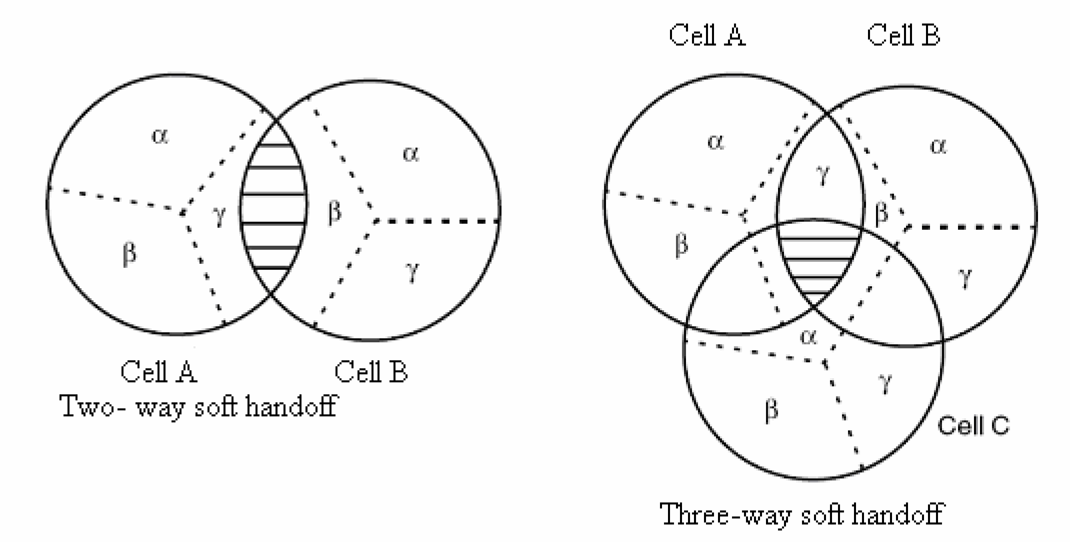


Figure 4.3 Inter-cell handoff

The primary base station can initiate the forward control message. Other base stations that do not have control over call processing are called the secondary base stations. Soft handoff ends when either the primary or secondary base station is dropped. If the primary base station is dropped, the secondary base station becomes the new primary for this call. A three-way soft handoff may end by first dropping one of the base stations and becoming a two-way soft handoff. The base stations involved to coordinate handoff by exchanging information via Signaling System 7 (SS7) (architecture for performing out-of-band signaling in support of the call-establishment, billing, routing, and information-exchange functions of the public switched telephone network (PSTN)). It identifies functions to be performed by a signaling-system network and a protocol to enable their performance. The Inter-cell handoff uses considerably more network resources than the Inter-sector handoff.

4.2.2.3 Soft-softer handoff

The mobile communicates with two sectors of one cell and one sector of another cell. Network resources required for this type of handoff include the resources for a two-way soft handoff between cell A and B plus the resources for a softer handoff at cell B. Figure 4.4 describes this process.

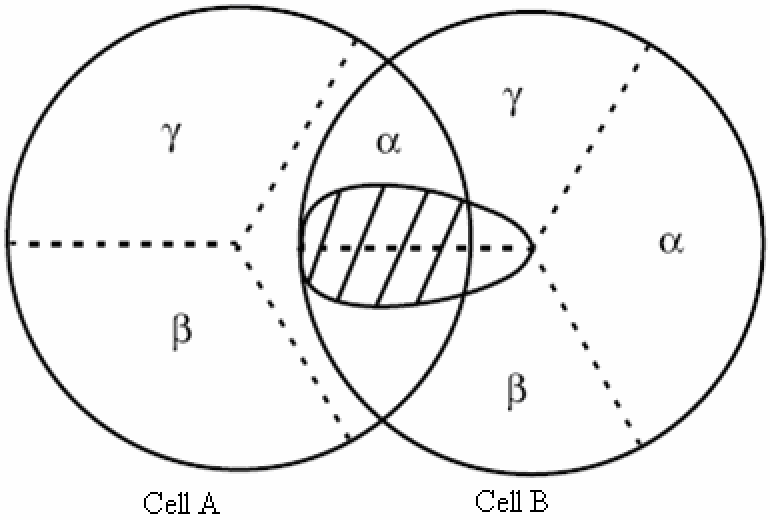


Figure 4.4 soft-softer Handoff

4.3 Principles of soft handoff

Soft handoff is different from the traditional hard handoff process. With hard handoff, a definite decision is made on whether to handoff or not and the mobile only communicates with one BS at a time. With soft handoff, a conditional decision is made on whether to handoff or not. Depending on the changes in pilot signal strength from the two or more BSs involved, a hard decision will eventually be made to communicate with only one. This normally happens after it is clear that the signal coming from one BS is considerably stronger than those coming from the others. In the interim period of soft handoff, the mobile communicates simultaneously with all the BSs in the active set. The active set is the list of cells that are presently having connections with the mobile. Figure 4.5 shows the basic process of hard and soft handoff (2-way case). Assuming there is a mobile terminal inside the car moving from cell 1 to cell 2, BS1 is the mobile’s original serving BS. While moving, the mobile continuously measures the pilot signal strength received from the nearby BSs. With hard handoff shown as (a) in Figure 4.5, the trigger of the handoff can be simply described as: If (pilot_ ${E_c}/{I_o}$) of cell 2 - (pilot_ ${E_c}/{I_o}$) of cell 1 > d and BS1 is the serving BS, Handoff to BS2 otherwise do not handoff. Where (pilot_${E_c}/{I_o}$) of cell 1 and (pilot_E_c/I_o) of cell 2 are the received pilot E_c/I_o from BS1 and BS2 respectively, and d is the hysteresis margin.

The reason for introducing the hysteresis margin in the hard handoff algorithm is to avoid a “ping-pong effect”, the phenomenon that when a mobile moves in and out of cell’s boundary, frequent hard handoff occurs. Apart from the mobility of the mobile, fading effects of the radio channel can also make the “ping-pong” effect more serious. By introducing the hysteresis margin, the “ping-pong” effect is mitigated because the mobile does not handoff immediately to the better BS. The bigger the margin, the less the “ping-pong” effect. However, a big margin means more delay. Moreover, the mobile causes extra interference to neighboring cells due to the poor quality link during the delay. Therefore, to hard handoff, the value of the hysteresis margin is fairly important. When hard handoff occurs, the original traffic link with BS1 is dropped before the setting up of the new link with BS2 so hard handoff is a process of “break before make”. In the case of soft handoff, shown as (b) in Figure 4.5, before (pilot_ E_c/I_o) of cell 2 goes beyond (pilot_ E_c/I_o) of cell 1, as long as the soft handoff trigger condition is fulfilled, the mobile enters the soft handoff state and a new link is set up. Before BS1 is dropped (handoff dropping condition is fulfilled), the mobile communicates with both BS1 and BS2 simultaneously. Therefore, unlike hard handoff, soft handoff is a process of “make before break”. So far, several algorithms [4] have been proposed to support soft handoff and different criteria are used in different algorithms. The soft handoff process is not the same in the different transmission directions. Figure 4.6 illustrates this. In the uplink, the mobile transmits the signals to the air through its omni-directional antenna. The two BSs in the active set can receive the signals simultaneously because of the frequency reuse factor of one in CDMA systems. Then the signals are passed forward to the Radio network controller (RNC) for selection combining. The better frame is selected and the other is discarded. Therefore, in the uplink, there is no extra channel needed to support soft handoff.

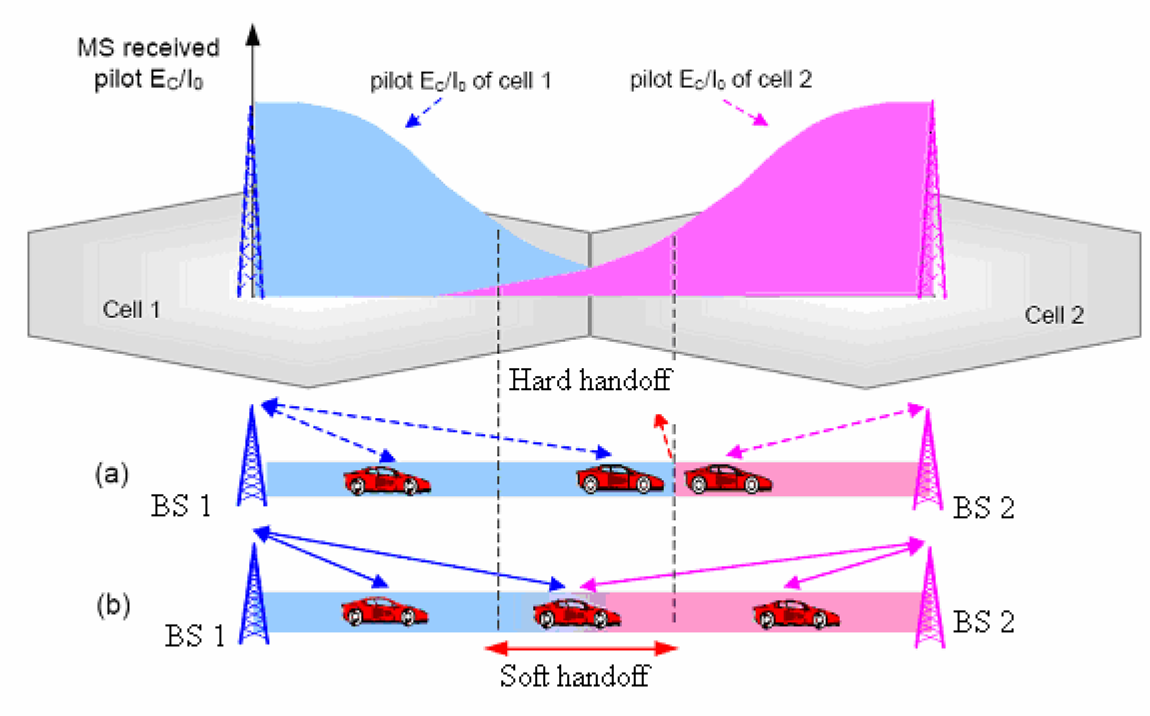


Figure 4.5 Comparison between hard and soft handoff

In the downlink, the same signals are transmitted through both BSs and the mobile can coherently combine the signals from different BSs since it sees them as just additional multi-path components. To support soft handoff in the downlink, at least one extra downlink channel (2-way soft handoff) is needed. This extra downlink channel acts to other users like additional interference in the air interface.

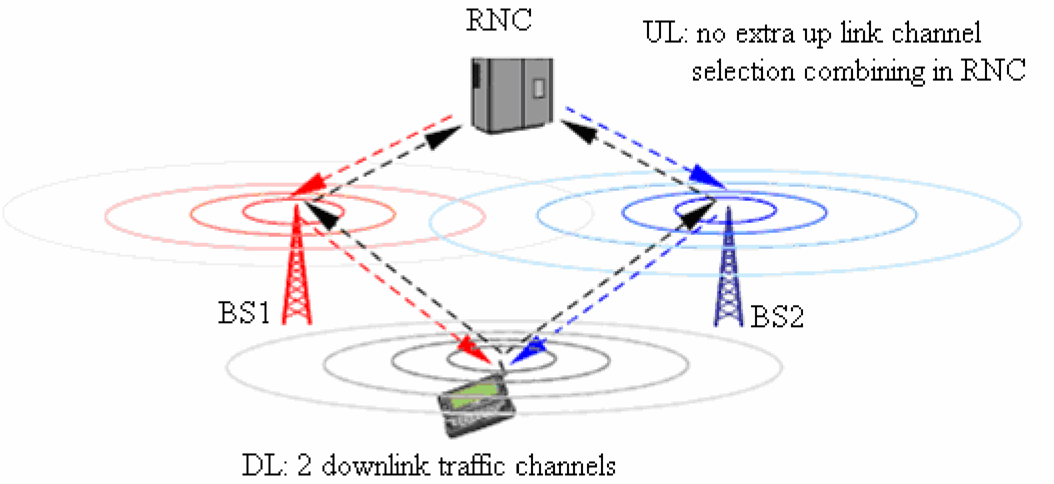


Figure 4.6 Principles of soft handoff (2-way case)

Thus, to support soft handoff in the downlink, more resource is required. As a result, in the downlink direction, the performance of the soft handoff depends on the trade-off between the macro diversity gain and the extra resource consumption.

4.4 Soft Handoff Operations

The sequence of events in soft handoff is as follows:

- After a mobile call is initiated, the mobile station continues to scan the neighboring cells to determine if the signal from another cell becomes stronger than that of the original cell.
- When this happens, the mobile station knows that the call has entered a new cell's coverage area and that a handoff can be initiated.
- The mobile station transmits a control message to the mobile telephone switching Office (MTSO), which states that the mobile is receiving a stronger signal from the new cell site, and the mobile identifies that new cell site.
- The MTSO initiates the handoff by establishing a link to the mobile station through the new cell while maintaining the old link.
- While the mobile station is located in the transition region between the two cell sites, the call is supported by the communication through both cells. This eliminates the ping-pong effect of repeated requests to hand the call back and forth between two cell sites.
- The original cell site will discontinue handling the call only when the mobile station is firmly established in the new cell.

4.5 Pilot Sets

The term pilot refers to a pilot channel identified by a pilot sequence offset and a frequency assignment. A pilot is associated with the forward traffic channels in the same forward CDMA link. Each pilot is assigned a different offset of the same short PN code. The mobile search for Pilots is facilitated by the fact that the offsets are the integer multiples of a known time delay (64 chips offset between adjacent pilots). All pilots in a pilot set have the same CDMA frequency assignment. The pilots identified by the mobile, as well as other pilots specified by the serving sectors (neighbors of the serving base stations/sectors), are continuously categorized by the mobile into four groups.

•**Active set.** It contains the pilots associated with the forward traffic channels (Walsh Codes) assigned to the mobile. Because there are three fingers of the RAKE receiver in the mobile, the active set size is a maximum of three pilots. IS-95 CDMA allows up to six pilots in the active set, with two pilots sharing one RAKE finger. The base station informs the mobile about the contents of the active set by using the Channel Assignment message and/or the Handoff Direction message (HDM). An active pilot is a pilot whose paging or traffic channels are actually being monitored or used.

•**Candidate set.** This set contains the pilots that are not currently in the active set. However, these pilots have been received with sufficient signal strength to indicate that the associated forward traffic channels could be successfully demodulated. Maximum size of the candidate set is six pilots.

•**Neighbor set.** This set contains neighbor pilots that are not currently in the active or the candidate set, and are expected candidate for handoff. Neighbors of a pilot are all the sectors/ cells that are in its close vicinity. The initial neighbor list is sent to the mobile in the System Parameter message on the paging channel. The maximum size of the neighbor set is 20.

•**Remaining set.** This set contains all possible pilots in the current system, excluding pilots in the active, candidate, or neighbor sets. While searching for a pilot, the mobile is not limited to the exact offset of the short pseudo noise (PN) code. The short PN offsets associated with various multi-path components are located a few chips away from the direct path offset. In other words, the multi-path components arrive a few chips later relative to the direct path component. The mobile uses the search window for each pilot of the active and candidate set, around the earliest arriving multi-path component of the pilot. Search window sizes are defined in number of short PN chips. The mobile should center the search window for each pilot of the neighbor set and the remaining set on the pilot's PN offset using the mobile time reference.

4.6 Handoff Parameters

There are four handoff parameters. T_add, T_comp, and T_drop relate to the measurement of pilot or energy per chip to total received power (E_c/I_t) and T_tdrop is a timer. Whenever the strength of a pilot in the active set falls below a value of T_drop, the mobile starts a timer. If the pilot strength goes back above T_drop, the timer is reset; otherwise the timer expires when a time T_TDROP has elapsed since the pilot strength has fallen below T_drop. Mobile maintains a handoff drop timer for each pilot in the active set and in the candidate set.

4.6.1 Pilot Detection Threshold (T_ADD)

Any pilot that is strong but is not in the HDM is a source of interference. This pilot must be immediately moved to the active set for handoff to avoid voice degradation or a possible dropped call. T_add affects the percentage of mobiles in handoff. It should be low enough to quickly add useful pilots and high enough to avoid false alarms due to noise.

4.6.2 Comparison Threshold (T_COMP)

It has effect on handoff percentage similar to T_add. It should be low for faster handoff and should be high to avoid false alarms.

4.6.3 Pilot Drop Threshold (T_DROP)

It affects the percentage of mobiles in handoff. It should be low enough to avoid dropping a good pilot that goes into a short fade. It should be high enough not to quickly remove useful pilots in the active or candidate set. The value of T_drop should be carefully selected by considering the values of T_add and T_tdrop.

4.6.4 Drop Timer Threshold (T_TDROP)

It should be greater than the time required to establish handoff. T_tdrop should be small enough not to quickly remove useful pilots. A large value of T_tdrop may be used to force a mobile to continue in soft handoff in a weak coverage area. Table 4.1 provides typical values of the handoff parameters.

4.7 Handoff Messages

Handoff messages in IS-95 are a sequence of Pilot Strength Measurement Messages (PSMM), HDM, Handoff Completion message (HCM), and Neighbor List Update message (NLUM). The mobile detects pilot strength (E_c / I_t) and sends the PSMM to the base station. The base station allocates the forward traffic channel and sends the HDM to the mobile. On receiving the HDM, the mobile starts demodulation of the new traffic channel and sends HCM to the base station.

The PSMM contains the following information for each of the pilot signals received by the mobile:

- Estimated E_c/I_0
- Arrival time
- Handoff drop timer

The HDM contains the following information:

- HDM sequence number
- CDMA channel frequency assignment
- Active set (now has old and new pilots [PN offsets])
- Walsh code associated with each pilot in the active set

Table 4.1 Handoff parameter values

Parameter	**Range**	**Suggested value**
T-ADD	-31.5 to 0 dB	-13 db
T-COMP	0 to 7.5 dB	2.5 dB
T-DROP	-31.5 to 0 dB	-15 dB
T-TDROP	0 to 15 seconds	2 seconds

- Window size for the active and candidate sets
- Handoff parameters (T_add, T_drop, T_comp, T_tdrop).

The HCM contains the following information:

- A positive acknowledgment
- PN offset of each pilot in the active set

The base station sends the NLUM. It contains the latest composite neighbor list for the pilots in the active set. The mobile continuously tracks the signal strength for all pilots in the system. The signal strength of each pilot is compared with the various thresholds such as the pilot detection threshold, the pilot drop threshold, the comparison threshold, and the drop timer threshold. A pilot is moved from one set to another depending on its signal strength relative to the thresholds

1. Pilot strength exceeds T_add. Mobile sends a PSMM and transfers pilot to the candidate set.
2. Base station sends an HDM to the mobile with the pilot to be added in active set.
3. Mobile receives HDM and acquires the new traffic channel. Pilot goes into the active set and

mobile sends HCM to the base station.

4. Pilot strength drops below T_drop; mobile starts the handoff drop timer.

4.8 Handoff Initiation algorithms

It is assumed that the signal is averaged over time, so that rapid fluctuations due to the multi path nature of the radio environment can be eliminated. Figure 4.7 shows a MS moving from one BS (BS1) to another (BS2). The mean signal strength of BS1 decreases as the MS moves away from it. Similarly, the mean signal strength of BS2 increases as the MS approaches it. This figure is used to explain various approaches described in the following subsection.

4.8.1 Relative Signal Strength

This method selects the strongest received BS at all times. The decision is based on a mean measurement of the received signal. In Figure 4.7, the handoff would occur at position A. This method is observed to provoke too many unnecessary handoffs, even when the signal of the current BS is still at an acceptable level.

4.8.2 Relative Signal Strength with Threshold

This method allows a MS to hand off only if the current signal is sufficiently weak (less than threshold) and the other is the stronger of the two. The effect of the threshold depends on its relative value as compared to the signal strengths of the two BSs at the point at which they are equal. If the threshold is higher than this value, say *T*1 in Figure 4.7, this scheme performs exactly like the relative signal strength scheme, so the handoff occurs at position A. If the threshold is lower than this value, say *T*2 in Figure 4.7, the MS would delay handoff until the current signal level crosses the threshold at position B. In the case of *T*3, the delay may be so long that the MS drifts too far into the new cell. This reduces the quality of the communication link from B*S*1 and may result in a dropped call. In addition, this results in additional interference to co channel users. Thus, this scheme may create overlapping cell coverage areas. A threshold is not used alone in actual practice because its effectiveness depends on prior knowledge of the crossover signal strength between the current and candidate BSs.

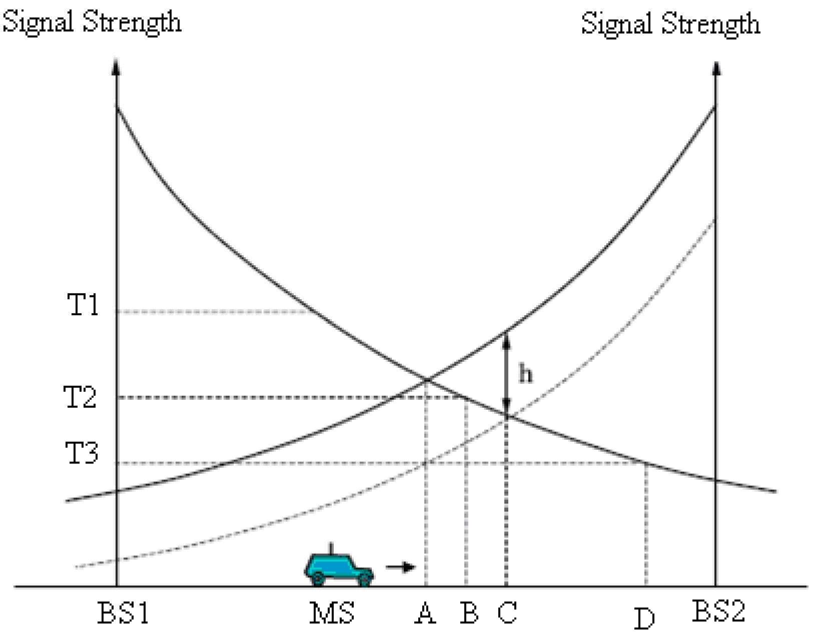


Figure 4.7 Signal strength and hysteresis between two adjacent BSs for potential handoff.

4.8.3 Relative Signal Strength with Hysteresis

This scheme allows a user to hand off only if the new BS is sufficiently stronger (by a hysteresis margin, *h* in Figure 4.7) than the current one. In this case, the handoff would occur at point C. This technique prevents the so-called ping-pong effect, the repeated handoff between two BSs caused by rapid fluctuations in the received signal strengths from both BSs. The first handoff, however, may be unnecessary if the serving BS is sufficiently strong.

4.8.4 Relative Signal Strength with Hysteresis and Threshold

This scheme hands a MS over to a new BS only if the current signal level drops below a threshold and the target BS is stronger than the current one by a given hysteresis margin. In Figure 4.7, the handoff would occur at point D if the threshold is *T*3.

4.9 Handoff measurements and procedures

The handoff procedure can be divided into three phases: measurement, decision and execution phases as illustrated in Figure 4.8. In the handoff measurement phase, the necessary information needed to make the handoff decision is measured. Typical downlink measurements performed by the mobile are the E_c/I_o of the Common Pilot Channel (CPICH) of its serving cell and neighboring cells. For certain types of handoff, other measurements are needed as well. For example, in a wide band CDMA, the relative timing information between the cells needs to be measured in order to adjust the transmission timing in soft handoff to allow coherent combining in the Rake receiver.

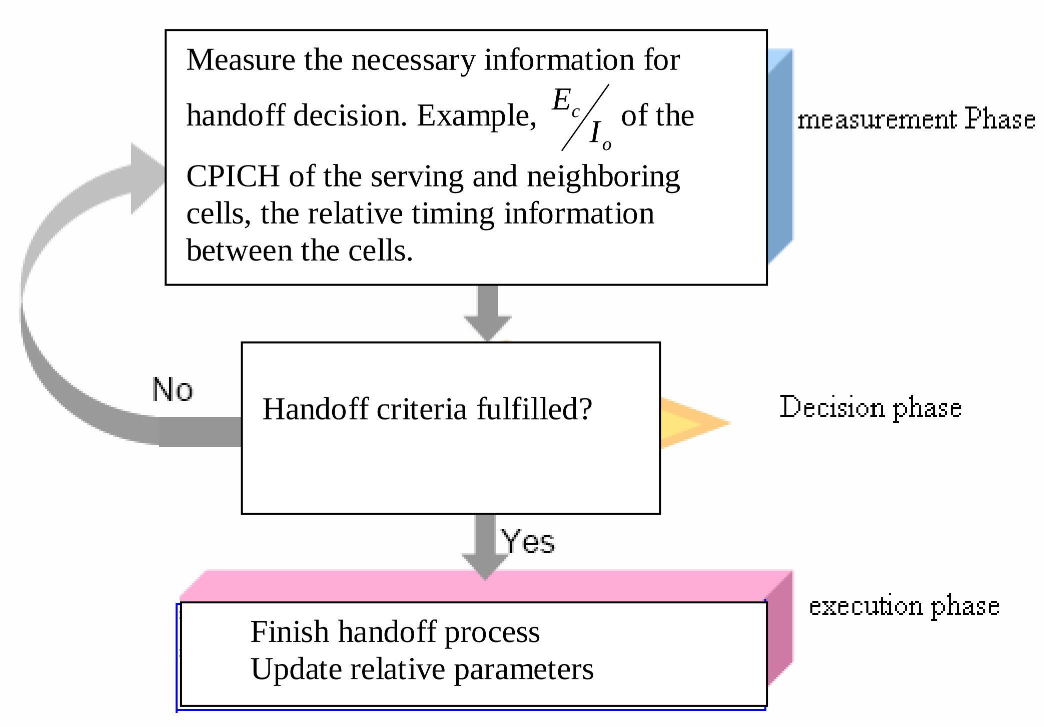


Figure 4.8 Handoff Procedures

Otherwise, the transmissions from the different BSs would be difficult to combine and especially the power control operation in soft handoff would suffer additional delay.

In the handoff decision phase, the measurement results are compared against the predefined thresholds and then it is decided whether to initiate the handoff or not. Different handoff algorithms have different trigger conditions.

In the execution phase, the handoff process is completed and the relative parameters are changed according to the different types of handoff. For example, in the execution phase of the soft handoff, the mobile enters or leaves the soft handoff state, a new BS is added or released, the active set is updated and the power of each channel involved in soft handoff is adjusted.

4.10 Handoff decision algorithms

There are numerous methods for performing handoff, at least as many as the kinds of state information that have been defined for MSs, as well as the kinds of network entities that maintain the state information [13]. The decision-making process of handoff may be centralized or decentralized (i.e., the handoff decision may be made at the MS or network). From the decision process point of view, we can find three different kinds of handoff decisions.

4.10.1 Network-Controlled Handoff

In a network-controlled handoff (NCHO) protocol, the network makes a handoff decision based on the measurements of the MSs at a number of BSs. In general, the handoff process (including data transmission, channel switching, and network switching) takes 100–200s. Information about the signal quality for all users is available at a single point in the network that facilitates appropriate resource allocation. In NCHO, the surrounding BSs measure the signal from the MS, and the network initiates the handoff process when some handoff criteria are met. Network-controlled handoff is used in first-generation analog systems such as AMPS and TACS.

4.10.2 Mobile-Assisted Handoff

In a mobile-assisted handoff process (MAHO), the MS makes measurements and the network makes the decision. In the circuit-switched GSM, the BS controller (BSC) is in charge of the radio interface management. This mainly means allocation and release of radio channels and handoff management. The handoff time between handoff decision and execution in such a circuit-switched GSM is approximately 1 second. In MAHO, the network asks the MS to measure the signal from the surrounding BSs. The network makes the handoff decision based on reports from the MS. MAHO is used in GSM and IS-95 CDMA

4.10.3 Mobile-Controlled Handoff

In mobile-controlled handoff (MCHO), each MS is completely in control of the handoff process. This type of handoff has a short reaction time (on the order of 0.1 second). MS measures the signal strengths from surrounding BSs and interference levels on all channels. A handoff can be initiated if the signal strength of the serving BS is lower than that of another BS by a certain threshold. In this handoff decision method, the MS continuously monitors the signals of the surrounding BSs and initiates the handoff process when some handoff criteria are met. MCHO is used in Digital enhanced cordless telephone (DECT) and Personal Access Communications systems (PACS).

The BSs involved in the handoff may be connected to the same mobile station controller (MSC) (inter-cell handoff or inter-BS handoff) or two different MSC (not further considered). In inter-BS handoff, the new and the old BSs are connected to the same MSC. Assume that the need for handoff is detected by the MS; the following actions are taken:

1. The MS momentarily suspends conversation and initiates the handoff procedure by signaling on an idle (currently free) channel in the BS. Then it resumes the conversation on the old BS.
2. Upon receipt of the signal, the MSC transfers the encryption information to the selected idle channel of the new BSs and sets up the new conversation path to the MS is through that channel, the switch bridge the new path with old and in forms MS to transfer from the old channel to the new channel.
3. After the MS has been transferred to the new BS, it signals the network, and resumes conversation using the new channel.
4. Upon receipt of the handoff completion signal, the network removes the bridge from the path and releases resources associated with old channel.

This handoff procedure is used in MCHO handoff strategy. From the network-controlled handoff strategy, all handoff signaling messages exchanged between the MS and the old BS through the failing link. The whole process must be completed as quickly as possible to ensure that the new link is established before the old link fails.

If the new BS does not have an idle channel, the handoff call may be dropped (or forced to terminate). The forced termination probability is an important criterion in the performance evaluation of a PCS network. Forced termination of an ongoing call is considered less desirable than blocking a new call attempt. Most PCS networks handle a handoff in the same manner as a new call attempt. That is, if no channel is available, the handoff is blocked and the call is held on the current channel in the old cell until the call is completed or when the failing link is no longer available. This is referred to as the non-prioritized scheme.

4.11 Channel Assignment Strategies

Channel assignment schemes attempt to achieve a high degree of spectrum utilization for a given grade of service with the least number of database lookups and the simplest algorithm employed in both the MS and the network. Some trade-offs occur when trying to accomplish the following goals:

- Service quality
- Implementation complexity of the channel assignment algorithm
- Number of database
- Spectrum utilization

Handoff requests and initial access requests compete for radio resources. At a busy BS, call attempts that fail because there are no available channels called blocked calls. Handoff requests for existing calls that must be turned down because there is no available channel are called forced terminations. It is generally believed that forced terminations are less desirable than blocked call attempts. Note that the successful handoff process is intimately tied to the radio technology of the channel assignment process, which may be dynamic channel assignment (DCA) or fixed channel assignment (FCA).

To reduce forced termination and to promote call completion, four channel assignment schemes have been proposed. These are the non-prioritized scheme, the reserved channel scheme, the queuing priority scheme, and the sub-rating scheme.

4.11.1 Non-prioritized scheme and reserved channel scheme

The non-prioritized scheme (NPS), the BS handles a handoff call in exactly the same manner as a new call; that is, the handoff call is blocked immediately if no channel is available. The flowchart of NPS is given in figure 4.9. This scheme is employed by most PCS radio technologies.

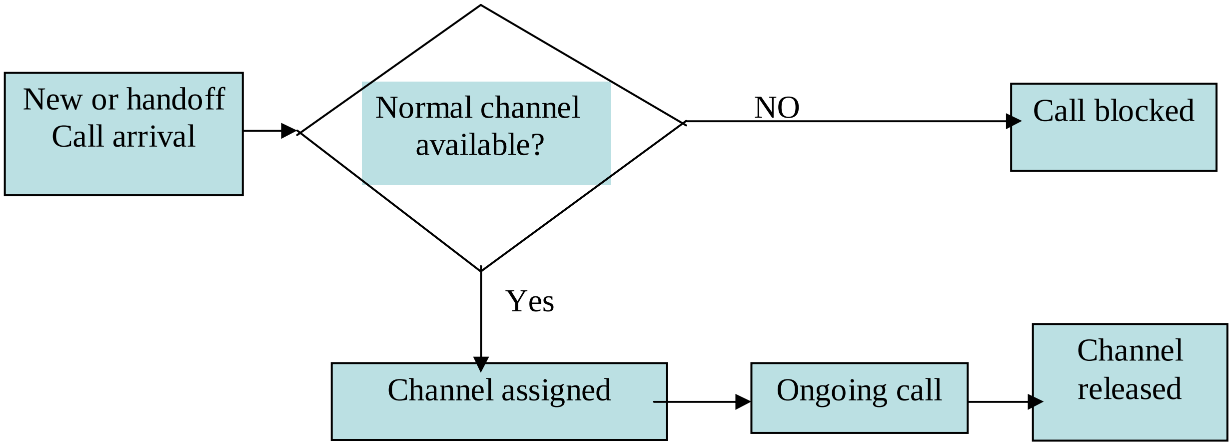


Figure 4.9 The flow chart for NPS

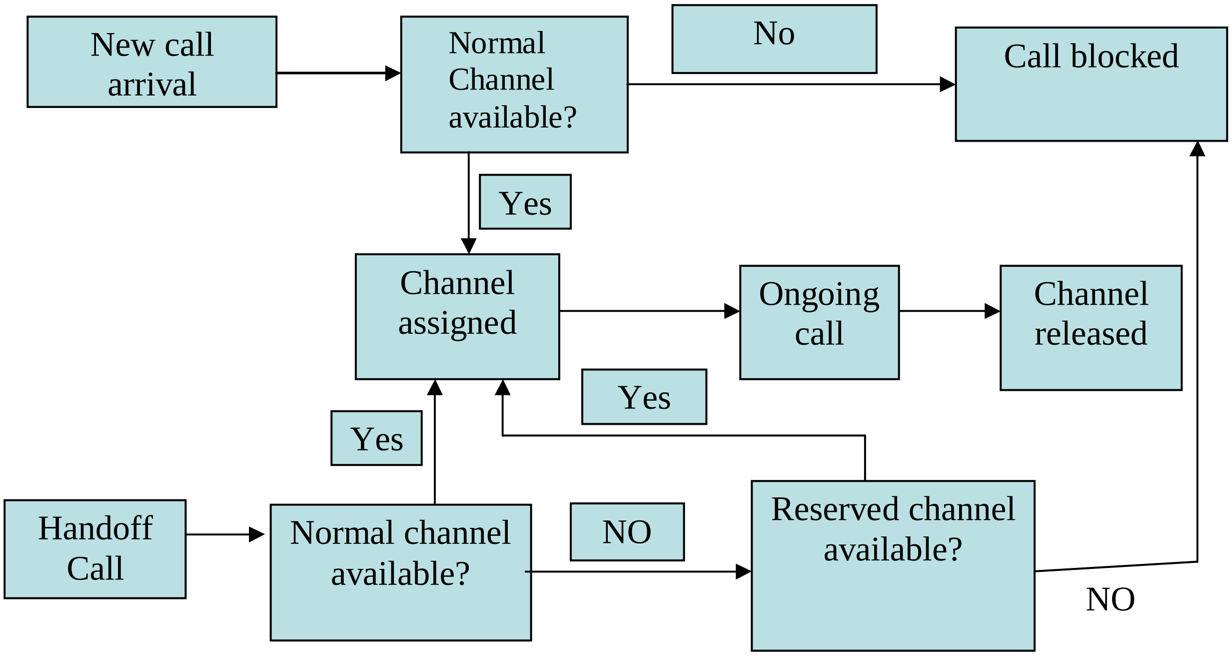


Figure 4.10 The flowchart for RCS

The reserved channel scheme (RCS) is similar to NPS except that a number of channels or transceivers in each BS are reserved for handoffs. In other words, the channels are divided into two groups: The normal channels, which serve both new calls and handoff calls, and the reserved channels, which only serve handoffs calls. The flowchart for RCS is shown in figure 4.10.

4.11.2 Queuing Priority scheme

The queuing Priority scheme (QPS) is based on the fact that adjacent cells in a PCS network overlap. Thus, there is considerable area where a call can be handled by either BS of the adjacent cells, called the handoff area. The time that an MS spends in the overlapped area is referred to as the degradation interval.

The channel assignment for a QPS new call is the same as that for NPS. If a channel in the new cell is available for the handoff, the handoff actually occurs. If no channel is released, the BS first checks if the waiting queue is empty. If not, the released channel is assigned to a handoff call in the queue. The next handoff to be served is selected based on the queuing policy. Two scheduling policies for the QPS waiting queue have been considered. In the FIFO scheme, the next handoff call is selected on a first-in-first-out basis. The measured based priority scheme (MBPS) uses a non pre-emptive dynamic priority policy. The power level that the MS receives from the BS of the new cell defines the priorities. The network dynamically monitors the power levels of the handoff calls in the waiting queue. We may view a handoff call as having a higher priority if its degradation interval is closer to expiration. The candidate selected by the network will be the radio link with the lowest received signal strength and the poorest quality, as measured by the MS. This implies the existence of a mechanism for the MS to relay this information to the network over the failing radio link between the MS and the old BS. A released channel is assigned to the handoff call with the highest priority in the waiting queue.

4.11.3 Sub-rating scheme

The sub-rating scheme (SRS) creates a new channel on a blocked BS for a handoff call by sharing resource or sub-rating an existing call if no channel is available in the new BS. Sub rating means an occupied full-rate channel is temporarily divided into two channels at half the original rate: one to serve the existing call and the other to serve the handoff request. When occupied channels are released, the sub rated channels are immediately switched back to full-rate channels. Studies have indicated that under certain conditions, these handoff schemes can significantly reduce the probability of forced termination as well as the probability of call incompletion (new call blocking plus handoff call forced termination) [4], [26].

In general, when a subscriber makes or receives a call, the MS has to acquire an available traffic channel for the connection. For some PCS radio systems using dynamic channel assignment, the MS launches an access request on a common signaling channel (CSC), and is then directed to a traffic channel. In these cases, there are a limited number of servers or transceivers in a BS. When a BS is blocked, there is often no transceiver for the CSC since they have all been used for existing calls. In other PCS radio systems, the access attempt can be made directly on an available control channel.

4.12 Cellular system deployment scenarios

The radio propagation environment and related handoff challenges are different in different cellular structure. A handoff algorithm with fixed parameter cannot perform in the same way in different system environments. Specific charactersitics of the communication system should be taken into account while designing handoff algorithms. Several basic cellular structures: macrocells, microcells, picocells, and overlay systems and special architectures include underlay, multichannel bandwidth systems, and evolutionary architectures.Only macrocells are described next. Because our system model is designed and best fit to the macrocell environment only.

4.12.1 Macrocells

The BS trsnsciever in macrocell transmits high output power with the antenna mounted several meters high on a tower to cover a large area. Macrocell radaii are several kilometers. Due to the low cell-crossing rate, centralized handoff is possible despite the large number of MSs the MSC has to manage. The quality of the transmission in the uplink and the downlink is approximately the same. The transition region between the BSs is large; handoff schemes should allow some delay to avoid filp-flopping. To preserve the signal quality, the delay must be short enough because the signal interfereence increases as the MS penetrates to the new cell, which is called cell dragging. Macrocells are characterized by relatively high path-loss [15]**.** To overcome this problem, the time period used to average the signal strength variations should be long enough to get rid of fading fluctuations.

4.12.2 Macro diversity

It is the diversity of BSs for the purpose of handoff process. There are two situations to which we apply the term macro diversity. The first is when two or more base stations are reasonable potential candidates to be the serving base station of a user. Since the user has a choice of base stations, the outage probability at a given distance is reduced, or cell coverage is increased over the single base station cell coverage range for the same outage probability. However, only one base station provides actual service at a given time. The second situation is more specific and only possible in some system designs like CDMA systems: when more than one base station can provide actual service simultaneously, even if they might individually be unable to sustain service to the user. For example, in IS-95 this type of macro diversity is provided on the downlink in a soft handoff situation, when two Rake receivers in the user might be receiving from one base station, and another receiver from another base station. On the uplink, however, only selection combining is used. It is sometimes said that the major advantage of soft handoff is macroscopic diversity.

CHAPTER 5

SYSTEM MODEL AND ANALYSIS.

5.1 System model

5.1.2 Propagation Models

This section outlines the propagation model that will be used to determine the distance between a BS and the MS. Mobile communication is burdened with particular propagation complications, making reliable wireless communication more difficult than fixed communication between and carefully positioned antennas. The antenna height at a mobile terminal is usually very small. Hence, the antenna is expected to have very little 'clearance', so obstacles and reflecting surfaces in the vicinity of the antenna have a substantial influence on the characteristics of the propagation path. Moreover, the propagation characteristics change from place to place and, if the terminal moves, from time to time.

If the received power is strong, it will introduce interference to other users in the cell and degrade their performance. However, if a received signal at the BS is too weak, it will be obscured by stronger signals. The capacity of a CDMA system is maximized if each mobile station is power controlled such that the received signals at the base station are of equal power. In ideal situations, perfect power control can eliminate the near-far effect resulting in less interference affecting the system performance. However, in real systems, power control is not ideal. This thesis assumes ideal power control at the BS. If all users within a given cell are power controlled by the same BS, all users receive the same power.

5.1.3 Hata-Okumura Macroscopic Propagation Models

The most widely used path loss model for signal strength prediction and simulation in macro-cellular environments is the Hata-Okumura model [1, 2]. This model provides an expression of the path loss of the signal transmitted by the BS transmitter (Tx) and received at the MS receiver (Rx) as a function of the distance between the two entities (BS and MS). The following parameters will appear on the path loss equation of this model: The carrier frequency, $f_c \in [150,$

$1000]$ MHz, antenna heights of BS, $h_b \in [30, 200]$ m, and MS height, $h_m \in [1, 10]$ m, and the distance between the BS and MS, $d \in [1,20]$ Km. The path loss in dB is given by [9]:

$L_p(d) = A + B\log_{10}(d)$ for urban area.

Where $A = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_b) - \alpha(h_m)$ and

$B = 44.9 - 6.55\log_{10}(h_b)$. Therefore, for the received signal strength measurements of the mobile from the BS, the Hata-Okumara path loss model is given by [9]:

$$L_p(d) = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_b) - \alpha(h_m) + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d)$$

and $\alpha(h_m)$ is the correction factor for mobile antenna height, and is given by

$$\alpha(h_m) = [1.1\log_{10}(f_c) - 0.7]h_m - [1.56\log_{10}(f_c) - 0.8]$$

This model is however applicable only for a flat urban environment and to make the model applicable to suburban and rural area, a ground cover factor has to be introduced. The ground cover factor is a function of the percentage of the area covered by buildings. To calculate this, a database of buildings and roads is required. A limitation of this model is that it does not consider the structure of buildings and roads.

We also compared the Free Space path loss model with the Hata-Okumura model as shown in figure 6.1. Free space propagation does not apply in a mobile radio environment and the propagation path loss depends not only on the distance and wavelength, but also on the antenna heights of the MS and BS, and the local terrain characteristics such as buildings and hills. The Free Space Path loss equation is given by

$$L(free) = 32.4 + 20\log_{10}(f_c) + 20\log_{10}(d)$$

The average received power at the mobile station is calculated as

$$P_r(d) = EIRP(dB) - L(urban)(dB) + G_r(dB)$$

Where EIRP is the Effective Isotropic Radiated Power (1 kw) and G_r is the gain of the receiving antenna.

5.2 Handoff Resource management

Once a handoff decision has been made, a receiving radio access port (BS) is to be determined. The candidate to become the receiving access port can be selected on the grounds of signal quality. Now the question arises where there are radio resources available in the receiving access port. This could involve the availability of channels. Or the quality in co-channel links in the vicinity of the receiving access port may become too poor to allow the handoff. In such cases the handoff may be denied and either the current access port has to be kept, or a new candidate access port for handoff has to be selected. It is clear that mobile terminals arriving to an access port as a consequence of a handoff complete for the same radio resources with terminals having selected that particular access port in trying to set up a new session. In many applications protecting the ongoing sessions is considered more important than denying new terminals access to the system. In a classical mobile telephony system, it is found to be more detrimental to the users to lose an ongoing call than to block a newly arrived call. The latter reasoning makes it obvious to reserve resources for handoff mobiles such that these resources such as channels, time slots can only be used by mobile terminals performing a handoff and not by newly arriving call set-up requests in the own cell. Such an arrangement is evaluated in the following section.

5.2.1 Call Admission control (CAC)

The performance requirements of users are measured interms of QoS and GoS. QoS is packet level factor which includes packet loss rate, packet delay, packet delay variation, and throughput rate. GoS is a call level factor, which includes new call blocking probability (NCBP), handoff call dropping probability (HCBP), and connection forced termination probability (CFTP). CFTP is a measure of call (connection) being forced to terminate at some point during the lifetime of the connection. In terms of CAC at the call-level, we are more concerned with NCBP and HCDP as GoS measures.

CAC ensures network integrity by restricting access to the network so as to avoid overload and congestion, and to ensure that QoS requirements of all ongoing connections are satisfied. The CAC problem can be phrased as follows. Suppose there are $(N-1)$ ongoing calls. When the N^{th} request arrives, the network calculates the amount of available resources. If there are enough resources to admit the N^{th} call, such that its QoS requirement and those of the ongoing calls are satified, the new request is admitted by a new call or a handoff call.

Before making admission decisions, the CAC algorithm needs to determine the amount unallocated capacity (i.e., the number of basic channels available for accepting new and handoff request). Also, a handoff request tries to maintain service continuity of an ongoing session. If the available capacity for accepting connection requests is limited, handoff call requests are admitted in preference to new call requests. For example, if only one basic channel is available and there are two computing requests, one new and one handoff, the decision should be to accept the handoff request and reject the new request. Thus handoff requests should be offered a higher admission priority than new requests.

Quality of service is measured in terms of call blocking probability and call dropping probability. The call is blocked if there are no available channels. The blocking probability can be obtained from the analysis of an *M/M/n/n* queue. In general, the first *M* indicates call arrivals are modeled as Poison process with arrival rates of λ call/s, the second M refers to exponential service time with mean $1/\mu$ s/call, the first n refers to the number of channels, and finally, the second n refers to maximum number of acceptable users before blocking occurs. The famous Erlang-B equation (also called blocked calls cleared formula) [21] under the conditions of *M/M/n/n* is given by: $P_B = \dfrac{\left(\lambda/\mu\right)^n / n!}{\sum_{k=0}^{n} (\lambda/\mu) / k!}$

5.2.1.1 Prioritized call admission

Handoff calls can be admitted at a higher priority than new calls. To manage the admission of requests based on priority, it is necessary to reserve capacity for admitting handoff requests. Let N_g be the number of basic channels reserved for admitting handoff requests. A common technique to reserve capacity for handling handoff requests is the guard channel method [9]. This is the reason that we assign the subscript g to denote the amount of reserved capacity for accepting handoff requests. Let N_u denote the number of unallocated channels. With the gurad channel method [9], the admission rule is the following: If $N_u > N_g$, admit a new or handoff request. Otherwise if $N_u \le N_g$, admit a handoff request only.

The above guard channel method is a fixed reservation strategy. One can also introduce dynamic reservation methods to reserve the right amount of capacity to satisfy the demand –supply problem. The dynamic approach would offer higher resource utilization efficiency, but may entail fairly complex parameter estimation issues. For example, if the controller knows exactly the number (or the rate) handoff requests during any epoch, it can determine the value of N_u exactly. This information is never available; at best, the number or the rate of handoff may be estimated.

5.2.2 Capacity reservation and cost of mobility

In capacity reservation scheme, priority is given to handoff requests by reserving η_0 channels exclusively for handoff calls among the total η channels in a cell. The remaining $\eta - \eta_0$ channels are shared by both new calls and handoff requests. The new call is blocked if the number of available channels in the cell is less than or equal to η_0. A handoff request is blocked if no channel is available in the target cell. The system model is shown in figure 5.1.

Both new calls and handoff calls can be assumed to arrive as independent Poisson processes with mean rates λ_N and λ_H respectively. Calls have a lifetime in the cell, that is, they are terminated or leave the cell with in a time interval that is exponentially distributed with average $1/\mu$. So we determine the blocking and dropping probabilities as a function of the traffic load when 50% of the total calls arriving at the cell are handoffs and a total of η channels are available.

Denote the total number of calls in progress in the cell at time t by $N(t)$. Note that whenever a call has arrived and is assigned a channel, it is no longer of any consequence to the number of calls in the cell, whether this call originally was handed off to the cell, or if it was a new call arriving at that cell. Due to the memory-less properties of the Poisson arrivals and the exponential distribution of the call lifetime in the cell, $N(t)$ will be a Birth-Death Markov chain with the state-transition diagram in figure 5.2.

We proceed to derive the stationary state probabilities [14].

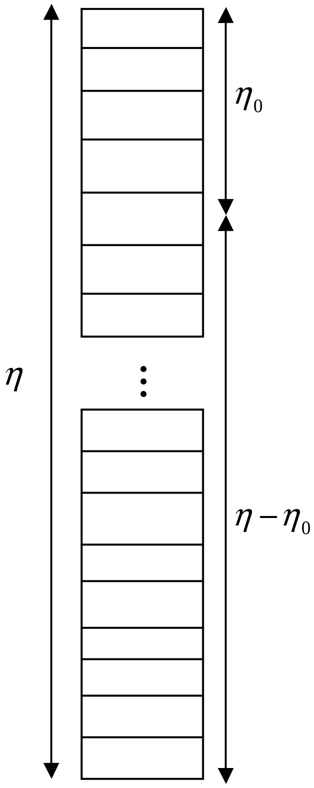


Figure 5.1 Capacity reservation model for handoff call.

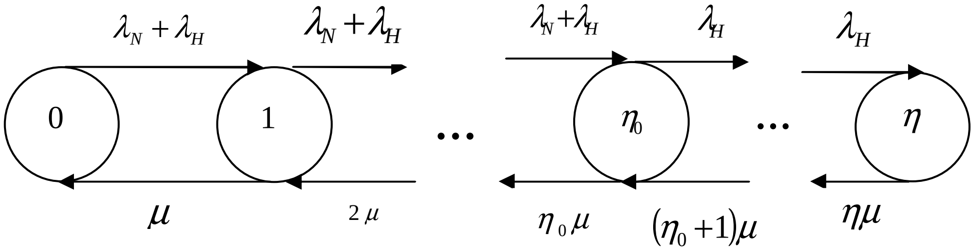


Figure 5.2 State diagram of Markov process for figure 5.1.

By means of the flow cut equations:

$$(\lambda_N+\lambda_H)P_{k-1}=k\mu P_k \qquad 1\le k\le \eta_0$$

$$\lambda_H P_{k-1}=k\mu P_k \qquad \eta_0<k\le \eta$$

Iteratively solving these equations yields

$$P_k = P_0 \frac{(\lambda_N + \lambda_H)^k}{\mu^k k!} \quad \text{for } k \le \eta_0 \text{ else } P_k = P_0 \frac{(\lambda_H + \lambda_N)^{\eta_0} (\lambda_H)^{k-\eta_0}}{\mu^k k!} \quad \text{for } \eta_0 < k \le \eta$$

Using the fact that all P_k add up to unity, we can solve for p_0. Using the notation

$\rho_{tot} = \frac{\lambda_N + \lambda_H}{\mu}$ and $\rho_H = \frac{\lambda_H}{\mu}$ we get:

$$P_k = \frac{\frac{(\rho_{tot})^k}{k!}}{\sum_{j=0}^{\eta_0} \frac{(\rho_{tot})^j}{j!} + \sum_{j=\eta_0+1}^{\eta} \frac{(\rho_{tot})^{\eta_0} (\rho_H)^{j-\eta_0}}{j!}} \quad \text{for } k \le \eta_0$$

Else $P_k = \frac{\frac{(\rho_{tot})^k (\rho_H)^{k-\eta_0}}{k!}}{\sum_{j=0}^{\eta_0} \frac{(\rho_{tot})^j}{j!} + \sum_{j=\eta_0+1}^{\eta} \frac{(\rho_{tot})^{\eta_0} (\rho_H)^{j-\eta_0}}{j!}}$ if $k < \eta_0 \le \eta$

Now deriving the blocking and handoff dropping probabilities yields

$P_{block} = \sum_{k=\eta_0}^{\eta} P_k$ and $P_{drop} = P_\eta$

Defining the relative mobility a as $a = \frac{\lambda_H}{\lambda_N + \lambda_H}$ and evaluating the $\eta = 35$, and a = 0.7, 0.5 and 0.3, figure 6.4 provides the required numerical results.

Figure 6.5, 6.6, 6.7 and 6.8 shows the dependence of the results on the relative mobility, whereas figure 6.9 gives the grade of service (GOS) as $GOS = P_{block} + \alpha P_{drop}$, $\alpha > 1$ is balancing factor for some different values of a. GOS is a measure of the ability of a user to access a trunked system during the busiest hour. The busy hour is based upon the customer demand at the busiest hour during a week, month, or year.

The reservation policy has its limitations, in particular when the traffic load is high and mobile terminals are moving rapidly. On the other hand, in a high-density, high-capacity network, usually the list of candidates for receiving a session in a handoff may be quite long. If the (from a signal quality point of view) best candidate access port is chosen, the session may be rejected due to resource limitation. On the other hand, there may be several candidates that have acceptable (if not the best) signal quality and available resources (channels).

In IS-95 CDMA system, the soft handoff state of a terminal is based on the pilot strength measurement. The active set contains the identifications that the terminal is undergoing soft handoff. There are basically three thresholds that determine the soft handoff status of the terminal, T_add, T_drop and T-tdrop. If the received ${E_c}/{I_0}$ of a pilot channel of a base station in the active set is below T_drop and stays there until a timer expires (T_tdrop), then the connection to the base station is removed. If the received ${E_c}/{I_0}$ of a pilot channel currently not belonging to the active set is above T_add, then the pilot channel is moved to the active set, that is, a new connection is established.

In IS-95 soft handoff, if both threshold T_add and T_drop are increased simultaneously, then the soft handoff region will be decreased, whereas if they are decreased simultaneously, then soft handoff region is increased. By shifting handoff parameters (for example from T_add=-14dB and T_drop=-16dB (Threshold 1) to T_add=-12dB and T_drop=-13dB (Threshold 2)), the handoff rate is obviously decreased. The same phenomenon will happen if the ${E_c}/{I_0}$ from both BSs is either decreased or increased, without changing the thresholds. Thus if the interference amount in the down link side is decreased (or increased ${E_c}/{I_0}$), that is, light traffic load, then the soft handoff region will be enlarged.

CHAPTER 6

SIMULATION RESULTS AND DISCUSSIONS

The performance parameters measured in this work is pilot signal measurement for handoff decision, call-blocking probability, P_b, handoff dropping probability, $P_{d,}$ and Grade of service (GoS). In our simulation results in IS-95 CDMA, figures 6.2 and 6.3 shows variation of received

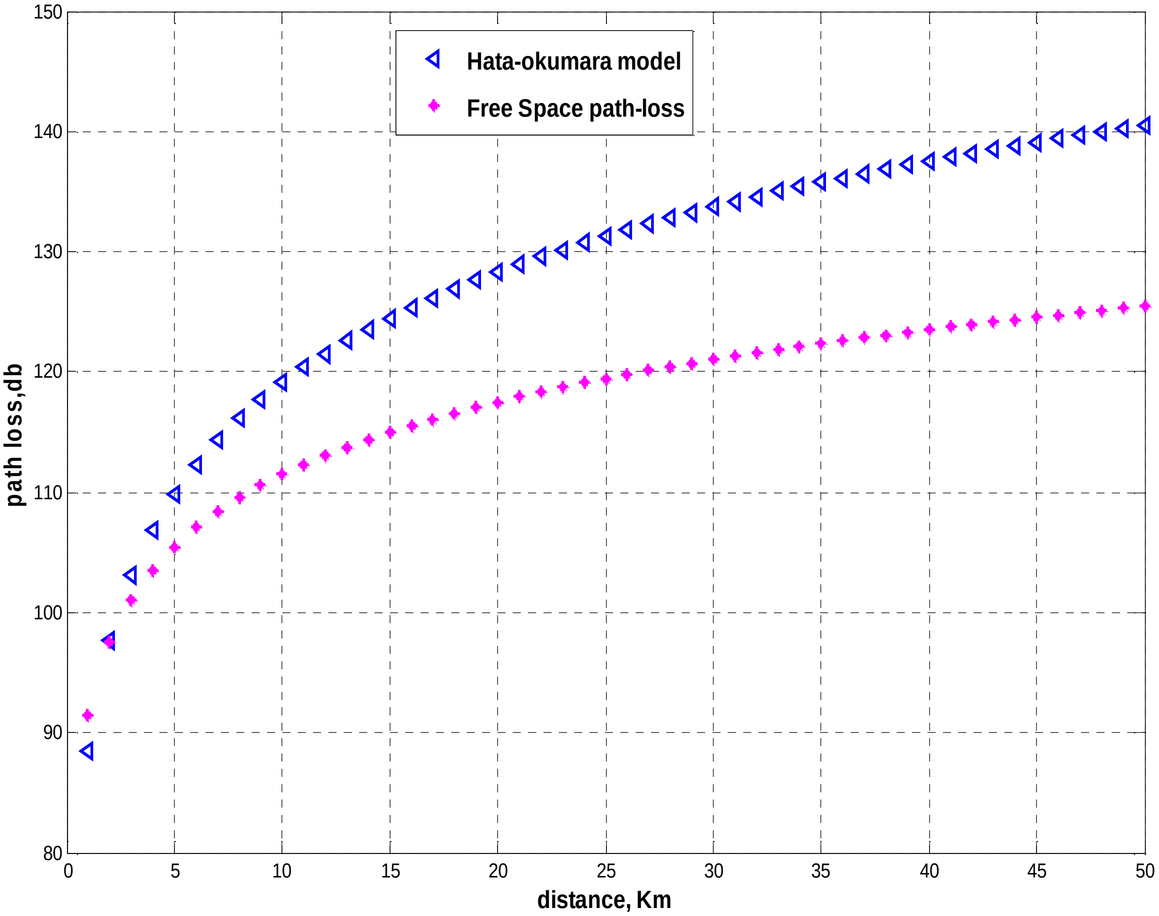


Figure 6.1 Path loss versus distance in Km

Signal strength of the mobile from both base stations when no noise and noise were present in the system respectively, i.e., received power at B without noise, received power at A with Gaussian noise 3 dB and received power at B with Gaussian noise 5 dB.

Okumura-Hata is an empiric model for how the signal strength between a base station and a terminal is attenuated as a function of distance, carrier frequency, base station antenna height and mobile antenna height.

To analyze a slightly more realistic cellular environment two Gaussian noise sequences were introduced. By introducing a hysteresis margin, it is clearly seen that number of handoffs decrease (Figure 6.4 has a hysteresis margin of -5 dB). But in figure 6.3 we see that handoffs taking place at different points than taking place at one place). However excess hysteresis margin

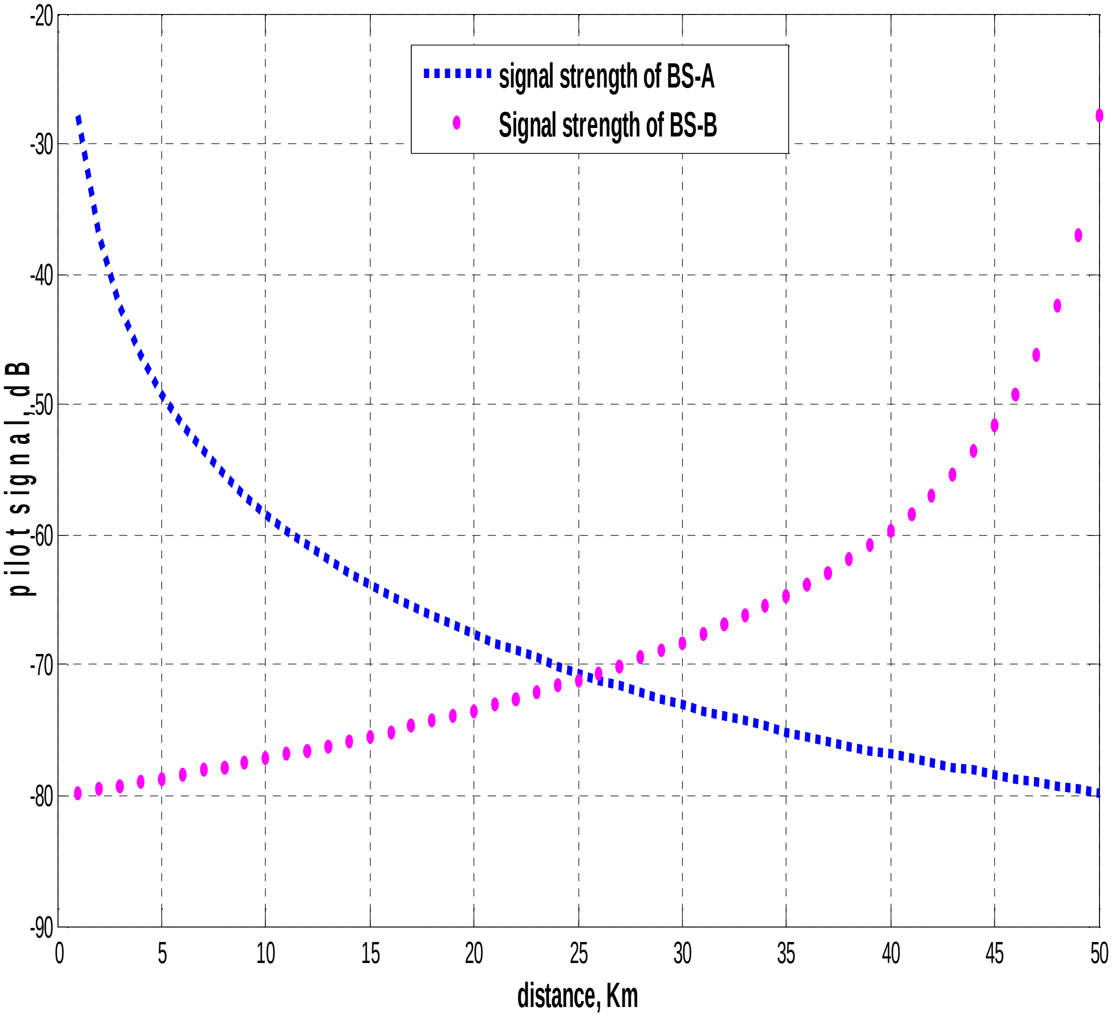


Figure 6.2 Received power at Base stations A and B without noises

will cause an initiation delay. If the delay persists for longer intervals of time the call will be dropped due to deteriorating signal conditions. Clearly, there exists a tradeoff between hysteresis and initiation delay.

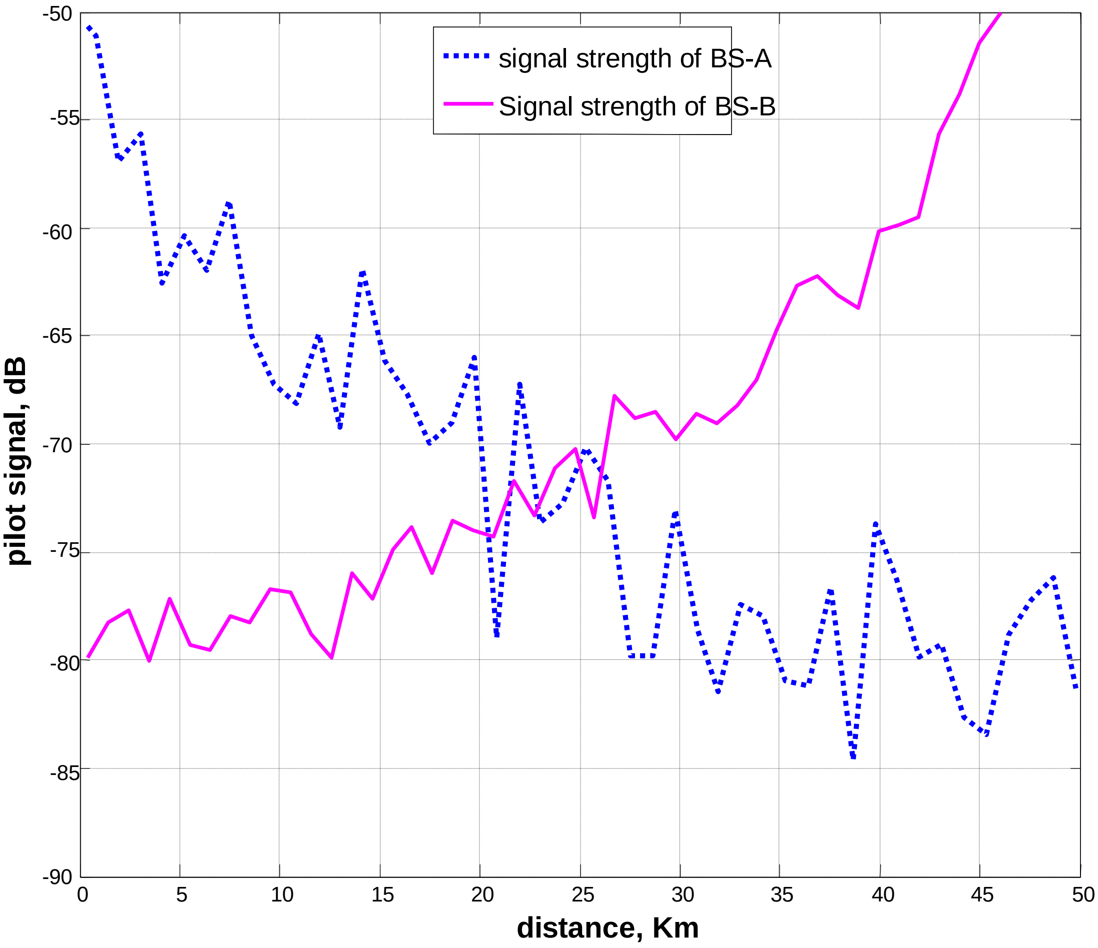


Figure 6.3 Received power at Base stations A and B with noises

Handoff rate is changing according to the traffic density. For example, at midnight, handoff rate (region) is increasing whereas during the busy hours the handoff region shrinks. To avoid such phenomenon, a slightly different scheme has been considered in WCDMA. When the incoming BS's beacon channel power is larger than the current BS by T_add then a new BS is connected and a soft handoff starts. Similarly, when the current BS's beacon channel power is less than that of the incoming BS by T_drop, the connection to the current BS is removed.

It can easily be seen from figure 6.2 that the soft handoff region is invariable to the traffic load and ping pong phenomenon is avoided. But there is a slight variation in traffic load and minimum number of handoffs in figure 6.4.

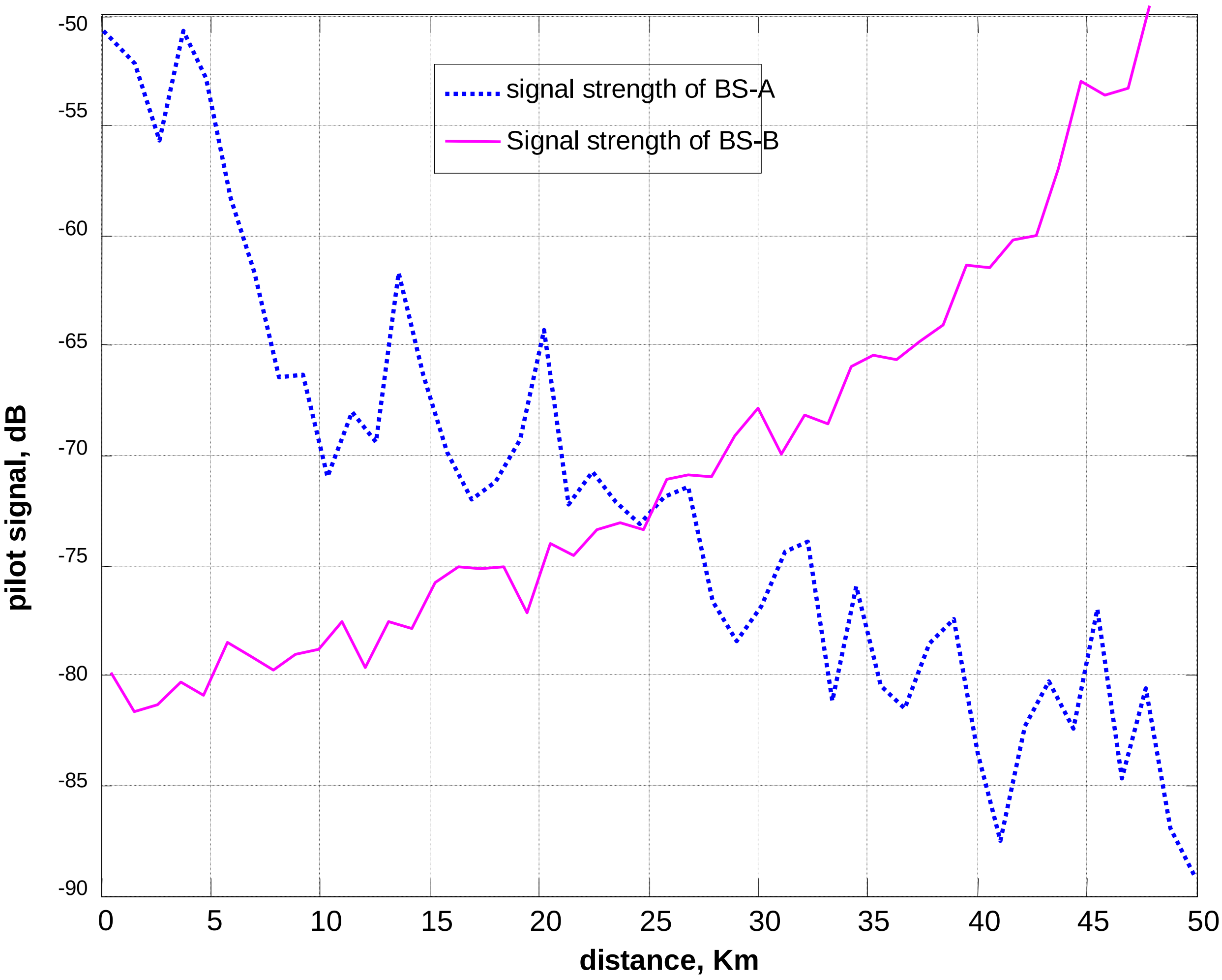


Figure 6.4 Received power at Base stations A and B with equal Gaussian noises of 3 dB.

The simulation observations do show the decrease in the number of unnecessary handoffs on incorporation of an optimum Gaussian noise and hysteresis margin. It also gives an insight of the tradeoffs involved in introducing an optimum hysteresis margin and the associated initiation delays.

An increase in relative mobility will cause an increase in handoff dropping and new call blocking

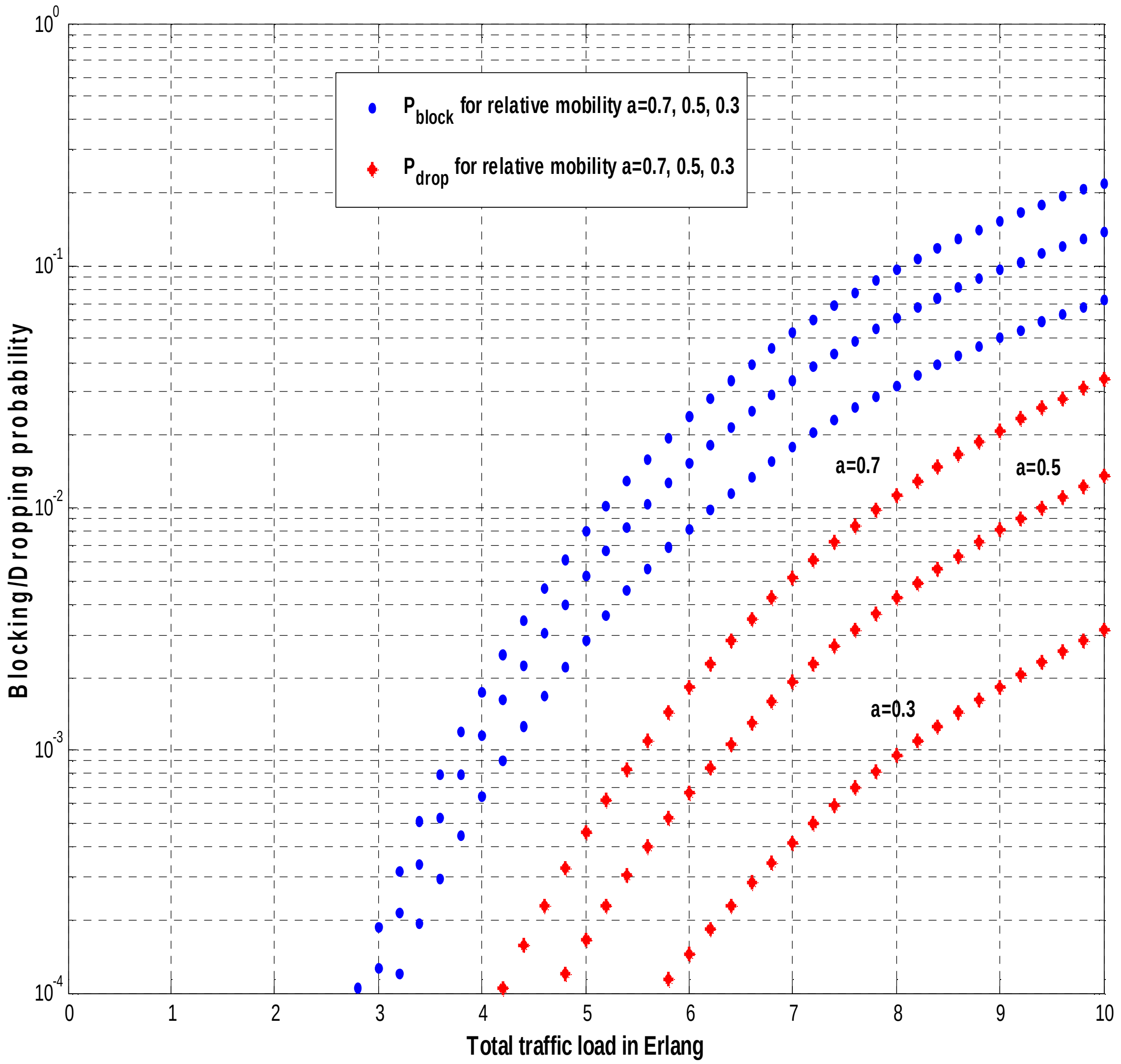


Figure 6.5 Blocking and handoff dropping probability as a function of total traffic load when 3 channels out of a total of η channels are reserved.

probabilities. Keeping the traffic load constant and varying the mobility will affect the system performances such as blocking and dropping of new and handoff requests respectively.

From figure 6.5 we can easily realize that at a reasonable increase in traffic load, both the new blocking and handoff dropping probability will increase significantly. Also a decrease in relative mobility will decrease blocking and dropping probabilities of on going calls.

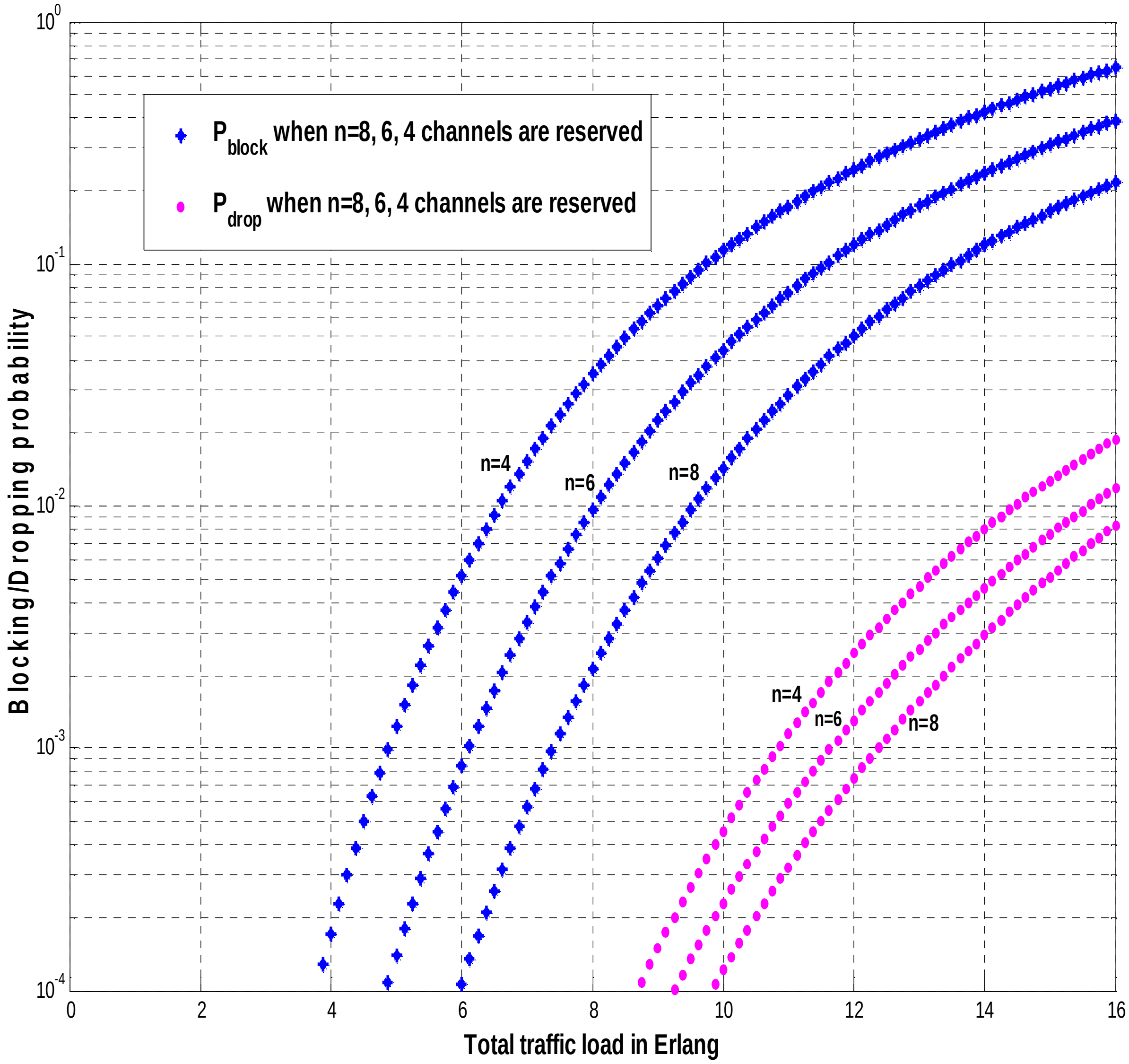


Figure 6.6 Blocking and Handoff dropping probability as a function of total traffic load when η_0 out of a total of η channels are reserved for relative mobility a=0.7

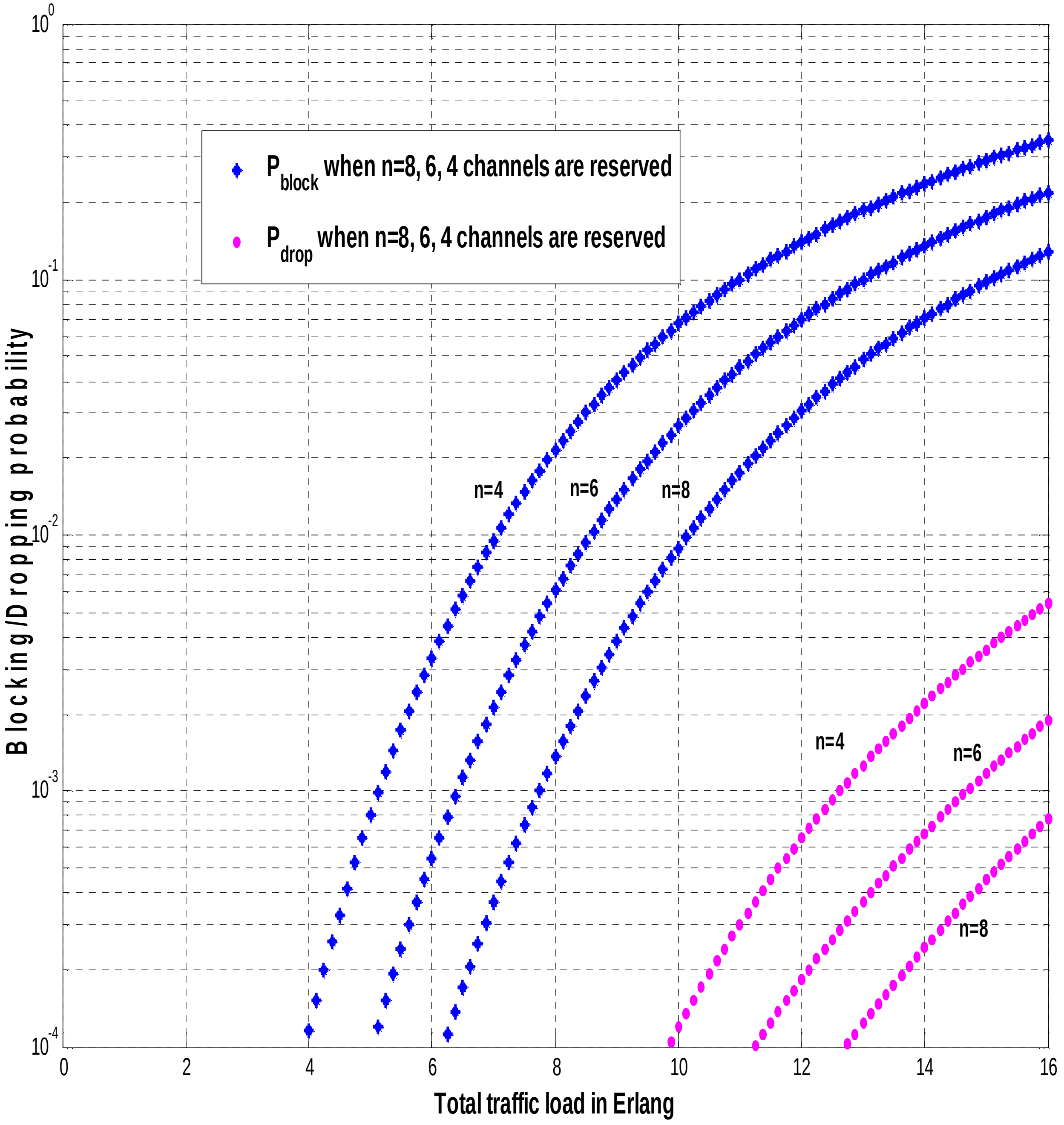


Figure 6.7 Blocking and Handoff dropping probability as a function of total traffic load when η_0 out of a total of η channels are reserved for relative mobility a=0.5

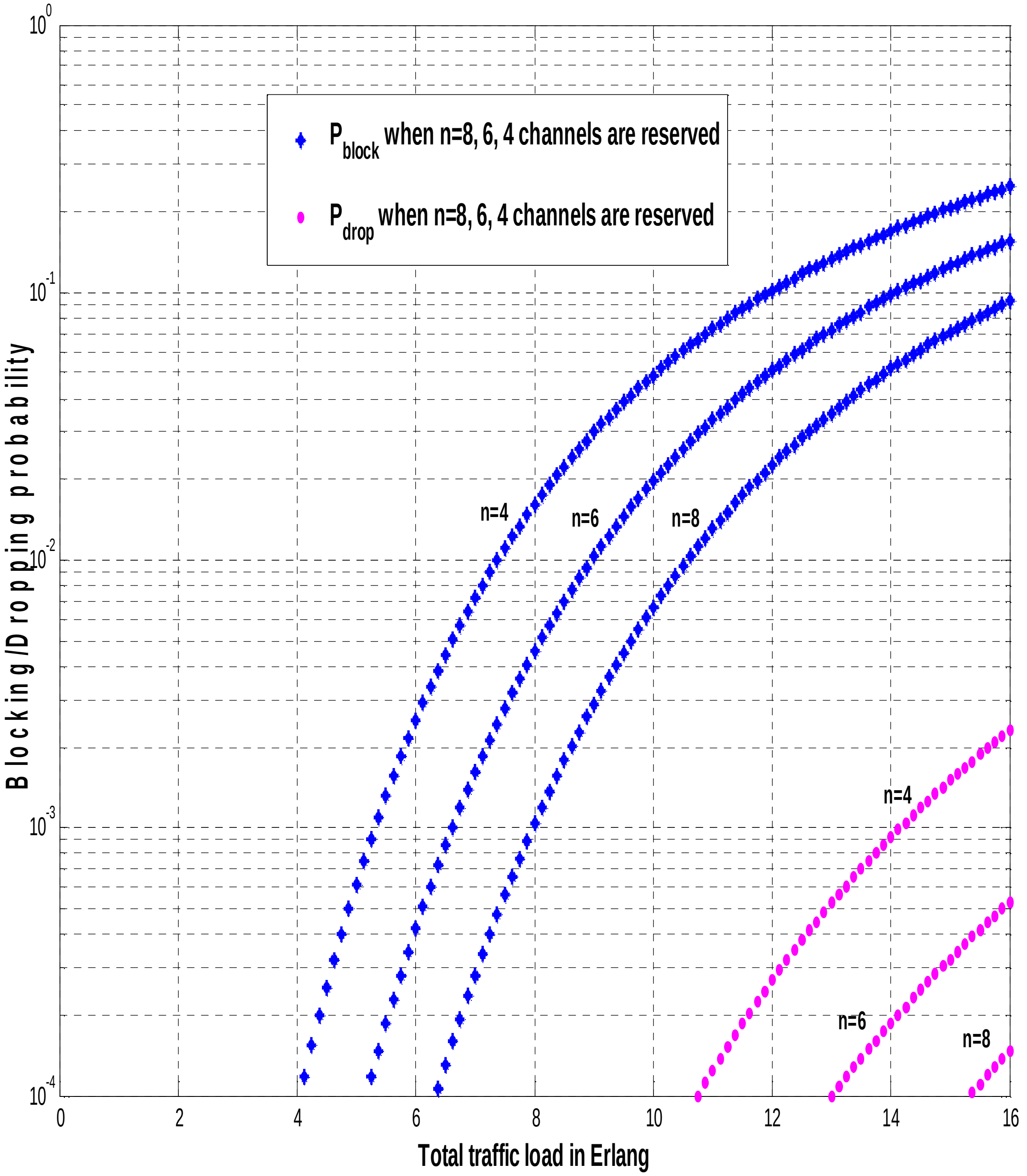


Figure 6.8 Blocking and Handoff dropping probability as a function of total traffic load when η_0 out of a total of η channels are reserved for relative mobility a=0.4

It can be seen that the forced termination probability decreases and tends to a minimum level as the offered traffic decreases. When the offered traffic is low, the forced terminations are mainly due to handoff initiations.

It is observed that unrealistically low forced termination probability is obtained if channel availability is not considered.

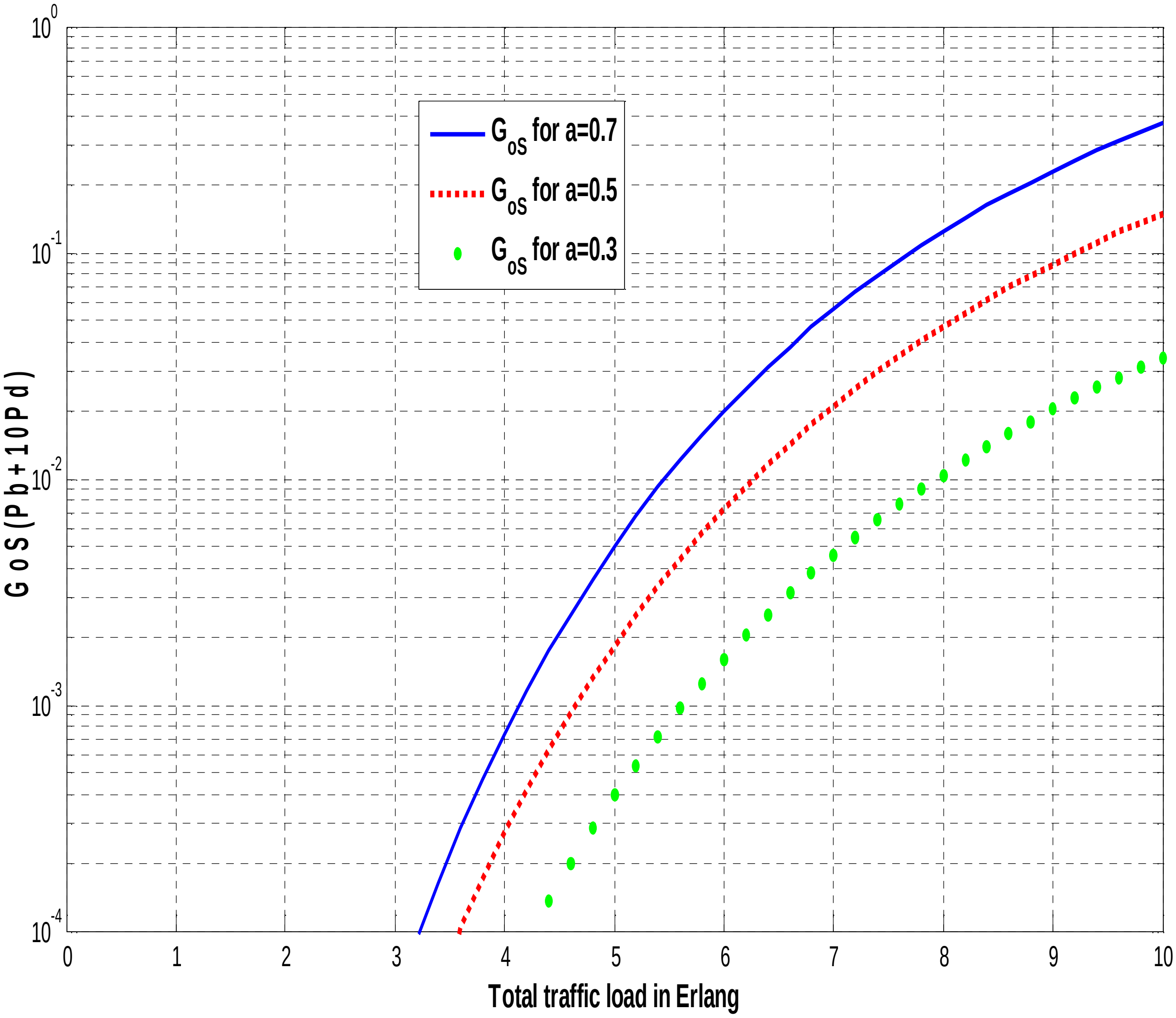


Figure 6.9 GoS as a function of total traffic load when 3 out of a total of η channels are reserved for handoff traffic for different relative mobilities.

Studying the graphs, it is clear that there is a trade-off between blocking of newly arrived calls and handoff calls. If there is a requirement to keep the dropping probability low, more channels for handoff calls have to be reserved. As the relative mobility of the terminals is increased (more handoffs per cell), the required number of reserved channels is getting larger and a smaller fraction of the channels can be used for newly arriving calls. As a consequence the capacity drops. At some given QoS level, a system with highly mobile users, or very small cells, has lower capacity than a system where mobility is lower.

6.1 Performance Measures

In urban mobile radio systems, especially when the cell size becomes relatively small, the handoff procedure has a significant impact on system performance. Blocking probability of originating calls and the forced termination probability of ongoing calls are the primary criteria for indicating performance.

Table 6.1 Blocking Conditions

Channel conditions Signal Conditions	1	2	3	4
M	S	S	S	B
O	S	S	B	B
H	S	B	S	B
J	B	B	B	B

B: Blocked, S: Successful

M: Both signals received from BS- A&B acceptable.

O: Signal received from base station A is acceptable but that received from BS- B is not.

H: Signal received from BS- B is acceptable but that received from A is not.

G: Both signals received from A & B are not acceptable

1: Channel at both BS-A & B is available, 2: Channel at BS-A is available but at B is not

3: Channel at BS- B is available but at A is not, 4: No channels at BS-A & B are available

Table 6.1 summarizes all the cases including those of blocked new call attempts. The number of blocked new call attempts N_B is calculated as follows:

$N_B = N_{M4} + N_{O3} + N_{O4} + N_{H2} + N_{H4} + N_{J1} + N_{J2} + N_{J3} + N_{J4}$

The blocking probability PB is defined by:

$P_B = N_B/N_G$, Where N_G represents the total number of generated new call attempts.

Table 6.2 Dropping Conditions.

Initiation &Channel conditions Signal Conditions	1	2	3
E	C	C	C
F	C	D	D
G	D	D	D

D: Drop, C: continue

E: Signal quality of the current link is acceptable, F: Signal quality of the current link is not acceptable but that of the alternative link is acceptable, G: Both the current and alternative signal qualities are not acceptable

1: Handoff is initiated and there is an available channel in the alternative base station

2: Handoff is initiated and there is no available channel in the alternative base station.

3: Handoff is not initiated

Table 6.2 shows all the cases for which an ongoing call is dropped. Dropping of a call at any time during its intended duration time results in forced termination of the call. Any call, which enters service and is subsequently dropped, encounters one of the events F_2, F_3, G_1, G_2 or G_3. Thus, the number of observed call-dropping events can be calculated as:

$N_D= N_{F2}+N_{F3}+N_{G1}+N_{G2}+N_{G3}$. The forced termination probability, P_{FT} is defined by:

$P_{FT} = N_D/(N_G – N_B)$.

CHAPTER 7

CONCLUSIONS AND FUTURE WORKS

7.1 Conclusion

In this work, the resources such as channels available in IS-95 CDMA under the assumption of power controlled are used. The simulation observations do show the decrease in the number of unnecessary handoffs on incorporation of an optimum hysteresis margin and also gives an insight of the tradeoffs involved in introducing an optimum hysteresis margin and the associated initiation delays.

This thesis shows that handoff initiations as well as channel availability (capacity in CDMA) have significant impact on the forced termination probability. If either one of them is not considered, one may obtain unrealistically low forced termination probability. The simulation results show that new call blocking and handoff call dropping probability with a variation of traffic load. The unnecessary handoffs (the continuous movement of mobiles around a cell corner) attempts per call and the forced termination probability are minimized. Handoff call dropping probability is decreased to a minimum and reasonable value. The dropping probability measured in percentage is about 0.1% as indicated in the result. The GoS decreases with an increase in traffic load (2%). Tradeoffs have to be made between the forced termination probability and number of handoff attempts per call.

Soft handoff promises a better performance than hard handoff, through the exploitation of macroscopic diversity and minimizing the Gaussian noise.

Due to an increase in priority or reservation of sufficient channels for handoff request, dropping probability of a call is decreased to a reasonable level. But an increase in traffic load with decrease in number of reserved channel for handoff call will increase dropping and blocking of a call. The results obtained from this work and its performance measures are valuable for mobile cellular network planning, and to take decision for continues services during communications.

7.2 Future works

To make the communication environment more realistic there is a need to consider the effects of fading and shadowing in the propagation model. It is also possible to extend the study by comparing other Propagation Loss Prediction Models like the Walfisch-Bertoni Model to investigate microcellular environments, effects of structure of the buildings etc. to get a better understanding on the factors effecting system design.

The soft handoff Uniform load distribution and different mobility class of the mobile users need to be considered. Moreover, the trade-off between the benefits coming from soft handoff and the increasing signaling load needs future evaluation as well.

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CHAPTER 5

SYSTEM MODEL AND ANALYSIS.

5.1 System model

5.1.2 Propagation Models

This section outlines the propagation model that will be used to determine the distance between a BS and the MS. Mobile communication is burdened with particular propagation complications, making reliable wireless communication more difficult than fixed communication between and carefully positioned antennas. The antenna height at a mobile terminal is usually very small. Hence, the antenna is expected to have very little 'clearance', so obstacles and reflecting surfaces in the vicinity of the antenna have a substantial influence on the characteristics of the propagation path. Moreover, the propagation characteristics change from place to place and, if the terminal moves, from time to time.

If the received power is strong, it will introduce interference to other users in the cell and degrade their performance. However, if a received signal at the BS is too weak, it will be obscured by stronger signals. The capacity of a CDMA system is maximized if each mobile station is power controlled such that the received signals at the base station are of equal power. In ideal situations, perfect power control can eliminate the near-far effect resulting in less interference affecting the system performance. However, in real systems, power control is not ideal. This thesis assumes ideal power control at the BS. If all users within a given cell are power controlled by the same BS, all users receive the same power.

5.1.3 Hata-Okumura Macroscopic Propagation Models

The most widely used path loss model for signal strength prediction and simulation in macro-cellular environments is the Hata-Okumura model [1, 2]. This model provides an expression of the path loss of the signal transmitted by the BS transmitter (Tx) and received at the MS receiver (Rx) as a function of the distance between the two entities (BS and MS). The following parameters will appear on the path loss equation of this model: The carrier frequency, $f_c \in [150,$

1000] MHz, antenna heights of BS, $h_b \in [30, 200]$ m, and MS height, $h_m \in [1, 10]$ m, and the distance between the BS and MS, $d \in [1,20]$ Km. The path loss in dB is given by [9]:

$L_p(d) = A + B\log_{10}(d)$ for urban area.

Where $A = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_b) - \alpha(h_m)$ and

$B = 44.9 - 6.55\log_{10}(h_b)$. Therefore, for the received signal strength measurements of the mobile from the BS, the Hata-Okumara path loss model is given by [9]:

$$L_p(d) = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_b) - \alpha(h_m) + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d)$$

and $\alpha(h_m)$ is the correction factor for mobile antenna height, and is given by

$$\alpha(h_m) = [1.1\log_{10}(f_c) - 0.7]h_m - [1.56\log_{10}(f_c) - 0.8]$$

This model is however applicable only for a flat urban environment and to make the model applicable to suburban and rural area, a ground cover factor has to be introduced. The ground cover factor is a function of the percentage of the area covered by buildings. To calculate this, a database of buildings and roads is required. A limitation of this model is that it does not consider the structure of buildings and roads.

We also compared the Free Space path loss model with the Hata-Okumura model as shown in figure 6.1. Free space propagation does not apply in a mobile radio environment and the propagation path loss depends not only on the distance and wavelength, but also on the antenna heights of the MS and BS, and the local terrain characteristics such as buildings and hills. The Free Space Path loss equation is given by

$$L(free) = 32.4 + 20\log_{10}(f_c) + 20\log_{10}(d)$$

The average received power at the mobile station is calculated as

$$P_r(d) = EIRP(dB) - L(urban)(dB) + G_r(dB)$$

Where EIRP is the Effective Isotropic Radiated Power (1 kw) and G_r is the gain of the receiving antenna.

5.2 Handoff Resource management

Once a handoff decision has been made, a receiving radio access port (BS) is to be determined. The candidate to become the receiving access port can be selected on the grounds of signal quality. Now the question arises where there are radio resources available in the receiving access port. This could involve the availability of channels. Or the quality in co-channel links in the vicinity of the receiving access port may become too poor to allow the handoff. In such cases the handoff may be denied and either the current access port has to be kept, or a new candidate access port for handoff has to be selected. It is clear that mobile terminals arriving to an access port as a consequence of a handoff complete for the same radio resources with terminals having selected that particular access port in trying to set up a new session. In many applications protecting the ongoing sessions is considered more important than denying new terminals access to the system. In a classical mobile telephony system, it is found to be more detrimental to the users to lose an ongoing call than to block a newly arrived call. The latter reasoning makes it obvious to reserve resources for handoff mobiles such that these resources such as channels, time slots can only be used by mobile terminals performing a handoff and not by newly arriving call set-up requests in the own cell. Such an arrangement is evaluated in the following section.

5.2.1 Call Admission control (CAC)

The performance requirements of users are measured interms of QoS and GoS. QoS is packet level factor which includes packet loss rate, packet delay, packet delay variation, and throughput rate. GoS is a call level factor, which includes new call blocking probability (NCBP), handoff call dropping probability (HCBP), and connection forced termination probability (CFTP). CFTP is a measure of call (connection) being forced to terminate at some point during the lifetime of the connection. In terms of CAC at the call-level, we are more concerned with NCBP and HCDP as GoS measures.

CAC ensures network integrity by restricting access to the network so as to avoid overload and congestion, and to ensure that QoS requirements of all ongoing connections are satisfied. The CAC problem can be phrased as follows. Suppose there are $(N-1)$ ongoing calls. When the N^{th} request arrives, the network calculates the amount of available resources. If there are enough resources to admit the N^{th} call, such that its QoS requirement and those of the ongoing calls are satified, the new request is admitted by a new call or a handoff call.

Before making admission decisions, the CAC algorithm needs to determine the amount unallocated capacity (i.e., the number of basic channels available for accepting new and handoff request). Also, a handoff request tries to maintain service continuity of an ongoing session. If the available capacity for accepting connection requests is limited, handoff call requests are admitted in preference to new call requests. For example, if only one basic channel is available and there are two computing requests, one new and one handoff, the decision should be to accept the handoff request and reject the new request. Thus handoff requests should be offered a higher admission priority than new requests.

Quality of service is measured in terms of call blocking probability and call dropping probability. The call is blocked if there are no available channels. The blocking probability can be obtained from the analysis of an *M/M/n/n* queue. In general, the first *M* indicates call arrivals are modeled as Poison process with arrival rates of λ call/s, the second M refers to exponential service time with mean ${}^{1}\!/_{\mu}$ s/call, the first n refers to the number of channels, and finally, the second n refers to maximum number of acceptable users before blocking occurs. The famous Erlang-B equation (also called blocked calls cleared formula) [21] under the conditions of *M/M/n/n* is given by: $P_B = \dfrac{\left.\left(\lambda/\mu\right)^{n}\right/ n!}{\left.\sum_{k=0}^{n}(\lambda/\mu)\right/ k!}$

5.2.1.1 Prioritized call admission

Handoff calls can be admitted at a higher priority than new calls. To manage the admission of requests based on priority, it is necessary to reserve capacity for admitting handoff requests. Let N_g be the number of basic channels reserved for admitting handoff requests. A common technique to reserve capacity for handling handoff requests is the guard channel method [9]. This is the reason that we assign the subscript g to denote the amount of reserved capacity for accepting handoff requests. Let N_u denote the number of unallocated channels. With the gurad channel method [9], the admission rule is the following: If $N_u > N_g$, admit a new or handoff request. Otherwise if $N_u \leq N_g$, admit a handoff request only.

The above guard channel method is a fixed reservation strategy. One can also introduce dynamic reservation methods to reserve the right amount of capacity to satisfy the demand –supply problem. The dynamic approach would offer higher resource utilization efficiency, but may entail fairly complex parameter estimation issues. For example, if the controller knows exactly the number (or the rate) handoff requests during any epoch, it can determine the value of N_u exactly. This information is never available; at best, the number or the rate of handoff may be estimated.

5.2.2 Capacity reservation and cost of mobility

In capacity reservation scheme, priority is given to handoff requests by reserving η_0 channels exclusively for handoff calls among the total η channels in a cell. The remaining $\eta - \eta_0$ channels are shared by both new calls and handoff requests. The new call is blocked if the number of available channels in the cell is less than or equal to η_0. A handoff request is blocked if no channel is available in the target cell. The system model is shown in figure 5.1.

Both new calls and handoff calls can be assumed to arrive as independent Poisson processes with mean rates λ_N and λ_H respectively. Calls have a lifetime in the cell, that is, they are terminated or leave the cell with in a time interval that is exponentially distributed with average $1/\mu$. So we determine the blocking and dropping probabilities as a function of the traffic load when 50% of the total calls arriving at the cell are handoffs and a total of η channels are available.

Denote the total number of calls in progress in the cell at time t by $N(t)$. Note that whenever a call has arrived and is assigned a channel, it is no longer of any consequence to the number of calls in the cell, whether this call originally was handed off to the cell, or if it was a new call arriving at that cell. Due to the memory-less properties of the Poisson arrivals and the exponential distribution of the call lifetime in the cell, $N(t)$ will be a Birth-Death Markov chain with the state-transition diagram in figure 5.2.

We proceed to derive the stationary state probabilities [14].

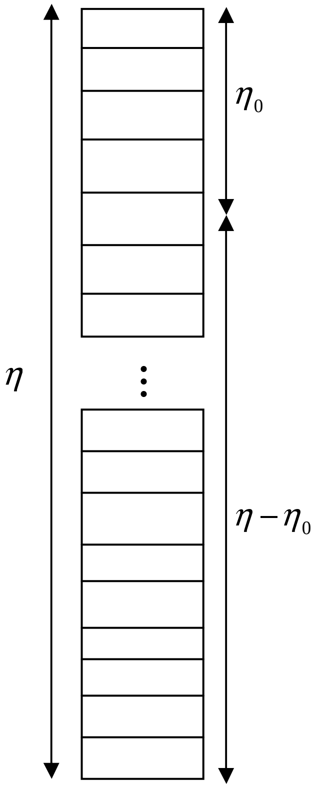

Figure 5.1 Capacity reservation model for handoff call.

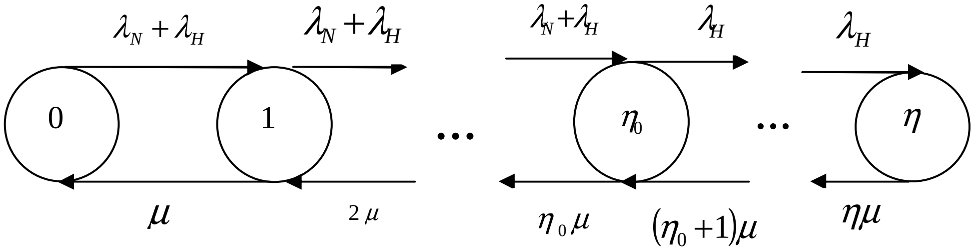

Figure 5.2 State diagram of Markov process for figure 5.1.

By means of the flow cut equations:

$$(\lambda_N+\lambda_H)P_{k-1}=k\mu P_k \qquad 1\le k\le \eta_0$$

$$\lambda_H P_{k-1}=k\mu P_k \qquad \eta_0<k\le\eta$$

Iteratively solving these equations yields

$$P_k = P_0 \frac{(\lambda_N + \lambda_H)^k}{\mu^k k!} \quad \text{for } k \le \eta_0 \text{ else } P_k = P_0 \frac{(\lambda_H + \lambda_N)^{\eta_0} (\lambda_H)^{k-\eta_0}}{\mu^k k!} \quad \text{for } \eta_0 < k \le \eta$$

Using the fact that all P_k add up to unity, we can solve for p_0. Using the notation

$\rho_{tot} = \frac{\lambda_N + \lambda_H}{\mu}$ and $\rho_H = \frac{\lambda_H}{\mu}$ we get:

$$P_k = \frac{\frac{(\rho_{tot})^k}{k!}}{\sum_{j=0}^{\eta_0} \frac{(\rho_{tot})^j}{j!} + \sum_{j=\eta_0+1}^{\eta} \frac{(\rho_{tot})^{\eta_0} (\rho_H)^{j-\eta_0}}{j!}} \quad \text{for } k \le \eta_0$$

Else $P_k = \frac{\frac{(\rho_{tot})^k (\rho_H)^{k-\eta_0}}{k!}}{\sum_{j=0}^{\eta_0} \frac{(\rho_{tot})^j}{j!} + \sum_{j=\eta_0+1}^{\eta} \frac{(\rho_{tot})^{\eta_0} (\rho_H)^{j-\eta_0}}{j!}}$ if $k < \eta_0 \le \eta$

Now deriving the blocking and handoff dropping probabilities yields

$P_{block} = \sum_{k=\eta_0}^{\eta} P_k$ and $P_{drop} = P_\eta$

Defining the relative mobility a as $a = \frac{\lambda_H}{\lambda_N + \lambda_H}$ and evaluating the $\eta = 35$, and a = 0.7, 0.5 and 0.3, figure 6.4 provides the required numerical results.

Figure 6.5, 6.6, 6.7 and 6.8 shows the dependence of the results on the relative mobility, whereas figure 6.9 gives the grade of service (GOS) as $GOS = P_{block} + \alpha P_{drop}$, $\alpha > 1$ is balancing factor for some different values of a. GOS is a measure of the ability of a user to access a trunked system during the busiest hour. The busy hour is based upon the customer demand at the busiest hour during a week, month, or year.

The reservation policy has its limitations, in particular when the traffic load is high and mobile terminals are moving rapidly. On the other hand, in a high-density, high-capacity network, usually the list of candidates for receiving a session in a handoff may be quite long. If the (from a signal quality point of view) best candidate access port is chosen, the session may be rejected due to resource limitation. On the other hand, there may be several candidates that have acceptable (if not the best) signal quality and available resources (channels).

In IS-95 CDMA system, the soft handoff state of a terminal is based on the pilot strength measurement. The active set contains the identifications that the terminal is undergoing soft handoff. There are basically three thresholds that determine the soft handoff status of the terminal, T_add, T_drop and T-tdrop. If the received ${E_c}/{I_0}$ of a pilot channel of a base station in the active set is below T_drop and stays there until a timer expires (T_tdrop), then the connection to the base station is removed. If the received ${E_c}/{I_0}$ of a pilot channel currently not belonging to the active set is above T_add, then the pilot channel is moved to the active set, that is, a new connection is established.

In IS-95 soft handoff, if both threshold T_add and T_drop are increased simultaneously, then the soft handoff region will be decreased, whereas if they are decreased simultaneously, then soft handoff region is increased. By shifting handoff parameters (for example from T_add=-14dB and T_drop=-16dB (Threshold 1) to T_add=-12dB and T_drop=-13dB (Threshold 2)), the handoff rate is obviously decreased. The same phenomenon will happen if the ${E_c}/{I_0}$ from both BSs is either decreased or increased, without changing the thresholds. Thus if the interference amount in the down link side is decreased (or increased ${E_c}/{I_0}$), that is, light traffic load, then the soft handoff region will be enlarged.

CHAPTER 6

SIMULATION RESULTS AND DISCUSSIONS

The performance parameters measured in this work is pilot signal measurement for handoff decision, call-blocking probability, P_b, handoff dropping probability, $P_{d,}$ and Grade of service (GoS). In our simulation results in IS-95 CDMA, figures 6.2 and 6.3 shows variation of received

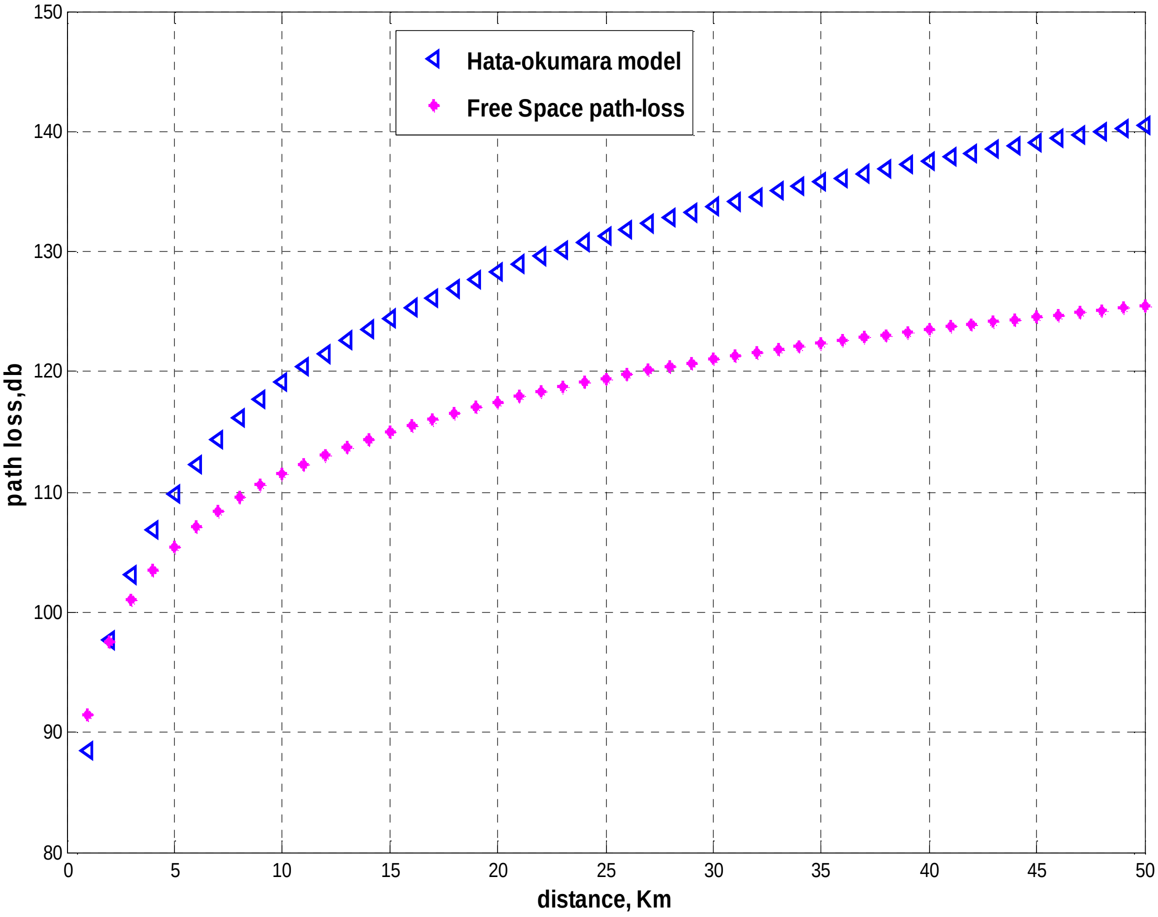

Figure 6.1 Path loss versus distance in Km

Signal strength of the mobile from both base stations when no noise and noise were present in the system respectively, i.e., received power at B without noise, received power at A with Gaussian noise 3 dB and received power at B with Gaussian noise 5 dB.

Okumura-Hata is an empiric model for how the signal strength between a base station and a terminal is attenuated as a function of distance, carrier frequency, base station antenna height and mobile antenna height.

To analyze a slightly more realistic cellular environment two Gaussian noise sequences were introduced. By introducing a hysteresis margin, it is clearly seen that number of handoffs decrease (Figure 6.4 has a hysteresis margin of -5 dB). But in figure 6.3 we see that handoffs taking place at different points than taking place at one place). However excess hysteresis margin

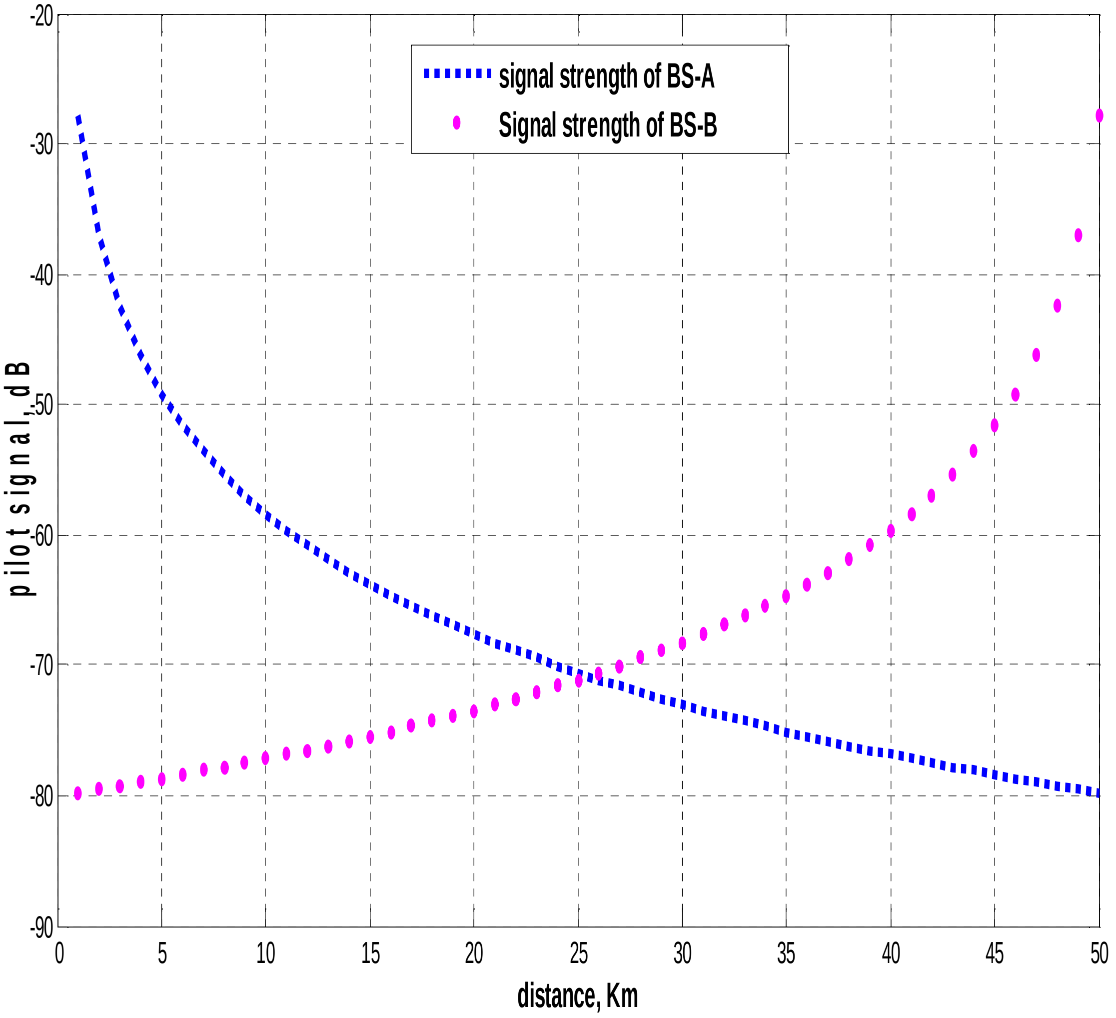

Figure 6.2 Received power at Base stations A and B without noises

will cause an initiation delay. If the delay persists for longer intervals of time the call will be dropped due to deteriorating signal conditions. Clearly, there exists a tradeoff between hysteresis and initiation delay.

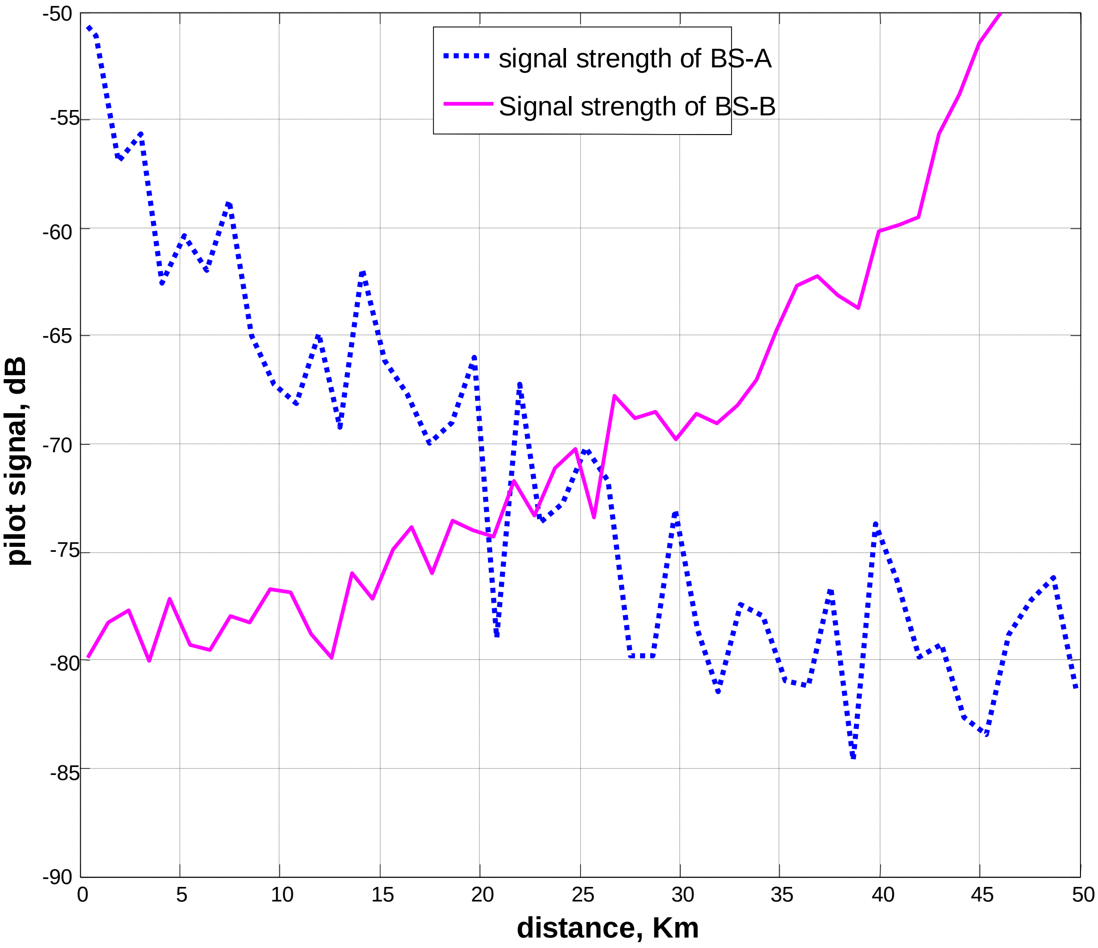

Figure 6.3 Received power at Base stations A and B with noises

Handoff rate is changing according to the traffic density. For example, at midnight, handoff rate (region) is increasing whereas during the busy hours the handoff region shrinks. To avoid such phenomenon, a slightly different scheme has been considered in WCDMA. When the incoming BS's beacon channel power is larger than the current BS by T_add then a new BS is connected and a soft handoff starts. Similarly, when the current BS's beacon channel power is less than that of the incoming BS by T_drop, the connection to the current BS is removed.

It can easily be seen from figure 6.2 that the soft handoff region is invariable to the traffic load and ping pong phenomenon is avoided. But there is a slight variation in traffic load and minimum number of handoffs in figure 6.4.

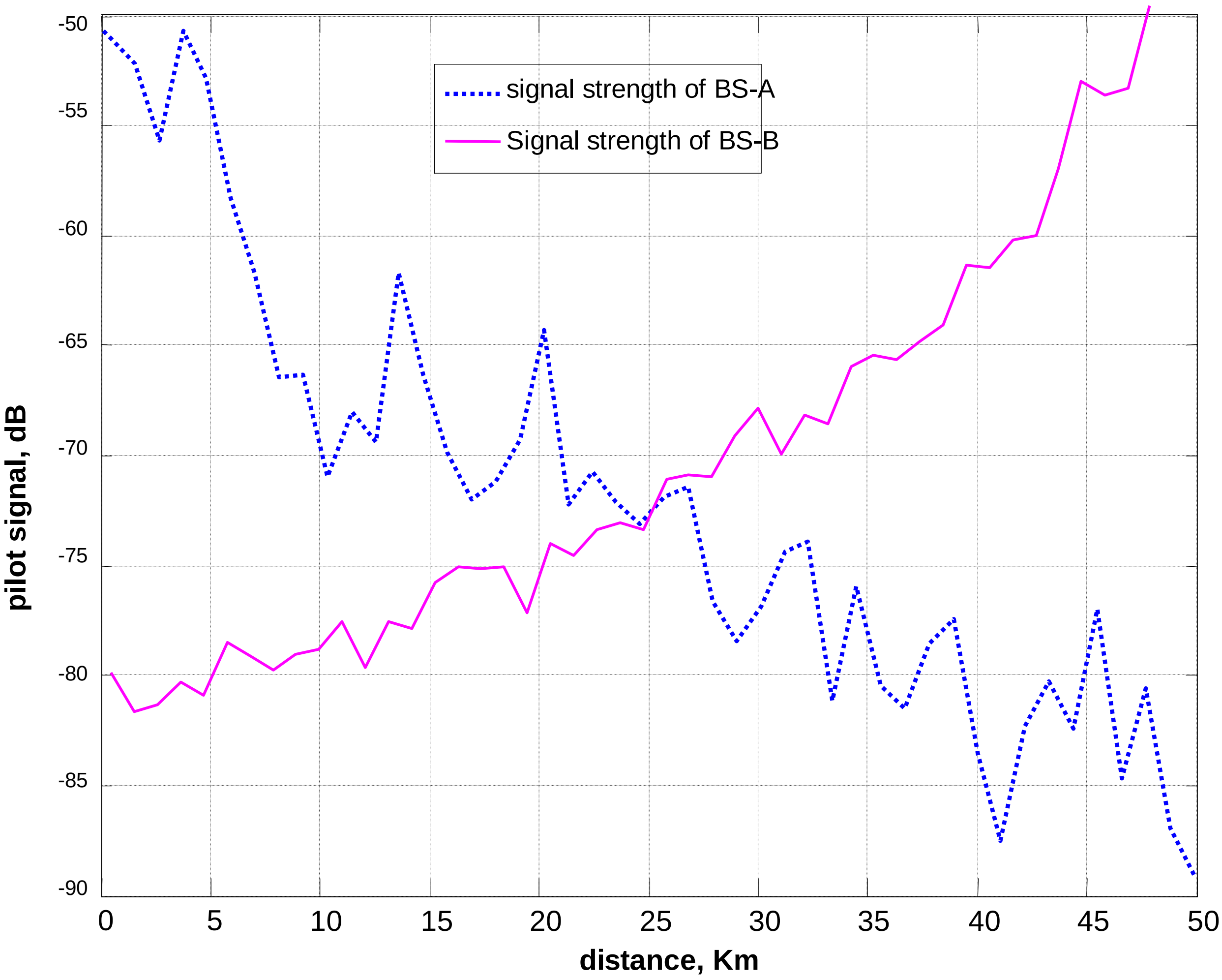

Figure 6.4 Received power at Base stations A and B with equal Gaussian noises of 3 dB.

The simulation observations do show the decrease in the number of unnecessary handoffs on incorporation of an optimum Gaussian noise and hysteresis margin. It also gives an insight of the tradeoffs involved in introducing an optimum hysteresis margin and the associated initiation delays.

An increase in relative mobility will cause an increase in handoff dropping and new call blocking probabilities. Keeping the traffic load constant and varying the mobility will affect the system performances such as blocking and dropping of new and handoff requests respectively.

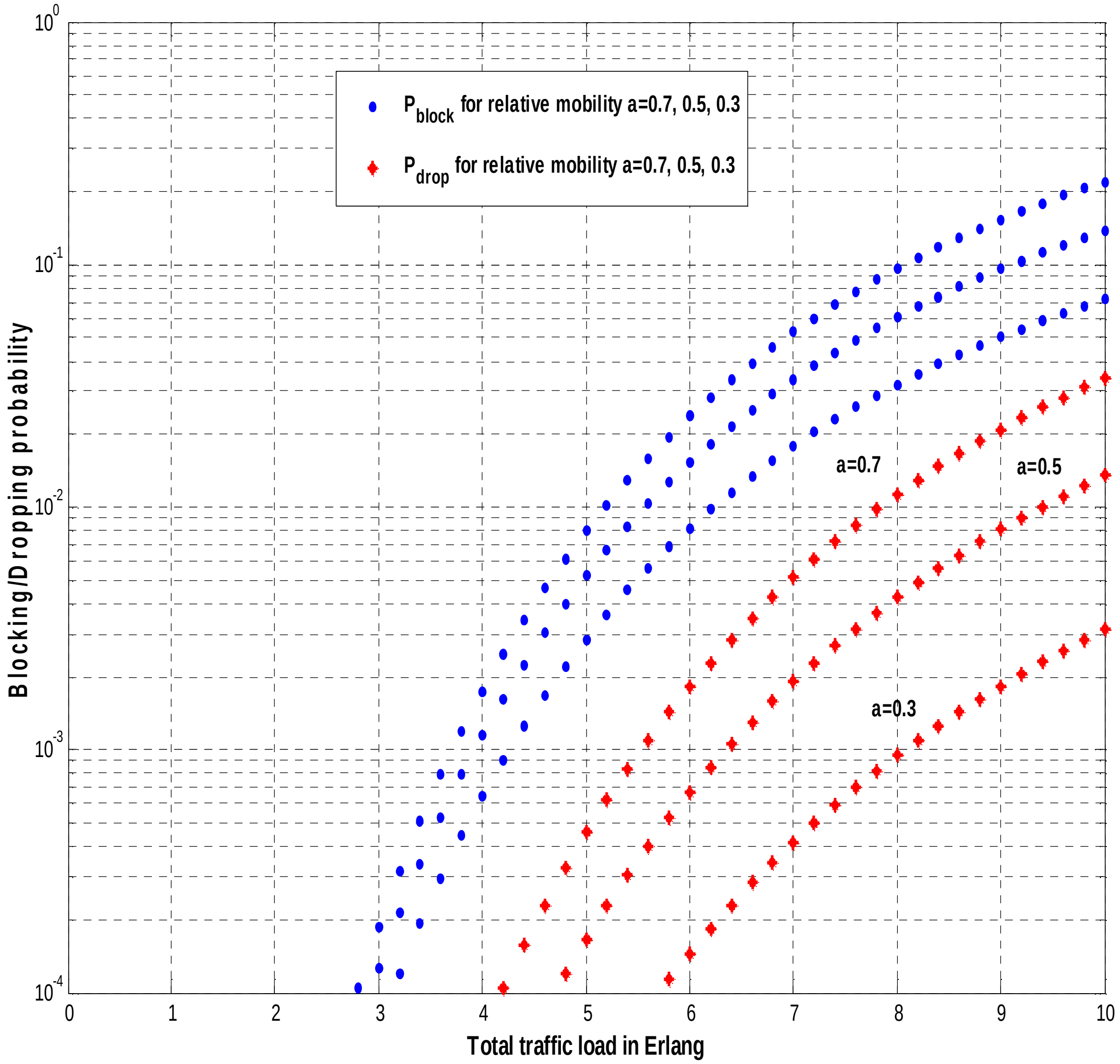

Figure 6.5 Blocking and handoff dropping probability as a function of total traffic load when 3 channels out of a total of η channels are reserved.

From figure 6.5 we can easily realize that at a reasonable increase in traffic load, both the new blocking and handoff dropping probability will increase significantly. Also a decrease in relative mobility will decrease blocking and dropping probabilities of on going calls.

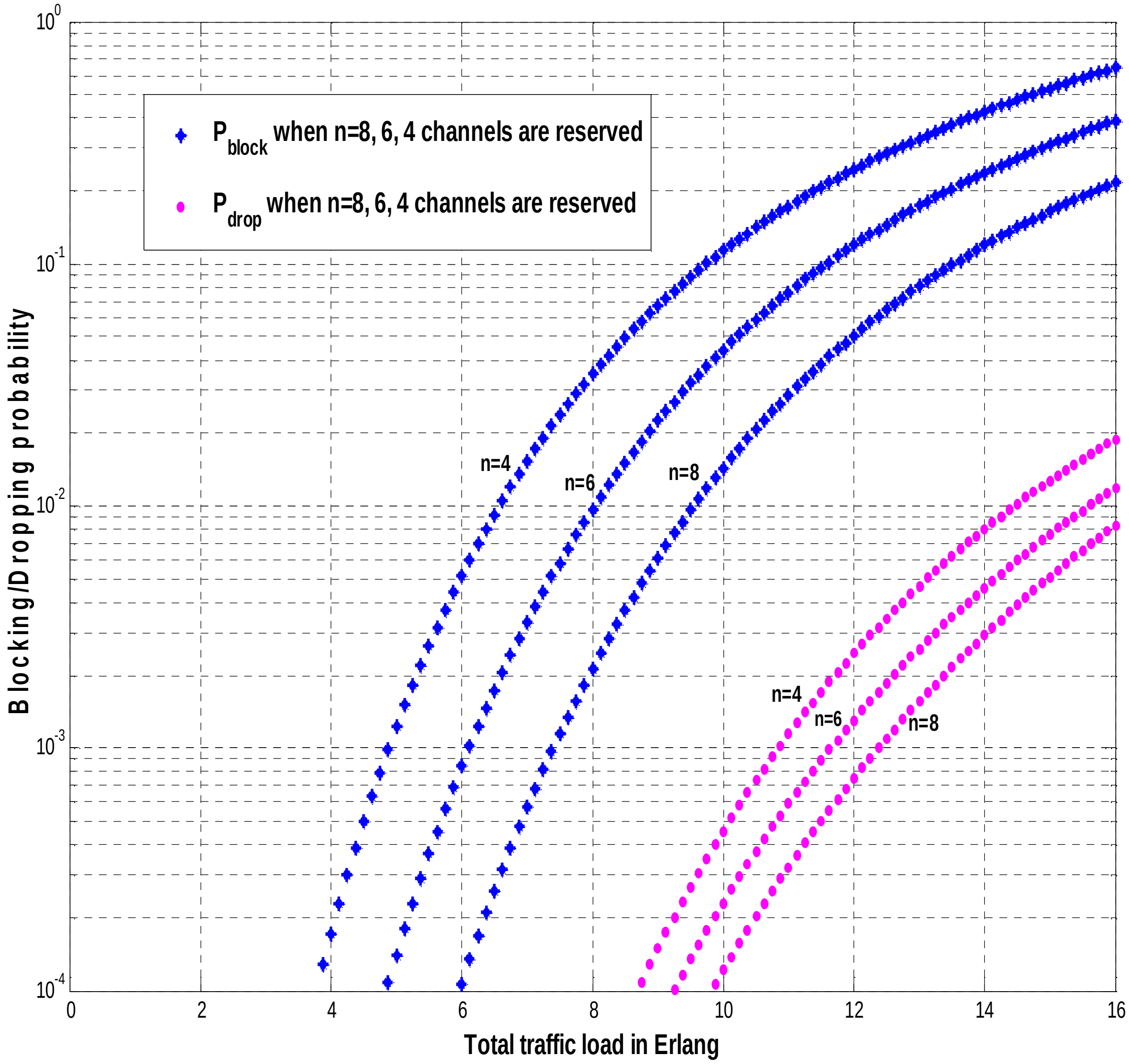

Figure 6.6 Blocking and Handoff dropping probability as a function of total traffic load when η_0 out of a total of η channels are reserved for relative mobility a=0.7

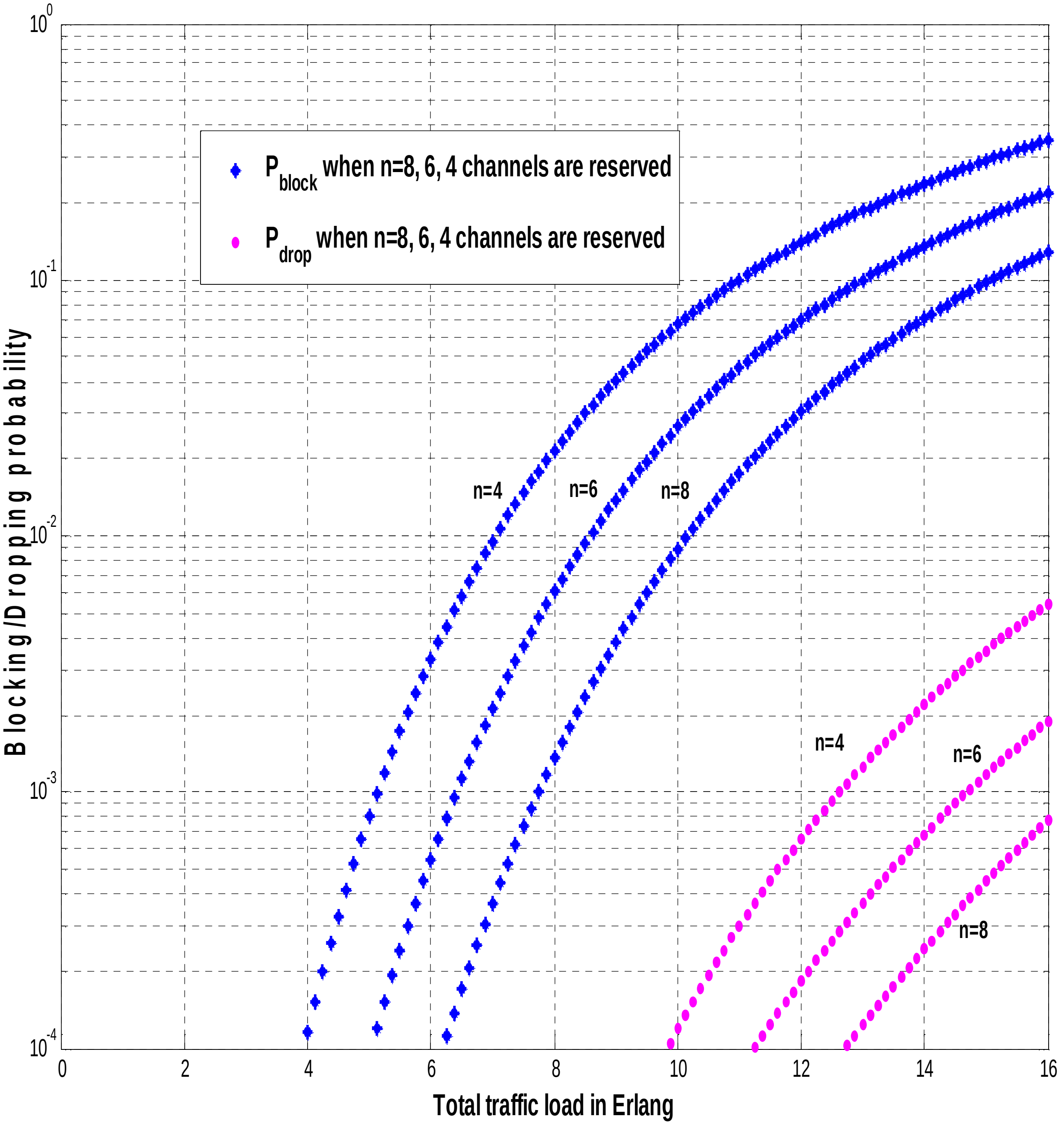

Figure 6.7 Blocking and Handoff dropping probability as a function of total traffic load when η_0 out of a total of η channels are reserved for relative mobility a=0.5

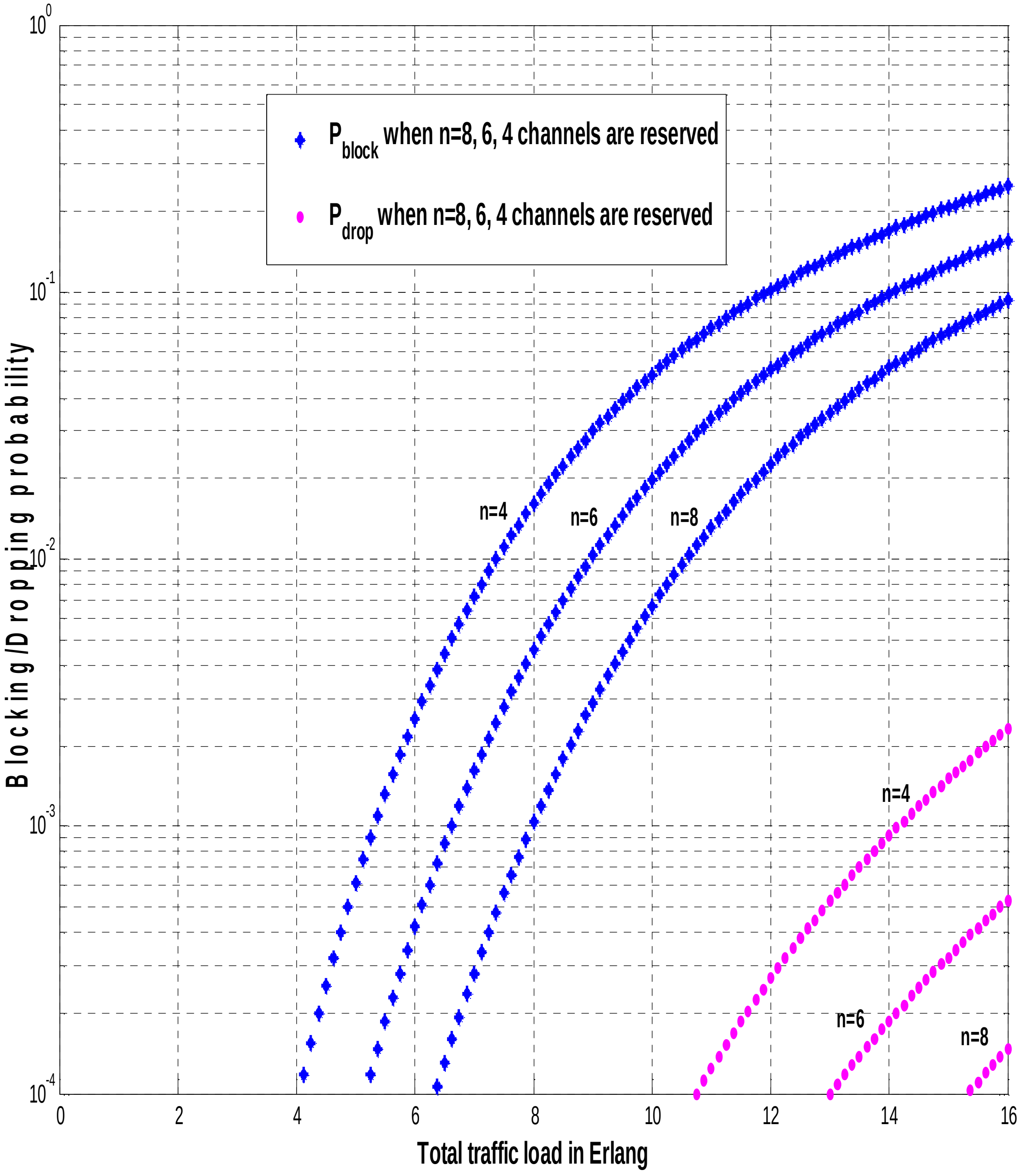

Figure 6.8 Blocking and Handoff dropping probability as a function of total traffic load when η_0 out of a total of η channels are reserved for relative mobility a=0.4

It can be seen that the forced termination probability decreases and tends to a minimum level as the offered traffic decreases. When the offered traffic is low, the forced terminations are mainly due to handoff initiations.

It is observed that unrealistically low forced termination probability is obtained if channel availability is not considered.

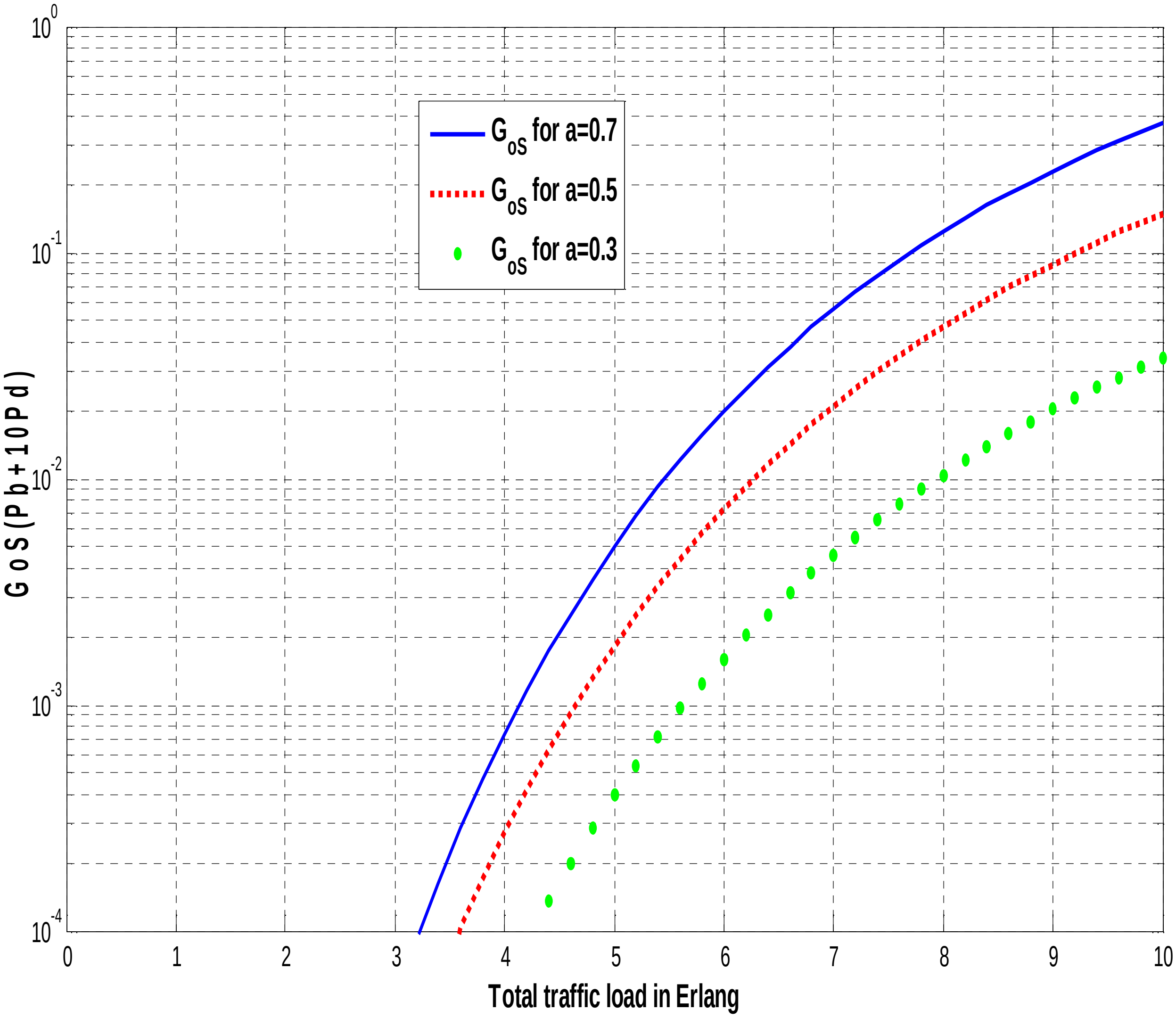

Figure 6.9 GoS as a function of total traffic load when 3 out of a total of η channels are reserved for handoff traffic for different relative mobilities.

Studying the graphs, it is clear that there is a trade-off between blocking of newly arrived calls and handoff calls. If there is a requirement to keep the dropping probability low, more channels for handoff calls have to be reserved. As the relative mobility of the terminals is increased (more handoffs per cell), the required number of reserved channels is getting larger and a smaller fraction of the channels can be used for newly arriving calls. As a consequence the capacity drops. At some given QoS level, a system with highly mobile users, or very small cells, has lower capacity than a system where mobility is lower.

6.1 Performance Measures

In urban mobile radio systems, especially when the cell size becomes relatively small, the handoff procedure has a significant impact on system performance. Blocking probability of originating calls and the forced termination probability of ongoing calls are the primary criteria for indicating performance.

Table 6.1 Blocking Conditions

Channel conditions Signal Conditions	1	2	3	4
M	S	S	S	B
O	S	S	B	B
H	S	B	S	B
J	B	B	B	B

B: Blocked, S: Successful

M: Both signals received from BS- A&B acceptable.

O: Signal received from base station A is acceptable but that received from BS- B is not.

H: Signal received from BS- B is acceptable but that received from A is not.

G: Both signals received from A & B are not acceptable

1: Channel at both BS-A & B is available, 2: Channel at BS-A is available but at B is not

3: Channel at BS- B is available but at A is not, 4: No channels at BS-A & B are available

Table 6.1 summarizes all the cases including those of blocked new call attempts. The number of blocked new call attempts N_B is calculated as follows:

$N_B = N_{M4} + N_{O3} + N_{O4} + N_{H2} + N_{H4} + N_{J1} + N_{J2} + N_{J3} + N_{J4}$

The blocking probability PB is defined by:

$P_B = N_B/N_G$, Where N_G represents the total number of generated new call attempts.

Table 6.2 Dropping Conditions.

Initiation &Channel conditions Signal Conditions	1	2	3
E	C	C	C
F	C	D	D
G	D	D	D

D: Drop, C: continue

E: Signal quality of the current link is acceptable, F: Signal quality of the current link is not acceptable but that of the alternative link is acceptable, G: Both the current and alternative signal qualities are not acceptable

1: Handoff is initiated and there is an available channel in the alternative base station

2: Handoff is initiated and there is no available channel in the alternative base station.

3: Handoff is not initiated

Table 6.2 shows all the cases for which an ongoing call is dropped. Dropping of a call at any time during its intended duration time results in forced termination of the call. Any call, which enters service and is subsequently dropped, encounters one of the events F_2, F_3, G_1, G_2 or G_3. Thus, the number of observed call-dropping events can be calculated as:

$N_D = N_{F2}+N_{F3}+N_{G1}+N_{G2}+N_{G3}$. The forced termination probability, P_{FT} is defined by:

$P_{FT} = N_D/(N_G - N_B)$.

CHAPTER 7

CONCLUSIONS AND FUTURE WORKS

7.1 Conclusion

In this work, the resources such as channels available in IS-95 CDMA under the assumption of power controlled are used. The simulation observations do show the decrease in the number of unnecessary handoffs on incorporation of an optimum hysteresis margin and also gives an insight of the tradeoffs involved in introducing an optimum hysteresis margin and the associated initiation delays.

This thesis shows that handoff initiations as well as channel availability (capacity in CDMA) have significant impact on the forced termination probability. If either one of them is not considered, one may obtain unrealistically low forced termination probability. The simulation results show that new call blocking and handoff call dropping probability with a variation of traffic load. The unnecessary handoffs (the continuous movement of mobiles around a cell corner) attempts per call and the forced termination probability are minimized. Handoff call dropping probability is decreased to a minimum and reasonable value. The dropping probability measured in percentage is about 0.1% as indicated in the result. The GoS decreases with an increase in traffic load (2%). Tradeoffs have to be made between the forced termination probability and number of handoff attempts per call.

Soft handoff promises a better performance than hard handoff, through the exploitation of macroscopic diversity and minimizing the Gaussian noise.

Due to an increase in priority or reservation of sufficient channels for handoff request, dropping probability of a call is decreased to a reasonable level. But an increase in traffic load with decrease in number of reserved channel for handoff call will increase dropping and blocking of a call. The results obtained from this work and its performance measures are valuable for mobile cellular network planning, and to take decision for continues services during communications.

7.2 Future works

To make the communication environment more realistic there is a need to consider the effects of fading and shadowing in the propagation model. It is also possible to extend the study by comparing other Propagation Loss Prediction Models like the Walfisch-Bertoni Model to investigate microcellular environments, effects of structure of the buildings etc. to get a better understanding on the factors effecting system design.

The soft handoff Uniform load distribution and different mobility class of the mobile users need to be considered. Moreover, the trade-off between the benefits coming from soft handoff and the increasing signaling load needs future evaluation as well.

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Matlab code developed for simulation in this research work.

1. Source Code for Hata-Okumara Model

This code is used to Avoid Ping pong effect in Hard handoff.

```
%MATLAB CODE
% Study of a propagation loss  using Okumura-Hata Model , and comparing it with Free space model
% Making analysis for various frequencies and also varying antenna heights
% Velocity is being kept constant, analysis has been done for various distance cells
% The program calculates the path loss and received power for the uplink , downlink and urban environment frequencies
clc
clear all;
hte=150; %height of transmitting base station antenna in meters
hre=1;  %height of receving antenna of mobile station in meters
sdA=3.5; %standard deviation of noise for Base station A
sdB=1; %standard deviation of noise for Base station B
noiseA=sdA*randn(1,50);
noiseB=sdB*randn(1,50);
disp('uplink freq=835 Mhz')
disp('downlink freq=880 Mhz')
disp('urban environment =900 Mhz')
fc=input('Do You want path loss for uplink, downlink or urban environment frequency?=')
fc=800
for d=1:50
```

```
% path loss calculation Between Mobile & Base station A
   LA(d)=(69.55+26.6*log10(fc))-(13.82*log10(hte))-
((1.11*log10(fc)-0.7)*(10)+(1.56*log10(fc)-0.8))+((44.9-
6.55*log10(hte))*log10(d));
   %path loss calculation Between Mobile & Base station B
   LB(d)=(69.55+26.6*log10(fc))-(13.82*log10(hte))-
((1.11*log10(fc)-0.7)*(10)+(1.56*log10(fc)-0.8))+((44.9-
6.55*log10(hte))*log10(51-(d)));
   % path loss calculation for free space model
   LF(d)=32.4+20*log10(fc)+20*log10(d);
   % Received power at A without noise
   SrA(d)=60-LA(d);
   % Received power at B without noise
   SrB(d)=60-LB(d);
   % Received power at A with Gaussian noise sd=3
   PrA(d)=60-LA(d)+noiseA(d) ;
   % Received power at B with Gaussian noise sd=5
   PrB(d)=60-LB(d)+noiseB(d);
end
 figure(1)
 %subplot(2,1,1);
 plot (PrA,'b:');
hold on
plot (PrB,'m-');
axis([0 50 -90 -20]);
xlabel('distance, Km');
ylabel('pilot signal, dB');
legend('signal strength of BS-A','Signal strength of BS-B')
grid
%subplot(2,1,2);
figure(2)
plot(SrA,'b:');
```

```
hold on
plot(SrB,'m.');
axis([0 50 -90 -20]);
xlabel('distance, Km');
ylabel('pilot signal, dB');
legend('signal strength of BS-A','Signal strength of BS-B')
grid
figure(3)
plot(LA, 'b<');
hold on
plot(LF, 'm*');
%axis([0 11 0 250]);
xlabel('distance, Km');
ylabel('path loss,db');
legend('Free-Space-path-loss','Hata-okumara-model')
grid;
```

2. Evaluation of Handoffs in CDMA

A. When channels are reserved for handoff calls

```
%function[]=callblock(a,Atot,ntot,n)
[n1]=input('enter the reserved channnel, n1=');
[n2]=input('enter the reserved channel, n2=');
[n3]=input('enter the reserved channel, n3=');
[Atot]=input('enter the maximum offerd call ,A=');
[ntot]=input('enter the total avalible channels ,ntot=');
[a]=input('enter the relative mobility , a=');
%for a=.2
raa=0:2/Atot:Atot;
n01=ntot-n1;
pdrodpp =[];
pblockpp =[];
```

```
for raa=0:2/Atot:Atot
    pblock=[];
   s=0;
   for j=0:n01
    s=s+raa.^j./factorial(j);
     end;
 for k=n01+1:ntot;
    P=raa.^n01.*(a*raa).^(k-n01)./factorial(k);
    s=s+ raa.^n01.*(a*raa).^(k-n01)./factorial(k);
    pk=P/s;
   pblock =[pblock pk];
   end;
pdrodpp = [pdrodpp pblock(end)];
pblockpp = [pblockpp sum(pblock)];
 end;
 raa=0:2/Atot:Atot;
semilogy(raa,pblockpp,'b*');
hold on
semilogy(raa,pdrodpp,'m.');
hold on
%for a=.5

raa=0:2/Atot:Atot;
n02=ntot-n2;
pdrodpp =[];
pblockpp =[];
for raa=0:2/Atot:Atot
    pblock=[];
   s=0;
   for j=0:n02
    s=s+raa.^j./factorial(j);
     end;
```

```
 for k=n02+1:ntot;
    pk=raa.^n02.*(a*raa).^(k-n02)./factorial(k);
    s=s+ raa.^n02.*(a*raa).^(k-n02)./factorial(k);
    pk=pk/s;
   pblock =[pblock pk];
   end;
pdrodpp = [pdrodpp pblock(end)];
pblockpp = [pblockpp sum(pblock)];
 end;
 raa=0:2/Atot:Atot;
semilogy(raa,pblockpp,'b*');
hold on
semilogy(raa,pdrodpp,'m.');
hold on
% for a=.8
raa=0:2/Atot:Atot;
n03=ntot-n3;
pdrodpp =[];
pblockpp =[];
for raa=0:2/Atot:Atot
    pblock=[];
   s=0;
   for j=0:n03
    s=s+raa.^j./factorial(j);
     end;
 for k=n03+1:ntot;
    pk=raa.^n03.*(a*raa).^(k-n03)./factorial(k);
    s=s+ raa.^n03.*(a*raa).^(k-n03)./factorial(k);
    pk=pk/s;
   pblock =[pblock pk];
   end;
pdrodpp = [pdrodpp pblock(end)];
```

```
pblockpp = [pblockpp sum(pblock)];
 end;
 raa=0:2/Atot:Atot;
semilogy(raa,pblockpp,'b*');
hold on
semilogy(raa,pdrodpp,'m.');
hold off
%title(' probabilty of new call blocking and handoff droping
for different values of reserved channels')
axis([0 raa(end) 1e-4 1]);
xlabel('Total traffic load in Erlang');
ylabel('Blocking/Dropping probability');
legend('P_b_l_o_c_k when n=8, 6, 4 channels are
reserved','P_d_r_o_p when n=8, 6, 4 channels are reserved')
grid
```

B. When different relative mobilities are considered

```
%function[]=callblock(a,Atot,ntot,n)
[a1]=input('enter the relative mobility value, a1=');
[a2]=input('enter the relative mobility value, a2=');
[a3]=input('enter the relative mobility value, a3=');
[Atot]=input('enter the maximum offerd call ,A=');
[ntot]=input('enter the total avalible channels ,ntot=');
[n]=input('enter the number of reserved channels , n=');
%for a=.2
raa=0:2/Atot:Atot;
n0=ntot-n;
pdrodpp =[];
pblockpp =[];
for raa=0:2/Atot:Atot
    pblock=[];
```

```
   s=0;
   for j=0:n0
    s=s+raa.^j./factorial(j);
     end;
 for k=n0+1:ntot;
    P=raa.^n0.*(a1*raa).^(k-n0)./factorial(k);
    s=s+ raa.^n0.*(a1*raa).^(k-n0)./factorial(k);
    pk=P/s;
   pblock =[pblock pk];
   end;
pdrodpp = [pdrodpp pblock(end)];
pblockpp = [pblockpp sum(pblock)];
 end;
 raa=0:2/Atot:Atot;
semilogy(raa,pblockpp,'b.');
hold on
semilogy(raa,pdrodpp,'r*');
hold on
%for a=.5

raa=0:2/Atot:Atot;
n0=ntot-n;
pdrodpp =[];
pblockpp =[];
for raa=0:2/Atot:Atot
    pblock=[];
   s=0;
   for j=0:n0
    s=s+raa.^j./factorial(j);
     end;
 for k=n0+1:ntot;
    pk=raa.^n0.*(a2*raa).^(k-n0)./factorial(k);
```

```
    s=s+ raa.^n0.*(a2*raa).^(k-n0)./factorial(k);
    pk=pk/s;
   pblock =[pblock pk];
   end;
pdrodpp = [pdrodpp pblock(end)];
pblockpp = [pblockpp sum(pblock)];
 end;
 raa=0:2/Atot:Atot;
semilogy(raa,pblockpp,'b.');
hold on
semilogy(raa,pdrodpp,'r*');
hold on
% for a=.8
raa=0:2/Atot:Atot;
n0=ntot-n;
pdrodpp =[];
pblockpp =[];
for raa=0:2/Atot:Atot
    pblock=[];
   s=0;
   for j=0:n0
    s=s+raa.^j./factorial(j);
     end;
 for k=n0+1:ntot;
    pk=raa.^n0.*(a3*raa).^(k-n0)./factorial(k);
    s=s+ raa.^n0.*(a3*raa).^(k-n0)./factorial(k);
    pk=pk/s;
   pblock =[pblock pk];
   end;
pdrodpp = [pdrodpp pblock(end)];
pblockpp = [pblockpp sum(pblock)];
 end;
```

```
 raa=0:2/Atot:Atot;
semilogy(raa,pblockpp,'b.');
hold on
semilogy(raa,pdrodpp,'r*');
hold off
%title(' probabilty of new call blocking and handoff droping
for different values of relative mobilities')
axis([0 raa(end) 1e-4 1]);
xlabel('Total traffic load in Erlang');
ylabel('Blocking/Dropping probability');
legend('P_b_l_o_c_k for relative mobility a=0.7, 0.5,
0.3','P_d_r_o_p for relative mobility a=0.7, 0.5, 0.3')
grid;
```

C. Grade of Servce (GoS)

```
%function[]=callblock(a,Atot,ntot,n)
[a1]=input('enter the relative mobility, a1=');
 [a2]=input('enter the relative mobility, a2=');
 [a3]=input('enter the relative mobility, a3=');
[Atot]=input('enter the maximum offerd call ,A=');
[ntot]=input('enter the total avalible channels ,ntot=');
[n]=input('enter the reserved channel , n=');
%for a=.3
raa=0:2/Atot:Atot;
n0=ntot-n;
pdrodpp =[];
pblockpp =[];
pGoSp=[];
for raa=0:2/Atot:Atot
    pblock=[];
   s=0;
```

```
   for j=0:n0
    s=s+raa.^j./factorial(j);
     end;
 for k=n0+1:ntot;
    pk=raa.^n0.*(a1*raa).^(k-n0)./factorial(k);
    s=s+ raa.^n0.*(a1*raa).^(k-n0)./factorial(k);
    pk=pk/s;
   pblock =[pblock pk];
   pdrop=pk;
   pGoS=pk+ 10*pdrop;
   end;
pdrodpp = [pdrodpp pblock(end)];
pblockpp = [pblockpp sum(pblock)];
pGoSp=[pGoSp pGoS(end)];
end;
 raa=0:2/Atot:Atot;
semilogy(raa,pGoSp,'b-');
legend('G_o_S for a=0.3')
hold on
%a=.5
raa=0:2/Atot:Atot;
n0=ntot-n;
pdrodpp =[];
pblockpp =[];
pGoSp=[];
for raa=0:2/Atot:Atot
    pblock=[];
   s=0;
   for j=0:n0
    s=s+raa.^j./factorial(j);
     end;
 for k=n0+1:ntot;
```

```
    pk=raa.^n0.*(a2*raa).^(k-n0)./factorial(k);
    s=s+ raa.^n0.*(a2*raa).^(k-n0)./factorial(k);
    pk=pk/s;
   pblock =[pblock pk];
   pdrop=pk;
   pGoS=pk+ 10*pdrop;
   end;
pdrodpp = [pdrodpp pblock(end)];
pblockpp = [pblockpp sum(pblock)];
pGoSp=[pGoSp pGoS(end)];
 end;
 raa=0:2/Atot:Atot;
semilogy(raa,pGoSp,'r:');
legend('G_o_S for a=0.5')
hold on
%for a=.7
raa=0:2/Atot:Atot;
n0=ntot-n;
pdrodpp =[];
pblockpp =[];
pGoSp=[];
for raa=0:2/Atot:Atot
    pblock=[];
   s=0;
   for j=0:n0
    s=s+raa.^j./factorial(j);
     end;
 for k=n0+1:ntot;
    pk=raa.^n0.*(a3*raa).^(k-n0)./factorial(k);
    s=s+ raa.^n0.*(a3*raa).^(k-n0)./factorial(k);
    pk=pk/s;
   pblock =[pblock pk];
```

```
   pdrop=pk;
   pGoS=pk+ 10*pdrop;
   end;
pdrodpp = [pdrodpp pblock(end)];
pblockpp = [pblockpp sum(pblock)];
pGoSp=[pGoSp pGoS(end)];
 end;
 raa=0:2/Atot:Atot;
semilogy(raa,pGoSp,'g.');
hold off
%title(' probabilty of new call blocking and handoff droping for different values of relative mobilities')
axis([0 raa(end) 1e-4 1]);
xlabel('Total traffic load');
ylabel('GoS(Pb+10Pd)');
legend('G_o_S for a=0.7','G_o_S for a=0.5','G_o_S for a=0.3')
grid;
```