AN ANALYSIS OF PILOT POWER BASED POWER CONTROL AND DYNAMIC LOAD SHARING IN CELLULAR CDMA NETWORKS

MAHESWARAN SUBRAMANIAM

B.Sc.Eng.(Hons), Computer Science and Engineering,

University of Moratuwa, Sri Lanka

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Ryerson University

Toronto, Ontario, Canada

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Abstract

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Masters of Applied Science,
Dept. of Electrical and Computer Engineering,
Ryerson University, Toronto, Ont, Canada

Power control is one of the most important processes in cellular CDMA networks as the interference is the predominant factor that influences the capacity and signal to noise and interference ratio (SINR). In mobile communication, minimizing the mobile transmitted power subject to maintaining the link quality is a challenging task. In this thesis, a pilot power based power control (PPBPC) algorithm integrated with base station assignment is proposed which is decentralized, uses transmit power control and adapts cell sizes for load distribution.

In the proposed algorithm, each base station transmits its forward link pilot power inversely proportional to the total reverse link received power. The mobile station senses the strongest pilot power received and determines its home base station. Using the proposed algorithm, dynamic propagation of base station assignment occurs which leads to re-assignment of home base stations system-wide reducing the total mobile transmit power. The simulation results are the evidence for the feasibility of the implementation of the algorithm.

It is shown that using the PPBPC algorithm, uniform SINR is achieved for all users in each cell in homogeneous (in terms of required bit rate and bit error rate) user environment and it occurs when the algorithm converges at a load balanced point. Theoretical and simulation results are in very close agreement.

Unlike previously proposed algorithms in the literature, our proposed algorithm does not require prior knowledge of the channel gains between the users and the base stations, and this scheme does not require extensive computation as well. We also investigate the system performance with various load conditions and conclude that the load balanced system performs better than a load unbalanced system. The simulation study shows that in a load balanced system, the maximum received power at the base stations is minimized that leads to interference balancing of the system.

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Dedication

This work is dedicated to my parents, brother, maamaa family, and my friends for their love and support. To all of them for encouraging me each step along the way.

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Chapter 1

Introduction

THE world is demanding more from wireless communication technologies than ever before. In recent years the cellular communications market has exploded. More people around the world are subscribing to wireless services and consumers are using their phones more frequently. The third generation wireless data services and applications such as wireless email, web browsing, digital picture exchange and global positioning system (GPS) applications are more demanding to the radio communication resources.

In order to meet the growing demands of subscribers for different kinds of services, such as conferencing , multimedia, database access and Internet, it is necessary to have higher data rates and more stringent Quality of Service (QoS) requirements. Consequently, new transmission technologies and improved radio resource management techniques such as base station assignment, channel assignment, transmit power control, and handoff are required in cellular communication systems. We will discuss some of the important aspects of the wireless communication system and definitions in this chapter. Now let us see how the wireless communication system has grown over the past decades.

1.1 Historical Overview

In 1979 the first analog cellular communication, Nippon Telephone and Telegraph (NTT) system, became operational. Subsequently, the Nordic Mobile Telephone (NMT) system and the Advanced Mobile Phone Service (AMPS) were introduced in 1981 and 1983 respectively. These systems were based on frequency division multiple access (FDMA) and are known as first generation cellular systems. The first digital cellular standard, the Global Standard for Mobile Communications (GSM), based on time division multiple access (TDMA), was deployed in 1992 in Europe. Two digital standards developed in the United States are IS-54, based on TDMA, and IS-95, based on narrowband direct sequence code division multiple access (DS-CDMA). The first digital cellular system in Japan was Personal Digital Cellular (PDC), introduced in 1994. Now the system has evolved up to 3G standard and it uses a high data rate technology such as CDMA-2000, wide-band CDMA (WCDMA) and time division synchronous code division multiple access (TD-SCDMA). The most important things in the evolution of the wireless communication system are the evolution of the multiple access technologies and other improvements in wireless communications techniques such as base station assignment, channel assignment, power control techniques, and handoff techniques, and etc. Now we will discuss some of the above technologies and techniques briefly [1].

1.2 Multiple Access Technologies

The support of parallel transmission on the reverse link and forward link is called multiple access, whereas the exchange of information in both directions of a connection is referred to as duplexing. Hence, multiple access and duplexing are the methods that facilitate the sharing of the broadcast communication medium. The necessary insulation is achieved by assigning to each user, different parts of the domains (space, frequency, time, code) that carries the signals. The access technologies can be mainly divided into 3 preliminary techniques according to the domains. They are FDMA, TDMA and CDMA.

1.2.1 Frequency Division Multiple Access (FDMA)

FDMA is the division of the frequency band allocated for wireless cellular telephone communication into a fixed number of channels, each of which can carry a voice conversation or, with digital service, carry digital data. FDMA is a basic technology in the analog Advanced Mobile Phone Service (AMPS), the most widely installed cellular phone system in North America. With FDMA, each channel can be assigned to only one user at a time. FDMA is also used in the Total Access Communication System (TACS) [2].

1.2.2 Time Division Multiple Access (TDMA)

Time division multiple access (TDMA) is digital transmission technology that allows a number of users to access a single radio-frequency (RF) channel without interference by allocating unique time slots to each user within each channel. Hence, in TDMA system, the filters at the receivers are simply time windows instead of the bandpass filters required in FDMA. As a consequence, the guard time between transmissions can be made as small as the synchronization of the network permits. Guard times of $30-50\mu s$ between time slots are commonly used in TDMA based systems. As a consequence, all users must be synchronized with the base station to within a fraction of the guard time. It is noted that the GSM uses the TDMA technology [1].

1.2.3 Code Division Multiple Access (CDMA)

There are three common types of spread spectrum techniques such as direct sequence (DS), frequency hopping (FH), and time hopping (TH). The commercial IS-95 CDMA system is specified for reverse link operation in the 824 - 849 MHz band and 869-894 MHz for the forward link. Each user within the cell is to use the same radio channel. IS-95 uses DS method and a baseband signal with bit duration T multiplied with a pseudo random sequence (PN) with a much smaller duration T_c to obtain a signal with a bandwidth that is much larger than the original bandwidth. The shift registers with feedback connections are used to generate this PN sequence practically. Different spreading sequences are used for different users to implement the multiple access. To reduce the interference, the spreading sequence should be orthogonal among themselves, i.e., they have very less cross correlation [1]. The first CDMA network was commercially launched in 1995. It is noted that the spread-spectrum technology is more secure and offers higher transmission quality. Power-controlled multi-cell CDMA increases the cellular system capacity [3].

Interference in CDMA

CDMA systems are interference limited. Therefore, in order to increase the capacity, reducing the interference is important. The interference could be reduced by introducing directional antennas, thereby, dividing the cells into sectors. Dividing the cells into sectors increases the number of base stations, handoffs and system complexity. Introducing microcell zone concept is also another approach in reducing the antennas. Another approach is the activation/deactivation of transmitter. For example, on the average, each voice circuit is active for only a fraction of time due to listening and pauses in speech. The carrier can be turned off during idle periods. In practice, the power is reduced to a non-zero value to facilitate synchronization. This active fraction of time is known as speech activity factor.

The interference can be reduced by implementing power control which is investigated in this thesis. Power control is a single most important system requirement in cellular CDMA networks.

1.3 Thesis Contribution and Organization

In mobile communication, minimizing the mobile transmitted power subject to maintaining the link quality is a challenging task. In this thesis, an integrated pilot power based power control (PPBPC) algorithm with base station assignment is proposed which is decentralized, uses transmit power control and adapts cell sizes for real-time load distribution. The iterative algorithm helps compute the mobile transmit power and perform the base station assignment for each mobile user.

We analyze the behavior and performance of the algorithm and show that uniform SINR is achieved for all users in each cell in homogeneous (in terms of required bit rate and bit error rate) user environment and it occurs when the algorithm converges at a load balanced point. Unlike previously proposed algorithms in the literature, our proposed method does not require prior knowledge of the channel gains between the users and the base stations, and this scheme does not require extensive computation.

We show that the theoretical and simulation results are in very close agreement. It will be seen that using the proposed algorithm, dynamic propagation of base station assignment occurs which leads to re-assignment of home base stations system-wide reducing the total mobile transmit power. The adaptive power adjustment in hot-spot congestion scenario is demonstrated by comparing the sensitivity of the results with another existing algorithm (by Hanly's [4]). We show that the system has flexibility in the required SINR by dynamically adjusting the value of a parameter which depends on two other parameters, namely K_f and K_r, which are used in adjusting the forward and reverse link power respectively.

We investigate the system performance with various load conditions and conclude that the load balanced system performs better than a load unbalanced system. The simulation study shows that in a load balanced system, the maximum power received at the base stations is minimized that leads to interference balancing of the system.

We validate the algorithm by creating appropriate system model and implementing different simulation scenario. The dynamic load sharing and the sensitivity of the algorithm are analyzed by adjusting different system parameters such as different load conditions and total received power ratios. The feasibility of the implementation of the algorithm is also demonstrated.

The thesis is organized in the following way. In Chapter 2 we describe various power control techniques and its importance to CDMA-based mobile communication systems. We also discuss some of the related work in power control in the literature.

In Chapter 3, pilot power based power control (PPBPC) algorithm's system model is described with necessary assumptions. The important parameters and notations that we discuss later in this thesis are also defined.

Chapter 4 details the pilot power based power control algorithm (PPBPC) and its technical details. The important steps of the algorithm and the base station assignment technique are also discussed. This chapter discusses how the SINR balanced system is achieved by implementing this algorithm. We describe the power assignment solution through the matrix transformations. Finally, the load sharing technique is also explained.

Chapter 5 presents the simulation setup and the results. We validate our algorithm's performance in handling the hot-spot scenario by adaptive adjustment of the cell's footprint. The impact on the uniform SINR with the load variations are discussed using the simulation results and the mathematical derivation was validated through the simulation results. We also show that the load balanced system has a better performance than a load unbalanced system. Finally, the sensitivity of the algorithm for various system conditions and adaptation of the proposed algorithm are compared with that of Hanly's algorithm.

The Chapter 6 concludes with a brief discussion about the main contribution of the thesis, and points out directions for future work based on this thesis work.

Chapter 2

Power Control in Cellular Systems

POWER control is one of the most important system requirements in every radio access technology such as FDMA, TDMA and most importantly in DS-CDMA in cellular networks. In most modern systems, both base stations and mobile stations have the capability of real-time (dynamic) adjustment of their transmit power. Proper base station assignment is also important when we investigate the power control.

Power control comprises the techniques and algorithms to manage and adjust the transmit power of base stations and mobile stations. It also serves several purposes, including reducing co-channel interference, managing connection quality, maximizing cell capacity, and minimizing mobile station mean transmit power. The necessity for power control in FDMA/TDMA-based cellular networks was from the requirement for co-channel interference management. This type of interference is caused by the frequency reuse due to limited available frequency spectrum. By proper power adjustment, the harmful effects of co-channel interference can also be reduced. This allows a more "dense" reuse of resources and, thus, contributes to higher capacity. In CDMA cellular systems, one user's desired signal power is interference seen by other users. Hence, reducing the interference is important in cellular CDMA networks.

2.1 Near-far Problem and Overcoming in CDMA Networks

Let us consider the reverse link communication in CDMA networks. The mobiles that are closer to the base station will cause significant interference to the mobiles that are farther from the base station because of very different signal attenuation along with non-zero cross-correlation between signature sequences assigned to users. This effect is known as near/far effect.

The reverse link requires power control primarily to solve the "near-far" problem. All mobile stations transmit the signal on the same frequency channel at the same time but with different codes. Therefore, one mobile station's signal may interfere with others. A mobile's received signal quality at the base station is inversely proportional to the power of the interference from other mobiles. The near-far problem arises when two mobiles at different distances from the base station transmit the signal power at the same level. Due to different propagation loss, the transmitted signal power received at the base station will be different. The mobile near the base station, which has high received signal power, greatly interferes with the distant mobile, which may not be able to be detected.

Power control on the reverse link also deals with the rapidly changing characteristics of multipath fading channels common in urban environment. In this environment, the received power of a typical wireless channel varies dramatically with time for a specific velocity and multipath characteristics. To solve problems encountered in urban environment, the power control algorithm ensures that the received power levels of all mobile stations are the same at the base station. The algorithm does this by controlling the mobile's transmit power. Mobile stations are commanded to transmit at a higher power level when their received power is low, such as when they are far from the base station or when they undergo severe fading. Similarly, mobile stations are commanded to transmit at a lower power level when their received power is high, such as when they are near the base station or when they have line-of-sight. To control power in this manner, the algorithm continuously monitors the received power of each mobile device and continuously adjusts its transmit power to achieve the predefined performance levels, such as bit error rate (BER) or the signal to interference noise ratio (SINR).

Power control adjusts mobile transmit power in such a way that the received power at home base station from every mobile station is almost equal regardless of the locations. This can be clearly shown in Fig. 2.1. Well-defined power control is essential for proper function of DS-CDMA system. In the absence of power control, the capacity of the DS-CDMA mobile system will be very low, even lower than that of mobile systems based on

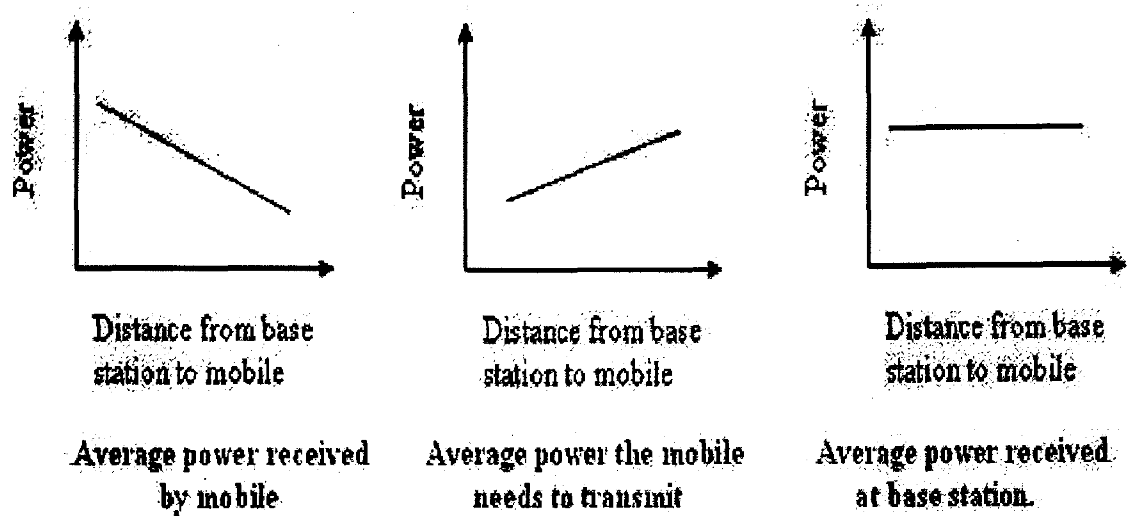

Figure 2.1: Received power level at the base station after power control.

FDMA [5]. One of the reasons for the use of power control is that it reduces the average mobile transmit power. Hence, the mobile's battery life is increased.

According to the above mentioned facts, for proper operation of modern high-capacity cellular radio systems, power control is an essential feature. Power control techniques can be classified into the following categories discussed in the next section.

2.2 Classification of Power Control

Power control can be classified into several categories according to different criteria that are used in the power control method. Fig. 2.2 shows some important classification of power control methods that we discuss in this section.

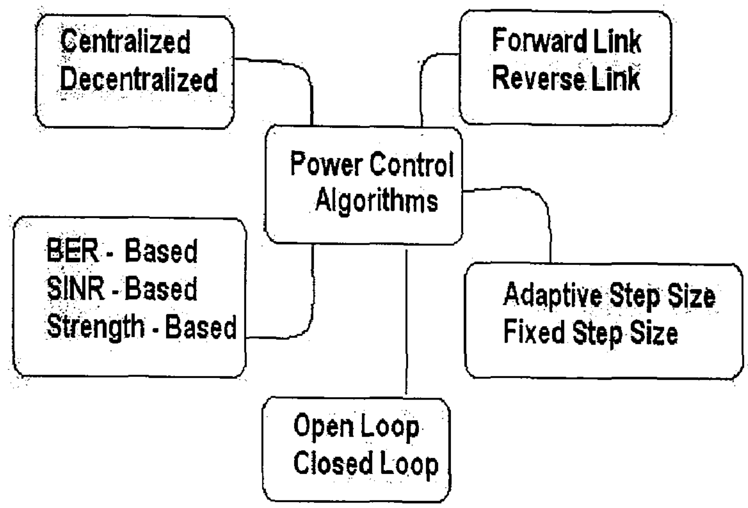

Figure 2.2: Some important classifications of power control.

A. Forward link and Reverse link

Reverse link Power Control

Reverse link power control manages the transmit power on a mobile's access channel and reverse traffic channel. Power control for DS-CDMA reverse link is the most important system requirement because of the near/far effect. CDMA is interference limited; therefore reducing interference is important in increasing the capacity. Power control reduces the average mobile transmitted power as well.

Forward link Power Control

For the forward link, no power control is required in a single cell system, since all signals are transmitted together and hence vary together. However in multiple cell systems, interference from neighboring cells fades independently from the given cell and therefore degrades the performance. Thus, it is also necessary to apply power control in this case to reduce inter-cell interference.

B. Centralized and Decentralized

Centralized Power Control

A centralized controller has all information about the established connections and channel gains, and controls all the power levels in the network or part of the network. Centralized power control requires extensive control signaling in the network and cannot be used in practice.

Decentralized Power Control

A decentralized controller controls only the power of one single transmitter, and the algorithm depends only on local information, such as measured SINR or channel gain of the specific user. These algorithms perform well in ideal cases, but in real systems there are a number of undesired effects. Measuring and control signaling takes time, which results in time delay in the system. The possible output power of the transmitters are constrained due to physical limits and quantized nature. Different external constraints such as the use of maximum power on specific channels affect the output power as well.

C. Strength, SINR and BER based

Strength based power control

In strength based schemes the strength of a signal arriving at the base station from a mobile is measured to determine whether it is higher or lower than the desired strength. The command to lower or raise the transmit power is sent accordingly.

SINR based power control

In the SINR based schemes the measured quantity is the SINR where interference consists of channel noise and multi-user interference. Strength based power control is easier to implement but SINR based power control exhibits better system performance. A serious problem associated with SINR based power control is the potential to get positive feedback to endanger the stability of the system. Positive feedback arises in a situation when one mobile under instructions from the base station to increase its transmit power in order to deliver a desirable SINR to the base station. But the increase in its power also results in an increase in interference to other mobiles so that other mobiles are then forced to also increase their power and so on. We often get infeasible solutions commonly in fixed base station assignment where the mobile cannot change its home base station even if it would be able to have a good link with very less transmitted power with an adjacent base station. If the required SINR is less for a mobile, it has to increase the transmit power to increase the SINR. This increases the interference also. Then again the SINR may reduce. In the case of N mobiles in the system, this becomes a typical non-cooperative N-person game problem where each user is trying to achieve their own goal and one user's goal is an obstacle for the other user [6].

BER based power control

Bit error rate (BER) is defined as the ratio of received bits that are in error, relative to the amount of bits received. Transmit power can be controlled based on BER. If the signal and interference power are constant, the BER will be a function of the SINR, and in this case it is equivalent to QoS. However, in reality the SINR is time-variant and, thus, the average SINR will not correspond to the average BER. In this case the BER is a better quality measure. Since the channel coding is implemented in every practical system, power control can be based on the average number of erroneous frames as well.

$$\frac{E_b}{I_0} = \frac{W}{R} SINR. \tag{2.1}$$

The SINR and $\frac{E_b}{I_0}$ relationship is given in (2.1). The transmission bandwidth W and the transmission rate R are constants in our system model that we will describe later. Therefore, BER can be defined as a function of SINR.

D. Open-loop and Closed-loop

Open-loop power control

In open-loop power control, the mobile's transmit power is determined by measuring the received signal strength of the base station and by estimating the forward link path loss. Assuming a similar (average) path loss for the reverse link, the mobile uses this information to determine its transmitter power. The first time a mobile station transmits, it will do so on its access channel as a reply to a message on the paging channel, or to place an outgoing call. The mobile user estimates the channel state on the forward link, and this estimate is used as a measure of the channel state on the reverse link. These techniques can compensate for path loss and large-scale variations such as shadowing, but it is not possible to compensate for multipath fading because reverse and forward links are generally not correlated.

Closed-loop power control

Closed-loop control involves both the forward and reverse traffic channels, so successful optimization of the algorithm requires the simultaneous analysis and simulation of both of these physical layer channels. Closed-loop power control is feasible in a terrestrial cellular environment. However, in mobile communication systems using multiple low earth orbital satellites, the fades occur too rapidly for the closed-loop power control to track, due to the large round trip propagation delay.

E. Fixed and Adaptive Step Size

Another method of classification is based on whether or not the transmit power step size is made adaptive to the channel variation which increases or decreases the mobile users' transmit power by the actual difference between the received signal power and the desired received signal power. Power control command in fixed step size algorithms is a simple 1-bit command. Adaptive step size algorithm is superior to the fixed step size algorithm. However, the fixed step size algorithm is easier to implement because adaptive size algorithm needs additional bandwidth on the return channel to carry the power control step size instead of the 1-bit control command as in fixed step size algorithm.

2.3 Power Control Literature

In [7], the performance of a CDMA system was analyzed in a mobile satellite environment and it has been shown that CDMA approach provides greater capacity. In [3], Gilhousen *et al.* showed that the power-controlled multi-cell CDMA increases the cellular capacity. Grandhi [8] proposed a centralized power control (CPC) scheme which requires some kind of central controller that needs to have knowledge about all the radio links in the system. Their focus was on maximizing the minimum carrier to interference ratio (CIR) or attaining a common CIR over the network. A CPC scheme was constructed by Zander [9] that has an optimal solution in terms of minimum transmit power. A de-centralized power control implementation was proposed in [10] and [11], and each distributes the power control operation among the users.

This distributed control process was combined with the base station assignment by Hanly in [4] in which an algorithm was presented for controlling mobiles' transmit power levels and also for selecting their home base stations. In this algorithm, each base station measures the total interference in the reverse link in the network. Every mobile station communicates with its surrounding base stations by measuring the interference at each base station. Then it calculates their transmit power to every base station to achieve the required quality of service. Then, the mobile station selects its home base station which requires the minimum mobile transmit power. That is, the mobile station selects its home base station in such a way that the interference is minimized.

In [12], Qiu et al. introduced an algorithm to effectively adjust the size of a cellular area to maximize overall system capacity. When the SINR at the base station is reduced below the required level, the base station reduces the pilot power at a predefined pace. The mobile station chooses its home base station with the strongest pilot power among all received pilot signals. Some subscribers in the overlapping region will be forced to handoff to a less loaded neighboring cell.

In [13], the base station assignment mechanism was performed by estimating the forward link pilot power strength received at the mobile station. In [13], the pilot power transmitted by the base station is inversely proportional to the estimated total reverse link power at the base station. In our work, each base station transmits its forward link pilot power inversely proportional to the total reverse link received power. The mobile station senses the strongest pilot power received and determines its home base station. Deviating from other approaches in the literature, in our scheme, mobile transmits the signal power which is inversely proportional to the received pilot power from its home base station. We will discuss the algorithm in the next chapters in detail.

Chapter 3

System Model and Description

IN this chapter, we detail the cellular mobile CDMA system model with appropriate assumptions for which our transmit power control and base station assignment algorithm is proposed and analyzed. The system parameters and model assumptions needed for establishing the various simulation scenarios are also described in this chapter.

3.1 General System Description

We consider a standard, uniform hexagonal layout of cells with base stations at the center of every cell in the CDMA cellular network. This cellular system consists of N base stations, labelled as *1,2,3....N*. Fig. 3.1 shows hexagonal cell layout that is appropriate for the FDMA channel allocation model as used in AMPS. Here, the frequency is reused in the network where the different numbers denote the different frequency set. The cell

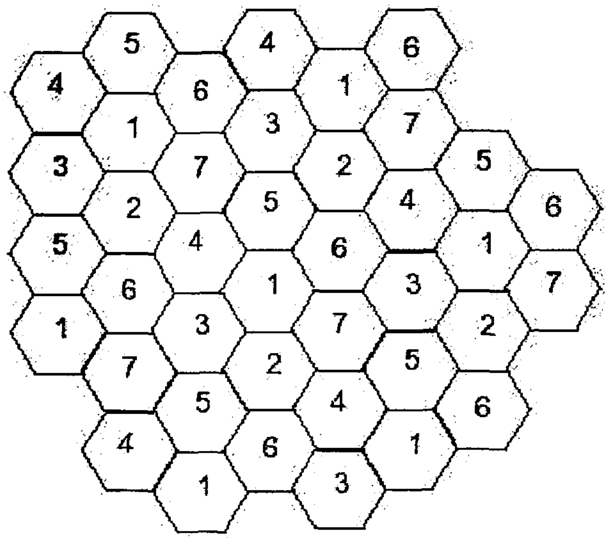

Figure 3.1: Channel allocation model of FDMA in AMPS.

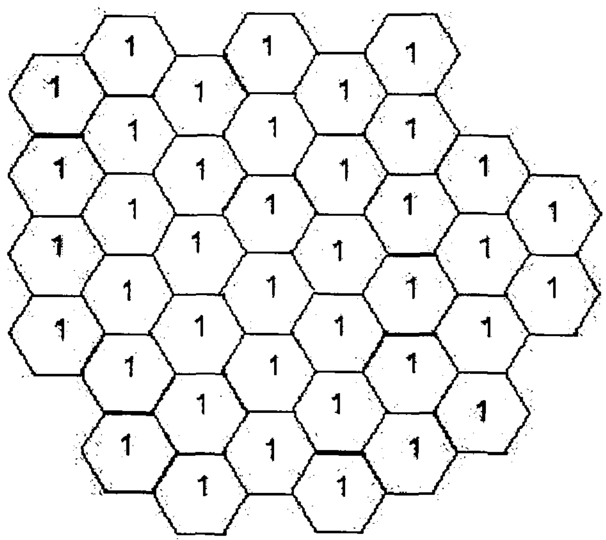

Figure 3.2: Channel allocation model in CDMA.

numbers assigned from 1 to 7 are considered as one cluster. In this system, the same frequency set is reused and a considerable minimum distance is maintained to minimize the effect of the co-channel interference.

The channel or the frequency allocation in our model is the same as used in the IS-95 commercial CDMA channel allocation. That is, all hexagonal cells use the same frequency band. To distinguish one user's transmission signal from another, each user's data symbols are modulated by a unique binary spreading sequence. Fig. 3.2 shows the way the frequency channels are allocated in our proposed model. This figure has a single number "1" assigned to all the cells. That is, unlike in FDMA system shown in the Fig. 3.1, all the channels use the same frequency set. The spreading bandwidth of the channel (in Hz) is denoted by W.

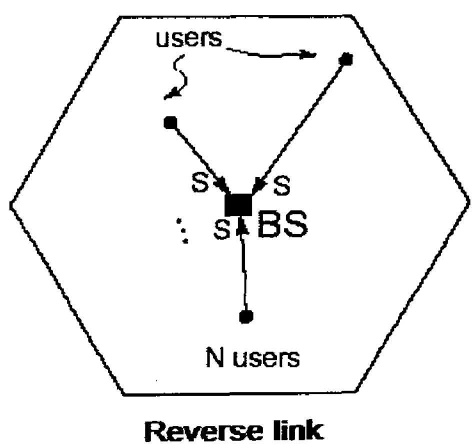

Figure 3.3: Reverse link with power control in a cell.

Our algorithm is proposed to implement the power control for the reverse link only and it adjusts the mobile's transmit power as shown in Fig. 3.3. The power is controlled in such a way that the received signal power at the base station is equal S as shown in Fig. 3.3.

The cellular system model consisting of M users, labelled *1,2,...* M transmits information on the reverse link of a system. Each mobile user is assigned to a particular base station as its home base station. We assume that the users are uniformly distributed within each cell and there are no perfect cell boundaries in the network. The user j communicates with its home base station, $i = b_j$. All the users in all the cells are treated equally in terms of required bit rate and bit error rate. That is, a homogeneous system environment is considered.

In our cellular system model, we do not consider the mobility of the users while implementing the algorithm. No soft handoff is implemented in the system. Therefore, there may be a possibility for excessive number of sudden switching in our model's implementation. However, this effect could be minimized by implementing the soft-handoff in practical considerations. To avoid aggressive switching and unnecessary handoff of very close mobiles to base stations, we assume that there is a minimum threshold level in the forward link pilot power. Hence, the very close users of the base station will always be communicating with its closest base stations. We also assume that our system always operate above this pilot power level limit.

Users are assumed to be in communication with the closest base station by the measured power. If a user suddenly has a good line of sight or if the obstacles were removed, then the user may switch back to a base station with the better-link. More discussion about this issue related with our algorithm will follow in the next chapter.

The thermal noise is present in both the forward and reverse link in a practical cellular CDMA system. We assume that the forward link noise power level is zero throughout the thesis. We consider a large capacity CDMA system, in which multiple access interference is the dominant source of interference in the reverse link. That is, the value of the noise power level is much less compared to the total reverse link interference power at the base station. Hence, we assume non-zero thermal noise power at the base station.

3.2 Radio Channel Model

In the cellular system, the system coverage area is divided into cells and each cell has a fixed base station. The base station serves each cell through its allocated frequency. These frequencies are divided into channels, such as in IS-95 (CDMA) the channel bandwidth is 1.25 MHz with multiple channels. The channels have traffic channels which carry the voice or the data from one mobile station to another and the control channels are used for control purposes.

The received signal level fluctuates as the mobile channel varies with changing environment with time. This behavior is known as fading and the channel is said to be a fading channel. This channel is described by several mathematical models such as probability models and empirical models. The fading is expressed in two major categories as small scale fading and large scale fading [1].

3.2.1 Small Scale Fading

The random phase and amplitudes of the different multipath components cause fluctuations in signal strength, thereby, inducing small-scale fading. The speed of the mobile or the speed of the surrounding objects induce a time-varying Doppler shift on multipath components. These effects dominate the small-scale fading. The small-scale multipath fading could be analyzed by expressing the channel statistically as Rayleigh or Ricean models. But these are out of scope of this thesis and we assume that the multipath components could be considered in the following way in the system.

Fast fading is assumed not to affect the average power level and the proposed algorithm (PPBPC) is implemented fast enough to compensate for it. We assume no Doppler shifts and an immobile network in our system model; hence, no rapid change in the received signal.

3.2.2 Large Scale Fading

Large scale propagation models predict the local average power, that is, the average power of the small-scale variations. Power measurements used to develop these models are averaged over short distances. The models predict power attenuation or received power as a function of large distance variation.

Real propagation occurs in environment where buildings, trees, cars, etc. exist. These objects obstruct the waves and cause additional attenuation than in free space. The radio waves undergo reflection, diffraction and scattering. Due to the complexity of the environment it is impossible to derive theoretically a model which predicts the net resulting wave as a function of a distance in a real environment.

Analysts have resorted to deriving models empirically. Thousands of measurements are taken in a certain class of environment (urban cities, suburbs, rural, indoors, etc). Using statistics tools, the observed power variations are characterized. This type of radio propagation is generally modelled as Radar cross sectional model, distance dependent path loss model, log-normal shadowing model, and Okumura model [1].

Distance Dependent Path Loss

The distance dependent path loss model depends on the transmitter-receiver separation. Our model is described as the distance dependent path loss model. The received power of a transmitter-receiver separation by a distance r in a cellular environment can be represented as

$$p_r = p_t \left(\frac{r_{ref}}{r} \right)^n, \tag{3.1}$$

where p_r and p_t are the received and transmitted power respectively, n is the path loss exponent and r_{ref} is the reference distance. r_{ref} defines a close-in reference distance to which the received signal power at all farther distances can be compared. Table 3.1 shows the typical values of n, which vary depending on different environment [1]. The use of r_{ref} is not strict, and in real channels it will not be necessarily valid, since it depends on the antenna heights and patterns. However, for analysis of CDMA cellular networks, it is necessary to recalculate all of the power levels to some known reference power level, which is considered to depend on r_{ref} [1].

Environment	Path Loss Exponent n
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line of sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Table 3.1: Environment and corresponding path-loss exponent.

This simple model is accurate in areas with little terrain profile variation. Therefore, the model is reasonable for conventional cellular networks which employs antennas in flat service areas. But it is not accurate in ad-hoc kind of broadcast system which employs small cells and low antennas.

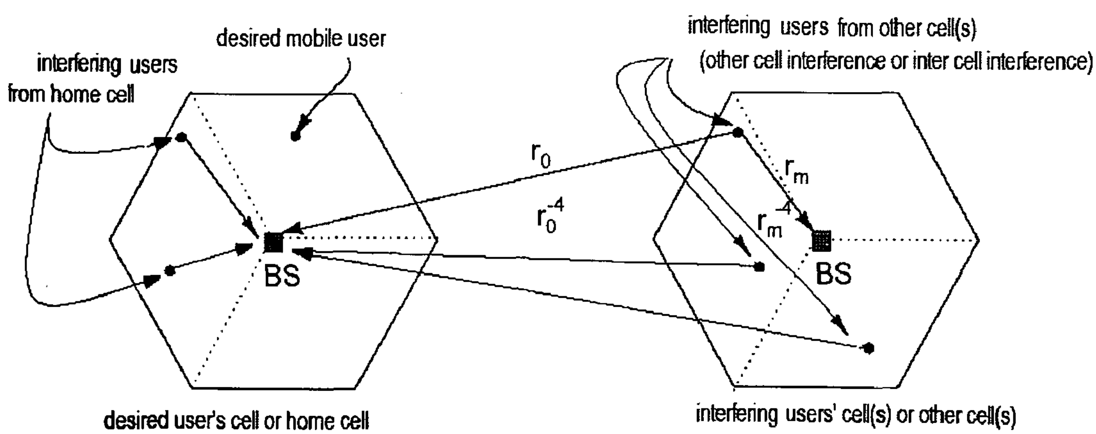

Figure 3.4: Intercell and intracell interference at a base station in the reverse link.

We assume that the large scale fading is due to the distance, and the propagation is obstructed in building environment and the signal is to fade according to $r^{-\alpha}$ law, where r is the distance from the transmitter to the receiver.

Fig. 3.4 shows a 2-cell environment of a cellular CDMA system. If the distance from the home base station to the mobile station is r_m and the distance from other cell base station to the mobile station is r_o, then the desired signal and the interference signal from the mobile is proportional to $r_m^{-\alpha}$ and $r_o^{-\alpha}$ respectively.

Here, the theoretical and measurement based propagation models indicate that average received signal power decreases logarithmically with distance. This model has been used extensively in the power control literature [13]. The average-scale path loss for an arbitrary transmitter-receiver large separation is expressed as a function of distance by using a path loss exponent, n

$$\overline{PL} \propto \left[\frac{r}{r_{ref}}\right]^n,$$

where $\overline{PL}$ is the average path loss between the transmitter-receiver separation of distance r and, r_{ref} is the reference distance in the log-distance path loss model.

The log-normal distribution describes the random shadowing effects which occur over a large number of measurement locations which have the same transmitter-receiver separation, but have different levels of clutter on the propagation path. This phenomenon is referred to as log-normal shadowing. We only assume that the path loss is due to the distance and no shadowing is considered in our analysis.

3.2.3 Handoff in Wireless System

Handoff occurs when a mobile moves into a new cell while a conversation is in progress. The mobile switching center automatically transfers the call to a new channel belonging to the new base station. The handoff process could be initiated by the base station or the mobile station depending on the strategy used. When a higher signal power is received from a different base station or when the received signal power is below a threshold, the handoff process may be initiated. Handoff could be classified as soft handoff and hard handoff.

Hard Handoff

In the hard handoff, the mobile station first releases the previous connection with the base station and it communicates with the new base station. This strategy is known as "break before make". In this type of handoff, the user may hear a click sound when the base station switching occurs. There may be a ping pong effect (oscillation of the home base station assignment) when the mobile is closer to the boundary.

Soft Handoff

In the soft handoff, the mobiles keep communicating with the current base station while it is also communicating with the new base station. This prevents extra switching and helps to increase the reliability. Soft handoff needs the overlapping of base station coverage zones, so that every mobile station is always well within the range of at least one base station.

Soft handoff technology is used by the CDMA system. In CDMA, all base stations use the same frequency channel to communicate with each mobile station, no matter where the mobile is physically located. Each mobile has an identity based on a code, rather than on a frequency or sequence of time slots. Because no change in frequency or timing occurs as a mobile passes from one base station to another, there are practically no dead zones. As a result, connections are almost never interrupted or dropped.

3.3 Problem Statement

Let us denote the mobile transmit power from the mobile user k by $p_k(n)$ in iteration n, then the total received power at the base station i, $Q_i(n)$, is given by

$$Q_i(n) = \sum_{j=1}^{M} G_{ij} p_j(n) + v_i, \tag{3.2}$$

where G_{ik} is the uplink gain from the mobile station k to base station i and v_i is the noise power at the base station i. Then the interference power for mobile user k at base station i is given by

$$I_{ik}(n) = \sum_{j \neq k} G_{ij} p_j(n) + v_i. \tag{3.3}$$

$I_{ik}(n)$ is the total unwanted power at base station i for user k.

It is assumed that W is the spread spectrum bandwidth and R is the required rate of transmission. We assume homogeneous user scenario, which means that all the quality of service requirements such as transmission rate, required SINR are the same for all the users in the network.

The most important parameter for a reliable digital communication system is the bit energy to noise density ratio, $\frac{E_b}{N_0}$. The multiplication of processing gain and the signal to interference ratio will give the bit energy to noise density ratio. One of the ways to measure the quality of the communication of any communication system is the signal to noise interference ratio. Users could also be classified according to their bit rate R and $\frac{E_b}{N_0}$ requirements. Since we consider homogeneous users, SINR is an appropriate tool to quantify the performance.

The signal to noise interference ratio at the iteration index n for the mobile station k at the base station i is given by $SINR_{ik}(n)$ where

$$SINR_{ik}(n) = \frac{p^r_{ik}(n)}{I_{ik}(n)} = \frac{G_{ik}p_k(n)}{\sum_{j \neq k} G_{ij}p_j(n) + v_i}, \tag{3.4}$$

where $p^r_{ik}(n)$ is the desired signal power at base station i for mobile station k at the n^{th} iteration. In order to increase the SINR of a mobile at a base station, the mobile transmit power may be increased. However, the increase in its transmission signal power also results in an increase of the interference to other mobiles, which will force other mobiles to also increase their power. In the case of N mobiles in the system, this becomes a typical non-cooperative N-person game problem. Therefore, proper optimization should be done in selecting the value of the power for each mobile user.

Chapter 4

Pilot Power Based Power Control (PPBPC) Algorithm

OUR goal is to determine (a) home base station and (b) transmit power for each user subject to satisfying the SIR requirement in a cellular CDMA system with homogeneous users while minimizing the total (or average) transmit power in the system. This problem has been studied extensively in the literature. However, we propose an algorithm that (a) is based on pilot power strength, (b) achieves the above goals, (c) is flexible in system operations through the adjustable forward link and reverse link parameters (K_f, K_r - which will be defined later), (d) that achieves uniform SINR in the system via load balancing.

4.1 Iterative Steps in PPBPC Algorithm

In this chapter we present pilot power based power control (PPBPC) algorithm that iteratively adjusts the mobile transmit power and also the cells' coverage area (i.e., base station footprint) in order to decrease the interference power. In every iteration, each mobile selects its home base station and determines its transmitter power which is needed to maintain an acceptable quality of service. Throughout this thesis, we assume that the quality of service is dependent only on the SINR.

The basic idea of this algorithm is, when the base station is heavily loaded, the base station starts directing some of its mobile stations to the lightly loaded adjacent cells by decreasing the pilot signal power, thereby, shrinking the cell size. The algorithm runs as described below.

In PPBPC algorithm, we need the estimation of the received pilot power at the mobile stations and the estimation of total received signal power at the base stations. The algorithm iteratively goes through the following four important steps.

1. *StepI* : **Load measurement**

   In each iteration of the algorithm, every base station estimates the total reverse link received power.

2. *StepII* : **Load adjustment**

   The base station transmits forward link pilot power, which is inversely proportional to the total received reverse link power.

3. *StepIII* : **Home base station assignment**

   Each mobile station senses the strongest pilot power received and selects the base station which sent the strongest pilot power, as its home base station.

4. *StepIV* : **Transmit power assignment**

   The mobile station transmits its signal at a power level which is inversely proportional to the strongest sensed received pilot power.

The algorithm runs through the above 4 steps iteratively until the algorithm converges. Next, we discuss the above steps in detail.

4.1.1 Load Measurement

The base station measures its total received power. This has the reverse link signal power from the mobile stations and the reverse link noise power. It can be expressed as given in (3.2). Since we consider a large capacity CDMA system, the interference power is dominant and it is almost equal to the total reverse link received power. This step helps to determine the congestion level of a particular cell.

4.1.2 Load Adjustment

The base station transmits its forward link pilot power inversely proportional to the total reverse link power received as

$$\rho_i(n) \;\propto\; \frac{1}{Q_i(n)},$$

$$\rho_i(n) = \frac{K_f}{h(n)^* \times Q_i(n)}, \tag{4.1}$$

where K_f is assumed to be a time-invariant constant, which can be used to adjust the forward link pilot power level to the desired operating level, $\rho_i(n)$ is the pilot power transmitted from base station i and $h(n)^*$ is a time-varying constant and it is used as a normalizing factor. However, it should be noted that, at a particular time, the value of $h(n)^*$ is the same for all base stations. The pilot power received from base station i at mobile station k is given by

$$p_{ik}^r(n) = G'_{ik}\rho_i(n), \tag{4.2}$$

where G'_{ik} is the forward link gain from base station i to the mobile station k and $p_{ik}^r(n)$ is the pilot power received from base station i at the mobile station k. By implementing this step, the heavily congested base station is attempting to handoff its more-distanced home users to the neighboring cells, and the lightly congested base stations attempt to accept some adjacent heavily loaded cell's users into its home cell.

4.1.3 Home Base Station Assignment

This step is known as home base station assignment. The mobile station k senses the strongest forward link pilot power received from the base stations, and it selects the base station which transmits the strongest sensed pilot power as its home base station b_k.

$$b_k = \arg\left(\max_i \left[p^r_{ik}(n)\right]\right) = \arg\left(\max_i \left[G'_{ik}\rho_i(n)\right]\right), \quad \forall k. \tag{4.3}$$

In the base station assignment step, for example, in a hot-spot where there is a high concentration of users, the base station reduces its pilot power as in Step II, causing more distant users to link up with their neighboring base stations. So each cell adapts its footprint according to the load distribution. That is, the base station starts directing some mobile stations to lightly loaded surrounding cells by reducing the pilot signal power, thus shrinking the cell size for the load sharing. This nature is known as "cell breathing".

4.1.4 Transmit Power Assignment

In this step, mobile station k transmits the reverse link power inversely proportional to the pilot power $p^r_{b_k k}(n)$ received from its selected home base station b_k. It can be expressed as:

$$p_k(n+1) \;\propto\; \frac{1}{p^r_{b_k k}(n)}, \tag{4.4}$$

$$p_k(n+1) = \frac{K_r}{p^r_{b_k k}(n)} = \frac{K_r}{G'_{b_k k}\rho_i(n)}, \quad (4.5)$$

where K_r is a constant, which can be used to control the reverse link signal power level to the desired nominal range. By substituting (4.1) in (4.5), we will get the following equation:

$$p_k(n+1) = \frac{K_r h(n)^* Q_{b_k}(n)}{K_f G'_{b_k k}}. \quad (4.6)$$

Let $h(n)$ be defined as:

$$h(n) = \frac{K_r h(n)^*}{K_f}. \quad (4.7)$$

Since (4.6) is valid for all the base stations, we drop the cell index b_k and denote it as base station index of i,

$$p_k(n+1) = \frac{h(n)Q_i(n)}{G'_{ik}}. \quad (4.8)$$

Discussion

Users strictly within one cell are limited to communication with the base station in that cell. In this case we assume that the pilot signal power received from other base stations are very weak. They do not have strong pilot power received from surrounding base stations and, therefore, are unable to establish reliable connections. But users in the overlapping region, i.e., between two cells, receive strong enough pilot power from at least two base stations to make reliable communication. In our algorithm the mobile station indirectly measures the traffic load of the surrounding base stations by estimating the pilot signal power strength and determine its home base station. It selects the base station which sends the strongest pilot power as its home base station.

PPBPC algorithm does not need to have the reverse link and the forward link gain information from the mobile station to all the base stations. Appropriate base station assignment allows the mobiles to reduce the transmit power by reducing the congested cell assignment and trying to keep the required SINR above the minimum. This leads to total system interference being reduced and total capacity being increased. Unbalanced interference power requires reallocation of power and reassignment of base stations. For the efficient use of the channel, no more power than necessary is required in meeting the minimum required SINR. Our consideration here is a dynamic propagation of base station assignment based on congestion and it leads to reassignment of the base station system-wide.

4.2 Analysis of PPBPC Algorithm

With regular matrix notations, we define the reverse link power vector as:

$$\mathbf{P}(n) = [p_1(n), p_2(n), \ldots, p_M(n)]^T. \tag{4.9}$$

Then, by defining the channel gain matrix as

$$\mathbf{G} = [\mathbf{G}_{b_k k}]_{M \times M}, \tag{4.10}$$

and

$$\mathbf{D} = [d_{uv}]_{M \times M} ,$$

$$d_{uv} = \begin{cases} \frac{1}{\mathbf{G}'_{b_k k}}, & u = v \\ 0, & u \neq v, \end{cases} \tag{4.11}$$

we can represent (4.8) in matrix form as:

$$\mathbf{P}(n+1) = h(n)\mathbf{DGP}(n) + h(n)\mathbf{DV}, \tag{4.12}$$

where

$$\mathbf{V} = [v_{b_k}]_{M \times 1} , \tag{4.13}$$

and v_i is the noise power at base station i and $i = b_k$. We will analyze $h(n)$ later in this chapter.

Let **A** be an MxM matrix with complex or real elements with eigenvalues $\lambda_1, \lambda_2, ..., \lambda_M$ of matrix **A**. The spectrum of the matrix **A** is all the eigenvalues of the matrix **A**. Then the spectral radius $\varrho(A)$ of the matrix **A** is defined as:

$$\varrho(A) = \max_{1 \le i \le M} |\lambda_i|.$$

Let us consider (4.12) after enough iterations. At the convergence, the mobile transmit power vector reaches a fixed point and the values do not get changed. Hence, $\mathbf{P}(n+1)$

and $\mathbf{P}(n)$ are equal.

Therefore, if we let the iteration index n to approach ∞, (4.12) can be expressed as:

$$\mathbf{P} = h(\infty)\mathbf{DGP} + h(\infty)\mathbf{DV}. \tag{4.14}$$

The matrix $\mathbf{DG}$ is a positive (non-negative) full rank irreducible matrix since each element in $\mathbf{D}$ and $\mathbf{G}$ is a positive random variable. If the spectral radius of $h(\infty)\mathbf{DG}$ is less than unity, i.e., $\varrho(h(\infty)\mathbf{DG}) < 1$, then $[\mathbf{I} - h(\infty)\mathbf{DG}]$ is invertible and positive [14], where $\mathbf{I}$ is the MxM identity matrix. In such a situation, the network is called *feasible* and the optimal solution to the power control problem is given in [15] and [16].

We can find out the optimal power vectors $\hat{\mathbf{P}}$ as follows:

$$\hat{\mathbf{P}} = \Big[\mathbf{I} - h(\infty)\mathbf{DG}\Big]^{-1} h(\infty)\mathbf{DV}. \tag{4.15}$$

It has been shown in [15] that the solution is Pareto optimal. That is, $\hat{\mathbf{P}}$ is a minimal vector among all the feasible solutions. Pareto optimality is an optimality criterion for optimization problems with multi-criteria objectives. A state $\mathbf{A}$ is said to be Pareto optimal, if there is no other state $\mathbf{B}$ dominating the state $\mathbf{A}$ with respect to a set of objective functions. A state $\mathbf{A}$ dominates a state $\mathbf{B}$, if $\mathbf{A}$ is better than $\mathbf{B}$ in at least one objective function and not worse with respect to all other objective functions. Relating to the game theory [17], an outcome of a game is Pareto optimal if there is no other outcome that makes every player at least as well off and at least one player strictly better off. That is, a Pareto optimal outcome cannot be improved upon without hurting at least one player [17].

The SINR at base station i for a particular mobile station k is given by

$$SINR_{ik}(n) = \frac{G_{ik}p_k(n)}{\sum_{j \neq k} G_{ij}p_j(n) + v_i}, \tag{4.16}$$

where v_i is the noise power at the base station i and $p_k(n)$ is kth mobile station's reverse link transmit power.

In the above optimality problem, for the feasibility of the system, the spectral radius of $h(\infty)\mathbf{DG}$ should be less than unity, i.e., $\varrho(h(\infty)\mathbf{DG}) < 1$. Hence we may adjust the value of $h(\infty)$ to reach the required conditions for the optimality. In order to adjust $h(n)$, we can adjust K_f and K_r. However, we cannot adjust those coefficients arbitrarily. Because we have to consider other system constraints such as the maximum transmit power limit of the mobile stations, the maximum pilot power limit of base station and the required SINR requirements.

In general, the value of $h(n)$ may be set equal to the inverse of the norm of power vector. A simple choice can be

$$h(n) = \frac{1}{\| \mathbf{GP}(n) + \mathbf{V} \|} = \frac{1}{\max\{Q_i(n)_{i=1}^{N}\}} \tag{4.17}$$

Let us consider (4.12). In order to find the optimal power vector using eigenvalue problem, we should write this equation in $\mathbf{AX} = \lambda\mathbf{X}$ format with regular matrix notations and the matrix should satisfy the appropriate conditions. Hence, the right hand side of (4.12) should be adjusted properly. We introduce v_0 in (4.9) and define a matrix $\bar{\mathbf{P}}(n)$ as shown in 4.18.

$$\bar{\mathbf{P}}(n) = [\mathbf{P}(n); v_0] = [p_1(n), p_2(n) \ldots p_M(n), v_0]^T, \tag{4.18}$$

where

$$v_0 = \max_i \{v_i\}.$$

We define a matrix $\mathbf{Z}$ from (4.2) and (4.10) as follows:

$$\mathbf{Z} = \mathbf{DG}. \tag{4.19}$$

Let us also define a matrix $\mathbf{C}$ as follows:

$$\mathbf{C} = \mathbf{D}\bar{\mathbf{g}}, \tag{4.20}$$

where $\bar{\mathbf{g}}$ is defined as follows:

$$\bar{\mathbf{g}} = [g_v]_{M \times 1}, \qquad \text{and} \qquad g_v = \frac{v_v}{v_0}. \tag{4.21}$$

Now we create a matrix $\bar{\mathbf{Z}}(n)$ with $\mathbf{Z}$ and $\mathbf{C}$ from (4.19) and (4.20) respectively and define it as described below:

$$\bar{\mathbf{Z}}(n) = \begin{pmatrix} \mathbf{Z} & \mathbf{C} \\ 0 & \frac{1}{h(n)} \end{pmatrix}. \tag{4.22}$$

It is noted that the above definitions in (4.2), (4.9), (4.10), (4.13), (4.18) and (4.22) satisfy the following equation.

$$h(n)\bar{\mathbf{Z}}(n)\bar{\mathbf{P}}(n) = [h(n)\mathbf{DGP}(n) + h(n)\mathbf{DV}; v_0] \tag{4.23}$$

Hence, (4.18) can be written as follows:

$$\bar{\mathbf{P}}(n+1) = h(n)\bar{\mathbf{Z}}(n)\bar{\mathbf{P}}(n). \tag{4.24}$$

Therefore, (4.12) can be made as a single matrix similar to $\mathbf{AX} = \lambda\mathbf{X}$. Hence, (4.8) can be expressed in the matrix form as in (4.24).

Let us consider the O. Perron and G. Frobenius's theory of stochastic matrices [18], [14].

Theorem 1: If the M x M matrix $\mathbf{A}$ is a non-negative and irreducible, then:

(a) The matrix $\mathbf{A}$ has a positive eigenvalue, r, equal to the spectral radius of $\mathbf{A}$;

(b) There is a positive eigenvector associated with the eigenvalue r;

(c) The eigenvalue r has algebraic multiplicity 1.

Let us consider (4.24). At the convergence of the algorithm, the power vector at the n^{th} and $(n+1)^{th}$ iterations are equal. Therefore, we can drop the iteration index n and we assume that n is large enough. Hence, (4.24) can be expressed as:

$$\bar{\mathbf{P}} = h(\infty)\bar{\mathbf{Z}}\bar{\mathbf{P}} \tag{4.25}$$

In (4.25), the matrix $\bar{\mathbf{Z}}$ is non-negative and irreducible. Hence we can apply the Perron-Frobenius theory to find the solution. It can be shown that the existence of unique positive eigenvalue solution to (4.25) together with the corresponding all-positive eigenvectors, is guaranteed by the Perron-Frobenius theory of stochastic matrices [18], [14], [8], [19] and [20].

4.3 SINR Balancing using PPBPC Algorithm

In our system, we assume that the quality of the communication is dependent on the SINR only. The SINR at the iteration index n is $SINR_{ik}(n)$ for the mobile station k at the base station i is given by

$$SINR_{ik}(n) = \frac{p^{r'}_{ik}(n)}{I_{ik}(n)} = \frac{G_{ik}p_k(n)}{\sum_{j\neq k} G_{ij}p_j(n) + v_i}, \tag{4.26}$$

where $p^{r'}_{ik}(n)$ is the signal power of interest received at base station i from the mobile station k. The SINR also can be expressed in terms of the total signal power received at the base station, and the power of interest from the mobile station. That is,

$$SINR_{ik}(n) = \frac{G_{ik}p_k(n)}{Q_i(n) - G_{ik}p_k(n)}. \tag{4.27}$$

If we apply the result in (4.8), we will get the SINR of the mobile station k at n^{th} iteration $SINR_{ik}(n)$ as

$$SINR_{ik}(n) = \frac{Q_i(n-1)h(n-1)\left[\frac{G_{ik}}{G'_{ik}}\right]}{Q_i(n) - Q_i(n-1)h(n-1)\left[\frac{G_{ik}}{G'_{ik}}\right]} \tag{4.28}$$

$$SINR_{ik}(n) = \frac{h(n-1)}{\frac{Q_i(n)}{Q_i(n-1)}\left[\frac{G'_{ik}}{G_{ik}}\right] - h(n-1)} \tag{4.29}$$

At the convergence, i.e., when the algorithm saturates after enough iterations ($n \rightarrow \infty$, theoretically), $p(n-1) = p(n)$. Let us denote the transmit power value at convergence as $p(\infty)$. Therefore, at the convergence of the algorithm, $\max\{Q_i(n)\} = \max\{Q_i(n-1)\}$. For large n, we substitute the result $h(n-1) = h(n) = h(\infty)$ in (4.28), we will get the following equation assuming that the forward and reverse link gain are equal. i.e., $G_{ik} = G'_{ik}, \forall i, k$.

$$SINR_{ik}(\infty) = \frac{h(\infty)}{1 - h(\infty)} = \frac{1}{\frac{1}{h(\infty)} - 1}$$

$$SINR_{ik}(\infty) = \frac{1}{Q_{\max}(\infty) - 1} \tag{4.30}$$

For simplicity, we have assumed that the parameters K_f and K_r are equal and unity.

Also we chose the value for the time varying constant $h(n)^*$ as $h(n)^* = \frac{1}{Q_{\max}(n)}$, where $Q_{\max}(n)$ is the maximum received power among all the base stations in the system at the iteration index n. We apply the above assumptions and get the SINR equation as given in (4.30).

Let us analyze (4.30). The value of SINR is dependent only on $h(n)$. This value is independent of the locations of mobile stations and the base stations. Also this is a unique value for all mobile stations at their respective home base stations. This means that the SINR is balanced system-wide and that is not dependent on the mobiles' signal transmit power or the base stations since we implement transmit power control. As a result, the received signal power at every home base station from its mobile station is equal.

Let us consider this result for two mobile stations j and k at a base station i, and we will get

$$\frac{G_{ij}p_j(n)}{Q_i(n) - G_{ij}p_j(n)} = \frac{G_{ik}p_k(n)}{Q_i(n) - G_{ik}p_k(n)}. \tag{4.31}$$

This implies

$$G_{ij}p_j(n) = G_{ik}p_k(n),$$

$$p_{ij}^{r'}(n) = p_{ik}^{r'}(n).$$

That is, the received power at a base station from all its home users is equal in the SINR-balanced system. We assume that the pilot power strength should not be reduced further below a minimum value. This is to ensure that the critical situations are minimized. That is, mobile transmit power does not converge to zero or diverge to infinity.

4.4 Load Sharing using PPBPC Algorithm

Managing the system resources efficiently is one of the most important requirements in any engineering design. Load sharing is essential in handling large capacity CDMA communication system. When a base station is heavily loaded with mobile stations, the heavily loaded cell may need additional resources than the allocated resources. Hence, the system needs to block additional users which cause the extra congestion. However, at this time, the neighboring cells may have system unused resources. Hence, if the load is shared among the base stations, then there may be opportunities for the additional users to be accepted by the system rather than blocking.

In the proposed pilot power base power control algorithm, when the base station is heavily loaded with the mobile stations, the total received power at the base station will be relatively high. Then the algorithm reduces the forward link pilot signal power comparatively as the load is inversely proportional to the pilot power. Hence, the more distanced users of the congested base station will link up with the adjacent base stations. That is, the hot-spot cell by lowering the pilot signal power, thus shrinking the cell size can distribute the more distanced users to its adjacent base stations. Then the capacity can be increased. That is, the system could adapt itself according to its traffic distributions.

4.5 Limitations of PPBPC Algorithm

The most important aspect of the communication system is the achieved quality of service. Throughout the algorithm, it does not have a direct control of the deliverable quality of service requirements. Therefore, there is a possibility for the total system to suffer as the achieved system-wide uniform SINR goes below the required threshold. One way to overcome this problem is to block the new connections or disallow for the handoff when the SINR is dropped below the required level. Another way is to adjust the time-varying constant coefficients such as K_f, K_r and $h(n)^*$ to bring the SINR to the required level by maintaining the other constraints, which is a complex problem and can be further researched.

Since this algorithm does not check the achievable quality of the communication, a detailed statistical analysis is important in the performance analysis of system. Since the abnormal mobility of users or increased number of calls in any abnormal event (less probable) can also make the entire system to fail. Therefore, thresholds combined with an appropriate call admission control mechanism should be introduced in this system.

Chapter 5

Performance Evaluation

IN order to verify the analytical results in implementing the pilot power based power control algorithm, we performed simulation studies. In this chapter, we describe how the simulation was done and discuss the results. The objective of the simulation is to determine the validity and the performance of the proposed algorithm. It also helps to determine the sensitivity of the system performance with subscriber and network load conditions in using the proposed algorithm.

5.1 Simulation Setup

We describe the simulation setup with parameters here.

- The system bandwidth is $W = 1.25$ MHz as in IS-95. The bit rate requirement is 8000 bits/sec as the voice transmission is considered.

- We assume a cellular network with 36 base stations.

- The cells are assumed to be square in shape. We marked each base station's position by X and Y co-ordinates in the system coverage area. The base stations are located at integer points (x,y), x=1,2,3.......6, y=1,2,3....6. For example, the cell corresponding to base station (4,4) is the square region of coordinate points [3.5,4.5] and [3.5,4.5].

- It is assumed that the base station is located at the center of each square cell, i.e., at the diagonal crossing point of the cell.

- We uniformly distributed 400 users throughout the network, i.e., over [0.5,6.5] X [0.5,6.5]. We assume that all the distributed users are actively participating in the conversations (i.e., activity factor=1).

- The more distanced user from the base station is along the diagonal corner of the cell. We normalize the distance in such a way that the more distanced user's transmitter-receiver separation to be unity. Hence, the density of users is $\frac{M}{72}$ per unit area, where $M(=400)$ is the total number of mobile stations actively participating in the conversations.

- It is assumed that the path loss exponent α is 4. Also we assume that the link gain is only dependent on the distance and it is given by $G_{ik} = 1/d_{ik}^4$, where d_{ik} is the distance between user k and the base station i.

- In our simulation, we assume that the effect of fast fading is mitigated by several techniques such as introducing RAKE receiver, channel coding etc. Therefore, we do not consider the fast fading factors in the model.

- The multiple access interference (MAI) is the dominant interference in our system. We assume that our system is sufficiently loaded with the users.

- The forward link gain G' and the reverse link gain G are assumed to be equal in our simulation model. Since we considered the distance dependent path loss only, for a particular uniform distribution of the users, G' and G are equal through all the iterations of the algorithm.

- We assume that the initial home base station that a mobile links up with is by the strongest pilot power strength. Also the algorithm starts by transmitting an equal amount of pilot power from all the base stations.

- Throughout the simulation, we assume that the thermal noise is present in the reverse link and we do not consider the forward link noise power.

- We do a snap-shot analysis in a network under different load conditions.

- In our simulation, the PPBPC algorithm runs for 20 iterations for a particular immobile situation. These 20 iterations are for a particular instance of a distribution of users in the network. The results are analyzed after the algorithm saturates.

- Soft handoff is not considered in the system. Instead, every mobile station is assigned to only one base station at any time according to the pilot power strength received. No actual handoff is implemented, rather, all the mobile stations are assigned to base stations in every iteration, hence the mobile stations may switch between base stations during the running of the algorithm.

- We created a hot-spot around (4.0,4.0). That is, in the region [3.5,4.5] X [3.5,4.5], we added extra 20 users by distributing them uniformly. The goal is to analyze the behavior of the algorithm in and around the hot-spot.

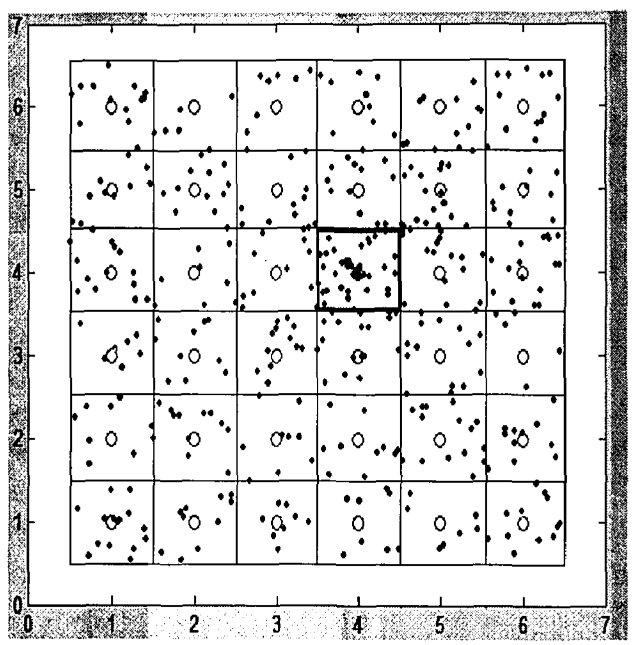

Figure 5.1: The grid cell layout with a hot-spot cell around (4,4).

Fig. 5.1 shows the physical layout of the cellular network: square grid cells, base stations at the center of the cells, the uniform distribution of the mobile users and the hot-spot cell congested with additional users. Around the base station (4,4), there are

20 additional users uniformly distributed. Hence, the hot-spot cell has more density of users as shown in Fig. 5.1.

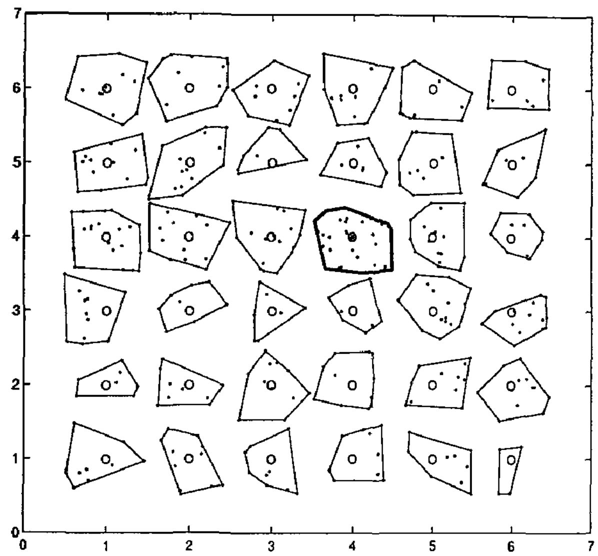

Figure 5.2: Hot-spot before PPBPC algorithm is implemented.

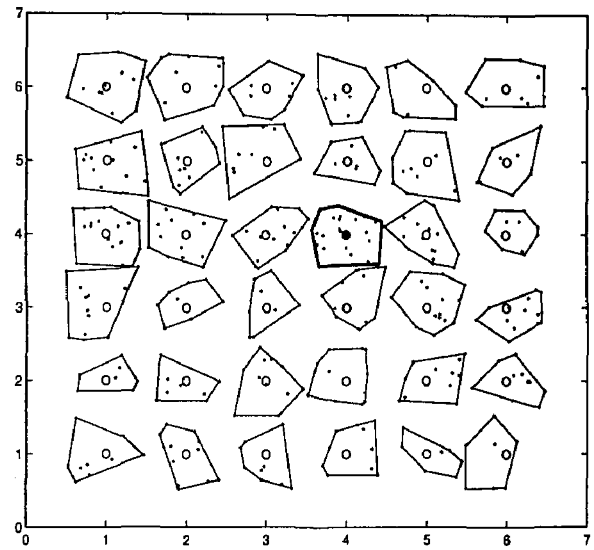

Figure 5.3: Hot-spot after 1 iteration of PPBPC.

Fig. 5.2 shows the initial base station assignment in the simulation before the algorithm starts to run. In the figure, a dot, '·' indicates a mobile station and a circle 'o' denotes a position of a base station. The base stations are equally spaced and placed at the center of the square grid where the diagonal distance square is 2. The highlighted cell '⊗' is the hot-spot base station which is heavily loaded with extra 20 users.

5.2 Simulation Results

Fig. 5.2 shows the initial base station assignment across the network. Initially, an equal amount of pilot signal power is transmitted from all the base stations. Since each mobile station assigns its home base station based on the received pilot power strength, the base stations are assigned proportional to the distance. The more distanced home users of every base station is connected together by the encircling line, and this closed area is considered as a cell's footprint.

5.2.1 Cell Breathing

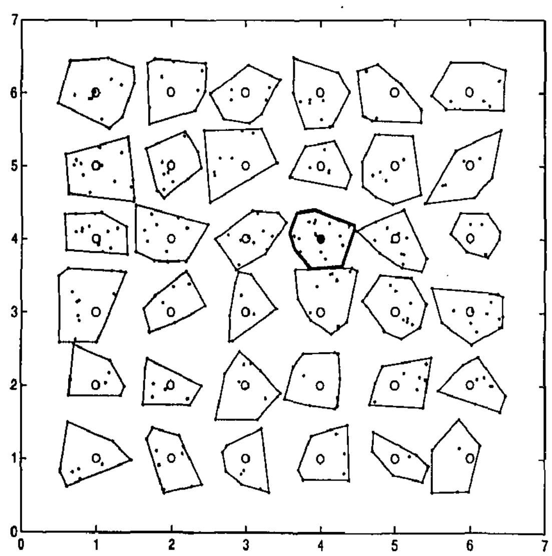

Figure 5.4: Hot-spot after 2 iterations of PPBPC.

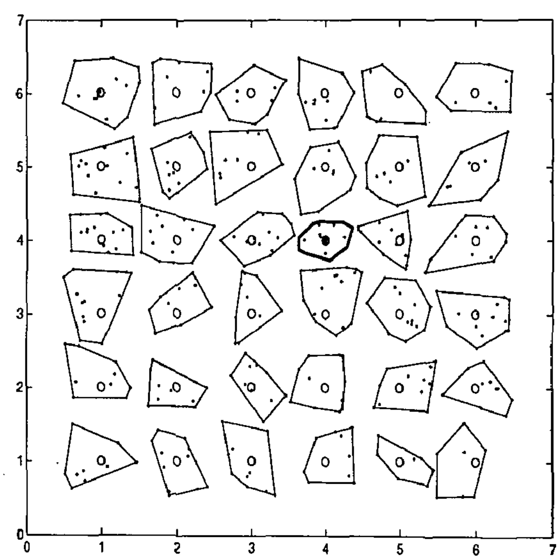

Figure 5.5: Hot-spot after 4 iterations of PPBPC.

Figs. 5.2 to 5.7 show the cell's footprint with the number of iterations. Initially, the hot-spot cell's more distanced users switch to the neighboring cells around the hot-cell (4,4). The adjacent base stations of the hot-spot base station are located at (3,3), (3,4), (3,5), (4,3), (4,5), (5,3), (5,4) and (5,5). Then the cell breathing occurs at the adjacent cells around the hot-spot.

Fig. 5.2 through Fig. 5.7 show the initial through the final base station assignment for a particular mobile user distribution in an immobile network. The size of the hot-spot was initially large (see Fig. 5.2) with 20 additional users. Hence, the total received power at the hot-spot base station was higher than that of the adjacent base stations. Later, the hot-spot base station reduces its pilot power, shrinking its coverage area and allowing the more distanced users to link up with the adjacent base stations. That is, the PPBPC algorithm attempts to distribute the overload to the adjacent base stations.

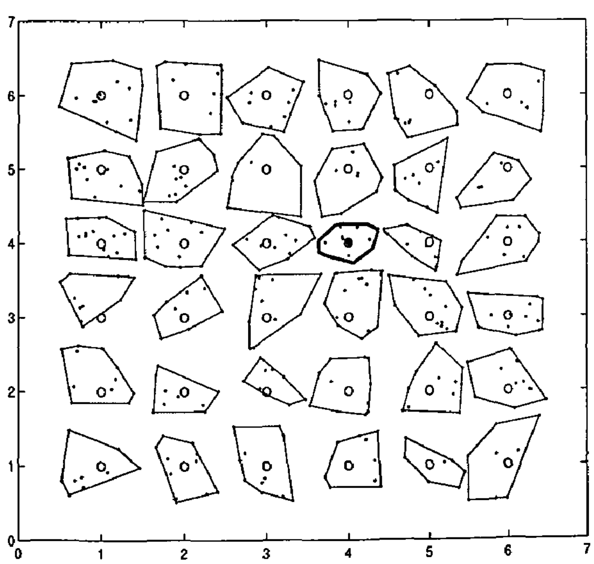

Figure 5.6: Hot-spot after 13 iterations of PPBPC.

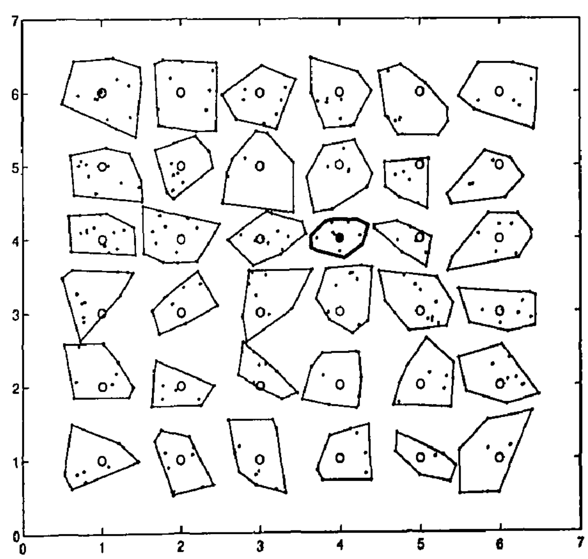

Figure 5.7: Hot-spot after 19 iterations of PPBPC.

Fig. 5.3 and Fig. 5.4 show the base station assignment and cell coverage area of the system after the 2^{nd} and the 4^{th} iterations of the algorithm respectively. In these figures, the size of the hot-spot base station is reduced in size and the more distanced mobile users are connected to the lightly loaded adjacent base stations. This clearly shows that the load is shared when the PPBPC algorithm runs with time iteratively.

Fig. 5.6 and Fig. 5.7 further show the system footprint and the base station assignment after the 13^{th} and 19^{th} iteration of the algorithm respectively. In these figures, the hot-spot size does not change significantly. However, some of the other cells which are away from the hot-spot cell have some changes in their footprint. This is due to the fact that those base stations are trying to distribute their load to their adjacent lightly loaded cells.

Since we considered the immobile network, the users are assumed not to be moving and the algorithm is running fast enough to compensate the fading effects on the signal power. Fig. 5.7 shows the final base station assignment after the algorithm saturates. There is no significant change occurred after this situation. This is one of the evidences that the PPBPC algorithm with the base station assignment converges.

5.2.2 Short Term Handoff During Algorithm Implementation

Initially, some of the hot-spot cell users switch into the neighboring cells around the hot-spot cell (4,4). As we have seen previously, the cell breathing would be propagated to the other neighboring cells of these cells.

We can also see the total number of switching vs the number of iterations in Fig. 5.8. Another evidence for the saturation of the system is that the total number of switching with the number of iterations. There is no switching after some iterations in Fig. 5.8. That is, the system saturates after some iterations. This clearly shows that the base station switching occurs as soon as a hot spot is detected in the system and after some iterations the switching converges.

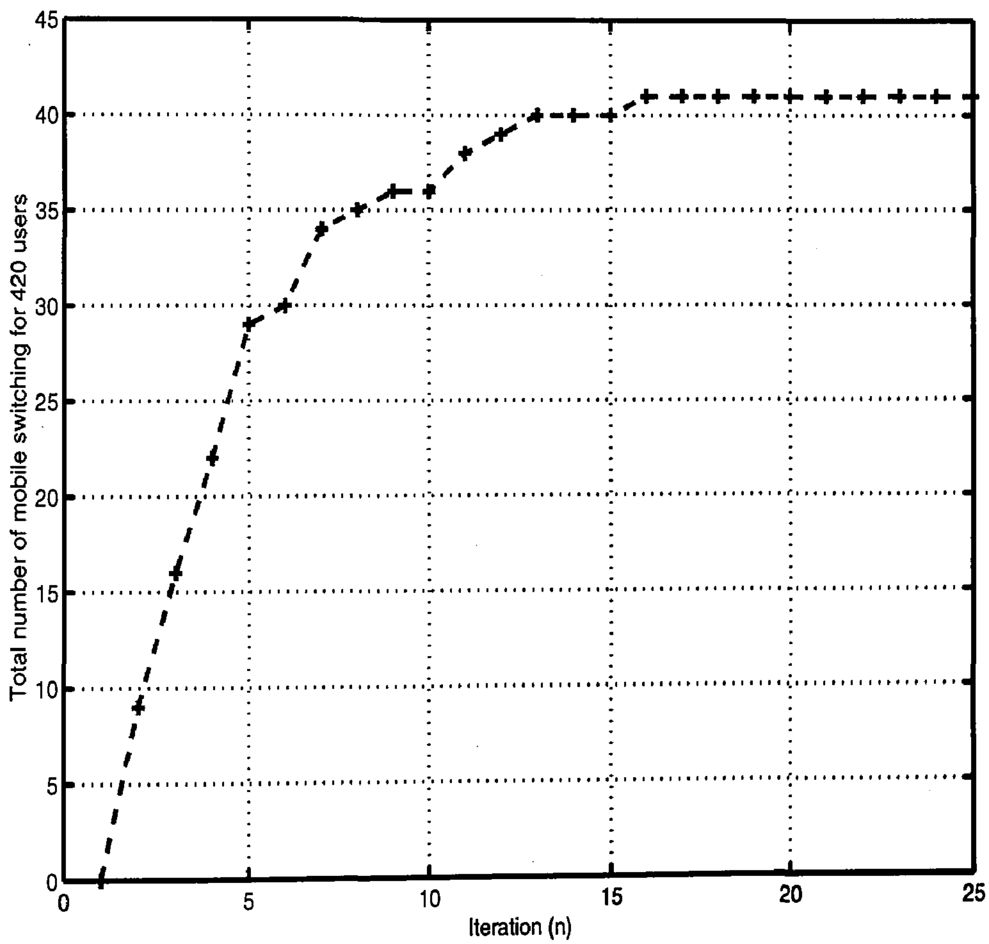

Figure 5.8: Base station switching.

5.2.3 SINR with Load Variation

In order to show the variations of the SINR with the network load conditions, we have performed simulation for the above mentioned simulation setup. We increased the total number of users distributed in the network gradually and observed the uniform SINR level that the system could achieve. We plot the observed values in Fig. 5.9 with the maximum received power at the base station in the system which is proportional to the network load.

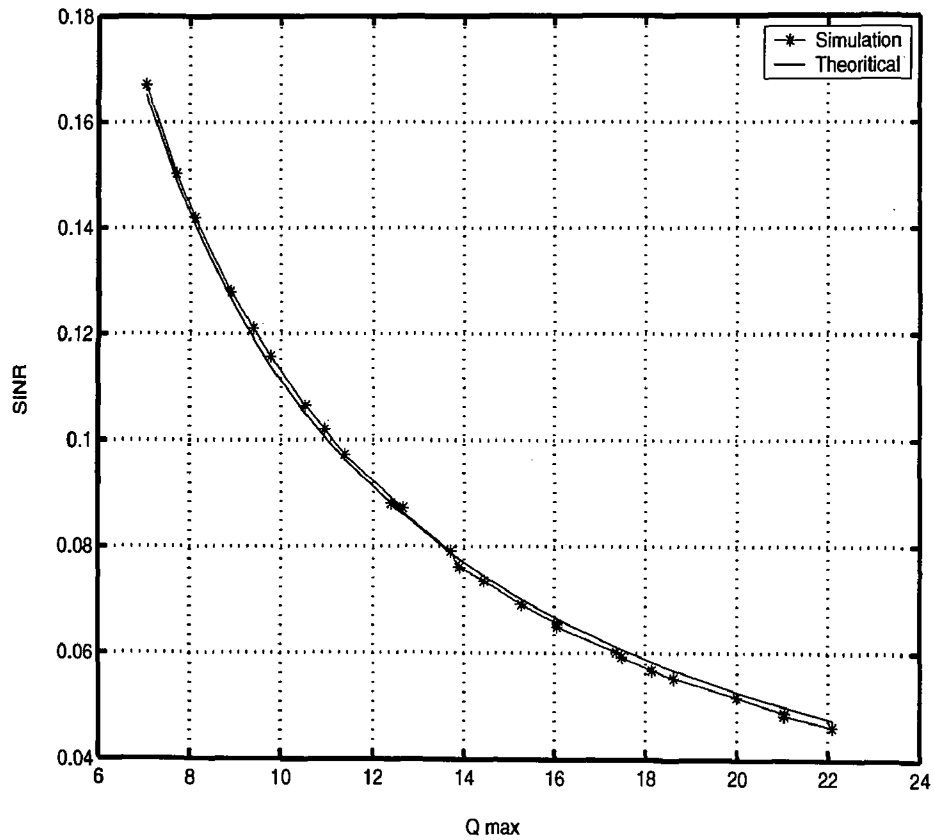

Figure 5.9: Theoretical and simulation values of SINR with total received power at a base station.

We have shown that the theoretical value of SINR received for mobile j at its home base station i is given in (4.30) by,

$$SINR_{ij}(\infty) = \frac{1}{Q_{\max}(\infty) - 1}, \forall j$$

We have plotted the simulation and the theoretical results for the SINR in Fig. 5.9, which explicitly shows that the SINR is reduced when the maximum of the total received power at the base stations is increased. The simulation and the theoretical values are in very close agreement with each other.

Another observation is that if we can reduce the value of the Q_{max}, i.e., the maximum received power at the base stations in the network, we can improve the SINR in the system. This will lead to load balancing.

5.2.4 Load Balanced System

SINR with Q_{min}/Q_{max}

We further investigated the PPBPC algorithm to analyze the performance in load balancing situation. For the analysis, we have modified the above simulation setup with only two base stations and with 26 users uniformly distributed throughout the network. The other parameters are the same as it was in the previous simulations setup. We have run the algorithm for 500 different distribution of users in the network and observed the total received power ratio Q_{min}/Q_{max} at the base stations. For every run, the algorithm runs for 20 iterations until the system converges. This is a monte-carlo simulation and the results reveal that the SINR is maximum when the total received power at the base stations become equal. That is, the load balanced system has a higher SINR than a load unbalanced system. Fig. 5.10 clearly manifests the result we obtained.

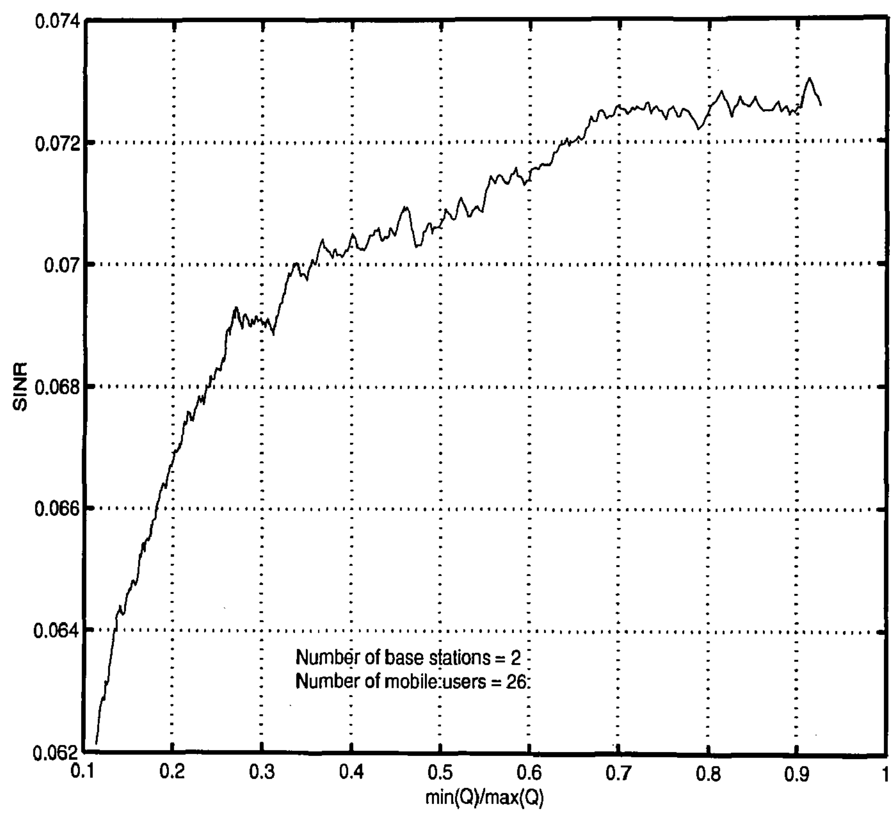

Figure 5.10: Load balanced system provides maximum SINR.

SINR with Load

For the above simulation setup, (i.e., in a 2-cell system) the system was loaded with different number of users and the variation of the SINR in the load balanced system was analyzed in detail. According to the result shown in Fig. 5.11, we can conclude that the SINR decreases with the load. Further, we can estimate the maximum number of subscribers that the system can support for a given SINR. If the required SINR is increased, then the number of mobile subscribers should be decreased according to the curve. However, the average data rate, Erlang factors and other probability factors should be considered in calculating the maximum number of subscribers that the system could support at any time. However, these results are primary factors in provisioning a wireless communication network.

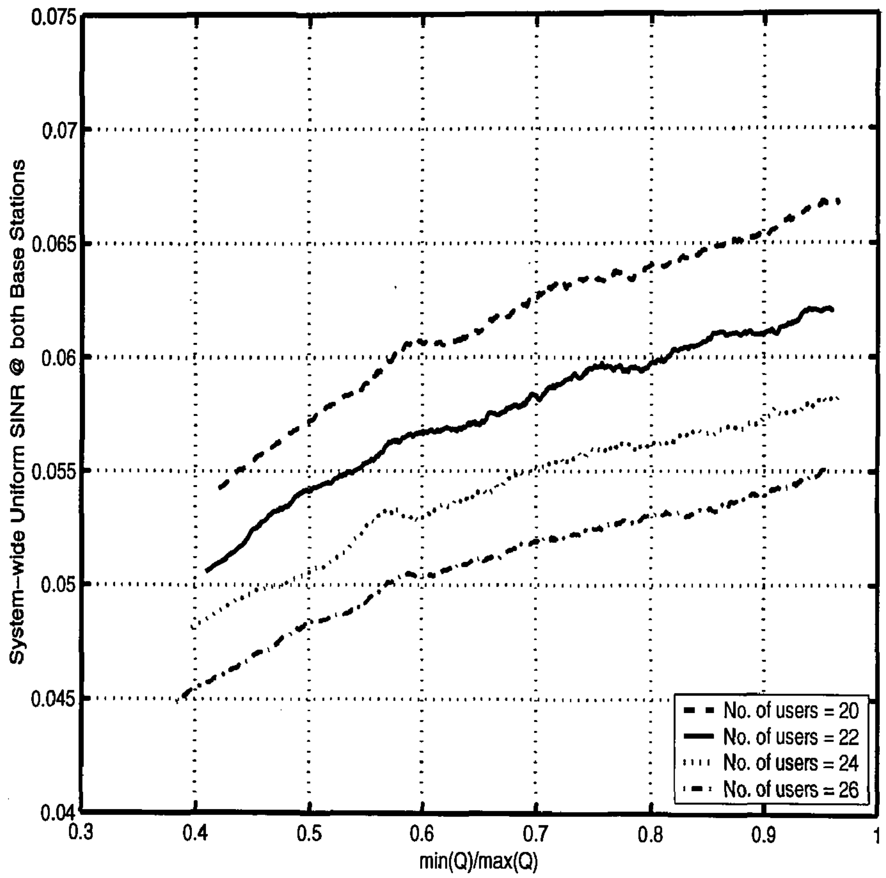

Figure 5.11: Load balanced SINR with users.

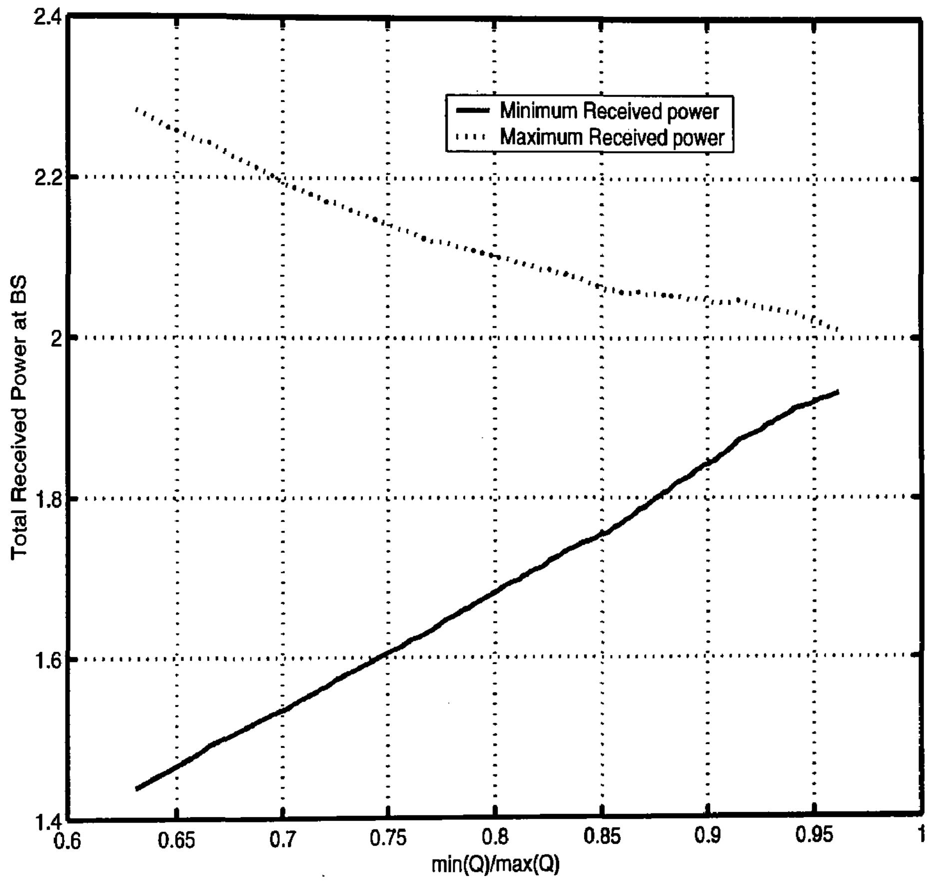

Figure 5.12: Load at base stations with load balanced SINR.

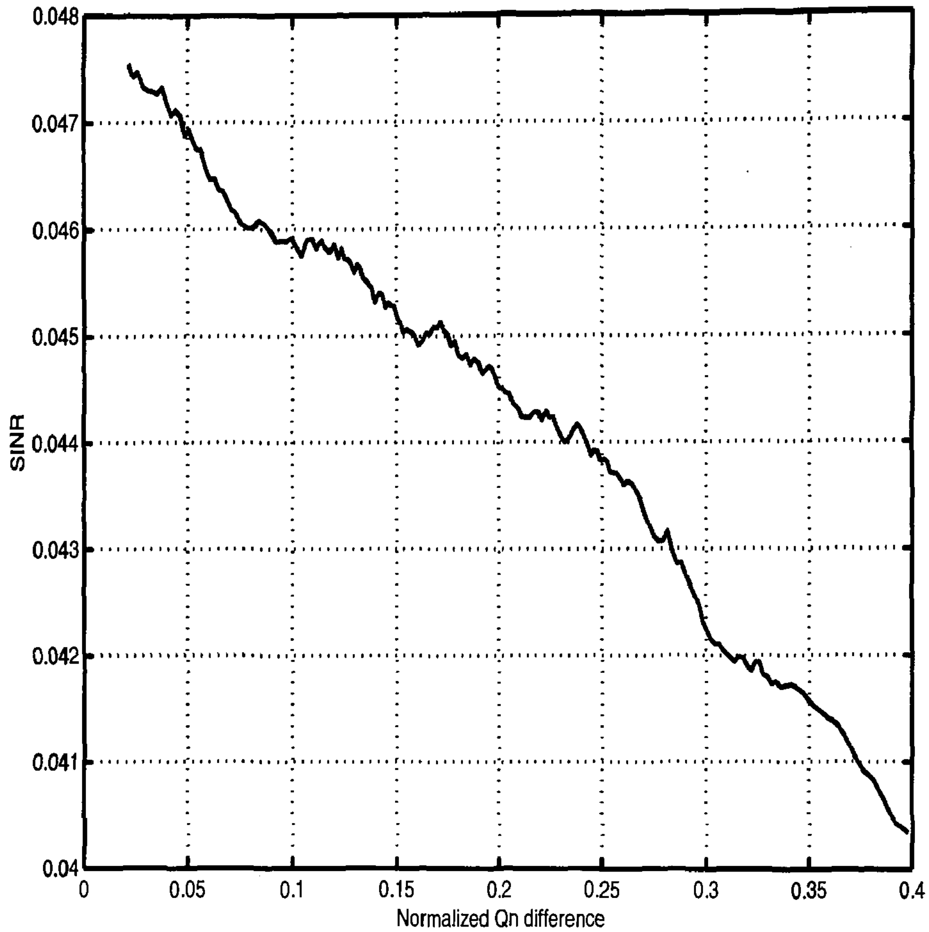

Figure 5.13: Load sharing gives more SINR than a load unshared system.

For the same simulation setup, we have observed previously that the maximum received power at the base station is minimized when the load is balanced. Fig. 5.10 is the evidence for the higher SINR at this point. Fig. 5.13 shows the SINR versus the difference between the total received power at the base stations. It clearly shows that the SINR is high when the difference between the total received power is smaller. That is, the system performs better at the load balanced situation.

Hence, in order to increase the SINR, decreasing the maximum received power at the base station is important as shown in Fig. 5.12. That is, the load should be shared among the base stations.

5.2.5 Dynamic Load Sharing Feature of PPBPC

The algorithm was further analyzed by introducing a hot-spot when the system reached the saturation point. To analyze the effect, a cellular system is created as defined in the previous simulation setup. However, the hot-spot was not initially created in the system. The system was allowed to run for 40 iterations with uniform user distribution throughout the cell. After the 40^{th} iteration is completed, 20 additional users were uniformly distributed inside the cell served by the base station located at (4,4). The hot-spot base station (4,4) is assigned as the home base station for all the newly created mobile stations. At this stage, determining the newly created mobiles' transmit power is a problem. We cannot directly assign the mobile transmit power inversely proportional to the distance from the base station. Because the system's mobile transmit power is determined according to the congestion level of the base station as well as the distance from the base station. To reduce the complexity, we calculated the average mobile transmit power of the system at the 40^{th} iteration and assigned that power for all the newly created 20 mobiles as their transmit power. The algorithm was allowed to run for another 40 iterations for further analysis.

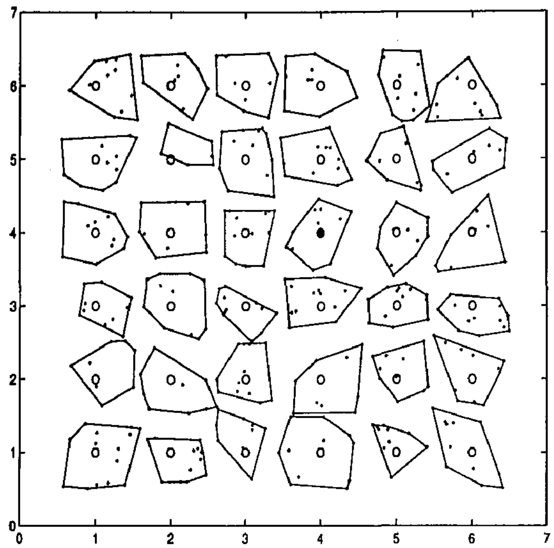

Figure 5.14: The cell at saturation before becoming a hot-spot.

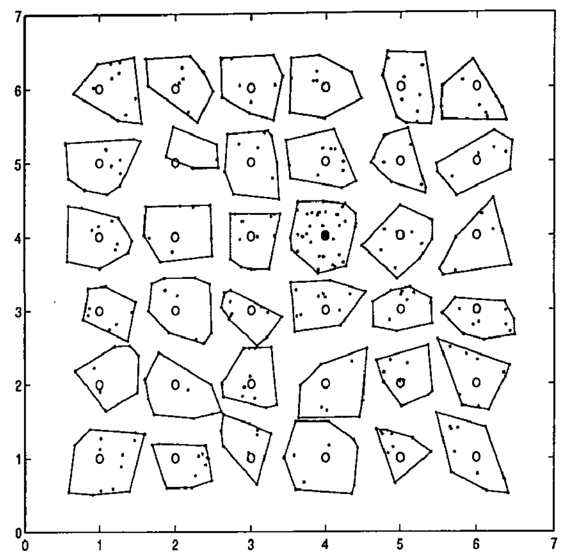

Figure 5.15: The hot-spot base station before the algorithm starts.

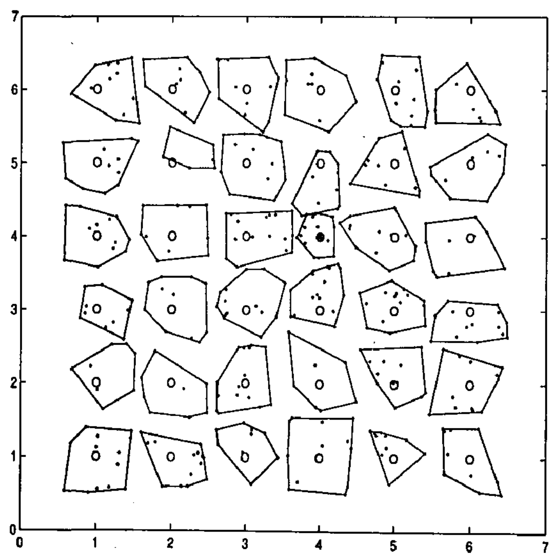

Figure 5.16: The footprint after the hot-spot saturation.

When the algorithm detects a new hot-spot, the algorithm adaptively changes the mobile transmit power and its home base station coverage area. The algorithm runs repeatedly until the system saturates.

Fig. 5.14 shows the footprint of the network at the first saturation point. At this time, there is no hot-spot users detected and all the users are uniformly distributed among the cells. Fig. 5.15 shows the footprint of the cellular system immediately after a hot-spot is introduced. In this figure, the number of mobile stations around (4,4) is higher and the base station's coverage area is also large compared to all other base station coverage area in the system.

When the algorithm detects the hot-spot, the base station dynamically adjust its coverage area and shares the load among the adjacent base stations. That is, the more distanced users of the hot-spot base stations link up with its lightly loaded adjacent base stations. Hence, the coverage area of the hot-spot will reduce and the adjacent base stations will extend its coverage area towards the hot-spot base station. Fig. 5.16 shows the footprint of the system at the saturation of the algorithm following the introduction of the hot-spot. The hot-spot base station's coverage area can be easily compared in these figures.

5.2.6 Comparison with Hanly's Algorithm

In [4], Hanly proposed an algorithm to achieve cell breathing which is similar to our proposed algorithm. Next, through simulation, we compare our algorithm with Hanly's algorithm in certain situation.

In Hanly's algorithm, each base station measures the total interference power in the reverse link in the network. Every mobile station communicates with its surrounding base stations by measuring the interference power at each base station. Then it calculates its transmit power to every base station to achieve the required quality of service. Then, the mobile station will select its home base station which requires the minimum mobile transmit power. That is, the mobile station selects its home base station in such a way that the interference is reduced. The reverse link gain could be calculated by measuring the pilot power strength received by the mobile station. Then it calculates the transmit power in order to achieve the required SINR at the surrounding base station at the reverse link. Then it takes the minimum transmit power calculated and determines its home base station and switch to or stays with its associated home base station. That is, a mobile station will select its home base station which requires the minimum mobile transmit power in such a way that the interference is reduced. In a heavily congested cell, a mobile station which is in the overlapping cellular region could transmit at a lower power level if it belongs to a less crowded neighboring cell. However, this algorithm needs high intensive computation since it has to calculate transmit power for surrounding base stations iteratively. There are excessive amount of signaling to iteratively update the information of other cell's interference power within acceptable delay. Therefore, the control channel should have relatively high bandwidth. Also the base station should have relatively large storage capacity to store the broadcast information from all base stations in the system. Therefore, this algorithm is very difficult in implementation point of view. We use this algorithm for the comparison purposes with our PPBPC algorithm.

Comparison of Dynamic SINR Variation

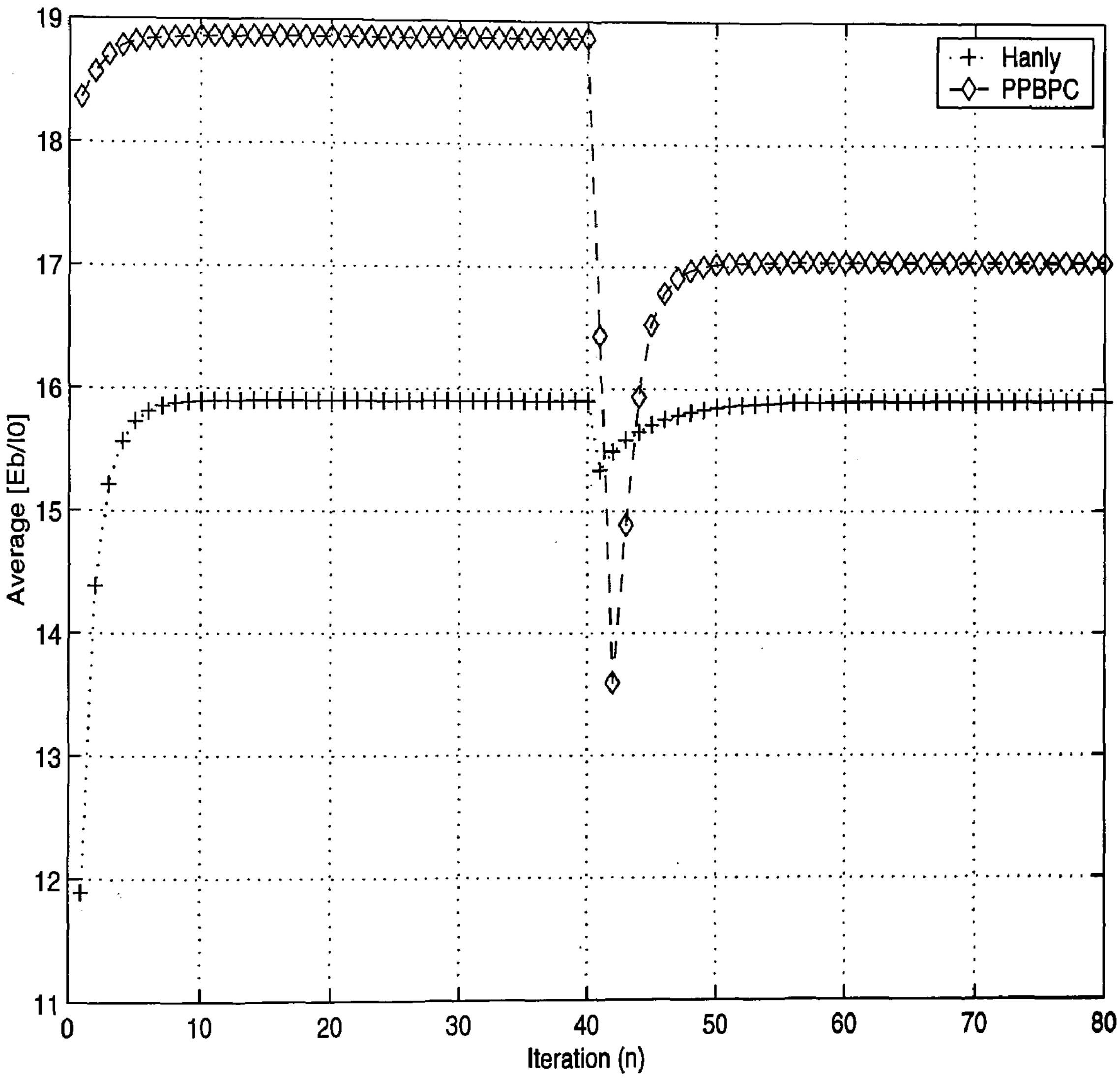

Figure 5.17: The E_b/I_0 variation with iterations (after 40^{th} iteration, a new set of mobile users was introduced)

We have analyzed the SINR variation with the total number of users using both algorithm. The quality of the signal in terms of average $\frac{E_b}{I_0}$ is analyzed when introducing the users when the system is in saturation. Fig. 5.17 shows the variation of average $\frac{E_b}{I_0}$ with the number of iterations. These $\frac{E_b}{I_0}$ results are compared with Hanly's [4] algorithm, and it is shown in the same figure.

Hanly's algorithm works in such a way that the mobile transmit power is adjusted to achieve the required SINR in each iteration. Hence, the algorithm attempts to achieve the required SINR, and the mobile transmit power may be increased or decreased according to the load conditions. Fig. 5.17 shows the $\frac{E_b}{I_0}$ for Hanly's algorithm and PPBPC algorithm. In Hanly's algorithm, the sudden increase in the total number of mobile transmit power after the 40^{th} iteration increases the total interference power. As the total interference power increases suddenly, there is a sudden drop in the achieved $\frac{E_b}{I_0}$ in the 40^{th} iteration as seen in Fig. 5.17. However, the mobile transmit power was adjusted to compensate for the power drop in the SINR. Throughout the iterations of Hanly's algorithm, mobile transmit power is adjusted to achieve the required SINR level.

The $\frac{E_b}{I_0}$ of the PPBPC algorithm was very low at the beginning of the algorithm. Throughout the iterations of the algorithm, the algorithm achieved a higher quality signal after around 8^{th} iteration. From 8^{th} to 40^{th} iteration, the system converges and achieve a constant $\frac{E_b}{I_0}$. When the hot-spot is introduced after the 40^{th} iteration, the total interference is increased and hence the $\frac{E_b}{I_0}$ was suddenly decreased to a lower value. The system wide SINR of the PPBPC algorithm does not have a direct control on the quality of the signal. That is, the system has no direct control for increasing or decreasing the

SINR as done in the Hanly's algorithm. However, this adjusts the pilot power of the hot-spot base station and shares the load of the hot-spot base station dynamically to its adjacent base stations and reduces the total interference power throughout the iteration of the PPBPC algorithm. Hence, the total interference power is gradually reduced and the achieved $\frac{E_b}{I_0}$ is increased to another level through the following iterations. However, the algorithm did not achieve the earliest signal quality level that was maintained before the 40^{th} iteration. That is, because the total interference power was increased by the newly introduced mobile users.

Comparing the signal quality level, $\frac{E_b}{I_0}$, is not enough for comparing the performance of the algorithm. Because, the SINR heavily depends on the interference power, that is directly proportional to the mobile transmit power. Hence, comparing the mobile transmit power is indispensable.

Comparison of Dynamic Mobile Transmit Power Variation

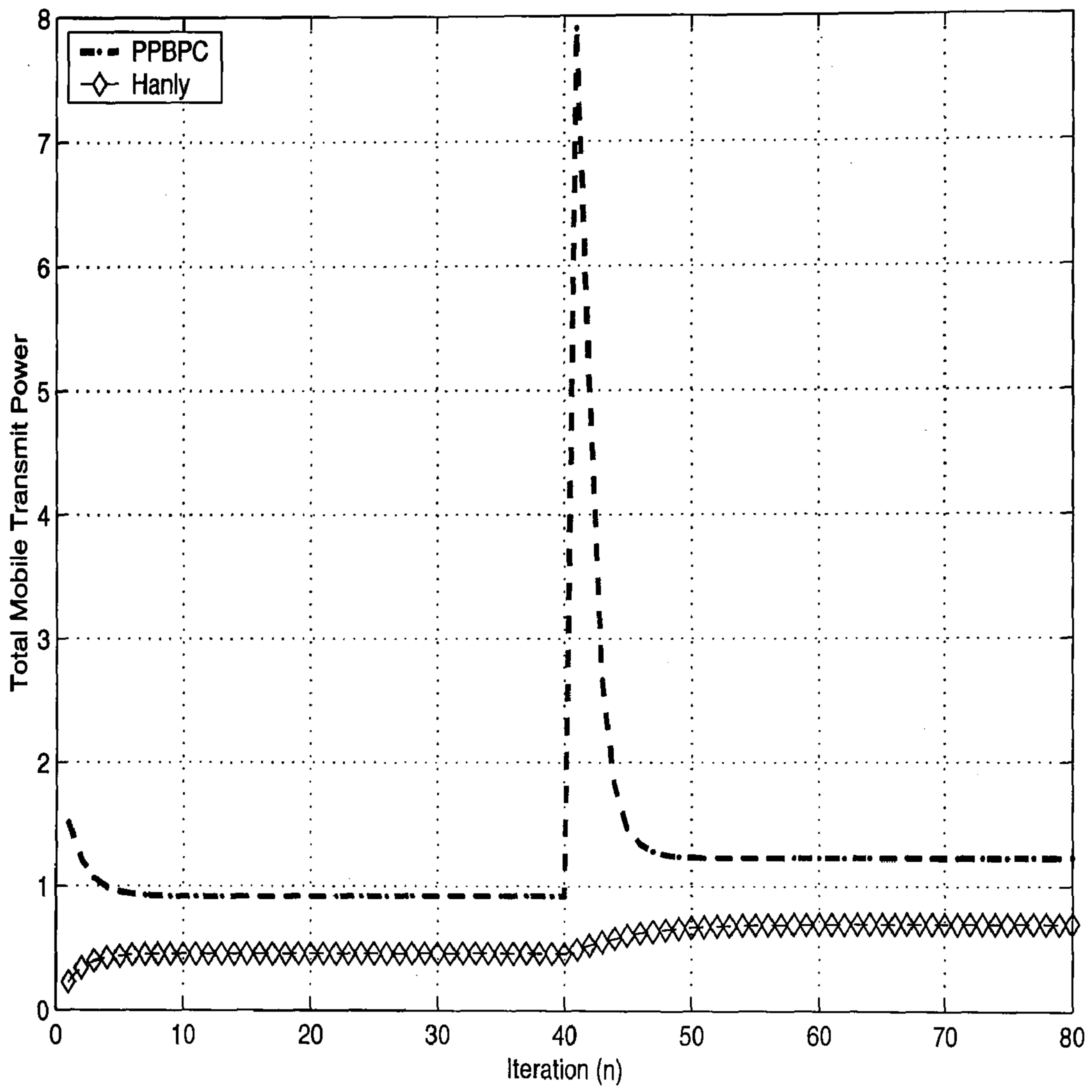

Figure 5.18: Total mobile transmit power variation with iterations.

Fig. 5.18 shows the mobile transmit power variation with iterations. At the initial stage the mobile transmit power decreases or increases depending on the initial mobile transmit power or the initial total received power assigned to the base station to initiate the algorithm. During the iterations of the execution of the algorithm, the total mobile transmit power of the algorithm saturates to a certain value. In Hanly's algorithm, the total mobile transmit power saturated through the iterations up to the 40^{th} iteration as shown in Fig. 5.18. At the 40^{th} iteration, due to the newly introduced mobiles, the interference power is increased. Therefore, to achieve the required SINR, the mobiles increase their total transmit power. Hence after the 40^{th} iteration, the algorithm increases the mobile transmit power until the system converges by achieving the required SINR. The probability of having sudden increase in total mobile transmit power is very less in practical system. Because a large number new calls will not be initiated at the same time, and the algorithm adjust the mobile power very quickly as shown in the Fig. 5.18. Therefore, there will not be a chance for the sudden increase in the practical system. A combined call admission control mechanism could be introduce to prevent these kind of spikes.

In the PPBPC algorithm, the total mobile transmit power is at a constant level at the saturation before the 40^{th} iteration. At the 40^{th} iteration, the total mobile transmit power is suddenly increased. This will increase the total received power at the base station. Hence, the hot-spot base station transmits a pilot power which is inversely proportional to the total received power at the base station. Hence, the total received power at the mobile station will be very less, which leads for the mobile station to increase its transmit power higher. However, due to the load sharing, the mobile transmit power is reduced gradually throughout the algorithm's iterations. After some iterations of the PPBPC algorithm, the total mobile transmit power reaches a saturation value.

To increase the required SINR, in the PPBPC algorithm, the value of the reverse link constant K_r can be adjusted dynamically. According to the K_r, the value of the total mobile transmit power will be increased or decreased. Here, the algorithm can be improved by adaptively changing the reverse link power constant K_r in the future work.

Comparison of Standard Deviation of the Total Received Power at the Base Stations

The standard deviation of the total received power of the base stations was compared for both Hanly's and PPBPC algorithm. Fig. 5.19 shows the variation of the standard deviation of the total received power at base stations with iterations. The standard deviation becomes constant throughout the iteration of the algorithm. This is also one of the evidence that our algorithm saturates after some iterations. Also this is another evidence that the algorithm adaptively adjusts and saturats if a hot-spot is introduced or in other words if the environment changes.

In Fig. 5.19, the variance of the total received power is higher for the PPBPC algorithm compared to the Hanly's algorithm. In this result, the load sharing in the Hanly's algorithm performs better than the load sharing of the PPBPC algorithm. However, the load sharing may vary according to the load conditions, achieved SINR, the mobile transmit power. Hence, for the direct comparison, all these factors should be considered. However, the above results show that the PPBPC algorithm can be used for the load sharing in the mobile communication systems.

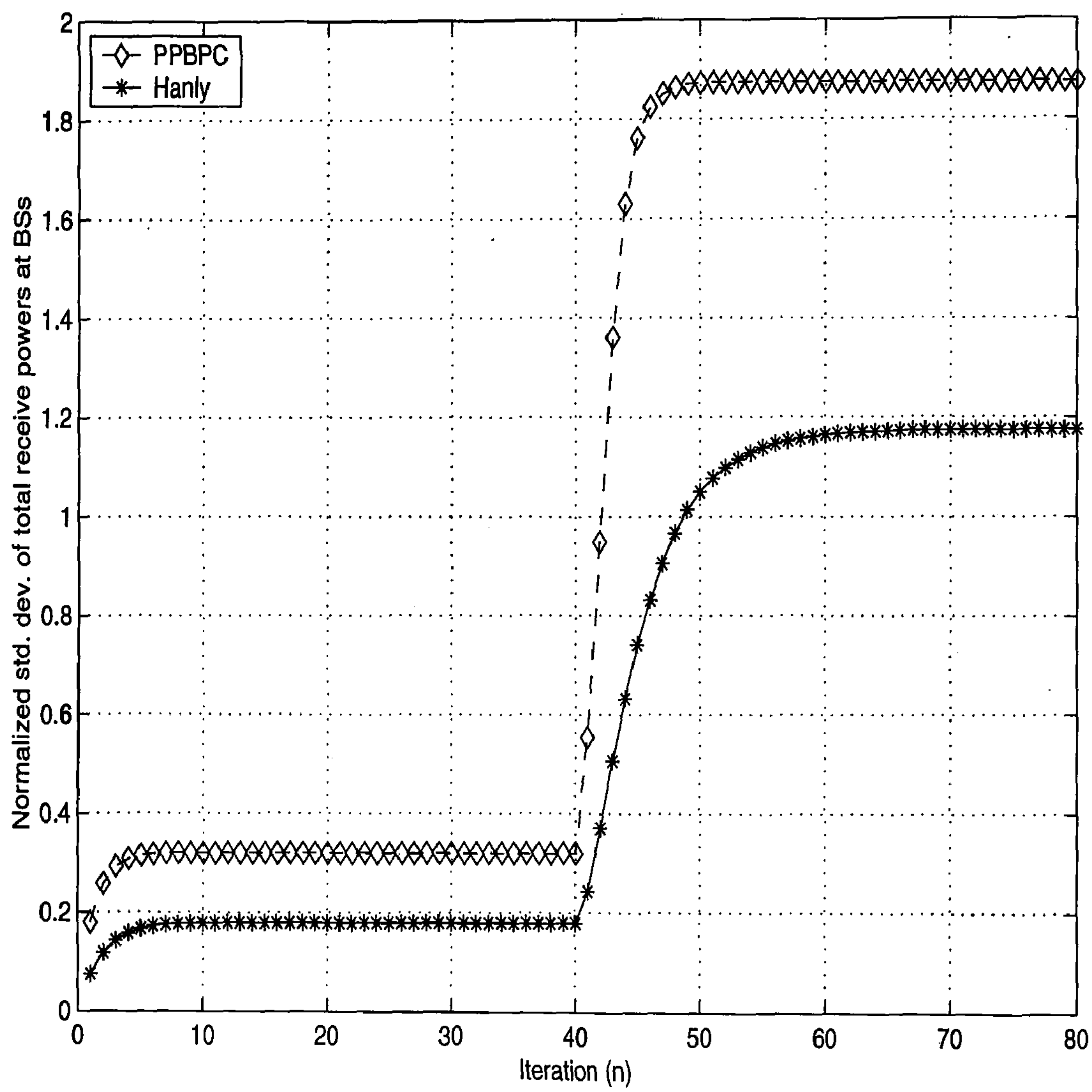

Figure 5.19: The standard deviation of the total received power at the BSs.

5.3 Summary of Results

In the previous chapter, we have showed that the proposed algorithm will achieve an SINR balanced system theoretically in a homogeneous user environment provided that the forward link and reverse link are equal. Convergence of the algorithm and the existence of minimum average mobile transmit power were also analyzed mathematically. It was inevitable to analyze and validate the algorithm in practical situations. Hence, we have implemented our proposed pilot power based power control algorithm using an appropriate simulation model. Further, the results were compared with that of Hanly's [4] algorithm. The results obtained in this simulation study are summarized as follows:

1. The load sharing mechanism is triggered when a hot-spot is detected in the system when implementing the proposed algorithm. The algorithm adaptively adjusts its coverage area and directs the base station's more distanced users to link up with its adjacent lightly loaded cell's base stations. Hence, around a hot-spot, the cell coverage area is reduced. This effect is propagated system-wide until the system reached a fixed point.

2. The load sharing starts to occur when there detects a hot-spot and consequently the algorithm facilitates the SINR to improve adaptively. With the iterations of the algorithm, the system-wide uniform SINR is improved. The theoretical and simulation results are in very close agreement.

3. The load balanced system performs better than a load unbalanced system. When other system parameters are kept constant, if the difference of the total received power among base stations decreases, the SINR increases giving rise to load balanced system. That is, by minimizing the maximum mobile transmit power the PPBPC algorithm increases the system-wide uniform SINR.

4. When a congestion is experienced, the total received power variance is increased and hence the SINR is reduced. However, the algorithm adaptively adjusts its mobile transmit power and the coverage area to improve the SINR.

Chapter 6

Conclusions and Future Work

Conclusions

IN this thesis we have presented an algorithm which computes the mobile transmit power and also performs the base station assignment. In this proposed algorithm each base station transmits its forward link pilot power inversely proportional to the total reverse link received power. The mobile station senses the strongest pilot power received and determines its home base station. The power assignment is also based on the received pilot power. If the reverse link and forward link are reciprocal as usually in TD-CDMA systems, the base station assignment and mobile transmit power assignment can easily and simply be done based on received pilot power in the proposed algorithm.

In the homogeneous user environment where the required bit rate and bit error rate are equal, the uniform SINR is achieved system-wide and the simulation results are the evidence for the feasibility of the algorithm. Unlike previous power control algorithms in the literature, our proposed method does not require prior knowledge of the channel gains between the users and the base stations, and our proposed scheme does not require extensive computations as well.

By transforming the equations of the PPBPC algorithm in to matrix forms, we have shown that the PPBPC algorithm could be optimized by the Perron-Forbenius theory as done in other power control methods.

Dynamic propagation of cell assignment leads to reassignment of the base station system-wide which reduces the total mobile transmit power. We have also shown that the load balancing system performs better than a load unbalanced system. Our simulation study shows that the load balanced system occurs when the base station's maximum received power is minimized.

The PPBPC algorithm offers flexibility in the achievable required SINR and the capacity in the system by dynamically adjusting the value of $h(n)$, which depends on constants K_f and K_r, that are used in adjusting the forward and reverse link power respectively.

Future Work

In this thesis, the algorithm was proposed and the performance was evaluated for the homogeneous (i.e., with equal required transmission bit rate and the bit error rate). Multiple classes of users were not considered in our study. Practically, the general communication system will have different classes of users in terms of required quality of services. Our system can be extended by modifying the same system to work for different classes of mobile users.

When a mobile moves, it might have a line of sight with a different base station other than the home base station. Also if the obstacles are removed from another base station, the pilot power signal strength may become higher than its home base station's received pilot power. If the pilot power strength is almost equal for the mobile stations which are almost at the border of both base stations' footprint, there will be higher possibility for the mobile stations to have sudden switching. To avoid this kind of unnecessary switchings a threshold-based base station assignment could be introduced in our algorithm.

The quality of service or the system performance is most important in any communication system. There is no control on the system-wide SINR in implementing the proposed algorithm. In an unusual situation, if the load is suddenly increased, there is a possibility for the system-wide SINR to drop below a certain limit. This will lead to the system-wide network outage. Hence, it is indispensable to improve the system by introducing a mechanism to monitor the SINR. A well defined call admission control mechanism should be implemented along with our algorithm in the system.

Our algorithm does not consider the shadowing effects in the system. The careful analysis of the shadowing effects will reveal more accurate results in the system.

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