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高速分碼多工存取系統之軟式交遞
及下行功率分配性能分析研究

On the Performance of Downlink Power Allocation Mechanisms and Soft Handoff for Supporting High Bit Rate Multimedia Services in CDMA Systems

研 究 生： 陳　磊

指導教授： 王蒞君 博士

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摘要

在這篇論文中，我們研究了軟式交遞(Soft Handoff)和功率分配(Power Allocation)機制在寬頻分碼多工存取系統(Wide-Band Code Division Multiple Access, WCDMA)中的效能分析。在此論文中，我們提出了一套等高線重疊法(Contour Overlapping)來優化寬頻分碼多工存取系統的軟式交遞參數。除此之外，我們針對不同的功率分配機制從不同角度進行評量。我們從以下三個方向評量功率分配機制：1. 功率分配效能(Power Efficiency)； 2. 對功率控制錯誤(Power Control Errors)的敏感度； 3. 對頻道快速變動衰減(Channel Fast Fading)的抵抗能力。本篇論文主要分成三個部份。

首先，我們提出了一套利用等高線重疊法來優化寬頻分碼多工存取系統的軟式交遞參數的方法。優化軟式交遞參數的優化是一個相當具有挑戰性的研究題材，因為在進行優化的過程中，必須同時考量到數個系統效能需求。在本論文中，我們考慮了四個主要的軟式交遞參數，其中包括 AS_TH、AS_TH_HYSY、AS_REP_HYST 和 AS_MAX_SIZE。不同的參數設定會影響從以下幾個層面影響系統效能： 1. 執行軟式交遞的機率； 2. 軟式交遞連線個數(Active Set Size)； 3. 連線品質

(Link Quality)。從以上三個系統效能評量，我們針對每個參數進行單獨的評量。由個別評量的結果發現，並不是所有的參數對於系統效能都有顯著的影響，例如 AS_REP_HYST 和 AS_MAX_SIZE 這兩個參數的影響就很有限。根據以上觀察，我們針對另外兩個參數(AS_TH 和 AS_TH_HYSY)設計出一套優化參數流程，以期同時滿足數個系統效能要求。

第二部份中，我們利用數學分析在不同功率分配機制下，因為功率效能不張以及對功率控制錯誤所造成通訊中斷(Outage)的機率。功率分配機制主要是在進行軟式交遞的時候，分配同時連線中基地台的傳送功率，以期達到要求的雜訊比(Signal to Interference Ratio)。在本論文中我們分析四種不同的功率分配機制，其中包括品質平衡工率分配法(Quality Balancing Power Allocation, QBPA)、等能量功率分配法(Equal Power Allocation, EPA)、基地台多樣化選擇分配法(Site Selection Diversity Transmission, SSDT)和連線比例式分配法(Link Proportional Power Allocation, LPPA)。在同時考慮基地台功率不足和功率控制錯誤的影響下，我們提出了一個評量中斷的計算方式。從我們的結果顯示，儘管 SSDT 是最有效率的分配法則，但是同時也因為對功率控制錯誤比較敏感，其中斷機率在一般的系統

負載下相對比較高。反之 LPPA 不但幾乎可以達到 SSDT 的系統容量，同時也可以維持相對較低的中斷機率。

最後，我們提出了一個分析方法用來計算在不同功率分配機制下因為通道快速衰減的影響下所造成的通訊中斷機率；以及計算預估使用者在不同功率分配機制下所消耗的能量。在此分析中，我們考慮了萊斯衰減(Rician Fading)通道並且考慮了同頻段干擾(Co-channel Interference)。根據計算結果，SSDT 所送出的功率最低，驗證了我們在前一個部份的証明。再者，從對快速衰減的抵抗力來看，SSDT 最差而 QBPA 最好。比較 SSDT 和 LPPA，我們發現 LPPA 藉由損失些許功率效率，提供較高對快速衰減的抵抗力。

綜合整篇論文重點，主要進行了軟式交遞和功率分配機制在寬頻分碼多工存取系統中的效能分析，預期藉由選擇適當的系統參數以及能量分配機制，提升系統整體的效能。

Summary

In this thesis, we investigate the soft handoff mechanism and power allocation mechanism for the wide-band code division multiple access (WCDMA) system. We propose a contour overlapping technique for soft handoff parameters design in the WCDMA system. Moreover, we evaluate the performance of different power allocation schemes subject to power efficiency, sensitivity to power control errors and resistance to the fast fading. This thesis includes three parts.

First, we presents a contour overlapping technique to design downlink soft handoff parameters for the WCDMA system. Optimizing soft handoff performance in the WCDMA system is a challenging task because it is necessary to determine many parameters to meet different requirements simultaneously. There are four key soft handoff parameters, including AS_TH, AS_TH_HYST, AS_TH_REP, and AS_MAX_SIZE. Each soft handoff parameter affects different system performance aspects, including handoff probability, active set size, and link quality. Through simulations, we evaluate the impact of each handoff parameter on different performance metrics. Our results indicate that AS_TH and AS_TH_HYST significantly affect the target E_b/N_o, handoff probability, and average active set size, while the other two parameters, AS_TH_REP and AS_MAX_SIZE, have little effect. Based on this observation, we develop a simple contour overlapping technique to determine handoff parameters AS_TH and AS_TH_HYST subject to various performance requirements simultaneously. The proposed design method can facilitate the soft handoff parameters design for the WCDMA system.

Second, we derive the closed-form expressions for the outage probabilities of different power allocation mechanisms subject to transmission power control errors. In addition to site selection diversity transmission (SSDT), we consider the equal power allocation (EPA), quality balancing power allocation (QBPA), and link proportional power allocation (LPPA) schemes. From both the perspectives of base station power shortage and power control errors, we develop a semi-analytical approach to evaluate the outage performance of different power allocation schemes. Our numerical results show that due to power control errors, the system with SSDT suffers from a higher outage probability with a moderate traffic load although it can achieve the lowest outage probability performance in the heavy traffic condition. Furthermore, the LPPA system can almost approach the same capacity as SSDT system, while maintaining lower outage probability than SSDT in the typical traffic condition.

Third, we present an analytical approach to evaluate the outage probability of a handoff user in the WCDMA system when applying different downlink power allocation mechanisms in the log-normally shadowed and Rician fading channel subject to co-channel interference. We consider the following power allocation mechanisms, including SSDT, LPPA, EPA and QBPA. An analytical formula for calculating the power efficiency of the above schemes is also derived in the paper. Out results show that although the SSDT method is most power efficient, it is also most sensitive to the fast fading and co-channel interference. As compared to the SSDT method, the LPPA mechanism achieves better outage in presence of fast fading at the cost of slightly sacrificing power efficiency. The proposed analytical frame work can also evaluate the effects of soft handoff threshold, orthogonality factor of channelization codes, and the Rician factor.

To summarize, we analyze the soft handoff and power allocation mechanism in the WCDMA system. For soft handoff study, we provide a systematic methodology to design the optimal soft handoff parameters subject to multiple system requirements. For power allocation schemes study, we evaluate the performance of different power allocation schemes, including EPA, QBPA, SSDT, and LPPA, from the perspective of power efficiency, resistance to power control errors and sensitivity to Rician fast fading effects considering co-channel interference. Through the study of this thesis, we provide some guidelines to improve the system performance by adjusting soft handoff parameters and power allocation schemes, which can be implied to the real systems at least cost.

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CHAPTER 1

Introduction

Wireless communications are becoming increasingly popular nowadays. The evolution of wireless communications has been incredibly fast and the future of this technology is unlimited. Mobility, portability, and instant access data from Internet are the selling points of the wireless communication system. Since the first commercial mobile phone network was opened for business in Tokyo in 1979, billions of people have experienced the convenience of talking anytime, anywhere by mobile phone. Twenty-five years have passed, people require more than only voice services. The growing demand of multimedia services has encouraged the telecommunication industry to start a business of data-oriented services. Because the data rate of the second generation mobile systems is not sufficient to support the high quality multimedia services, the third generation (3G) mobile systems is going to be in the market soon.

The 3G system is based on the the wide-band code division multiple access (WCDMA) system. In the WCDMA system, the soft handoff mechanism is critical technique to provide seamless services. During soft handoff process, the downlink power allocation mechanisms calculate the transmission power of each base station in the active set. Soft handoff has been viewed as an inevitable technique of the code division multiple access (CDMA) system since the introduction of the second generation cellular mobile systems. However, as the downlink transmission power grows with increasing downlink traffic volume, more interference is generated especially when assigning multiple channels to one mobile. Since the performance of the WCDMA system is interference-limited, how to adjust soft handoff and power allocation mechanisms in the WCDMA system is still a hot research issue.

1.1 Problems and Solutions

Usually, quality of service (QOS) and capacity are two contradictory objectives. How to improve QOS and achieve high capacity is an important issue in wireless communication systems. Soft handoff and power allocation mechanisms are two important technique in the WCDMA system. For soft handoff, it is challenging to design optimal handoff parameters, because there are many parameters and multiple system requirements have to be achieved simultaneously. On the other hand, the challenge for power allocation mechanism selection is to achieve high power efficiency and low outage probability at the same time. Appropriate soft handoff parameters and suitable power allocation schemes can enhance system performance dramatically. We illustrate each research topic in details as follows.

1.1.1 A Contour Overlapping Technique for Soft Handover Parameters Design in the WCDMA System

We presents a contour overlapping technique to design downlink soft handoff parameters setting for the WCDMA system. Optimizing soft handoff performance in the WCDMA system is a challenging task because it is necessary to determine many parameters to meet different requirements simultaneously. There are four key soft handoff parameters: 1) active set threshold (AS_TH); 2) active set threshold hysteresis (AS_TH_HYST); 3) active set threshold for replacement (AS_TH_REP); and 4) maximum active set size (AS_MAX_SIZE). Each soft handoff parameter affects system performance differently on various performance measures, including handoff probability, active set size, and link quality. Through simulations, we evaluate the impact of each handoff parameter on the above performance measures. Our results indicate that AS_TH and AS_TH_HYST significantly affect the target E_b/N_o, handoff probability, and average active set size, while the other two parameters, AS_TH_REP and AS_MAX_SIZE, have little effect. Based on this observation, we develop a simple design methodology and a contour overlapping technique to determine handoff parameters AS_TH and AS_TH_HYST subject to various performance requirements simultaneously, which can facilitate the soft handoff parameters design for the WCDMA system.

1.1.2 Performance Evaluation of Downlink Power Allocation Mechanisms for Soft Handoff in the WCDMA System with Power Control Errors

We derive the closed-form expressions for the outage probabilities of different power allocation mechanisms subject to transmission power control errors. In addition to site selection diversity transmission (SSDT), we consider the equal power allocation (EPA), quality balancing power allocation (QBPA), and link proportional power allocation (LPPA) schemes. From both the perspectives of base station power shortage and power control errors, we develop a semi-analytical approach to evaluate the outage performance of different power allocation schemes. Our numerical results show that due to power control errors, the system with SSDT suffers from a higher outage probability with a moderate traffic load although it can achieve the lowest outage probability performance in the heavy traffic condition. Furthermore, the LPPA system can almost approach the same capacity as SSDT system, while maintaining lower outage probability than SSDT in the typical traffic condition.

1.1.3 Performance Analysis of Downlink Power Allocation Mechanisms for Soft Handoff in the WCDMA System with Co-channel Interference

We present an analytical approach to evaluate the outage probability of a handoff user in the WCDMA system when applying different downlink power allocation mechanisms in the log-normally shadowed and Rician fading channel subject to co-channel interference. We consider the following power allocation mechanisms, including SSDT, LPPA, EPA and QBPA. An analytical formula for calculating the power efficiency of the above schemes is also derived in the paper. Out results show that although the SSDT method is most power efficient, it is also most sensitive to the fast fading and co-channel interference. As compared to the SSDT method, the LPPA mechanism achieves better outage in presence of fast fading at the cost of slightly sacrificing power efficiency. The proposed analytical frame work can also evaluate the effects of soft handoff threshold, orthogonality factor of channelization codes, and the Rician factor.

1.2 Thesis Outline

The rest of this thesis is organized as follows. Chapter 2 reviews the WCDMA system, soft handoff mechanism, power allocation, and other related techniques. In Chapter 3, we propose a contour overlapping technique to optimize the soft handoff parameters in downlink WCDMA system. In Chapter 4, we analyze the power efficiency and sensitivity to power control errors of four power allocation schemes, including link proportional power allocation (LPPA), equal power allocation (EPA), quality balancing power allocation (QBPA), and site selection diversity transmission (SSDT). Chapter 5 discusses the outage performance of the four power allocation mechanisms in the log-normally shadowed and Rician fading channel subject to co-channel interference. Chapter 6 gives our conclusions and provides suggestions for future research.

CHAPTER 2

Background

In this chapter, we review the techniques related with wide-band code division multiple access (WCDMA) system, soft handoff technique, and power allocation schemes.

2.1 WCDMA System

The telecommunication industry is now shifting their focus from second generation (2G) to third generation (3G) system due to growing demand on wireless data and multimedia services [1]. The wireless network of 3G is based on wide-band code division multiple access (WCDMA) system [2] [3]. The WCDMA system supplies data rate up to 2 Mbps. Figure 2.1 shows the evolution of telecommunication systems from 1G to 3G.

Two operating mode are applied, namely frequency division duplex (FDD) and time division duplex (TDD). Figure 2.2 illustrates the difference of frequency allocation between FDD and TDD methods. One can find that the FDD method needs a pair of frequency band for both uplink and downlink transmission, while the TDD method only need a frequency band but switch the transmission direction in time. We briefly summarize the important characteristics of the FDD-CDMA and TDD-CDMA systems in Table 2.1 as follows.

TECHNOLOGY			FEATURES
1G	**AMPS**	Advanced Mobile Phone Service	-Analog voice service - No data service
2G	**CDMA**	Code Division Multiple Access	- Digital voice service - 9.6K to 14.4K bit/sec.
	TDMA	Time Division Multiple Access	- CDMA, TDMA and PDC offer one-way data transmissions only
	GSM	Global System for Mobile Communications	- Enhanced calling features like caller ID
	PDC	Personal digital cellular	- No always-on data connection
3G	**W-CDMA**	Wide-band Code Division Multiple Access	- Superior voice quality - Up to 2M bit/sec. always-on data
	CDMA-2000	Based on the Interim Standard-95 CDMA standard	- Broadband data services like video and multimedia
	TD-SCDMA	Time-division synchronous code-division multiple-access	- Enhanced roaming

Figure 2.1: Telecommunication system evolution.

2.2 Soft Handoff Mechanism

Handoff mechanism is activated when a mobile station moves from the coverage area of a base station to another base station [4]. For the TDMA system, such as GSM, hard handoff is usually adopted. For hard handoff, a mobile station connects to only one base station any time. However, CDMA systems usually implement soft handoff, which allows a mobile station to connect to multiple base stations simultaneously [5–7]. Soft handoff can improve link quality by assigning multiple channels to a user. On the other hand, soft handoff consumes more system resource. Thus, there exists a tradeoff between link quality maintenance and system capacity [8, 9]. That is, the higher the soft handoff probability, the lower the system capacity. Thus we can control the timing and probability of handoff by choosing appropriate soft handoff parameters. However, it is a challenging task to determine a set of optimal soft

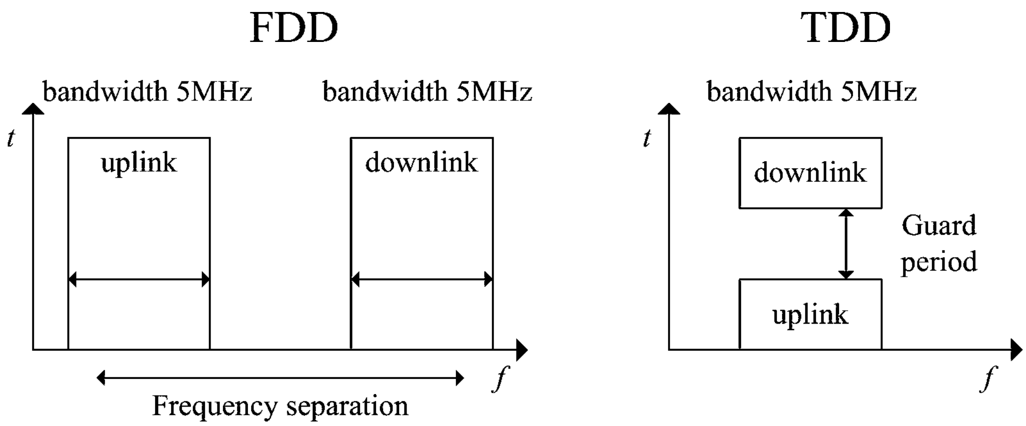


Figure 2.2: Spectrum utilization of FDD and TDD modes

handoff parameters to meet all the system requirements simultaneously.

Figure 2.3 show the scenario of soft handoff. When a mobile terminal moves the the cellular boundary and proceed the soft handoff, the mobile establish links to both base stations. Two base stations transmit the same data to the mobile and the mobile uses rake receiver and maximum ratio combining mechanism to combine the signal [10] [11]. Mobiles in handoff process get a soft handoff gain with appropriate system parameters [12] [13]. Soft handoff mechanism improves cell coverage and QOS by assigning multiple channels to one mobile station.

2.3 Power Allocation Mechanism

Power allocation mechanism calculate the transmission power of each base station in the active set during the process of soft handoff. The goal of power allocation mechanism is to coordinate all the base station in the active set and adjust the transmission power to meet the signal to interference ratio (SIR) requirement. There are four power allocation schemes are taken into consideration, including the site selection diversity

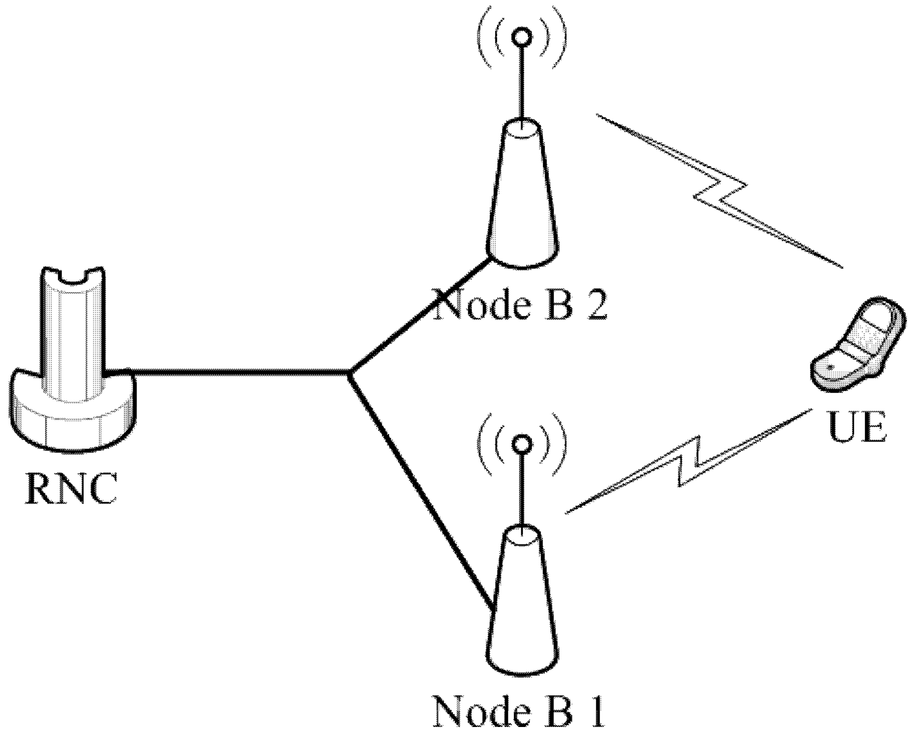


Figure 2.3: Scenario of soft handoff.

transmission (SSDT) [14–16], the link proportional power allocation (LPPA) [17–19], the equal power allocation (EPA) [20–22], and the quality balancing power allocation (QBPA) [23]. Each power allocation scheme has different impact on the performance of power efficiency, sensitivity to power control errors, and sensitivity to fast fading effects.

Table 2.1: Comparison of UTRA FDD and TDD physical key parameters.

	UTRA TDD	UTRA FDD
Multiple access method	CDMA(inherent FDMA)	CDMA(inherent FDMA)
Duplex method	TDD (suitable for asymmetric services, e.g., web browsing.)	FDD (suitable for symmetric services, e.g., voice.)
Channel spacing	5 MHz (nominal)	
Carrier chip rate	3.84 Mcps	
Timeslot structure	15 slots/frame	
Frame length	10 ms	
Multirate concept	Multicode, multislot and orthogonal variable spreading factor (OVSF)	Multicode and OVSF
Modulation	QPSK	
Detection	Coherent, based on midamble	Coherent, based on pilot symbols
Intra-frequency handover	Hard handover	Soft handover
Inter-frequency handover	Hard handover	
Channel allocation	DCA supported	No DCA required
Intra-cell interference cancellation	Support for joint detection	Support for advanced receivers at base station

CHAPTER 3

A Contour Overlapping Technique for Soft Handover Parameters Design in the WCDMA System

This chapter and [24] presents a contour overlapping technique to design downlink soft handoff parameters setting for the WCDMA system. Optimizing soft handoff performance in the WCDMA system is a challenging task because it is necessary to determine many parameters to meet different requirements simultaneously. There are four key soft handoff parameters: 1) active set threshold (AS_TH); 2) active set threshold hysteresis (AS_TH_HYST); 3) active set threshold for replacement (AS_TH_REP); and 4) maximum active set size (AS_MAX_SIZE). Each soft handoff parameter affects system performance differently on various performance measures, including handoff probability, active set size, and link quality. Through simulations, we evaluate the impact of each handoff parameter on the above performance measures. Our results indicate that AS_TH and AS_TH_HYST significantly affect the target E_b/N_o, handoff probability, and average active set size, while the other two parameters, AS_TH_REP and AS_MAX_SIZE, have little effect. Based on this observation, we develop a simple design methodology and a contour overlapping technique to determine handoff parameters AS_TH and AS_TH_HYST subject to various performance requirements simultaneously, which can facilitate the soft handoff parameters design for the WCDMA system.

3.1 Introduction

Soft handoff is an important technique to improve the quality of service in cellular mobile systems. For the wide-band code division multiple access (WCDMA) system, many soft handoff parameters are required to be designed appropriately to achieve high performance gain. The key soft handoff parameters in the WCDMA system include: 1) active set threshold (AS_TH); 2) active set threshold hysteresis (AS_TH_HYST); 3) active set threshold for replacement (AS_TH_REP); and 4) active set maximum size (AS_MAX_SIZE) [25]. Thus, it is a challenging task to find a set of soft handoff parameters subject to many different performance requirements.

The performance of a handoff algorithm can be gauged mainly by the following three requirements: 1) the radio link quality in terms of the ratio of bit energy to noise power density (E_b/N_o); 2) the average active set size; 3) handoff probability, which is defined as the ratio of the number of snap shots in handoff to the number of total snap shots. Obviously, it is desirable to set he handoff parameters to achieve a higher E_b/N_o performance. On the contrary, handoff requests consume more system resource. Thus, it is preferred to have a lower handoff probability or active set size.

In the literature, some papers have discussed how to choose handoff parameters [26] [27] [21]. In [26] [27], the authors compared limited sets of handoff parameters in various propagation environments. In [21], the authors studied the effect of the maximum allowed active set size and the handoff threshold on the outage probability and the total average base station transmit power for a handoff user in a omni-directional cellular system. In general, these works analyze the effect of a certain set of soft handoff parameters in the WCDMA system. In this chapter, we consider the handoff design issue from different angles. Specifically, given a set of system performance requirements, we want to design suitable handoff parameters subject to the impact of terminal mobility and channel varieties.

The goals of this chapter are two folds. First we aim to discuss the effect of each soft handoff parameter, including AS_TH, AS_TH_HYST, AS_TH_REP, and AS_MAX_SIZE. Second, we develop a systematic methodology to search all the feasible solutions of handoff parameters to meet the predetermined performance requirements in forward link, including E_b/N_o, handoff probability and active set size.

The rest of this chapter is organized as follows. Section 3.2 introduces our simulation model. Section 3.3 illustrates soft handoff for the WCDMA system in details. In Section 3.4 we evaluate the effects of handoff parameters by using WINDSP. Section 3.5 details the contour overlapping technique for handoff parameters optimization. We give our concluding remarks in Section 3.6.

3.2 System Model

To evaluate the effect of handoff parameters in terms of different performance requirements. It is important to incorporate the impacts of both radio channel impairments and terminal mobility. We have developed such a simulator called WIreless Network Dynamic Simulation Platform (WINDSP). Figure 3.1 shows input parameter fields, cellular layout, and some performance outputs of WINDSP. The simulation environments in WINDSP are introduced as follows.

3.2.1 Directional Antenna

Three different types of antennas are used in WINDSP: omni-directional, 60 degree and 120 degree directional antennas. Because of different antenna patterns, the cell layouts with 60 and 120 degree antenna are slightly different [28], as shown in Figure

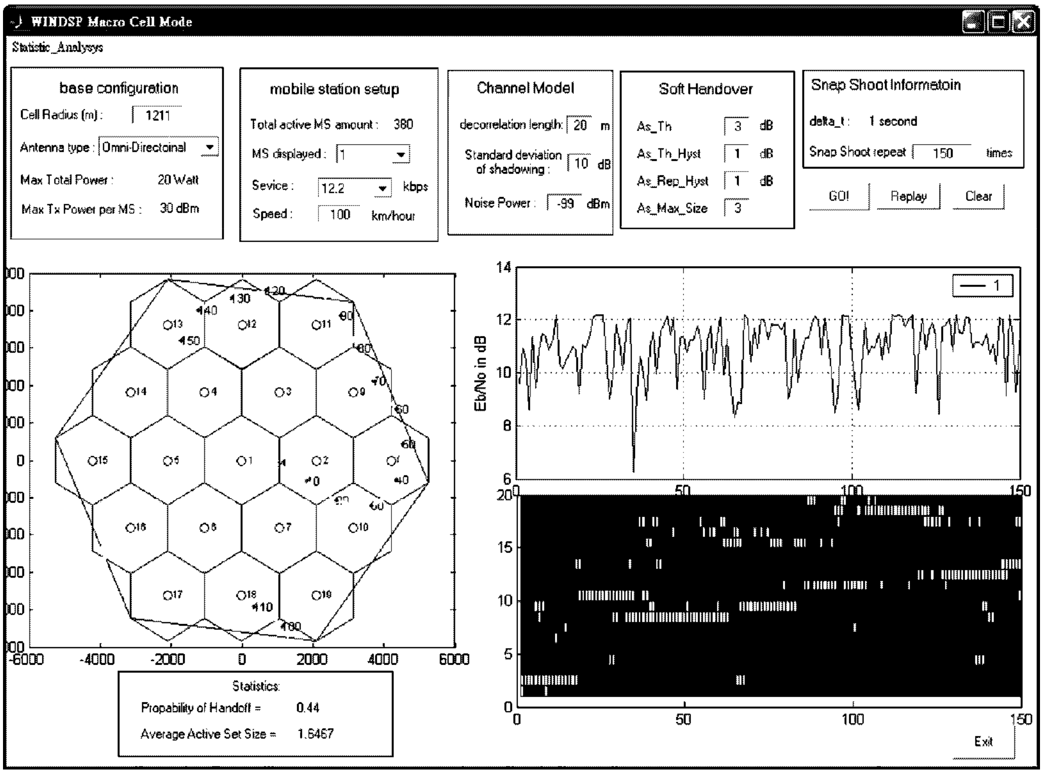


Figure 3.1: User interface of WIreless Network Dynamic Simulation Platform (WINDSP).

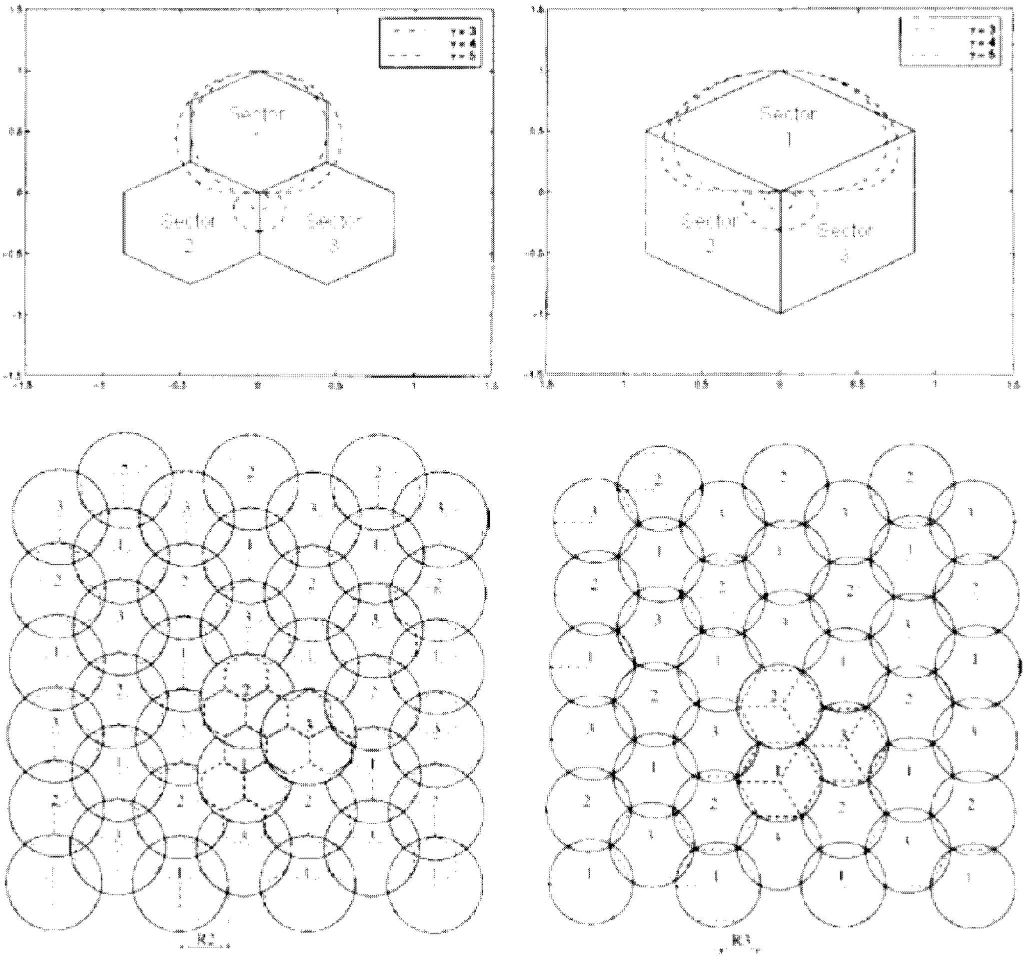


Figure 3.2: Base station scenarios for 60^0 and 120^o antenna.

3.2.

3.2.2 Mobile Configuration

We consider mobiles with the mobility model of Table 3.1 in WINDSP [29]. The average speed of mobile terminals is 80 km/hr. A mobile terminal can change its direction within $\pm 45^o$ with probability of 0.2. Each mobile has rake receiver and uses maximum ration combining to combine signals from different base stations.

Table 3.1: Mobility model parameters

Speed value	80 km/hr
Probability to change direction at position update	0.2
Maximal angle for direction update	45^o
Decorrelation length	20 meters

3.2.3 Path Loss Model

According to the 3GPP specification, there are at least two different channel models: macro-cell propagation model and micro-cell propagation model. We adopt the macro cell propagation model as follows:

$$L = 40 \cdot (1 - 4 \cdot 10^{-3} \cdot H_b) \cdot Log_{10}(R) - 18 \cdot Log_{10}(H_b) + 21 \cdot Log_{10}(f) + 80, \quad (3.1)$$

where R represents the distance between a base and a mobile in kilometers; f represents the carrier frequency in hertz; H_b represents the antenna height of base station in meters.

3.2.4 Shadowing Effect

The shadowing effect of a WCDMA system channel can be modelled as a log-normal random variable S. The standard deviation of S is usually set to be 6 to 10 dB in an urban area. We define the link gain between two locations as

$$Link\_Gain = L + S. \quad (3.2)$$

Note that the shadowing component S is highly related to the mobile terminal's locations. A correlation of shadowing on locations should be also modelled. Define the de-correlation distance d_{cor} as the distance at which the correlation co-efficient of the shadowing components between two locations are equal to 0.5. Let $R(\Delta x)$ be the auto-correlation function of the shadowing component between two locations with a distance of Δx. According to [29], we can express $R(\Delta x)$ as

$$R(\Delta x) = e^{-\frac{|\Delta x|}{d_{cor}} \cdot ln(2)}. \tag{3.3}$$

Let Ω_i be the shadowing component with a standard deviation of σ for a mobile terminal at location x_i in time t_i. Then the correlated shadowing Ω_{i+1} at location x_{i+1} in time t_{i+1} is:

$$\Omega_{i+1} = R(\Delta x) \cdot \Omega_i + \eta \cdot \sigma_c, \tag{3.4}$$

where $\Delta x = |x_{i+1} - x_i|$, $\sigma_c = \sigma\sqrt{1 - R^2(\Delta x)}$, and η is a normal radom variable with zero mean and standard deviation of 1 dB.

3.3 Handoff Algorithm

Handoff mechanism is activated when a mobile station moves from the coverage area of a base station to another base station. For the TDMA system, such as GSM, hard handoff is usually used. For hard handoff, a mobile station connects to only one base station any time. However, CDMA systems usually implement soft handoff, which allows a mobile station to connect multiple base stations simultaneously. Soft handoff can improve link quality by assigning multiple channels to a user. On the other hand, soft handoff consumes more system resource. Thus, there exists a tradeoff between link quality maintenance and system capacity. That is, the higher the soft handoff probability, the lower the system capacity. Thus we can control the timing and probability of handoff by choosing appropriate soft handoff parameters. However, it is a challenging task to determine a set of optimal soft handoff parameters to meet all the system requirements simultaneously. In the following, we will detail a systematic methodology to determine the optimal soft handoff parameters.

Figure 3.3 shows the flow chart of the soft handoff algorithm in the WCDMA system. The figure illustrates the relationship among all key soft handoff parameters. We first describe soft handoff algorithm in brief [25] [30] [31]. To begin with, we respectively denote Best_SS as the best signal strength of the cell in the active set, Worst_Old_SS as the worst signal strength of the cell in the active set, Best_Cand_SS as the cell with the best signal strength in the monitored set, and $S_{measured}$ as the measured signal strength. With the information of Best_SS, Worst_Old_SS, Best_Cand_SS, and $S_{measured}$, the soft handoff algorithm checks the following conditions to dynamically add or remove a base station from the active set. Specifically,

$$S_{measured} < Best\_SS - AS\_TH - AS\_TH\_HYST \tag{3.5a}$$

$$S_{measured} > Best\_SS - AS\_TH + AS\_TH\_HYST \tag{3.5b}$$

$$Best\_Cand\_SS > Worst\_Old\_SS + AS\_REP\_HYST \tag{3.5c}$$

1. If (3.5a) is satisfied for a period of T, the system removes the worst cell from the active set;

2. If (5b) is satisfied for a period of T and the active set size is below the maximum value, the system adds the cell with $S_{measured}$ into the active set;

3. If (3.5c) is satisfied for a period of T, the system adds the cell with Best_Cand_SS and removes the Worst_Old_SS from the active set.

We consider only equal power allocation cases in the following simulation.

To summarize, the parameters AS_TH and AS_TH_HYST can be used to decide when a base station is qualified to be added into the active set, or to be removed. AS_MAX_SIZE limits the maximum number of base stations in the active

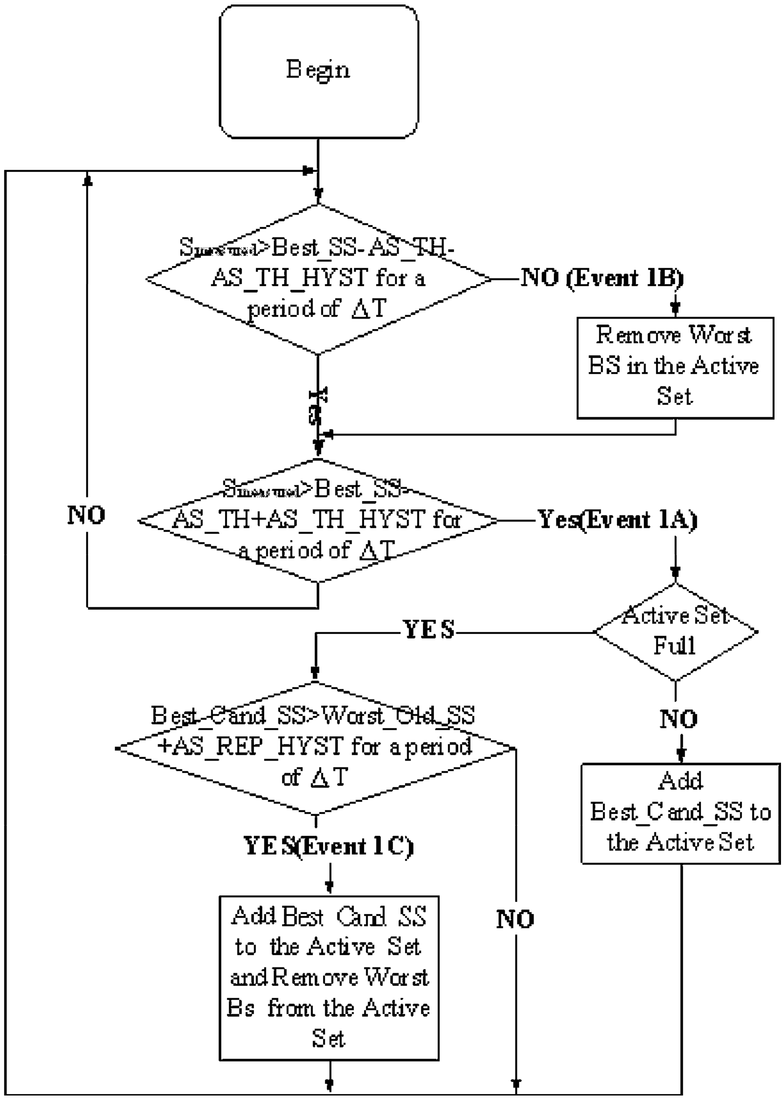


Figure 3.3: Flow chart of soft handoff algorithm.

set. AS_REP_HYST is used to control the occurrence of the replacement of base stations in the active set. The aforementioned soft handoff parameters will influence the system performance from different aspects, which will be discussed in the next section.

3.4 Effect of Soft Handoff Parameters

We apply our developed WINDSP to evaluate the impact of four key handoff parameters from different aspects. System environment parameters are listed in Table 3.2. Observing Figure 3.4, we find that multiple base stations are in the active set only when the link quality of a mobile terminal is relatively poor. When the link quality becomes good, the system will remove some base stations in the active set. Most of the time a mobile terminal connects to only one base station. We can control the timing of soft handoff by modifying key soft handoff parameter.

We consider the effects of soft handoff in terms of the following three performance measures, (1) E_b/N_o distribution, (2) average active set size, and (3) handoff probability. Recall that there are four key soft handoff key parameters: (1) AS_TH, (2) AS_TH_HYST, (3) AS_TH_REP, and (4) AS_MAX_SIZE. It would be complicated to analyze the impact of all the parameters at the same time. Thus we evaluate these parameters once at a time, while using the default values in Table 3.3 for other parameters. In our simulation, more than $30,000$ samples are taken to collect the statistics of E_b/N_o, average active set size, and handoff probability.

Figure 3.5 shows the impact of the soft handoff parameter AS_TH on soft handoff gain, average active set size, and handoff probability, respectively. Soft handoff gain is defined as the E_b/N_o improvement as compared to the case without soft handoff. Handoff probability here is defined as the ratio of the number of snap shots in handoff to the number of total snap shots. Thus a higher soft handoff gain means

Table 3.2: Parameters of soft handoff behavior simulation.

System Environment	
Base Radius	1211 Km
Antenna	60^o directional antenna
Max total BS TX Power	20 Watt
Max Tx Power per MS	30 dBm
Total Mobile amount	$20 * 19 = 380$
Mobile velocity	100 km/Hr
Service rate	12.2 kbps
E_b/N_o target [32]	7.9 dB
Soft Handoff Parameters	
AS_Th	3 dB
AS_Th_Hyst	1 dB
AS_Rep_Hyst	1 dB
AS_Max_Size	3

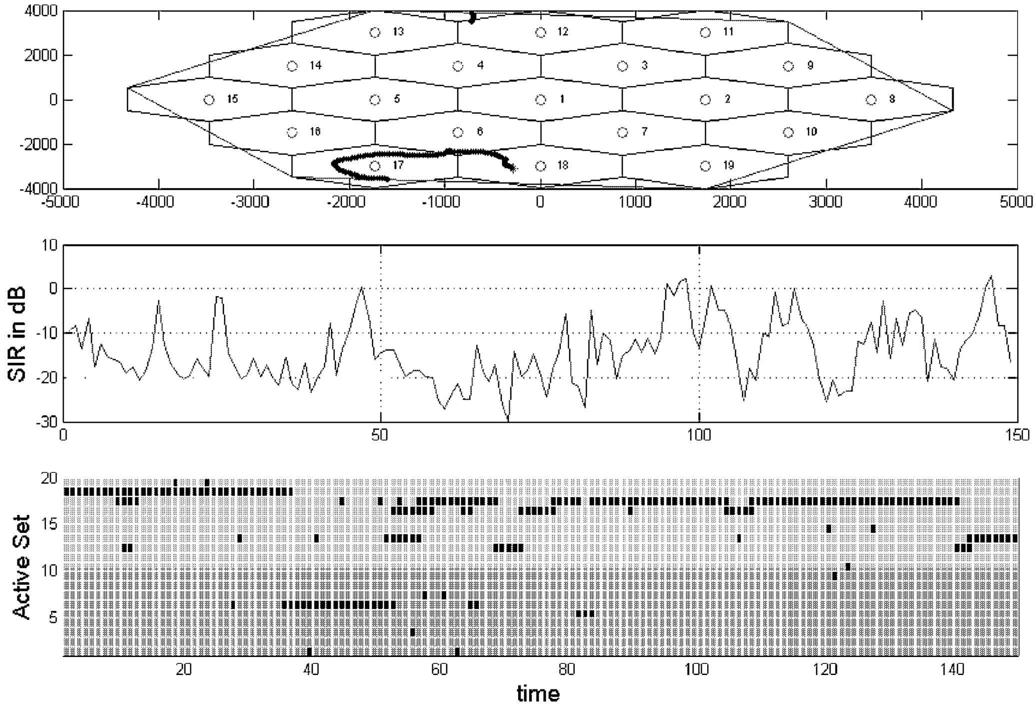


Figure 3.4: Soft Handoff behavior simulations. Upper part of this figure shows the trajectory of a mobile; the corresponding E_b/N_o is shown in the middle part; and the bottom part illustrates the content of active set. The y-axis of bottom part of this figure represents the base station number from 1 to 19 while x-axis represents the time. The blocks with dark color represent the base stations in the active set. For example, the mobile terminal connects to base station number 3 and 11 in the beginning, while it connects to base station number 15 at time around 20.

Table 3.3: Default value of simulation.

Parameter	Default Value
#MS / Sector	20
AS_Th	3 dB
AS_Th_Hyst	1 dB
AS_Rep_Hyst	1 dB
AS_Max_Size	3

a better E_b/N_o performance. As shown in the figure, the larger the value of AS_TH, the larger the E_b/N_o. Meanwhile, a larger AS_TH also leads to a higher handoff probability and a larger active set size. For example, when AS_TH is set to be 1 dB in the omni-directional antenna case, the soft handoff gain is 0.5 dB and average active set size is 1.15. For AS_TH is 5 dB, the soft handoff gain becomes 2 dB and average active set size becomes 1.5.

Figure 3.6 illustrates the effect of AS_TH_HYST in soft handoff. One can observe that a larger AS_TH_HYST will discourage the occurrence of a large-sized active set (middle plot), thereby decreasing the E_b/N_o performance (top plot) and handoff probability (bottom plot).

Figures 3.7 and 3.8 show that AS_REP_HYST and AS_MAX_SIZE have little effect on the E_b/N_o performance. According to our observation and [32], active set size is usually less than three in most cases. Therefore, when AS_MAX_SIZE is larger than three, the system performance is rarely influenced. In the meantime, AS_REP_HYST is effective only when the number of base stations involved in the handoff process is equal to AS_MAX_SIZE. Because the active set size is usually equal to one or two, the chance for AS_REP_HYST to be effective is also relatively low.

We have analyzed the impact of four key handoff parameters individually. The information we obtained so far is still not enough to decide the optimal handoff parameters with respect to the performance of E_b/N_o, average active set size, and handoff probability. Because each parameter is affected mutually, it is necessary to develop a systematic design methodology to decide a set of optimal handoff parameters. In the next section, we will propose such a systematic design approach subject to the performance requirements of E_b/N_o, average active set size, and handoff probability.

3.5 Contour Overlapping Technique

3.5.1 Design Procedures

According to our observations in the previous section, we find that AS_TH and AS_TH_HYST significantly influence the system performance, while AS_TH_REP and AS_MAX_SIZE have little effect. Based on this observation, we suggest a simple soft handoff parameter design approach. That is, we can determine a set of better soft handoff parameters by focusing on the design of AS_TH and AS_TH_HYST, while setting AS_MAX_SIZE and AS_REP_HYST as the default values. Figure 3.9 illustrates the flow chart of the proposed contour overlapping methodology in the soft handoff parameter design. First, we set the system requirements, including: 1) the required 99^{th} percentile E_b/N_o; 2) average active set size; and 3) handoff probability. Second, we perform simulations to obtain the performance contours in terms of AS_TH and AS_TH_HYST. Third, we overlap the contours of E_b/N_o, handoff probability and average active set size. From the intersections of the overlapping contours, we can find the optimal soft handoff parameters satisfying all the system requirements.

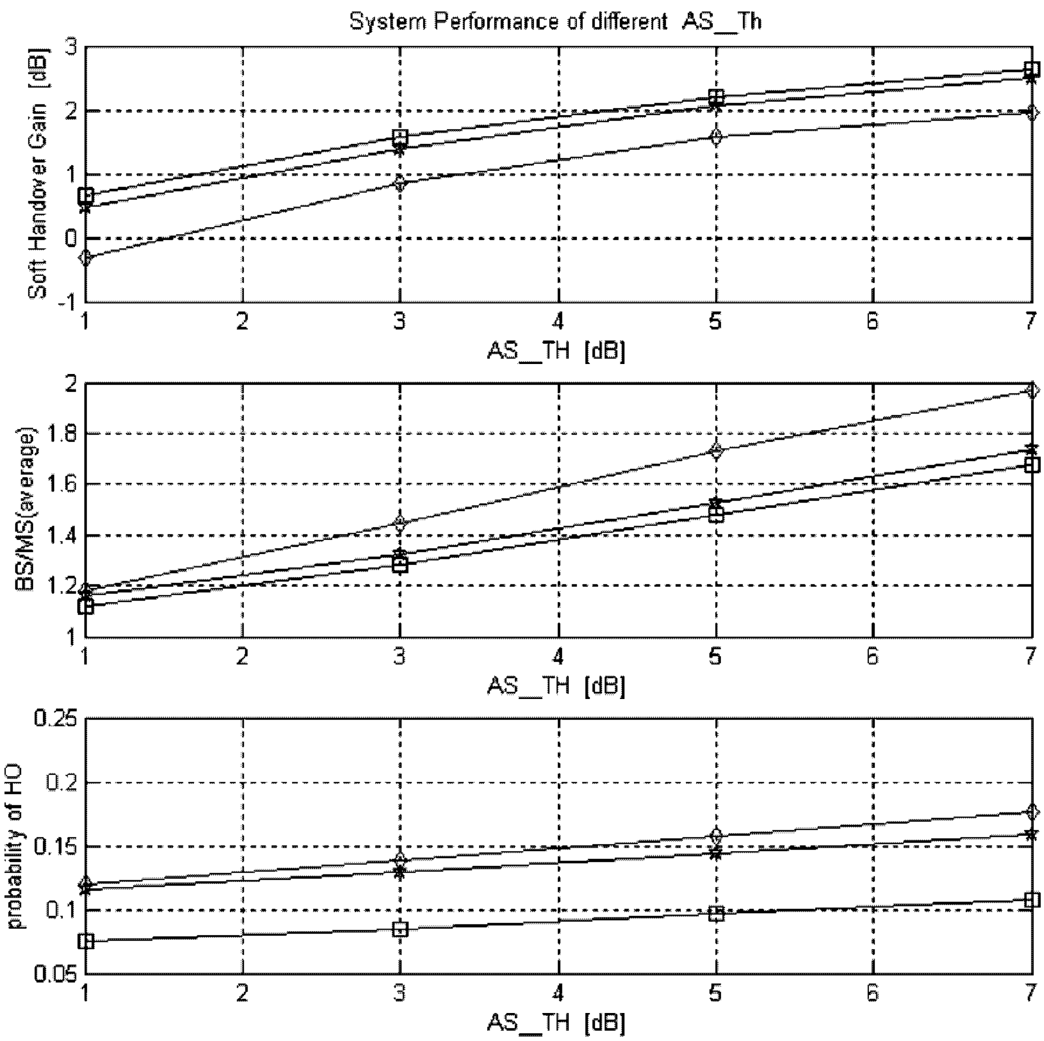


Figure 3.5: Impact of AS_TH on system performance. Legend: -□- is omni directional antenna with 20 MS/BS; -◇- is 120 degree directional antenna with 60 MS/BS; -∗- is 60 degree directional antenna with 60 MS/BS.

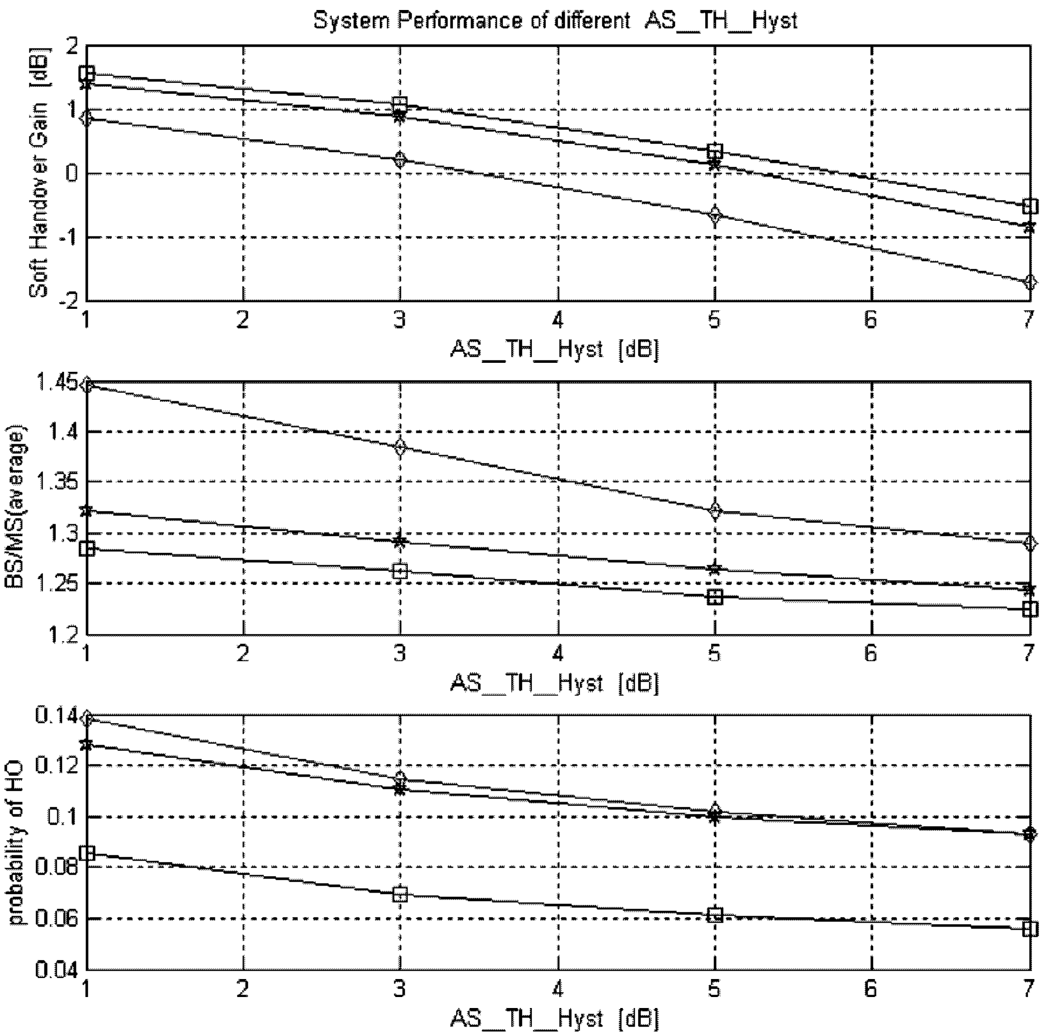


Figure 3.6: Impact of AS_Th_Hyst on system performance. Legend: -□- is omni directional antenna with 20 MS/BS; -◇- is 120 degree directional antenna with 60 MS/BS; -∗- is 60 degree directional antenna with 60 MS/BS.

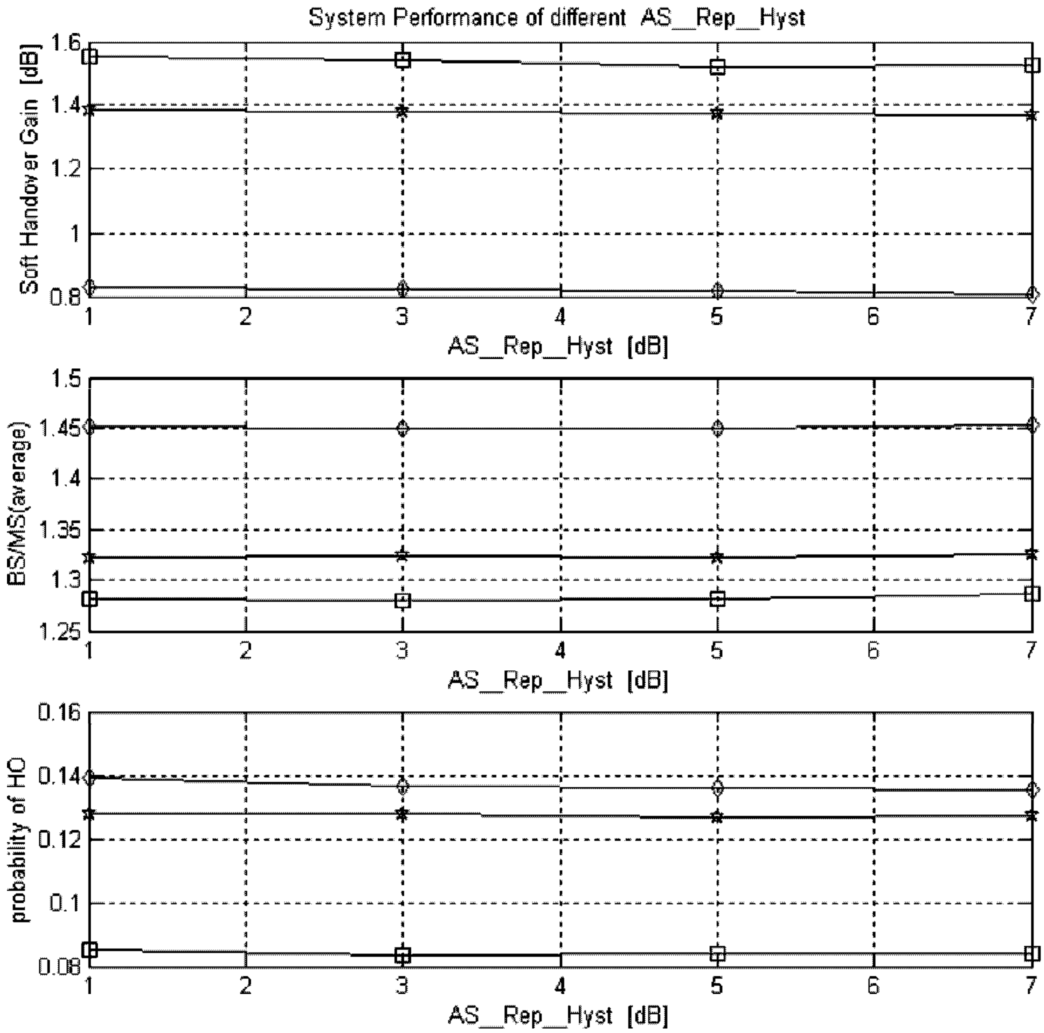


Figure 3.7: Impact of AS_Max_Size on soft handoff gain.

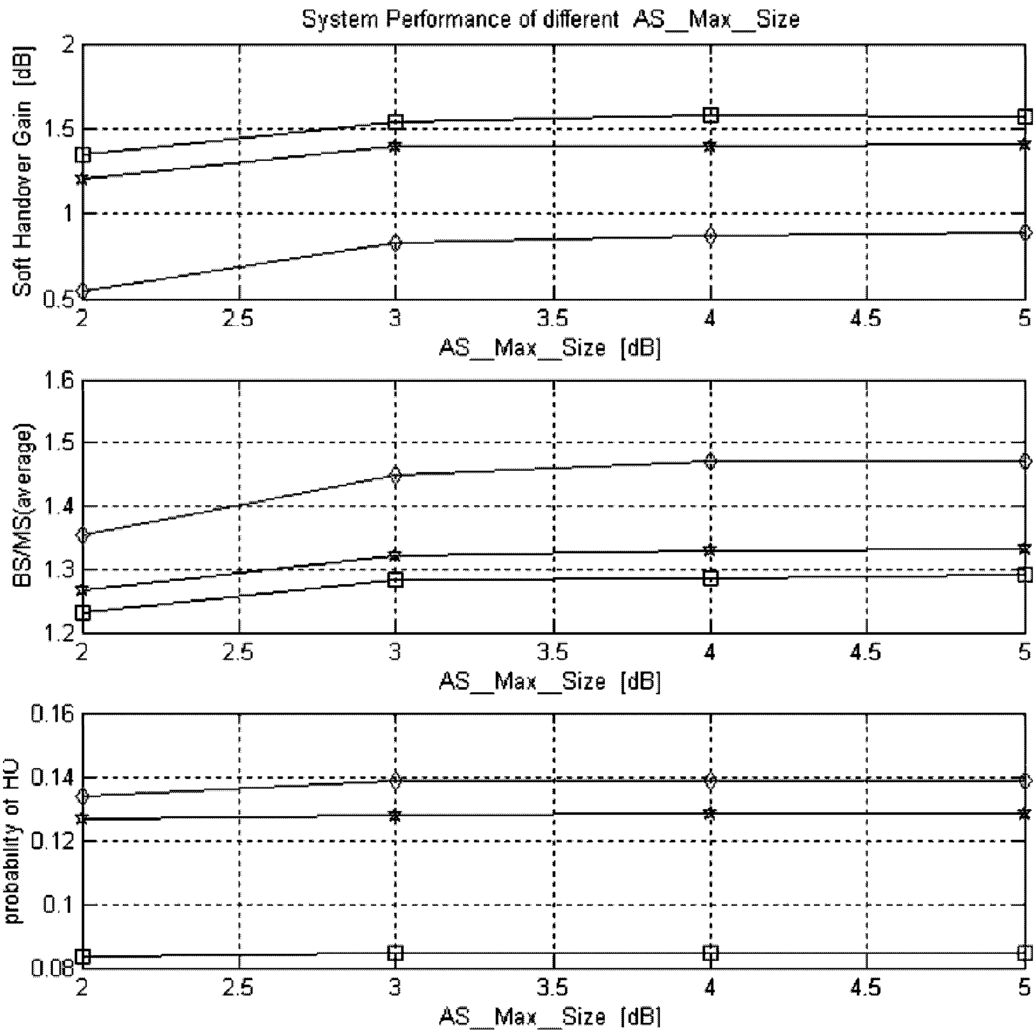


Figure 3.8: Impact of AS_Max_Size on soft handoff gain.

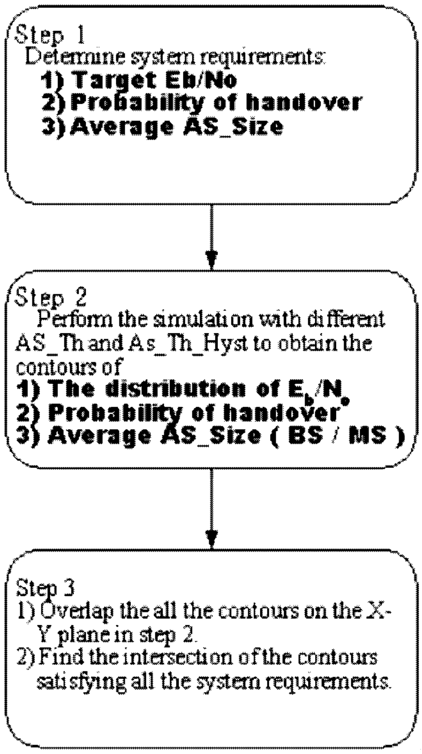


Figure 3.9: Flow chart of the proposed 3-step contour overlapping method for handoff parameters optimization.

3.5.2 An Example

The following example demonstrates the procedure of the proposed soft handoff parameters design methodology:

1. We list the system performance requirements for 12.2 kbps service as shown in Table 3.4.

2. We generate the 99^{th} percentile of E_b/N_o, handoff probability, and average active set size in terms of different values of AS_TH and AS_TH_HYST. As shown in Fig. 3.10, we project these curves onto the X-Y plane to obtain the performance contours in terms of AS_TH_HYST and AS_TH.

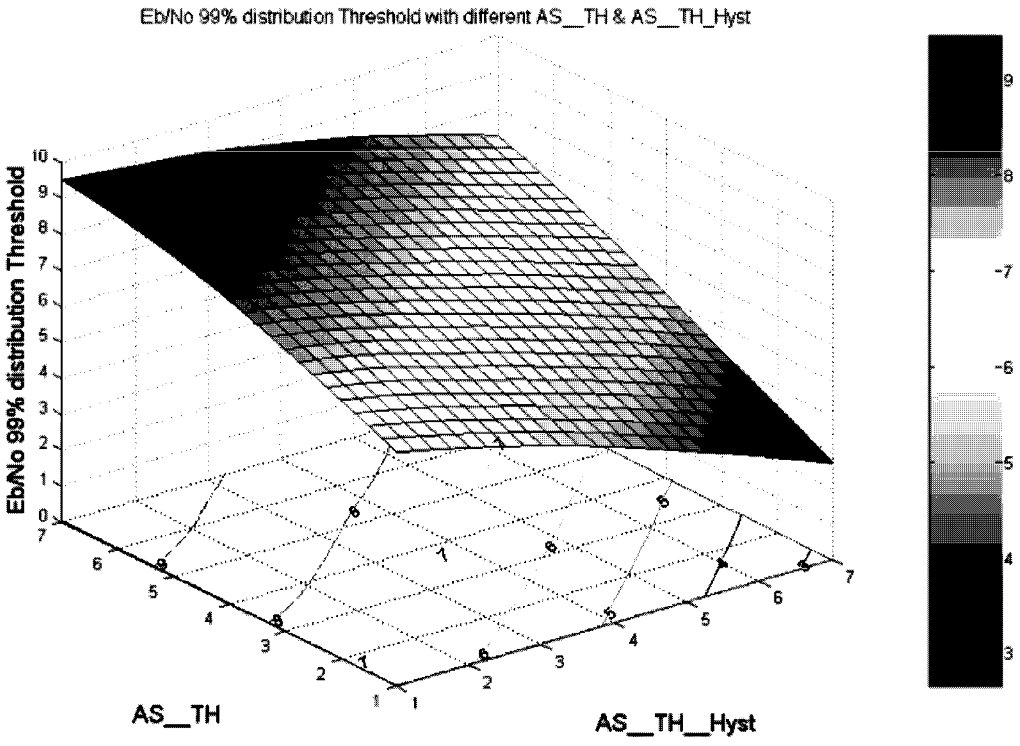
3. We overlap these performance contours obtained in step 2. Figure 3.11 (a) shows the overlapping contours for the target E_b/N_o and the handoff probability. The circled region satisfies the requirement of the 99^{th} percentile E_b/N_o equal to 7.9 dB and handoff probability less than 12%. Figure 3.11 (b) shows the overlapping contours of the target E_b/N_o and the average active set size. The circled region satisfies the requirement of the 99^{th} percentile E_b/N_o equal to 7.9 dB and average active set size less than 1.4. Figure 3.11 (c) shows the overlapping contours of all the three performance requirements. The intersection of circled region in Figure 3.11 (c) satisfies all the performance requirements. Hence from the intersection of the figure, we find the optimal parameters for the 12.2 kbps service, which are AS_TH_HYST is 2 dB and AS_TH is 3.5 dB.

3.6 Conclusion

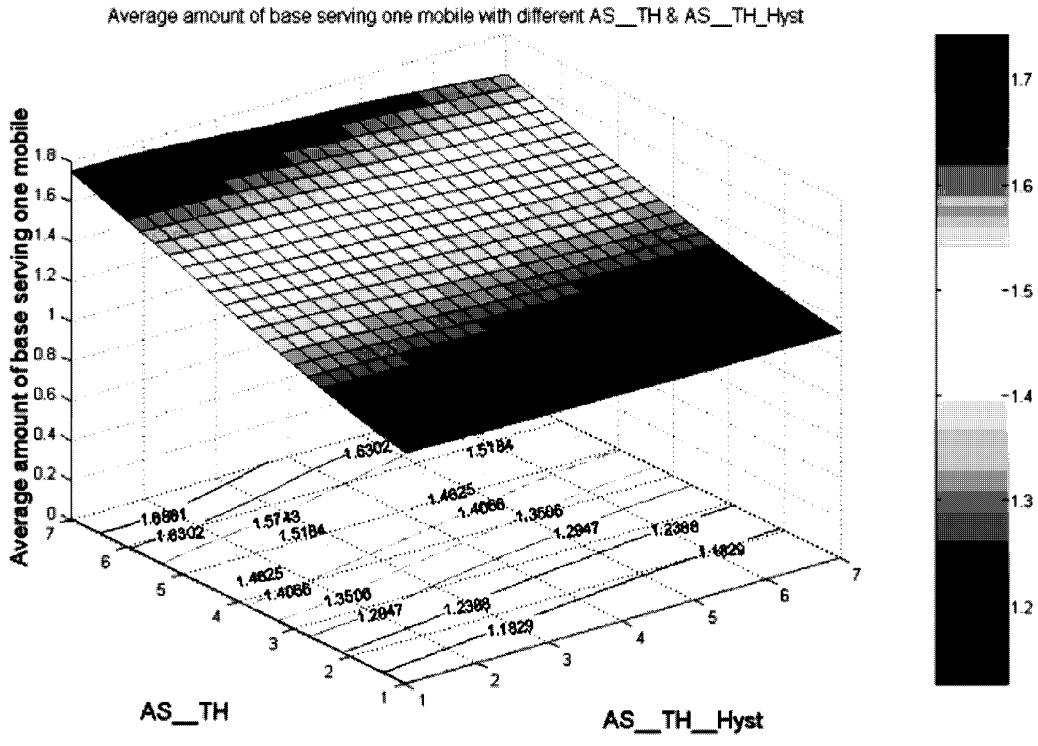
In this chapter we have discussed the impact of the soft handoff parameters with respect to the WCDMA system. We find that only two parameters, i.e. AS_TH and

Table 3.4: System performance requirements in example

System performance requirements	
99^{th} percentile E_b/N_o	7.9 dB
Average active set size	1.4
Handoff probability	12%

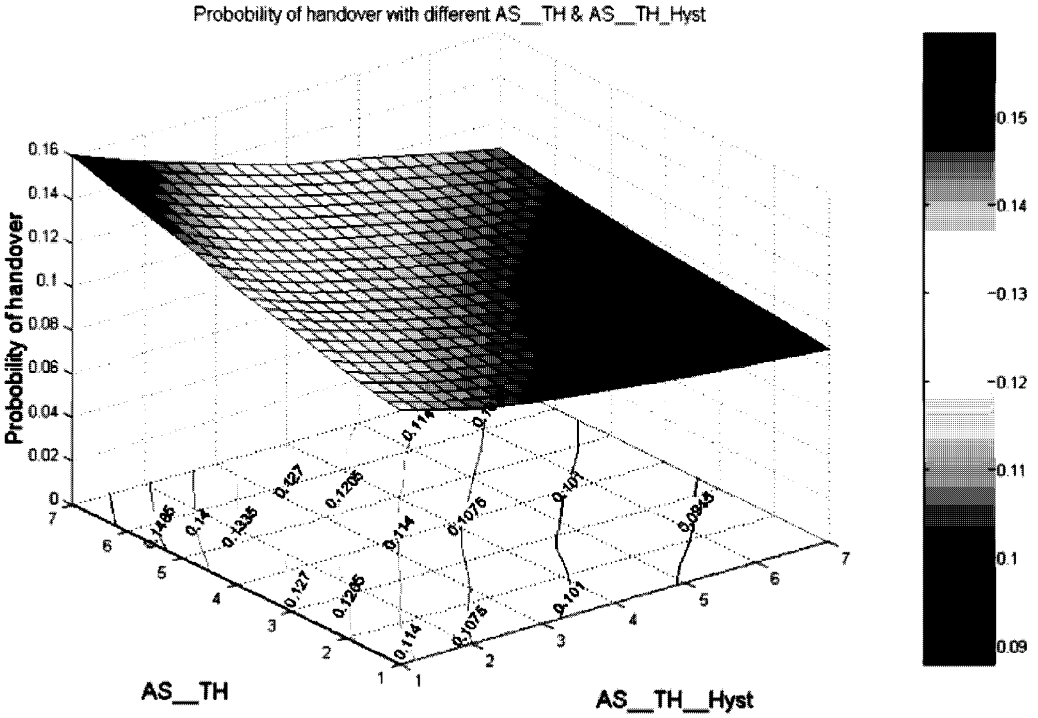


(3.10a)



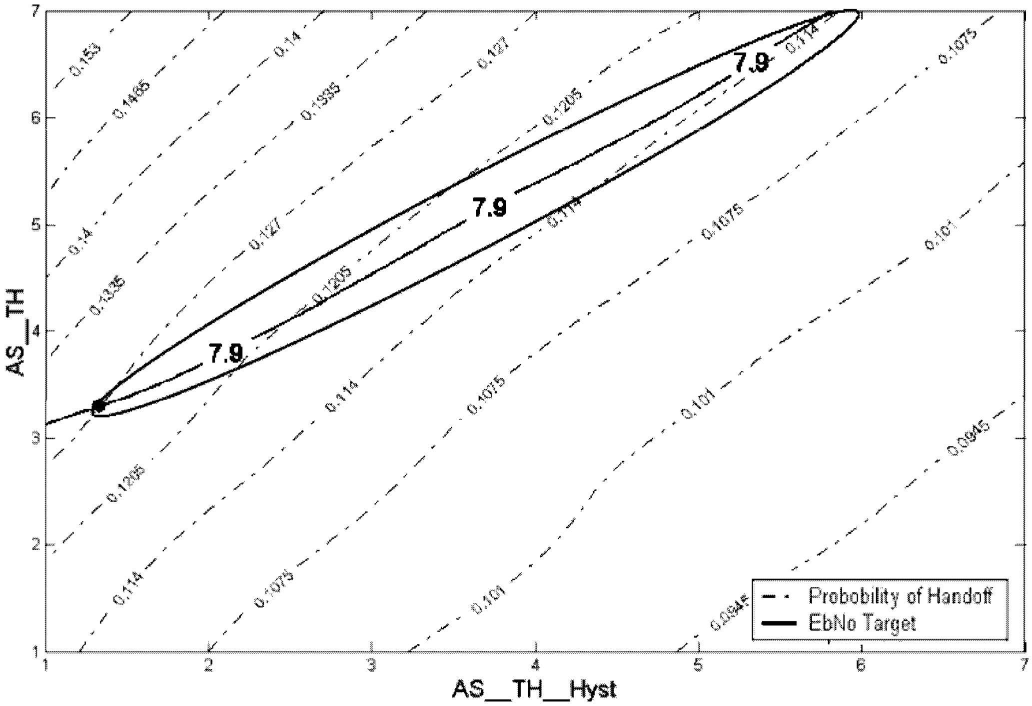
Average amount of base serving one mobile with different AS__TH & AS__TH_Hyst
Average amount of base serving one mobile
AS__TH
AS__TH__Hyst

(3.10b)

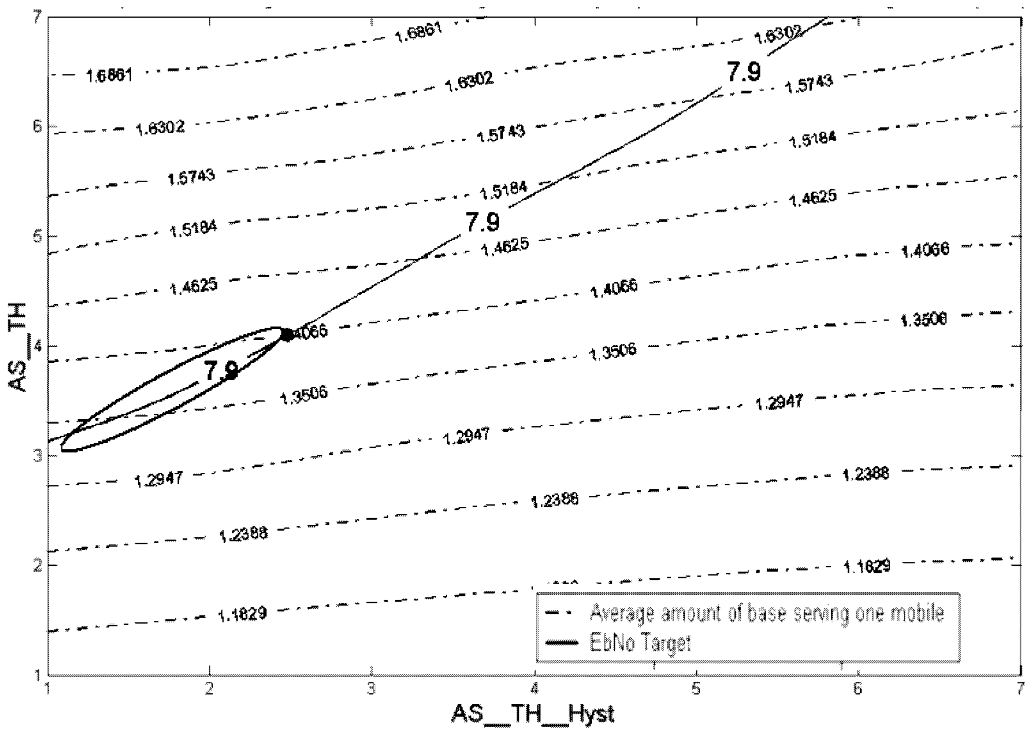


(3.10c)

Figure 3.10: Simulation results with different values of AS_TH and AS_TH_HYST, where (a) distribution and contours of 99 percentile E_b/N_o; (b) distribution and contours of average active set size; (c) distribution and contours of handoff probability.


Probability of Handoff
EbNo Target
AS__TH
AS__TH__Hyst
7.9

(3.11a)


Average amount of base serving one mobile
EbNo Target
AS__TH
AS__TH__Hyst
7.9

(3.11b)

(3.11c)

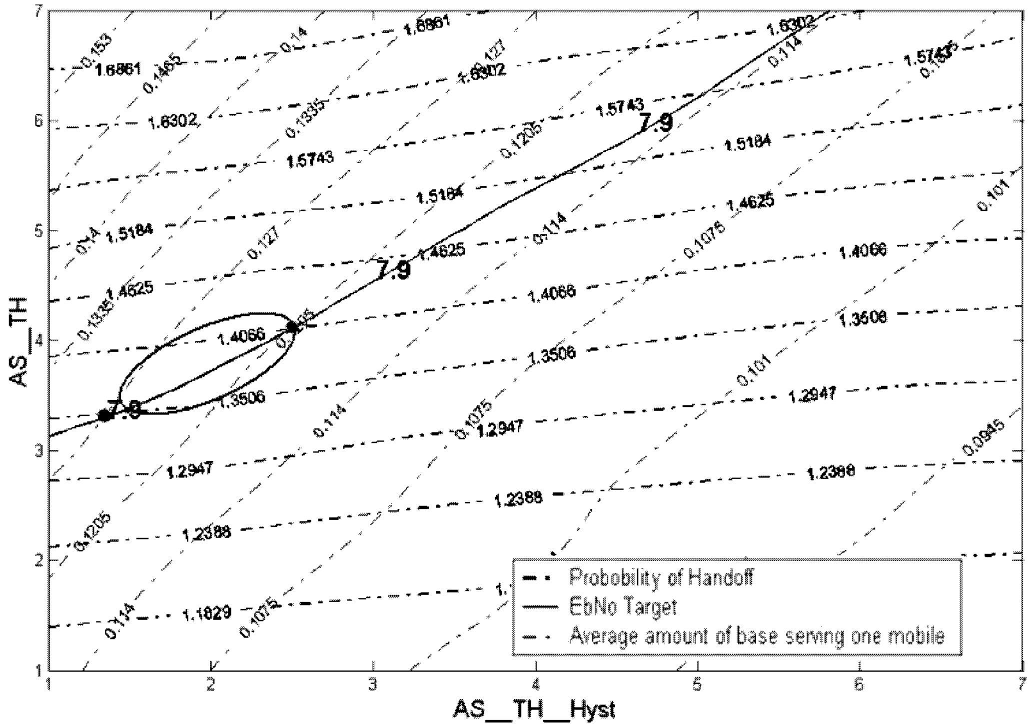


Figure 3.11: Overlapping contours of Figure 3.6: plot (a) shows the overlapping contours for the target E_b/N_o equal to 7.9dB and handoff probability requirement, where the circled region satisfies E_b/N_o equal to 7.9dB and handoff probability less than 12%; plot (b) shows the overlapping contours of the target E_b/N_o equal to 7.9dB and requirement on average active set size, where the circled region satisfies the E_b/N_o equal to 7.9dB and average active set size less than 1.4; plot (c) shows the overlapping of all the three contours. The intersection in circled region in plot (c) satisfies all the performance requirements.

AS_TH_HYST, affect the system performance significantly. Based on this observation, we propose a contour overlapping technique to simplify soft handoff parameters design with emphasis on the setting of AS_TH and AS_TH_HYST. By using the proposed methodology, we can easily find the optimal handoff parameters subject to different performance requirements. Thus the proposed handoff parameter design approach can be used to optimize the performance for the WCDMA system.