國立臺灣大學資訊管理研究所碩士論文

指導教授：林永松 博士

考慮服務品質限制及整合語音與資料傳輸之 WCDMA 系統允入控制演算法

A QoS Constrained Call Admission Control Algorithm in Voice/Data Integrated WCDMA Systems

研究生： 顧育先 撰

中華民國九十三年七月

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本 論 文 係 提 交 國 立 台 灣 大 學
資 訊 管 理 學 研 究 所 作 為 完 成 碩 士
學 位 所 需 條 件 之 一 部 份

研 究 生： 顧 育 先 撰

中 華 民 國 九 十 三 年 七 月

僅以此篇論文獻給我親愛的家人~~

謝　　詞

兩年研究所的求學生涯也隨著本篇論文的完成而告一段落，而即將邁向人生的另一個階段。首先，要感謝恩師林永松老師，在論文寫作期間老師的指導與教誨對我無不受益良多，而老師嚴謹的研究態度、風趣幽默的待人接物皆值得學生作為學習的明鏡與做人做事的典範。在論文口試過程中，感謝口試委員莊裕澤主任與蔡益坤老師給予學生許多寶貴的建議與指正，讓本論文能更加完備。

感謝博士班國忠學長在百忙之中抽空與我們討論，給予建議與指引研究方向。感謝博士班柏皓學長不吝給予鼓勵，與工作上的諮詢與協助。也要感謝一起奮鬥的好友們瑩珍、俊達、翔騰、耿宏、明立、大鈞、閔元、坤威、柏鈞，生活上與課業上大家互相扶持、互相鼓勵，也因為你們讓我這兩年研究生涯豐富了起來，充滿多采多姿的回憶。還有感謝實驗室的學弟妹們，建宏、孝澤、書平、琳智、明源在口試期間的協助，讓我能專心準備論文口試。

在此，我要將這篇論文獻給在天上的母親，從小沒有您辛勤的栽培，不辭勞苦的付出，就沒有今日的我。另外也獻給我敬愛的父親、阿姨及家人們，經由你們的包容與鼓勵，讓我能在論文沉重的壓力中，站穩自己的腳步，面對一次又一次的考驗，完成碩士學位論文，我要與我的家人共同分享這份喜悅。

最後，我要感謝過去所有曾經幫助過我的人，因為你們的協助與支持，才帶給我今日的成長，謝謝大家！

顧育先 謹識

于臺大資訊管理研究所

九十三年七月

論文摘要

論文題目：考慮服務品質限制及整合語音與資料傳輸之WCDMA系統允入控制演算法

作　　者：顧育先　　　　　　　　　　　　　　　　　　**九十三年七月**

指導教授：林永松 博士

近年來行動通訊網路快速地發展，從語音傳輸逐漸增加了資料傳輸，而隨著照相攝影手機的普及，多媒體與大量資料傳輸成為未來的趨勢，所以第三代行動通訊系統也因此而誕生。為了維持所有連線者的服務品質，允入控制必須在系統容量與通訊品質進行權衡決策，來評斷是否允許新用戶之加入。

第三代行動通訊的無線介接採用 CDMA 的技術，透過分碼多工所有用戶同時使用同樣的頻寬進行傳輸，但是每個用戶的傳輸功率均成為其他用戶的干擾訊號，系統的容量受到所能夠容忍的訊噪比 (signal-to-interference ratio, SIR)所影響，所以此為影響 CDMA 允入控制重要的因素。

本篇論文針對 WCDMA 系統，同時考慮上行與下行的系統容量限制(包含訊噪比及最大傳輸功率限制)，並且加上軟式訊號交遞(Soft Handover)機制，提出一個考慮服務品質限制的允入控制演算法。本論文透過最佳化數學模型，將此問題轉換為一個線性混合整數規劃問題(linear mix-integer programming problem)，並且採用拉格蘭日鬆弛法(Lagrangean Relaxation)為基礎的方法來處理此一複雜問題。

關鍵字：寬頻分工多重擷取系統(WCDMA)、允入控制、容量管理、服務品質、軟式訊號交遞、第三代行動通訊系統、數學最佳化、拉格蘭日鬆弛法。

THESIS ABSTRACT

GRADUATE INSTITUTE OF INFORMATION MANAGEMENT

NATIONAL TAIWAN UNIVERSITY

NAME：KU, YU-HSIEN **MONTH/YEAR：JUL, 2004**

ADVISER：YEONG-SUNG LIN

A QoS Constrained Call Admission Control Algorithm in Voice/Data Integrated WCDMA Systems

Data and multimedia services are becoming more and more dominant, and worldwide operators are announced that they are ready to provide 3G (3rd Generation Wireless Systems) service. 3G will allow more advanced added-value data services for mobile users, who can, for example, view downloaded or streaming video content at a data rate of 384 Kbps to 2 Mbps over the radio spectrum. Call admission control plays an important role in providing different QoS guarantee for each user.

UMTS (Universal Mobile Telecommunications System) using WCDMA (Wideband Code Division Multiple Access) is one of popular standard of 3G. By using CDMA technique, messages for different users are identified, and all users use the same bandwidth to transfer messages in the same time slot. However, the interference caused by the transmission power of other users will be the limit of system capacity.

This thesis focuses on the viewpoint of the capacity and the maximum revenue of the whole system to achieve the optimal network resource utility and the maximum total revenue for the subscribers. In past, researches in WCDMA call admission control are only consider unidirectional (uplink or downlink) interference and most of

them discuss voice traffic only. In this thesis, we combined the most important issues, such as downlink interference, uplink interference, voice/data integrated traffic, power control and soft handover into consideration.

This thesis developed a mathematical programming model to formulate this joint design optimization problem. This problem turns out to be a linear mixed integer programming problem. A set of heuristic solution procedures based on Lagrangian relaxation methods is proposed to solve the complicated problem.

Keywords: WCDMA, Call Admission Control, Capacity Management, Quality of Service, Soft Handover, 3rd Generation Wireless System, Mathematical Optimization, Lagrangian Relaxation Method.

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Chapter 1 Introduction

1.1 Background

In the last ten years, there is an extraordinarily evolution to the wireless telecommunication systems. The first generation systems are the analog cellular systems and can only transfer voice. The second generation systems are the digital cellular systems currently in use, such as GSM, PDC, and IS-95. Recently, more and more multimedia and higher rate data services requirement are emerge, and this drive the birth of third generation mobile systems. The third generation systems are designed for multimedia communication: with them person-to-person communication can be enhanced with high quality images and video, and access to information and services on public and private networks will be enhanced by higher data rates and new flexible communication compatibilities of third generation systems.[1][5]

WCDMA technology has emerged as the most widely adopted third generation air interface, and its specification has been created by 3GPP (the 3rd Generation Partnership Project). Based on WCDMA, IMT-2000/UMTS (International

Mobile Telecommunications 2000/Universal Mobile Telecommunications System) is the well known third generation system.[1] The main objectives for the IMT-2000 air interface can be summarized as: (i) full coverage and mobility for 144 Kbps, preferably 384 Kbps; (ii) limited coverage and mobility for 2 Mbps; (iii) high spectrum efficiency compared to existing systems; (iv) high flexibility to introduce new services. WCDMA also provide several advantages for mobile cellular network, such as high spectral efficiency, soft capacity, soft handoff and increased system capacity.

Among the new services offered by IMT-2000/UMTS, the packet data service is one of the most critical mainly because of the characteristics of the code division access scheme adopted at the radio interface.[6] Not only the circuit-switched traffic (voice) but also packet-switched traffic (data) will exist in IMT-2000/UMTS systems. Mixed voice and data traffic will let the analysis of system performance more difficult.

1.2 Motivation

In order to achieve each user's QoS requirement, admission control is needed to keep the system load and performance. The admission control allows a new user into the radio access network if the admission does not cause an excessive interference in the system. The target of the admission control is to prevent the overload of the CDMA system and to guarantee the quality of the existing connections and to guarantee the planned coverage area of the system. Before a new user is admitted to the system, the admission control algorithm must calculate the increase in the total interference level due to a new user.[1]

In formal research[1], admission control for IMT-2000/UMTS is considered uplink traffic or downlink traffic only. Besides, in third generation mobile system more and more packet data traffic will be the trend. Therefore, in this thesis we try to take account of both uplink and downlink traffic, and also consider different type of traffic to conform the real environment.

For subscribers, to minimize call blocking rate and to satisfy each user's QoS requirement is an important issue. A good criterion of call admission control would maximize the total throughput and bring a goodly sum of revenue for the company. Our work is supposed to be helpful for telecom industry.

The network planning and capacity management includes five major modules depicted in Figure 1-1.

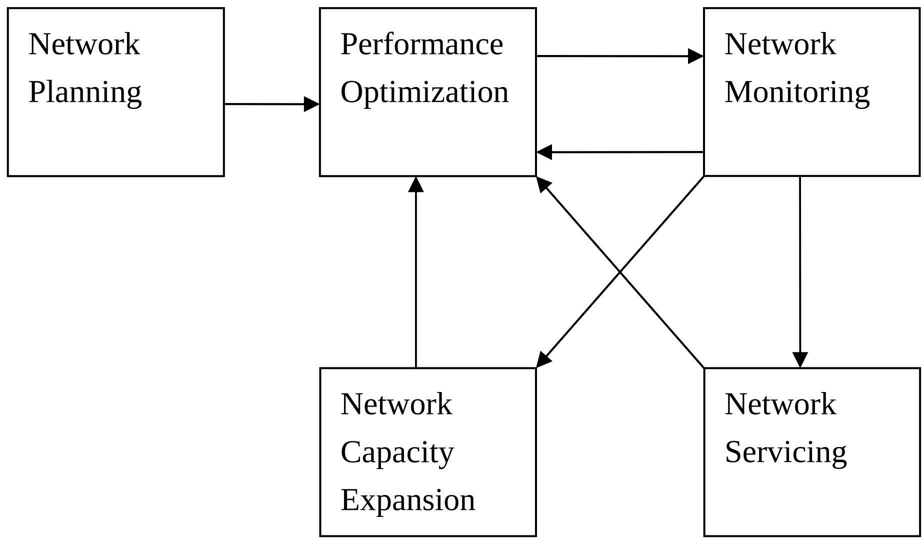

Figure 1-1 Operation support and capacity management model

This thesis will model the problem of the WCDMA wireless communications networks operational call admission control issues. We focus on traffic analysis of mobile data, performance optimization, network monitoring, network capacity expansion, and network servicing. Figure 1-1 shows the relationship among these issues.

1.3 Literature Survey

1.3.1 WCDMA technique

To accommodate a number of users transmitting and receiving signals simultaneously, multiple access technique is needed. There are three basic ways to have many channels within an allocated bandwidth: frequency, time and code division multiplexing and is addressed by three multiple access technique. In FDMA (frequency division multiple access) system, it employs difference carrier frequency to transmit the signal for each user. In TDMA (time division multiple access) system, it uses distinct time to transmit the signal for difference users. In CDMA (code division multiple access) system, it uses different code to transmit the signal for each user. Contrary to FDMA and TDMA, CDMA makes all users share the same radio frequency at the same time.

Direct Sequence Code Division Multiple Access (DS-CDMA) technique is adopted as an air interface multiple access scheme in 3G systems. In DS-CDMA, user information bits are spread over a wide bandwidth by multiplying the user data with quasi-random bits (called chips) derived from CDMA spreading codes.

By spread spectrum, the original information becomes a thin and ineffective slip of noise transferring to the receiver (Figure 1-2). In other word, the wideband signal can be below the thermal noise level. When the receiver receives the modulated signal, it can decode it to get the correct information with the PN code of this connection. [1]

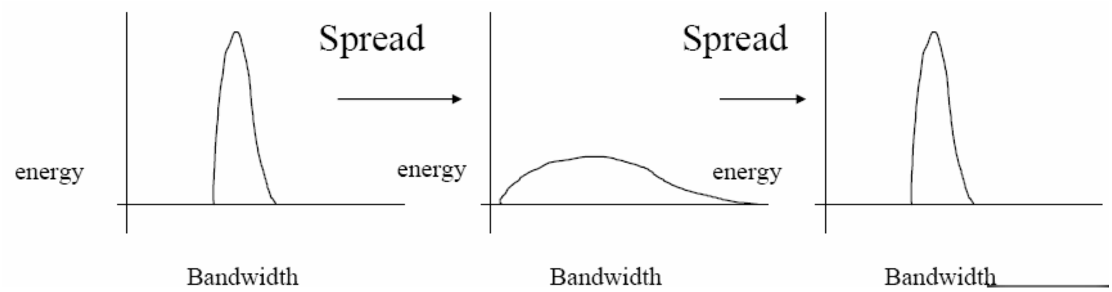

Figure 1-2 Concept of direct sequence spread spectrum

WCDMA, standardized by 3GPP (The 3rd Generation Partnership Project), and CDMA2000, standardized by 3GPP2 (The 3rd Generation Partnership Project 2), are the two main technologies of 3G, and they both adopt DS-CDMA technique. CDMA2000 uses a multi-carrier approach for n times of 1.25 MHz bandwidth. On the other hand, WCDMA uses one 5 MHz frequency band to provide higher data rate services and better coverage. Figure 1-3 represent the time-frequency-code space of WCDMA.

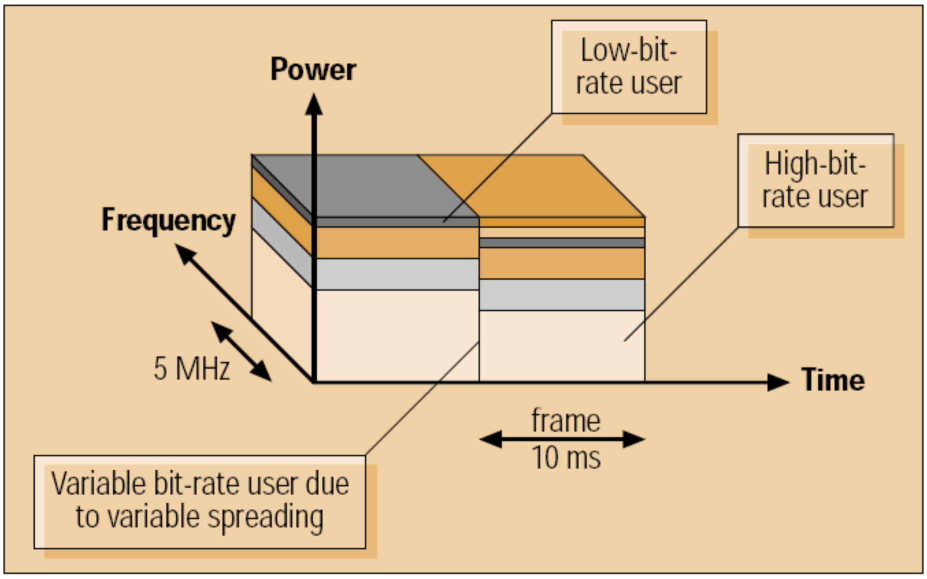

Figure 1-3 Variable bandwidth allocation in WCDMA

The spreading process of WCDMA is based on two codes, namely the spreading code and the scrambling code (Figure 1-4). The spreading code increase the flow bit rate to the chip rate of the air interface according to the spreading factor (SF). Different values of SF ranging from 4 to 512 are available and they are obtained using a tree of orthogonal codes. The tree has the characteristic that two codes, even with difference SF, are orthogonal if they are located in different branch of the tree. Multiple trees can be generated using a scrambling code which varies the order of chips. The spreading process provides the processing gain for each user.[22]

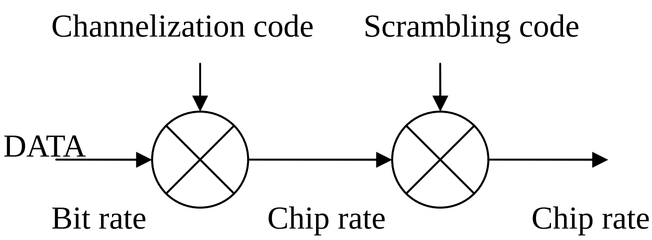

Figure 1-4 Spreading and scrambling in WCDMA

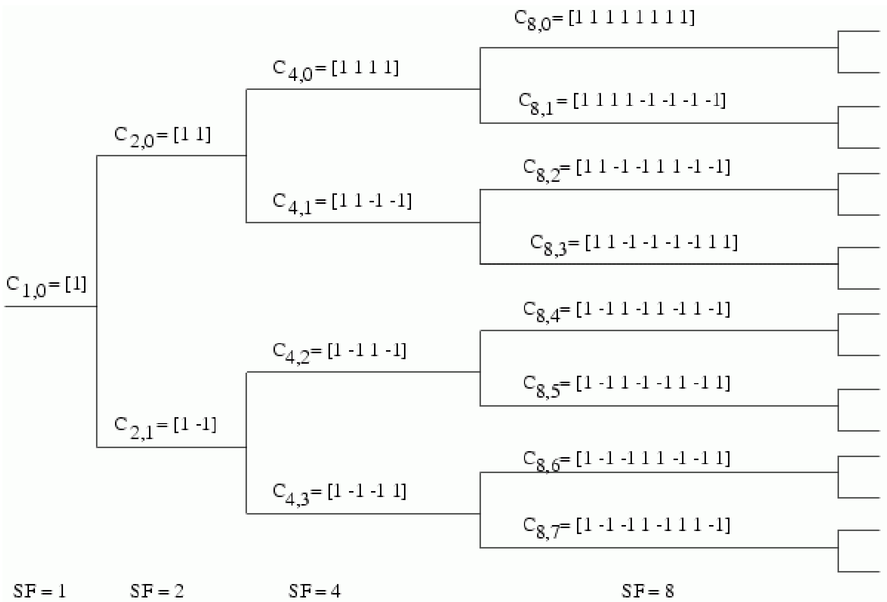

Figure 1-5 orthogonal variable spreading factor technique

Another important feature of WCDMA is that it supports highly variable user data rates, in other words the concept obtaining Bandwidth on Demand (BoD) is well supported. By using orthogonal variable spreading factor (OVSF) like Figure 1-5, WCDMA can support very high bit rates (up to 2 Mbps) and also can support highly variable user data rate as demonstrated in Figure 1-3 [22]

1.3.2 WCDMA interference model and capacity issues

The characteristic of a WCDMA system is that the frequency reuse factor is 1 and the same frequency band is shared by all users, and is reused in each cell.[5] The main difference to CDMA is that there is no absolute number of maximum available channels that can be allocated to potential users. The system is typically interference-limited. The amount of interference and delivered cell capacity, therefore, must be estimated. The received signal quality at a receiver is typically measured by the signal-to-interference ratio (SIR), which is the ratio of the power of the wanted signal to the total residue power of the unwanted signals. In order to correctly interpret the wanted signal, the SIR must be above a given threshold.

In WCDMA we use the E_b / N_0, energy per user bit divided by the noise spectral density, to represent the SIR. [15]

$$(E_b / N_0)_j = \text{Processing gain of user } j \cdot \frac{\text{Signal of user } j}{\text{Total received power (exclude own signal)}}$$

The major interference to a given cell includes inter-cell interference, intra-cell interference and thermal noise.[15] The thermal noise is the background noise that exists in nature. Intra-cell interference is from the signal power of mobile terminals that are active in the same cell with the given mobile terminal. Inter-cell interference is from the signal power of mobile terminals that are active in the other cells.

Another important issue of WCDMA system is the total transmission power.[20] In order to service more mobile terminal, the base station should increase its transmission power. A base station has maximum total transmission power constraint, so the total system capacity will also be limited by power issue.

1.3.3 Admission Control Policy

Admission control accepts or rejects a request to establish a radio access bearer in the radio access network. The decision is based on (1) Does the new connection affect the QoS of the connections currently being carried by the network? (2) Can the network provide the QoS requested by the new connection? Once a request is accepted, the required resources must be guaranteed. The admission control algorithm is executed when a bearer is set up or modified. In WCDMA, the admission control algorithm estimates the load increase that the establishment of the bear would cause in the radio network, and this has to be estimated separately for the uplink and downlink direction. The requesting bearer can be admitted only of both uplink and downlink admission control admits it, otherwise it is rejected because of the excessive interference that it would produce in the network.[6][9][16]

1.3.4 Soft Handover

Soft handover was introduced by CDMA technology. Compared to the conventional hard handover, soft handover has quite a few inherent advantages. However, it also has the disadvantages of complexity and extra resource consumption. With hard handover, a definite decision is made on whether to handover or not and the mobile only communicates with one base station at a time. With soft handover, a conditional decision is made on whether to handover or not. Depending on the changes in pilot signal strength from the two or more base stations involved, a hard decision will eventually be made to communicate with only one. This normally happens after it is clear that the signal coming from one base station is considerably stronger than those come from the others. In the interim period of soft handover, the mobile communicates simultaneously with all the base stations in the active set. Hard handover happens on a time point; while, soft handover lasts for a period of time. Figure 1-6 shows the difference between hard handover and soft handover. [15]

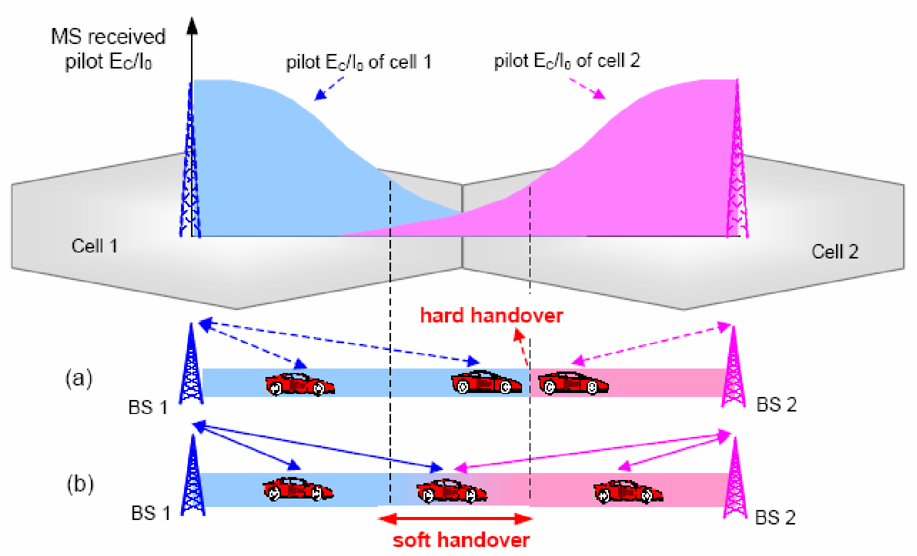

Figure 1-6 Comparison between Hard and Soft Handover

The soft handover process is not the same in the different transmission directions. In the uplink, the mobile transmits the signals to the air through its omni-directional antenna. The two base stations in the active set can receive the signals simultaneously because of the frequency reuse factor of one in CDMA systems. Then, the signals are passed forward to the RNC for selection combining. The better frame is selected and the other is discarded. Therefore, in the uplink, there is no extra channel needed to support soft handover. In Figure 1-7, the best signal from BS2 is selected and the other two signals from BS1 and BS3 is discarded.

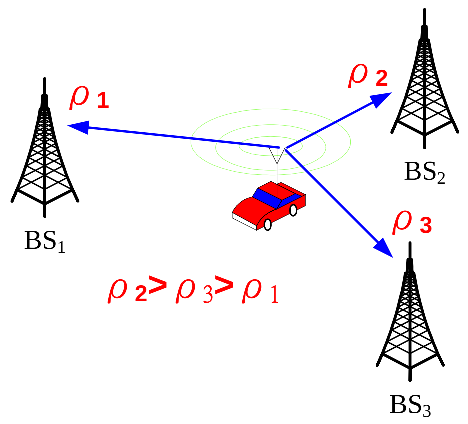

Figure 1-7 Selection Combining of Soft Handover in Uplink

In the downlink, the same signals are transmitted through both base stations and the mobile can coherently combine the signals from different base stations since it sees them as just additional multipath components, like Figure 1-8. Normally maximum ratio combining strategy is used, which provides an additional benefit called macrodiversity. However, to support soft handover in the downlink, at least one extra downlink channel (2-way SHO) is needed. This extra downlink channel acts to other users acts like additional interference in the air interface. Thus, to support soft handover in the downlink, more resource is required. As a result, in the downlink direction, the performance of the soft handover depends on the trade-off between the macrodiversity gain and the extra resource consumption.

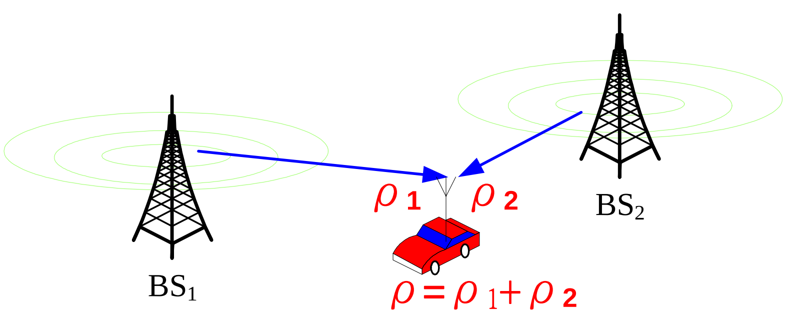

Figure 1-8 Maximum Ratio Combining of Soft Handover in Downlink

1.3.5 Lagrangian Relaxation

Lagrangian methods were widely used in scheduling and the general integer programming problems in the 1970s [12]. Lagrangian relaxation can provide the proper solutions for those problems. Lagrangian relaxation has several advantages, for example, Lagrangian relaxation could let us to decompose mathematical models in many different ways, so it is a flexible solution approach. Besides, Lagrangian relaxation solves the subproblems that we have decomposed as stand-alone problems. In fact, it has become one of the best tools for optimization problems such as integer programming, linear programming combinatorial optimization, and non-linear programming. Form now on, we can optimally solve the subproblems using any proper algorithm [12][13].

Lagrangian relaxation permits us to find out the boundary of our objective function, we can use it to implement heuristic solution for getting feasible solutions. Lagrangian relaxation is a flexible solution strategy that permits modelers to exploit the underlying structure in any optimization problem by relaxing complicating constraints. This method permits us to “pull apart” models by removing constraints and instead place them in the objective function with associated Lagrangian multipliers. The optimal value of the relaxed problem is always a lower bound (for minimization problems) on the objective function value of the problem. To obtain the best lower bound, we need to choose the for minimization multiplier so that the optimal value of the Lagrangian subproblem is as large as possible. We can solve the Lagrangian multiplier problem in a variety of ways. The subgradient optimization technique is possibly the most popular technique for solving the Lagrangian multipliers problem [12][13].

1.4 Proposed Approach

We model the WCDMA admission control problem as a linear integer mathematical programming problem. In this optimization problem, we maximize the total revenue for system operator subject to QoS (SIR) constraint, power (capacity) constraint and priority constraint.

We will apply the Lagrangian relaxation method and the subgradient method to solve the problems.

Chapter 2 Problem Formulation

2.1 Problem Description

This thesis focuses on finding out an admission control policy by determining which mobile terminal can be admitted into the system such that the revenue to the operator can be maximized. We establish a mathematical model to discuss admission control problem.

In this problem, we consider that there are already some existing mobile stations in the system and are some new mobile stations will enter the system. The decision is made by RNC (Radio Network Controller, who owns and control the radio resources for the base stations connected to it) to evaluate overall system status to maximize the system total revenue. The new mobile terminals in this model can either homed to the controlling base stations or blocked.

We also consider soft handover issues in WCDMA. Every mobile station in the system can simultaneously connect to different base station to improve its QoS when at boundary of base station. In addition, we consider different class of traffic, for example, the real time video streaming traffic will have higher priority than the web browsing traffic. Hence, higher class traffic will be processed before the lower class traffic. Table 3-1 summarizes the problem description. Shown as follow:

Table 2-1 Problem Description

Given:
➢ Locations of each BS
➢ Distribution of mobile users
➢ Traffic types of mobile users and its corresponding SIR requirement
➢ Users' homing status
To Determine:
➢ Mobile users' admission status
➢ Transmission power of mobile terminals and base stations
Subject to:
➢ QoS (SIR) constraint
➢ Base stations and mobile terminals power constraint
➢ Priority constraint
Assumption:
➢ Global information of all base stations and all mobile terminals is known
➢ Orthogonal code resource is infinite
➢ Signal of SHO in Uplink can all adopt selective combining
➢ Temporal dimension is ignored
➢ Users' movement is not considered

2.2 Notation

Table 2-2 Notation of given parameters

Given Parameters	
Notation	**Descriptions**
B	The set of base stations
M	The set of mobile stations ($M = M' \cup M''$)
M'	The set of existing mobile stations
M''	The set of new mobile stations
T	The set of traffic types ($T = T_V \cup T_D$)
T_V	The set of voice traffic types
T_D	The set of data traffic types
ρ_t^{UL}	SIR requirement for a mobile terminal with traffic type *t* in uplink
ρ_t^{DL}	SIR requirement for a mobile terminal with traffic type *t* in downlink
v_t	Activity factor of mobile terminal with traffic type *t*
P_N	Thermal noise strength
P_{BS}	Maximum transmission power of a base station
P_{MS}	Maximum transmission power of a mobile terminal
τ	Attenuation factor
α	Orthogonality factor in downlink
D_{mi}	Distance between mobile terminal *m* and base station *i*
β_{mi}	Indicator function which is 1 if mobile terminal *m* can be served by base station *i* and 0 otherwise

γ_{mt}	Indicator function which is 1 if the request traffic type of mobile station *m* is *t* and 0 otherwise
$\sigma(m)$	Request data type of mobile terminal *m*
B_m	The set of base stations that mobile terminal *m*, $m \in M'$, was originally connected
r_t	Revenues get from serving a mobile user with traffic type *t*
f_t^D	Cost of disconnect a mobile user with traffic type *t*
f_t^R	The cost of rehoming a mobile user with traffic type *t*
H	A huge positive number which approaches to infinity
S	A small positive number which approaches to 0
Z	Maximum number of soft handoff base stations
$\hat{q}_t$	Maximum transmission power of base stations to mobile terminals with traffic type *t*
$\underline{q}$	Minimum transmission power of base stations to mobile terminals

Table 2-3 Notation of decision variables

Decision Variables	
Notation	**Descriptions**
z_{mit}	Decision variable which is 1 if mobile terminal *m* with traffic type *t* is admitted into the base station *i* and 0 otherwise
z_{mit}^{UL}	Decision variable which is 1 if mobile terminal *m* with traffic type *t* is admitted into the base station *i* in uplink and

	0 otherwise
y_{mt}	Decision variable which is 1 if mobile terminal *m* with traffic type *t* is admitted into system
p_m	Uplink transmission power of mobile terminal *m*
q_{im}	Downlink transmission power of base station *i* to mobile terminal *m*

2.3 Problem Formulation

Optimization problem (IP1):

Objective function:

$$
\begin{aligned}
Z_{IP1} &= \max \left(\begin{array}{l} \sum_{m \in M''} \sum_{t \in T} r_t y_{mt} - \sum_{m \in M'} \left(1 - \sum_{t \in T} y_{mt} \right) f^{D}_{\sigma(m)} \\ - \sum_{m \in M'} \sum_{i \in B - B_m} \sum_{t \in T} z_{mit} f^{R}_{\sigma(m)} \end{array} \right) \\
&= \min \left(- \left(\begin{array}{l} \sum_{m \in M''} \sum_{t \in T} r_t y_{mt} - \sum_{m \in M'} \left(1 - \sum_{t \in T} y_{mt} \right) f^{D}_{\sigma(m)} \\ - \sum_{m \in M'} \sum_{i \in B - B_m} \sum_{t \in T} z_{mit} f^{R}_{\sigma(m)} \end{array} \right) \right)
\end{aligned}
\qquad \text{(IP1)}
$$

Subject to:

$$
\frac{\dfrac{p_m}{L(D_{mi}, \tau)} + H\left(1 - z^{UL}_{mit}\right)}{P_N + \sum_{\substack{n \in M \\ n \neq m}} v_{\sigma(n)} \dfrac{p_n}{L(D_{ni}, \tau)}} \geq \rho^{UL}_t \qquad \forall i \in B, m \in M, t \in T \qquad (2.1)
$$

$$
p_m \leq \sum_{t \in T} y_{mt} P_{MS} \qquad \forall m \in M \qquad (2.2)
$$

$$
p_m \geq \sum_{t \in T} y_{mt} \underline{p} \qquad \forall m \in M \qquad (2.3)
$$

$$
\sum_{i \in B} \frac{\dfrac{q_{im}}{L(D_{mi}, \tau)}}{\left(\begin{array}{l} P_N + \sum_{\substack{n \in M \\ n \neq m}} \left((1-\alpha) v_{\sigma(n)} \dfrac{q_{in}}{L(D_{mi}, \tau)} \right) \\ + \sum_{\substack{j \in B \\ j \neq i}} \sum_{n \in M} v_{\sigma(n)} \dfrac{q_{jn}}{L(D_{nj}, \tau)} \end{array} \right)} \geq y_{mt} \rho^{DL}_t \qquad \forall m \in M, t \in T \qquad (2.4)
$$

$$\sum_{i\in B}\frac{\dfrac{q_{im}}{L\left(D_{mi},\tau\right)}}{\left(\begin{array}{l}P_N+\sum\limits_{\substack{n\in M\\n\neq m}}\left((1-\alpha)v_{\sigma(n)}\dfrac{\beta_{mi}\hat{q}_{\sigma(n)}}{L\left(D_{mi},\tau\right)}\right)\\+\sum\limits_{\substack{j\in B\\j\neq i}}\sum\limits_{n\in M}v_{\sigma(n)}\dfrac{\beta_{nj}\hat{q}_{\sigma(n)}}{L\left(D_{nj},\tau\right)}\end{array}\right)}\geq y_{mt}\rho_t^{DL} \qquad \forall m\in M,t\in T \qquad (2.4.1)$$

$$\sum_{m\in M}q_{im}\leq P_{BS} \qquad \forall i\in B \qquad (2.5)$$

$$q_{im}\leq H\sum_{t\in T}z_{mit} \qquad \forall i\in B,m\in M \qquad (2.6)$$

$$q_{im}\geq \underline{q}\sum_{t\in T}z_{mit} \qquad \forall i\in B,m\in M \qquad (2.7)$$

$$z_{mit}^{UL}\leq z_{mit} \qquad \forall i\in B,m\in M,\ t\in T \qquad (2.8)$$

$$S\sum_{i\in B}\sum_{t\in T}z_{mit}\leq\sum_{i\in B}\sum_{t\in T}z_{mit}^{UL}\leq 1 \qquad \forall m\in M \qquad (2.9)$$

$$z_{mit}^{UL}=0\text{ or }1 \qquad \forall i\in B,m\in M,\ t\in T \qquad (2.10)$$

$$z_{mit}=0\text{ or }1 \qquad \forall i\in B,m\in M,\ t\in T \qquad (2.11)$$

$$z_{mit}\leq\gamma_{mt} \qquad \forall i\in B,m\in M,\ t\in T_V \qquad (2.12)$$

$$z_{mit}\leq\gamma_{mt} \qquad \forall i\in B,m\in M',\ t\in T_D \qquad (2.13)$$

$$z_{mit}\leq\sum_{\substack{t'\in T\\C_{t'}\geq C_t}}\gamma_{mt'} \qquad \forall i\in B,m\in M'',\ t\in T_D \qquad (2.14)$$

$$z_{mit}\leq\beta_{mi} \qquad \forall i\in B,m\in M,\ t\in T \qquad (2.15)$$

$$\sum_{t\in T}z_{mit}\leq 1 \qquad \forall i\in B,m\in M \qquad (2.16)$$

$$\sum_{i\in B}\sum_{t\in T}z_{mit}\leq Z_{MAX} \qquad \forall m\in M \qquad (2.17)$$

$$y_{mt}\leq\sum_{i\in B}z_{mit} \qquad \forall m\in M,t\in T \qquad (2.18)$$

$$y_{mt}=0\text{ or }1 \qquad \forall m\in M,t\in T \qquad (2.19)$$

The objective function of (IP1) is to maximize the total revenue added by admittance of new mobile terminal into the system, where r_t is the revenue the mobile station of traffic type *t* contributed. In terms of convenience, we can translate the problem into an equivalent description that is to minimize the negative system total revenue.

The set of constraints is explained bellow.

1) Uplink QoS and power constraints:

Constraints (2.1), (2.2) and (2.3). Each admitted mobile station should hold its uplink SIR (QoS) constraint and its maximum power constraint. Constraint (2.1) require the received power of mobile station *m* at base station *i* divided by sum of received power from all other mobile station plus background noise power is larger than mobile station *m*'s SIR requirement if base station *i* is the connecting base station of mobile station *m* in uplink; otherwise, the transmission power of mobile station *m* is not restricted by this constraint. Constraint (2.2) is to ensure the transmission power of mobile station *m* is not exceed its maximum power and also restrict the transmission power of mobile station *m* equal to 0 if it is not admitted. Constraint (2.3) requires that if mobile station *m* is admitted, its transmission power must larger than minimum power level of transmission power.

2) Downlink QoS and power constraints

Constraints (2.4), (2.5), (2.6) and (2.7). Each admitted mobile station should hold its downlink SIR (QoS) constraint and all base stations' maximum power constraint should also be satisfied. Constraints (2.4) is to ensure that sum of the SIR (received power strength of base station *i* divided by total power from other base stations plus background noise) form all the active set of mobile station *m* is larger than its downlink SIR requirement if it is admitted; otherwise, the total SIR mobile station *m* received is not limited. Because the non-linear constraint (2.4) makes the problem more complicated and harder to solve, we make some approximation to reduce the difficulty of this problem. We use average transmission power of base station *i* to mobile station *m* replace its real power level in the denominator of constraint (2.4) if mobile station *m* is in the coverage area of base station *i*. Therefore, we use constraint (2.4.1) to substitute for the constraint (2.4) in this problem. Constraint (2.5) ensures the total transmission power of base station *i* is not over maximum power of base station. Constraint (2.6) requires the transmission power from base station *i* to mobile station *m* (q_{im}) is equal to 0 if mobile station m is not admitted; otherwise q_{im} is not limited. Constraint (2.7) requires the transmission power from base station *i* to mobile station *m* (q_{im}) is larger than minimum power from base station to mobile station if mobile station *m* is admitted.

3) Admission policy constraints

Constraints (2.8) to (2.19). We use decision variables z_{mit}, z_{mit}^{UL} and y_{mt} to represent the admission policy status, and so we need some constraints to retain their relationship. Constraints (2.10), (2.11) and (2.19) guarantee the integer property of these decision variables. Constraint (2.8) ensures the connecting base station in uplink is in the active set of base station. Constraint (2.9) limit the maximum number of connecting base station in uplink to 1 and if the number of base station in active set is larger than 0, mobile station *m* should connect to one of them in uplink. Constraint (2.12), (2.13) and (2.14) limit the traffic type mobile station *m* can use. For all exist mobile stations and voice users of new mobile stations can only use the traffic type they request, but data users of new mobile stations can adopt traffic type which transmission data rate is lower than they request. Constraint (2.15) is to ensure that mobile station *m* can connect to base station *i* if in its coverage area. Constraint (2.16) guarantee mobile station *m* can only adopt one traffic type *t*. Constraint (2.17) limit the maximum number of base station in active set of mobile station *m*. Constraint (2.18) describe the relationship of decision variables z_{mit} and y_{mt}, let y_{mt} means the admission status of mobile station *m* in traffic type *t*.

Chapter 3 Solution Approach

3.1 Lagrangean Relaxation

As a convention, we can transform the maximization problem to minimization without loss of correctness. By using the Lagrangean relaxation method, the primal problem (IP1) can be transform in the following Lagrangean relaxation problem (LR) where constraints (2.1), (2.2), (2.3), (2.4.1), (2.6) and (2.7) are relaxed. For a vector of non-negative Lagrangean multipliers, a Lagrangean relaxation problem of IP1 is given by an optimization problem (LR) as below:

Optimization Problem (LR):

$$Z_D\left(u^1_{mit}, u^2_m, u^3_m, u^4_{mt}, u^5_{mi}, u^6_{mi}\right) =$$

$$\min -\left(\sum_{m\in M''}\sum_{t\in T} r_t y_{mt} - \sum_{m\in M'}\left(1-\sum_{t\in T} y_{mt}\right) f^D_{\sigma(m)} - \sum_{m\in M'}\sum_{j\in B-B_m}\sum_{t\in T} z_{mjt} f^R_{\sigma(m)}\right)$$

$$+\sum_{m\in M}\sum_{i\in B}\sum_{t\in T} u^1_{mit}\left(\rho^{UL}_t P_N + \sum_{\substack{n\in M\\ n\neq m}} \rho^{UL}_t v_{\sigma(n)} \frac{p_n}{L\left(D_{ni},\tau\right)} - \frac{p_m}{L\left(D_{mi},\tau\right)} - H\left(1-z^{UL}_{mit}\right)\right)$$

$$+\sum_{m\in M} u^2_m\left(p_m - \sum_{t\in T} y_{mt} P_{MS}\right) + \sum_{m\in M} u^3_m\left(\underline{p}\sum_{t\in T} y_{mt} - p_m\right)$$

$$+\sum_{m\in M}\sum_{t\in T}u_{mt}^{4}\left(y_{mt}\rho_t^{DL}-\sum_{i\in B}\frac{\dfrac{q_{im}}{L\left(D_{mi},\tau\right)}}{P_N+\sum_{\substack{n\in M\\ n\neq m}}\left((1-\alpha)v_{\sigma(n)}\dfrac{\beta_{ni}\hat{q}_{\sigma(n)}}{L\left(D_{mi},\tau\right)}\right)+\sum_{\substack{j\in B\\ j\neq i}}\sum_{n\in M}v_{\sigma(n)}\dfrac{\beta_{nj}\hat{q}_{\sigma(n)}}{L\left(D_{nj},\tau\right)}}\right)$$

$$+\sum_{m\in M}\sum_{i\in B}u_{mi}^{5}\left(q_{im}-H\sum_{t\in T}z_{mit}\right)+\sum_{m\in M}\sum_{i\in B}u_{mi}^{6}\left(\underline{q}\sum_{t\in T}z_{mit}-q_{im}\right) \qquad \text{(LR)}$$

Subject to:

$\sum_{m\in M}q_{im}\le P_{BS}$	$\forall i\in B$	(3.1)
$z_{mit}^{UL}\le z_{mit}$	$\forall i\in B, m\in M, t\in T$	(3.2)
$S\sum_{i\in B}\sum_{t\in T}z_{mit}\le\sum_{i\in B}\sum_{t\in T}z_{mit}^{UL}\le 1$	$\forall m\in M$	(3.3)
$z_{mit}^{UL}=0$ or 1	$\forall i\in B, m\in M, t\in T$	(3.4)
$z_{mit}=0$ or 1	$\forall i\in B, m\in M, t\in T$	(3.5)
$z_{mit}\le\gamma_{mt}$	$\forall i\in B, m\in M, t\in T_V$	(3.6)
$z_{mit}\le\gamma_{mt}$	$\forall i\in B, m\in M', t\in T_D$	(3.7)
$z_{mit}\le\sum_{\substack{t'\in T\\ C_{t'}\ge C_t}}\gamma_{mt'}$	$\forall i\in B, m\in M, t\in T_D$	(3.8)
$z_{mit}\le\beta_{mi}$	$\forall i\in B, m\in M, t\in T$	(3.9)
$\sum_{t\in T}z_{mit}\le 1$	$\forall i\in B, m\in M$	(3.10)
$\sum_{i\in B}\sum_{t\in T}z_{mit}\le Z_{MAX}$	$\forall m\in M$	(3.11)
$y_{mt}\le\sum_{i\in B}z_{mit}$	$\forall m\in M, t\in T$	(3.12)
$y_{mt}=0$ or 1	$\forall m\in M, t\in T$	(3.13)

where u^1, u^2, u^3, u^4, u^5 and u^6 are the vectors of non-negative Lagrangean multipliers $\{u^1_{mit}\},\{u^2_m\},\{u^3_m\},\{u^4_{mt}\},\{u^5_{mi}\}$ and $\{u^6_{mi}\}$. To solve (LR), we decompose the problem into the following four independent and easily solvable optimization subproblems.

3.1.1 Subproblem 1 (related to decision variables z_{mit}, z^{UL}_{mit} and y_{mt})

$$\min -\left(\sum_{m\in M''}\sum_{t\in T} r_t y_{mt} + \sum_{m\in M'}\sum_{t\in T} y_{mt} f^D_{\sigma(m)} - \sum_{m\in M'}\sum_{j\in B-B_m}\sum_{t\in T} z_{mjt} f^R_{\sigma(m)}\right)$$
$$+H\sum_{m\in M}\sum_{i\in B}\sum_{t\in T} u^1_{mit} z^{UL}_{mit} - \sum_{m\in M}\sum_{t\in T} u^2_m y_{mt} P_{MS} + \sum_{m\in M}\sum_{t\in T} u^3_m y_{mt} \underline{p} + \sum_{m\in M}\sum_{t\in T} u^4_{mt} y_{mt} \rho^{DL}_t$$
$$-\sum_{m\in M}\sum_{i\in B} u^5_{mi} H \sum_{t\in T} z_{mit} + \sum_{m\in M}\sum_{i\in B} u^6_{mi} \underline{q} \sum_{t\in T} z_{mit} \quad \text{(SUB 3.1)}$$

Subject to:

$$z^{UL}_{mit} \le z_{mit} \qquad \forall i\in B, m\in M, t\in T \qquad (3.2)$$

$$S\sum_{i\in B}\sum_{t\in T} z_{mit} \le \sum_{i\in B}\sum_{t\in T} z^{UL}_{mit} \le 1 \qquad \forall m\in M \qquad (3.3)$$

$$z^{UL}_{mit} = 0 \text{ or } 1 \qquad \forall i\in B, m\in M, t\in T \qquad (3.4)$$

$$z_{mit} = 0 \text{ or } 1 \qquad \forall i\in B, m\in M, t\in T \qquad (3.5)$$

$$z_{mit} \le \gamma_{mt} \qquad \forall i\in B, m\in M, t\in T_V \qquad (3.6)$$

$$z_{mit} \le \gamma_{mt} \qquad \forall i\in B, m\in M', t\in T_D \qquad (3.7)$$

$$z_{mit} \le \sum_{\substack{t'\in T \\ C_{t'}\ge C_t}} \gamma_{mt'} \qquad \forall i\in B, m\in M'', t\in T_D \qquad (3.8)$$

$$z_{mit} \le \beta_{mi} \qquad \forall i\in B, m\in M, t\in T \qquad (3.9)$$

$$\sum_{t\in T} z_{mit} \le 1 \qquad \forall i\in B, m\in M \qquad (3.10)$$

$$\sum_{i\in B}\sum_{t\in T} z_{mit} \le Z_{MAX} \qquad \forall m\in M \qquad (3.11)$$

$$y_{mt} \le \sum_{i\in B} z_{mit} \qquad \forall m\in M, t\in T \qquad (3.12)$$

$$y_{mt} = 0 \text{ or } 1 \qquad \forall m\in M, t\in T \qquad (3.13)$$

To rewrite SUB 3.1, we can get

$$
\begin{aligned}
&-\left(\sum_{m\in M''}\sum_{t\in T} r_t y_{mt} + \sum_{m\in M'}\sum_{t\in T} y_{mt} f^{D}_{\sigma(m)} - \sum_{m\in M'}\sum_{j\in B-B_m}\sum_{t\in T} z_{mjt} f^{R}_{\sigma(m)}\right) \\
&+H\sum_{m\in M}\sum_{i\in B}\sum_{t\in T} u^{1}_{mit} z^{UL}_{mit} - \sum_{m\in M}\sum_{t\in T} u^{2}_{m} y_{mt} P_{MS} + \sum_{m\in M}\sum_{t\in T} u^{3}_{m} y_{mt} \underline{p} + \sum_{m\in M}\sum_{t\in T} u^{4}_{mt} y_{mt} \rho^{DL}_{t} \\
&-\sum_{m\in M}\sum_{i\in B} u^{5}_{mi} H \sum_{t\in T} z_{mit} + \sum_{m\in M}\sum_{i\in B} u^{6}_{mi} \underline{q} \sum_{t\in T} z_{mit} \\
&= \sum_{m\in M'}\left(\sum_{t\in T}\left(\begin{aligned}&\sum_{i\in B-B_m}\left(z_{mit}\left(f^{R}_{\sigma(m)} - u^{5}_{mi}H + u^{6}_{mi}\underline{q}\right) + z^{UL}_{mit}\left(u^{1}_{mit}H\right)\right)\\ &+\sum_{i\in B_m}\left(z_{mit}\left(-u^{5}_{mi}H + u^{6}_{mi}\underline{q}\right) + z^{UL}_{mit}\left(u^{1}_{mit}H\right)\right)\\ &+y_{mt}\left(-f^{D}_{\sigma(m)} - u^{2}_{m}P_{MS} + u^{3}_{m}\underline{p} + u^{4}_{mt}\rho^{DL}_{t}\right)\end{aligned}\right)\right) \\
&+\sum_{m\in M''}\left(\sum_{t\in T}\left(\begin{aligned}&\sum_{i\in B}\left(z_{mit}\left(-u^{5}_{mi}H + u^{6}_{mi}\underline{q}\right) + z^{UL}_{mit}\left(u^{1}_{mit}H\right)\right)\\ &+y_{mt}\left(-r_t - u^{2}_{m}P_{MS} + u^{3}_{m}\underline{p} + u^{4}_{mt}\rho^{DL}_{t}\right)\end{aligned}\right)\right)
\end{aligned}
$$

According to constraints (3.6), (3.7), (3.8) and (3.9), for a given mobile station *m* we can get the composition of all base stations it possibly connected to and all traffic types it can use. Therefore, we further decompose subproblem 1 into $|M|$ problems and exhaustively search all possible combination of mobile station *m*, base station *i* and traffic type t for existing mobile stations and new mobile stations respectively.

3.1.2 **Subproblem 2** (related to decision variable p_m)

$$\min \sum_{m\in M}\sum_{i\in B}\sum_{t\in T} u_{mit}^{1}\left(\sum_{\substack{n\in M\\ n\neq m}}\rho_t^{UL} v_{\sigma(n)}\frac{p_n}{L(D_{ni},\tau)}-\frac{p_m}{L(D_{mi},\tau)}\right)+\sum_{m\in M}u_m^2 p_m-\sum_{m\in M}u_m^3 p_m$$

(SUB 3.2)

Subject to:

$0 \le p_m \le P_{MS}$ $\qquad \forall m\in M \qquad$ (3.14)

Base on past experience, we add redundant constraint (3.14) to improve the efficiency of the subproblem solution, and the gap between the dual solution and primal feasible solution. We restrict the value of the power of mobile station *m* (p_m) must between 0 and mobile stations' maximum power P_{MS} . To rewrite SUB 3.2, we get

$$\sum_{m\in M}\sum_{i\in B}\sum_{t\in T} u_{mit}^{1}\left(\sum_{\substack{n\in M\\ n\neq m}}\rho_t^{UL} v_{\sigma(n)}\frac{p_n}{L(D_{ni},\tau)}-\frac{p_m}{L(D_{mi},\tau)}\right)+\sum_{m\in M}u_m^2 p_m-\sum_{m\in M}u_m^3 p_m$$

$$=\sum_{m\in M}\sum_{i\in B}\sum_{t\in T}\rho_t^{UL} v_{\sigma(m)}\frac{p_m}{L(D_{mi},\tau)}\sum_{\substack{n\in M\\ n\neq m}}u_{nit}^1-\sum_{m\in M}\sum_{i\in B}\sum_{t\in T}u_{mit}^1\frac{p_m}{L(D_{mi},\tau)}+\sum_{m\in M}u_m^2 p_m-\sum_{m\in M}u_m^3 p_m$$

$$=\sum_{m\in M}p_m\left(\sum_{i\in B}\sum_{t\in T}\left(\frac{\rho_t^{UL} v_{\sigma(m)}}{L(D_{mi},\tau)}\sum_{\substack{n\in M\\ n\neq m}}u_{nit}^1-\frac{u_{mit}^1}{L(D_{mi},\tau)}\right)+u_m^2-u_m^3\right).$$

We can further decompose SUB 3.2 into $|M|$ subproblems. For each mobile station *m*, we will determine how much power it transmits in uplink.

If $\left(\sum_{i\in B}\sum_{t\in T}\left(\frac{\rho_t^{UL} v_{\sigma(m)}}{L(D_{mi},\tau)}\sum_{\substack{n\in M\\ n\neq m}}u_{nit}^1-\frac{u_{mit}^1}{L(D_{mi},\tau)}\right)+u_m^2-u_m^3\right)$ is equal to or larger than zero, we assign mobile station *m*'s transmit power equal to zero. On the contrary, if $\left(\sum_{i\in B}\sum_{t\in T}\left(\frac{\rho_t^{UL}v_{\sigma(m)}}{L\left(D_{mi},\tau\right)}\sum_{\substack{n\in M\\ n\neq m}}u_{nit}^1-\frac{u_{mit}^1}{L\left(D_{mi},\tau\right)}\right)+u_m^2-u_m^3\right)$ is less than zero, we let mobile station m's transmit power equal to mobile stations' maximum power P_{MS} .

3.1.3 **Subproblem 3** (related to decision variable q_{im})

$$\min -\sum_{m\in M}\sum_{t\in T}\sum_{i\in B}u_{mt}^4\frac{\dfrac{q_{im}}{L\left(D_{mi},\tau\right)}}{P_N+\sum\limits_{\substack{n\in M\\ n\neq m}}\left((1-\alpha)v_{\sigma(n)}\dfrac{\beta_{ni}\hat{q}_{\sigma(n)}}{L\left(D_{mi},\tau\right)}\right)+\sum\limits_{\substack{j\in B\\ j\neq i}}\sum\limits_{n\in M}v_{\sigma(n)}\dfrac{\beta_{nj}\hat{q}_{\sigma(n)}}{L\left(D_{nj},\tau\right)}}$$

$$+\sum_{m\in M}\sum_{i\in B}u_{mi}^5q_{im}-\sum_{m\in M}\sum_{i\in B}u_{mi}^6q_{im} \qquad \text{(SUB 3.3)}$$

Subject to:

$$\sum_{m\in M}q_{im}\le P_{BS} \qquad \forall i\in B \qquad (3.1)$$

$$0\le q_{im}\le\hat{q}_{\sigma(m)} \qquad \forall i\in B, m\in M \qquad (3.13)$$

The same as SUB 3.2, we add a redundant constraint (3.13) to improve the dual solution's quality. The constraint means the power transmitted from base station i to mobile station m is between 0 and the maximum power of a base station transmitted to any mobile station. To rewrite SUB 3.3, we can get

$$-\sum_{m\in M}\sum_{t\in T}\sum_{i\in B}u_{mt}^{4}\frac{\dfrac{q_{im}}{L(D_{mi},\tau)}}{P_N+\sum_{\substack{n\in M\\n\neq m}}\left((1-\alpha)v_{\sigma(n)}\dfrac{\beta_{ni}\hat{q}_{\sigma(n)}}{L(D_{mi},\tau)}\right)+\sum_{\substack{j\in B\\j\neq i}}\sum_{n\in M}v_{\sigma(n)}\dfrac{\beta_{nj}\hat{q}_{\sigma(n)}}{L(D_{nj},\tau)}}$$

$$+\sum_{m\in M}\sum_{i\in B}u_{mi}^{5}q_{im}-\sum_{m\in M}\sum_{i\in B}u_{mi}^{6}q_{im}$$

$$=-\sum_{m\in M}\sum_{i\in B}\frac{\dfrac{q_{im}}{L(D_{mi},\tau)}}{P_N+\sum_{\substack{n\in M\\n\neq m}}\left((1-\alpha)v_{\sigma(n)}\dfrac{\beta_{in}\hat{q}_{\sigma(n)}}{L(D_{mi},\tau)}\right)+\sum_{\substack{j\in B\\j\neq i}}\sum_{n\in M}v_{\sigma(n)}\dfrac{\beta_{nj}\hat{q}_{\sigma(n)}}{L(D_{nj},\tau)}}\sum_{t\in T}u_{mt}^{4}$$

$$+\sum_{m\in M}\sum_{i\in B}u_{mi}^{5}q_{im}-\sum_{m\in M}\sum_{i\in B}u_{mi}^{6}q_{im}$$

$$=\sum_{m\in M}\sum_{i\in B}q_{im}\left(\begin{array}{l}-\dfrac{\dfrac{1}{L(D_{mi},\tau)}}{P_N+\sum_{\substack{n\in M\\n\neq m}}\left((1-\alpha)v_{\sigma(n)}\dfrac{\beta_{ni}\hat{q}_{\sigma(n)}}{L(D_{mi},\tau)}\right)+\sum_{\substack{j\in B\\j\neq i}}\sum_{n\in M}v_{\sigma(n)}\dfrac{\beta_{nj}\hat{q}_{\sigma(n)}}{L(D_{nj},\tau)}}\sum_{t\in T}u_{mt}^{4}\\+u_{mi}^{5}-u_{mi}^{6}\end{array}\right).$$

The problem can be decomposed into $|B|$ subproblems. For each base station *i*, we want to decide how much power it transmits to every mobile station *m* in its coverage in downlink. To solve each of the $|B|$ subproblems, we first sort

$$h_{im}=\left(-\frac{\dfrac{1}{L(D_{mi},\tau)}}{P_N+\sum_{\substack{n\in M\\n\neq m}}\left((1-\alpha)v_{\sigma(n)}\dfrac{\beta_{ni}\hat{q}_{\sigma(n)}}{L(D_{mi},\tau)}\right)+\sum_{\substack{j\in B\\j\neq i}}\sum_{n\in M}v_{\sigma(n)}\dfrac{\beta_{nj}\hat{q}_{\sigma(n)}}{L(D_{nj},\tau)}}\sum_{t\in T}u_{mt}^{4}+u_{mi}^{5}-u_{mi}^{6}\right)$$

for every mobile station *m*. For all h_{im} is equal to or larger than zero, we let q_{im}, the power transmitted from base station *i* to mobile station *m*, equal to 0. And then, we assign the value of q_{im} to the minimum of $\hat{q}_{\sigma(m)}$ and remain quantity of power of the base station *i* in ascent order of h_{im} until the remain power of base station *i* is equal to zero.

3.2 The Dual Problem and the Subgradient Method

According to the weak Lagrangean duality theorem, for any $u^1_{mit}, u^2_m, u^3_m, u^4_{mt}, u^5_{mi}, u^6_{mi} \geq 0$, $Z_D\left(u^1_{mit}, u^2_m, u^3_m, u^4_{mt}, u^5_{mi}, u^6_{mi}\right)$ is a lower bound on Z_{IP1}. The following dual problem (D) is then constructed to calculate the tightest lower bound.

Dual Problem (D):

$$Z_D = \max Z_D\left(u^1_{mit}, u^2_m, u^3_m, u^4_{mt}, u^5_{mi}, u^6_{mi}\right)$$

subject to:

$$u^1_{mit}, u^2_m, u^3_m, u^4_{mt}, u^5_{mi}, u^6_{mi} \geq 0$$

The most common method for solving the dual problem is the subgradient method. Let g be a subgradient of $Z_D\left(u^1_{mit}, u^2_m, u^3_m, u^4_{mt}, u^5_{mi}, u^6_{mi}\right)$. Then, in iteration k of the subgradient optimization procedure, the multiplier vector $\pi = \left(u^1_{mit}, u^2_m, u^3_m, u^4_{mt}, u^5_{mi}, u^6_{mi}\right)$ is updated by $\pi^{k+1} = \pi^k + t^k g^k$. The step size t^k is determined by $t^k = \delta \frac{Z^h_{IP} - Z_D(\pi_k)}{\left\|g^k\right\|^2}$. Z^h_{IP} is the primal objective function value for a heuristic solution and δ is constant between 0 and 2.

Chapter 4 Getting Primal Feasible Solutions

To deal with our problem, we choose Lagrangean relaxation and subgradient method as our tools. Thus, we can get not only a theoretical lower bound of primal feasible solution, but also get some hints from solutions to the Lagrangean relaxation problem (LR) and Lagrangean multipliers resulted from iterations to help us to get our primal feasible solution under each solving dual problem iteration.

After an iteration solving dual problem, we will get a set of decision variable. If the calculated decision variables happen to satisfy all constraints in the primal problem, a primal feasible solution is found. However, it may not be feasible in dealing with our problems; for example, it may violate the constraints that we relaxed before. In addition to being a bounding procedure of large scale optimization problems, the solution procedure of Lagrangean dual problems usually provides important implications and nice starting points, which sheds light on the searching of good primal solutions. In order to ensure the decision variables are feasible, check or modification is needed, such as drop-and-add heuristics.

Here we propose a heuristic for getting primal feasible solution of this problem. It includes admission policy adjustment (main procedure), downlink power adjustment and uplink power adjustment.

4.1 Heuristic for Admission Policy Adjustment

By solving SUB 3.1, we get the decision variables related to admission control policy (z_{mit} , z_{mit}^{UL} and y_{mt}), but they may violate the downlink power constraint or uplink power constraint. To get the feasible sets of solutions, drop-and-add heuristic is used. Here we propose a heuristic for getting primal feasible solution of this problem, it described in the following Algorithm 4.1.

Table 4-1 Algorithm 4.1: Heuristic for Admission Policy Adjustment

Algorithm 4.1
Step 1. For each base station *i*, we using the heuristic in 4.2 to readjust downlink power assignment, to check the maximum power constraint and to check every base station to mobile station power upper bound restrictions. If the constraints are not satisfied, we go to Step 2; otherwise go to Step 5.
Step 2. For each base station *i*, if the power transmitted to some mobile station *m* violates the constraint, mobile station *m* is dropped.

Step 3. For each base station *i* that violates its maximum power constraint, sort by the revenue and the distance from each new mobile station that wants to be active in the coverage of the base station. Drop mobile station by order until base station's maximum power constraint is hold.

Step 4. Using the heuristic in 4.3 to readjust the uplink transmission power of every mobile station *m*, and check the mobile station's maximum power constraint. If some mobile station m is violated the constraint, we drop the mobile station. Repeat the check and drop progress until all mobile stations can satisfy their own maximum power constraint.

Step 5. In this step, we should reconsider the mobile stations that were blocked in previous steps. First, we arrange these mobile stations in the order of revenue. Then we recheck in order if these mobile stations can be served by any base station under both downlink and uplink power constraints are hold or not. If yes, readmission this mobile station into the system.

Step 6. For data users who still be blocked, we try to decrease their transmission rate and then recheck in order their admission the same as in Step 5.

Step 7. If there still have new mobile stations be blocked, we try to rehome exist mobile stations and new mobile stations that already be admitted. If we rehome a certain mobile stations already in the system that can be covered by any other base station in the system will permit those still blocked mobile terminals into the system, we do the rehoming. Also, all power constraints should be satisfied.

4.2 Heuristic for Downlink Power Adjustment

In SUB 3.2 and SUB 3.3, we get the transmission power of every mobile station and transmission power of each base station to every mobile station in its coverage area respectively. But we can find the solutions in SUB 3.2 and SUB 3.3 all are the extreme value, either maximum power or zero; hence, we need to readjustment both uplink power of mobile stations and downlink power of base stations.

The downlink power readjustment procedure for admitted mobile stations can be model as a linear programming mode as below:

Optimization problem (LP1)

Objective function:

$$\min \sum_{m\in M}\sum_{i\in B} q_{im} + C_1 \sum_{m\in M} s_m + C_2 \sum_{i\in B} o_i \qquad \text{(LP1)}$$

Subject to:

$$\sum_{i\in B} \frac{\dfrac{q_{im}}{L(D_{mi},\tau)}}{\left(P_N + \sum_{\substack{n\in M\\ n\neq m}} \left((1-\alpha) v_{\sigma(n)} \dfrac{\beta_{mi}\hat{q}_{\sigma(n)}}{L(D_{mi},\tau)} \right) + \sum_{\substack{j\in B\\ j\neq i}} \sum_{n\in M} v_{\sigma(n)} \dfrac{\beta_{nj}\hat{q}_{\sigma(n)}}{L(D_{nj},\tau)} \right)} + s_m \geq \rho_t^{DL} \qquad \forall m\in M \qquad (4.1)$$

$$\sum_{m\in M} q_{im} - o_i \leq P_{BS} \qquad \forall i\in B \qquad (4.2)$$

where s_m is the short of SIR to meet mobile station's QoS requirement, and o_i is the power over base station i's maximum power. C_1 and C_2 are the constant of penalty of SIR constraint and power constraint respectively. The objective function is trying to using minimum power to satisfy all mobile station's QoS requirement. Constraint (4.1) means all admitted mobile station should satisfy their QoS constraint. Constraint (4.2) restrict total transmission power of any base station should under its maximum power. And then, we solve this linear programming problem using simplex method. After solving the problem, if there are some s_m larger than 0, it means mobile station *m* can't satisfy its QoS requirement. In addition, if there are some o_i larger than 0, it stand for mobile station *i* is over its maximum power.

4.3 Heuristic for Uplink Power Adjustment

The same as downlink, solving SUB 3.2 we get the decision variable p_m, the transmission power of all mobile stations, but they all are the extreme value, either maximum power or zero. Therefore, we should recalculate every mobile station's transmission power.

In order to deal with this problem, we propose an iterative heuristic (Algorithm 4-2) as blow:

Table 4-2 Algorithm 4-2: Heuristic for Uplink Power Adjustment

Algorithm 4-2

Step 1. Initially, set all admitted user's transmission power (p_m) to 0

Step 2. At each iteration, for every mobile station *m*, set p_m to fit its uplink SIR requirement according to other mobile station's transmission power at last iteration.

Step 3. If the result between iteration *k* and iteration *k-1* is less than ε, the algorithm stop and p_m at iteration *k* is the adjustment result. On the other hand, if some p_m of mobile station *m* is larger than its maximum transmission power at any iteration, it represent mobile station *m* can't satisfy its uplink QoS constraint at this admission status.

Chapter 5 Computational Experiments

5.1 Lagrangean Relaxation Base Algorithm (LR)

This algorithm is based on the mathematical formulation described in Chapter 2. The relaxed problem is then optimally solved as described in Chapter 3 to get a lower bound to the primal problem. We adopt a heuristic algorithm to readjust downlink and uplink power arrangement and solve the admission policy problem in Chapter 4. And we use a subgradient method to update the Lagrangean multipliers. To sum up, the Lagrangean relaxation based algorithm (LR) is presented as follows:

Table 5-1 Algorithm 5-1: Lagrangean Relaxation Base Algorithm

Algorithm 5-1

Step 1. Read configuration file to construct distribution of base stations and information of every traffic type, and generate exist mobile users and new mobile users.

Step 2. Calculate constant parameters, such as D_{mi}, β_{mi} and γ_{mt}, and assign Lagrangean relaxation improve counter to 20.

Step 3. Initialize multipliers.

Step 4. According to given multipliers, optimally solve these problems of SUB 3.1, SUB 3.2, SUB 3.3 to get the value of Z_{dual}

Step 5. According to heuristics of Chapter 4, we get the total revenue, the value of Z_{IP}

Step 6. If Z_{IP} is small than Z_{IP}^{*}, we assign Z_{IP}^{*} to equal Z_{IP}. Otherwise, we minus 1 from improve counter.

Step 7. Calculate step size and adjust Lagrangean relaxation multipliers by using the subgradient method as described in section 3.2.

Step 8. Iteration counter increases by 1. If iteration counter is over the threshold of the system, stop the program. And, ZIP* is our best solution. Otherwise, repeat Step 4.

5.2 Parameters and Cases of the Experiment

The parameters used for all cases are listed in Table 5-2. The SIR requirement, revenue and cost of every traffic type are listed in Table 5-3 and Table 5-4.

Table 5-2 Parameters of the System

Uplink voice activity factor	0.67
Downlink voice activity factor	0.58
Data activity factor	1.0
Maximum power of base station	20W

Minimum power of a base station to a mobile station	0.5mW
Maximum power of voice mobile station	125mW
Maximum power of data mobile station	250mW
Minimum power of a mobile station	0.5mW
Background noise power	4.786e-11mW
Orthogonality factor	0.4
Attenuation factor	2
Maximum number of base stations in active set	3

Table 5-3 E_b/N_0 and SIR Requirement for Every Traffic Type

Traffic Type	Uplink		Downlink	
	E_b/N_0 (db)	SIR requirement	E_b/N_0 (db)	SIR requirement
Voice 4.75 kbps	3.9	0.0030	5.4	0.0043
Voice 7.95 kbps	3.4	0.0045	4.9	0.0064
Voice 12.2 kbps	2.9	0.0062	4.4	0.0088
Data 64 kbps	1.0	0.0210	2.5	0.0296
Data 144 kbps	0.4	0.0411	2.3	0.0637
Data 384 kbps	0.6	0.1148	2.4	0.1738

Table 5-4 Revenue and Cost of Every Traffic Type

	Revenue	Disconnect Cost	Rehoming Cost
Voice 4.75 kbps / 4.75 kbps	10.0	100	2.0
Voice 7.95 kbps / 7.95 kbps	8.0	100	2.0
Voice 12.2 kbps / 12.2 kbps	6.0	100	2.0
Data 64 kbps / 64 kbps	2.5	40	1.0
Data 64 kbps / 144 kbps	2.3	40	1.0
Data 144 kbps / 144 kbps	2.1	40	1.0
Data 64 kbps / 384 kbps	1.9	40	1.0

Data 144 kbps / 384 kbps	1.7	40	1.0
Data 384 kbps / 384 kbps	1.5	40	1.0

Figure 5-1 is the given distribution of base stations, and the site distance is estimated with $D = \sqrt{3}R$ where R is the cell range.

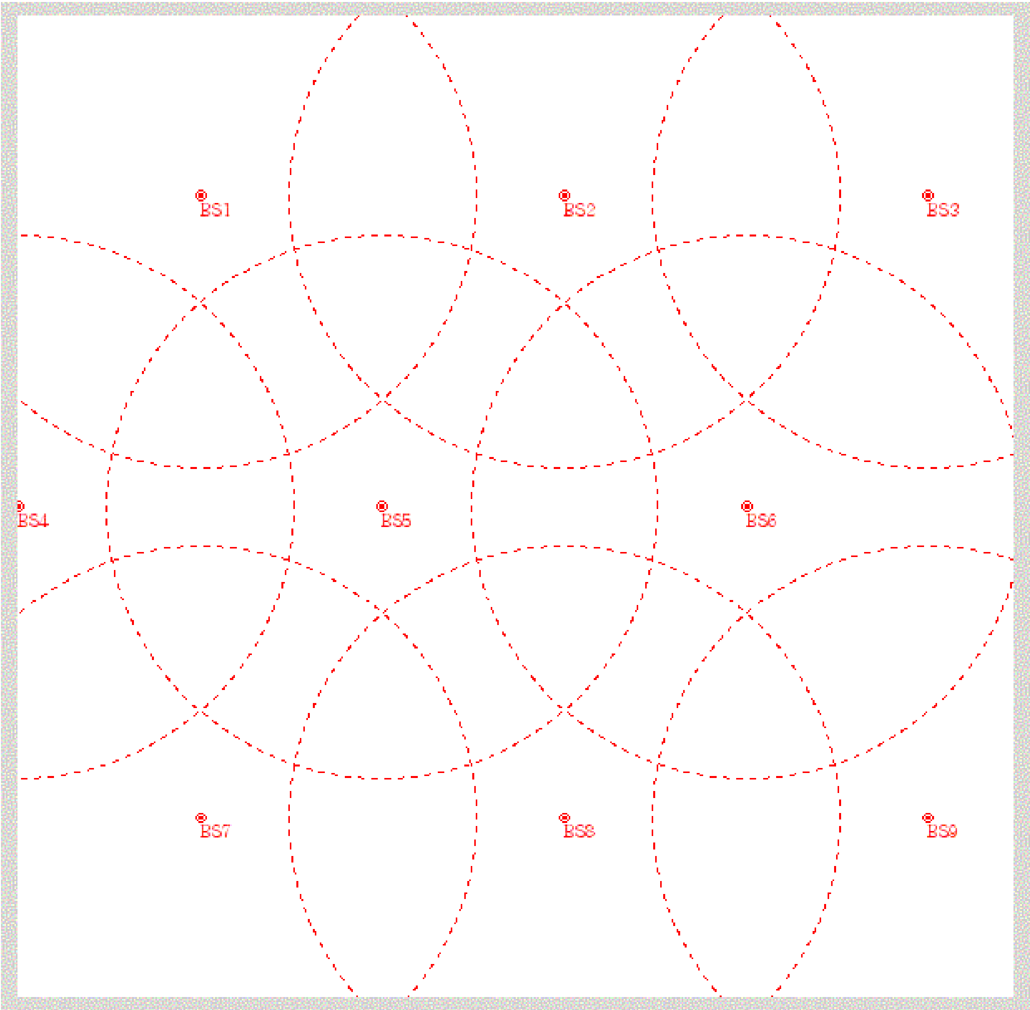

Figure 5-1 Location of Given Base Stations

In all experiment, the number of base station ($|B|$) are given to 9, and their distribution in like Figure 5-1 in 12 km * 12 km environment. The number of traffic type equal to 9. Concerning about the number of new mobile stations, it is generated in Poisson arrival process with $\lambda = 50$. The experiment cases list in Table 5-5. Each cases test 500 times.

Table 5-5 Experiment Cases

	Number of Exist MS	Ratio of Voice Users	Ratio of Data Users
Case 1	150	80%	20%
Case 2	200	80%	20%
Case 3	250	80%	20%
Case 4	300	80%	20%
Case 5	150	70%	30%
Case 6	150	60%	40%
Case 7	150	50%	50%

5.3 Experiment Result

The Lagrangean-based heuristic and the primal one are named “LR” and “SA”, respectively. We denote our dual solution as “Z_{dual}”. “Gap” is calculated to evaluate our Lagrangean-based heuristic. Gap = $\frac{LR - Z_{dual}}{Z_{dual}}$ * 100%. “Improvement” is our Lagrangean-based heuristic improvement on the simpler one —— SA. Improvement = $\frac{SA - LR}{LR}$ * 100%.

Case 1 ~ Case 4: 80% voice users, 20% data users

Table 5-6 The Result of Case 1 ~ Case 4

		Case 1	Case 2	Case 3	Case 4
No. of Exist MSs		150	200	250	300
	0.00	500	497	468	382
	0.25	0	2	18	39
	0.50	0	0	4	25
	0.75	0	0	2	14
	1.00	0	0	4	12
	1.25	0	1	0	6
	1.50	0	0	1	6
Gap(%)	1.75	0	0	0	3
	2.00	0	0	1	3
	2.25	0	0	2	3
	2.50	0	0	0	1
	2.75	0	0	0	2
	3.00	0	0	0	1
	3.25	0	0	0	2
	more	0	0	0	1
Average Gap (%)		0	0.01	0.036	0.172
Worst Gap (%)		0	1.24	2.224	4.223

Average Improvement (%)	0	0.001	0.0112	0.1234
Maximum Improvement (%)	0	0.34	1.1133	10.175

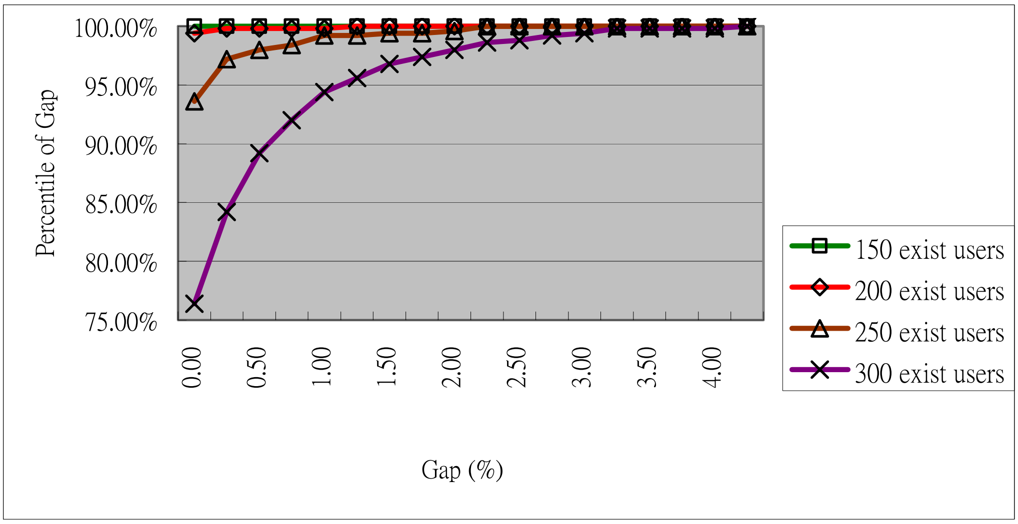

Figure 5-2 Percentile of Error Gap in Case 1 to Case 4

Case 1, 5~7: 150 exist mobile stations and 50 new mobile stations

Table 5-7 The Result of Case 1, Case 5 ~ Case 7

		Case 1	Case 5	Case 6	Case 7
Ratio of Voice/Data User		80%:20%	70%:30%	60%:40%	50%:50%
Gap(%)	0.00	500	296	150	14
	0.50	0	202	179	37
	1.00	0	2	43	27
	1.50	0	0	39	27
	2.00	0	0	31	35
	2.50	0	0	15	29
	3.00	0	0	10	33
	3.50	0	0	5	24
	4.00	0	0	5	28
	4.50	0	0	5	20
	5.00	0	0	4	23
	5.50	0	0	2	17
	6.00	0	0	4	18

	6.50	0	0	0	11
	7.00	0	0	1	13
	7.50	0	0	0	12
	8.00	0	0	1	18
	8.50	0	0	0	10
	9.00	0	0	1	11
	9.50	0	0	0	4
	10.00	0	0	0	11
	more	0	0	5	78
Average Gap (%)		0	0.01	0.82	5.83
Worst Gap (%)		0	0.87	16.27	57.57
Average Improvement (%)		0	0.01	0.28	1.63
Maximum Improvement (%)		0	0.48	13.14	84.73

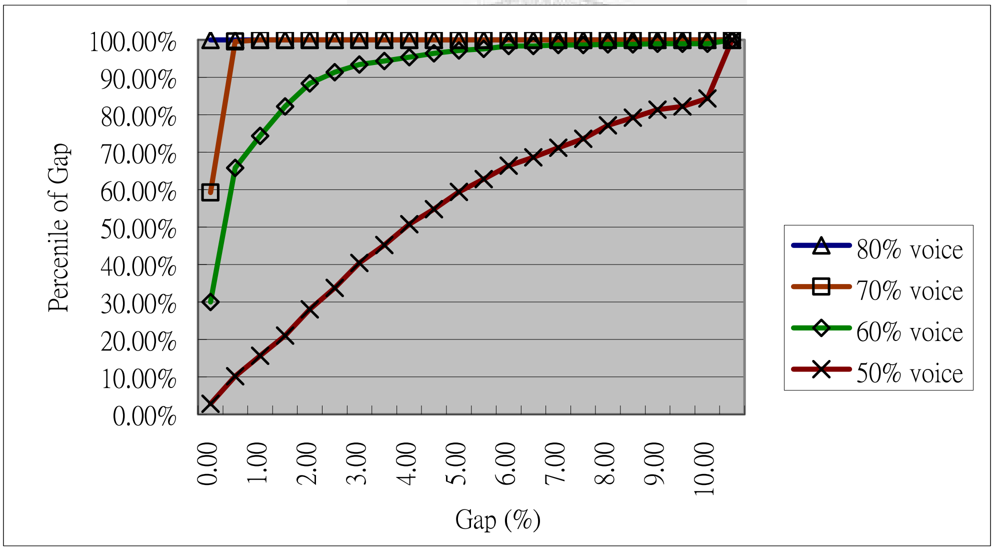

Figure 5-3 Percentile of Error Gap in Case 1 and Case 5 to Case 7

5.4 Result Discussion

In our computational results, the proposed Lagrangean relaxation base algorithm in most cases can get remarkable solution quality. From Case 1 to Case 4, almost 95% of 500 test cases' gap is less than 1%. The error gap would increase when the system loading increase or data user ratio increase. Although the gap in Case 4, Case 6 and Case 7 is larger than other cases, the proposed Lagrangean relaxation algorithm still has obvious improvements compared to other primal heuristics.

Chapter 6 Conclusion

6.1 Summary

As WCDMA system have emerged as a promising candidate of 3rd generation wireless telecommunication system, efficiently manage the radio resource to provide service to more users will provide much benefit to system operators; therefore, admission control in WCDMA system is become an important research issue. WCDMA system has many particular techniques, such as OSVF and soft handover, to provide more variable and higher quality services than past telecommunication systems. To the best of our knowledge, there are no mathematical formulation have proposed and solved both considering these issues.

To solve this problem, we propose an approach to WCDMA admission control problem to maximize the system operator's revenue while take QoS constraint, capacity constraint, soft handover issue and variable data rate service issue into account. The outcome of this thesis will be helpful for system subscribers to make integrated decision and maintain the system.

We can express our achievements in terms of formulation and performance. In terms of formulation, we model a mathematical expression to describe the admission control in voice/data integrated WCDMA wireless communication networks problem. In terms of performance, our Lagrangean relaxation based solution has more significant improvement than other intentional algorithm.

6.2 Future Work

In this thesis, we assume all base stations are under one RNC's control, and also assume we have global information about all base stations and mobile stations. However, this information may difficult to get in real environment. Discuss distributed admission control algorithm by some information be approximated may be an interesting topic.

Orthogonal code is another resource in CDMA network, and it could be another capacity constraint. Take orthogonal code resources into account would worth further investigation.

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簡　　歷

姓　　名：顧育先

出 生 地：臺北市

出 生 日：中華民國六十八年十月二十日

學　　歷：八十七年九月至九十一年六月

國立中央大學資訊管理學系

九十一年九月至九十三年七月

國立臺灣大學資訊管理學研究所