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碩士論文

WCDMA 系統下增波器對整體容量之最佳化演算法

Repeater capacity optimization in WCDMA

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中華民國九十九年八月

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Abstract

Repeaters have been employed on analogue and 2G generation mobile networks, which are designed to support voice, low data rates and short messages. The 3G mobile systems are designed to support high speed internet access with high transmission quality. The use of repeaters, to enhance the weak RF signals, taking the quality of service and costs into consideration is important. However repeater can enlarge interference and we must manage the deployment and the gain of repeater under tight control. In the thesis the main target is to optimize the system performance by appropriately adjusting repeater parameters. We first investigate the influence of repeater at three different kinds of scenarios to find a case in which optimization can be applied. Later the optimization formula is proposed and turned into a linear problem. We then do optimization on multi-cell system by adjusting parameters, i.e. repeater gain, SINR threshold etc, to suppress severe interference and improve system performance. An algorithm is proposed to give a more specifically criterion to adjust the parameters. The simulation results show repeater can effectively enhance user SINR and spectrum efficiency at no other-cell-variation interference circumstance and balance the tradeoff between system capacity and user SINR.

摘　要

在類比及二代行動通訊中，增波器已被廣泛使用於聲音、低速率傳輸和簡訊（short message）。而緊接而來的第三代行動通訊除了支援高傳輸速率同時也要求高通訊品質。因此，增波器無論在加強訊號強度、服務質量（Quality of Service）的需求或是成本的考量上，都可帶來長足的提升。但由於增波器會帶來嚴重的干擾，因此在佈建和運作時必須加以限制。在本篇論文中，主要的目的為調整增波器以最佳化系統效能。首先將探討增波器在三種不同環境下的使用對系統效能的影響，由此歸結出適用最佳化的環境。接著，以數學推導出最佳化的式子，將其轉為線性問題，對多蜂巢式系統進行最佳化處理，調整各種參數，例如增波器的增益、訊雜比（SINR）的門檻等等，抑制蜂巢間嚴重的干擾及提升整體的效益。在論文中會提出另外一個演算法以逼近最佳化的結果，讓我們可以更加了解調制增波器參數的準則。模擬結果顯示出增波器在無外來可變動的干擾下，能夠有效的提高使用者的 SINR 並且增加頻帶效率；而在多蜂巢系統下，則可以平衡系統容量及使用者訊雜比的牽制關係。

致　　謝

當我剛進研究所時，畢業離我還很遠，無法想像當這時刻來臨時，我會有什麼樣的變化、會做出什麼樣的研究以及會有什麼樣的心情。

現在，我準備要畢業了，不能說什麼都懂，但多方接觸的結果，至少有點頭緒。我並不是個聰明的人，很多東西要慢慢學；很多事情，在兩年的研究生活中，得細細體會。

黃經堯老師待學生極好，在硬體資源方面，從來不會短缺。老師在研究上採放任的態度，讓學生能夠選擇自己有興趣的題目。研究室也接了非常多的計畫，使我們在研究之餘也不會和現實脫軌。

前可億隆公司協理李永定先生，對我的研究和論文給了諸多建議，使最後的成果能夠盡善盡美。

這段時間和我相處最久的是實驗室裡的同學、學長和學弟。許多人不僅曾帶給我非常珍貴的回憶，在研究上也常適時的提點我。特別要感謝明憲，如果沒有他，就不會有今天的我。

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1. Introduction

In radio communication systems, due to the nature of wave propagation, there are areas that receive weak RF signal energy. Areas due to feature of nature likes valley or shadow of an intervening mountain, or manmade buildings such as tunnels, subway stations, underground parking, or railway tracks which basically needs to improve the RF strength. However it can be expensive and uneconomical to build a new BS at such areas. Repeaters turn out to be a good alternative solution as its low cost, easy to install and maintain and reducing transmitting power.

The usage of repeaters for overcoming weak RF signal areas and extending network coverage in cellular radio systems reduces significantly the overall network deployment expenses by decreasing the required number of base stations. Additionally, utilization of repeaters for capacity enhancements could provide great benefits.

However, deployment of repeaters in capacity limited UMTS (Universal Mobile Telecommunications System) networks differs fairly from implementation in conventional frequency channelized cellular systems due to assignment of users to the same carrier frequency. Hence, the utilization of repeaters becomes more complicated, since repeaters have a potential to affect the performance of the whole network.

In the thesis we provide an optimization method to reach an upper bound on system capacity and a proposed algorithm to reduce outage probability in addition to capacity enhancement. The thesis is organized as follows: we give a brief introduction to UMTS architecture, WCDMA system and repeater in chapter 2 and 3. Chapter 4 analyzes the repeater transmission planning in WCDMA system. A mathematical analysis of system capacity is proposed in chapter 5. The proposed algorithm is described in chapter 6 for easier to implement in real system. Chapter 7 presents the simulation performance in different scenarios and optimization results. Finally discussions and conclusions are summarized in chapter 8.

2. Overview of UMTS

2.1. UMTS architecture

The time of mobile communications can be separated into generations of different techniques. The era of mobile communication systems started from the time of analog data transmission. NMT (Nordic mobile telephony) and AMPS (advanced mobile phone service) were the most popular 1G (first generation) systems.

Digital techniques in mobile communication business were taken into use in Europe at the beginning of 1990's by introducing GSM. It was purely based on digital transmission. The GSM was based on TDMA (time division multiple access) and FDMA (frequency division multiple access).

The limited capacity of 2G systems and the never-ending need for higher data rates are the main reasons for developing next generation mobile communication systems. UMTS and CDMA2000 techniques are the solutions for the 3G (third generation) mobile communication systems.

The UMTS standard includes two different air interface duplexing schemes: UTRA FDD (universal terrestrial radio access frequency division duplex) and UTRA TDD (UTRA time division duplex). In UTRA FDD, uplink and downlink channels are separated in frequency-paired channels. UTRA TDD fits uplink and downlink data to the same frequency and separates them in time domain.

UMTS has three functional parts: a group of UEs (user equipments), UTRAN (UMTS terrestrial radio access network) and CN (core network). UE is the mobile user equipment that uses the services of the network which consists of ME (mobile equipment) and USIM (UMTS subscriber identity module). UTRAN includes all radio related functionality and it works as a connection point between the core network and UE. UTRAN can also be divided into two parts: Node B and RNC (radio network controller). The former handles the common tasks of a digital transmission system while the latter is responsible for the higher level tasks of radio resource management. Core network handles call switching and routing along with connections to external networks such as PSTN (public switched telephone network) or the Internet.

2.2. WCDMA and Spread Spectrum Systems

The second generation mobile communication systems use TDMA and FDMA to provide the multi-access scheme for the users of the network. In FDMA, the available frequencies are divided into narrow sub-frequencies so that different frequency slots are allocated for each user. TDMA uses same frequencies for each user, but divides the channel into time slots. Each user has its own time slot reserved for the transmission. These methods are called narrowband in sense of trying to minimize the resources allocated for one user. They suffer from limitations in capacity, because inefficiently designed multiple access system is limiting the number of simultaneous users of the common communication channel.

Completely new approach is introduced in 3G systems. A wideband DS-CDMA (direct sequence - code division multiple access) is used as multiple access method in UMTS. The key idea of WCDMA is to let all users to share the same wideband communication channel in the whole network simultaneously by using spread spectrum signals. In this approach, each user is assigned a unique code sequence that is used to spread the information signal on this common channel.

In direct sequence spread spectrum systems, signal spreading is carried out by modulating (multiplying) the data-modulated signal for the second time by a wideband spreading signal as Figure 2.1 presents. A parameter, spreading factor, defines how many chips (spreading code symbols) are used to represent one user data bit.

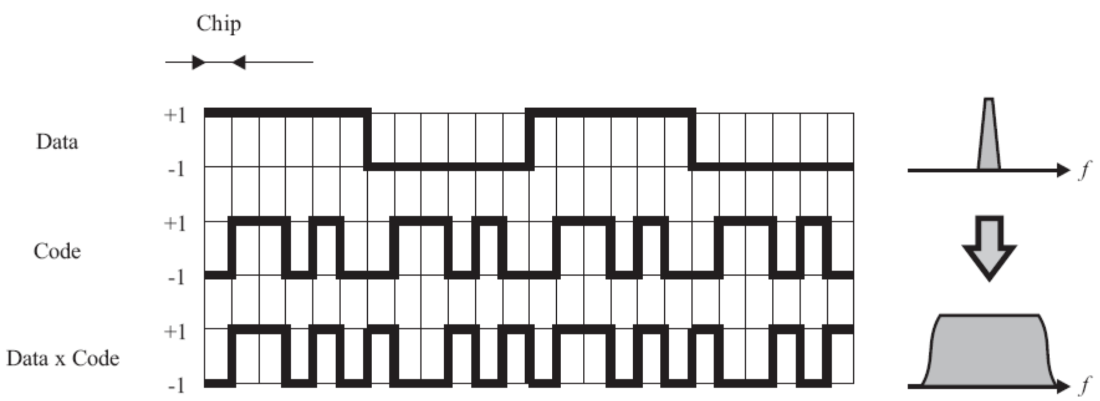

Figure 2.1. Signal spreading process in case of spreading factor 6.

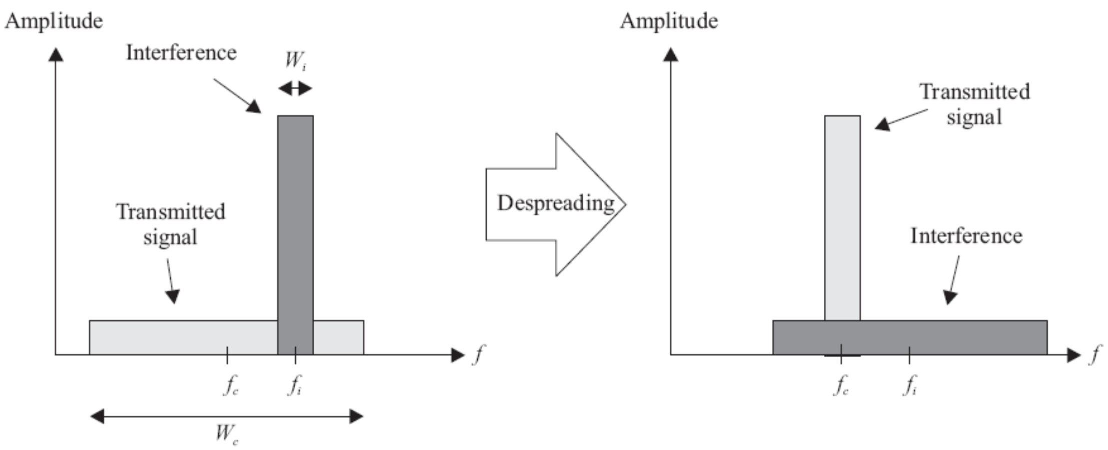

Figure 2.4. Despreading process in the presence of narrowband interference.

Signal spreading provides high tolerance to narrowband interference as depicted in Figure 2.2. In the despreading process, the narrowband interference spreads while the transmitted user signal despreads due to the multiplication operation. This makes the CDMA technique a valuable solution, e.g., for military purposes due to good protection against external radio jamming attacks.

3. WCDMA repeater

3.1. Introduction to WCDMA repeater

Repeater is an electronic device that receives a signal and retransmits it at a higher level and/or higher power, or onto the other side of an obstruction, so that the signal can cover longer distances.

Repeaters are often used to extend the range of a base station and to fill nulls that are blocked from receiving RF signal in the coverage area, e.g. hill, trees, building, etc. In addition to coverage extension repeater can also increase cell capacity. The main interests for using such repeaters are cost-efficiency and simplicity. No intelligent hardware or software implementations are needed. Figure 3.1 shows a variety of usage of repeater.

Repeaters can be applied to outdoor as well as to indoor propagation environments. Based on distinct demands repeaters can serve distances from several meters to hundred meters each with different transmitting power.

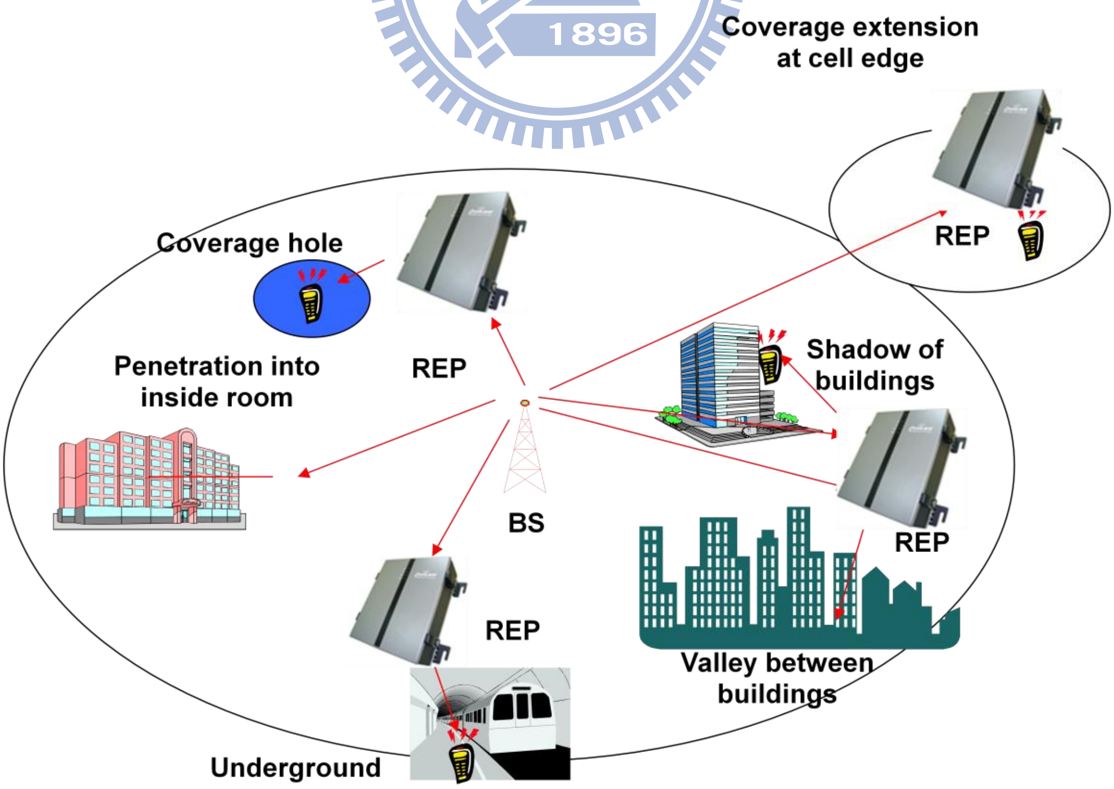

Figure 3.1. Metropolitan usage scenarios of repeaters.

Basically there are two kinds of repeaters: analog repeater and digital repeater. An analog repeater does not regenerate data. It only provide channel-based or band-based for the forward path and the reverse path. The handicaps of analog repeater are that it suffers from group delay and passband variations.

To overcome the drawbacks of traditional analog repeater, digital repeater is developed. The clear benefit of digital repeaters is the ability to select the wanted signal component from the total received signal and to clean off the noise and interference from the amplified signal. The main difference between analog repeater and digital repeater is shown in figure 3.2 and 3.3. There are four major parts in digital module: ADC, digital signal processing, CPU and DAC. The use of digital module has enhanced functions such as channel selection, self-feedback interference cancellation, noise elimination and co-channel interference suppression.

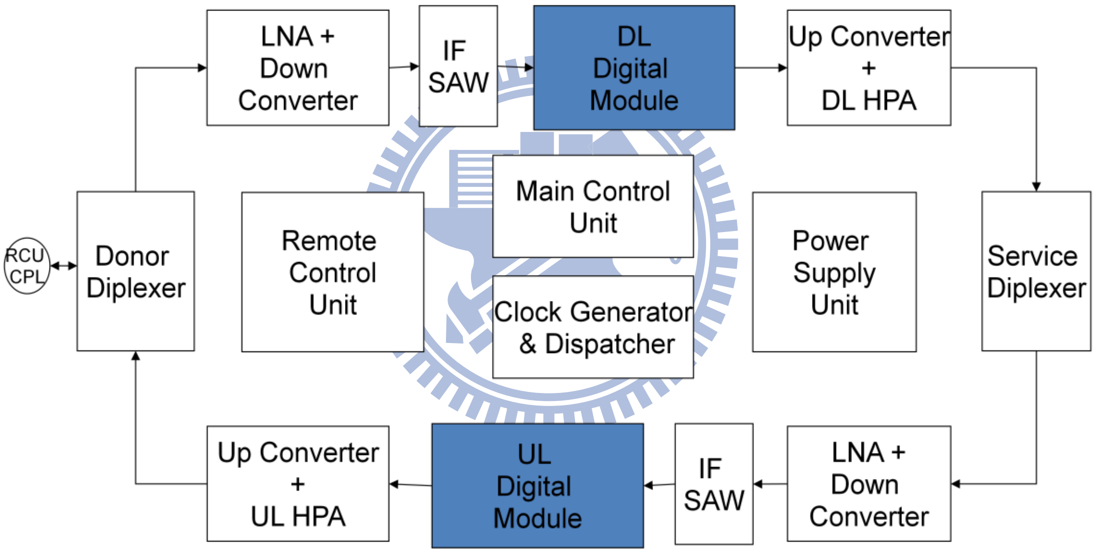

Figure 3.2. Difference part of digital repeater from analog repeater.

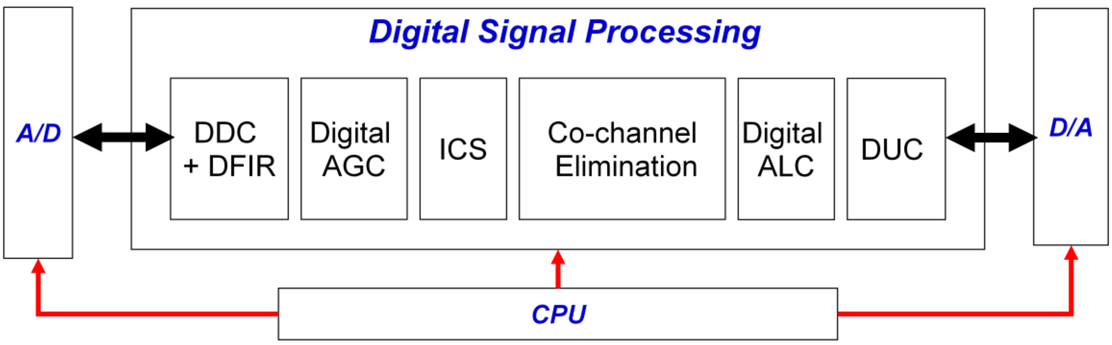

Figure 3.3. Functional blocks of digital modules.

3.2. Repeater equipments

A repeater system consists of repeater unit, donor and service antennas, and feeder cables as shown in figure 3.4. The main tunable equipment of repeater is the gain. The donor antenna is likely to be directional since it points straight to a particular base station (Node B). It intercepts the base station signal (downlink) as well as transmits back the amplified signal from the user equipment to the base station (uplink). Vice-versa, the service antenna transmits the downlink signal to as well as intercepts the uplink signal from the user equipment. Service antenna radiation pattern usually has wider beam width that depends on the intended coverage area.

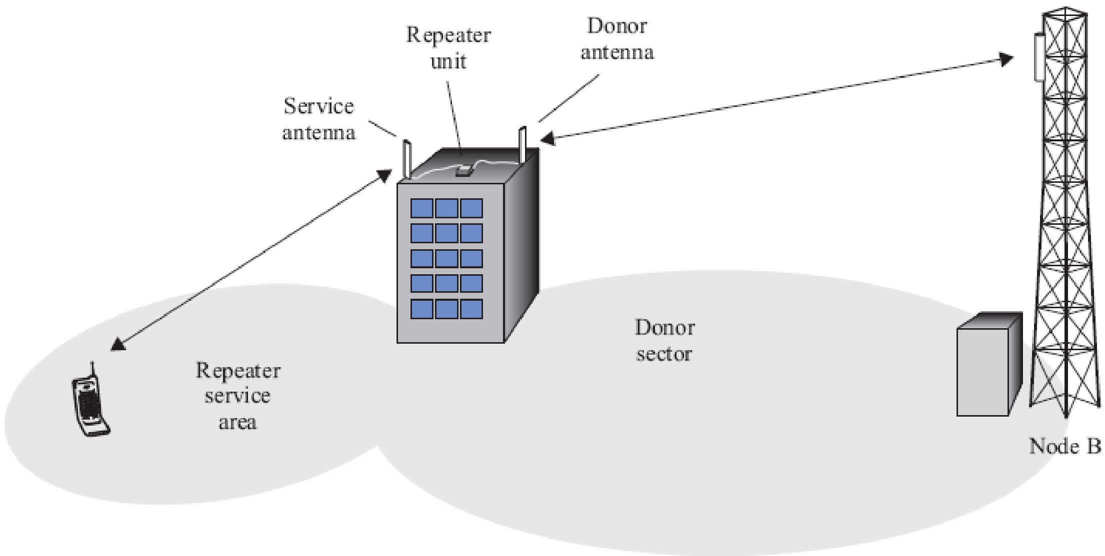

Figure 3.4. A typical repeater installation in a building rooftop.

WCDMA repeater is similar to analog repeater. It does not regenerate data. This means that also noise and interference are amplified. It is the main issue that we are going to deal with. Repeater is also transparent to the surrounding network. Neither the parent cell nor the user recognizes whether a repeater is installed under its coverage area or not. Repeaters are ‘invisible’ to both base station and users. More clearly repeater acts as a loud speaker, no one expects a repeater to show up somewhere. In the following chapter we will depict more characteristics of repeater transmission in WCDMA system. These properties help us to understand the behavior of repeater and also relate to the following works.

4. Radio network planning

4.1. Radio network characteristics

Before going further, we make some assumptions about repeater first.

A. Repeaters have perfect isolation.
Both donor and service antennas are characterized amongst others by their gain and radiation pattern. The antenna radiation pattern shows the angular attenuation in horizontal or vertical plane. There exists some degree of coupling or feedback path between donor and server antennas used. This attenuation or loss in the feedback path is called the antenna isolation and in general must be at least 15 dB higher than the repeater gain to give sufficient margin against potential self-oscillation in the repeater system. An oscillating repeater will not function properly and may present a large interfering signal into the network. We assume perfect isolation of repeater which means the antenna isolation is large enough so that there will be no oscillation.

B. No feedback interference.
In real world, feedback interference can be reflected from buildings, mountains, hills, and moving vehicles around the repeater. Signals received by donor antenna including designated BS signal (input signal), feedback interference (direct feedback) and reflected interference (multipath feedback). Repeater simultaneously transmit and receive, so feedback interference from transmit antenna to receive antenna can be significantly larger than the desired signal when these two antennas are closely located. Interference cancellation system (ICS) is used to cancel unwanted signal by repeater itself. ICS is a technique which estimates the amplitude, phase and delay of the feedback signal buried in the input signal to the repeater and cancels the feedback signal with the signal generated from the estimated amplitude, phase, and delay. Here we assume repeater can cancel unwanted signals by itself using ICS and neither feedback interference nor reflected interference is in consideration.

The repeater functions considered in this thesis are shown in figure 4.1 which consist of a repeater gain unit and a maximum output power limitation unit. The input signal *s* is multiplied by repeater gain *G* to form the output signal. If the output signal *Gs* exceeds the maximum output power restriction it is forced to lower down the output power to maximum output power level at most.

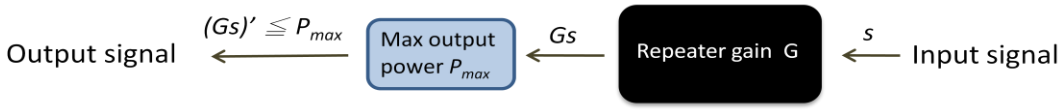

Figure 4.1. Repeater functions.

In WCDMA system signals are differentiated by PN (pseudo-noise) codes of users. Each user is assigned a unique code sequence that is used to spread the information signal on the common channel. At the receiving end each user exacts its own information by multiplying the received signal by the code. We can have the sense that in a repeater embedded system BS transmits signals to all the users and repeaters at the same time and users use their unique PN codes to differentiate signals from noise and interference. The same thing happens to the repeater.

BS knows which user is covered in the cell but it is not quite true for repeater. The size of repeater's coverage area depends on the repeater output power. The larger the output power is the more users it covers. The number of users served by a repeater is not constant. The relationship between repeater and user is not as close as in BS and user. It is conformed to the role repeater plays: an invisible loud speaker.

Repeater receives signal and re-transmits it without regenerate the data. Namely repeater does not decode signals it receives; it has no idea about the packet of what information it carries and whom it transmits to.

To summarize, due to the characteristics of repeater no power control over singer user is available. No matter the BS or repeater, every transmission carries all the signals of all users, rather than independent transmission. From the repeater's point of view it is not possible to do single user power allocation. In the contrast we need to consider the gain control of each repeater at every transmission.

Also we have to note that when dealing with repeater, interference is the major issue. Both BS and repeaters deliver the same signals in different power. The received signals of a user from different directions contain both wanted and unwanted information. Traditionally when talking about interference, there is only one node delivering useful information and the rest are regarded as interference sources. But repeater in WCDMA system is totally different. We cannot treat signals as pure useful information or interference. Instead we have to extract desired part of signal and regard the rest as interference.

4.2. Problem formulation

Under the characteristics of repeater-embedded WCDMA system, the problems we want to solve are classified into two categories as follows:

A. Find out the impact of repeater to the whole system in different scenarios. It is done by increasing the repeater gains from 0 to 80 dB (effective output power range).

   There are three situations:

   i. Single cell. Without inter-cell interference.
   ii. Multi cell with fixed inter-cell interference.
   iii. Multi cell with changeable inter-cell interference.

   Here the words ‘fixed’ and ‘changeable’ are comparative to the increasing repeater gains (from 0 to 80 dB). If the inter-cell interference is fixed during the center cell repeater gains increase it is defined as fixed inter-cell interference and vice versa.

   First we want to figure out if repeaters can really benefit the system on capacity and coverage area. If yes, further question is how much and what’s the behavior?

B. The most important part is to maximize the system capacity with the use of repeater gain control.

   We expect there are maximum values in three different scenarios. If there are no such optimum points, then what is the behavior and in what situation can we find an optimum value? In the following chapter we will find out.

   The methods to find the optimum value of capacity are done by applying the optimization algorithm and proposed algorithm which are introduced in the following chapters.

4.3. Radio Network Performance indicators

Indicators are defined to give information about the UMTS network performance. Some important indicators for the studies in this document are described shortly to understand the analysis performed in the following chapters in this document.

Repeater deployment threshold

This threshold which is based on user SINR is an indicator to determine which repeater should be turned on. Repeaters are built at fixed positions. The surrounding environment may change with time due to the buildings or constructions. Repeaters are adapted to the changing circumstances by turning on or off. This threshold gives a criterion of how worse the received SINR be should a repeater be turned on. The threshold also determines how many active repeaters are in a cell.

Spectrum efficiency

Spectrum efficiency refers to the information rate that can be transmitted over a given bandwidth. It is a measure of how efficiently a limited frequency spectrum is utilized by the physical layer protocol. Here we use Shannon capacity defined as follow:

$$Spectrum\ efficiency = log_2(1+SINR) \tag{1}$$

where SINR is the signal to noise and interference ratio of single user. It is sum up to all the cell users in the situations of without and with repeater embedded.

Outage number

Outage number is the number of users whose SINR are below a certain threshold. In the simulation we will set a threshold which can be a SINR value or the percentage of outage user number to all users.

5. Capacity analysis

The user SINR is a very important indicator in this thesis. In this chapter we are going to demonstrate the user SINR and the associated Shannon capacity.

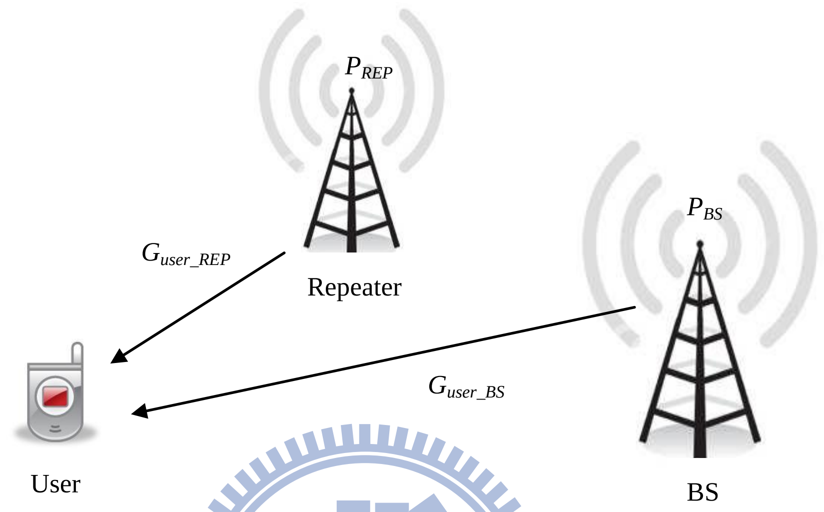

Figure 5.1. Transmission paths for a repeater installation.

Figure 5.1 shows the transmission paths from BS and repeater to user. Now we only consider single cell. BS transmits signals to both repeaters and users; repeaters amplify the signal and re-transmit to users. From the user's point of view the only possible paths it could receive are from BS and cell repeaters. P_{BS} and P_{REP} are transmitting power of BS and repeater. G_{ij} is the path gain from j^{th} transmitter to i^{th} receiver. It can encompass path loss, shadowing, antenna gain, coding gain, and other factors.

Assume each user is assigned different power. The total transmitted power (could be of BS or repeater) is P_{total}. For i^{th} user it is allotted

$$\beta_i P_{total} \tag{2}$$

β_i is the power ratio of user *i* to total power which value is between 0 and 1. It is the weighting of how much power is allocated to a user. And $\sum_i \beta_i = 1$. The rest of the power $(1 - \beta_i)P_{total}$ is regarded as interference from transmitter to other users except user *i*. The overhead channel power is P_{over}.

The signal power may decay during transmission, but the ratio of every user's power stay unchanged even the signal goes through fading. It becomes

$$\beta_i P_{total} G_{ij} \tag{3}$$

When user receives signal the above part is the desired information and the other is unwanted which has power

$$(1-\beta_i) P_{total} G_{ij} + P_{over} \tag{4}$$

Assume there are N_u users and N_r repeaters with power $P_1, P_2, \ldots, P_{N_r}$ in a cell and signals from different paths can be processed by the user (upper bound). The SINR of user *i* is

$$SINR_i = \frac{\beta_i\left(\sum_{j=1}^{N_r} P_j G_{ij} + P_{BS} G_{iBS}\right)}{\alpha\left[(1-\beta_i)\left(\sum_{j=1}^{N_r} P_j G_{ij} + P_{BS} G_{iBS}\right) + P_{over} G_{iover}\right] + N_0} \tag{5}$$

α is the orthogonality factor which ranges from 0 to 1. N_0 is the thermal noise. Both the numerator and denominator include signals from BS and repeaters.

Traditionally we do power allocation on each user according to its channel condition. However in repeater embedded system, every user's power is determined by BS, repeaters only amply signal. We can see from the above formula, P_j for $j = 1,\ldots,N_r$ are the variables and they are affected by repeater gains. The power allocation is done on repeaters not on users. Every transmission each repeater has to decide the gain associated with each other.

Equation (5) is the single cell case. If we consider multi-cell, the only difference from equation (5) is the inter-cell interference. The formula becomes

$$SINR_i = \frac{\beta_i\left(\sum_{j=1}^{N_r} P_j G_{ij} + P_{BS} G_{iBS}\right)}{\alpha\left[(1-\beta_i)\left(\sum_{j=1}^{N_r} P_j G_{ij} + P_{BS} G_{iBS}\right) + P_{over} G_{iover}\right] + I_{inter} + N_0} \tag{6}$$

I_{inter} can come from other-cell BS and/or repeaters.

The capacity of a user can be calculated as

$$log_2(1 + SINR_i) \tag{7}$$

And the cell capacity is

$$\sum_i log_2(1 + SINR_i) \tag{8}$$

So far we have proposed the user SINR and cell capacity. These are the measurements of the repeater buried system performance. The next thing we want to know is how much improvement can repeaters increase? This is done by solving the following optimization problem:

$$\begin{array}{lll} \text{maximize} & \sum_i log_2(1 + SINR_i) & \\ \text{subject to} & P_i \geq 0 & i = 1, \ldots, N_u \\ & P_i \leq P_{max} & i = 1, \ldots, N_u \end{array}$$

The objective function is the overall system throughput. It is optimized over the set of all feasible powers P_i. The transmit power of every repeater has to be a positive value. The second set of constrains gives a limit on repeater's output power. The last set of constraints is the data rates demanded by existing system users.

We use cvx which is a modeling system for disciplined convex programming developed by Michael Grant and Stephen Boyd to solve this problem. However since the mapping from repeater transmitting power to SINR function is not convex, it is impossible to directly deal with it via cvx. Alternatively we take the approach to approximate the non-convex Shannon capacity equation into piecewise linear functions, which can be managed by cvx.

To do so, we first look at the characteristic of Shannon capacity:

$$log_2(1 + SINR_i)$$

$$= log_2\left(N_0 + (\alpha - \alpha\beta_i + \beta_i)\left(\sum_{j=1}^{N_r} P_j G_{ij} + P_{BS} G_{iBS}\right) + \alpha P_{over} G_{iover} + I_{inter}\right)$$

$$- log_2\left((\alpha - \alpha\beta_i)\left(\sum_{j=1}^{N_r} P_j G_{ij} + P_{BS} G_{iBS}\right) + \alpha P_{over} G_{iover} + I_{inter} + N_0\right)$$

As seen above, Shannon capacity is decomposed into log and $-log$ functions, which takes the sum of linear variables as the input. Therefore, if we can approximate the log and $-log$ into linear functions, Shannon capacity is also approximated into linear functions. Fortunately log is a concave function, which can be easily approximated as the sum of piecewise affine functions:

$$a_n x + b_n \leq log(x) \leq a_n x + b_n + \Delta \tag{9}$$

where n is an index variable and Δ is a positive value. Specifically, the parameters of each line and the number of lines can be adjusted according to the required precision. By using this approximation technique, we can represent log part of Shannon capacity as follows:

$$S_i \leq a_n \left(N_0 + (\alpha - \alpha\beta_i + \beta_i) \left(\sum_{j=1}^{N_r} P_j G_{ij} + P_{BS} G_{iBS} \right) + \alpha P_{over} G_{iover} + I_{inter} \right) + b_n \tag{10}$$

where S_j is a real variable which delegates the intersection region of the affine functions; a_n and b_n are approximation parameters.

While $log(x)$ can be directly approximated through simple intersection, $-log(x)$ cannot be done in such way, but can be approximated by getting the union region. To do so, we need to select a proper affine function depending on domain x. More specifically we will add the virtual infinite value to the other affine functions except the proper affine function to safely ignore them. We take the selection technique again, and hence, an indicator variable v_{in} is introduced to choose the proper affine function, which gives the biggest value for a given input. Finally we obtain the inequality conditions given as follows:

$$Q_i \leq -a_n \left(N_0 + (\alpha - \alpha\beta_i) \left(\sum_{j=1}^{N_r} P_j G_{ij} + P_{BS} G_{iBS} \right) + \alpha P_{over} G_{iover} + I_{inter} \right) - b_n + Inf \times (1 - v_{in}) \tag{11}$$

A constrain for v_{in} is also required:

$$\sum_n v_{in} = 1 \tag{12}$$

Finally we can define the optimization problem as follows:

maximize $\sum_i (S_i + Q_i)$

subject to $P_i \geq 0 \qquad i = 1, \dots, N_u$

$P_i \leq P_{max} \qquad i = 1, \dots, N_u$

$$S_i \leq a_n \left(N_0 + (\alpha - \alpha\beta_i + \beta_i) \left(\sum_{j=1}^{N_r} P_j G_{ij} + P_{BS} G_{iBS} \right) + \alpha P_{over} G_{iover} + I_{inter} \right) + b_n$$

$$Q_i \leq -a_n \left(N_0 + (\alpha - \alpha\beta_i) \left(\sum_{j=1}^{N_r} P_j G_{ij} + P_{BS} G_{iBS} \right) + \alpha P_{over} G_{iover} + I_{inter} \right) - b_n + Inf \times (1 - v_{in})$$

$$\sum_n v_{in} = 1$$

Directly perceive through the sense, one might think the fourth and fifth constraints could be cancelled. In fact each round we only take one constraint of Q_i and there are N rounds. The final solution is the maximum of N optimization results. If we re-write it more clearly, it would be like this:

For $k = 1, \dots, N$

maximize $C_k = \sum_i (S_i + Q_i)$

subject to $P_i \geq 0 \qquad i = 1, \dots, N_u$

$P_i \leq P_{max} \qquad i = 1, \dots, N_u$

$SINR_i \geq SINR_{min} \qquad i = 1, \dots, N_r$

$$S_i \leq a_n \left(N_0 + (\alpha - \alpha\beta_i + \beta_i) \left(\sum_{j=1}^{N_r} P_j G_{ij} + P_{BS} G_{iBS} \right) + \alpha P_{over} G_{iover} + I_{inter} \right) + b_n \qquad n = 1, \dots, N$$

$$Q_i \leq -a_k \left(N_0 + (\alpha - \alpha\beta_i) \left(\sum_{j=1}^{N_r} P_j G_{ij} + P_{BS} G_{iBS} \right) + \alpha P_{over} G_{iover} + I_{inter} \right) - b_k$$

end

optimized capacity = *max*(C_k)

6. PROPOSED ALGORITHM

The optimization formula in last chapter does provide an upper bound on system capacity. However the computation is complex and it is hard to implement in real system. As a result we are going to propose an algorithm which shows the criterion used for repeater gain adjustment and is much simpler to implement while the performance is close to the optimization result.

With the knowledge of repeater the most apparent factors one might think of affecting repeater gains are the distance and user distribution. The former means the distance from repeater to users or repeater to the cell edge. With the existence of multi-cell interference the critical thing is to avoid repeater transmits severer interference which might damage the surrounding users and when the repeater is close to the cell edge the gain should be low for the same reason. The latter means to tune the repeater gains according to the user distribution.

We try to verify the above assumptions by observing the optimization result. The conclusion however does not conform the assumptions, namely it is not directly related to the distance and user distribution. The most critical factor is the SINR ratio of repeater to its posterior users. If the posterior users of a repeater are all good users (whose SINR are greater than their anterior repeater) the repeater should turn diminish its gain to avoid interfering the covered users. On the other hand if there are many bad users (whose SINR are smaller than their anterior repeater) the repeater should raise its gain in order to enhance the signal qualities of covered users.

There are three types of situations: 1). $Repeater\ SINR\ \geq\ all\ covered\ users\ SINR$. All of the posterior users get improvements on SINR and hence the capacity. The repeater gain can be as large as possible to increase the user qualities without any damage. 2). $Bad\ users\ SINR \leq\ Repeater\ SINR\ <\ good\ users\ SINR$. It is the most common situation in which the repeater is beneficial to some users but harmful to the others. High quality users are sacrificed to increase the SINR of low quality users. 3). $Repeater\ SINR\ <\ all\ covered\ users\ SINR$. It is the worst case that the repeater installation has no benefit to the posterior users. In this case the repeater gain should be as small as possible or just turned off.

The concept of the proposed algorithm is based on the above criteria and progressively converge the repeater gains.

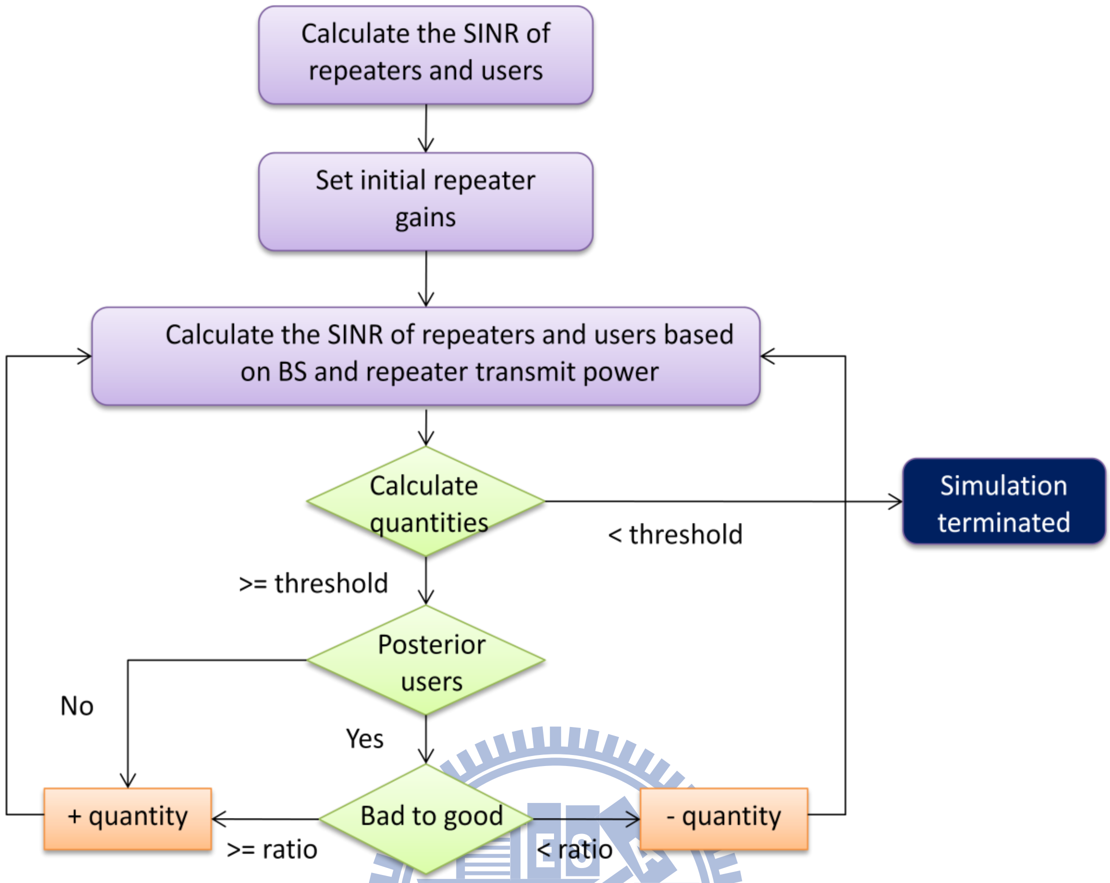

Figure 6.1. Flow chart of proposed algorithm.

Figure 6.1 is the flow chart of proposed algorithm. First we calculate the SINR of repeaters and users based on BS transmit power only and give initial values of repeater gains. The following steps are a repeated process to adjust repeater gains. After the initial gain setting the users receive signals from both BS and repeaters which makes a change on user SINRs and we can calculate the updated SINR values. Next we calculate the 'quantities', which are the amount of gains that repeaters will alter in next iteration. There is a relation on quantities: $quantities_i = quantities_{i-1} / 2$, and $quantities_0$ depends on the initial repeater gains. The values of quantities are set to ensure that no matter the initial gain values of repeaters are they have the possibility to be in any gain levels by adding or subtracting the quantities in the following iterations. If the quantities are smaller than the threshold it means the repeater gains are converged to a set of values and the simulation terminated. If the quantities are greater than the threshold we then decide the repeater gains are going to add or subtract the quantities. A repeater with no posterior users adds the quantity in every iteration. For repeater with posterior users we calculate the ratio of bad users to good users. Quantity is added to repeater gain if it exceeds the ratio and subtracted if it is below the ratio. The above process progresses until the terminated condition achieved.

Parameters	**values**
Repeater serving area	0~150 m
Quantities	$quantities_i = quantities_{i-1} / 2$ $quantities_0 = initial\_repeater\_gain / 2$ or $(80 - initial\_repeater\_gain) / 2$
Threshold	Smaller is more accurate
Bad user to good user ratio	< 1

Table 6.1. Parameter settings.

Table 6.1 lists the parameters used in the proposed algorithm. There are no specific values because they change from times to times. However these values give a possible range to simulate with.

7. SIMULATION RESULTS

7.1. Simulation environment

This chapter gives detailed information concerning the system level computer simulations performed for studying the effects of repeaters in 3G systems. Different elements of the radio network are modeled to provide as realistic network operation as possible. For example: propagation models for different radio propagation environments, digital maps for accurate terrain modeling, and antenna models for realistic coverage calculation. In the simulation we refer to the UMTS specification of 3GPP as a basis. Table 7.1 lists the parameter values used in simulation.

Parameter	**Value**
Macro cell	Hexagonal with BS in the middle of the cell
Micro cell	Manhattan
BS type	Omnidirectional
Macro cell radius	577 m
MCL macro	70 dB
MCL micro	53 dB
Log normal fading margin	10 dB
User distribution	Random and uniform across the network
User number	60
Common channel	Orthogonal
Maximum transmitting power	43 dBm macro 33 dBm micro
Common channel power	30 dBm macro
BS transmit power	37 dBm
Orthogonality factor	0.1
BS antenna gain	11 dB
Repeater donor antenna gain	11 dB
Repeater service antenna gain	11 dB
Repeater noise figure	5 dB
MS antenna gain	0 dB
Noise power	-99 dBm
MS power ratio	1/user number

Table 7.1. Summary of simulation parameters.

7.2. Repeater performance understanding

In the following sections, performance with repeater-embedded system is presented in different scenarios, i.e. single cell, multi cell with fixed inter-cell interference and multi cell with changeable inter-cell interference. There are distinct behaviors in addition to the common parts. Among these scenarios optimization is applied on necessary ones to show the difference and enhancement.

7.2.1. Single-cell

Before performing the improvement of system capacity, we first take a look on the variation of received power after installing repeaters.

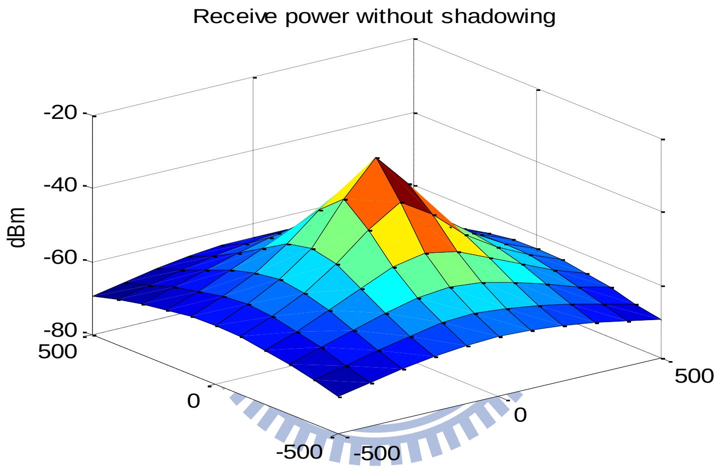

Figure 7.1. Received power without shadowing.

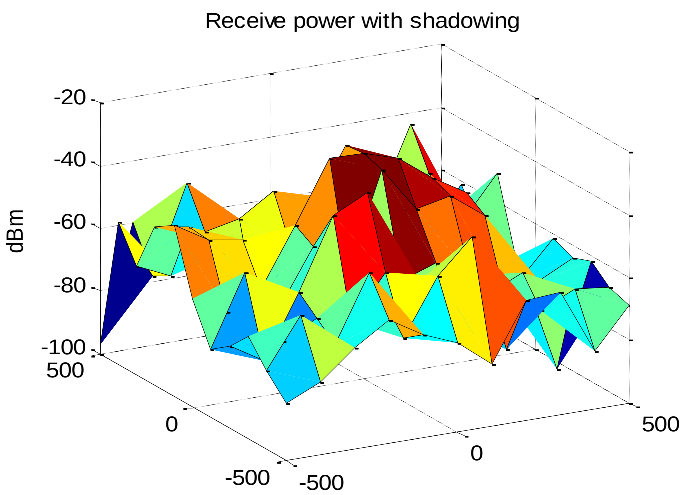

Figure 7.2. Received power with shadowing.

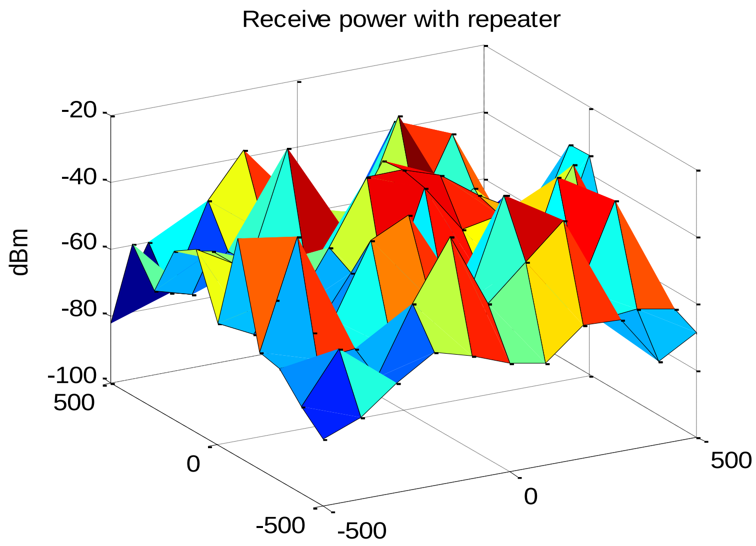

Figure 7.3. Received power with repeaters.

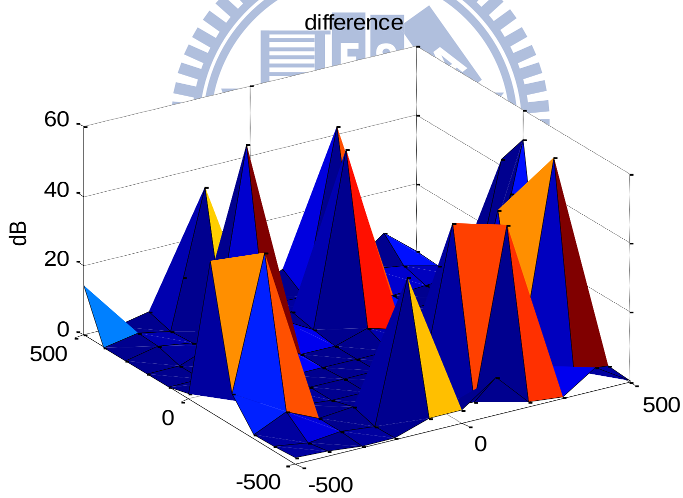

Figure 7.4. Difference of received power before and after repeater.

Figure 7.1 is the received signal strength with only one BS. To construct the realistic network, shadowing is added to the network area to present the effect of obstacles and nature features. The received powers then have large variation as depicted in figure 7.2. In some dead spaces the signal strength is below a certain threshold and a repeater is turned on. The repeaters are used to compensate the severe decrease of signal strength in those areas to increase the transmission quality as is figure 7.3. Figure 7.4 is the received power difference before and after repeaters being built.

Each peak stands for a repeater position. All the differences are positive which means repeaters can effectively enhance the signal strength.

In single cell scenario only one BS and cell repeaters are considered. As mentioned above repeaters are installed uniformly within the cell and turned on in areas where the signal strength is low, so the most obvious enhancement is on the received SINR of users. The active repeaters can be varied from situations, i.e. if a building or high way is constructed or the terrain is changed. From figure 7.5 the average SINR is growing with repeater gain increases. The curve is saturated due to the limited maximum output power of repeater and the limitation of the system. The drop high reveals the fact that the average SINR of a single cell case without any inter-cell interference behaves quite well. Even with the installation of repeaters the improvement is bounded.

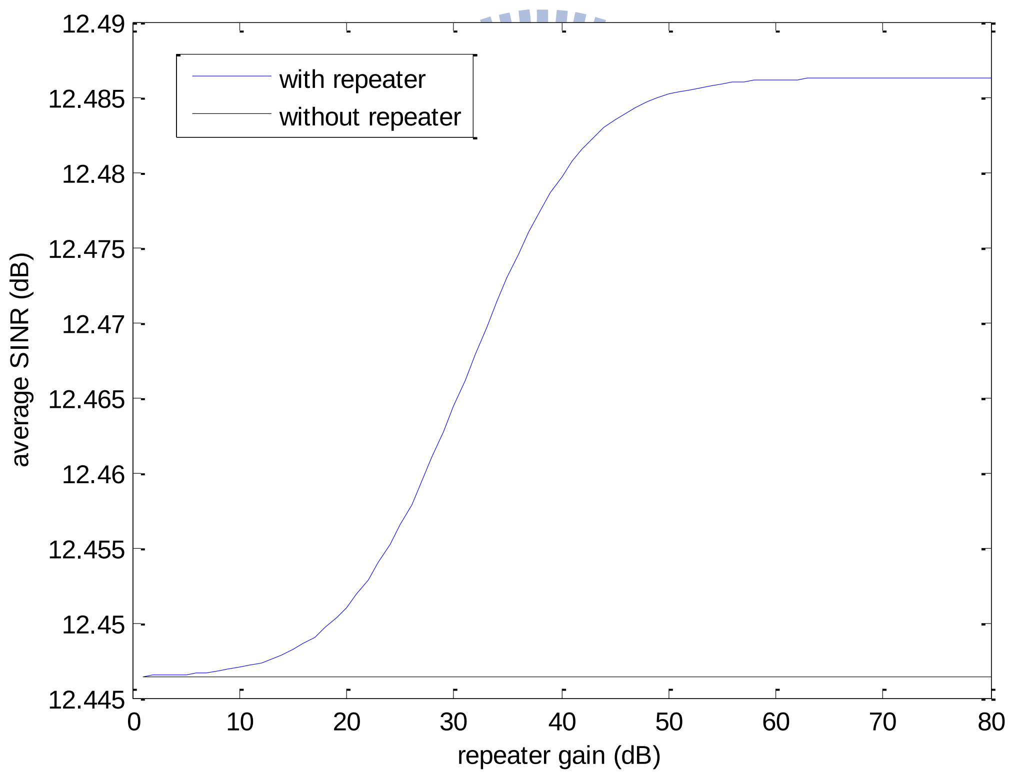

Figure 7.5. Average SINR of single cell case.

With the increase of repeaters, not surprisingly, the spectrum efficiency gets higher. Each curve has the trend that it saturates with high repeater gain.

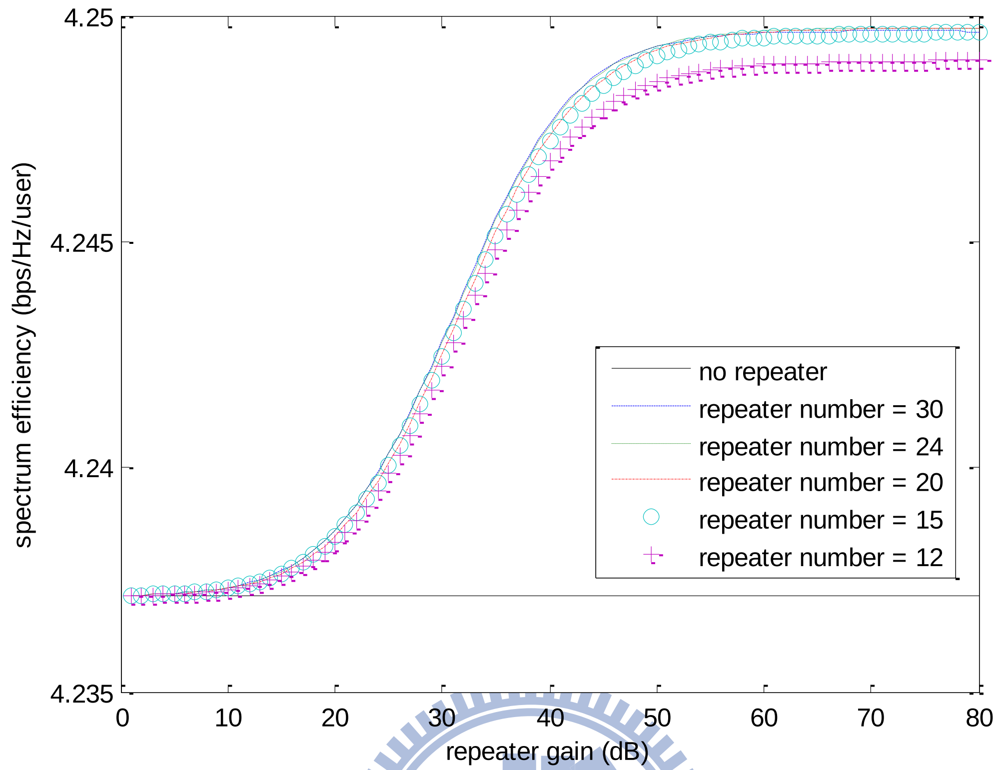

Figure 7.6. Spectrum efficiency of cell under different repeater numbers.

7.2.2. Multi-cell

Next we consider multi-cell case in which fixed and changeable inter-cell interference are added to the center cell for simulating. The performance of using repeaters is reflected on increasing repeater gains. The fixed inter-cell interference is relative to repeater gains, which means the interference of outside cells remain unchanged while the repeater gains of center cell are raising stage by stage. The fixed inter-cell interference sources could be repeaters as well as BSs. On the other hands, the changeable inter-cell interference means the outside interference is increasing with the center cell repeater gains. Usually the interference sources are repeaters. In the simulation we regard the fixed ones as BSs and the changeable ones as repeaters which are within 100 meters from center cell and they raise their gains as center cell repeaters simultaneously.

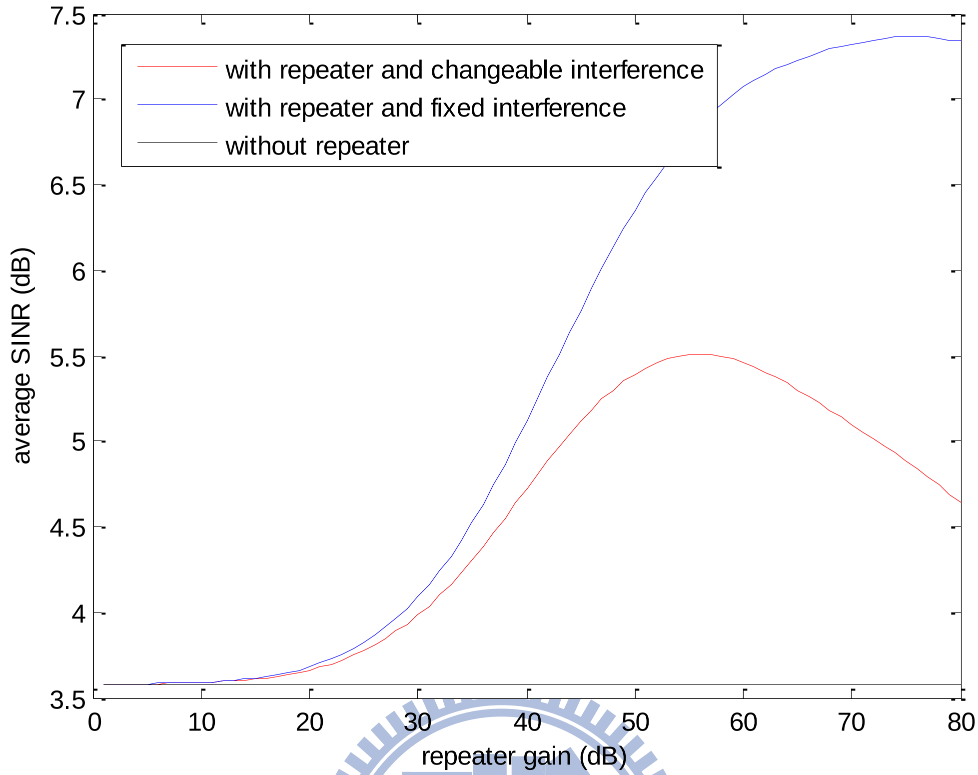

Figure 7.7. Average SINR of multi-cell with fixed and changeable interference.

From figure 7.7 if there are only fixed inter-cell interference sources the curve shifts down but remains the same trend in substance. If changeable interference added it shifts the curve and makes it decrease after the top. The drop high between repeater and no repeater case is much larger relative to single cell case. With the existence of interference the performance of repeater installed cell is more apparent.

The next two figures plot the spectrum efficiency curves of fixed and changeable inter-cell interference respectively. The first one is similar to single cell case except that the spectrum efficiency is lower and the improvement is larger. The second figure however has much difference. There is a peak at each curve and with the increase of repeater gain the spectrum efficiency decays severely. In other words, if each cell uses repeaters to enhance their capacity by sending large output power, the results may be disappointed. The relation of each cell is tightly connected due to the interference. A repeater enhances the interference it receives as well as desired signal.

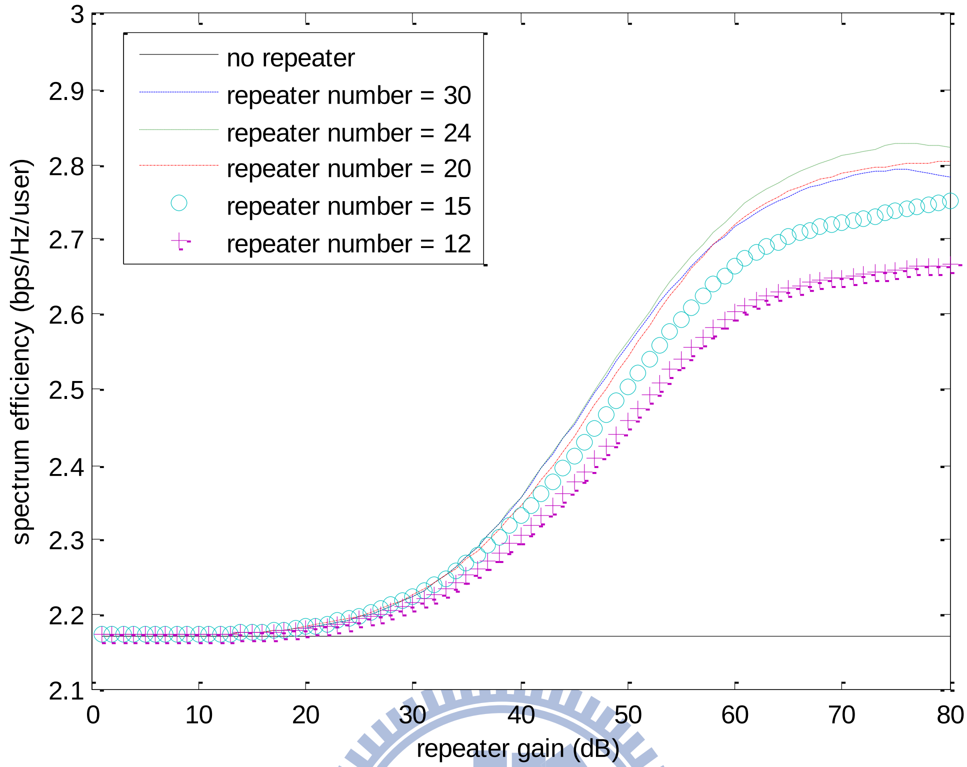

Figure 7.8. Spectrum efficiency of cell with fixed interference under different repeater numbers.

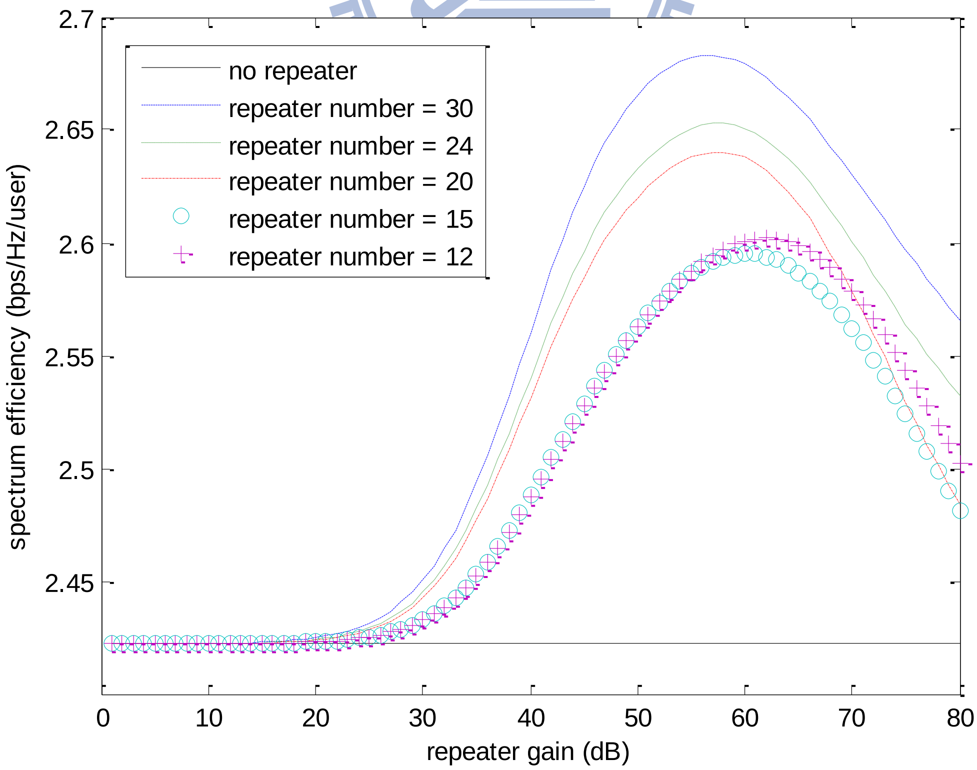

Figure 7.9. Spectrum efficiency of cell with changeable interference under different repeater numbers.

Repeaters have a positive effect to received SINR and spectrum efficiency in substance. So far from the above figures and discussions a temporary conclusion is stated:

A. Single cell

   There is no external interference. The spectrum efficiency curves get saturated only due to the output power restriction or they reach the system limit.

B. Multi cells with fixed interference only

   The maximum output power limits the performance before it reaches the system limit. If the maximum output power is large enough to be ignored we can observe a peak at high repeater gain and finally the curve get smooth because of the system limitation.

C. Multi cells with variational interference

   There is a spectrum efficiency degradation even though before the output power limit. The spectrum efficiency can be great damaged. The performance gets even worse as the repeater gain grows if there is no output power restriction.

Totally speaking repeater is harmless for the first two cases. Only in the third case we need to do optimization.

7.3. Multi-Cell Optimization

7.3.1. Scenario Deployment

In order to investigate the relationship of adjacent cells, the follow scenario is proposed. Consider a three-adjacent cell deployment each has its own repeaters as figure 7.10. The blue circles are BSs and red ones are repeaters. This deployment contains the most common situations in the real system.

The intersections among these cells are complicated. Raising repeater gains of one cell may damage the other two, so how to enhance the overall capacity rather than single cell is the issue discussed in this section. All the parameters are the same as the previous section the only difference is the user number which is set to 30 per cell.

We will use both the optimization formula and the proposed algorithm to do the simulation and compare the performances to see if the proposed algorithm can approach the optimization result.

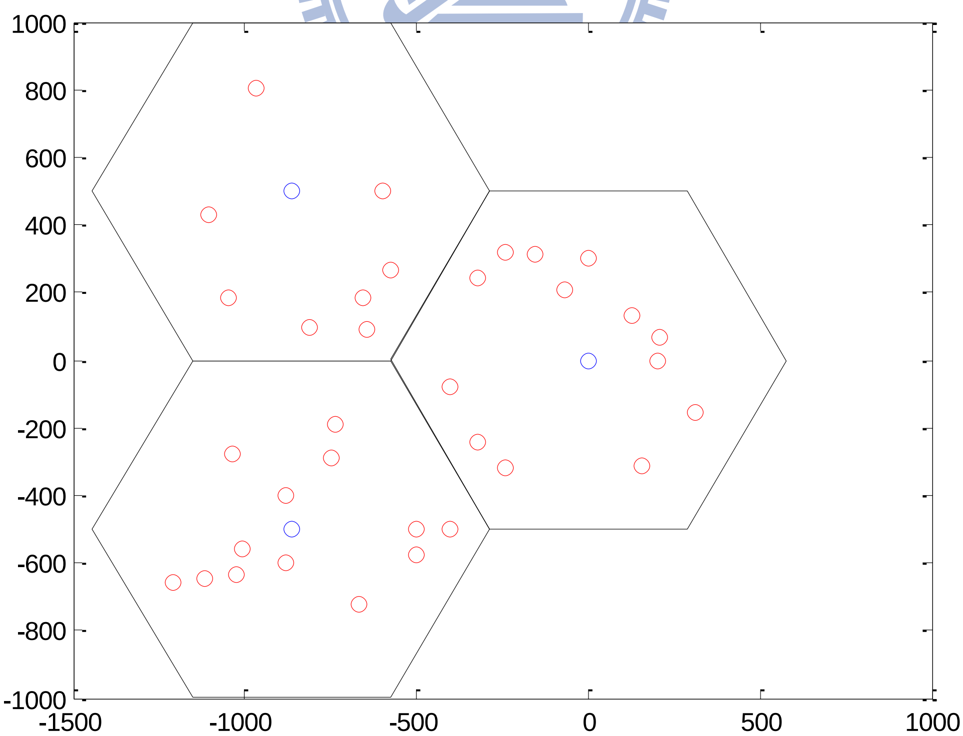

Figure 7.10. Scenario and repeater deployments.

7.3.2. Performance Comparison

We use the formula derived in chapter 5 to solve the problem. The objective function is the overall cell capacity (three cells) and the constraint functions give the restriction on repeater output power.

REP deployment threshold (dB)	User number	REP number of cell 1	REP number of cell 2	REP number of cell 3
-9.91	90	26	31	24
-9.95	90	17	19	10
-10	90	11	12	7

Table 7.2. Different repeater deployment threshold and the corresponding repeater number.

The simulation is based on different number of repeaters (table 7.2). Table 7.3 is the performance comparison of proposed algorithm and optimization method. In both methods the spectrum efficiency and average SINR grow as the number of repeater increases. The optimization gives an upper bound on system performance and the results of proposed algorithm are closed to the upper bound. From figure 7.11 we can further observe that as the repeater number increases the result of proposed algorithm is closer to the upper bound. It is because the fewer the repeater number the less the users covered by repeaters, so the impact of repeater reduced.

REP deployment threshold (dB)		-9.91	-9.95	-10
Spectrum efficiency (bps/Hz/user)	No repeater		4.1088	
	Algorithm	4.4524	4.3700	4.2993
	Optimized	4.4581	4.3860	4.3437
Average SINR (dB)	No repeater		11.7561	
	Algorithm	12.9286	12.6316	12.4001
	Optimized	12.9569	12.6838	12.5438
Number of outage users	No repeater		24/90	
	Algorithm	15/90	16/90	18/90
	Optimized	13/90	16/90	17/90

Table 7.3. Performance comparison.

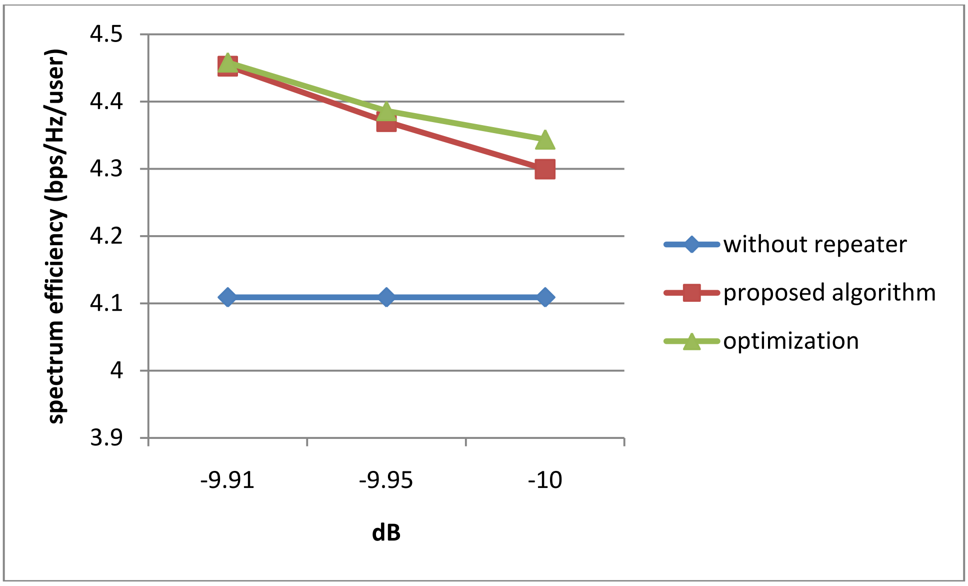

Figure 7.11. Spectrum efficiency comparison.

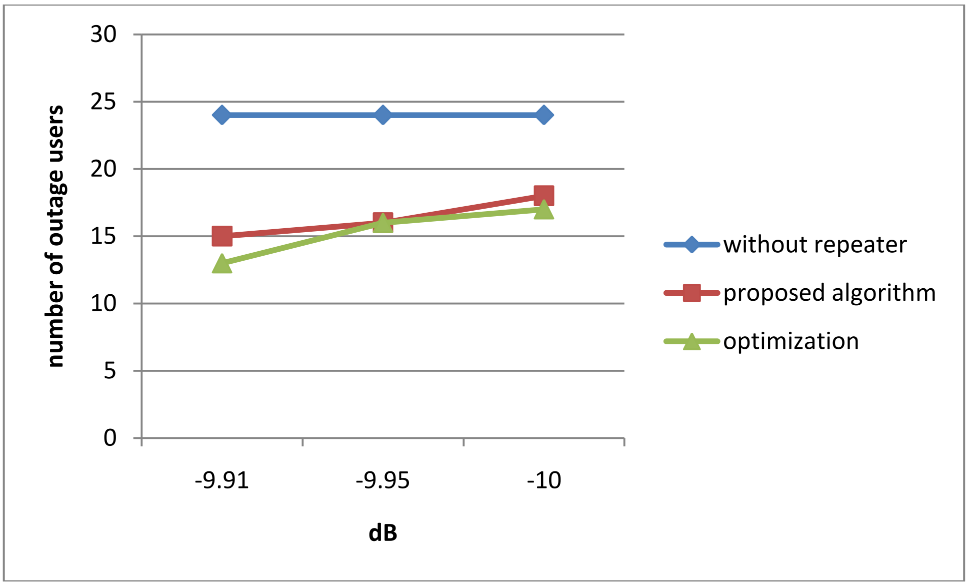

Figure 7.12. Outage user comparison.

The outage users are defined as those whose SINR are below the repeater deployment threshold. The proposed algorithm is only a little bit worse than optimization method. From figure 7.12 both the optimization and proposed algorithm can reduce the outage number by about 30%. Most of the rest of outage users are located at cell edge without anterior repeaters, so their SINR do not get promoted.

If we only consider users covered by repeaters the impact of repeaters is more obvious. In table 7.4 we compare the spectrum efficiency and average SINR of proposed algorithm and no repeater case. Usually repeaters are installed at low SINR areas to enhance users signal qualities or we can say the SINR of users are low at places where repeaters are deployed. So we can expect that both the average SINR and spectrum efficiency of posterior users will be lower than all user case before repeaters are installed as in table 7.4 with repeater deployment threshold is -10 dB. There also exist users who are in the coverage hole but no anterior repeaters. As repeater number increases more high SINR users are included in addition to low SINR users. That's the reason of spectrum efficiency and average SINR are larger than all user case with repeater deployment threshold are -9.91 and -9.95 dB. From the performance point of view the enhancement of repeater installation is obvious. The results show that if we only consider the users who are directly influenced by repeaters the performance enhancement is great.

REP deployment threshold (dB)		**-9.91**	**-9.95**	**-10**
Spectrum efficiency (bps//Hz/user)	No repeater	4.1715	4.1335	4.0372
	Algorithm	4.6159	4.5624	4.5400
Average SINR (dB)	No repeater	12.0622	11.8781	11.7082
	Algorithm	13.5643	13.3313	13.4032
Number of outage users	No repeater	17/82 (20.73%)	13/60 (21.67%)	12/45 (26.67%)
	Algorithm	8/82 (9.76%)	6/60 (10%)	5/45 (11.11%)

Table 7.4. Performance comparison of posterior users.

8. Conclusions

Repeater is a device to overcome the coverage holes and enhance the user signal quality. From the early introductions we understand the repeater characteristic and how it works. The goals of this research are to analysis the behavior of repeater in different scenarios and to maximize the system performance.

From the repeater performance understanding simulation we conclude that in single cell and multi-cell with fixed inter-cell interference cases repeaters cause no damage on user SINR and spectrum efficiency. Only in multi-cell with changeable inter-cell interference case the repeater has the probability to lower the system performance.

In this thesis we first provide an optimization method to coordinate repeaters in order to reach the capacity upper bound of the system. Another proposed algorithm is also proposed to enhance the system performance but with less computation complexity and easier to implement in real system.

Use the optimization and proposed algorithm on the multi-cell with changeable inter-cell interference case the simulation results show the upper bound of the user SINR and spectrum efficiency with the use of optimization and the proposed algorithm can approach the optimization performance. The outage user number is reduced as well as the enhancement on system capacity.

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