CHAPTER 5

SITE SELECTION DIVERSITY TRANSMISSION POWER CONTROL

5.1 INTRODUCTION

Soft handoff allows wireless user equipment to stay connected to several BSs in a WCDMA system. CDMA technique makes it possible to maintain an old connection while adding a new one (make before break). However, additional resources from several BSs are required [5]. In downlink, this is achieved by multiple site transmission which implies that several BSs transmit the same signal to a certain MS. The capacity in WCDMA system is commonly limited by interference. In order to reduce the interference level in downlink, power control techniques are proposed in WCDMA system. By using a power control algorithm that is based on SIR-based power control in downlink, the power that is transmitted to the MS is adjusted to achieve the $E_b/N_0$ requirements [5, 13]. Therefore, more users can be served by the system if SIR-based power control techniques are used, hence system interferences are reduced.

In 3G cellular systems, SSDT power control is employed to mitigate the interference produced by soft handoff multiple transmissions. When using SSDT during soft handoff mode, only the best server BS is transmitting to the MS, while the rest of the BSs included in the active set turn off the power transmitted to this MS, maintaining only their Dedicated Physical Control Channel (DPCCH). Two issues must be taken into account in soft handoff performance evaluation, namely the active set and the soft handoff margin ($M_{SH}$). The active set is the group of BSs to which a user terminal is connected [46]. $M_{SH}$ is the maximum allowed difference (measured in decibels) between the power that is received from the best server BS
and the power that is received from a candidate BS that is included in the active set of the user terminal.

The aim of this chapter is to improve system capacity by reducing interference in WCDMA system with SSDT power control during soft handoff mode and to analyze the optimum $M_{SH}$ in terms of maximum system capacity. In WCDMA, system with the increase in the $M_{SH}$ the capacity increases up to certain range but this capacity gain leads to an increase in the number of resources used in the radio interface (channeling and scrambling codes). This trade-off between the capacity gain and the increase of required resources can be controlled by the $M_{SH}$. The work mainly focuses on finding the optimum $M_{SH}$ for WCDMA system.

5.2 POWER CONTROL IN WCDMA SYSTEM

The capacity in WCDMA systems is commonly limited by interference. In order to reduce the interference level in downlink, power control techniques are proposed in WCDMA systems. By using a power control algorithm that is based on SIR based power control in downlink, the power that is transmitted to the MS is adjusted to achieve the $E_b/N_0$ requirements. Therefore, more users can be served by the system if SIR based power control techniques are used since system interferences are reduced.

The WCDMA air interface is organized in frames of 10 ms duration. A frame contains 15 time slots and each slot includes one power control command (up or down) which gives a power control update rate of 1500 b/s. The transmitted power has a fixed value during a given time slot. In general power control in a cellular network is needed to compensate for so called near-far problem arising from some MSs being close to the BS, while others may be far away. Some power balancing is needed in order for those closer MSs not to block the connections of the mobiles located far from the BS.
There are three separate power control mechanisms defined in WCDMA. Fast closed loop power control is employed both in up and downlink to account for Rayleigh fading. Fast operation is vital for compensating Rayleigh fading and in WCDMA a closed loop power control command is issued for every time slot, i.e. at a rate of 1500Hz. The sign of power control command is issued (power up down) is often based on a SIR measurement which is compared to a predefined SIR threshold. This SIR threshold is adjusted by the outer loop power control by measuring the link quality and comparing that to the requirements of each service. Finally, open-loop power control sets the initial power level the MS starts transmitting with. For this purpose, the uplink path loss is estimated from the down link path loss.

5.2.1 Purpose of Power Control

Power control is a necessary element in all mobile systems because of the battery life problem and safety reasons, but in CDMA systems, power control is essential because of the interference limited nature of CDMA. In GSM slow (frequency approximately 2 Hz) power control is employed. In IS-95 fast power control with 800 Hz is supported in the uplink, but in the downlink, a relatively slow (approximately 50 Hz) power control loop controls the transmission power. In WCDMA fast power control with 1.5 kHz frequency is supported in both uplink and downlink. Tight and fast power control is one of the most important aspects of WCDMA systems. The overall objectives of power control can be summarized as follows:

(i) Overcoming the near-far effect in the uplink.
(ii) Mitigates fading.
(iii) Compensates changes in propagation conditions.
(iv) Optimizing system capacity by controlling interference.
(v) Maximizing the battery life of mobile terminals.

Power control in uplink must make signal powers from different users nearly equal in order to maximize the total capacity in the cell. In downlink the
power control must keep the signal at minimal required level in order to decrease the interference to users in other cells. Figure 5.1 shows near-far problem in the uplink. Signals from different MSs are transmitted in the same frequency band simultaneously in WCDMA systems. Without power control, the signal coming from the MS that is nearest to the BS may block signals from other MSs that are much farther away from the BS. In the worst situation one over-powered MS could block a whole cell. The solution is to apply power control to guarantee that signals coming from different terminals have the same power or the same SIR when they arrive at the BS.

![Figure 5.1 Near-far problem](image1)

![Figure 5.2 Inter-cell interference](image2)

In the downlink direction, there is no near-far problem due to the one to many scenarios. Power control is responsible for compensating the inter cell
interference suffered by the mobiles, especially those near cell boundaries as shown in Figure 5.1. Moreover, power control in the downlink is responsible for minimizing the total interference by keeping the QoS at its target value. In Figure 5.2 mobile 2 suffers more inter-cell interference than mobile 1. Therefore, to meet the same quality target, more power needs to be allocated to the downlink channel between the BS and mobile 2.

5.2.2 Types of Power Control

There are three types of power control in WCDMA systems: open-loop power control, closed-loop power control and outer-loop power control.

Open-loop Power Control

Across the air interface open-loop power control is used in the UMTS FDD mode for the mobile initial power setting. The mobile estimates the path loss between the BS and the mobile by measuring the received signal strength using an AGC circuit. According to this estimate of path loss, the mobile can decide its uplink transmit power. Open-loop power control is effective in a TDD system because the uplink and downlink are reciprocal, but it is not very effective with FDD system because the uplink and downlink channels operate on different frequency bands and the Rayleigh fading in the uplink and downlink are independent. So open-loop power control can only roughly compensate distance attenuation. That is why it is only used as an initial power setting in FDD systems.

Closed-loop Power Control

Closed-loop power control, also called as fast power control in WCDMA systems, is responsible for controlling the transmitted power of the MS (uplink) or of the BS (downlink) in order to counteract the fading of the radio channel and meet the SIR target set by the outer-loop. Figure 5.3 represents the closed-loop power control mechanism. For example, in the uplink, the BS compares the received SIR from the MS with the target SIR once every time slot. If the received SIR is greater
than the target, the BS transmits a TPC command “0” to the MS via the downlink dedicated control channel. If the received SIR is lower than the target, the BS transmits a TPC command “1” to the MS. Since the frequency of closed-loop power control is very fast it can compensate fast fading as well as slow fading. Power control step in uplink is 1, 2, 3 dB and control range is 80 dB and in downlink power control step is 0.5 and 1 dB and control range is 30 dB changes of power are multiples of the minimum step size and it is mandatory for BS to support 0.5 and 1 dB step size.

**Figure 5.3 Closed-loop power control**

**Outer-loop Power Control**

Outer-loop power control is needed to keep the quality of communication at the required level by setting the target for the fast closed-loop power control. Depending on MS speed available, multipath diversity, adjust the SIR target to achieve the required FER/BER/BLER and compensates changes in environment. It aims at providing the required quality: no worse, no better. The frequency of outer-loop power control is typically 10-100Hz.

**Figure 5.4 General outer-loop power control algorithm**
Figure 5.4 shows the general algorithm of outer-loop power control. The outer-loop power control compares the received quality to the required quality. Usually the quality is defined as a certain target BER or FER. The relationship between the SIR target and the quality target depends on the mobile speed and the multipath profile. If the received quality is better, it means the current SIR target is high enough for guaranteeing the required QoS. In order to minimize the headroom, the SIR target will be reduced. However, if the received quality is worse than the required quality, the SIR target needs to be increased for guaranteeing the required QoS.

**Combined Power Control Method for WCDMA System**

Power control in WCDMA is a closed-loop power control which is a combination of outer and inner closed loop control (Figure 5.5). The inner (also called fast) closed loop power control adjusts the transmitted power in order to keep the received SIR equal to a given target. This SIR target is fixed according to the received BLER or BER. The setting of the SIR target is done by the outer loop power control which is part of the radio resource control layer (Layer 3), in order to match the required BLER. Outer loop power control update frequency is 10-100 Hz. The BLER target is a function of the service that is carried. Ensuring that the lowest possible, SIR target is used results in greater network capacity.

![Combined power control method diagram](image)

**Figure 5.5 Combined power control method**
The inner closed-loop power control measures the received quality, defined as the received SIR and sends commands to the transmitter (i.e., the mobile in the case of uplink) for the transmitted power update. In order to estimate the received SIR, the receiver estimates the received power of the connection to be power controlled and the received interference. The obtained SIR estimate, noted $SIR_{est}$, is then used by the receiver to generate power control commands.

5.3 SITE SELECTION DIVERSITY TRANSMISSION

In 3G cellular systems, SSDT power control is employed to mitigate the interference produced by SHO multiple transmissions [47]. While using SSDT in the SHO mode, only the best server BS is transmitted to the MS, while the rest of the BSs included in the active set turn off the power transmitted to this MS, maintaining only their DPCCH.

The major intention of the site selection is to mitigate interference caused by multiple site transmission done at conventional TPC. CDMA cellular systems including WCDMA for IMT-2000 employs an elaborate handoff method in which a MS is simultaneously connected to several BSs. Here the serving BSs as "active BSs" and to the set of serving BSs as the "active set." This method of handoff, the so called soft handoff, attains site diversity reception and unbroken exchange of communication links. Soft handoff is also desirable for maintaining the connection of an MS to a minimum path loss BS. By introducing soft handoff, candidate BSs which are to be minimum path loss BSs in the future can be included in the active set beforehand. This feature is important because the process for adding a new BS takes some time while the minimum path loss BS frequently changes in accordance with the MS movement.

5.3.1 Conventional Transmission Power Control

TPC is a key to achieve a high capacity and reliable CDMA cellular system. Reverse link TPC is required to combat the near-far problem because
reverse link signals are received at the BS from asynchronous and non-orthogonal MS’s. Forward link TPC, on the other hand, is mainly used to minimize the excess use of transmission power by BSs, but it is unnecessary for coping with the near-far problem which does not appear in the forward link. In both reverse and forward links, TPC allows the reduction of inter-cell interference and system capacity can thus be enhanced. TPC enables the BS to maintain its output power at a minimum level and this greatly enhances system capacity in conjunction with the minimum path loss BS connection achieved by SHO. Figure 5.6 represents both conventional and SSDT techniques.

**Figure 5.6 Conventional and SSDT power control**

The forward link TPC used in the first commercial cellular CDMA system which is capable of working in soft handoff mode, has slower power control feedback than the reverse link TPC. Compensation of shadowing has thus been considered, but fast fading has not. However, such an implementation can far less optimize the forward link and in some cases the result will be that the forward link capacity is more limited than the reverse link capacity. WCDMA achieves an efficient forward link by applying a fast closed loop TPC that modifies the BS output power in a cycle that is comparable to the cycle for the reverse link even though the additional signaling required for the TPC incurs a capacity reduction in the reverse link.

The straight forward realization of forward link TPC with fast power adjustment in SHO mode is that each active BS modifies its output power equally in accordance with TPC commands that are sent by the MS. The TPC commands transmitted by an MS requests a decrease in BS output power if the quality of
reception at the MS is better than a target quality and an increase if the quality is worse than a target. Each active BS modifies its output power by a fixed step size, on the basis of the TPC command from the MS. Such a TPC is going to attribute the same transmission power to all of the active BSs while maintaining the forward link in the target quality. In fact, BS output power among the active BSs will vary greatly due to the initial settings for transmission power and errors in TPC command reception. This scheme can be called as conventional TPC.

Problems in Conventional TPC

Although SHO can enhance the reverse link system capacity by a factor greater than 2, there are three major problems involved in implementing conventional TPC in the forward link during SHO.

(i) The multiple site transmission required for SHO results in increased interference that affects other radio links and thus limits the forward link capacity.

(ii) Path capturing efficiency at a RAKE receiver is reduced. In the implementation of practical MSs, the number of RAKE fingers is limited. Since SHO increases the number of paths to be resolved by an MS, this limitation prevents the RAKE receiver from capturing all of the resolved paths which is discussed in chapter7. As a result, the missing paths interfere with the captured paths at the RAKE receiver.

(iii) The transmission power of active BSs will become imbalanced due to errors in receiving TPC commands. TPC command reception errors cannot be avoided in practice which results in the imbalanced transmission power of active BSs even though their initial settings were the same. The biggest problem here is that these errors may cause the transmission power of some of the active BSs to become excessively high and thus increase the interference.
To overcome problem (i), the MS sends commands to the active BSs to select the BS that provides the minimum path loss for the MS and the other BSs in the same active set reduce their transmission power to a minimum level. The BSs election signaling is periodically transmitted to the active BSs in a cycle that is identical to the one used to reduce power or increase power signaling. The signals for BSs selection and BS output power control are combined into a composite control signal that requires no overhead to deliver the primary BS information. The selected BS is power controlled so that the signal maintains a constant quality at the MS. Multiple site transmission can thus be avoided and the total transmission power for all active BSs is minimized. The capacity of this forward link TPC method was compared to conventional TPC and the results indicated some promise in terms of improved capacity. Intensive link level analysis also confirms the benefits of such a BS selection. However, although the composite control signal is beneficial in terms of minimizing the signaling overhead, the complexity of the messages increases the likelihood of failure in decoding it which results in reducing the benefits of the BS selection. SSDT TPC, an advanced form of forward link TPC that can solve the problems incurred by conventional TPC. The best BS can be dynamically chosen as the transmitting site and the output power of the other BSs is reduced.

5.3.2 SSDT Power Control

SSDT realizes site selection transmission diversity instead of the full site transmission diversity used in conventional TPC during SHO mode. Figure 5.6 shows the comparison of SSDT and conventional TPC principles. In SSDT, an MS periodically chooses one of the active BSs having minimum path loss to the MS as a transmitting site and then the MS sends the identification of this BS to all the active ones so that the output power of the non minimum path loss BSs is reduced, as shown in Figure 5.6. Here the minimum path loss BS can be called as the “primary BS.”
Fast Site Selection

The intention of introducing SSDT is to cope with fast change of the primary BS due to fast fading. This feature of SSDT is discriminated from that of the hard handoff. In order to realize this, an MS must signal the site selection messages to the active BSs as frequently as possible. The required cycle of site selection mainly depends on a fading pitch, namely the speed of MS and the carrier frequency.

One solution of signaling the site selection is to insert the corresponding command in the higher layer signaling messages, example: Layer 2 or Layer 3 signaling messages in WCDMA used for controlling the system operations. Even though the higher layer signaling messages can be delivered with high accuracy, this signaling method cannot be actually used for SSDT because the time length of the message spans nearly 100 ms and thus the message is not relevant for the frequent site selection. In addition, the messages are delayed until reaching the active BSs because the message is in practice designed to reach the higher control station, example: BSC. So the use of a low layer signaling like a TPC signaling is promising for SSDT.

However, messages for the low layer signaling present a reception quality that is too poor to be acceptable in terms of reliable site selection especially when they are received at the BSs in an active set that do not have the minimum path loss on the reverse link. This is due to a feature of reverse link TPC during SHO; the BSs that do not have the minimum path loss in the reverse link are forced to accept poor reception because reverse link TPC works for the reverse link minimum path loss BS. This problem can be solved by adding some redundancy to the site selection messages. The redundancy in the site selection message as well as the frequent signaling of it increases the over head of the reverse link control signals. In other words, the site selection cycle is determined by the compromise of the redundancy and the limitation of the overhead.
**Detailed Operation of SSDT**

Although there are a number of channels defined in WCDMA, the focus is on the two major channels, i.e., common control channel and dedicated channel. The common control channel is a forward link channel by which the BS broadcasts system information and pilot signal. The dedicated channel is a channel dedicated to each radio link which connects an MS with a BS. Figure 5.7 shows the frame and slot structures of a reverse link dedicated channel. The slot length and the number of slots in one frame are 0.625 ms and 16 respectively and hence the time length of the frame is 10ms. The reverse link dedicated channel consists of data and control signals each of which is respectively transmitted as their phase and quadrature components of this channel.

In SSDT, each BS within an active set is assigned a temporary Identification Number (ID) and the BS with the minimum path loss to the connected MS is selected as a primary BS. An MS measures pilot reception level of the common control channel to detect the primary BS and then informs the primary BS ID to the entire active BSs within the same active set. The path capture required for the common control channel measurement shares one done in the typical path search for the traffic channel demodulation and therefore no extra circuit is needed for the purpose of primary BS selection.

An MS applying SSDT requires no assignment of RAKE fingers to the paths traveled from non primary BSs; however, these paths also have to be searched ordinarily in order to prepare for the quick change of primary BS. This is because the path searcher cannot quickly resolve the paths. In order to realize an effective RAKE receiver, the number of paths to be searched for a single active BS is greater than the number of RAKE fingers. Assume that the path searcher can capture all the paths given by the profile models to be used and all these paths are gathered in the measurement of pilot reception power. The BS selected as the primary station transmits its signal in the forward link dedicated channel with adequate power and the other BSs output power is forcefully held to a minimum level.
A BS manages two transmission power levels, i.e., a hidden power ($P_1$ [dBm]) and a real power ($P_2$ [dBm]). A BS maintaining minimum power can know how much power is adequate by referring to $P_1$ if the BS is chosen as the primary BS. A BS updates $P_1$ assuming that the BS is always primary whether or not it actually is. The forward link dedicated channels are actually transmitted with $P_2$ power. $P_1$ and $P_2$ are updated in accordance with a forward link TPC command send by the MS.

The forward link TPC command is produced such that if the reception quality of the forward link at an MS is lower than a predetermined threshold, then the MS produces “power-up” signal to make the active BSs increase their transmission power levels, if the quality is above the threshold the MS produces “power-down” signal to make the BSs decrease their transmission power levels. It should be noted that $P_{\text{min}}$ can be set to -$\infty$ [dBm] and thus the transmission of non primary BSs can be switched off. $P_1$ and $P_2$ are updated every TPC event. A BS initially deals with $P_1$ and then $P_2$, limiting both so as to ensure that they neither exceed the maximum level nor fall below the minimum level. Also note that if we
set $P_2$ equal to $P_1$ for non primary BSs, the power update map becomes identical to that used for conventional TPC.

In order to realize the fast and accurate site selection while taking into account the issues described in the previous sub section, a Code Word (CW) with a long bit length for expressing ID and FBI filed in the reverse link dedicated channel for delivering CW’s are used. If the number of CW bits is larger than the number of Feedback Indicator (FBI) bits per slot, CW is divided into a number of parts and then each part of CW is distributed to each FBI field of continuous slots. As a result, primary ID can be delivered every several slots depending on the length of CW and the number of FBI bits per slot.

This cycle of site selection is shorter than that obtained in case of employing the higher layer signaling. Before launching SSDT, or if the active set changes during operation, the ID of each active BS is assigned by the network and then the assignment result is informed to an MS and BSs in the same soft handoff situation. In order to detect a primary BS, the pilot reception levels of the common control channels in all active BSs are sensed. The BS with the highest level is chosen as the primary BS and then the primary ID CW is periodically transmitted by an MS to the active BSs. A BS recognizes its state as non primary if the following two conditions are satisfied simultaneously:

(i) The reception quality of reverse link exceeds a threshold level, $Q^{th}$.
(ii) A received ID does not match its own ID.

Condition (i) is used to ensure a reliable site selection so that all the active BSs do not reduce its output power simultaneously due to ID reception error.

*The Benefits of SSDT*

The benefits of introducing SSDT can be summarized as follows:
(i) Since one of the BSs within an active set provides adequate power to the connected MS and the output power of the other BSs within the same active set is reduced, the increase in interference can be avoided.

(ii) In conventional TPC, since multiple BSs transmit the same forward link signal with adequate power, a number of RAKE fingers must be equipped in order to collect many paths given by the active BSs. Since only one active BS serves the MS as a transmitting site in SSDT mode, the number of paths which should be collected by the RAKE receiver is smaller than that required for conventional TPC. This feature makes the path capturing efficiency of SSDT better than that of conventional TPC, given the same number of RAKE fingers.

(iii) The power imbalance problem due to TPC command reception error does not happen because only one BS transmits the forward link signal during SHO state.

5.4 SCENARIO MODELING AND CONNECTION PROBABILITIES

A cellular hexagonal layout has been considered where BS1 is the reference BS which is interfered by two tiers of BSs (18 BSs) is shown in Figure 5.8. The candidate BSs that are included in the active set are BS1, BS2 and BS3. Assume that a maximum of three BSs can be included in the active set. The results obtained for the selected area can be extended to the entire system area by using symmetry and rotation properties. To derive the average power transmitted from BS1 the area (triangular) is meshed using a grid of N points.

The signal received at the user terminal is affected by path loss and radio channel shadowing. In this thesis, only shadowing is taken into account since fast fading is compensated by averaging in the user terminal. This shadowing effect is modeled as a log-normal distribution. The probabilities of connecting the user
terminals to the three candidate BSs must be calculated for every location in the triangle. The possible connection events at an \( l \) location are as follows: a single BS in the active set (with probabilities \( P_{1,l}, P_{2,l} \) and \( P_{3,l} \) corresponding to BS\(_1\), BS\(_2\) and BS\(_3\) respectively), SHO with two BSs (\( P_{12,l}, P_{13,l} \) with BS\(_1\) being the best server, \( P_{21,l} \) and \( P_{23,l} \) with BS\(_2\) being the best server \( P_{31,l} \) and \( P_{32,l} \) with BS\(_3\) being the best server) and SHO with three BSs (\( P_{123,l}, P_{213,l}, P_{312,l} \)).

**Figure 5.8 Cellular Scenario**

To obtain these probabilities, the received power signals measured in the CPICH expressed in watts may be calculated from BS\(_1\), BS\(_2\) and BS\(_3\) for a \( l \) location in the area under study, assuming an Omni directional radiation diagram for both BS and MS antennas. The received power signals are given by

\[
P_{r,1,l} = \frac{\varepsilon \cdot p \cdot p}{d_{1,l}^\alpha} \cdot \frac{\eta_{1,l}}{10} \quad P_{r,2,l} = \frac{\varepsilon \cdot p \cdot p}{d_{2,l}^\alpha} \cdot \frac{\eta_{2,l}}{10} \quad P_{r,3,l} = \frac{\varepsilon \cdot p \cdot p}{d_{3,l}^\alpha} \cdot \frac{\eta_{3,l}}{10}
\]

(5.1)
where, $d_{j,l}$, $(j=1,2,3)$ is the distance from $BS_j$ to MS, $\alpha$ is the path loss exponent and $P_p$ is the CPICH power transmitted by BS in watt (which is assumed equal for every BS); the parameter $\eta_{j,l}$, $(j=1,2,3)$ is a Gaussian random variable with zero mean and standard deviation $\sigma$ (usually from 6 to 10 dB) [106]. This parameter represents the shadowing in the signal, as it propagates along the path from $BS_j$ to MS the parameter $\varepsilon_i$ is independent of $d_{j,l}$ and is given by

$$
\varepsilon_l = \frac{g_{t,l} \cdot g_r}{10^{\frac{L_{CL}}{10}} \cdot 10^{\frac{A_P}{10}}}
$$

(5.2)

The parameter $g_{t,l}$ is the BS antenna gain in the angle from BS to an $l$ location which is assumed to be equal for all BS for a given angle. The parameter $g_r$ is the MS antenna gain and $L_{CL}$ is the cable and connector losses in decibels. The parameter $A_P$ depends on the propagation model used (it includes the path loss term in decibels independent of the distance between the transmitter and the receiver).

Since the shadowing in the received signal depends on the MS environment, the variable $\eta_{i,l}$ and $\eta_{j,l}$, $(i, j=1,2,3, i \neq j)$ are correlated [107]. Therefore, a correlation coefficient between $\eta_{i,l}$ and $\eta_{j,l}$, $\rho$, defined as

$$
\rho = \frac{\text{cov}(\eta_{i,l}, \eta_{j,l})}{\sigma_i^2} \quad i,j=1,2,3, \quad i \neq j
$$

(5.3)

where, $\text{cov}(\eta_{i,l}, \eta_{j,l})$ denotes the covariance between $\eta_{i,l}$ and $\eta_{j,l}$. From equation (5.1), the best server $BS_j$ can be derived at an $l$ position as

$$
P_{r_{j,l}} = \max (P_{r_{1,l}}, P_{r_{2,l}}, P_{r_{3,l}})
$$

(5.4)
where $P_{r_{i,l}}$ ($i=1, 2, 3$) represent the received powers, which are expressed in logarithmic units. Therefore, the minimum received power signal required at an $l$ location to include a new BS in the active set is given by

$$P_{r_{\text{min},l}} = P_{r_{j,l}} M_{SH} \quad (5.5)$$

Signals arriving from BS$_i$ ($i=1, 2, 3$) at an $l$ position whose power is higher than $P_{r_{\text{min},l}}$ are included in the active set of the user terminal, where $M_{SH}$ is expressed in dB. Thus, the connection probabilities for the $l$ position in the triangle can be expressed as

$$(P_{1,l}) = \text{Prob}(P_{r_{1,l}} - P_{r_{2,l}} > M_{SH}, P_{r_{2,l}} - P_{r_{3,l}} \geq 0) + \text{Prob}(P_{r_{1,l}} - P_{r_{3,l}} > M_{SH}, P_{r_{3,l}} - P_{r_{2,l}} > 0) \quad (5.6)$$

$$(P_{2,l}) = \text{Prob}(P_{r_{2,l}} - P_{r_{1,l}} > M_{SH}, P_{r_{1,l}} - P_{r_{3,l}} \geq 0) + \text{Prob}(P_{r_{2,l}} - P_{r_{3,l}} > M_{SH}, P_{r_{3,l}} - P_{r_{1,l}} > 0) \quad (5.7)$$

$$(P_{3,l}) = \text{Prob}(P_{r_{3,l}} - P_{r_{1,l}} > M_{SH}, P_{r_{1,l}} - P_{r_{2,l}} \geq 0) + \text{Prob}(P_{r_{3,l}} - P_{r_{2,l}} > M_{SH}, P_{r_{2,l}} - P_{r_{1,l}} > 0) \quad (5.8)$$

$$(P_{12,l}) = \text{Prob}(0 \leq P_{r_{1,k}} - P_{r_{2,k}} < M_{SH}, P_{r_{1,k}} - P_{r_{3,k}} > M_{SH}) \quad (5.9)$$

$$(P_{21,l}) = \text{Prob}(0 \leq P_{r_{2,l}} - P_{r_{1,l}} < M_{SH}, P_{r_{2,l}} - P_{r_{3,l}} > M_{SH}) \quad (5.10)$$

$$(P_{13,l}) = \text{Prob}(0 \leq P_{r_{1,l}} - P_{r_{3,l}} < M_{SH}, P_{r_{1,l}} - P_{r_{2,l}} > M_{SH}) \quad (5.11)$$

$$(P_{31,l}) = \text{Prob}(0 < P_{r_{3,l}} - P_{r_{1,l}} < M_{SH}, P_{r_{3,l}} - P_{r_{2,l}} > M_{SH}) \quad (5.12)$$

$$(P_{23,l}) = \text{Prob}(0 < P_{r_{2,l}} - P_{r_{3,l}} < M_{SH}, P_{r_{2,l}} - P_{r_{1,l}} > M_{SH}) \quad (5.13)$$
\[(P_{32,l}) = \text{Prob} \left( 0 < P_{r_{3,l}} - P_{r_{2,l}} < M_{SH}, P_{r_{3,l}} - P_{r_{1,l}} > M_{SH} \right) \quad (5.14)\]

\[(P_{123,l}) = \text{Prob} \left( 0 \leq P_{r_{1,l}} - P_{r_{2,l}} < M_{SH}, 0 \leq P_{r_{1,l}} - P_{r_{3,l}} < M_{SH} \right) \quad (5.15)\]

\[(P_{213,l}) = \text{Prob} \left( 0 < P_{r_{2,l}} - P_{r_{1,l}} < M_{SH}, 0 \leq P_{r_{2,l}} - P_{r_{3,l}} < M_{SH} \right) \quad (5.16)\]

\[(P_{312,l}) = \text{Prob} \left( 0 < P_{r_{3,l}} - P_{r_{1,l}} < M_{SH}, 0 < P_{r_{3,l}} - P_{r_{2,l}} < M_{SH} \right) \quad (5.17)\]

The events involved in these probabilities are not independent since the received power signal variables are implicated simultaneously in several events and the received power signal variables have certain correlations, where \(\text{Prob}(.)\) denotes probability. Since \(P_{r_{1,l}}, P_{r_{2,l}}\), and \(P_{r_{3,l}}\) are assumed to be Gaussian distributed, the subtraction of two of them follows a Gaussian distribution \([108]\) whose standard deviation is given by

\[\sigma_{eq} = \sigma \sqrt{2(1-\rho)} \quad (5.18)\]

Using the bivariate normal distribution, the probabilities defined in equations (5.6)-(5.17) can be calculated. These probabilities values decrease as \(M_{SH}\) increases and the SHO areas increase as \(M_{SH}\) increases. It is to be noted that the sum of all the probabilities in every location of the triangle is equal to 1. The single BS connection probabilities \(P_{1,l}, P_{2,l}\) and \(P_{3,l}\) are symmetrically circular around the corresponding BS. Their value ranges from 1 (at the BS position) to 0 (at a certain distance from the BS position). Thus, the areas and values of the connection probabilities depend strongly on the \(M_{SH}\) parameter value. If \(M_{SH}\) is 0 dB, the percentage of users in handoff is zero. The percentage of users in the cell connected to one \(N_1\), two \(N_2\) or three \(N_3\) BSs simultaneously, given by
As SIR power control to be simulated, interference modeling is required. For the proposed scenario, the SIR value at each MS position in the area is calculated and fixed to its target value by modifying the corresponding DPCCH-BS transmitted power. The interferences in the cellular system can be divided into two types [109], namely 1) intra-cell (\(I_{\text{intra}}\)) and 2) inter-cell (\(I_{\text{inter}}\)). Both kinds of interference can be used to obtain the \(E_b/N_o\) relationship to derive the required transmission power to satisfy the quality requirements. Let \(\gamma_{i,l}\) be the \(E_b/N_o\) measured in the MS at an \(l\) location from \(BS_i\) \((i=1, 2, 3)\) given by

\[
\gamma_{i,l} = G_p \frac{C_{i,l}}{I_{\text{inter},i,l} + I_{\text{intra},i,l} + N_o}
\]

\[
= G_p \left( \frac{I_{\text{inter},i,l}}{C_{i,l}} + \frac{I_{\text{intra},i,l}}{C_{i,l}} + \frac{N_o}{C_{i,l}} \right)^{-1}
\]

\[
\sum_{l=1}^{N} \frac{P_{1,l}}{\sum_{l=1}^{N} \left( P_{1,l} + P_{12,l} + P_{13,l} + P_{123,l} \right)}
\]

\[
N_1 = \frac{\sum_{l=1}^{N} P_{1,l}}{\sum_{l=1}^{N} \left( P_{1,l} + P_{12,l} + P_{13,l} + P_{123,l} \right)}
\]

\[
N_2 = \frac{\sum_{l=1}^{N} \left( P_{12,l} + P_{13,l} \right)}{\sum_{l=1}^{N} \left( P_{1,l} + P_{12,l} + P_{13,l} + P_{123,l} \right)}
\]

\[
N_3 = \frac{\sum_{l=1}^{N} P_{123,l}}{\sum_{l=1}^{N} \left( P_{1,l} + P_{12,l} + P_{13,l} + P_{123,l} \right)}
\]
The parameter $N_0$ is the receiver thermal noise power given by

$$N_0 = 10 \log \left( kTB_W \right) + F$$  \hspace{1cm} (5.23)$$

where, $k$ is Boltzmann’s constant $(1.38 \cdot 10^{-23} \text{ J/K})$, $T$ is the noise temperature of the antenna (290 K), $B_W$ is the MS band width, $F$ is the noise figure of the receiver and $C_{i,l}$ is the power signal received from BS$_i$($i=1,2,3$) by the MS at an $l$ location for a given service is given by

$$C_{i,l} = p_{i,l} e^{-10^{-\alpha} d_{i,l}^{10} / 10}$$  \hspace{1cm} (5.24)$$

The parameter $p_{i,l}$ is the power transmitted by BS$_i$ to the $l$ location study in the DPCCH and $G_P$ is the process gain defined as

$$G_P = \frac{W}{R}$$  \hspace{1cm} (5.25)$$

where, $W$ is the spread signal chip rate expressed in chips per second and $R$ is the bearer signal bit rate in bits per second which depends on the service bit rate. If expectations are considered in the second term of, as this term is a convex function, Jensen’s inequality can be written for convex functions as

$$\bar{\gamma}_{i,l} \geq G_P \left( E \left[ \frac{I_{\text{inter},i,l}}{C_{i,l}} \right] + E \left[ \frac{I_{\text{intra},i,l}}{C_{i,l}} \right] + E \left[ \frac{N_0}{C_{i,l}} \right] \right)^{-1}$$  \hspace{1cm} (5.26)$$

where, $E [\cdot]$ denotes expectation. In order to satisfy quality requirements, equation (5.26) must satisfy the following condition at an $l$ position:
\[
\gamma_{i,l} \geq \frac{E_b}{N_o}_{\text{req}} \tag{5.27}
\]

where, \( \frac{E_b}{N_o}_{\text{req}} \) is the threshold energy-per-bit to noise power spectral density ratio in linear units for each service.

**Intra-cell Interference**

The intra-cell interference received at a certain \( l \) position of MS is produced by the power transmitted to other users in the same BS. Assuming identical total transmitted power for all BS, the total power transmitted by each BS\(_i\) \((i=1,2,3)\) is given by

\[
p_t = p_p + \sum_{l=1}^{N} p_{i,l} \quad i=1,2,3 \tag{5.28}
\]

For a certain user at an \( l \) location, all the power transmitted by the BS\(_i\) is considered as interfering except for \( p_{i,l} \), which is the required power transmitted by BS\(_i\) to satisfy the \( E_b/N_o \) target for this user. The interference power received by MS at an \( l \) location from its own BS\(_i\) can be written as

\[
I_{\text{intra}_{i,l}} = \left[ p_p + a\delta \sum_{j=1}^{N} p_{i,j} \right] e_l d_{i,l}^{-\alpha} 10^{-\frac{\eta_{i,l}}{10}}
\]

\[
= \left( p_p + a\delta \left( p_t - p_p - p_{i,l} \right) \right) e_l d_{i,l}^{-\alpha} 10^{-\frac{\eta_{i,l}}{10}} \tag{5.29}
\]

where, ‘\( a \)’ is the orthogonality factor among spreading codes (considered 0.5 due to the multipath effect) [29] and \( \delta \) is the activity factor.
From equations (5.22) and (5.29),

\[
\frac{I_{\text{intra}_{i,l}}}{C_{i,l}} = a \left( \frac{p_p + \delta (p_t - p_p - p_{i,l})}{p_{i,l}} \right)
\]

\[
= a \delta \left( \frac{p_p}{\delta p_{i,l}} + \frac{(p_t - p_p)}{p_{i,l}} - 1 \right)
\]

(5.30)

**Inter-cell Interference**

Inter-cell interferences are those produced by transmissions from BSs that are not the BS that the MS is connected. In order to calculate these interferences, assume two different situations, namely (1) the MS is connected to a single BS, i.e., it is not in SHO (without macro diversity), or (2) the MS is connected to two or three BSs simultaneously, i.e., it is in SHO (with macro diversity).

First, the interferences without macro diversity are calculated. Since the user equipment is connected to only one BS (its best server), the signals received from other BSs are interferences. In this thesis, it is assumed that the 18 interfering BSs are transmitting the same power \( p_t \). The inter-cell interference power received by an MS at an \( l \) position whose best server is BS\( i \) is given by

\[
I_{\text{inter}_{i,l}} = \delta \epsilon_i \sum_{j=2, j\neq i}^{19} p_t q^{-\alpha_j} 10^{-\eta_j l/10}
\]

(5.31)

To take this condition into account, mathematical expectations are used. These expectations can be stated as the integral of the probability density function of the log-normal Gaussian random variable. Using the function \( Q \), this integral can be
evaluated. The minimum value for the transmitted power $p_{1,l}$ from BS$_1$ to the user at the location by assuming $p_{1,l} = p_{2,l} = p_{3,l}$ for simplicity can be obtained. The weighted average transmitted power in DPCCH over $N$ points of the triangle can be derived as

$$\frac{1}{p_1} = \frac{\sum_{l=1}^{N} \left( P_{1,l} + P_{12,l} + P_{13,l} + P_{123,l} \right) p_{1,l}}{\sum_{l=1}^{N} \left( P_{1,l} + P_{12,l} + P_{13,l} + P_{123,l} \right)}$$

(5.32)

In order to satisfy the quality requirements in the overall area, the available power at BS$_1$ ($p_t$) must be distributed among the users of the area under study whose best server is BS$_1$. The average number of users that require power from BS$_1$ yields the number of transmitted codes, i.e., the cell capacity, $\eta_{\text{trx}}$ given by

$$\eta_{\text{trx}} = \frac{p_t}{p_1}$$

(5.33)

If several users are connected to more than one BS, the number of required codes $\eta_{\text{req}}$ can be obtained as

$$\eta_{\text{req}} = \eta_{\text{trx}} \left( 1 - N_2 - N_3 \right) + 2\eta_{\text{trx}} N_2 + 3\eta_{\text{trx}} N_3.$$  

(5.34)

The average number of users that require power from BS1 yields the number of transmitted codes $\eta_{\text{trx}}$, i.e., cell capacity, By taking into account several users are connected to more than one BS, then the codes required $\eta_{\text{req}}$ to meet the situation are number of required codes are analyzed.
5.5 RESULTS AND DISCUSSION

The system capacity and required resources dependency on $M_{SH}$ for voice service and combined multimedia mobile services (profile: 80% voice users, 15% 144 Kbits/s data users and 5% 384 Kbits/s data users) are analyzed. System capacity dependency on $M_{SH}$ is analyzed by considering two types of user distributions, namely 1) uniform user distribution and 2) a concentration of all the users in the location that requires maximum transmitted power (the worst case). The system capacity dependency on $M_{SH}$ is analyzed for different cell radii and for different path loss exponents. The parameter values used in the simulations are shown in Table 5.1.

Table 5.1 Simulation parameters for SSDT power control

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spread signal chip rate</td>
<td>3.84 Mchips</td>
</tr>
<tr>
<td>Speech bit rate</td>
<td>12200 b/s</td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>0.5</td>
</tr>
<tr>
<td>Path loss</td>
<td>$Lt(dB) = A + 10\alpha \log d_{j,i}$</td>
</tr>
<tr>
<td>Antenna cable loss</td>
<td>6 dB</td>
</tr>
<tr>
<td>Orthogonality factor</td>
<td>0.5</td>
</tr>
<tr>
<td>Activity factor (for speech users)</td>
<td>0.5</td>
</tr>
<tr>
<td>Threshold energy per bit to noise</td>
<td>6.4 dB</td>
</tr>
<tr>
<td>spectral density (for speech users)</td>
<td></td>
</tr>
<tr>
<td>Shadowing standard deviation</td>
<td>8 dB</td>
</tr>
<tr>
<td>Total transmitted power</td>
<td>20w</td>
</tr>
<tr>
<td>Transmitted power in pilot channel</td>
<td>2w</td>
</tr>
<tr>
<td>Noise equivalent band width</td>
<td>5 MHz</td>
</tr>
<tr>
<td>Noise figure of receiver</td>
<td>5 dB</td>
</tr>
<tr>
<td>Cell radius</td>
<td>400m</td>
</tr>
<tr>
<td>Distribution of users</td>
<td>Uniform</td>
</tr>
</tbody>
</table>

The required and transmitted codes (number of users) by $BS_i$ versus $M_{SH}$ (in decibels) for a uniform distribution of users for voice service ($R=12.2$ Kbits/s), $W=3.84$ Mchips/s, $\sigma=8$ dB, $\alpha=3.5$, $\rho=0.5$ and the cell radius of 400m is analyzed.
The average number of users that require power from $BS_i$ yields the number of transmitted codes $\eta_{trx}$, i.e., cell capacity. The number of transmitted codes (number of users) required, increases up to 5.5 dB of $M_{SH}$ and further increase in $M_{SH}$ decreases the number of transmitted codes. The transmitted code is nearly maximum at 87 for $M_{SH}$ value of 5.5 dB.

![Graph showing transmitted and required codes as a function of $M_{SH}$](image)

**Figure 5.9** Transmitted and required codes as a function of $M_{SH}$

By taking into account that several users are connected to more than one BS, the number of codes required will be more. The number of required codes increases with a high rate up to 11 dB of $M_{SH}$. At 5.5 dB of $M_{SH}$, the required codes is nearly 117. Figure 5.9 represents the required and transmitted codes (number of users) versus $M_{SH}$ (in decibels) for a uniform distribution of users for voice service. From this situation, the optimum $M_{SH}$ is achieved at 5.5 dB and the capacity gain is 19.3%, while increase in required resource is 56.67%.
The required and transmitted codes (number of users) versus $M_{SH}$ (in decibels) for a uniform distribution of users for combined multimedia mobile services with the following profile: 80% voice users, 15% 144 Kbits/s data users and 5% 384 Kbits/s data users, $W=3.84$ Mchips/s, $\sigma=8$ dB, $\alpha=3.5$, $\rho=0.5$ and the cell radius of 400m is analyzed.

![Graph](image)

**Figure 5.10** Combined multimedia services

The system capacity and required resources for a uniform distribution of users for combined multimedia mobile services corresponding with $M_{SH}$ is shown in Figure 5.10. The increase percentage of the capacity and required resources for combined multimedia mobile services are similar to voice service. For voice service, the optimum $M_{SH}$ achieved is 5.5 dB and the capacity gain is 19.3%, while the required resource is increased by 56.67%. For combined multimedia mobile services, the optimum $M_{SH}$ was around 5.5 dB, the capacity was increased by 18.88% and the number of resources for $M_{SH}=$5.5 dB increased by 54.44%. Thus the optimum $M_{SH}$ and the increase of capacity are not affected substantially by the combination of services.
Figure 5.11 represents the system capacity dependency on $M_{SH}$ for different cell radii and it is observed that the optimum $M_{SH}$ is around 5.5 dB. The cell radius is varied from 300 to 600m and observed that higher the radius lower the system capacity.

![Figure 5.11 System capacity for different cell radii](image)

Figure 5.12 represents the system capacity dependency on $M_{SH}$ for different path loss exponents and it is observed that the optimum $M_{SH}$ is around 5.5 dB. The path loss exponent $\alpha$ is varied from 3 to 3.75, it is found that the system capacity is improved when $\alpha$ is increased.
Figure 5.12 System capacity for different path loss exponents

The system capacity depends on $M_{SH}$ is analyzed for different cell radii and different path loss exponents and it is observed that the optimum $M_{SH}$ is around 5.5 dB.

5.6 CONCLUSION

The system capacity and required resources by $BS_i$ versus $M_{SH}$ (in decibels) with uniform distribution of users for voice service ($R=12.2$ Kbits/s) and for combined multimedia mobile services (profile: 80% voice users, 15% 144 Kbits/s data users and 5% 384 Kbits/s data users) are analyzed. For voice service, the optimum $M_{SH}$ achieved is 5.5 dB and the capacity gain is 19.3%, while the required resources increase is 56.67%. For combined multimedia mobile services, the optimum $M_{SH}$ was around 5.5 dB, the capacity was increased by 18.88% and the number of resources for $M_{SH} = 5.5$ dB increased by 54.44%. The increased percentages of the capacity and required resources are similar to voice service. Thus, the optimum $M_{SH}$
and the increase of capacity are not affected substantially by the combination of services.

The system capacity based on $M_{SH}$ is analyzed and simulated for different cell radii and different path loss exponents; found that the optimum $M_{SH}$ is around 5.5 dB. The cell radius is varied from 300 to 600m; observed that higher the radius is, lower the system capacity. The path loss exponent is varied from 3 to 3.75, observed that the system capacity is improved when $\alpha$ is increased.