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Power Control in Wideband Cellular CDMA Systems

by

Christine Q. Cai, M. Eng.

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of

Master of Engineering

Ottawa-Carleton Institute for Electrical and Computer Engineering

Faculty of Engineering

Department of System and Computer Engineering

Carleton University

October, 1998

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the Faculty of Graduate Studies
acceptance of the thesis

**Power Control in Wideband
Cellular CDMA Systems**

submitted by **Christine Q. Cai, M. Eng.**
in partial fulfillment of the requirements for
the degree of Master of Engineering

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Abstract

The third generation (3G) wireless systems will support varieties of voice and non-voice applications. Modeling of such heterogeneous networks is a very active research area. In the wireless environment, there are two competing multiple access methods: TDMA and CDMA. Each scheme has its unique problems in handling multimedia traffic. In this project, we investigate, by means of modeling and computer simulations, some problems associated with CDMA multimedia access. In particular, power control being one of the most critical issues in CDMA network is a major focus of this project. While power control has been studied in voice only wireless networks, the introduction of burst transmission modes with long silence gaps and variable bit rate requirements will change the nature of the problem.

The main thrust of the research is to develop appropriate models for power control in 3G wideband CDMA systems. The particular issues addressed in this project are power allocation among different types of services, power control algorithm for the packet data services, and interference distribution in such systems. The proposed models have been tested by means of computer simulations. The simulated wideband CDMA system is based on the proposed 3G CDMA system. A test bed has been built upon an existing IS-95 based simulator.

The simulation results demonstrate that the relationship between power allocation plan and QoS is non-linear in wideband CDMA system, and interference distribution in such a system is no longer Gaussian distributed. For the high rate data services, by employing a low transmission rate dedicated control channel, the implementation of power control of high rate supplemental channel can be simplified and more efficient. Power allocation plans should make all QoS to be only marginally kept above required thresholds when system capacity is reached.

Acknowledgments

I would like to express my deepest gratitude to my supervisor Professor Roshdy H. M. Hafez, for all his great guidance and kindly encouragement during the course of my graduate studies and the course of my thesis.

I am very much thankful to my co-supervisor Dr. Ning Guo for his guidance and support during my thesis project work.

I would like to thank Dr. Wei Huang for his helpful discussions and recommendations.

I would also like to thank Nortel, TRIO, and Carleton University for the financial support during this research.

Table of Contents

ABSTRACT	iii
ACKNOWLEDGMENT	iv
TABLE OF CONTENTS	v
LIST OF FIGURES	vii
LIST OF TABLES.....	viii
LIST OF ACRONYMS	ix
CHAPTER 1 INTRODUCTION	1
1.1 THESIS OBJECTIVES.....	1
1.2 THESIS ORGANIZATION	2
CHAPTER 2 CDMA CELLULAR SYSTEM AND POWER CONTROL	3
2.1 CELLULAR SYSTEMS AND FREQUENCY REUSE FACTOR.....	3
2.2 SPREAD SPECTRUM MULTIPLE ACCESS AND CDMA SYSTEMS.....	3
2.3 MOBILE RADIO CHANNEL	5
2.4 POWER CONTROL AND SYSTEM CAPACITY	7
2.5 SINGLE SERVICE CDMA SYSTEM AND WIDEBAND CDMA SYSTEM.....	10
2.5.1 <i>IS-95 in North America</i>	10
2.5.2 <i>Requirements of the 3G mobile system</i>	11
CHAPTER 3 POWER CONTROL IN SINGLE SERVICE CDMA SYSTEM	13
3.1 FORWARD LINK AND REVERSE LINK POWER CONTROL	13
3.1.1 <i>Forward link power control and system capacity</i>	13
3.1.2 <i>Reverse Link Power Control</i>	16
3.2 POWER CONTROL IMPERFECTION AND SYSTEM CAPACITY.....	19
3.3 POWER CONTROL IN IS-95.....	21
CHAPTER 4 POWER CONTROL IN MULTIMEDIA CDMA NETWORK	22
4.1 APPROACHES TO INCREASE SYSTEM CAPACITY.....	23
4.2 POWER CONTROL FOR PACKET DATA SERVICES.....	24
4.2.1 <i>Power Control Imperfection effect on Packet Data Service</i>	24
4.2.2 <i>Retransmission and graceful performance degradation</i>	25
4.3 POWER ALLOCATION IN MULTIMEDIA CDMA NETWORK	25
4.3.1 <i>Fixed power allocation schemes</i>	27
4.3.2 <i>Adaptive power allocation schemes</i>	28
4.4 ADMISSION POLICY.....	29
4.5 PROPOSED POWER CONTROL AND POWER ALLOCATION SCHEMES.....	32
CHAPTER 5 SYSTEM MODELING AND SIMULATOR STRUCTURE	33
5.1 SYSTEM CONFIGURATION AND ASSUMPTIONS.....	33
5.1.1 <i>Services</i>	33
5.1.2 <i>Simulation Plane</i>	34
5.1.3 <i>System Configuration</i>	35
5.1.4 <i>System Bandwidth and Channelization</i>	35
5.1.5 <i>Assumptions</i>	37
5.2 MULTIPLE ACCESS CONTROL	37

5.3	PROPAGATION MODEL	41
5.3.1	<i>Calculation of E_b/I_o, E_c/I_o</i>	42
5.4	TRAFFIC GENERATOR MODEL.....	44
5.4.1	<i>Voice Traffic and Stream Data Traffic.....</i>	44
5.4.2	<i>Burst Data Traffic.....</i>	45
5.5	POWER ALLOCATION AND POWER CONTROL IMPLEMENTATION.....	46
5.5.1	<i>Fundamental Channel Power Control.....</i>	46
5.5.2	<i>Supplemental Channel Power Control.....</i>	48
5.6	HANDOFF.....	49
5.7	HIGHLIGHTS OF SYSTEM MODEL.....	49
5.8	SIMULATOR STRUCTURE AND FLOW CHART.....	50
CHAPTER 6 SIMULATION RESULTS		53
6.1	SIMULATION SCOPE.....	53
6.2	SYSTEM STABILITY.....	54
6.3	INTERFERENCE.....	56
6.4	FREQUENCY REUSE FACTOR.....	62
CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS		64
7.1	CONCLUSIONS	64
7.2	SUMMARY OF CONTRIBUTIONS	66
7.3	FUTURE WORK.....	67
REFERENCE		68

List of Figures

FIGURE 1 TYPES OF MULTI-PATH FADING.....	6
FIGURE 2 FORWARD LINK INTERFERENCE	14
FIGURE 3 REVERSE LINK INTERFERENCE.....	16
FIGURE 4 BLOCK DIAGRAM OF THE REVERSE LINK CLOSED LOOP POWER CONTROL MECHANISMS.....	18
FIGURE 5 TYPES OF POWER CONTROL SCHEMES.....	26
FIGURE 6 ADAPTIVE ADMISSION CONTROL.....	30
FIGURE 7 SIMULATION PLANE	34
FIGURE 8 SYSTEM CONFIGURATION.....	35
FIGURE 9 SHARED MODE OPERATION	38
FIGURE 10 RL RANDOM ACCESS	39
FIGURE 11 STATE DIAGRAM OF A PACKET DATA MS.....	40
FIGURE 12 UMTS BURST DATA SESSION MODEL	45
FIGURE 13 SIMULATOR MODULE ARCHITECTURE.....	51
FIGURE 14 W_CNS SIMULATOR FLOW CHART.....	52
FIGURE 15 NUMBERS OF STREAM DATA & VOICE USERS IN SYSTEM.....	55
FIGURE 16 FL INTERFERENCE DISTRIBUTION WHEN ONLY STREAM DATA TRAFFIC PRESENTS.....	58
FIGURE 17 RL INTERFERENCE DISTRIBUTION.....	60
FIGURE 18 INTERFERENCE DISTRIBUTION WHEN ONLY BURST DATA TRAFFIC PRESENTS.....	61
FIGURE 19 FL & RL TRAFFIC CHANNEL FRF DISTRIBUTION	63

List of Tables

TABLE 1 PATH LOSS EXPONENTS FOR DIFFERENT ENVIRONMENTS	5
TABLE 2 FORWARD LINK CAPACITY FOR AN OUTAGE PROBABILITY OF 0.01 IN THE PRESENCE OF SHADOWING	14
TABLE 3 MAXIMUM NUMBER OF USERS PER CELL (N) WITH AND WITHOUT FORWARD POWER CONTROL	15
TABLE 4 LAYERED AIR INTERFACE STRUCTURE AND APPROACHES TO INCREASE SYSTEM CAPACITY	23
TABLE 5: CHANNELIZATION IN A CELL	36
TABLE 6: SYSTEM OVERVIEW	50
TABLE 7 SIMULATION SCOPE	53
TABLE 8: SIMULATION CASE PARAMETERS	54
TABLE 9 AVERAGE NUMBER OF USERS IN SYSTEM AND THEIR STANDARD DEVIATION	55

List of Acronyms

3G	The 3 rd Generation
AMPS	Advanced Mobile Phone Service
ARQ	Automatic Retransmission Request
BER	Bit Error Rate
BS	Base Station
BSC	Base Station Controller
CDF	Cumulative probability distribution function
CDMA	Code Division Multiple Access
CH	Channel
CIR	Carrier to Interference Ratio
DCCH	Dedicated Control Channel
DM	Delta Modulation
DS-CDMA	Direct Sequence Code Division Multiple Access
EEP	Equal Error Probability
ESS	Equal Signal Strength
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FER	Frame Error Rate
FL	Forward Link
FWPC	Future Wireless Personal Communication
MS	Mobile Station
MSC	Mobile Switch Center
RL	Reverse Link
PCM	Pulse Code Modulation
PCS	Personal Communication System
PN	Pseudo-noise
QoS	Quality of Service

RLP	Radio Link Protocol
SIR	Signal to Noise Ratio
SSMA	Spread Spectrum Multiple Access
TDMA	Time Division Multiple Access
W-CNS	Wideband CDMA Network Simulator

Chapter 1 Introduction

1.1 Thesis Objectives

Using pocket-sized units, future wireless personal communication (FWPC) systems will provide communication services to any person in any place at any time without excessive delay. Such a system should achieve this goal at minimum cost with acceptable quality and security by using a personal telecommunication reference number [1]. Future third generation (3G) systems are expected to support several traffic types with different source characteristics (information rates, activity factor, and burstiness), various Quality of Service (QoS) and latency requirement through the same bandwidth simultaneously. The issues in system architecture and bandwidth management and methods for efficient integration of wireless multi-media traffic are important research topics.

Code Division Multiple Access (CDMA) is being proposed as one of the multiple access techniques for future personal communication systems. This technology is very attractive because it utilizes low power spectral density. Other desirable properties of CDMA include jamming protection, multipath mitigation, privacy, soft handoff, high system capacity by exploiting voice activity, and flexibility in accommodating multi-media traffic. All these advantages make CDMA the most attractive candidate.

Power control and power allocation are essential to the operation of multi-media CDMA systems. Power control is the mechanism that aims to keep the power of all received signals at preferred level, while power allocation determines what is the “preferred level” for each service. It is well known, that for single service (voice) CDMA systems, power control plays a critical role in increasing the system capacity and overcoming the near-far problem as well as minimizing the co-channel interference. For multi-media CDMA systems, the natural dissimilarities of services scenario introduces new challenges in

power control algorithm and power allocation plan. Proper power assignment can control mutual interference among different media and keep QoS of all services satisfied.

The main objective of this thesis is to study power control algorithms and power allocation plans for multi-media cellular CDMA systems through simulation. The mutual interference statistics in such a system will be discussed based on simulation results.

1.2 Thesis Organization

The thesis is organized as follows. Chapter 2 provides a brief introduction to CDMA system and the power control problem. Chapter 3 presents an overview of both forward link and reverse link power control algorithms and factors that degrade the perfection of power control in single service CDMA systems. Chapter 4 discusses power control algorithms for packet data services and power allocation plans in wideband CDMA systems, and addresses closely related issues on admission policy. Chapter 5 presents simulation details including system modeling and assumptions, and simulator structure. Chapter 6 presents simulation results. Finally, Chapter 7 concludes with a discussion and recommendations for future research.

Chapter 2 CDMA Cellular System and Power Control

In this Chapter, we review some useful background information, concepts and terminology. This will be helpful in the explanation of the subsequent chapters.

2.1 Cellular Systems and Frequency Reuse Factor

The cellular concept is a major breakthrough in solving the problem of spectral congestion. It increases system capacity by providing the possibility of frequency reuse. A cellular system uses many low power base stations. Each station covers only a small portion of the service area, and is allocated a portion of the total number of channels available to the entire system. And adjacent base stations are assigned different groups of channels so that all the available channels are assigned to a relatively small number of neighboring base stations. By limiting the coverage area to within the boundaries of a cell, the same group of channels may be used in the different cells that are separated from one another by distances large enough to keep the interference level within tolerable limit. Therefore it's possible to provide additional radio capacity with no additional increase in radio spectrum, only through proper frequency reusing. The *Frequency reuse factor* is defined as the ratio of number of channels in the group over the number of total available channels in the system.

2.2 Spread Spectrum Multiple Access and CDMA Systems

Spread Spectrum Multiple Access (SSMA) technology uses signals whose transmission bandwidth is several order of magnitudes greater than the minimum required RF bandwidth. A pseudo-noise (PN) sequence converts a narrow band signal to a wideband noise-like signal before transmission, thus SSMA provides immunity against multi-path interference while providing robust multiple access capacity. Since many users can share the same spread spectrum bandwidth simultaneously, spread spectrum systems become

bandwidth efficient in a multiple user environment [1]. Frequency reuse factor can be maximized and the frequency reuse plan can be simplified.

Direct Sequence Code Division Multiple Access (DS-CDMA) is the most important member of the SSMA family. In CDMA systems, a narrow band message signal is multiplied by a very large bandwidth signal called spreading signal. A spreading signal is a pseudo-noise code sequence that has a chip rate that is several orders of magnitudes greater than the data rate of the message. All users in a DS-CDMA system use the same carrier frequency and may transmit simultaneously. Each user has its own pseudo-random code word, which is approximately orthogonal to all other code words. The receiver performs a time correlation operation to detect only the specific desired code word. All other code words appear as noise due to de-correlation. Since all users transmit the messages by using the same bandwidth at the same time and therefore users interfere with each other.

The system processing gain is defined as:

$$G = \frac{W_s}{W_d} = \frac{T_d}{T_s} \quad (1)$$

Where W_s is the bandwidth of spread spectrum signal and W_d is the bandwidth of the signal before spreading. T_d and T_s are the time duration of data bit and spread chip respectively.

The system capacity, defined as the maximum number of Mobile Stations (MSs) that can be supported in a cell, is given by:

$$N \approx \frac{W_s/W_d}{(E_b/N_0)_{req}} \alpha F \quad (2)$$

where α and F are voice activity factor and frequency reuse factor respectively.

$(E_b/N_0)_{req}$ is the required signal to noise ratio.

The main reason for choosing CDMA is that it can provide a higher system capacity for a given amount of spectrum due to universal frequency reuse, along with some other features considered advantageous over the traditional FDMA and TDMA. Those features are: multi-path mitigation capability, voice activity detection, soft capacity and soft handoff. However, CDMA needs tight power control.

2.3 Mobile Radio Channel

The characteristics of a mobile radio channel directly affects the fluctuation of the received signal. Each transmitted signal between MS and BS through a radio channel experiences path loss, multi-path fading and shadowing.

Path loss is determined by the distance d between the MS and the BS and the propagation environment, which is proportional to $d^{-\eta}$, where η is a propagation exponent depending on the environment. Table 1 shows path loss exponents η for different environment [2].

Table 1 Path loss exponents for different environments

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

Log-normal shadowing is due to the blockage of buildings and other objects. It causes the path loss of the measured signal to have a normal distribution in dB with zero mean and standard deviation σ which is usually assumed to be 8 dB [3].

Multi-path fading [2] is caused by the interference between two or more versions of a transmitted signal which arrives at a receiver at slightly different times. The factors in the radio propagation channel which influence multi-path fading are multi-path propagation, speed of the mobile, speed of surrounding objects and the transmission bandwidth of the signal. Depending on the relation between the signal parameters (such as bandwidth, symbol period, etc.) and channel parameters (such as rms delay spread and Doppler spread), different transmitted signals will undergo different types of fading. Figure 1 shows types of multi-path fading. They are flat fading, slow fading, frequency selective fading and fast fading.

Figure 1 Types of Multi-path Fading

Among these four types of fading, flat fading is the most common type of fading described in the technical literature. In mobile radio channels, the Rayleigh distribution is commonly used to describe the statistical time varying nature of the received envelope of a flat fading signal. The phase of a flat fading signal is uniformly distributed random variable over $[0, 2\pi]$.

When all these three factors are taken into account , the relationship between received power P_r and the transmitted power P_t is given by

$$P_r \propto P_t d^{-\eta} 10^{\xi/10} \beta^2 \quad (3)$$

Where ξ represents the shadowing factor and typically has a Gaussian distribution. β represents fast fading and has a Rayleigh distribution.

Due to different path delay, signals from different paths interfere with each other at the receiver. A RAKE receiver with L fingers can resolve the signals from L different paths and combine them to improve the receiver's performance. The condition of distinguishing individual paths is that the paths are mutually separated by delays longer than the chip duration T_s . Fast fading can be mitigated by interleaving, diversity combining and error control coding. The cost of employing these sophisticated techniques is longer delay, and more complicated reception.

2.4 Power Control and System Capacity

In cellular networks, a BS serves all MSs in its service area. Two-way communication is conducted between the BS and all the active MSs. The forward link is in the direction from BS to MSs and the reverse link is from MS to BS. In the current CDMA standard (IS-95), there is a pilot signal transmitted over the forward link, (FL) but not over the reverse link (RL). Since all MSs share the same frequency spectrum simultaneously, co-channel interference exists. The forward link interference is generated by several non-moveable BSs in neighboring cells, and also by the fact that each signal is made up from several overlapped signals. The reverse link interference is generated by a large number of moving MSs which are in the reference cell and its neighboring cells. CDMA system capacity is interference limited and any reduction in interference directly contributes to a capacity increase. Because the power control can reduce excessive mutual interference, it is a very important approach to increase system capacity.

Due to the non-zero cross correlations between the spreading sequences of the different MSs and/or asynchronous transmission, co-channel multi-user interference limits the capacity of CDMA systems. Due to the path loss, in the reverse link, an MS closer to the BS could be received at a higher power level than other MSs without power control. If the difference between the received power level is too high, the closer one may cause a great interference to other MSs. This is the so called near-far effect. Fortunately, the near-far effect on the forward link is not significant. If the power of an MS stays away from a suitable level, the MS may either interfere with others or be interfered with by others, resulting in a smaller system capacity. Therefore, power control is necessary. Due to the different nature of forward and reverse links, different power control schemes are used. Power control aims to keep the received power at a preferred level to maximize the system capacity. It is essential to the operation of CDMA cellular networks. In brief, some form of power control mechanism is required in an environment that experiences excessive path loss (shadowing), and/or slow and fast fading, in order to compensate for the fluctuations in the power levels, and to mitigate the near-far problem.

Power control can be implemented by two means: **closed loop power control** and **open loop power control**. The closed loop power control accomplishes close estimate to the desired level at the receivers. The receivers constantly observe the received signal quality (may be reflected by signal strength, i.e., signal-to-interference ratio (SIR), bit-error rate (BER), and delay) and determine appropriate power control commands. A feedback channel is necessary to transmit these commands to the senders for power adjustments. For example, power control commands are transmitted from a BS to an MS to raise or lower the MS's transmitted power according to whether the measured SIR at the BS was lower or unnecessarily higher than a desired value. Therefore, the reverse link power level is controlled by the BS. The open loop power control does not need a feedback channel. The transmitting power level adjustment is determined based on the estimation of the channel quality of the opposite direction. The estimation error of the open loop power control can be rather high, especially when the forward link and the reverse link are not highly correlated. When the open loop power control is adopted in the reverse

link, an MS measures the received power level of the pilot from the BS in the forward link and sets the transmitted power level inversely proportional to the pilot level. The following assumption is implied in this power control: A stronger pilot indicates a better forward link; a better forward link indicates a better reverse link; and a better reverse link needs to reduce MS's transmission power.

Closed loop power control and open loop power control have both advantages and disadvantages. Closed loop power control is more complex, has more overhead cost, and longer response delay compared to the open loop power control. The two schemes meet different requirements and accomplish different purposes. Power control changes the statistical characteristics of both the interference and the signal. Moreover, as BSs can be more complex than MSs, the calculations of power control should be placed at the BS. It has been shown that a poorly power controlled CDMA system dramatically loses its capacity compared with a well power controlled one [1].

The target value of the controlled power can be presented either in terms of power strength or signal to interference ratio (SIR). When power strength is used, referred to as a strength-based power control, all MS's power at the BS should be controlled equal in strength. Similarly, a SIR-based power control keeps all MSs having the same SIR at the BS. Since the received power level of an MS, which is required to keep a certain SIR, may vary depending on the population of active MSs (the more MSs, the higher the mutual interference and the higher the signal power needed), the power level might not be constant in a SIR-based power control as that in a strength-base power control. Of course, either the chosen target strength or the chosen target SIR are minimized, such that the power consumption at MSs is minimized while keeping the quality of the communications.

2.5 Single Service CDMA System and Wideband CDMA System

2.5.1 IS-95 in North America

A CDMA-based second-generation system standard IS-95 has been adopted besides Digital AMPS (IS-54) in north America. It is a standard for systems working on the 900 MHz frequency band. The total allocated system bandwidth is 25MHz. The Basic user channel rate is 9.6 Kb/s. This is spread to a channel chip rate of 1.2288 MChip/s (a total spreading factor of 128) using a combination of techniques. The spreading process is different on the FL and RL. On the FL, the user data stream is encoded using a rate $\frac{1}{2}$ convolutional code, interleaved and spread by one of 64 orthogonal spreading sequences (Walsh functions). Each mobile in a given cell is assigned a different spreading sequence, providing perfect separation among the signals from different users, at least for a single-path channel. To reduce interference between mobiles that uses the same spreading sequence in different cells and to provide the desired wideband spectral characteristics (not all of the Walsh functions yields a wideband power spectrum), all signals in a particular cell are scrambled using a pseudo-random sequence of length 2^{15} chips.

Orthogonality among users within a cell is preserved because they all use the short code scrambling code. A pilot channel (code) is provided on the forward channel for channel estimation. This allows coherent detection. The pilot channel is transmitted at higher power than user channels.

On the RL, a different spreading is used because each received signal arrives at the base via a different propagation channel. The user data stream is first convolutionally encoded at rate $\frac{1}{3}$. After interleaving, each block of six encoded symbols is mapped to one of the 64 orthogonal Walsh functions (i.e., 64-ary orthogonal signaling). A final fourfold spreading, giving a rate of 1.2288Mchip/s, is achieved by spreading the resulting 307.2 kchips/s stream by user-specific and base station specific codes of periods $2^{42}-1$ and 2^{15} chips, respectively.

Another essential element of the RL is tight control of the mobile's transmit power, to avoid the near-far problem that arise from different fading, shadowing, and path loss situations experienced by the different signals. A combination of open loop and fast closed-loop power control is used, with the commands for the closed-loop power control being transmitted at a rate of 800b/s. These bits are punched into the speech frames.

RAKE receivers are used at base and mobile stations to resolve and combine multi-path components, hence significantly reducing the fading fluctuation. This receiver architecture is also used to provide base station diversity during soft handoff, whereby a mobile making the transition between cells maintains links with both base stations during the transition. The mobile's receiver combines the signals from the two base stations in the same manner as it would combine signals associated with different multipath components.

The IS-95 CDMA approach offers a number of benefits, including increase of capacity, elimination of the need for planning frequency assignments to cell, and flexibility for accommodating different transmission rates. More over, the variable-rate speech coding, power control, reduction of fade margin, and forward error correction all contribute to the reduction of the required RF transmit power.

However the current second-generation CDMA systems are primarily designed as low rate voice and data micro-cellular systems and fall short of meeting important requirements of third generation system [3].

2.5.2 Requirements of the 3G mobile system

The objectives and system framework of third-generation systems [4] go far beyond the capabilities of the second-generation systems such as IS-136, GSM or IS-95 especially with respect to:

- The wide range of services and service bit rates(up to 2 Mbps) to be supported
- The high quality of service requirements(e.g.: toll quality speech, data services with BER less than 10^{-6})
- Operation in different environments (in door/outdoor, business/domestic, cellular/cordless, etc.)
- The required flexibility in frequency and radio resource management, system deployment, and service provision)

What is the optimum multiple access scheme for 3G mobile system? Different forms of multiple access schemes have been proposed [8], such as wideband CDMA(W-CDMA), multi-rate CDMA(MR-CDMA), multi-carrier CDMA(MC-CDMA), multi-tone CDMA(MT-CDMA), multi-code CDMA(MC-CDMA) hybrid DS/FH CDMA, hybrid CDMA/FDMA, hybrid CDMA/TDMA, hybrid CDMA/ISMA and so on. Among these schemes, wideband CDMA and multi-carrier CDMA are the two most prosperous candidates.

Chapter 3 Power Control in Single Service CDMA System

Power control in single service CDMA system is used on both FL and RL to overcome the near-far problem and to increase system capacity. This chapter starts by analyzing the mechanisms of power control to increase system capacity, followed by reviewing how power control imperfection affects the system capacity, and ends with the implemented power control schemes.

3.1 Forward Link and Reverse Link Power Control

In cellular networks, a base station serves all mobile stations in its covered area. Two-way communications is conducted between the base station and all the active mobile stations. Since all mobile stations share the same frequency spectrum simultaneously, co-channel interference exists. The characteristics of the interference on forward and reverse links are different. Besides, there is a pilot signal transmitted over the forward link but not over the reverse link. All those differences further determine that power control mechanisms should be different between forward link and reverse link.

3.1.1 Forward link power control and system capacity

In a DS-CDMA system, each base station transmits signals to all active users in its service area using one antenna. Therefore each mobile receives a composite signal from its home base station and from its neighboring base station in the system. It consists of the desired signal and interfering signals from all active base stations to all other active mobile stations in the system. As shown in figure 2.

Figure 2 Forward link interference

In single cell systems, no power control is required for the forward link, since for each user, any interference caused by other user signals remains at the same level relative to the desired signal.

In a multiple cell system, the situation becomes more complicated, because each user receives the interference not only from its own cell sites but also from surrounding cells. Interference from surrounding cells fades independently to the given cell site and thereby degrades performance. This becomes a particularly serious problem in the region where two or even three cell transmissions are received at nearly equal strengths. The multi-user interference on the forward link put a limit on the capacity especially in shadowed environments, as shown in table 2.

Table 2 Forward link capacity for an outage probability of 0.01 in the presence of shadowing
($G=156$ and Voice activity factor $\alpha=0.375$, no power control)

Forward link without power control								
Amount of shadowing σ dB	0	1	2	3	4	6	8	10
Number of users	13	9	5	3	1	1	1	1

Forward link power control is performed by allocating large transmission power to those signals to the MSs which receive large neighboring-cell interference. Therefore uniform service quality is provided to all users in the service area.

Two conventional power control schemes are Carrier to Interference Ratio (CIR) driven and distance-driven power control [1]. **CIR-driven** power control minimizes each user's transmission power according to the individual needs of CIR. Each mobile sends information about its CIR to the base station and the base station adjusts the transmission power level to the specific user. **Distance-driven** power control scheme requires base station's knowledge of positions of mobiles. The base station transmits at a lower level to users closer to the base station, so that it is possible to minimize the total transmitted power.

Table 3 Maximum number of users per cell (N) with and without forward power control
($G=156$, $\alpha=0.375$)

	No power control	CIR driven	Distance driven
Shadowing (8dB)	1 users	38 users	-
No shadowing	13 users	-	30 users

Table 3 compares these two power control schemes with and without shadowing. It shows that the CIR-driven power control scheme outperforms distance-driven power control scheme in shadowed environment. A distance-driven power control system is not very appropriate in shadowed environments because then the received power not only is a function of the distance between the user to the base station but also depends on the log-normal shadowing spread. Besides, CIR driven power control system minimizes the total transmitting power more accurately than a distance driven power control scheme.

In order to improve the quality of forward traffic channels and to increase system capacity, in [27], the authors proposed a forward power control scheme utilizing

neighboring-cell pilot power. In this scheme, each mobile station measures pilot powers received from neighboring cells. Transmission power of the forward traffic channel is then controlled by the base stations, according to the pilot powers measured at the respective mobile station, and uniform service quality is provided to all channels. Simulation results show that this scheme reduces outage and forced termination probability of 1% by 50% and 60% in the case of soft handoff and hard handoff.

3.1.2 Reverse Link Power Control

In a DS-CDMA system, mobile stations are distinguished by their respective spreading code. Since the spreading codes are not completely orthogonal, co-channel interference exists. The transmitted power has to be regulated so as to minimize mutual interference and maintain communication quality. On the reverse link, interference is caused by a large number of MSs in both home cell and neighboring cells, as shown in figure 3.

Figure 3 Reverse link interference

In a single cell system, the principle of power control is straight forward, though the implementation may not be. Prior to any transmission, each MS monitors the total received signal power from the BS. According to the power level it detects, it transmits at an initial level which is much below (above) its nominal level in decibel as the received

pilot power level is above (below) its nominal level. This is so called **open loop power control**. Experience has shown that this may require a dynamic range of control on the order of 80dB. The **closed loop power control** can further refine the power level. The BS measures the power level received from the MS and sends a power adjustment command over a control channel, so that the MS adjusts its transmitting power level accordingly.

The relatively fast power level variations associated with Rayleigh fading may be too rapid to be tracked by the closed loop power control. However, variations related to path losses and shadowing effects, which are modeled as an attenuation with log-normal distribution, are generally slow enough to be controlled by the closed loop power control.

There are two power control mechanisms based on different objectives. They are **strength-based power control** and **SIR-based power control**. The *strength-based* mechanism is based on the original idea of power control, to keep the power level of all signals received at the BS as nearly the same as possible to mitigate the near-far effect. The *SIR-based* mechanism is based on the objective of directly controlling the communication quality or the system performance according to the SIR received at the base station. These two mechanisms adjust the MS's transmitting power to track the variation in the channel gain.

It has been shown that the outage probability of strength-based power control mechanism is generally higher than that of SIR-based power control mechanism, whereas MSs' mean transmitted power is more stable when strength-based power control mechanism is used than when SIR-based mechanism is used. Note that system traffic load profile and that the desired level are also influential factors. [29]

The block diagram of the reverse link closed loop power control mechanism is shown in figure 4.

Figure 4 Block diagram of the reverse link closed loop power control mechanisms

When the SIR-based power control mechanism is used, it is important that the desired level D be selected carefully. Setting the desired level too high or too low in the SIR-based mechanism will significantly degrade the system performance. In particular, if the desired level is too high, most mobiles will be forced to transmit at maximum power.

Efforts also have been made to reduce power control error. Power control error is defined as the difference between the target value and the actual value. Power control errors can be quantified by mean of Pulse Coded Modulation (PCM) or Delta Modulation (DM). In[46], PCM realization of strength based and SIR based power control are investigated by simulation. For PCM (n mode) power control, the command set is: $\{-n, -(n-1), \dots, -1,$

$0, 1, \dots, n-1, n\}$, where n is an integer. For DM power control, the command set is $\{-1, 1\}$. PCM power control outperforms DM power control in strength based mechanism because it has a lower outage probability. The PCM power control can respond more flexibly to channel variation. High order mode (i.e. higher n) outperforms due to wider dynamic range. However, the improvement becomes insignificant when $n > 3$. The same conclusion holds for SIR based mechanism. Therefore, limited order is good enough and has advantage of less complexity and lower capacity cost on the command transfer [29].

Selection of power control step size is another important issue. Power control step size should be selected to minimize quantization noise. An optimum step size around 1 dB is found regardless of n . Variable step size scheme slightly outperforms the fixed step one.

3.2 Power Control Imperfection and System Capacity

The performance of a power controlled system depends on the power control algorithm, speed of the adaptive power control system, dynamic range of the transmitter, spatial distribution of users in the system, and propagation statistics (such as fading and shadowing). All these factors influence the probability density function of the received power. The compound effect of these factors on the received power has been shown to be log-normal distributed with zero mean and standard deviation σ [1][13]. The imperfection in the power control system is determined by the logarithmic variance σ^2 of the log-normal power distribution of the received signal. In the case of perfect power control, the logarithmic variance is 0 dB. The power control error is 0.

Power control error dramatically degrades system performance. Table 4 shows a comparison between the reverse link capacity for a single cell situation and a multiple cell situation with and without power control error [1][13]. The system is found to be very sensitive to power control errors on the reverse link. If we also consider the interference from users in surrounding cells, the capacity decreases even more.

Table 4 Reverse link capacity for DS-CDMA systems with a single cell and multiple cells

	Perfect Power Control		Imperfect Power Control							
	$\sigma=0\text{dB}$		$\sigma=1\text{dB}$		$\sigma=2\text{dB}$		$\sigma=3\text{dB}$		$\sigma=4\text{dB}$	
	S	M	S	M	S	M	S	M	S	M
$G=100/a=1$	21	18	12	11	7	6	5	3	3	2
$G=156/a=1$	33	28	19	17	10	10	7	5	4	3
$G=156/a=.375$	59	51	43	39	23	21	12	11	5	5

Note: S stands for single cell system; M stands for multiple cell system.

From the table we also can get the following conclusion: the capacity can be improved by increasing the processing gain G or decreasing the voice activity, as table 4.

The **dynamic range** of power control is another important factor that affects power control perfection. In general, the wider the *dynamic range* of the power control, the better the power controlled system performance. A wider dynamic range of power adjustment enables it to track the variation in the channel gain more accurately. It has been shown that the PCM power control outperforms DM power control and higher order mode in the PCM power control performs better than the lower mode regardless of the system load N_u .

Also, **loop delay** has an important effect on the system performance. The shorter the loop delay, the better the system performance. Over an observation period of loop delay, each mobile is assumed to move continuously with a small geographical area, and the radio reverse link has uniform path loss and shadowing, such that the long-term fading on the reverse link can be considered to be constant during the observation period. Under this assumption the power control is accurate. However, if the loop delay is too large, the power control command received by the mobile will already be obsolete and the mobile will be unable to track the variation in the channel fading accurately. As a result, the effectiveness of the power control mechanism deteriorates.

3.3 Power Control in IS-95

In IS-95 systems, both reverse and forward link power control are implemented. The reverse power control mechanism in IS-95 systems [4] comprises of two parts. The first part is open loop power estimation in which the mobile station autonomously adjusts its transmit power level based on the forward link received signal strength. The second part is called closed loop power correction wherein the base station commands the mobile to adjust its transmitting power based on the reverse link received signal to interference ratio. Closed loop power correction itself is comprised of two parts: the inner (fast) loop power control and the outer (slow) loop power control. The inner loop assumes knowledge of a target energy-per-bit to interference density ratio, E_b/I_o , and the base station sends increase/decrease transmit power commands to the mobile station to assist reaching that target. The outer loop, on the other hand, is responsible for setting target E_b/I_o . In IS-95 systems, the inner loop updates take place every 1.25 ms, while the outer loop updates take place every 20ms. The forward power control is implemented by CIR-driven power control. The base station adjusts transmitting power according to the reported Frame Error Rate (FER).

Chapter 4 Power Control in Multimedia CDMA Network

Many efforts have been made to define power control algorithm for single service CDMA system. Basically in these systems, the power control law is proportional to the distance between base station and mobile station and the interference level so that the received signal power for each mobile is maintained at a minimum level while meeting the bit error rate requirement. However, those power control laws may be insufficient for multimedia CDMA systems.

A multimedia CDMA system will support the following [48]:

- a wide range of operating environments (indoor, low mobility, full mobility, and fixed wireless);
- a wide performance range (from voice and low speed data to very high speed packet and circuit data services);
- a wide range of advanced services (including voice only, simultaneous voice and data, data only, and location service);
- an advanced multimedia QoS control capability supporting multiple concurrent voice, high speed packet data, and high speed circuit data services along with sophisticated QoS management capability.

Since new services such as high speed packet data service are introduced to systems, two issues come out immediately. One is the power control for the high speed packet data services. The other is the power allocation plan among multiple services.

This chapter is organized as follows, section 4.1 discusses approaches to increase system capacity through layered air interface structure of the wideband CDMA system. Section 4.2 discusses power control for packet data services in wideband CDMA system. Section 4.3 presents reverse link power allocation schemes in wideband DS-CDMA systems. Section 4.4 addresses admission policy. Finally, with Section 4.5, we close this chapter

with the proposed power control and power allocation plan for the wideband CDMA system.

4.1 Approaches to increase system capacity

Power control is essential to increasing the system capacity. Along with power control, there are several other approaches to help achieve this goal. Within the layered air interface structure of CDMA network, these approaches can be accomplished in the different layers, as shown in Table 4 [7].

Table 4 Layered air interface structure and approaches to increase system capacity

Layers	Functionality			Approaches
Layer 3	Call Control	Management	Voice Data IP	Admission control & Handoff
Layer 2	Data link control Media access control			Retransmission & ARQ Power allocation (Out loop power control)
Layer 1	Transmission layer			Power Control (Inner loop) FEC, Interleaving RAKE Receiver

Layer 1 is the transmission layer or physical layer. The power control on this layer mainly mitigates the radio channel fading, and overcomes the near-far problem. Forward error correction (FEC), code block interleaving and RAKE receiver are also employed to further reduce bit error rate (BER). Layer 2 is the data link layer. In this layer, the power allocation plan (or outer loop power control) are used to determine the transmission power level of each type of traffic, so that the system can accommodate maximum number of users. Retransmission and automatic retransmission request (ARQ) are employed for the non-real time traffic to reduce error rate, so that a trade off can be made between the transmission power level and retransmission rate, and optimization can be

used to achieve the highest total throughput. Layer 3 is multiple access control layer. Issues on admission control and handoff shall be addressed in this layer to increase system capacity.

4.2 Power Control for Packet Data Services

4.2.1 Power Control Imperfection effect on Packet Data Service

In [18], through a simulation study, it is shown that power control error affect the multi-media system capacity remarkably. Here, power control error means power level deviation from a desired setting. Under the condition of keeping the maximum number of voice users N_v as constant, the power control error of 2 dB results in 57% less users than the case of 0.5 dB power control error. The same conclusion holds for non-real time traffic [46]. Therefore, the accuracy of power control should be well maintained.

However, the effects of power control error on the system capacity for non-real time traffic and real time traffic are different [46]. For non-real time traffic, with a processing gain of 128 and mean SNR of 20dB, it is observed that a power level standard deviation of 1dB reduces the traffic capacity in terms of 10^{-4} average error rate from 16 Erlangs to 13 Erlangs (18.7%). Under the same circumstances, the traffic capacity in terms of 10^{-2} outage probability is reduced from 16 Erlangs to 12 Erlangs (25%). Compared with the voice CDMA system, the reduction in the simultaneous active users supported by system is 38%. This shows that non-real time traffic is less affected by power control imperfections than real time traffic. For non-real time traffic, the lower the *BER requirements*, the more the power control error affects the system performance. For prescribed average error rates of 10^{-3} and 10^{-4} , with $G_p=128$, $\mu=20\text{dB}$, when $\sigma=1$, the traffic capacity decreases by 18% for an average error rate of 10^{-4} and by 13% for an average error rate of 10^{-3} .

The *limiting factor* for CDMA system capacity with imperfect power control is the *power control error* of the desired user, not the interference power variation. It is possible to

compensate the power level variations up to a certain limit by increasing the average signal to noise ratio (SNR). At average error rate of 10^{-4} , the system can compensate up to 1 dB shadowing by increasing the SNR.

4.2.2 Retransmission and graceful performance degradation

In order to meet required BER, non-real time traffic might use some retransmission protocol to handle the error packets. A trade off can be made to reduce transmitting power by increasing retransmission rate. In this case, the performance index for data transmission should be throughput and delay instead of BER.

A **graceful performance degradation** means that a CDMA system can accommodate more users with just a little bit performance degradation. It is shown in [18], by using retransmission schemes and allowing 1% throughput degradation, the system can accommodate 2.35 times of data packets in a time slot. It is observed that graceful performance degradation can be obtained by using Equal Signal Strength (ESS) power control law for non-real time traffic while using Equal Error Probability (EEP) power control law for real time traffic. The ESS rule maintains the received signals' power level from all users at the minimum required level, while the EEP rule keeps the BER of all users at the minimum required level. Details will be discussed later.

By the comparison between the results of systems with and without data retransmission, the capacity of a system with retransmission scheme should not be hard limited by a low packet error rate (PER) threshold which is generally used to guarantee the quality of packet receptions.

4.3 Power Allocation in Multimedia CDMA Network

When we deal with power control in multi-media CDMA networks, the most important issue is the power allocation among different types of traffic, which affects system's capacity significantly. A multimedia network carries a number of services with different

quality of service (QoS) requirements. Therefore, each service should be assigned a suitable power level based on those QoS requirements that maximize the overall capacity. This is called power allocation. All the MSs of a service are power controlled according to power level allocated to that service by the power control schemes discussed before. Because of the dissimilarity and bandwidth sharing of multiple services, power control and power allocation become more complex. Power level becomes service dependent. Power allocation greatly affects the system capacity and an optimum one is difficult to find if the number of services is high. The power allocation of a particular service should be as low as possible to reduce its interference to others and high enough to assure its own QoS. Either strength based power allocation or SIR based power control is possible. Of course, many factors, such as the system bandwidth, service types and service quality requirements, will affect the allocated power level of each type of service.

Many efforts have been made to power allocation schemes. In order to clearly explain the state of art in research of power control in multi-media CDMA networks, the proposed power allocation schemes can be grouped into two groups: Fixed power allocation and adaptive power allocation, as shown in figure 5.

Figure 5 Types of power control schemes

Fixed power allocation means that the power control target values for each kind of media are determined when we design the system. They are not changed as the traffic load fluctuating. Adaptive power allocation means that the power control target values are changed as the traffic load changes.

4.3.1 Fixed power allocation schemes

Fixed power allocation schemes keep power control target values constant regardless traffic load. It is simple for implementation.

Equal bit-energy strategy[18]: As indicated by the name, all the signals from the MSs within the coverage area are power controlled such that the receiver at BS maintain equal received bit-energy for every mobile no matter what transmission rate it uses.

ESS (Equal Signal Strength) rule falls in this category. This power allocation scheme is that for all the voice (data) signals are power controlled such that they have the same received power P_v (P_d) at the base station. The allocated power level may be different for the different kind of media. In [18], the received power ratio $\gamma = P_v/P_d$ is chosen based on the bit rates and performance requirements of voice and data users. i.e. $\gamma = P_v/P_d = R_v/R_d$. So that the received bit-energy are the same for all media.

Equal bit energy strategy implies the received SIR is the same for all types of media at one time instant. This scheme doesn't balance well the natural dissimilarity between voice and data traffic. In our multi-media system, high-rate data traffic with lower BER requirements and lower-rate voice traffic with higher BER requirements are transmitted through the same channel. Clearly, the interference that voice users can tolerate and the one that data users can tolerate are different. Moreover the interference that data users cause to voice users is also different from the interference that voice users cause to data users. Hence the performance of the more vulnerable traffic may degrade drastically when the user number is increased.

Optimal equal bit-energy within each severice class strategy [28]: A refined equal bit-energy strategy is proposed in [28]. This scheme allocates different received bit-energy for different type of media. Required QoS of voice traffic is achieved by controlling the link frame error rate for a given number of voice users. This leaves a fixed total additional multiple access interference allowed to be introduced by data users. The author [28] found that there is an optimum bit energy ratio $R = E_d/E_v$, which yields the highest throughput and this optimum only depends on the link error performance. The required voice SNR is independent of the number of voice users supported by the system. It is independent of the information bit rate ratio of the two services, and it is also shown that for IS-95 PCS system, the optimal value is about 0.72.

4.3.2 Adaptive power allocation schemes

The difference between adaptive power control and fixed power allocation lies in the dynamic power allocation during a dynamic traffic situation. With fixed power allocation, the allocated power level is fixed for each type of media, no matter what kind of traffic profile it is. While with adaptive power allocation, the target power level is changed as traffic load changes.

Strength-based optimal power allocation: With this strategy, strength-based power control is used for individual traffic. At the mean time, traffics are grouped into two groups according to its priority. Those media with a set maximum allowed BER are media with high priority, and media without set maximum are media with low priority. The proposed power control method is to maximize throughput or minimize BER of media with low priority while maintaining the required BER of media with high priority. In other words, by changing the power allocation of high/low priority media to keep the BER of high priority ones below the threshold and maximizing the total throughput or minimum BER of low priority media. The optimal power distribution that is obtained according to channel measurements is transmitted to every MS through a common

controlled channel at the same time. Each MS adjust its transmission power level accordingly.

The simulation results demonstrate that the BER of media with high priority can be kept below the allowed maximum even in the case of heavy traffic and in dynamic channel condition. The power control error due to delay has different impact on the different media. To the low priority media, delay almost has no effect; while to the high priority media, the more the delay time increases, the more the system performance degrades. Furthermore, the impact of power control error caused by delay decreases for increased average traffic and vice versa.

Strength and SIR-based optimal power allocation: This Scheme [18] uses strength-based power control for data users and SIR-based power control for voice users. The objective is to always guarantee to meet the minimum required voice quality and reserve the highest possible system capacity to data users. In other words, the system adjusts the relationship between P_d and P_v according to the system traffic load in order to make the BER of voice users equal to required value. This scheme outperforms equal bit-energy strategy in both non-fading and fading channel. Besides, this scheme can take advantage of graceful degradation characteristics, so that the system can accommodate more users with just a little bit performance degradation. This power allocation scheme will be implemented in our simulation system.

4.4 Admission Policy

As discussed above, adaptive power control outperforms conventional power control. It stays true with admission policy. Adaptive access control can achieve more capacity. In order to accommodate a combination of traffic types, channels can be partitioned into several sections, each operating under its own protocol. Adaptive admission control attempt to provide good performance over a large range of conditions. The access scheme itself changes, adapting smoothly to network load fluctuations, yielding an access

procedure appropriate for the actual state of the network. In [32], the author proposed a framework for adaptive admission control in the reverse link. The framework is based on the estimation of interference at the base station receivers, which takes into account the interference measurement and interference predicted from source type and traffic declaration.

Figure 6 Adaptive admission control

As shown in Figure 6, there are three information flow categories to the base station admission controller. The first category comprises information about connection traffic parameters. These parameters can be defined by source type and traffic characteristics specified by the source itself. The second category concerns information about measured channel characteristics, such as current SIR distribution and the distribution of channel BER's. Note that current value of SIR is not sufficient to make an accurate decision since the decision should provide the required quality of service for some period in the future, while SIR may change significantly in this period due to the variation in the propagation and traffic parameters. The third category contains information that can be retrieved from neighboring base station. Basically this is the same type of information as in category one

and two, except that it may be transformed into more useful form by the admission controller. According to these three information flow categories, the author proposed three alternatives for traffic admission algorithms.

- Fixed strategy: The admission decision is based on traffic source declaration only. The admission controller ensures that the declared traffic parameters don't exceed the threshold. The threshold is defined so that the information BER constraint is met for any source and propagation distribution.
- Local adaptive strategy: The admission decision is based on both the source traffic declarations and the channel characteristics measured at the local base stations.
- Global adaptive strategy: This is an extension of the local adaptive strategy where the decision is also based on information from the neighboring base station. In this case, the level of traffic accepted by the local base stations takes into account the propagation conditions in a larger region. This is achieved at the expense of the overhead associated with the exchange of the information between the base station.

The results indicate that this admission control management architecture is robust and can adapt to different traffic and propagation patterns. This feature is translated into a larger system capacity when compared with an optimal fixed traffic threshold strategy. The comparison of the two generic variants of the adaptive control architecture (local and global) shows that the scheme based on the local information only can provide adequate performance. This is explained by the fact that the information about the traffic status in the neighboring bases is partly sensed via local interference measurement. Nevertheless, use of explicit information about the interference status of the neighboring base can further increase the network utilization. One of the important conclusion from the numerical study is that the local base station should reserve some of its interference budget for new connections in the neighboring base stations in order to increase bandwidth utilization of the total system.

4.5 Proposed Power Control and Power Allocation Schemes

Based on the above literature review and discussion, we have the following proposal on power control and power allocation plan:

- For the voice service, SIR based power control will be used. IS-95 power control algorithm will be implemented.
- For the high rate packet data service, strength based power control will be used. Power control will be completed on a dedicated control channel. Retransmission and ARQ will be employed to meet the FER target value.
- Strength & SIR based optimal power allocation scheme will be employed for the power allocation plan.

The algorithm details will be present in Chapter 5.

Chapter 5 System Modeling and Simulator Structure

The proposed power control algorithm and power allocation plan are tested by means of computer simulation. The simulated wideband CDMA system is based on the proposed 3G CDMA system. A test bed has been built upon an existing IS-95 based simulator.

This chapter is organized as follows. Section 5.1 presents system configuration and assumptions. Section 5.2 describes multiple access control protocols used in this simulated system. Section 5.3 and 5.4 provides propagation model and traffic generator model respectively. Section 5.5 presents the details of implemented power allocation plan and power control algorithms. Section 5.6 deals with handoff. In order to give readers a general picture, Section 5.7 is the highlights of system model, and Section 5.8 describes the simulation structure and flow chart.

5.1 System Configuration and Assumptions

5.1.1 Services

The simulated system supports voice, high rate stream data and burst packet data traffic in vehicular, pedestrian and indoor environments. It provides both circuit-switched and packet-switched services.

5.1.2 Simulation Plane

The simulation plane consists of 19 equal-sized omni hexagon cells of radius 3.85 km, as shown in figure 7. It consists of a central cell, 1st tier and 2nd tier. In this uniform cell deployment, each cell is equipped with a BS. MSs with specific traffic types are generated uniformly in each cell based on Poisson call arrival model.

Figure 7 Simulation plane

5.1.3 System Configuration

The system has several mobile switch centers (MSCs). Each MSC controls a number of base station controllers (BSCs), and each BSC controls a number of base stations (BSs). Mobile stations communicate with base stations. The system configuration is shown in figure 8.

Figure 8 System configuration

5.1.4 System Bandwidth and Channelization

The simulated system operates at 2GHz band with 5MHz bandwidth and direct spreading at 3.6864 Mcps chip rate [48].

Each cell has 90 fundamental channels (CH) which either can be traffic channel or dedicated control channel (DCCH), one FL supplemental CH, one RL supplemental CH,

one access CH, one pilot CH, one sync CH, one paging CH and one common control CH. The physical channel configuration of the simulator is shown in Table 5.

Table 5: Channelization in a cell

(the figure in the brackets indicating the number of channels)

Forward Link		Reverse Link	
Pilot Channel (1)		Access Channel (1)	
Sync Channel (1)		Dedicated Control Channel (vary)	
Control Channel	Paging Channel(1)	Traffic Channel	Fundamental Channel(≤ 90)
	Common Packet Channel(1)		Supplemental Channel (1)
	Dedicated Control Channel (vary)		
Traffic Channel	Fundamental Channel (≤ 90)		
	Supplemental Channel(1)		

Note: The maximum total number of fundamental channels and DCCHs is 90 for each cell

Comparing with IS-95 system, it can be found that

- Pilot, Sync, and Paging/Access channels are the same as IS-95.
- Separate dedicated control channels are introduced in both forward link and reverse link to the system. Power control will be performed through the separate dedicated control channel.
- Fundamental channels are equivalent to an existing IS-95 traffic channel. They serve voice and low rate data services. Their behaviors in call setup, power control and handoff are the same as in IS-95. The fundamental channel transmission rate is 9.6 kbps.
- Supplemental channels are introduced for high rate packet data services. The transmission rate is 144kbps.

Features of Supplemental Channel:

Supplemental channels have the following features:

- Transmission rate is either constant or specified by a dedicated control channel. Therefore, rate detection is not required.
- Radio Link Protocol (RLP) is used to achieve the target packet error rate (after retransmission).

- Both circuit-switched and packet-switched services are supported.
- Suitable for high-rate data service.

5.1.5 Assumptions

The assumptions used in the simulator are as follows:

- Each Mobile is capable of generating any type of traffic including voice, variable data stream and burst packet data, but one type at a time.
- The percentage of each traffic type is a simulation parameter, which is specified at the beginning of each simulation run.
- Different MS may have different transmission rate and different QoS requirements.
- Circuit-switched and packet-switched services are provided.
- Retransmission techniques are employed for data transmission.

5.2 Multiple Access Control

Upon generating a voice MS, either due to originating a call or being paged, a setup process takes place. The process uses the IS-95 probing technique to determine the initial MS transmission power. After a successful call setup, a traffic CH is assigned and the MS starts to move on the simulation plane. It measures the neighboring cell pilot signal strengths, FL E_b/I_o and RL E_b/I_o ; checks soft handoff conditions and the call drop condition; and performs power control every half second. Necessary actions are taken whenever a condition is met, and the statistics are collected accordingly.

A data MS uses supplemental CH to communicate with its BS. Once a data MS is generated, a setup process takes place. Both FL and RL DCCHs are first assigned to setup the call and then to perform the initial probe that determines the optimum MS transmission power. In RL, Aloha type random access control is used. A blocking flag at BS is used to indicate the availability of RL supplemental CH. All data MSs check the blocking flag before attempting call setup or handoff. After a data call is established, the MS starts to move on the simulation plane and a data session generator is invoked. The

MS state is changed according to packet arrival condition. The supplemental CH is occupied until the end of the session. In the FL, the supplemental CH operates in a shared mode. Once a data call is generated, the associated MS starts to move and after the call has been setup, a session generator is activated. Packets can be queued in the BS (if necessary) until FL supplemental CH becomes available. MS state transitions occur according to the packet transmission condition. Specifically, In the FL, a shared mode is operated for the supplemental CH.

Figure 9 Shared mode operation

When the supplemental channel operates in a shared mode, several users share the channel in time domain. The supplemental channel conveys data packets to a designed MS during an assigned time period. The scheduling information is transmitted through the common packet control channel.

In the RL, the supplemental channels use Aloha type random access control, as shown in Figure 10.

In the reverse link, once the channel is occupied, the blocking flag is set "ON" in the common control channel. When the blocking flag is "OFF", the supplemental channel is free and a MS can transmit if it has something to transmit. However, if two of the users start transmitting at the same time, then blocking occurs.

Figure 10 RL random access

A MS requesting data service employs supplemental channels. The state diagram of a MS requesting data service is shown in Fig 11.

The states in the simulator are defined as follows:

- Null state: MS is not active and is out of simulation scope.
- Initialization State: The simulator initializes system's parameters and defines MS's type, position, and mobility.
- Connecting State: The MS and BS are in the process of establishing the connections, and performing the initial probe to determine the initial transmission power.
- Active State: MS and BS are transmitting or receiving information.
- Standby State: There is no dedicated traffic channel assigned, but dedicated control channel is active.
- Suspended State: This is a logic state that exists between MS, BS and MSC. For example there could be RLP, service option connections or PPP but no dedicated channel connection.
- Dormant State: This is a logical state that exists between MS and IWF only. For example, there is no service option connection; no RLP but PPP connected.

Note: NAK indicates negative acknowledgement.

Figure 11 State diagram of a packet data MS

Once a data MS is generated, the MS enters the initialization state. After the simulator initializes system's parameters and defines MS's type, position, and mobility, the MS checks RL supplemental channel's availability. If the blocking flag on the FL common control channel is off, the MS enters connecting state. Other wise, the MS enters dormant state. In the connecting state, both FL and RL DCCHs are first assigned to setup the call and then to perform the initial probe that determines the optimum MS transmission power. Upon a successful supplemental channel assignment, the MS starts to move on the simulation plane and starts receiving and/or transmitting information, which is the active state. In this state, the MS's state is changed according to packet arrival condition. In the FL, since a shared mode is operated, when it is the transmission gap, the MS enters standby state. In the RL, since ALOHA type random access is used, when it is the end of packet, the MS enters suspended state. In both cases, if there is no more data to transmit, the call is completed and the MS enters null state. In the standby state, if the MS have data to send, the MS resumes active state. However, in the suspended state, if the MS has data to send and the blocking flag is off, the MS resumes connecting state. If the blocking flag is on, the MS enters dormant state. Once the blocking flag turns off, the MS resumes connecting state. A session timer is set on upon the MS enters dormant State. When the timer is timed out before the blocking flag turns off, the MS is disconnected and enters null state.

5.3 Propagation Model

The primary propagation environment is modeled by the Hata plane model. The path loss of the propagation model can be briefly summarized as follows:

Hata Plane Model:

Using the Hata model, the path loss is given by:

$$L_p(db) = -(120.5 - 20\log(H_s) + 1.9\log(H_s^2)) - (36.6 - 1.9\log(H_s)) * \log(R) \quad (4)$$

Where

R = distance in km between the mobile and base station

H_s = Height of the base station antenna in meters (assumed 50m)

Log-normal shadowing with standard deviation of 6dB is used without correlation between links. Average white Gaussian Noise is used and the noise floor is -118 dBm at 1.25Mhz.

5.3.1 Calculation of Eb/Io, Ec/Io

Pilot Ec/Io and Forward Link Eb/Io:

The pilot signal strength received by a mobile from a given base station is calculated according to the following equations:

$$(E_c / I_o)_i = \frac{S_i^{pilot} / R_c}{N_o W + \sum_{j=1}^k S_j^{total}} \quad (5)$$

Where $S_i^{pilot} = P_i^{pilot} \cdot L_i \cdot G_i \cdot G_m \quad (6)$

$$S_j^{total} = \left(P_j^{pilot} + P_j^{sync} + P_j^{page} + v_f \cdot \sum_{k=1}^{Nj} P_{k,j}^{voice} + \sum_{l=1}^{Mj} P_{l,j}^{dcch} + U \cdot P_j^{sup pl.} \right) \cdot L_j \cdot G_j \cdot G_m \quad (7)$$

Where

U=1 if the j-th base station's supplemental channel is in use,

U=0 otherwise.

W is the carrier bandwidth (3.6864MHz); N_o is the thermal noise density including the mobile noise figure; S_j^{pilot} is the received pilot power from base station, and S_j^{total} is the total received power from base station j. Also, P_j^{pilot} , P_j^{sync} , P_j^{paging} are transmit power allocation of pilot, sync and paging channels for base station j, respectively; $P_{k,j}^{voice}$ is the

full rate(9.6kbps) transmit power allocation for the k-th traffic channel at base station j; $P_{i,j}^{dcch}$ is the full rate (4.8kbps) transmit power for the l-th dedicated control channel. $P_j^{sup pl}$ is the supplemental channel transmitting power from base station j. N_j is the total number of voice mobiles served by base station j, and V_f is the forward link voice activity factor. M_j is the total number of data mobiles served by base station j. G_j and G_m are the antenna gain (including cable loss) for base station j and the mobile, respectively. Finally, L_j is the path loss between base station j and the mobile.

Similarly, the received full rate Eb/Io at a given mobile i, assuming that one path exists between each base station and the mobile station, can be calculated as follows:

$$E_b/I_o = \sum_{i=1}^m \frac{S_i^{traf} / R_b}{(N_o W + \sum_{j=1}^K S_j^{total}) / W} \quad (8)$$

Where $S_i^{traf} = P_i^{traf} L_i G_i G_m$ is the received full rate traffic power from a base station i at the mobile; P_j^{traf} is the transmitted traffic (either voice or data traffic) power from a base station i. R_b is the full data rate; W/R_b is the processing gain; and m is the number of the base stations involved in soft handoff.

Reverse Link Eb/Io:

In the reverse link, the received full rate Eb/Io from a given mobile i can be expressed as follows:

$$(E_b/I_o)_i = \frac{S_i^{traf} / R_b}{(N_o W + v_r B_v \sum_{j \in \{M_0-i, M_n\}} S_j^{voice} + B_d \sum_{j \in \{M_0-i, M_n\}} S_j^{sup pl} + B_d \sum_{j \in \{M_0-i, M_n\}} S_j^{dcch}) / W} \quad (9)$$

Where $B_v = 1$ if mobile j is a voice mobile ; otherwise , $B_v = 0$.

$B_d = 1$ if mobile j is a data mobile; otherwise $B_d = 0$.

S_i and S_j are the received full rate power from mobile i and j, respectively. The set $\{ M_0 \}$ represents all mobiles belonging to the base station serving the i-th mobile, and $\{ M_n \}$ represents all mobiles belong to all neighboring base stations. v_r is the reverse

voice activity factor. N_0 is the thermal noise density including the base station noise figure.

Frequency Reuse Factor

The reverse link frequency reuse efficiency for a base station, defined as the ratio of intra-cell interference to total interference, can be calculated as following [47]:

$$F = \frac{\sum_{j \in \{M_0\}} S_j}{\sum_{j \in \{M_0\}} S_j + \sum_{j \in \{M_{b1}\}} S_j} \quad (10)$$

5.4 Traffic Generator Model

We assume there are three types of traffic: voice traffic, stream data traffic and burst data traffic. For each type of service there is a separate process to generate call arrival. This process for each service only generates the time instants when service calls begin and it has nothing to do with call termination. Each type of traffic arrives according to its own arrival rate λ . Assume that the system has a total traffic load ρ_{total} (in Erlang), voice call load $\rho_v = \alpha_v \rho_{total}$, stream data call load $\rho_s = \alpha_s \rho_{total}$, burst data call load $\rho_b = \alpha_b \rho_{total}$, where $\alpha_v, \alpha_s, \alpha_b$ are percentage of each type of traffic over the total traffic, and $\alpha_v + \alpha_s + \alpha_b = 1$. Call holding time $1/\mu$ for each type of call is a predetermined value.

Then call arrival rate is given by

$$\lambda = \mu \rho \quad (11)$$

5.4.1 Voice Traffic and Stream Data Traffic

For both voice and stream data services, call is generated according to a Poisson process assuming a mean call duration of 120 seconds. For voice traffic, the traffic model should be an on-off model, with activity and silent periods being generated by exponential distribution. Mean values for activity and silent periods have to be defined to reach the specified activity factor. In the simulation, the voice activity is assumed to be 0.42 in the FL and 0.40 in the RL. For stream data services, the traffic model is a constant bit rate model, with 100% of activity.

5.4.2 Burst Data Traffic

The burst data session arrival process is also modeled as a Poisson process. For burst data, session generator generates burst packet call arrival using UMTS model [3]. A packet service session contains one or several packet calls, N_{pc} . A packet call constitutes of a burst sequence of packets, N_d . The time interval between two packet calls D_{pc} is called reading time. The time interval between two packets, D_d is called inter-arrival time. The model is shown in Figure 12.

Figure 12 UMTS Burst Data Session Model

The parameters follow the following distributions.

- Number of packet calls per session, N_{pc} : Geometrically distributed random variable with a mean $\mu_{N_{pc}} = 5$.
- Reading time between packet calls, D_{pc} : Geometrically distributed random variable with a mean $\mu_{D_{pc}} = 12$ seconds.

- Number of packets within a packet call, N_d : Geometrically distributed random variable with a mean $\mu_{N_d}=15$.
- Inter arrival time between two packets, D_d : Exponentially distributed random variable with a mean $\mu_{D_d}=0.96$ seconds.
- Packet size, S_d :Pareto distributed number with parameters:
 $\alpha=1.1$ and $k=81.5$

5.5 Power Allocation and Power Control Implementation

5.5.1 Fundamental Channel Power Control

In this simulation work, both forward power control and reverse power control are implemented. Without physical layer modeling, instead of using frame error rate as basis of power adjustment, we use a target E_b/I_o of 5.5dB to adjust forward and reverse power. Specifically, each forward traffic channel power is adjusted every simulation cycle, which occurs every 0.5 second (the simulation update interval) to achieve a target E_b/I_o of 5.5 dB. A step size of 0.5 dB is used for power adjustment, and each adjustment can take multiple steps to reach the target. However, since the relationships between E_b/I_o and FER for a few typical scenarios from some sources are obtained, power adjustment can also be based on FER by using lookup table. In this case, each forward traffic channel power is adjusted on sample-by-sample basis every 0.5 second to achieve a target FER of 1%.

For the particular cell size used in the simulator (cells with radii of 3.85 kms are used), system wide power allocation is made as follows:

<i>Cell (EIRP)</i>	<i>36.6 dBm</i>
<i>Pilot(EIRP)</i>	<i>28.55 dBm</i>
<i>Sync(EIRP)</i>	<i>16.6 dBm</i>
<i>Paging(EIRP)</i>	<i>22.6 dBm</i>
<i>Traffic (EIRP)</i>	<i>19.224 dBm</i>

RL Open Loop Power Control:

Mobile transmitted power is updated every 0.5 seconds as following [4]:

$$P_t \text{ (dBm)} = -73\text{dBm} - P_r + \text{NOM_PWR} + \text{INIT_PWR} + \text{Access Probe Corrections} \quad (12)$$

The initial mobile transmission power is determined through the probing process to obtain target E_b/I_o , the open loop power control is triggered every half second to compensate for path loss and shadowing loss. Open loop power control is based on the mobile measuring AGC power and adjusting transmitting power accordingly. Open loop power control deals with macroscopic fading that is assumed correlated between down link and up link frequencies.

RL Closed Loop Power Control:

Closed loop power control is also implemented on top of open loop power control in similar fashion to that of forward power control, i.e., based either on frame error rate or on target E_b/I_o of 5.5 dB, to compensate for fluctuation in interference level. Note that since Rayleigh fading is not modeled in the simulator, the main purpose of closed loop power control is to compensate for changes in interference level and slow shadowing rather than fast Rayleigh fading.

RL closed loop power control is implemented as follows. Every update period (0.5 second) the reverse link E_b/I_o (or FER) is computed and compared with a target value of E_b/I_o (or FER). Based on the difference between the target and the received values of E_b/I_o , the base station directs the mobile to increase or decrease its transmitted power by $0.5x$ dB (x is equal to the number of power control adjustment steps).

It is worthwhile noting that the frequency of closed loop power control in IS-95 and in the simulator is 800Hz and 2Hz, respectively. Finer power control cannot be implemented in the simulator because the simulator fundamental time clock is 0.5 seconds. To bridge the difference between the two implementations, it is assumed that multiple power control steps can be done in the simulator every update period.

Forward Power Control:

Transmitted FL traffic channel power is updated every 0.5 seconds in order to maintain a target value of E_b/I_o at the mobile station. The target value depends on the mobile speed, channel profile and on whether the mobile is in soft handoff or not. However, in the simulator a fixed target E_b/I_o of 5.5 dB is assumed.

5.5.2 Supplemental Channel Power Control

Since DCCH and supplemental channel share the same bandwidth and use orthogonal Walsh code, they suffer almost the same interference. We perform open loop power control and closed loop power control for the fundamental CH and DCCH using IS-95 power control algorithm. For supplemental CH, power adjustment is based on the power control of associated DCCH.

As supplemental channels support high rate packet data service, retransmission and ARQ are used to achieve the target packet error rate and to reduce transmitting power. We assume the BER of the packet data QoS is BER_1 , and the target BER for power control is BER_2 , then the difference between BER_1 and BER_2 is compensated by retransmission. The data virtual transmission rate is given by:

$$R_{virtual} = R_{tr} * \frac{1}{1 + N_f * (BER_2 - BER_1)} \quad (13)$$

Where N_f is number of bits per frame; $R_{virtual}$ is the data virtual transmission rate; and

R_{tr} is the data channel transmission rate. (In this case, $R_{tr}=144\text{kbps}$)

We set target bit error rate for the supplemental channel equal to that for DCCH, this also implies that the received bit energy of supplemental channel should be the same as that of DCCH. Under this strategy, we have the following power assignment.

When a data mobile is in the active state, the transmission power is chosen:

$$P_{sup\ pl} = \left(P_{dcch} * \frac{R_{sup\ pl}}{R_{dcch}} \right) * \eta \quad (14)$$

Where $P_{sup\ pl}(R_{sup\ pl})$ is supplemental channel transmission power (data rate = 144kbps);

$P_{dcch}(R_{dcch})$ is the DCCH transmission power (data rate = 4.8kbps).

The Bit Energy Ratio η between supplemental channel and DCCH is given by:

$$\eta = \frac{E_{sup\ pl}}{E_{dcch}} \quad (15)$$

When a data mobile is in standby state or idle state, no transmission happens in the supplemental channel.

5.6 Handoff

For fundamental channel (voice service) and DCCHs, IS-95 like soft hand off (SHO) is used in the simulation.

For the supplemental channel (data service), asymmetrical traffic is considered in the simulation: hard hand off is implemented. A supplemental channel active set(SCAS) is introduced to support supplemental channel handoff procedure. A SCAS in our simulation cases contains a handoff target pilot that is the strongest one in the MS's current DCCH active set. A timer T_{HHO} is used to prevent a ping-pong effect and a MS must stay with a BS for at least T_{HHO} seconds is used for supplemental CH.

5.7 Highlights of System Model

Table 6 highlights the simulated system model.

Table 6: System Overview

System Model		Generator Model		Environment Model	
Chip Rate	3.6864	Voice	FL/RL activity: 0.42/0.40	Path Loss	Hata
MS mobility	F/M/S=4/3.3			Shadowing σ	6dB
BS antenna	Non-sectorized	Stream Data	FL/RL activity: 1	Rayleigh Fading	Not considered
Eb/Io Requirement	5.5db for all	Burst Data	ETSI's UMTS model	Noise Floor	-118 dBm @1.25MHz
Data Rate	144kbps	Call Arrival	Poisson		

5.8 Simulator Structure and Flow Chart

The Wideband CDMA Network Simulator (W_CNS) simulates the behavior of a proposed wideband CDMA communication system and generates a number of statistics that describe the performance of the system. This section describes the module architecture, and its major flow control. The W_CNS allows mobile to move around in the simulation plane. Consequently, the high-level algorithms such as handoff, power control and call setup must be simulated.

Figure 13 shows the simulator module architecture and the way they exchange information. The W_CSN simulator consists of 9 modules, including Generators, Resource management, Initialize and control, Call setup, Mobile, Handoff control, Measurements, Power control and Statistics. The modules' names are self-explanatory in terms of accomplished tasks.

As it is shown in the module architecture, when a mobile is generated, a call setup process takes place. The call could be either origination or termination. The call setup process involves base station assignment based on pilot strengths measurement by the mobile, power allocation, access probe to determine the optimal mobile transmission power, and traffic channel allocation. After call setup, a voice mobile is assigned an exponentially distributed call holding time with a mean value of 120 seconds, while a

burst data mobile invokes a session generator. Then the mobile moves around following a defined mobility model. The mobility model defines the speed change and direction change. As the mobile moves, forward power control and reverse open loop power control constantly adjust the power at both base station and mobile, handoff is performed whenever handoff conditions are satisfied. The other two modules are Measurements and Statistics. The Measurements module is responsible for calculating path loss, interference and E_b/I_o etc. The Statistics module collects the statistics.

Figure 13 Simulator module architecture

The flow chart of the simulator is shown in Figure 14.

Figure 14 W_CNS Simulator Flow Chart

Chapter 6 Simulation Results

The main objective of this chapter is to investigate the impact of power control and power allocation plan on system behaviors in wideband CDMA systems. The system behaviors of interest are: system stability (in terms of variance of numbers of users in the system), interference distributions and frequency reuse factor.

In a CDMA system, a sophisticated power allocation plan combined with appropriate power control algorithms provides stable system behavior. Users in such a system exhibit tolerable level of interference and their QoS are well met. Under such stable conditions the system performance is less sensitive to system parameters' selection.

6.1 Simulation Scope

The simulation focuses on: (1) The power allocation plan among data traffic (either burst data traffic or stream data traffic) and voice traffic and (2) Power control algorithms for high rate data traffic. The factors that have been investigated are listed in Table 7.

Table 7 Simulation Scope

Issues to be Simulated		Investigation Scope
Power Allocation	Data Traffic vs. Voice Traffic	$\eta = 0.6, 0.8, 1, 1.2$
Interference	Reverse Link	Central Cell, the First Tier and the Second Tier
	Forward Link	
System Stability	Num of Burst Data Users vs. Num of voice users	Traffic load profile: 0.3:0.7, 0.2:0.8, 0.06:0.94
	Num of Stream Data Users vs. Num of Voice Users	Traffic load profile: 0.3:0.7, 0.2:0.8, 0.06:0.94
Eb/Io	Data Traffic & Voice Traffic	Central Cell, the First Tier and the Second Tier

Note: η is the bit energy ratio between supplemental and DCCH channels.

According to the simulation scope, the following simulation cases have been completed, as shown in Table 8.

Table 8: Simulation Case Parameters

Case No.	Load (Erlangs)	Load profile (V, BD, SD)	η	Total Simulation Time
Case 1	42	0.8, 0.0, 0.2	1.0	2000 s
Case 2	42	0.8, 0.0, 0.2	0.8	2000 s
Case 3	42	0.8, 0.2, 0.0	1.0	380 s
Case 4	42	0.8, 0.2, 0.0	0.8	380 s
Case 5	20	0.7, 0.0, 0.3	1.0	2000 s
Case 6	20	0.7, 0.0, 0.3	0.8	2000 s

Where

- V stands for percentage of voice traffic, BD stands for percentage of burst data traffic and SD stands for stream data traffic;
- η is the bit energy ratio between supplemental and DCCH channel, which is defined in Eq. 15 ;
- A certain amount of warm-up time is needed to build up the MS population on the simulation plane. The total simulation time includes 200s warm-up time (when no statistic is collected) and 1800s or 180s simulation time (when statistics are collected).

6.2 System Stability

System stability is described by the variance of numbers of users in a system during the simulation time. The mean value of the number of users in a system reflects the system capacity (when the system is in the heavy traffic load condition) or system carried traffic load (when the system is in light traffic condition). A sophisticated power control mechanism provides stable system behavior while inappropriate power control causes dynamically changing number of active users in the system. Figure 15 shows the system stability when the proposed power control and power allocation plan is used and only stream data traffic is presented with voice traffic (Case 1).

Stream Data and Voice Users in System

Figure 15 Numbers of stream data & voice users in system

Along with power allocation plan and power control algorithm, traffic load condition and traffic profiles are also important factors that affect system stability. Table 9 summarizes the results of comparing the mean value and the ratio of the standard deviation over the mean of numbers of data users and voice users under different conditions.

Table 9 Average number of users in system and their standard deviation

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
μ_d	23.33	22.43	25.89	38.67	26.06	25.14
σ_d / μ_d	0.124	0.133	0.106	0.138	0.159	0.150
μ_v	605.67	645.97	565.67	588.28	263.77	268.36
σ_v / μ_v	0.046	0.045	0.042	0.043	0.060	0.058

Note: μ_d (μ_v) stands for the mean value of numbers of data (voice) users in the system;
 σ_d (σ_v) stands for the standard deviation of numbers of data (voice) users in the system.

For odd numbered cases, the bit energy ratio η is equal to 1, and for even numbered cases, η is equal to 0.8.

In the case when stream data traffic is presented with voice traffic (Case1, Case2, Case5 and Case6), as the bit energy ratio η decreases, the average number of stream data users decreases while the average number of voice users increases. Under the condition of heavy traffic load, σ_d / μ_d increases as η decreases, which indicates that data users' behavior is less stable. Under light traffic load condition, σ_d / μ_d decreases as η decreases, which means that data users behavior is more stable. In all cases, voice users behavior gets more stable as η decreases.

When the burst data traffic is present with voice traffic as case 3 and case 4, system behavior is different. As the bit energy ratio η decreases, both number of burst data users and number of voice users increase. However, system stability tends to be slightly worse.

Comparing stream data cases and burst data cases, we can get the following conclusion: When the system supports stream data, the number of data users must kept small. On the other hand, when the system supports burst data the number of data users could be large but the system may become unstable.

In general, system behavior is less sensitive to the bit energy ratio η selection than to traffic load profile, as we compare the first four cases with the last two cases.

6.3 Interference

In the cases of stream data plus voice (case1 and case2), on the FL, the interference distribution is insensitive to the selection of the bit energy ration η as shown in figure 16.

Central Cell FL Interference

16-a) Central cell FL interference

1st_Tier FL Interference

16-b) 1 st_Tier FL interference

16-c) 2 nd_Tier FL interference

Figure 16 FL interference distribution when only stream data traffic presents

However, in the reverse link, the interference distribution is more sensitive to η as shown in figure 17. As the bit energy ratio η decreases, high interference appears less frequently on the RL. That is because as η decreases, the transmitted power of stream data users decreases which directly reduces their interference contribution to the system, and users suffer less interference, which is consistent with the simulation results.

Central Cell RL Interference

17-a) Central cell RL interference

1st_Tier RL Interference

17-b) 1 st_Tier RL interference

17-c) 2 nd_Tier RL interference

Figure 17 RL Interference distribution

In the cases when only burst data traffic occupies the supplemental channel, the interference distributions on both RL and FL are less sensitive to the bit energy ratio η , as shown in Figure 18.

In all simulation cases, it is shown that the interference does not follow Gaussian distribution as may be the case when only voice traffic is present.

18-a) FL interference

18-b) RL interference

Figure 18 Interference distribution when only burst data traffic presents

6.4 Frequency Reuse Factor

Another key system performance measure used extensively in the literature is the frequency reuse efficiency. It is defined by Eq. (10) and is an important parameter which gives a good indication of the spectral utilization efficiency of CDMA systems. Note that in this work we use the frequency reuse factor (FRF) to mean frequency reuse efficiency. On the FL, the FRF distribution remains the same among the simulated cases. On the RL, the FRF distribution varies from case to case as shown in figure19. However, it still insensitive to the bit energy ratio η .

Figure 19 FL & RL Traffic Channel FRF Distribution

Chapter 7 Conclusions and Recommendations

7.1 Conclusions

In this thesis, we have focused on power control and power allocation plan in multimedia wideband DS-CDMA systems through simulation. Interference distribution in such a system has been discussed. In order to provide design recommendations for the next generation multimedia wireless networks, the simulation cases have been selected to be very close to real world systems.

First we reviewed the state of the art research on power control and power allocation plan in both single service (voice) and wideband DS-CDMA systems. In single service (voice) CDMA systems, power control algorithms have been well studied and deployed in current generation CDMA systems such as IS-95. It has been shown that power control efficiency directly affects the system capacity. The factors that affect power control efficiency are power control algorithm, power control error modulation method, dynamic range and step size, power control loop delay and mobile's mobility. The received power is a log-normal distributed random variable and the variation of the received power impacts system capacity as discussed in chapter 3. In wideband DS-CDMA systems, power control for the fundamental channel has the same characteristics as that for single service (voice) CDMA system, while power control for high rate, high burst packet data channels will be different. All factors that affect the power control efficiency of the voice service also affect that of packet data service too, but the degree is different. In general, the power control error reduces traffic capacity of packet data service less than that of voice service. Besides, packet data service can employ retransmission and ARQ to reduce BER, so that system can take advantage of graceful QoS degradation to achieve the highest system capacity as addressed in chapter 4. Power allocation plan is another important issue discussed in chapter 4. Power assignments to different type of media plays a very important role in increasing the capacity of wideband CDMA systems. There are fixed power allocation and adaptive power allocation strategies. A fixed power

allocation is that a fixed power level is assigned for each type of media regardless of the system traffic load. An adaptive power allocation optimizes the power levels to achieve maximal traffic capacity while guaranteeing the BER requirement of real time traffic. Fixed power allocations are simple to implement, while adaptive power allocations can further increase the system capacity.

In this simulation study, in order to achieve stable system behavior and high system capacity in wideband CDMA system, equal signal strength strategy has been deployed for packet data services and equal error probability strategy for low rate voice service. Retransmission and ARQ has been employed to achieve target BER of high rate packet data service. The power assignment to high rate packet data service is proportional to data transmission rate and the bit energy ratio η as presented in chapter 5. The power control for supplemental channel is done through a dedicated control channel.

A simulation environment was developed for some relatively “real-world-like” simulation cases as described in chapter 5. It was found that the system’s state in terms of number of active users in the system is quite stable for small amount of system capacity assigned for high rate code channels. This means that no system crash and sudden disastrous degradation of quality of services. It is shown that the total interference level varies over a relatively small range. System behavior is insensitive to the bit energy ratio η selection. This implies that power management methods are sophisticated. The traffic profile has impact on the traffic frequency reuse factor (FRF). The FRF on the forward link shows little change for different service mixtures, while there are more variations on the reverse link. Due to only one supplemental channel deployed in each cell, the blocking rate, call drop rate and HO blocking rate of supplemental channel are high for traffic load of 42 Erlangs. Sudden switch of a supplemental channel from inactive state to active state causes degradation of voice services.

Therefore, we can make the following conclusions.

- The optimum power allocation plan is a compromise among the requirement of dissimilar services. The relationship between power allocation plan and the QoS is complex, i.e. non-linear. The proposed power allocation plan takes advantage of the characteristics of different services by employing different power control strategy for different services and utilize the interference similarity of DCCH and supplemental channel to complete supplemental channel power control through power control of DCCH. It is simple in implementation and the simulation results are very encouraging.
- System performance is sensitive to the accuracy of power control, but the sensitivity is service and traffic profile dependent. Packet switched service is less sensitive than that of circuit switched service. And under heavy traffic load condition, it is more sensitive than that under light traffic load conditions. Service with retransmission can take advantage of graceful performance degradation to achieve the highest system capacity. Since power control error has different impacts on different services, we should take this factor into account when choosing a power allocation plan.
- Power allocation plans should make all service qualities to be only marginally kept above required thresholds when the system capacity is reached. Over-good service quality wastes system resources. Power allocation should be adjusted if this happens.
- Power level assignment and power control are effective ways to integrate multi-service into one DS-CDMA cellular system. Beyond this, other control issues in multi-service scenario, such as admission control, are also important and should be addressed in future work. The preliminary results are very encouraging, which in turn suggests the benefit of further research in this area.

7.2 Summary of Contributions

Power control and power allocation plan are essential to the deployment of 3G CDMA system. This thesis has focused on the issues of power control and power allocation plan for 3G wideband CDMA system. The major contributions of this thesis are as follows:

- Proposed a simple but effective power allocation plan for 3G wideband CDMA system;
- Established a real world like simulation environment which can be expanded to a test bed for 3G wideband CDMA system;
- Provided recommendations for power control of 3G wideband CDMA system deployment

7.3 Future Work

In order to provide concise recommendation for 3G CDMA systems, the recommended future work is as follows:

- A simulation system with multiple supplemental channels should be built as a more sophisticated system test bed for 3G CDMA systems;
- Optimal power control law shall be further investigated and deployed in such a system;
- Forward link power control shall be studied and deployed in the system;
- Admission control issues in wideband DS-CDMA system shall be investigated.

Reference

1. Ramjee Prasad, "CDMA for Wireless personal Communications", *Artech House* , Boston London, 1996
2. T. S. Rappaport, "Wireless Communications : Principles and practice", *Prentice Hall*, New Jersey, 1996
3. Jay E. Padgett, Christoph G. Gunther, and Takeshi Hattori, "Overview of Wireless Personal Communications" *IEEE Comm. Mag. Jan, 1995, pp28-41*
4. TIA/EIA/IS-95, "Mobile Station - Base Station Compatibility Standard for Dual - Model Wideband Spread Spectrum Cellular System" , 1993
5. Alfred Baier, "Design Study for a CDMA-Based Third-Generation Mobile Radio System", *IEEE J. Sel. Areas in Comm. Vol. 12, No. 4, May 1994, pp 733-742*
6. Ning Guo "An Overview of Third Generation Wireless System Development" , *Technical Report #960903, Nortel, March 17,1997*
7. "3G Mobile Wireless System Strawman Concept Presentation", *Department 2W21-1, Nortel , June, 1997*
8. Norihiko Morinaga, Masao Nakagawa and Ryuji Kohno, "New Concepts and Technologies for Achieving Highly Reliable and High Capacity Multimedia Wireless Communications Systems", *IEEE Comm. Mag., January 1997, pp 34-40*
9. Michel G. Jansen and Ramjee Prasad, "Capacity, Throughput, and Delay Analysis of a cellular DS-CDMA system with Imperfect Power Control and Imperfect sectorization", *IEEE Trans. Vehi. Technol., Vol. 44, Feb. 1995, pp 67-72*
10. Klein S. Gilhousen, "On the Capacity of a Cellular CDMA System", *IEEE Trans. Vehi. Technol. Vol. 40 No.2, May 1991, pp 303-311*
11. Sudheer a Grandhi, " Centralized Power Control in Cellular Radio Systems", *IEEE Trans. Vehi. Technol. Vol. 42 No.4, Nov 1993, pp 466-468*
12. Lee J, "Erlang Capacity of OC-CDMA with Imperfect Power-Control", *Electronic Letters, Vol.33 , No.4, Feb.13 1997, pp 259-261*

13. Priscoli FD, "Effects of Imperfect Power-Control and User Mobility on a CDMA Cellular Network", *IEEE J. Sel. Areas in Communication*, Vol.14 No.9, Dec. 1996 , pp 1809-1817
14. Lee CC, "Closed-Loop Power-Control In CDMA System", *IEE Proc. Commun.* Vol.143, No.4 Aug. 1996 pp231-139
15. Chang PR, " Adaptive Fuzzy Power-Control for CDMA Mobile Radio Systems", *IEEE Trans. Vehi. Technol.* Vol. 45 No.2, May 1996, pp225-236
16. Zorzi M, " Simplified Forward-link Power-Control Law in Cellular CDMA", *IEEE Trans. Vehi. Technol.* Vol.43 No. 4 Nov 1994, pp1088-1093
17. Sheikh A, "Throughput Enhancement of Direct-Sequence Spread-Spectrum Packet Radio Networks by Adaptive Power-Control", *IEEE Trans. Commun.* Vol.42 No. 2-4 Feb-Aprl. 1994, pp 884-890
18. Jason T.-H. Wu; Evaggelos Geraniotis "Power control in multi-media CDMA networks" , 1995 *IEEE 45th Vehicular Technology Conference.* pp. 789-93 vol.2
19. Jianming Wu; Kohno, R. "Wireless multimedia CDMA system based on transmission power control" *Sixth IEEE International Symposium on Personal, Indoor and Mobile Radio Communications. PIMRC'95. Wireless: Merging onto the Information Superhighway* vol.1, pp. 36-40
20. Sampath, A.; Sarath Kumar, P.; Holtzman, J.M., "Power control and resource management for a multimedia CDMA wireless system" *Sixth IEEE International Symposium on Personal, Indoor and Mobile Radio Communications. PIMRC'95. Wireless: Merging onto the Information Superhighway* p. 21-5 vol.1
21. Yuming Lu; Brodersen, R. "Unified power control, error correction coding and scheduling for a CDMA downlink system" *Proceedings IEEE INFOCOM '96* pp. 1125-32 vol.3
22. Wu, J.; Kohno, R., "Wireless CDMA systems with flexible traffic control for multi-media communications" 1995 *Fourth IEEE International Conference on Universal Personal Communications* .pp. 728-32
23. Shee Yao; Geraniotis, E., "Optimal power control law for multimedia multirate CDMA systems" 1996 *IEEE 46th Vehicular Technology Conference*, vol.1 pp. 392-6
24. Teck-Hon Hu and Max M.K. Liu, "Power control for wireless multimedia CDMA systems", *Electronic letters*, 10th April 1997, vol.33 No.8 pp.660-662

25. Bo Wu, Qiang Wang , “Performance analysis of a multimedia CDMA network with coding and power control”, *ICCT'96, vol.2, pp. 1118-22*
26. Ashwin Sampath, P. Sarath Kumar and Jack M. Holtzman, “On Setting Reverse link Target SIR in a CDMA System”, *IEEE 47th Vehicular Technology Conference, vol. 2, pp.929-933*
27. Kojiro Hamabe, Shousei Yoshida and Akihisa Ushirokawa, “Forward-link Power Control Utilizing Neighboring-cell Pilot Power for DS-CDMA systems”, *IEEE 1997*
28. Qiang Shen “Power Assignment In CDMA Personal Communication Systems With Integrated Voice/Data Traffic”, *IEEE 1996*
29. C-J. Chang, J-H. Lee, and F-C. Ren, “Design of Power control mechanisms with PCM realization for the uplink of a DS-CDMA cellular mobile radio System”, *IEEE Trans. Veh. Technol., vol. 45, no.3, pp522-530, Aug. 1996*
30. Dong Geun Jeong and Wha Sook Jeon, “Rate-Controlled Data Transmission for IS-95 CDMA Networks”, *IEEE VTC'1997 vol 3. pp 1567-1571*
31. Ning Guo, Salvatore D. Morgera, and Paul Mermelstein, “Common Packet Data Channel (CPDC) for integrated Wireless DS-CDMA Networks”, *IEEE J. Sel. Areas in Comm. Vol 14, No.4, May 1996, pp.735-749*
32. Zbigniew Dziong, Ming Jian and Paul Mermelstein, “Adaptive Traffic Admission for Integrated Services in CDMA Wireless-Access Networks.” *IEEE J. Sel. Areas in Comm. Vol. 14, No.9, Dec. 1996, pp1737-1747*
33. Wen-Bin Yang, Evangelos Geraniotis, “Admission Policies for Integrated Voice and Data Traffic in CDMA Packet Radio Networks”, *IEEE J. Sel. Areas in Comm. Vol. 12, No.4, May 1994, pp654-664.*
34. Jeffrey M. Capone and Lazaros F. Merakos, “Integrating data traffic into a CDMA cellular voice system”, *Wireless Networks 1, 1995 , pp389-401*
35. J.E. Wieselthier and A. Ephremides, “A distributed reservation scheme for spread spectrum multiple access channels,” *GLOBECOM, San Diego, CA, 1983, pp. 659-665*
36. Jianming Wu, Ryuji Rohno, “Performance Evaluation of Wireless Multimedia CDMA Networks Using Adaptive Transmission control.”, *IEEE J. Sel. Areas in Comm. Vol. 14, No. 9, Dec. 1996 pp 1688-1697*

37. Dong In Kim, June Chul Roh, "Random Assignment/Transmitter-oriented Code Scheme for Centralizes DS/SSMA packet Radio Networks" *IEEE J. Sel. Areas in Comm. Vol 14, No. 8. Oct. 1996, pp. 1560-1568*
38. Roman Pichna, Qiang Wong, "A medium-Access Control Protocol for a cellular packet CDMA Carrying Multirate traffic.", *IEEE J. Sel. Areas in Comm. Vol. 14, No. 9, Dec. 1996, pp 1728-1735*
39. Alex E. Brand and A. Hamid Aghvami, "Performance of a joint CDMA/PRMA protocol for mixed voice data transmission for third generation mobile communication", *IEEE J. Sel. Areas in Comm. Vol. 14, No. 9, Dec. 1996, pp 1698-1707*
40. Lijun Tan , Qi Tu Zhang, "A Reservation Random Access Protocol for Voice/Data Integrated Spread-Spectrum Multiple-Access Systems." *IEEE J. Sel. Areas in Comm. Vol. 14, No. 9, Dec. 1996, pp 1717-1727*
41. Mohsen Soroushnejad, Evaggelos Genaniotis, "Multiple-Access Strategies for an Integrated Voice/Data CDMA packet Radio Network", *IEEE Trans. on Comm. Vol. 43, No2/3/4, April 1995, pp934-945*
42. Fook Loong Lo, Tung Sang Ng, and Tony T.Y., "Performance Analysis of a Fully-Connected, Full-Duplex CDMA ALOHA Network with Channel Sensing and Collision Detection." *IEEE J. Sel. Areas in Comm. Vol. 14, No. 9, Dec. 1996, pp. 1708-1716*
43. Wei Huang and vijay K. Bhargava, "Power control in Multimedia cellular CDMA networks: Literature Review", Technical Report, University of Victoria, June 1997
44. S. Ariyavisitakul, "SIR-based Power Control in CDMA system", *IEEE GLOBECOM'92, pp868-873*
45. Ashwin Sampath, Narayan, B. Mandayan and JACK M. Holtzman " Erlang Capacity of a power controlled integrated voice and data CDMA system", IEEE 1997
46. Chin Fong Kou and Harry Leib, "Power Imbalance Effects on Packet CDMA", *IEEE J. Sel. Areas in Comm. Vol14, No. 9, Dec. 1996, pp 1830-1840*
47. Adnan Abu-Dayya, Chang_gang Zhang, "Fuzzy Logic Controlled Soft Handoff for IS-95 CDMA systems", *Technical Report #970603, Nortel*
48. Steve Dennett, "The cdma200 ITU-R RTT Candidate Submission to US TG8/1: cdma2000 System Description" V0.17, June 1, 1998

IMAGE EVALUATION TEST TARGET (QA-3)

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