Key Technologies for Hierarchical CDMA Cellular Wireless Systems

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Brief Introduction

This book concentrates mainly on the study of a CDMA system. Eight general problems of wireless cellular system including the perfect/imperfect power control, perfect/imperfect sectorization, integrated voice/data services, burst admission strategy, static analysis, dynamic analysis, hierarchical architectures, and overlaid situations with TDMA are addressed as they relate to the CDMA. Basic propagation characteristics are summarized.

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Preface

The third generation wireless cellular systems have been under intense research and discussion recently and will emerge around 2001. Extensive investigations have been carried into the application of a Code Division Multiple Access (CDMA) system as a wireless interface for IMT2000/UMTS (International Mobile Telecommunications system 2000/Universal Mobile Telecommunications System). Especially, many research and development (R & D) projects in the wideband CDMA have been going on in U.S, Europe, Japan and Korea. The mobile system can supply multimedia communication with anyone at any time from anywhere. What will be the multiple access schemes for IMT2000/UMTS? According to many research results, the wide band CDMA will be the strongest candidate for it[1-4].

CDMA will play a major role in establishing a global IMT - 2000/UMTS, which is very different from the previous FDMA and TDMA. Then, there are many topics left for us to study and difficult issues which will be solved in the future development and challenge. This book concentrates mainly on the study of a CDMA system. Eight general problems of wireless cellular system including the perfect/imperfect power control, perfect/imperfect sectorization, integrated voice/data services, burst admission strategy, static analysis, dynamic analysis, hierarchical architectures, and overlaid situations with TDMA are addressed as they are related to the CDMA. Basic propagation characteristics are summarized.

Chapter 1 Introduction: An overview of CDMA development is presented. Especially, the milestones for CDMA development starting from the 1950s after the invention of the Shannon theorem. The CDMA protocols in Japan, USA, Europe, and Korea and Its merits in the application are also mentioned.

Chapter 2 Fundamentals of Radio Communications: In this chapter, we give the fundamentals of cellular communications, cell splitting, and propagation and multipath characteristics of a radio wave. The models often used in the investigation of cellular wireless systems are given.

Chapter 3 Outage Probability and Capacity of Forward Link: For a better understanding of the effect of Forward Link Power Control Strategy (FLPCS) on the outage probability and fading environments on the system, this chapter has presented a theoretical analysis of forward link in a CDMA cellular system by introducing the τ-th power of distance driven control strategy[11] under practical fading environments. Based on the power control, the user capacity and outage probability of the system are estimated and discussed. In particular, we consider the impact of fading environments

and investigate the "hole" phenomenon proposed by R. R. Gejji[12] about the analysis of forward link. The "hole" point is defined as the upper bound point of the total Interference-to-Signal Ratio (ISR).

Chapter 4 Static Analysis and Dynamic Analysis in a CDMA Cellular System: In this chapter, using a standard propagation model, the performance evaluation of a CDMA cellular system with the high data rate services and the burst admission for the reverse and forward links is investigated. In this approach, we propose "Equivalent Load" to estimate two cases of the system termed as the static analysis and the dynamic analysis. Performance measures of the static analysis obtained include the system capacity plane, outage probability and throughput. Performance measures of the dynamic analysis obtained include the allowed maximum data rate and the constraint sets between the load situation and the data rate.

Chapter 5 Reverse Link of Macrocell/Microcell Hierarchical Structure: For hot spot areas, macrocell/microcell hierarchical cellular architectures have been proposed for future cellular mobile communication system. In this chapter, assuming the imperfect power control as the received signal as the random variable which follows log-normal statistics, and employing different attenuation models for macrocells and microcells, the reverse link capacity plane and outage probability of the system in the perfect/imperfect power control are examined and quantified with and without perfect cell sectorization based on IS-95.

Chapter 6 Forward Link of Macrocell/Microcell Hierarchical Structure: In order to depress the multi-user interference and increase capacity, the forward link power control strategy is adopted in the macrocell/microcell hierarchical cellular system using CDMA. The effects of the hierarchical structure and the power control are estimated and discussed on the forward link in this chapter. The forward link outage probability and capacity plane for this hierarchical cellular system are investigated. Its feasibility is also discussed.

Chapter 7 TDMA/W-CDMA and N-CDMA/W-CDMA Overlaid Systems: A simplified analysis is presented for the reverse link maximum capacity trade-offs, spectrum efficiency and its multi-rate features of TDMA/W-CDMA and N-CDMA/W-CDMA overlaid systems based on the measurement of Signal-to-Interference Ratio (SIR). In order to increase spectrum efficiency, the other important interference suppression techniques used in the analysis are the ideal notch filter and the signal level clipper for W-CDMA system transmitters and receivers. We first propose the concepts of the notch filtering depth and signal level clipping depth in this chapter.

Chapter 8 Cellular System with Cell Splitting into Macrocell and Microcell: In this chapter we develop a general model to study the forward link capacity and outage probability of a DS-CDMA cellular system with mixed cell sizes. The numerical results and discussions with previous published results of reverse link are summarized.

Chapter 9 Spatial Correlation Functions and Their Applications: In this chapter, we derive spatial correlation functions of linear and circular antenna arrays for three types of angular energy distributions: a Gaussian angle distribution, the angular energy distribution arising from a Gaussian spatial distribution, and uniform angular distribution. The spatial correlation functions are investigated carefully. The spatial correlation is a function of antenna spacing, array geometry and the angular energy distribution. In order to emphasize the research and their applications in diversity reception, as an example, performance of the antenna arrays with Maximal Ratio Combining (MRC) in correlated Nakagami fading channels is investigated, in which analytical formulas of average Bit-Error-Rate (BER) for the spatial correlation are obtained.

Chapter 10 Space Time Coding and OFDM Technology: In this chapter, we first mainly study the performance of OSTBCs (Orthogonal Space-Time Block Coding) over correlated and uncorrelated Rayleigh channels and get the results by computer simulation. In the following, we proposed a reasonable approach that uses OFDM (Orthogonal Frequency Division Multiplexing) technology to reduce ISI (Inter-Symbol Interference) in frequency-selective fading channels. The theoretical analysis and simulation of STBC-OFDM system show that the STBC with a combination of broadband OFDM can reduce the impact of multipath fading and achieve a very high data rate transmission robustness in the MIMO (Multiple-Input Multiple-Output) frequency selective fading channel, simulation results confirm the superiority of our approach, and lay a theoretical basis and applications for further study of the combination of STBC technology and MIMO-OFDM system.

In this book, we have investigated eight important issues in CDMA cellular wireless system shown in Fig. 1.4. These issues are treated in Chapters 3, 4, 5, 6, 7, 8, 9 and 10. We hope this book will help the researchers in their work in this technology field.

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CONTENTS

1 Introduction

1.1 Motivation of This Research

The third generation wireless cellular systems have been under intense research and discussion recently and will emerge around 2001. Extensive investigations have been carried into the application of a code division multiple access (CDMA) system as a wireless interface for IMT2000/UMTS (International Mobile Telecommunications system 2000/Universal Mobile Telecommunications System). Especially, many research and development (R & D) projects in the wide-band CDMA have been going on in U.S, Europe, Japan and Korea. The mobile system can supply multimedia communication with anyone at any time from anywhere. What will be the multiple access schemes for IMT2000/UMTS? According to many research results, the wide band CDMA will be the strongest candidate for it[1-4].

1.2 Review of CDMA Wireless Cellular Communication

1.2.1 An Overview of CDMA Cellular System

Spread spectrum communication technology has been used in military communications for over half a century, primarily for two purposes: to overcome the effects of strong intentional interference (jamming), and to hide the signal from the eavesdropper (covertness). Techniques developed to counteract intentional jamming have also been proved suitable for communication through dispersive channels in cellular network applications. At first, we highlight the milestones for CDMA development as follows[2-4]:

Pioneer Era

(1) 1949 John Pierce: Time hopping spread spectrum

(2) 1949 Claude Shannon and Robert Pierce: basic ideas of CDMA

(3) 1950 De Rosa-Rogoff: Direct Sequence spread spectrum (DS-CDMA)

(4) 1961 Magnuski: near-far issue

(5) 1970 Several developments for military field and navigation systems

Narrowband CDMA Era

(1) 1978 Cooper and Nettleton: cellular application of spread spectrum

(2) 1980 Investigation of narrowband CDMA techniques for cellular application

(3) 1986 Verdu: Formulation of optimum multiuser detection

(4) 1993 IS-95 protocols

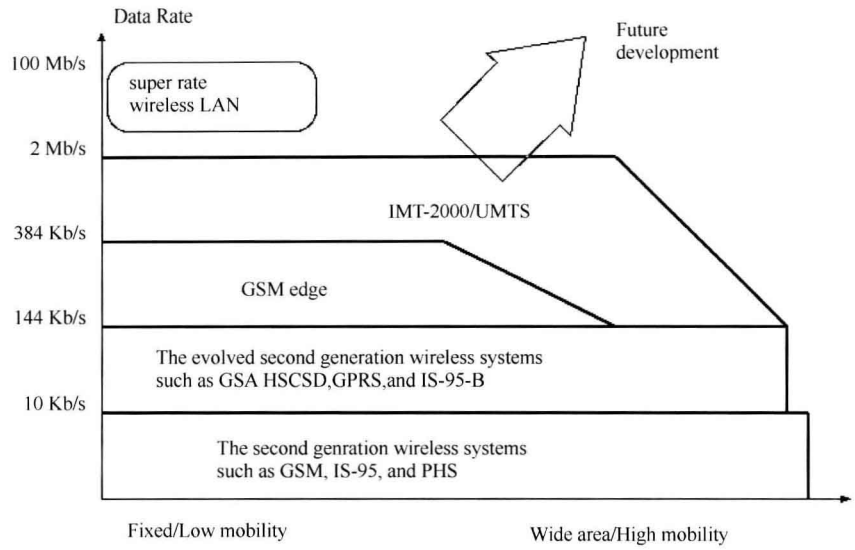

Fig. 1.1 Data rate vs. coverage and mobility.

Wideband CDMA Era

(1) 1995 Japan Core-A
Europe FRAMES FM2
USA CDMA2000
Korea TTA-I, TTA-II

(2) 2001 Commercialization of wideband CDMA applications

The development of an appropriate multiple access technique is going to be one of the major challenges. In fact, one of the most important aspects in achieving the ultimate goal of future wireless personal communication systems is the proper choice of a multiple access technique. The necessities for such placement of CDMA are as follows: 1) it can achieve synchronous communication, 2) the frequency band for each terminal does not need partitioning, 3) simultaneously transmitting two or more terminals can be captured successfully, and 4) the probability of success for packet transmission decreases with the number of simultaneously transmitting terminals and CDMA system is highly resistant to multi-path propagation.

Recently, extensive investigations have been carried out into the application of CDMA system as an air interface multiple access scheme for IMT-2000/UMTS, because it appears that it is a strong candidate for these systems. Some positive points of the CDMA systems are 1) soft capacity (i.e., there is no hard limit on the system capacity), 2) soft handover, 3) inherent diversity, 4) enhanced the spectrum efficiency, 5) unity cluster size (Cluster size is equal to a constant value in CDMA), and 6) simplified frequency planning and system deployment. Then, many research and development projects in the filed of CDMA have been going on in Europe, Japan, USA, and Korea.

It has also the introduction of research work.

1.2.2 An Overview of Mixed Rate Traffic in CDMA System

The third generation is expected to be deployed by the year 2000 via Universal Personal Communication Systems (UPCS), which will provide universal services and local multimedia services. The emerging requirements for higher rate data services and better spectrum efficiency are the main drivers identified for the third generation systems. Therefore, the research on the call admission of data users, admission schemes and the limited coverage have drawn attentions all over the world. In ITU, the third generation systems are termed as IMT-2000, and in Europe, UMTS. In ITU, these networks have been developed and they were previously called Future Public Land Mobile Telephone System (FPLMTS). In ETSI, UMTS standardization began from 1990 when the sub-technical committee SMG5 was established. For the mixed rate services, the main objective for the third generation networks can be summarized as follows[4-6]:

(1) Full coverage and mobility for 144 Kb/s, preferably 384 Kb/s,

(2) Limited coverage and mobility 2 Mb/s,

(3) High spectrum efficiency compared to the existing systems, such as TDMA, N-CDMA,

(4) High flexibility to introduce new services in the system, such as image transmission, data file transmission, and wireless internet access.

The bit rate targets have been specified according to the Integrated Services Digital Network (ISDN) rate. The rate, 144 Kb/s can provide the ISDN 2B + D digital channel composed of two B channels and one D channel, 384 Kb/s can provide the ISDN H0 channel for the conference TV, and 2 Mb/s can provide the basic rate transmitted in the public networks. However, recently it may be that the third generation services are neither the ISDN nor B-ISDN based services. Market demands will determine what data rates will be offered in the commercial systems. Then, the supply of the mixed rate services in the future CDMA system has drawn the attentions of the researchers to study. Figure 1.1 shows the relationship among data rate, coverage area and mobility. With the development of advanced techniques, the users with higher data rates and higher mobility will be supported wherever they are located.

1.2.3 An Overview of Macrocell/Microcell Hierarchical CDMA System

IMT-2000/UMTS is intended to provide a wide range of mobile services to the users via a range of mobile terminals that enable the use of pocket telephone in anywhere, indoor or outdoor, in a home, in an office, on a street or at an airport[6-8]. For these purposes, USA and Japan are also equally engaged in developing these systems. Figure 1.2 shows a view of a global mobile system consisting of satellite, macrocells, microcells and picocells. An integrated satellite cellular system is a real goal of our future wireless personal communication system.

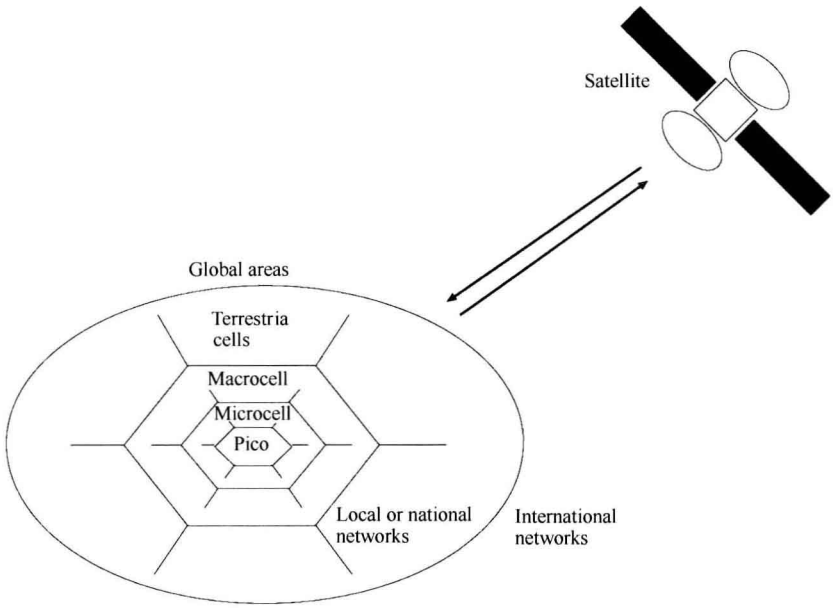

Fig. 1.2 The structure of wireless system.

For this goal, microcells and picocells are capable of providing more capacity than macrocell per unit area and are also attractive, recently. There were some researches on the hierarchical systems of CDMA or TDMA. Using different antenna elevations allows the cell size and radio interference to be restricted using the shielding effects of the surrounding buildings. It makes the macrocell/microcell hierarchical system to become the possible applications when the bandwidths are shared in the each tier. Under what conditions, the systems have the improvement in spectrum efficiency compared to the spectrum partitioning that becomes the important problem for us to study.

In these systems, how to increase the capacity and spectrum efficiency becomes significant issues in which much research studies have to be done, for example on the impact of imperfect power control, on the imperfect sectorization that could decrease the feasibility of the systems, but power control, the titled antenna and other techniques will enhance the ideas considering the hierarchical system useful. Then there are many themes left for us to research.

1.2.4 An Overview of Overlaid Systems

One of the major problems in introducing a new system is that the new system must coexist with the old system. This means that the performance of W-CDMA systems in the presence of existing TDMA carrier based systems or N-CDMA systems is vitally important to the way in which the potential benefits of each system can be taken advantage of.

Due to their well-known multiple-access capability, anti-multipath capability, and

anti-interference capability, CDMA techniques[9,10] have been widely studied and applied. Because of the expected scarcity in the available bandwidth, techniques optimizing spectrum efficiency for mobile communication systems will become increasingly important. That is the reason why Dynamic Channel Allocation (DCA), Frequency Hopping (FH), and the possibilities of such overlaid systems as N-CDMA/W-CDMA overlaid systems and W-CDMA/TDMA overlaid systems are frequently studied.

The cellular concept seems quite conductive to the overlaid system, which is feasible only when the existing narrow-band CDMA system or TDMA system are sparsely populated. In cellular overlay, a system with high capacity and high spectrum efficiency could be implemented by utilizing the infrastructure of the existing systems, which would be quite beneficial in a situation. Based on the basic principles of overlay, the capacity and spectrum efficiency would decrease rapidly if there are no protection techniques among the overlaid systems. Multiple-cross interference suppression techniques are major factors which make the overlaid systems available applications. Then, these techniques have drawn more and more attentions all over the world.

Figure 1.3 depicts the conceptual example of frequency and power allocation in the overlaid system. It becomes the important issues for us to study how to optimize the bandwidth allocation, suppress the multiple-cross interference and optimize the power allocation.

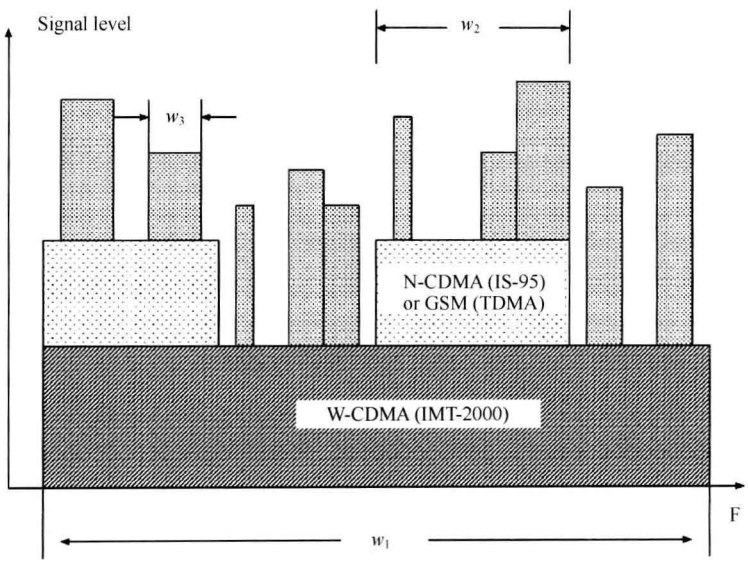

Fig. 1.3 A conceptual example of signal level versus frequency (F) in the overlaid system.

1.3 Main Objectives of the Book

1.3.1 Main Issues

CDMA will play a major role in establishing a global IMT-2000/UMTS, which is very different from the previous FDMA and TDMA. Then, there are many topics left for us to study and difficult issues which will be solved in the future development and challenge. These main issues are shown as follows:

(1) How to effectively investigate the performance of CDMA system and entirely consider the every situation become a difficult problem whether the used methods are simulation approach or theorematic analysis.

(2) In the future, universal services and local multimedia services will be needed. Then, the emerging requirements for higher rate data services and better spectrum efficiency are the main drivers. Deriving from the effective call admission strategies and investigating the performance of the CDMA system with multimedia services are also the difficult issues.

(3) The research of power control, rake receiver, soft handover strategies, multiuser detection and hybrid modulation will be significant topics in CDMA systems.

(4) The other important topic is the research of the cellular architectures. Effectively deriving from the system layout, such as macrocell/microcell hierarchical systems and spectrum overlaid systems, will be a matter of great importance to us.

(5) One of the essential problem is the research of interference rejection technique because it is a necessary and sufficient condition for achieving the systems with higher capacity and spectrum efficiency. How to do for this goal is also one of the difficult issues.

This book concentrates mainly on the study of a CDMA system. Eight general problems of wireless cellular system including the perfect/imperfect power control, perfect/imperfect sectorization, integrated voice/data services, burst admission strategy, static analysis, dynamic analysis, hierarchical architectures, and overlaid situations with TDMA are addressed as they are related to the CDMA. Basic propagation characteristics are summarized. The detailed book abstracts are described in the following Fig. 1.4.

1.3.2 Main Concept

Theoretical Analysis and Simulation

The facility or process of interest is usually called a system and in order to study it scientifically we often have to make a set of assumptions about how it works. These assumptions usually take the form of mathematical or logical relationships. If the relationships that compose the model may be possible to use mathematical methods (such as algebra, calculus, or probability theory) to obtain exact information on questions of

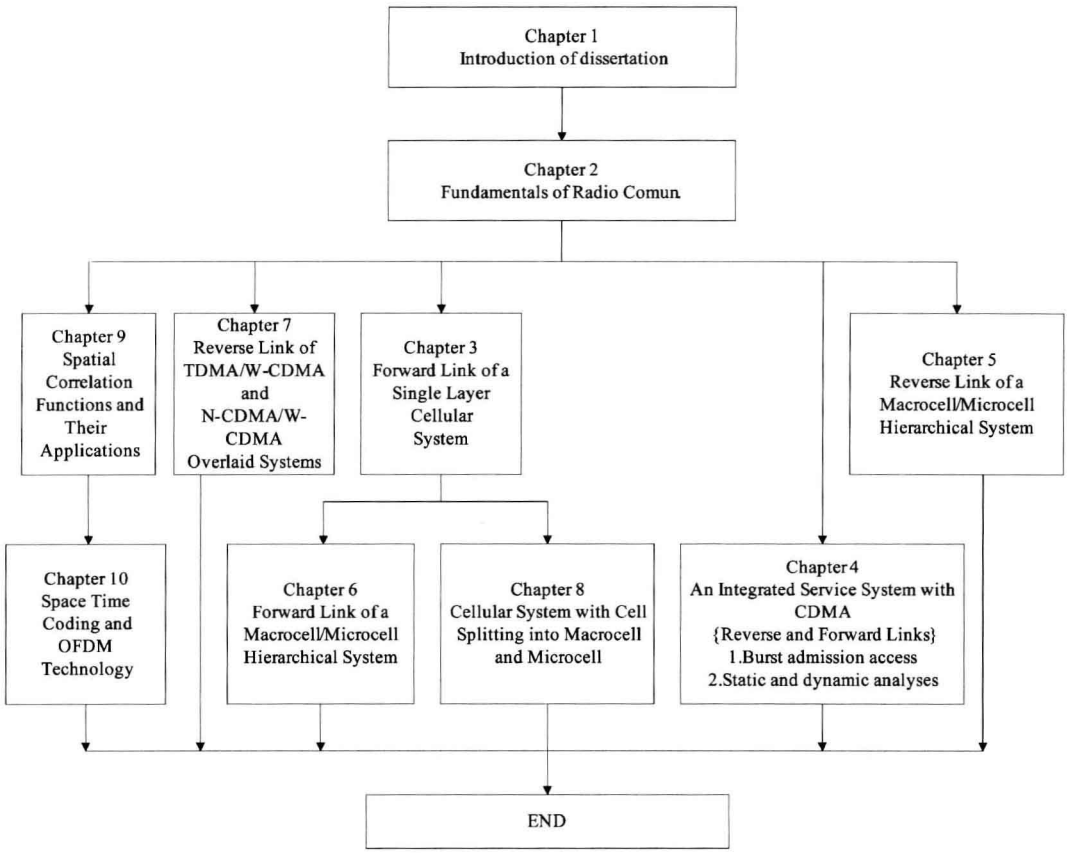

Fig. 1.4 Diagram of the book.

interest, this is termed as an analytical solution. However, most real-world systems are too complex to allow realistic models evaluated analytically and these models must be studied by means of simulation which we use a computer to evaluate a model numerically and data are gathered in order to estimate the desired true characteristics of the model.

At some point, as for the lives of most systems, there is a need to study them to gain some insight into the relationships among various components or to predict performance under some new conditions being considered. Figure 1.5 maps out different ways in which a system might be studied. In this book, the DS-CDMA system is modeled as mathematical model by using analytical solution. According to this, the analytical solutions are got.

Assumptions of the DS-CDMA cellular system

(1) Power Control

Co-channel interference caused by the frequency reuse in each cell with DS-CDMA is the single most restraining factor on the system capacity. Transmitter power control schemes have been proposed to control the interference for a given channel, in particular

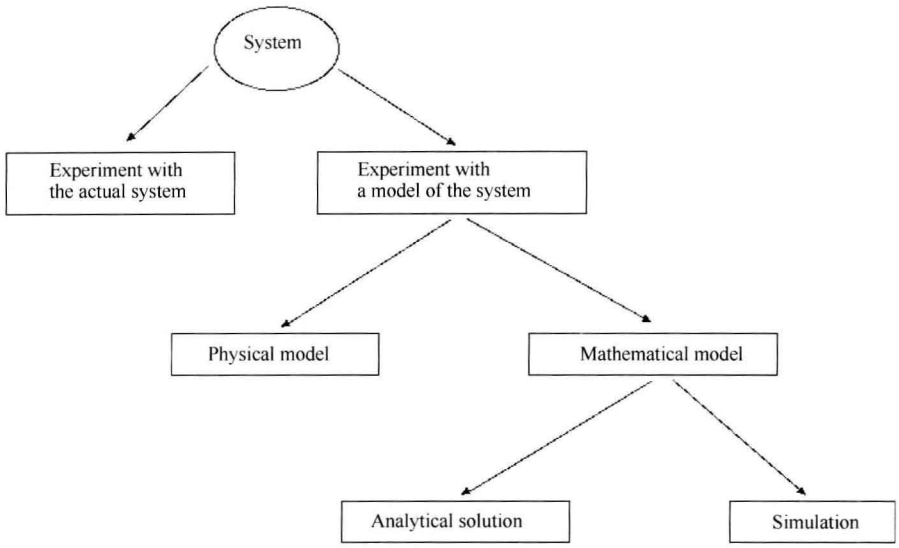

Fig. 1.5 Ways to study a system.

for DS-CDMA system[12-15]. Transmitter power control is an effective way of increasing the system capacity and transmission quality in cellular wireless systems.

Because of the differences between the reverse link and forward link, the power control schemes used in the analysis are different from each other. Whether the link is reverse or forward links, the purpose of the power control schemes is the same as to make ISR of each user in the system. According to vast literature, the power control schemes adopted in theoretical analysis are summarized in Fig. 1.6.

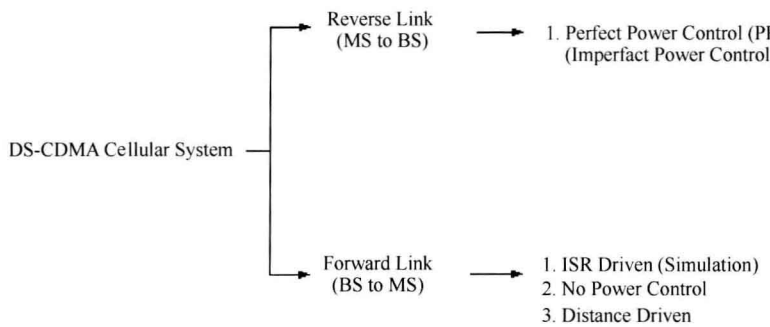

Fig. 1.6 Power control schemes.

(2) Wireless media

Figure 1.7 illustrates the fading characteristics of a mobile radio signal. The rapid fluctuations caused by the local multipath are known as the fast fading (Rayleigh fading)[1,2]. The long-term variation in the mean level is known as slow fading (log-normal fading)[1,2]. The slow fading is caused by movement over distances large enough to produce gross variations in the overall path between the base station and the mobile.