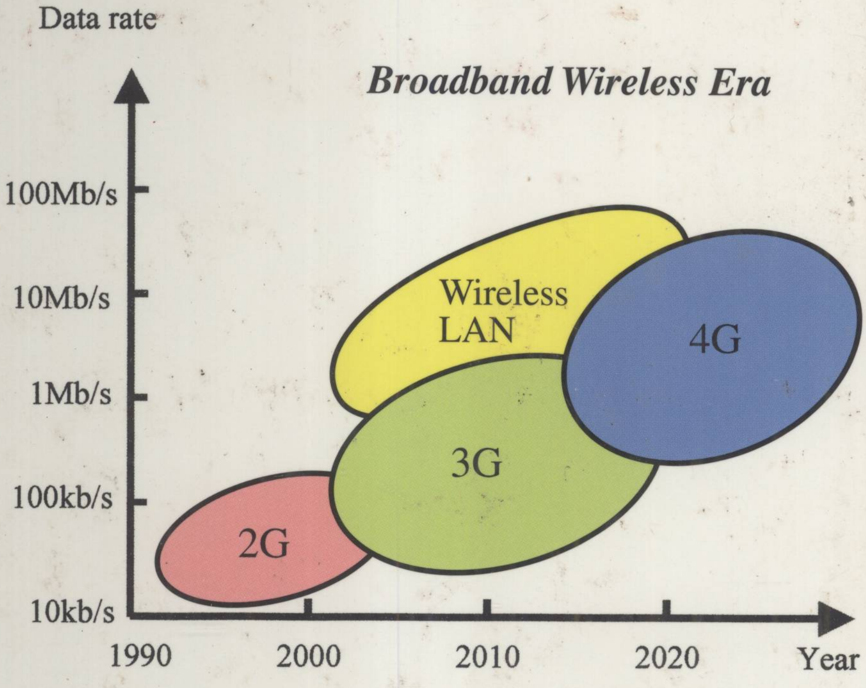
BROADBAND WIRELESS COMMUNICATIONS

3G, 4G and Wireless LAN



Jiangzhou WANG

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3G, 4G and Wireless LAN

by

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University of Hong Kong

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Broadband Wireless Communications

3G, 4G and Wireless LAN

To

Leiping, April, Angela and Larry

Preface

The broadband wireless communications field is growing at an explosive rate, stimulated by a host of important emerging applications ranging from 3G, 4G and wireless LAN. Wideband CDMA and CDMA2000 will be used for 3G. OFDM+CDMA might be a good choice for 4G, CDMA overlay will possibly be used for new-generation broadband wireless LAN. For system planners and designers, the projections of rapidly escalating demand for such wireless services present major challenges and meeting these challenges will require sustained technical innovation on many fronts.

The text of this book has been developed through years of research by the author and his graduate students at the University of Hong Kong. The aim of this book is to provide a R&D perspective on the field of broadband wireless communications by describing the recent research developments in this area and also by identifying key directions in which further research is needed. As a background, I presume that the reader has a thorough understanding of digital communications and spread spectrum/CDMA.

The book is arranged into 13 chapters. In **chapter 1**, some key specifications of 3G WCDMA are described and discussed. These techniques include channel coding, rate matching, modulation and spreading, power control, cell search, transmit diversity, soft-handoff, and so son.

In **Chapter 2**, the coherent RAKE reception of Wideband CDMA signals with complex spreading is considered. A dedicated pilot channel, which is separate from data channels, is used for the purpose of channel estimation. Based on a digital implementation, the coherent demodulation scheme is presented. Pilot channel estimation error due to multiple access and multipath interference is studied. System performance is evaluated by means of bit error rate. The analysis shows that the error of channel estimation significantly degrades system performance and can be effectively suppressed by low pass filters (LPFs). A discussion on the envelope variation of complex spread signals is also included, which illustrates that the complex spread signal has more stable envelope than the dual-channel spread signal.

Multicode CDMA is a new transmission scheme for flexible and high-speed data communications. The basic idea of multicode CDMA is to assign multiple channelization codes to any given user. If these channel codes are orthogonal, the self-interference among them can be eliminated in an AWGN channel. However, in a multipath environment, these intra-user signals from different delay paths no longer maintain orthogonality and thus cause interference, i.e. multicode interference (MCI), to each other. In high-speed data networks, where the number of users is much less than in the voice networks, the MCI may represent a large portion of the total interference and has great impact on the system performance. In **Chapter 3**, a complex spreading multicode wideband CDMA receiver with RAKE structure and MCI cancellation is studied. By pilot aided channel estimation, the MCI associated with the reference user is regenerated and subtracted from the received signal. A complete and consolidated theoretical analysis is presented to show that the system performance is significantly improved by the MCI cancellation.

In **Chapter 4**, half-sine and triangular chip waveforms are proposed for the locally generated early and late despreading codes in a coherent DLL for a single user in a DS/SS systems. Both ideal and band-limited received signals are investigated. These non-rectangular waveforms reduce the effective loop noise power with only minor effect on the DLL sensitivity.

Chapter 5 is concerned with a direct sequence code division multiple access (DS-CDMA) system sharing common spectrum with a narrowband waveform for wireless LAN applications. A suppression filter at a receiver is employed to reduce the narrowband interference. The average up-link bit error rate (BER) performance is investigated how to be influenced by various parameters. **Chapter 6** presents the behavior of reflection coefficients of a stochastic gradient lattice (SGL) filter applied to a CDMA overlay system. Analytic expressions for coefficients for a two stage filter are derived with the presence of narrowband interference and additive white gaussian noise (AWGN). It is shown that the coefficients of the lattice filter exhibit separate tracking and convergent properties and that compared to a LMS filter, the lattice filter provides fast rate of convergence, while having good capability of narrowband interference suppression.

Adaptive power control has widely been used in DS/CDMA systems to overcome the so-called "near-far" problem. **Chapter 7** studies the adaptive open-loop power control of a cellular CDMA system, which is overlaid in downlink by a narrowband signal. The effects of downlink power allocation schemes to power control error in the presence of narrowband interference are analyzed and numerically computed. In order to get a minimum power control error in the CDMA overlay situations, an optimum downlink power allocation scheme is used, which works well for wide range of signal to narrow-band interference ratio. In **Chapter 8**, we investigate the effect of power control error of a closed-loop power controlled CDMA system with imperfect power estimation. By use of a simplified log-linear power control model, the power control error of a strength-based power control algorithm is studied in the presence of narrowband interference.

In **Chapter 9**, uplink multicarrier direct-sequence/slow-frequency-hopping (MC DS/SFH) CDMA systems are proposed, in which multiple

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Professor Milstein introduced me to CDMA overlay during my postdoctoral research. Since then, I have published extensively in this area. Professor Ng has been giving me much encouragement and support in my professorial carrier. Professor Adachi selflessly introduced me to several key issues in wideband CDMA. Professor Moeneclaey effectively supervised my Ph.D. dissertation. Dr. Sawahashi helped me much with patience in the understanding of 3G standard during my visit to NTT DoCoMo. Dr. Zhang was a Group Leader when I worked in a US company. Dr. Li was my classmate during my early Ph.D. study.

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Jiangzhou Wang received the B.S. and M.S. degrees from Xidian University, Xian, China, in 1983 and 1985, respectively, and the Ph.D. degree (with Greatest Distinction) from the University of Ghent, Belgium, in 1990, all in electrical engineering.

From 1990 to 1992, he was a Postdoctoral Fellow at the University of California at San Diego, USA, where he worked on the research and development of cellular CDMA systems. From 1992 to 1995, he was a Senior System Engineer at Rockwell International Corporation, Newport Beach, California, where he worked on the development and system design of wireless communications. Since 1995, he has been with the University of Hong Kong, where he is currently an Associate Professor. Dr. Wang has held a Visiting Professor position at NTT DoCoMo, Japan. He was a Research Fellow for two years in Southeast University, China, in 1980's. He was a Technical Chairman of the IEEE Workshop in 3G Mobile Communications, 2000. Dr. Wang has published over 100 papers, including more than 20 IEEE Transactions/Journal papers in the areas of wireless mobile and spread spectrum communications. He has written/edited two books, including this book.

Dr. Wang is an Editor for IEEE Transactions on Communications and a Guest Editor on Wideband CDMA for IEEE Journal on Selected Areas in Communications. He holds one US patent in the GSM system. He is a Senior Member of IEEE and listed in Marquis Who's Who in the World.

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Chapter 1

3G MOBILE COMMUNICATIONS

Abstract The standardization of third generation (3G) mobile systems is accelerating at a fast pace due to the proliferation of high-speed wireless multimedia communications and wireless internet services. There are three main standards for 3G: Wideband CDMA, CDMA2000 and EDGE. The first one is single carrier CDMA with bandwidth of 5MHz, whereas the second one is multicarrier CDMA based on US narrowband CDMA (IS-95). EDGE is TDMA based. Many enabling techniques including software radio, smart antennas and digital processing devices are greatly improving the spectral efficiency of 3G systems. In this chapter, some key specifications of only WCDMA are described and discussed.

Keywords: Wideband CDMA, Channel Coding, Rate Matching, Modulation and Spreading, Power Control, Cell Search, Transmit Diversity, Soft-handoff.

1.1 INTRODUCTION

Mobile communications services are penetrating into our society at an explosive growth rate. The major services the second generation mobile systems provide are limited to basic services (e.g. voice and low-bit rate data). We have entered the 21st century, when demands for a variety of wideband services (e.g. high speed Internet access and the video/high quality images transmission) will continue to increase. The third generation (3G) mobile systems (called IMT-2000, see Fig. 1.1) are being designed to support wideband services, at data rates as high as 2Mbps, with the same quality as fixed networks. It is everyone's wish that wireless could act like a wired connection. To realize true IMT-2000 systems, a new wideband wireless access technology incorporating as many recent technology developments as possible is necessary.

Wideband direct sequence code division multiple access (Wideband CDMA) is emerging as the predominant wireless access technology for the 3G systems and is being developed in the world. Wideband CDMA is designed to flexibly offer wideband services, such as wireless Internet services (i.e., peak rate of 384 kbps to download information from the Web) and video transmissions (data rate can be up to 2 Mbps) (see Figs. 1.1 and 1.2). Wideband is essentially about data rate. The physical limitations and impairments on radio channels (bandwidth constraints, multipath fading, noise and interference) present a fundamental technical challenge to reliable high data rate communications.

Wideband CDMA supports inter-cell asynchronous/synchronous operation, adaptive (variable rate) transmission and applications of advanced techniques such as adaptive antenna arrays and Turbo codes.

- Cell acquisition for inter-cell asynchronous operation, which does not require inter-base-station synchronization; therefore, there is no requirement on any external system such as GPS to allow for easy deployment in all types of environments.
- Adaptive (variable rate) transmission provides multimedia services. To achieve higher bit rates, multiple downlink physical channels (or multi-code) can be transmitted in parallel on one direction.
- The adaptive antenna array directs beam nulls to interference sources to maximize the signal to interference ratio of each user. In the case of voice-only services, the application of the antenna arrays is rather impractical because a large number of antenna elements is required. However, antenna arrays are particularly useful for multimedia communications in which different users are transmitting with different data rates. High rate users (Internet and video) although the number of them is not large, give significant interference to low rate users (in particular, voice users); thus, without adaptive antenna array, the link capacity would be significantly reduced. In Wideband CDMA, dedicated pilot symbols in both up- and downlink facilitate user-unique antenna patterns.

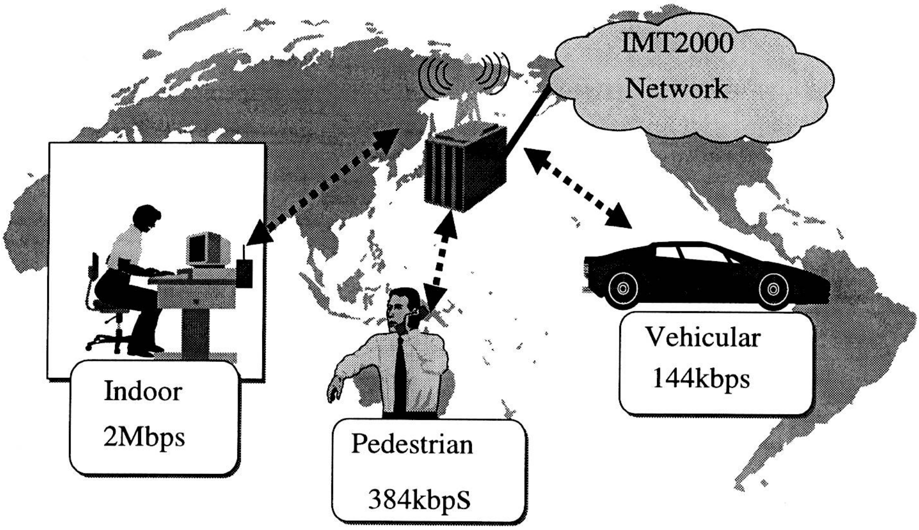

Fig. 1.1 3G mobile communications environment [12]

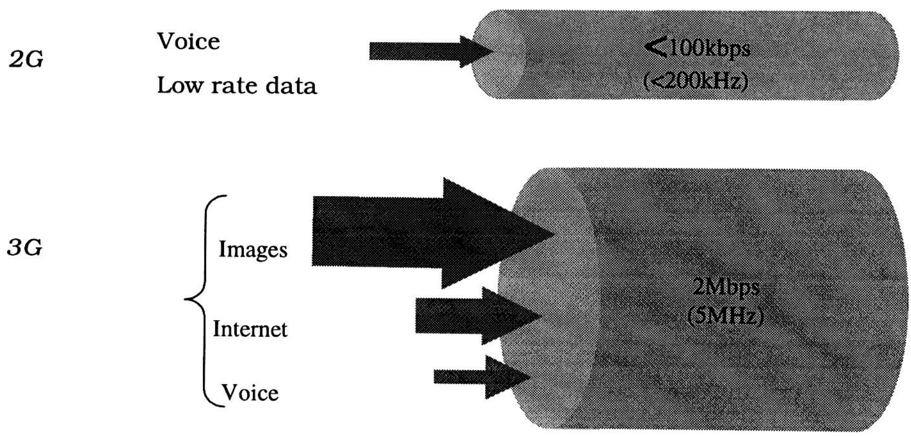

Fig. 1.2 Difference in data rate (bit pipe) between 2G and 3G systems.

control information consists of known pilot bits to support channel estimation for coherent detection, transmit power-control (TPC) commands, feedback information (FBI), and an optional transport-format combination indicator (TFCI). The transport-format combination indicator informs the receiver about the instantaneous transport format combination of the transport channels mapped to the simultaneously transmitted uplink DPDCH radio frame. There is one and only one uplink DPCCH on each radio link, no matter how many codes are used for data channels. Figure 1.3 shows the frame structure of the uplink dedicated physical channels. Each radio frame of length 10 ms is split into 15 slots, each of length T_{slot} = 2560 chips, corresponding to one power-control period.

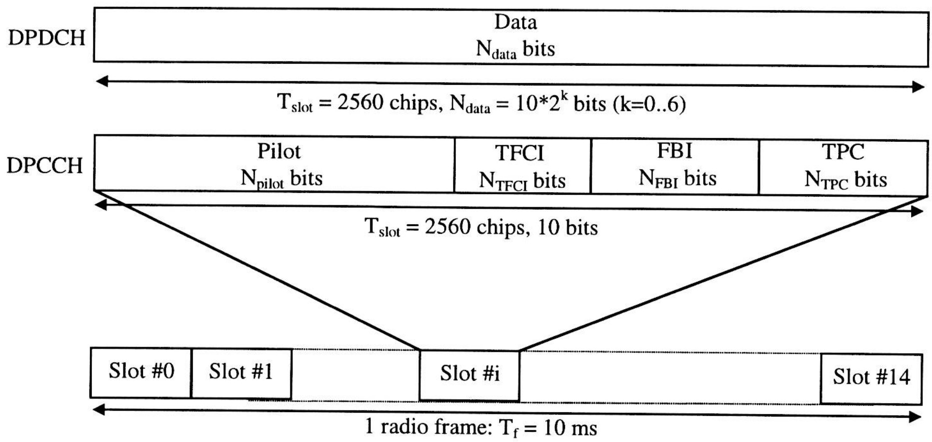

Figure 1.3 Frame structure for uplink DPDCH/DPCCH [4]

The parameter k in the figure determines the number of bits per uplink DPDCH slot. It is related to the spreading factor SF of the DPDCH as SF = $256/2^k$. The DPDCH spreading factor may range from 256 down to 4. The spreading factor of the uplink DPCCH is always equal to 256, i.e. there are 10 bits per uplink DPCCH slot. However, the exact number of bits of the uplink DPDCH and the different uplink DPCCH fields (N_{pilot}, N_{TFCI}, N_{FBI}, and N_{TPC}) is dependent on the channel data rate. For details, please see [4].

1.2.2 Downlink Channels

There is only one type of downlink dedicated physical channel, the Downlink Dedicated Physical Channel (downlink DPCH). Within one downlink DPCH, dedicated data, i.e. the dedicated transport channel (DCH), is transmitted in time-multiplex with control information (known pilot bits, TPC commands, and an optional TFCI). The downlink DPCH can thus be seen as a time multiplex of a downlink DPDCH and a downlink DPCCH, compared to uplink. Figure 1.4 shows the frame structure of the downlink DPCH. Each frame of length 10 ms is split into 15 slots, each of length T_{slot} = 2560 chips, corresponding to one power-control period. The spreading factor in the downlink may range from 512 down to 4.

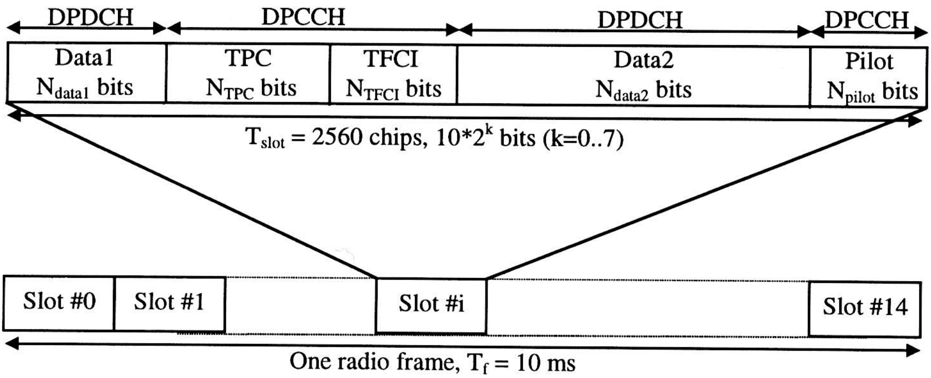

Figure 1.4 Frame structure for downlink DPCH

Common downlink pilot channels (CPICH)

In downlink, there are CPICHs. The CPICH is a fixed rate (30 kbps, SF=256) downlink physical channel that carries a pre-defined bit/symbol sequence. Figure 1.5 shows the frame structure of the CPICH.

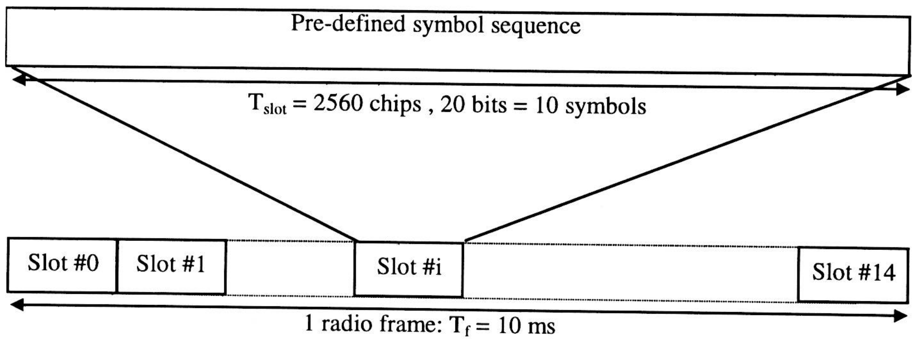

Figure 1.5 Frame structure for Common Pilot Channel