CDMA for Wireless Personal Communications

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Artech House
Boston • London

Library of Congress Cataloging-in-Publication Data
Prasad, Ramjee.
CDMA for wireless personal communications / Ramjee Prasad.
p. cm.
Includes bibliographical references and index.
ISBN 0-89006-571-3 (alk. paper)
1. Code division multiple access. 2. Wireless personal communications.
I. Title.
TK5103.45.P73 1996
621.3845–dc20 95-53774
CIP

British Cataloguing in Pubilcation Data
Prasad, Ramjee
CDMA for wireless personal communications
1. Code division multiple access 2. Wireless communication systems
I. Title
621.3'82

ISBN 0-89006-571-3

685 Canton Street
Norwood, MA 02062

International Standard Book Number: 0-89006-571-3
Library of Congress Catalog Card Number: 95-53774

10 9 8 7 6 5 4 3 2 1

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To
my parents
Chandrakala and Sabita Nath,
who inspired me in my childhood in making
deductions of geometry that taught me to think of
the horizon of current knowledge of science and technology.

Later on:

To my parents-in-law
Kamal and Aditya Narain,
who motivated me to fly beyond the horizon that taught me to write the thoughts.

I dedicate this book to these four souls to rest with peace in heaven.

Preface

सहजं कर्म कौन्तेय सदोषमपि न त्यजेत् ।
सर्वारम्भा हि दोषेण धूमेनाग्निरिवावृताः ॥

saha-jaṁ karma kaunteya
sa-doṣam api na tyajet
sarvārambhā hi doṣeṇa
dhūmenāgnir ivāvṛtāḥ

Every endeavour is covered by some fault, just as fire is covered by smoke. Therefore one should not give up the work born of his nature, even if such work is full of fault.

-The Bhagvad-Gita (18.48)

Code division multiple access (CDMA) and hybrid CDMA are discussed in this book as they apply to wireless personal communications. Hybrid CDMA is defined as a combination of any two types of CDMA (e.g., direct sequence DS and frequency hopping FH) or CDMA with any other contention (e.g., ALOHA) or contentionless (e.g., time division multiple access, TDMA) multiple access protocols or CDMA with any other techniques (e.g., orthogonal frequency division multiplexing OFDM). Techniques (e.g., interference cancellation IC, joint detection JD) are introduced to enhance the performance of a wireless personal communication system. CDMA is treated here from the point of view of multiple access protocol. Therefore a separate

chapter is devoted to multiple access protocols. This is the first book to give a broad treatment to CDMA as a multiple access protocol for a wireless channel.

This book is the outcome of research contributions by the master, doctoral, and postdoctoral candidates of the Telecommunications and Traffic-Control Systems Group of Delft University of Technology (DUT), The Netherlands, under my supervision. The idea of converting our research contributions into a book came to me in 1992 when I gave a course on "Code Division Multiple Access (CDMA) for Wireless Personal Communications" for the Advanced Studies in Electrical Engineering (ASEE) programme. I realized a shortage of teaching material for this course. The teaching material, which I prepared in 1992 with the help of Casper van den Broek and Michel G. Jansen, was revised during the lecture preparations in 1993, 1994, and 1995. Until now no such book was available on the market. An attempt has been made to fill this gap in the literature.

The research program in the field of CDMA for wireless communications started in DUT in 1989. My first master student for the CDMA studies was Howard Sewberath Misser. He studied direct-sequence spread-spectrum multiple access for indoor wireless communications. Later on Casper A.J. Wijffels and several other students investigated throughput and delay of a CDMA network. The effect of imperfect power control has been studied by Michel G. Jansen. Richard D.J. van Nee and some other students applied the investigation of direct-sequence spread-spectrum to land mobile satellite communications.

In the beginning the study of the direct-sequence spread-spectrum was a very high priority; the research activities in hybrid direct-sequence (DS)/slow frequency (SFH) CDMA had been carried out at a low profile by some master students. Luc Vandendorpe from the Catholique University of Louvain-la-Neuve, Belgium, who worked with me as a postdoctoral research scholar, made interesting contributions in hybrid DS/SFH CDMA. Later on René G.A. Rooimans continued this research activity. He is still active in the investigation of hybrid DS/SFH CDMA with Omar Fatah.

Before the CDMA investigations at DUT, significant research activities had been carried out in the field of random multiple access protocols with the capture effect for wireless communications which was originally developed by Jens C. Arnbak. Jens and I investigated the inhibit sense multiple access (ISMA) protocol and concluded that ISMA is a good random multiple access scheme for indoor wireless communications. Later we also concluded that direct-sequence CDMA is a good access scheme for indoor wireless communications. Therefore we thought that a combination of CDMA and ISMA could be a very good hybrid CDMA protocol for indoor wireless computer communications. This subject was deeply studied by Jos A.M. Nijhof, Huub R.R. van Roosmalen, and master students. Random multiple access protocols in the wireless environment are still one of the key research topics at DUT. Casper van den Broek is currently studying several multiple access protocols for his doctoral research.

Bas W. 't Hart studied code synchronization. Interference cancellation was investigated by Roy K. Sukdeo with Zeke Bar-Ness from the New Jersey Institute of Technology, USA, who was on sabbatical at DUT during 1993-1994. Gerard J.M.

Janssen and Frank van der Wijk developed the concept of groupwise successive interference cancellation. Coexistence of CDMA and TDMA was investigated by Michael B.K. Widjaja. Joint detection CDMA has been investigated in great depth at the University of Kaiserslautern, Germany, by the radio research group headed by Walter Baier. This particular topic was contributed for the sake of completeness of the book by Peter Jung. Research activity in the field of multicarrier CDMA was initiated by Jean-Paul M.G. Linnartz. Later, this subject was investigated in great detail by Shinsuke Hara from the University of Osaka, Japan, who is a visiting scientist at DUT, doing postdoctoral research with me.

Completing this book gives me the same pleasure as a gardener feels upon seeing his garden full of flowers. Since this book has been completed with the help of several research contributions, I have tried my best to make each chapter quite complete in itself. This book provides an overview of CDMA for the benefit of young research students, engineers, and scientists in the field of wireless personal communications. This book will help generate many new research problems and solutions for future wireless personal communications. I cannot claim that this book is errorless. Any remarks to improve the text and correct the errors would be highly appreciated.

Acknowledgments

I would like to express my heartfelt gratitude to colleagues and students without whom this book would have never been completed. Jens Arnbak, with whom I had started this book, gave me full encouragement to finish it. Adriaan Kegel, Jos Nijhof, Dirk Sparreboom, Han Reijmers, Jean-Paul Linnartz, and Gerard Janssen supported me in supervising many graduate students whose results have been used in this book. Nel Kay helped me plan the book and gave her full support while I finished it. Eefje Ooms gave the final shape of the book. During the preparation of the text, Eefje Ooms, Antoinette Steinman, Sophia Chlimintzas, Claudia Hoogervorst, and Esmeralda van Dijke prepared the typescript of the book. Jane Zaat improved the English language.

I had interesting discussions with Zeke Bar-Ness from the New Jersey Institute of Technology, USA.Walter Baier and Peter Jung from the University of Kaiserslautern, Germany, are deeply acknowledged for their valuable contributions. The postdoctoral research scholars Luc Vandendorpe from the Catholique University of Louvain-la-Neuve, Belgium, and Shinsuke Hara from the University of Osaka, Japan, are acknowledged for their contributions. Richard van Nee, Homayoun Nikookar, Casper van den Broek, and Mqhele Dlodlo are thanked for use of their doctoral research results in the book. Michel G. Jansen, Frank van der Wijk, and Bas 't Hart, predoctoral students, are especially thanked for their valuable contributions.

Last but not least, the following master students are greatly acknowledged in generating several new results which have been used throughout in this book: H.S. Misser, C.A.J. Wijffels, E. Walther, R.R.J. Ponson, M.G. Jansen, H.R.R. van Roosmalen, A. Daryanto, R.G.A. Rooimans, P.H. Sinaga, H. Satyanegara, M.B.K. Widjaja, S. Srivastava, A. Soelaksono, R.K. Sukdeo, D.Y. Zhang, F. Çakmak, R.N. van Wolfswinkel, O. Fatah, H.L.A. Le, T.H. Lee, S. Grujev, J. Wigard, Z.Q. Lie, A.R. Prasad, N.R.Prasad, H. Çakil, A. Nollen, and F. Harmsze.

Contents

Chapter 1
Introduction

With the current rapid growth of technology, it can now emphatically be said that the objective of today's communication engineers to achieve a future wireless personal communication (FWPC) system, which was yesterday's myth (before 1970), will be tomorrow's reality (beyond 2000). FWPC systems will convert the already shrinking world into a global village. A future wireless personal communication system, defined as being the ultimate goal of today's communication engineers, will provide communication services from any person to any person in any place at any time without any delay in any form through any medium by using one pocket-sized unit at minimum cost with acceptable quality and security through using a personal telecommunication reference number.

1.1 FWPC EVOLUTION

A family tree for the FWPC system is shown in Figure 1.1 [1]. The objectives of the research and development of FWPC systems are focused in three technological platforms, namely, universal mobile telecommunication systems (UMTS), mobile broadband systems (MBS), and wireless customer premises networks (WCPN) [2]. UMTS is a multi-function, multi-service, multi-application digital system, evolving from currently operational second-generation systems, and several other ongoing second-generation systems.

The first generation was introduced in 1980 in analog form to provide local mobile speech services and it was then further extended to nationwide coverage. Various standard systems were developed worldwide: AMPS (advanced mobile phone service) in the United States, NTT (Nippon Telephone and Telegraph) systems in Japan, TACS (total access communications system) in the United Kingdom, NMT (Nordic Mobile Telephones) in European countries, and so on.

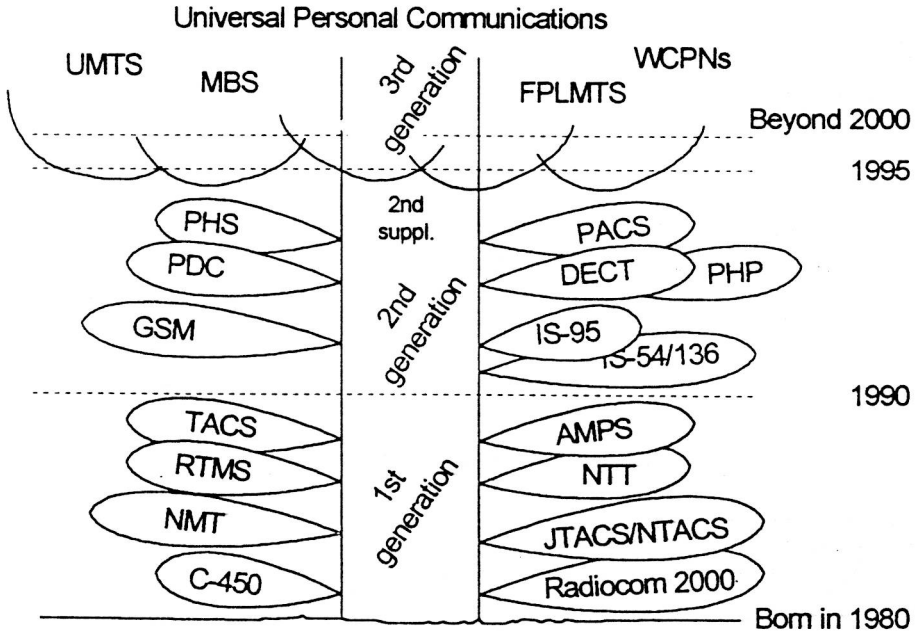

Figure 1.1 Family tree of wireless personal communications systems.

Fast user growth was observed. It penetrated up to 10% of the calls in North America, Western Europe and Japan. The access technique used was frequency division multiple access (FDMA). Capacity and quality were the major problems in the first-generation systems. In addition, systems were not compatible.

The advancement in digital technology gave birth to Pan-European digital cellular mobile (DCM) GSM (Groupe Spécial Mobile) systems in Europe, PDC (personal digital cellular) systems in Japan, and IS-54/136 and IS-95 in North America, which are the second-generation systems. Time division multiple access (TDMA) is used as the access technique, except for IS-95, which is based on CDMA (code division multiple access). The second-generation systems provide digital speech and short message services. These services are expected to penetrate to more than 20% of the call population. GSM has become deeply rooted in Europe and in several other countries worldwide [3]. Now GSM stands for "global systems for mobile communications." The development of new digital cordless technologies gave birth to the second supplement generation systems, namely, PHS (personal handyphone systems, formerly PHP) in Japan, DECT (digital European cordless telephone) in Europe, and PACS (personal

access communication services) in North America. It may increase the call penetration depth up to 30% and introduce many new services. Although the second generation and its supplement will cover local, national, and international services, it will still have one major drawback in terms of a universal service facility.

The third-generation is expected to be deployed by the year 2000 via universal personal communications systems (UPCS), which will provide universal speech services and local multimedia services. It is expected that the third-generation system will penetrate up to 50% of the telecommunication services population. The third-generation personal communication systems are in the process of development worldwide by the ITU (International Telecommunications Union) within the framework of the FPLMTS (future public land mobile telecommunications systems) activities. In Europe this is supported by the UMTS program within the European community. Both FPLMTS and UMTS programs are tightly related and expected to lead to consistent and compatible systems. Figure 1.2 shows the possible configuration for UMTS subnetworks and fixed networks.

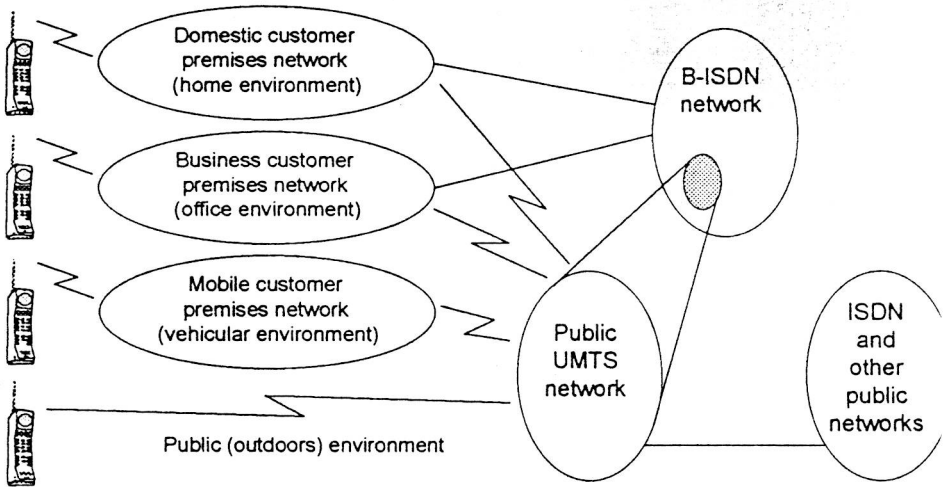

Figure 1.2 UMTS possible service configuration.

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 the pocket telephone in almost any location, indoor or outdoor, in home, office, or street. North America and Japan are also equally engaged in developing the third-generation systems in the UMTS direction. Looking at