FOUNDATIONS of MOBILE RADIO ENGINEERING

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CRC Press
Boca Raton Ann Arbor London Tokyo

Library of Congress Cataloging-in-Publication Data

Yacoub, Michel Daoud.
Foundations of mobile radio engineering / Michel Daoud Yacoub.
p. cm.
Includes bibliographical references and index.
ISBN 0-8493-8677-2
1. Mobile radio stations. 2. Mobile communication systems.
I. Title
TK6570.M6Y33 1993
621.3845—dc20 92-38563
CIP

Direct all inquiries to CRC Press, Inc., 2000 Corporate Blvd., N.W., Boca Raton, Florida 33431.

International Standard Book Number 0-8493-8677-2

Library of Congress Card Number 92-38563

Printed in the United States of America 1 2 3 4 5 6 7 8 9 0

Printed on acid-free paper

Preface

In the past few years that I have been involved with mobile radio communications I have felt the need for a textbook or a reference that would treat the various topics related to this challenging area in an accessible and comprehensive way. However, mobile radio engineering involves virtually all the areas of telecommunications, and a book covering the subject thoroughly would require many volumes and several authors.

Some of the phenomena of mobile radio communications have already been explored in various classic textbooks, where mobile radio would appear just as an advanced application case. Moreover, many techniques, initially used in other applications, are found to be perfectly suited to mobile radio needs. Therefore, writing a specialized book on this area would require a careful compilation of the various materials in the well-established literature.

This is only partially true. Since the emergence of the first cellular systems, a great deal of research has been undertaken and a significant amount of interesting results obtained. What initially used to belong to a very restricted area of research has now become the main part of most of the investigations. It seems to me that all the communications research and development activities are steering toward mobile radio applications.

To compile both the basic and the more advanced materials in a one-volume–one-author book is literally impossible. In this book I have endeavored to address what I consider to be a useful and broad subset of this vast field.

Intended for use by advanced students and professional engineers involved in mobile communications research, the book includes both basic and advanced materials covered in considerable depth. The chapters are ordered so that knowledge is acquired in a logical and progressive way. The reader will find, in sequence, an introduction to the subject, the description and analysis of the basic phenomena, some practical solutions to the problems, and more advanced materials. Each chapter starts with a preamble, abstracting the topics to be found in it, and ends with a section of summary and conclusions, where the main results and general comments are included. The mathematical derivations are meant to be clear, logical, and thorough; whenever necessary, additional information is appended at the end of the corresponding chapter, providing a self-contained book.

The book covers both analog and digital systems, making use of analytical as well as Monte Carlo simulation solutions to the various problems. The problem of cell coverage area is tackled on a deterministic and on a statistical

basis, whereas adjacent-channel and cochannel interference problems take into account the system traffic load. Digital techniques include speech coding and modulation schemes, with emphasis given to those used by the American and European systems. Multiple-access architectures, such as FDMA, TDMA, and CDMA, are investigated and the ALOHA access protocol is analyzed in a mobile radio environment. The book also explores the traffic engineering aspects, studying several channel allocation techniques where some new algorithms are included.

The book is divided into six parts.

Part I Introduction comprises Chapters 1 and 2.

Chapter 1 traces a brief history of mobile radio communications engineering, bringing up the main events that have contributed to its development. It also describes the various mobile radio services and explores the spectrum allocation problems.

Chapter 2 addresses the basic principles of cellular mobile radio systems, giving an overview of the main points to be considered in a system design.

Part II Mobile Radio Channel comprises Chapters 3 and 4.

Chapter 3 analyzes the mobile radio propagation phenomena, such as path loss, shadowing, and multipath propagation, and their statistics. The problem of cell coverage area is tackled on a deterministic and statistical basis. The boundaries between cells are also investigated, with the aim of determining the proportion of overlapped service areas.

Chapter 4 is entirely devoted to the various topics related to multipath propagation phenomena, such as time delay, delay spread, Doppler effect, coherence bandwidth, random FM, etc. It outlines the main points to be considered in field measurements. Finally, it describes some analog and digital mobile radio channel simulators.

Part III Diversity-Combining Methods comprises Chapters 5 and 6.

Chapter 5 analyzes the various diversity schemes used to combat fading. The problem is first approached from the macroscopic side and then from the microscopic side. The chapter also investigates envelope-combining methods, where they are assessed by a measure of the SNR obtained at the output of the combiners.

Chapter 6 examines the performance of digital transmission over a fading environment where several diversity techniques are used and compared. The chapter also includes an appendix on channel coding.

Part IV Noise, Interference, and Modulation comprises Chapters 7, 8, and 9.

Chapter 7 is concerned with noise and with cochannel and adjacent-channel interference problems. It investigates the influence of the traffic load on the adjacent-channel and cochannel interferences. Monte Carlo simulation is used to approach the problem of cochannel interference in a more realistic way.

Chapter 8 examines the analog modulation schemes, such as AM, SSB, and FM, in a mobile radio environment.

Chapter 9 describes and analyzes some speech-coding and digital modulation techniques in a mobile radio environment. Emphasis is given to those schemes used by the American and European mobile digital systems.

Part V Multiple Assess comprises Chapters 10 and 11.

Chapter 10 describes multiple-access architectures such as FDMA, TDMA, and CDMA. In particular, CDMA systems are investigated in the light of the information of spread-spectrum technology.

Chapter 11 analyzes the various multiple-access protocols such as CSMA, slotted ALOHA, and PRMA. In particular, the performance of the slotted ALOHA scheme is investigated in a mobile radio environment.

Part VI Traffic comprises Chapter 12.

Chapter 12 examines some of the main channel allocation techniques that can be used in a mobile radio system. More specifically, it analyzes one global approach by means of Monte Carlo simulation and a local approach by means of analytical methods, using some well-known tools from queueing theory.

The tutorial value of this book would make it suitable for use both in the classroom and as a reference. The book can be used as a textbook for a two-term graduate course, with the first six chapters and the remaining six comprising each term, respectively.

Acknowledgments

I am grateful to Professor Attílio J. Giarola for his encouragement and patient review of the manuscript. I am indebted to my colleagues of the Department of Communications, School of Electrical Engineering, at The State University of Campinas (UNICAMP) for their assistance and helpful inputs.

I have been privileged to share the wisdom and experience of the many engineers attending my courses who stimulated discussions and gave me valuable suggestions. In the same way, I have had the honor of supervising the research projects of many students who have contributed with original results, some of them partially included in this book. In particular, I thank J. C. E. Mencia, O. C. Branquinho, J. L. A. D'Annibale, G. Fernandes, E. J. Leonardo, N. F. Keffer, A. A. Shinoda, A. F. Victória, and E. Nisembaum.

I acknowledge the support of the School of Electrical Engineering at UNICAMP, the R & D Center of Telebrás (CPqD-Telebrás), Serifa Editoração e Informática, CNPq, Capcs, and Fapcsp.

Among those who have lent their help in different ways I would like to mention Professor K. W. Cattermole, Professor C. J. Hughes, Dr. J. Szajner, Dr. B. S. Ramos, Dr. C. D. Yacoub, Mr. J. Claypool, Ms. Sarah W. Roesser, and Ms. Janete S. Toma.

Finally, my wholehearted gratitude to my wife, Maria Nídia, and my children, Alexandre, Helena, Carolina, Ricardo, and Vinícius, for enduring the apparently endless writing period of this book.

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PART I
Introduction

CHAPTER 1

Mobile Radio System

This chapter traces a brief history of mobile radio communications, bringing up the main events that have contributed to the development of such an efficient and successful means of communication. Spectrum allocation problems and technological evolution—the latter addressing equipment packaging, modulation schemes, and system architecture aspects—are outlined. Some mobile radio services are then briefly described and system design considerations are examined. It is also shown that, because radio propagation does not recognize geopolitical boundaries, effective use of the spectrum is possible only if international agreement is achieved. Under such circumstances the International Telecommunication Union (ITU) has emerged to provide "worldwide harmony". The international frequency allocation for some radio services is then presented in tabular form.

1.1 INTRODUCTION

The first successful use of mobile radio dates from the late 1800s, when M. G. Marconi established a radio link between a land-based station and a tugboat, over an 18-mile path. Since then mobile systems have developed and spread considerably. The usefulness of mobile radio services was first recognized by the public safety services (police and fire departments and the forestry conservation, highway maintenance, and local government services), followed by the private sector (power, oil, motion picture, telephone maintenance, and transportation services, as well as taxis and lorry fleets). The growth rate of these services in the United States by the 1950s (when the number of subscribers was just a few thousands) was greater than 20% per year.[1] Consequently, by 1963 the number of users exceeded 1.3 million although only a few channels (about 12) were available.

These early systems (conventional mobile systems [CMS]) consisted of a base station whose transmitter and receiver were assembled on a hilltop. The coverage area was chosen to be large, in a way similar to the radio or

television broadcast services. The transmitter usually operated with high power (200 or 250 W [Reference 3]), assuring a large coverage area (25-mi radius).

Conventional mobile systems are usually isolated from each other, with only a few of them accessing the public switched telephone network. Those having connection with the telephone network are named *mobile telephone systems*, where the communication unit is assigned to the subscriber and not to a physical location.

1.2 CONVENTIONAL MOBILE SYSTEMS

By the end of the nineteenth century H. G. Hertz, a German scientist, demonstrated that radio waves could propagate in a wireless medium, in fact, over a path of a few yards, between transmitter and receiver. Still before the twentieth century, Marconi showed the first wireless communication "on the move" between a land-based station and a tugboat. Thereafter, many maritime mobile services were established and operated successfully.

On land, the Detroit Police Department started its experiments with mobile radio in 1921, first operating as a dispatching system. Initially, only the base station could transmit. Later the mobile unit was also able to communicate to the base station. The frequency used was around 2 MHz. Soon, other police departments installed their own systems. As a consequence, the available frequency spectrum became congested. By the middle of the 1930s the Federal Communications Commission (FCC) authorized four more channels between 30 and 40 MHz. In 1946, six channels near 150 MHz were available for use. In fact, due to technological restraints, out of those six channels only three could be utilized because of adjacent-channel interference problems. These radio frequencies were first used by the mobile telephone services. Starting in St. Louis, this system quickly spread throughout the United States. Shortly after, frequencies around 40 MHz were available for use on highways. Again the highway mobile services grew rapidly, although this did not seem to have worked out well due to radio interference. By the middle of the 1950s, due to the reduction of the channel spacing from 60 kHz to 30 kHz, a total of 11 channels could be used at 150 MHz. Almost at the same time, the FCC released 12 channels at 450 MHz. Up to that time the mobile telephone systems were manually operated, with each call having to be handled through an operator. It was only in the 1960s that the automatic systems appeared, allowing the subscribers themselves to do the direct dialling. Automatic mobile telephone systems operated initially with frequencies around 150 MHz, later moving to 450 MHz.

Already in 1975, after a long period of negotiations involving the mobile industries and the FCC, a 40-MHz band between 800 and 900 MHz was released. The year 1978 was marked by the beginning of a new era in mobile

communications history, when the first cellular system was sent into the field testing.[22]

1.3 TECHNOLOGICAL EVOLUTION

Before the Second World War, mobile radio systems were largely dominated by military (and paramilitary) users. Consequently, the evolution and development of such systems were supported by and closely linked to military needs, requirements, and standards.

Recently, however, this tendency has been reversing, as more and more mobile services are steering toward civil applications. Consequently, as far as system design and technology are concerned, commercial mobile systems have taken the lead.[14]

1.3.1 Equipment Package Evolution

The early mobile radio systems were equipped with vacuum-tube equipment requiring powerful batteries. In fact, before 1930 only the receivers were mobile,[2] implying one-way communication. Mobile transmitters soon appeared, but they were still bulky and heavy, requiring special power supplies. The total apparatus could occupy most of a vehicle's trunk space.

By the 1950s equipment was already small enough to be man-transportable, although the volume was still quite considerable and the main application was for military purposes.

Transistorization of mobile radio products started in 1957 with the power supplies. Soon after, the vacuum tubes in receivers and in some parts of transmitters were replaced by transistors, contributing to a 50% reduction of the volume, lower power consumption, and higher reliability. The packages could then be mounted in a car's dashboard or even on motorcycles. Maintenance costs diminished because of the reduced number of spare parts required and also because of the very rapid decrease of transistor prices. By the 1960s the mobile products were all being built with solid-state components. The design of the equipment introduced some new components, such as printed circuit boards, sockets, and heat sinks.

The first hand-held portable radios appeared in the 1960s, initially for commercial and later for military systems. At this point, mobile civil applications started to take the lead.

The change from transistors to integrated circuits was an obvious and natural step, occurring by the middle of the 1970s. By this time cordless telephones were already available. Today the equipment includes LSI and VLSI circuits, rendering the products smaller, lighter, and less costly.