

# Mobile Satellite Communications

## Principles and Trends

Second Edition

Madhavendra Richharia



WILEY

# **MOBILE SATELLITE COMMUNICATIONS PRINCIPLES AND TRENDS**

**Second Edition**

**Madhavendra Richharia**

*Knowledge Space Ltd., UK*

**WILEY**

This edition first published 2014  
© 2014 John Wiley & Sons, Ltd

*Registered office*

John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at [www.wiley.com](http://www.wiley.com).

The right of the author to be identified as the author of this work has been asserted in accordance with the Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book.

**Limit of Liability/Disclaimer of Warranty:** While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. It is sold on the understanding that the publisher is not engaged in rendering professional services and neither the publisher nor the author shall be liable for damages arising herefrom. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

*Library of Congress Cataloging-in-Publication Data*

Richharia, M. (Madhavendra)

Mobile satellite communications principles and trends / M. Richharia. – Second edition.  
pages cm

Includes bibliographical references and index.

ISBN 978-1-119-99886-0 (cloth)

1. Artificial satellites in telecommunication. 2. Mobile communication systems. I. Title.  
TK5104.R528 2011  
621.3841'56–dc23

2013031745

A catalogue record for this book is available from the British Library.

ISBN: 9781119998860 (Hardback)

ePDF: 9781118810064

epub: 9781118810149

Book: 9781118810170

Typeset in 10/12pt TimesLTStd by Laserwords Private Limited, Chennai, India

Printed and bound in Malaysia by Vivar Printing Sdn Bhd

# MOBILE SATELLITE COMMUNICATIONS



To my parents



# Preface

Much has happened in the arena of mobile satellite communications since the release of the first edition of the book in 2001. After the commercial failure of several operators in the early part of the first decade, the industry has revived and matured. A healthy growth has been forecasted for the next 10 years and the stage is set for the industry to meet this challenge. The long gestation period of 5–10 years in the preparation and uptake of mobile satellite service (MSS) products has been amply demonstrated over this period. We had introduced numerous products and technologies in the first edition. Such products introduced around the turn of the millennium are now being upgraded to the next generation and those introduced in the middle of the last decade have peaked. The next generation MSS systems are rolling out, as we speak.

Various technical, regulatory and commercial advancements have accrued since. Consider a few examples. The viability of non-geostationary orbit for MSS has been established, considerable progress has been made towards MSS radio interface standardization, satellite mobile broadcast technology has matured and standardized, the concept of satellite-terrestrial hybrid architecture has matured, the  $K_a$  MSS band has finally emerged as a viable MSS proposition, lower-end fixed satellite service (FSS) products now support mobility akin to MSS, dense spot-beam/high-power technology has matured and extraordinary advancements in terrestrial mobile communication technology have opened new technological vistas for the future.

Due to a rapid proliferation of systems and network architecture and the availability of a plethora of innovative applications, many telecommunication professionals and technical managers lose sight of an MSS perspective. A huge amount of technical and related information lies scattered in publications such as journals, magazines, conferences, expensive and lengthy specialist reference books, and the Internet. It is therefore difficult for individuals and companies to obtain coherent up-to-date technical information.

This book, written to bridge the information gap, compiles current system concepts, architecture and trends in a structured and easily understandable style. The book is also expected to serve as a reference source, as it adheres to technical concepts. Mathematics is limited to essentials, and where possible, equations are illustrated graphically; a comprehensive list of references has been included for the curious reader. Scientific principles have been amalgamated with business models for a balanced perspective of a commercial mobile satellite system. The treatment is unbiased and views expressed are the author's own; examples of commercial systems are chosen singularly on technical novelty and uniqueness.



Three chapters have been added to the previous edition and others are thoroughly revised. Operational matters, which were dealt in the system architecture chapter previously, have now been instated in a new chapter. A chapter dealing with radio interface standards and recommendations has been added to reflect the significant advances and exemplify amalgamation of new technologies into operational systems. A chapter dealing with mobile satellite broadcast technology has been included to capture the advances in this area; although the technology formally belongs to the broadcast regime this is a subject of interest to the MSS industry, since the technology and products are similar and there is a potential of including MSS for user-interactivity.

The book, comprising 14 chapters and an appendix, presents an in-depth review of concepts, practices and trends of the gamut of mobile satellite systems. Topics include: satellite constellations; propagation aspects peculiar to mobile communications including the emerging  $K_a$  band; applicable modulation and coding techniques and trends; design issues of hand-held units – including a review of biological effects of radio frequency radiation on humans; regenerative satellite transponder technology, intersatellite links and multi-beam antenna systems; business aspects of MSS, highlighting the intertwined relationship between technical and business aspects of the MSS; network optimization and vital elements of network operations; salient features of innovative operational systems; services with products similar to MSS such as satellite navigation receivers and mobile FSS terminals, highlighting an emerging inter-service paradigm; and innovative technologies such as multi-user detection, cognitive radio, multiple-input-multiple-output systems, and *ad-hoc* networks, amongst others, as potential solutions of the future. Useful data and mathematical formulas are included in an appendix.

The reader can visit the web site [www.SatellitesAndYou.com](http://www.SatellitesAndYou.com) for information and software pertaining to the book.

I hope the reader finds the book useful and enjoyable.

*Madhavendra Richharia*

# About the Author

Madhavendra Richharia is a practising professional for well over three decades, with experience in diverse areas such as design and development of earth station products, satellite system design and operation, system planning, management, academics and research. He is currently a senior consultant and director of Knowledge Space Ltd, UK, prior to which he held senior technical positions at Inmarsat for over 15 years. Earlier, he was a faculty member at the University of Surrey. He has also contributed to satellite communication programmes of ISRO as an engineering scientist. He has published numerous technical papers on a variety of satellite communications topic, authored two books on satellite communication system design and co-authored a book covering concepts and technologies applicable to satellite systems for personal applications. The first edition of this book was well-received and continues to be recommended in many university courses. He was honored with the British Asian of the year award for technology in 2002 by the Guild of British Asians for his contributions to the field of satellite communications. He obtained his PhD degree from the University of Birmingham UK and Bachelor and Masters from the BHU. He is a member of the IEEE and the IET.



# Acknowledgements

The author wishes to express gratitude to his former Inmarsat colleagues for encouragement to take up this project. Grateful thanks are extended to those individuals and organizations who have contributed to this compilation through their published work and by granting permission for their material to be included. The author thanks the reviewers for their valuable time and constructive critique which have enriched the quality of the book.

Every effort has been made to obtain permission from the copyright holders but in the event that any have been inadvertently overlooked they should contact the author in the first instance (via the publisher), who will endeavour to make appropriate copyright permission arrangements at the earliest opportunity.

The figures extracted from the ITU material have been reproduced with prior authorization of the Union as copyright holder. The sole responsibility for selecting extracts for reproduction lies with the beneficiary of this authorization alone and can in no way be attributed to the ITU. The complete volume(s) of the ITU material, from which the texts (figures) are extracted, can be obtained from:

International Telecommunication Union

Sales and Marketing Service

Place des Nations: CH- 1211 GENEVA 20 (Switzerland)

Telephone: +41 22 730 61 41 (English)/ +41 22 730 61 42 (French)/ +41 22 730 61 43 (Spanish)

Telex: 421 000 uit ch/Fax: +41 22 730 51 94

X.400: S = sales; P = itu; A = 400net; C = ch

E-mail: sales@itu.int

Web access: <http://www.itu.int/publications>

The author gratefully acknowledges the effort of the editorial and production staff of John Wiley & Sons, Ltd.

My son, Anshuman, deserves a very special word of appreciation for creating a number of graphics, and for his assistance in the preparation of the accompanying web site during his vacations from Imperial College, London. These figures have been acknowledged as (Graphics AR).

I thank my wife, Kalpana, for her invaluable support and understanding as I endeavoured to grasp every spare moment to complete the book. Finally, it is a pleasure to recall the enthusiastic support of my daughter, Meha throughout.

# Contents

<b>Preface</b>	<b>xv</b>
<b>About the Author</b>	<b>xvii</b>
<b>Acknowledgements</b>	<b>xix</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Scope and Organization	1
1.2 Evolution of Mobile Telecommunications	5
1.2.1 Terrestrial Systems	5
1.2.2 Satellite Systems	8
1.3 Satellite System Architecture	13
1.3.1 Radio Frequency Environment	15
1.3.2 Orbit	18
1.3.3 Tolerable Delay in Data Delivery	20
1.3.4 Handover	20
1.3.5 Mobility Management	20
1.3.6 Physical Environment	21
1.3.7 Satellite Access	21
1.3.8 Spectrum Management	22
1.3.9 Radio Link Reliability	23
1.4 Business Plan	23
1.5 Regulatory Considerations	23
1.6 Operational Considerations	24
1.7 Mobile Systems – A Comparison	26
1.8 Example Applications	27
1.9 Practical Limitations	27
1.10 Related Satellite Systems	29
1.10.1 M-VSAT Systems	29
1.10.2 Satellite Navigation Systems	30
1.10.3 Direct Broadcasts to Individuals and Mobiles	30

1.11	Trends	31
1.11.1	<i>General</i>	31
1.11.2	<i>Market</i>	32
1.11.3	<i>System Architecture</i>	32
1.11.4	<i>Spectrum</i>	33
1.11.5	<i>Technology</i>	33
	Revision	34
	References	35
<b>2</b>	<b>Satellite Constellations</b>	<b>37</b>
2.1	Introduction	37
2.2	Satellite Orbits	38
2.2.1	<i>Orbital Mechanics Basics</i>	38
2.2.2	<i>Satellite Coverage</i>	56
2.2.3	<i>Space Environment</i>	57
2.2.4	<i>Eclipse on Satellites</i>	58
2.2.5	<i>The Sun's Interference</i>	61
2.2.6	<i>Doppler Effect</i>	61
2.2.7	<i>Orbital Debris</i>	61
2.2.8	<i>Summary of Orbital Characteristics</i>	68
2.3	Satellite Constellations	69
2.3.1	<i>Considerations in Constellation Design</i>	72
2.3.2	<i>Polar Constellations</i>	73
2.3.3	<i>Inclined Orbit Constellations</i>	75
2.3.4	<i>Hybrid Constellations</i>	79
2.3.5	<i>Regional Coverage</i>	79
2.3.6	<i>Constellations for Non-Real-Time Systems</i>	80
2.3.7	<i>Use of Spot Beams</i>	80
2.3.8	<i>Availability Considerations for Non-Geostationary Satellites</i>	80
	Revision	85
	References	86
<b>3</b>	<b>Radio Link</b>	<b>89</b>
3.1	Introduction	89
3.2	Spectrum Issues	89
3.2.1	<i>Spectrum Sharing Methods</i>	92
3.2.2	<i>Spectrum Forecast Methodology</i>	98
3.3	Propagation Characteristics	100
3.3.1	<i>General Propagation Characteristics</i>	101
3.3.2	<i>Land Mobile Channel</i>	111
3.3.3	<i>Maritime Channel</i>	146
3.3.4	<i>Aeronautical Channel</i>	153
3.3.5	<i>System Implications</i>	158
3.4	Radio Link Analysis	162
	Revision	170
	References	171

<b>4</b>	<b>Modulation, Coding and Multiple Access</b>	<b>175</b>
4.1	Introduction	175
4.2	Modulation	175
4.2.1	<i>MSS Requirements</i>	175
4.2.2	<i>Preferences</i>	177
4.2.3	<i>PSK Schemes</i>	179
4.2.4	<i>Performance Comparison of Conventional Digital Modulation Schemes</i>	183
4.2.5	<i>Coded Orthogonal Frequency Division Multiplexing (COFDM) Modulation Systems</i>	191
4.2.6	<i>Spread Spectrum Modulation</i>	194
4.3	Coding	197
4.3.1	<i>Trellis-Coded Modulation (TCM)</i>	204
4.3.2	<i>Modulation and Coding Trends and Issues</i>	205
4.3.3	<i>Automatic Repeat Request</i>	207
4.4	Multiple Access Schemes	208
4.4.1	<i>Comparison of Multiple Access Schemes</i>	212
4.4.2	<i>Comparison of Spectral and Power Efficiency</i>	214
	Revision	222
	References	223
<b>5</b>	<b>Fixed Earth Stations and User Terminals</b>	<b>227</b>
5.1	Introduction	227
5.2	Gateways	228
5.3	User Terminals	230
5.3.1	<i>Antennas</i>	231
5.3.2	<i>Hand-Held UT</i>	239
5.3.3	<i>Mobile Terminals</i>	248
5.4	Environmental Issues	264
5.4.1	<i>Biological Effects</i>	264
	Revision	269
	References	269
<b>6</b>	<b>Spacecraft</b>	<b>271</b>
6.1	Introduction	271
6.2	Satellites for MSS	272
6.2.1	<i>Transponders</i>	273
6.2.2	<i>Antenna Systems</i>	296
6.2.3	<i>Effect of Orbital Characteristics on Spacecraft Design</i>	298
6.3	Intersatellite links	302
6.3.1	<i>Frequency Bands</i>	304
6.3.2	<i>Implementation Issues</i>	306
6.4	Emerging Technologies	306
6.5	Launching Satellite Constellations	308
	Revision	312
	References	312



<b>7</b>	<b>System Architecture</b>	<b>315</b>
7.1	Introduction	315
7.2	Air Interface	316
7.2.1	<i>Ancillary Terrestrial Component</i>	319
7.3	System Development	320
7.3.1	<i>Influences</i>	322
7.3.2	<i>Constraints and Considerations</i>	324
7.3.3	<i>System Synthesis</i>	326
7.3.4	<i>Technical Trade-off Analysis</i>	327
7.3.5	<i>Impact of Satellite Altitude</i>	331
7.4	Network Considerations	334
7.4.1	<i>General</i>	334
7.4.2	<i>Functional Entities</i>	338
7.4.3	<i>Network Connectivity</i>	341
7.4.4	<i>Gateway Locations</i>	345
7.4.5	<i>Call Handling</i>	345
7.4.6	<i>Mobility Management</i>	348
	Revision	355
	References	356
<b>8</b>	<b>Satellite Radio Interface Standards</b>	<b>357</b>
8.1	Introduction	357
8.2	Satellite Radio Interface Standards	359
8.2.1	<i>GMR</i>	359
8.2.2	<i>Satellite Component of UMTS/IMT-2000</i>	380
8.3	Interactive Mobile Broadband Broadcast Standard	407
8.3.1	<i>DVB-S2/RCS+M</i>	407
	Revision	422
	References	423
<b>9</b>	<b>Operational Considerations</b>	<b>425</b>
9.1	Introduction	425
9.2	Perspective	425
9.3	Subscriber and Gateway Commissioning	428
9.3.1	<i>Gateways</i>	428
9.3.2	<i>Mobile Earth Stations</i>	429
9.4	Radio Resource Management	431
9.4.1	<i>Spectrum Management</i>	431
9.4.2	<i>EIRP Management</i>	454
9.5	Radio Frequency Monitoring	455
9.5.1	<i>Radio Frequency Interference</i>	460
9.5.2	<i>Radio Frequency Interference Management</i>	460
9.6	Quality of Service	463