
ULTRA WIDEBAND WIRELESS COMMUNICATION

Edited by

Hüseyin Arslan

University of South Florida, Tampa, Florida

Zhi Ning Chen

Institute for Infocomm Research, Singapore

Maria-Gabriella Di Benedetto

University of Rome La Sapienza, Italy

 **WILEY-
INTERSCIENCE**

A JOHN WILEY & SONS, INC., PUBLICATION

**ULTRA WIDEBAND
WIRELESS
COMMUNICATION**

ULTRA WIDEBAND WIRELESS COMMUNICATION

Edited by

Hüseyin Arslan

University of South Florida, Tampa, Florida

Zhi Ning Chen

Institute for Infocomm Research, Singapore

Maria-Gabriella Di Benedetto

University of Rome La Sapienza, Italy

 **WILEY-
INTERSCIENCE**

A JOHN WILEY & SONS, INC., PUBLICATION

This book is printed on acid-free paper. (∞)

Copyright © 2006 by John Wiley & Sons, Inc. All rights reserved.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.
Published simultaneously in Canada.

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, scanning, or otherwise, except as permitted under Sections 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400, fax 978-646-8600, or on the web at www.copyright.com. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008.

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. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. Neither the publisher nor author shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

For general information on our other products and services please contact our Customer Care Department within the U.S. at 877-762-2974, outside the U.S. at 317-572-3993 or fax 317-572-4002.

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

Library of Congress Cataloging-in-Publication Data:

Ultra wideband wireless communication / edited by Huseyin Arslan,
Zhi Ning Chen, Maria-Gabriella Di Benedetto.
p. cm.
Includes index.
ISBN 0-471-71521-2 (cloth)
1. Broadband communication systems. 2. Ultra-wideband devices.
3. Wireless communication systems. I. Arslan, Huseyin, 1968–
II. Chen, Zhi Ning. III. Di Benedetto, Maria-Gabriella.
TK5103.4.U44 2006
621.384 - - dc22

2006008457

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

CONTENTS

Preface	xv
Contributors	xix
Chapter 1 Introduction to Ultra Wideband	1
<i>Hüseyin Arslan and Maria-Gabriella Di Benedetto</i>	
1.1 Introduction	1
1.1.1 Benefits of UWB	2
1.1.2 Applications	3
1.1.3 Challenges	3
1.2 Scope of the Book	4
Chapter 2 UWB Channel Estimation and Synchronization	11
<i>Irena Maravic and Martin Vetterli</i>	
2.1 Introduction	11
2.2 Channel Estimation at SubNyquist Sampling Rate	14
2.2.1 UWB Channel Model	14
2.2.2 Frequency-Domain Channel Estimation	15
2.2.3 Polynomial Realization of the Model-Based Methods	16
2.2.4 Subspace-Based Approach	20
2.2.5 Estimation of Closely Spaced Paths	24
2.3 Performance Evaluation	25
2.3.1 Analysis of Noise Sensitivity	25
2.3.2 Computational Complexity and Alternative Solutions	27
2.3.3 Numerical Example	28
2.4 Estimating UWB Channels with Frequency-Dependent Distortion	29
2.4.1 Algorithm Outline	31
2.5 Channel Estimation from Multiple Bands	32
2.5.1 Filter Bank Approach	32
2.5.2 Estimation from Nonadjacent Bands	32
2.6 Low-Complexity Rapid Acquisition in UWB Localizers	34

2.6.1	Two-Step Estimation	36
2.7	Conclusions	39
Chapter 3	Ultra Wideband Geolocation	43
	<i>Sinan Gezici, Zafer Sahinoglu, Hisashi Kobayashi, and H. Vincent Poor</i>	
3.1	Introduction	43
3.2	Signal Model	44
3.3	Positioning Techniques	44
3.3.1	Angle of Arrival	45
3.3.2	Received Signal Strength	49
3.3.3	Time-Based Approaches	51
3.4	Main Sources of Error in Time-Based Positioning	52
3.4.1	Multipath Propagation	52
3.4.2	Multiple Access Interference	53
3.4.3	Nonline-of-Sight Propagation	53
3.4.4	High Time Resolution of UWB Signals	54
3.5	Ranging and Positioning	55
3.5.1	Relationship Between Ranging and Optimal Positioning Algorithms	55
3.5.2	ToA Estimation Algorithms	58
3.5.3	Two-Way Ranging Protocols	69
3.6	Location-Aware Applications	70
3.7	Conclusions	71
Chapter 4	UWB Modulation Options	77
	<i>Hüseyin Arslan, İsmail Güneç, and Sadia Ahmed</i>	
4.1	Introduction	77
4.2	UWB Signaling Techniques	78
4.2.1	UWB-IR Signaling	79
4.2.2	Multiband UWB	83
4.2.3	Multicarrier UWB	85
4.2.4	OFDM	85
4.3	Data Mapping	87
4.3.1	Binary Data Mapping Schemes	87
4.3.2	M -ary Data Mapping Schemes	89
4.4	Spectral Characteristics	91
4.5	Data Mapping and Transceiver Complexity	92
4.6	Modulation Performances in Practical Conditions	93

4.6.1	Effects of Multipath	93
4.6.2	Effects of Multiple Access Interference	95
4.6.3	Effects of Timing Jitter and Finger Estimation Error	96
4.7	Conclusion	99
Chapter 5	Ultra Wideband Pulse Shaper Design	103
	<i>Zhi Tian, Timothy N. Davidson, Xiliang Luo, Xianren Wu, and Georgios B. Giannakis</i>	
5.1	Introduction	103
5.2	Transmit Spectrum and Pulse Shaper	105
5.3	FIR Digital Pulse Design	108
5.4	Optimal UWB Single Pulse Design	110
5.4.1	Parks–McClellan Algorithm	110
5.4.2	Optimal UWB Pulse Design via Direct Maximization of NESP	111
5.4.3	Constrained Frequency Response Approximation	113
5.4.4	Constrained Frequency Response Design with Linear Phase Filters	114
5.5	Optimal UWB Orthogonal Pulse Design	115
5.5.1	Orthogonality Formulation	115
5.5.2	Sequential UWB Pulse Design	117
5.5.3	Sequential UWB Pulse Design with Linear Phase Filters	118
5.6	Design Examples and Comparisons	120
5.6.1	Single-Pulse Designs and their Spectral Utilization Efficiency	120
5.6.2	Multiband Pulse Design	122
5.6.3	Multiple Orthogonal Pulse Design	123
5.6.4	Pulse Designs for Narrowband Interference Avoidance	125
5.6.5	Impact of Pulse Designs on Transceiver Power Efficiency	126
5.7	Conclusions	128
Chapter 6	Antenna Issues	131
	<i>Zhi Ning Chen</i>	
6.1	Introduction	131
6.2	Design Considerations	132
6.2.1	Description of Antenna Systems	132

6.2.2	Single-Band and Multiband Schemes	134
6.2.3	Source Pulses	136
6.2.4	Transmit Antenna and PDS	136
6.2.5	Transmit–Receive Antenna System	141
6.3	Antenna and Pulse versus BER Performance	148
6.3.1	Pulsed UWB System	148
6.3.2	Effects of Antennas and Pulses	151
Chapter 7	Ultra Wideband Receiver Architectures	157
	<i>Hüseyin Arslan</i>	
7.1	Introduction	157
7.2	System Model	158
7.3	UWB Receiver Related Issues	160
7.3.1	Sampling	160
7.3.2	UWB Channel and Channel Parameters Estimation	161
7.3.3	Interference in UWB	164
7.3.4	Other Receiver-Related Issues	165
7.4	TH-IR-UWB Receiver Options	165
7.4.1	Optimal Matched Filter	167
7.4.2	TR-Based Scheme	171
7.4.3	Differential Detector	175
7.4.4	Energy Detector	176
7.5	Conclusion	178
Chapter 8	Ultra Wideband Channel Modeling and Its Impact on System Design	183
	<i>Chia-Chin Chong</i>	
8.1	Introduction	183
8.2	Principles and Background of UWB Multipath Propagation Channel Modeling	184
8.2.1	Basic Multipath Propagation Mechanisms	184
8.2.2	Classification of UWB Channel Models	185
8.3	Channel Sounding Techniques	187
8.3.1	Time-Domain Technique	187
8.3.2	Frequency-Domain Technique	188
8.4	UWB Statistical-Based Channel Modeling	189
8.4.1	Modeling Philosophy and Mathematical Framework	189
8.4.2	Large-Scale Channel Characterization	190
8.4.3	Small-Scale Channel Characterization	193

8.4.4	Temporal Dispersion and Correlation Properties	197
8.5	Impact of UWB Channel on System Design	199
8.6	Conclusion	200
Chapter 9	MIMO and UWB	205
	<i>Thomas Kaiser</i>	
9.1	Introduction	205
9.2	Potential Benefits of MIMO and UWB	206
9.3	Literature Review of UWB Multiantenna Techniques	208
9.3.1	Spatial Multiplexing	208
9.3.2	Spatial Diversity	209
9.3.3	Beamforming	209
9.3.4	Related Topics	210
9.4	Spatial Channel Measurements and Modeling	211
9.4.1	Spatial Channel Measurements	211
9.4.2	Spatial Channel Modeling	213
9.5	Spatial Multiplexing	215
9.6	Spatial Diversity	216
9.7	Beamforming	220
9.8	Conclusion and Outlook	223
Chapter 10	Multiple-Access Interference Mitigation in Ultra Wideband Systems	227
	<i>Sinan Gezici, Hisashi Kobayashi, and H. Vincent Poor</i>	
10.1	Introduction	227
10.2	Signal Model	228
10.2.1	Transmitted Signal	228
10.2.2	Received Signal	229
10.3	Multiple-Access Interference Mitigation at the Receiver Side	231
10.3.1	Maximum-Likelihood Sequence Detection	232
10.3.2	Linear Receivers	232
10.3.3	Iterative (Turbo) Algorithms	240
10.3.4	Other Receiver Structures	243
10.4	Multiple-Access Interference Mitigation at the Transmitter Side	244
10.4.1	Time-Hopping Sequence Design for MAI Mitigation	245
10.4.2	Pseudochaotic Time Hopping	246
10.4.3	Multistage Block-Spreading UWB Access	247
10.5	Concluding Remarks	248

Chapter 11	Narrowband Interference Issues in Ultra Wideband Systems	255
	<i>Hüseyin Arslan and Mustafa E. Sahin</i>	
11.1	Introduction	255
11.2	Effect of NBI in UWB Systems	258
11.3	Avoiding NBI	261
	11.3.1 Multicarrier Approach	261
	11.3.2 Multiband Schemes	263
	11.3.3 Pulse Shaping	264
	11.3.4 Other NBI Avoidance Methods	266
11.4	Canceling NBI	267
	11.4.1 MMSE Combining	268
	11.4.2 Frequency Domain Techniques	268
	11.4.3 Time–Frequency Domain Techniques	269
	11.4.4 Time Domain Techniques	270
11.5	Conclusion and Future Research	271
Chapter 12	Orthogonal Frequency Division Multiplexing for Ultra Wideband Communications	277
	<i>Ebrahim Saberina and Ahmed H. Tewfik</i>	
12.1	Introduction	277
12.2	Multiband OFDM System	278
	12.2.1 Band Planning	278
	12.2.2 Sub-Band Hopping	278
	12.2.3 OFDM Modulation	280
	12.2.4 Frequency Repetition Spreading	280
	12.2.5 Time Repetition Spreading	280
	12.2.6 Coding	281
	12.2.7 Supported Bit Rates	281
	12.2.8 MB-OFDM Transceiver	282
	12.2.9 Improvement to MB-OFDM	283
12.3	Multiband Pulsed-OFDM UWB system	284
	12.3.1 Pulsed-OFDM Transmitter	284
	12.3.2 Pulsed-OFDM Signal Spectrum	284
	12.3.3 Digital Equivalent Model and Diversity of Pulsed-OFDM	286
	12.3.4 Pulsed-OFDM Receiver	288
	12.3.5 Selecting the Up-sampling Factor	289
12.4	Comparing MB-OFDM and MB-Pulsed-OFDM systems	290

12.4.1	System Parameters	290
12.4.2	Complexity Comparison	290
12.4.3	Power Consumption Comparison	290
12.4.4	Chip Area Comparison	291
12.4.5	Performance Comparison	293
12.5	Conclusion	295
Chapter 13 UWB Networks and Applications		297
<i>Krishna M. Sivalingam and Aniruddha Rangnekar</i>		
13.1	Introduction	297
13.2	Background	298
13.2.1	UWB Physical Layer	298
13.2.2	IEEE 802.15.3 Standards	299
13.3	Medium Access Protocols	300
13.3.1	IEEE 802.15.3 MAC Protocol	300
13.3.2	Impact of UWB Channel Acquisition Time	303
13.3.3	Multiple Channels	305
13.4	Network Applications	310
13.5	Summary and Discussion	311
	Acknowledgments	311
Chapter 14 Low-Bit-Rate UWB Networks		315
<i>Luca DeNardis and Gian Mario Maggio</i>		
14.1	Low Data-Rate UWB Network Applications	315
14.1.1	802.15.4a: A Short History	315
14.1.2	The 802.15.4a PHY	316
14.1.3	PHY: 802.15.4a versus 802.15.4	316
14.1.4	Technical Requirements	317
14.1.5	Applications	319
14.2	The 802.15.4 MAC Standard	321
14.2.1	Network Devices and Topologies	321
14.2.2	Medium Access Strategy	322
14.2.3	From 802.15.4 to 802.15.4a	324
14.3	Advanced MAC Design for Low-Bit-Rate UWB Networks	324
14.3.1	(UWB) ² : Uncoordinated, Wireless, Baseborn Medium Access for UWB Communication Networks	325
14.3.2	Transmission Procedure	328
14.3.3	Reception Procedure	331
14.3.4	Simulation Results	333

Chapter 15	An Overview of Routing Protocols for Mobile Ad Hoc Networks	341
	<i>David A. Sumy, Branimir Vojcic, and Jinghao Xu</i>	
15.1	Introduction	341
15.2	Ad Hoc Networks	343
15.3	Routing in MANETs	345
15.4	Proactive Routing	345
15.4.1	DSDV	346
15.4.2	WRP	348
15.4.3	CGSR	350
15.4.4	STAR	351
15.4.5	HSR	352
15.4.6	OLSR	355
15.4.7	TBRPF	356
15.4.8	DREAM	358
15.4.9	GSR	360
15.4.10	FSR	360
15.4.11	HR	362
15.4.12	HSLs and A-HSLs	363
15.5	Reactive Routing	364
15.5.1	DSR	365
15.5.2	ARA	367
15.5.3	ABR	369
15.5.4	AODV	372
15.5.5	BSR	374
15.5.6	CHAMP	376
15.5.7	DYMO	377
15.5.8	DNVR	378
15.5.9	LAR	380
15.5.10	LBR	381
15.5.11	MPABR	383
15.5.12	NDMR	384
15.5.13	PLBM	385
15.5.14	RDMAR	387
15.5.15	SOAR	388
15.5.16	TORA	391
15.6	Power-Aware Routing	393
15.6.1	BEE	394

15.6.2	EADSR	395
15.6.3	MTPR/MBCR/MMBCR/CMMBCR	395
15.6.4	PARO	396
15.6.5	PAWF	398
15.6.6	MFP/MIP/MFP _{energy} /MIP _{energy}	400
15.7	Hybrid Routing	400
15.7.1	MultiWARP	401
15.7.2	SHARP	402
15.7.3	SLURP	403
15.7.4	ZRP	406
15.7.5	AZRP	408
15.7.6	IZR	408
15.7.7	TZRP	408
15.8	Other	410
15.9	Conclusion	411
	Appendix	418
Chapter 16 Adaptive UWB Systems		429
<i>Francesca Cuomo and Crishna Martello</i>		
16.1	Introduction	429
16.1.1	Related Work on Adaptive UWB Systems	431
16.2	A Distributed Power-Regulated Admission Control Scheme for UWB	432
16.2.1	Problem Formalization	434
16.2.2	Power Selection in UWB	435
16.2.3	Steps of the Access Scheme	438
16.3	Performance Analysis	439
16.3.1	Impact of the Initial MEI on Performance of MEI-Based Power Regulation Schemes	442
16.3.2	Performance Behavior as a Function of the Offered Load	445
16.4	Summary	449
Chapter 17 UWB Location and Tracking—A Practical Example of an UWB-Based Sensor Network		451
<i>Ian Oppermann, Kegen Yu, Alberto Rabbachin, Lucian Stoica, Paul Cheong, Jean-Philippe Montillet, and Sakari Tiuraniemi</i>		
17.1	Introduction	451
17.2	Multiple Access in UWB Sensor Systems	452