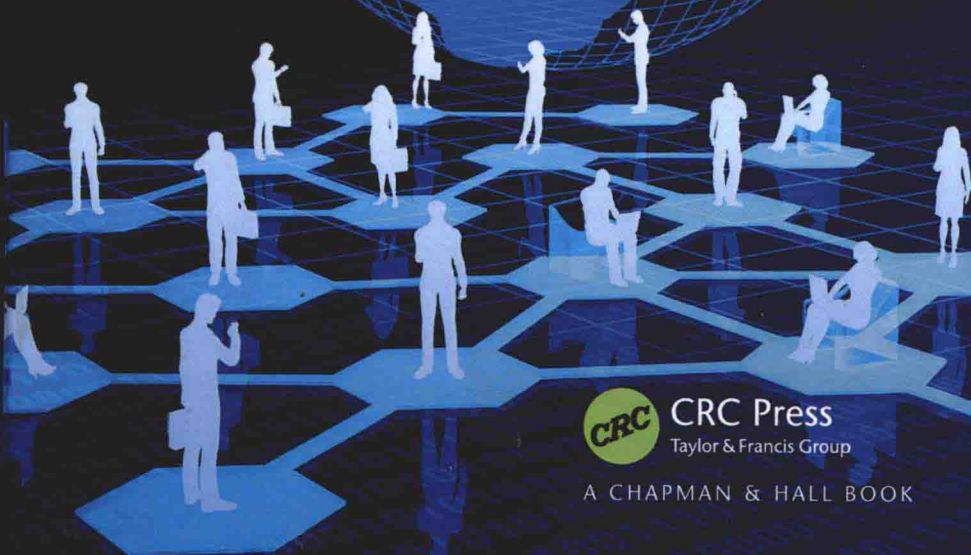


WIRELESS NETWORKS AND MOBILE COMPUTING

Koushik Sinha • Sasthi C. Ghosh
Bhabani P. Sinha



CRC Press

Taylor & Francis Group

A CHAPMAN & HALL BOOK

WIRELESS NETWORKS AND MOBILE COMPUTING

Koushik Sinha

Hewlett-Packard Labs, Bangalore, India

Sasthi C. Ghosh

Indian Statistical Institute, Kolkata, India

Bhabani P. Sinha

Indian Statistical Institute, Kolkata, India



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

A CHAPMAN & HALL BOOK

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2016 by Taylor & Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works

Printed on acid-free paper
Version Date: 20150929

International Standard Book Number-13: 978-1-4822-2793-2 (Hardback)

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Visit the Taylor & Francis Web site at
<http://www.taylorandfrancis.com>

and the CRC Press Web site at
<http://www.crcpress.com>

WIRELESS NETWORKS AND MOBILE COMPUTING

Preface

Wireless communication constitutes one of the fastest growing industry segments in recent years, encompassing a number of application domains such as cellular mobile networks, ad hoc networks, cognitive radio networks, ubiquitous and pervasive computing, sensor networks and so on. All these applications are becoming increasingly popular these days due to the multifaceted benefits they provide to society ranging from personal communication services, growth of business and economy to health-care, distant education services, disaster management, security services and defense applications. For sustained growth in these fields, we need trained personnel for further development and research in the areas of wireless networking and mobile computing. In a natural way, such a need has triggered the inclusion of formal courses on these topics in the undergraduate- and graduate-level engineering degree programs of many leading institutes and universities all over the world.

Also, there exist various issues and challenging research problems in all these areas which need urgent attention of scientists and engineers. In the area of cellular mobile networks, the major research areas include bandwidth management, mobility management, network security and energy-efficient communication, amongst others. Over the last decade, the number of such cellular mobile users has been increasing almost exponentially. Further, with the advances in technology, there has been an increasing demand from mobile users for providing multimedia services like voice, text, still-image and video through wireless networks. On the other hand, the available bandwidth required for such multimedia data communication for a large number of mobile users is very limited. Such limited availability of the radio spectrum, signal distortion and the interference caused by the environment and other mobile users imposes an inherent bound on the capacity of such wireless networks. Developing methods to utilize the scarce radio spectrum efficiently is more critical than ever. Along with this, secure communication through wireless and energy-efficient communication through the cellular mobile environment constitute other important problems which need immediate attention of scientists for an effective solution. In the same way, in the area of ad hoc networks, the challenging research problems include network security as well as energy-efficient communication requirements.

Similar to these cellular and ad hoc mobile networks, sensor networks also play a vital role in many real-life applications ranging from agriculture, health care, habitat monitoring, environmental monitoring, defense applications, and so on. Due to the limited battery life as well as limited computing and communication abilities of the constituent sensor nodes, efficient design and management of these sensor networks, handling user queries in various application domains over streaming sensor data and

also network security appear to be challenging problems to researchers. Summarily, there are various research problems in all these application domains of wireless communication, solutions of which are urgently demanded for the benefit of society.

The purpose for writing this book is two-fold. The primary objective is to introduce the basic concepts of wireless networks and mobile computing which will be enough for an engineering student at the undergraduate or graduate level to build a solid background in this area to enter into a professional life or to take up a research career. We have presented the materials in various chapters in a cohesive manner so that there will be a natural flow of concepts from one chapter to the next, which will be easy for a student to follow. This is in contrast to books whose chapters are written by different sets of authors, each with a different style and notations which often become difficult to follow during course work, as experienced by the authors while teaching this course to the students using available books in the market.

The second but no less important objective is to include recent research results along with the challenging problems in the areas mentioned above with extensive references to the existing literature at the end of each chapter. Recent results on various topics including those by the authors from their research endeavors over one and a half decades, are presented for comprehensive knowledge of the topics. This will certainly help researchers in these areas to get state-of-the-art pictures in the relevant fields and motivate them to innovate novel ideas for solutions to the unsolved challenging research problems for future generation wireless networks and mobile computing systems.

Taking into account the previously mentioned ideas this book has been surprisingly written containing only nine chapters. Chapter 1 gives an overall introduction to wireless networks and mobile computing. Chapter 2 deals with mobility management issues, discussing location management, handoff management and mobility models. Chapter 3 is devoted to bandwidth management in cellular mobile networks, starting from the basic concepts to various existing techniques, critical comparisons of their performances and future research challenges in the context of next-generation mobile communication systems. Chapter 4 discusses the localization issue in detail. In Chapter 5, we discuss the various existing techniques and protocols for message communication in ad hoc networks and future directions of research in this area. In Chapter 6, we introduce wireless local area networks (WLANs) along with recent research results and future directions of research in this area. Chapter 7 is devoted to the placement of base stations in a cellular network as well as deployment of sensor nodes in a wireless sensor network where we first model the problem from a geometrical point of view and then discuss existing techniques for an efficient solution to this problem. In Chapter 8, we address energy efficiency in wireless communication, with special emphasis on physical, MAC and network layers. Chapter 9 covers various aspects related to secure wireless communication including authentication, jamming, intrusion detection and stream cipher generation.

Exercises are given at the end of each chapter which will help the students get a better insight of the topics while solving those problems. Star (*) marked problems in the exercises indicate a higher level of difficulties and are, in fact, research problems that may be taken up by the researchers in the respective areas.

The authors are grateful to Ansuman Bhattacharya, Dibakar Saha, Pratham Majumder and Sayan Sen Sarma for their generous help in drawing a few figures and formatting some tables and algorithms while preparing the LaTeX source file for the book.

We will consider their efforts worthwhile if this book is found useful to the academic community, for both teaching and research, in the discipline of wireless networks and mobile computing.

Koushik Sinha

Sasthi C. Ghosh

Bhabani P Sinha

Contents

List of Figures	ix
List of Tables	xv
Preface	xvii
1 Introduction	1
1.1 Applications Involving Wireless Communication	3
1.2 Effects of Mobility of Devices	16
1.3 Issues in Cellular Mobile Networks	18
1.4 Issues in Ad Hoc Networks	25
1.5 Issues in Cognitive Radio Networks	31
1.6 Issues in Sensor Networks	31
1.7 Exercises	32
2 Mobility Management in Cellular Networks	41
2.1 Call Setup in Public Land Mobile Networks	42
2.2 Call Setup in Mobile IP Networks	56
2.3 Handoff Management	62
2.4 Mobility Models	65
2.5 Exercises	71
3 Bandwidth Management in Cellular Networks	77
3.1 Introduction	78
3.2 Benchmark Instances	84
3.3 Lower Bounds on Bandwidth	89
3.4 Genetic Algorithm for Channel Assignment	108
3.5 Coalesced CAP	133
3.6 Fast Near-Optimal Channel Assignment	147
3.7 Conclusion	164
3.8 Exercises	167

4	Localization of Nodes in Mobile Networks	177
4.1	System Model	178
4.2	Preliminaries	179
4.3	Estimation of Location Error	183
4.4	Beacon Node Selection Algorithm	192
4.5	Location Region Identification	194
4.6	Exercises	213
5	Message Communication in Ad Hoc Networks	217
5.1	Introduction	219
5.2	Broadcast in Ad Hoc Networks	220
5.3	Transmission Schedule	232
5.4	Slot Assignment Based on Location Information	237
5.5	Deterministic Broadcast and Gossiping	266
5.6	Point-to-Point Routing in Ad Hoc Networks	299
5.7	Destination-Sequenced Distance Vector Routing (DSDV) Protocol	301
5.8	Dynamic Source Routing (DSR)	303
5.9	Ad Hoc On-Demand Distance Vector Routing (AODV)	306
5.10	Temporally Ordered Routing Algorithm (TORA)	311
5.11	Zone Routing Protocol (ZRP)	314
5.12	Exercises	316
6	Wireless Local Area Networks	321
6.1	Introduction	321
6.2	Placement of APs and Channel Allocation	329
6.3	Exercises	330
7	Placement of Sensor Nodes in WSN	335
7.1	Introduction	335
7.2	Preliminaries	336
7.3	Deployment Algorithm	338
7.4	Experimental Results	341
7.5	Exercises	346
8	Energy-Efficient Communication	349
8.1	Introduction	351
8.2	Some Elegant Physical Layer-Centric Techniques	360
8.3	Redundant Binary Number Encoding with Silent Zero Communication (RBNSiZeComm)	363
8.4	Ternary with Silent Symbol (TSS) Communication Protocol	402
8.5	Compression with Null Symbol (CNS) Communication Protocol	418

8.6	Tri-Digit Fibonacci Number System (TFNS) Communication Protocol	448
8.7	Exercises	470
9	Security in Wireless Communication	477
9.1	Introduction	478
9.2	Measures against Attacks	482
9.3	Hardware Implementation of RC4 for One Byte per Clock	489
9.4	Exercises	509
	Index	513

List of Figures

1.1	Cellular mobile network architecture	8
1.2	Schematic view of a cognitive radio network	12
1.3	Wireless sensor network	15
1.4	Initialization in ad hoc networks	26
1.5	Leader election in ad hoc networks	27
1.6	Clustering in ad hoc networks	28
2.1	Call setup in PLMN	42
2.2	SS7 signaling network in PLMN	44
2.3	Time-based location update scheme	46
2.4	Movement-based location update scheme	47
2.5	Distance-based location update scheme	48
2.6	Dynamic location area-based update scheme	48
2.7	Location information caching scheme	54
2.8	Distributed tree-based database architecture	56
2.9	Partitioning scheme in database architecture	57
2.10	Mobile IP network architecture	58
2.11	Mobile IP location registration	59
2.12	Sequence of operations in mobile IP location registration	61
2.13	Call setup process in mobile IP network	62
2.14	Handoff management process	63
2.15	An example of random way point mobility	68
3.1	(a) Typical CAP graph; (b) and (c) two frequency assignments	85
3.2	The 21-node benchmark cellular network	86
3.3	The 55-node benchmark cellular network	86
3.4	Seven-node subgraph of hexagonal cellular network	91
3.5	Different frequency assignments to seven-node subgraph with minimum channel at central node for (a) $s_2 \leq s_1 \leq 2s_2$, and (b) $s_1 \geq 2s_2$	93
3.6	Different frequency assignments to seven-node subgraph with maximum channel at central node for (a) $s_2 \leq s_1 \leq 2s_2$, and (b) $s_1 \geq 2s_2$	94

3.7	Different frequency assignments to seven-node subgraph for $s_2 \leq s_1 \leq 2s_2$ when (a) $s_1 \leq s_0 \leq (2s_1 - s_2)$, (b) $(2s_1 - s_2) \leq s_0 \leq 6s_2$, (c) $6s_2 \leq s_0 \leq (s_1 + 5s_2)$, (d) $(s_1 + 5s_2) \leq s_0 \leq (2s_1 + 5s_2)$, and (e) $s_0 \geq (2s_1 + 5s_2)$	98
3.8	(a) MFP \mathcal{P}_1 to find α (b) MFP \mathcal{P}_2 to find β	106
3.9	Variation of mutation probability (q) with number of iterations (t)	109
3.10	(a) Subgraph of cellular graph and (b) frequency assignment when $s_1 = s_2$	117
3.11	Frequency assignment of two-band buffering system for $s_1 = s_2$	118
3.12	Three directions in hexagonal cellular graph	119
3.13	A nine-node subgraph of hexagonal cellular network	120
3.14	Frequency assignment of two-band buffering system using nine frequency channels	121
3.15	Frequency assignment of two-band buffering system for $s_2 < s_1 \leq 2s_2$	123
3.16	Frequency assignment of two-band buffering system for $s_1 \geq 2s_2$	124
3.17	Frequency assignments to nine-node subgraph for $s_2 < s_1 \leq 2s_2$	125
3.18	Frequency assignments to nine-node subgraph for $s_1 \geq 2s_2$	126
3.19	Frequency assignment of two-band buffering system using nine frequency channels	127
3.20	Frequency assignment of two-band buffering system for $s_1 \geq 3s_2$	129
3.21	Frequency assignments to nine-node subgraph for $s_1 \geq s_2$	130
3.22	Single channel assignment of benchmark Problem 5	142
3.23	Algorithm for finding increment	153
3.24	Algorithm for finding single assignment	154
3.25	Single channel assignment to benchmark cellular network	155
3.26	Set of assignment paths in first phase	156
3.27	Set of assignment paths in second phase	156
3.28	Set of assignment paths in third phase	159
3.29	Path augmented with triangle in fourth phase	159
3.30	Path augmented with quadrilaterals in fifth phase	159
3.31	Assignment of nodes in the last phase	160
4.1	Delay channel and receiver design	180
4.2	Location estimation using two beacon nodes	184
4.3	Location estimation when error in position of beacon nodes	184
4.4	BS location error estimation when using three beacon nodes	186
4.5	Contribution by ranging error when using three beacon nodes	188
4.6	Minkowski's sum of the two errors	190
4.7	Construction of viewed region of residence of node	196
4.8	Computation of minimum region of residence	198
4.9	Improving minimum regions of residence of neighbors	199
4.10	Refinements of regions of successive neighbor nodes	202
4.11	Variation of size of stable region of residence with λ	209
4.12	Variation of size of stable region of residence with σ	210

4.13	Variation of size of stable region of residence with percent of LOS signals	211
4.14	Variation of size of stable region of residence with percent of RNs	212
5.1	Partition tree for $n = 64$ and $r = 4$	229
5.2	Number of rounds τ in frame for different n, r, Δ	236
5.3	Conversion of hexagonal grid to hexagonal cellular graph	240
5.4	Complete Distance 2 clique and corresponding cellular Distance 2 clique	241
5.5	Slot assignment for a cellular graph with homogeneous unit demand	243
5.6	Optimal slot assignment schedule for homogeneous demand of unit slot	246
5.7	Heterogeneous demand. Seven-node CB fails to give minimum number of slots	248
5.8	Assignment scheme requiring 64 slots	249
5.9	Ten-node critical block	250
5.10	Actual critical block for Case 1	253
5.11	Example graph corresponding to Case 1	254
5.12	Actual critical block for Case 2	257
5.13	Example graph corresponding to Case 2	257
5.14	Ten-node critical block not formed by seven-node critical block	258
5.15	Structure of HELLO message	263
5.16	Structure of MOVE message	266
5.17	Collision resolution example 1	270
5.18	Collision resolution example 2	272
5.19	Role of control signals	273
5.20	Structure of round for algorithm <i>bf_broadcast</i>	275
5.21	State transition diagram	276
5.22	An example of collision resolution by the broadcast algorithm	280
5.23	Another example for collision resolution by the broadcast algorithm	281
5.24	Execution time of algorithm <i>bf_broadcast</i>	284
5.25	Execution time of algorithm <i>bf_broadcast</i>	286
5.26	Execution time of algorithm <i>bf_broadcast</i>	287
5.27	Execution time of algorithm <i>bf_broadcast</i>	288
5.28	Execution time of algorithm <i>bf_broadcast</i>	290
5.29	Execution time of algorithm <i>bf_broadcast</i>	291
5.30	Execution time of algorithm <i>bf_broadcast</i>	292
5.31	Execution time of algorithm <i>bf_broadcast</i>	293
5.32	Execution time of algorithm <i>bf_broadcast</i>	294
5.33	Collision-free message transmission from node u to its neighbors	296
5.34	Structure of round for algorithm <i>bf_gossip</i>	297
5.35	Dynamic source routing	304
5.36	Request flooding	309

5.37	Request reply	309
5.38	Route establishment using TORA	313
5.39	Route adjustment in TORA due to change in network topology . .	314
5.40	Zone routing	315
7.1	Illustration of abstract problem	337
7.2	Illustration of $vor(p'_i)$	339
8.1	Network graph G with 10 nodes	357
8.2	One possible dominating set of G	357
8.3	One possible connected dominating set of G	357
8.4	Typical application on a sensor network	359
8.5	Reduced number of communication hops in sensor network	359
8.6	Hardware circuit for output bits $x(i)$ and $y(i)$ of RBNS symbol $b_i^{r^{bn}}$ generated from b_i at transmitter	370
8.7	Circuit diagram for converting received i -th RBN symbol to its equivalent binary symbol b_i^* at receiver	371
8.8	Number of occurrences of different runlengths for $n = 8$	376
8.9	Plot of theoretical savings versus data frame size	383
8.10	Representative non-coherent FSK receiver for RBNS scheme . . .	390
8.11	Comparison of average transmitter power (scaled) for given BER .	395
8.12	Representative coherent FSK receiver for RBNS scheme	398
8.13	Average transmitter power (scaled) for various application data types	401
8.14	Relative energy savings for various wireless application data types	401
8.15	Peak and average transmitter power comparison	413
8.16	Representative coherent FSK receiver for TSS scheme	415
8.17	Plot of Equation ((8.31)) against k	420
8.18	Occurrence of codewords in different file types	423
8.19	Representative FSK receiver for CNS scheme	435
8.20	Comparison of average transmitter power (scaled) for given BER values	443
8.21	Comparison of transmitter energy savings among various energy efficient communication schemes	444
8.22	Comparison of energy savings generated by CNS and RBN- SiZeComm at transmitter for various application data types to bi- nary FSK	447
8.23	Tree for FNS	450
8.24	Tree for TFNS	456
8.25	FER versus peak transmitter power	466
9.1	Circuit to compute i_1 and i_2	490
9.2	Circuit to compute j_1 and j_2	492
9.3	Circuit to swap S values (data lines shown only for fixed k)	495
9.4	Circuit to compute Z_1	496