Wireless Ad Hoc and Sensor Networks

Theory and Applications

XIANGYANG LI
Illinois Institute of Technology

CAMBRIDGE UNIVERSITY PRESS
# Contents

 Preface  
 Acknowledgments  
 Abbreviations 

Part I Introduction  

1 History of Wireless Networks  
 1.1 Introduction  
 1.2 Different Wireless Networks  
 1.3 Conclusion  

2 Wireless Transmission Fundamentals  
 2.1 Wireless Channels  
 2.2 The Wireless Communication Graph  
 2.3 Power Assignment and Topology Control  
 2.4 The Wireless Interference Graph  
 2.5 Related Graph Problems and Geometry Concepts  
 2.6 Energy-Consumption Models  
 2.7 Mobility Models  
 2.8 Conclusion  

Part II Wireless MACs  

3 Wireless Medium-Access Control Protocols  
 3.1 Introduction  
 3.2 IEEE 802.11 Architecture and Protocols  
 3.3 WiMAX  
 3.4 Bluetooth  
 3.5 MAC Protocols for Wireless Sensor Networks  
 3.6 Conclusion  

<table>
<thead>
<tr>
<th>Preface</th>
<th>xiii</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgments</td>
<td>xxi</td>
</tr>
<tr>
<td>Abbreviations</td>
<td>xxiii</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part I Introduction</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 History of Wireless Networks</td>
<td>3</td>
</tr>
<tr>
<td>1.1 Introduction</td>
<td>3</td>
</tr>
<tr>
<td>1.2 Different Wireless Networks</td>
<td>4</td>
</tr>
<tr>
<td>1.3 Conclusion</td>
<td>14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part II Wireless MACs</th>
<th>45</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Wireless Medium-Access Control Protocols</td>
<td>47</td>
</tr>
<tr>
<td>3.1 Introduction</td>
<td>47</td>
</tr>
<tr>
<td>3.2 IEEE 802.11 Architecture and Protocols</td>
<td>49</td>
</tr>
<tr>
<td>3.3 WiMAX</td>
<td>60</td>
</tr>
<tr>
<td>3.4 Bluetooth</td>
<td>61</td>
</tr>
<tr>
<td>3.5 MAC Protocols for Wireless Sensor Networks</td>
<td>63</td>
</tr>
<tr>
<td>3.6 Conclusion</td>
<td>69</td>
</tr>
</tbody>
</table>
## TDMA Channel Assignment

4.1 Introduction 71  
4.2 System Model and Assumptions 73  
4.3 Centralized Scheduling 75  
4.4 Distributed Algorithms 85  
4.5 Weighted Coloring and Schedulable Flows 90  
4.6 Further Reading 94  
4.7 Conclusion and Remarks 96

## Spectrum Channel Assignment

5.1 Introduction 99  
5.2 Network System Model 101  
5.3 List-Coloring for Access Networks 102  
5.4 List-Coloring for Ad Hoc Networks 112  
5.5 Transition Phenomena on Channel Availability 114  
5.6 Further Reading 116  
5.7 Conclusion and Remarks 118

## CDMA Code Channel Assignment

6.1 Introduction 120  
6.2 System Model and Assumptions 123  
6.3 Throughput and Bottleneck of General Graphs 126  
6.4 Approximation Algorithms for Interference Graphs 129  
6.5 Maximum Weighted Independent Set for a General Wireless Network Model 136  
6.6 Further Reading 148  
6.7 Conclusion and Remarks 150

### Part III Topology Control and Clustering

## Clustering and Network Backbone

7.1 Introduction 155  
7.2 Network Models and Problem Formulation 155  
7.3 Centralized Algorithms for a Connected Dominating Set 157  
7.4 Message Lower Bound for Distributed-Backbone Construction 161  
7.5 Some Backbone-Formation Heuristics 163  
7.6 Efficient Distributed-Nontrivial-Backbone-Formation Method 166  
7.7 Efficient Distributed-Backbone-Formation Method 170  
7.8 Linear-Programming-Based Approaches 179  
7.9 Geometry-Position-Based Approaches 184  
7.10 Further Reading 186  
7.11 Conclusion and Remarks 187
## Contents

### 8 Weighted Network Backbone

8.1 Introduction
8.2 Study of Typical Methods
8.3 Centralized Low-Cost Backbone-Formation Algorithms
8.4 Efficient Distributed Low-Cost Backbone-Formation Algorithms
8.5 Performance Guarantee
8.6 Discussion
8.7 Further Reading
8.8 Conclusion and Remarks

### 9 Topology Control with Flat Structures

9.1 Introduction
9.2 Current State of Knowledge
9.3 Planar Structures
9.4 Bounded-Degree Spanner and Yao’s Family
9.5 Bounded-Degree Planar Spanner
9.6 Low-Weighted Structures
9.7 A Unified Structure: Energy Efficiency for Unicast and Broadcast
9.8 Spanners for Heterogeneous Networks
9.9 Fault-Tolerant Structures
9.10 Other Spanners
9.11 Conclusion and Remarks

### 10 Power Assignment

10.1 Introduction
10.2 Power Assignment for Connectivity
10.3 Power Assignment for Routing
10.4 Further Reading
10.5 Conclusion and Remarks

### 11 Critical Transmission Ranges for Connectivity

11.1 Introduction
11.2 Preliminaries
11.3 Critical Range for Connectivity
11.4 Critical Range for k-Connectivity
11.5 Connectivity with Bernoulli Nodes
11.6 Practical Performances
11.7 Further Reading
11.8 Conclusion and Remarks
## Contents

16.3 Problem Formulation for Cross-Layer Optimization 444  
16.4 Efficient Link, Channel Scheduling 449  
16.5 Further Reading 455  
16.6 Conclusion 458

### Part V Other Issues

17 Localization and Location Tracking 463  
17.1 Introduction 463  
17.2 Available Information 465  
17.3 Computational Complexity of Sensor Network Localization 470  
17.4 Progressive Localization Methods 476  
17.5 Network-Wide Localization Methods 482  
17.6 Target Tracking and Classification 485  
17.7 Experimental Location and Tracking Systems 498  
17.8 Conclusion and Remarks 500

18 Performance Limitations of Random Wireless Ad Hoc Networks 503  
18.1 Introduction 503  
18.2 Capacity of Unicast for an Arbitrary Network 506  
18.3 Capacity of Unicast for Randomly Deployed Networks 508  
18.4 Capacity of Broadcast for an Arbitrary Network 510  
18.5 Capacity of Broadcast for Randomly Deployed Networks 512  
18.6 Further Reading 517  
18.7 Conclusion and Remarks 518

19 Security of Wireless Ad Hoc Networks 521  
19.1 Introduction 521  
19.2 Cryptography Fundamentals 522  
19.3 Key-Predistribution Protocols 536  
19.4 Secure Routing Protocols 538  
19.5 Further Reading 542  
19.6 Conclusion and Remarks 543

Bibliography 547  
Index 579