CONTENTS

How to Use This Book xiii			
What are Wireless Sensor Networks?			
 1.1 Wireless Sensor Networks, 1 1.2 Sample Applications Around the World, 3 1.3 Types of Wireless Sensor Networks, 7 Summary, 10 Further Reading, 10 			
2 Anatomy of a Sensor Node			
 2.1 Hardware Components, 11 2.2 Power Consumption, 13 2.3 Operating Systems and Concepts, 15 2.3.1 Memory Management, 17 2.3.2 Interrupts, 23 2.3.3 Tasks, Threads, and Events, 24 			
 2.4 Simulators, 26 2.5 Communication Stack, 28 2.5.1 Sensor Network Communication Stack, 28 2.5.2 Protocols and Algorithms, 30 Anatomy of a Sensor Node: Summary, 30 Further Reading, 30 			
	What are Wireless Sensor Networks? 1.1 Wireless Sensor Networks, 1 1.2 Sample Applications Around the World, 3 1.3 Types of Wireless Sensor Networks, 7 Summary, 10 Further Reading, 10 Anatomy of a Sensor Node 2.1 Hardware Components, 11 2.2 Power Consumption, 13 2.3 Operating Systems and Concepts, 15 2.3.1 Memory Management, 17 2.3.2 Interrupts, 23 2.3.3 Tasks, Threads, and Events, 24 2.4 Simulators, 26 2.5 Communication Stack, 28 2.5.1 Sensor Network Communication Stack, 28 2.5.2 Protocols and Algorithms, 30 Anatomy of a Sensor Node: Summary, 30		

3 Radio Communications			33	
	3.3 Radi	Radio Waves and Modulation/Demodulation, 33 Properties of Wireless Communications, 36 3.2.1 Interference and Noise, 37 3.2.2 Hidden Terminal Problem, 38 3.2.3 Exposed Terminal Problem, 39 Medium Access Protocols, 39 3.3.1 Design Criteria for Medium Access Protocols, 41 3.3.2 Time Division Multiple Access, 42 3.3.3 Carrier Sense Multiple Access, 45 3.3.4 Sensor MAC, 48 3.3.5 Berkeley MAC, 50 3.3.6 Optimizations of B-MAC, 51 3.3.7 Other Protocols and Trends, 51 lio Communications: Summary, 53 estions and Exercises, 53 ther Reading, 54		
4	Link	k Management	57	
		Wireless Links Introduction, 57 Properties of Wireless Links, 59 4.2.1 Links and Geographic Distance, 59 4.2.2 Asymmetric Links, 60 4.2.3 Link Stability and Burstiness, 61 Error Control, 62 4.3.1 Backward Error Control, 62		
	4.4	 4.3.2 Forward Error Control, 63 Naming and Addressing, 64 4.4.1 Naming, 64 4.4.2 Addressing, 65 4.4.3 Assignment of Addresses and Names, 65 		
	4.5	 4.4.4 Using Names and Addresses, 66 Link Estimation Protocols, 66 4.5.1 Design Criteria, 66 4.5.2 Link Quality Based, 67 4.5.3 Delivery Rate Based, 68 4.5.4 Passive and Active Estimators, 69 4.5.5 Collection Tree Protocol, 69 Topology Control, 71 		
	Link	4.6.1 Centralized Topology Control, 71 4.6.2 Distributed Topology Control, 72 k Management: Summary, 73 estions and Exercises, 73 ther Reading, 74		

5	Mul	ulti-Hop Communications		
	5.2	Routing Basics, 77 Routing Metrics, 80 5.2.1 Location and Geographic Vicinity, 80 5.2.2 Hops, 81 5.2.3 Number of Retransmissions, 82 5.2.4 Delivery Delay, 83		
	5.3	Routing Protocols, 84 5.3.1 Full-Network Broadcast, 85 5.3.2 Location-Based Routing, 87 5.3.3 Directed Diffusion, 90 5.3.4 Collection Tree Protocol, 92 5.3.5 Zigbee, 94 ti-Hop Communications: Summary, 95		
		stions and Exercises, 96		
	Furt	her Reading, 96		
6	Data Aggregation and Clustering			
	6.1	Clustering Techniques, 99 6.1.1 Random Clustering, 101 6.1.2 Nearest Sink, 102 6.1.3 Geographic Clustering, 103 6.1.4 Clustering Summary, 104		
		In-Network Processing and Data Aggregation, 104 6.2.1 Compression, 104 6.2.2 Statistical Techniques, 107 Compressive Sampling, 109		
	Data Que	a Aggregation and Clustering: Summary, 110 stions and Exercises, 111 her Reading, 111		
7 Tin		ne Synchronization	113	
	7.2 7.3	Clocks and Delay Sources, 113 Requirements and Challenges, 114 Time Synchronization Protocols, 117 7.3.1 Lightweight Tree Synchronization, 117 7.3.2 Reference Broadcast Synchronization, 118 7.3.3 NoTime Protocol, 118 se Synchronization: Summary, 120		
	77	estions and Exercises, 121 ther Reading, 121		

	8	Localization Techniques		123	
		8.1.1 8.1.2 8.1.3 8.2 Pre-De 8.3 Proxim 8.4 Rangin 8.4.1 8.4.2 8.5 Range- 8.6 Range- 8.6.1 8.6.2 Localization:	Costs, 125 ployment Schemes, 126 ity Schemes, 126 g Schemes, 128 Triangulation, 129 Trilateration, 129 Based Localization, 129 Free Localization, 130 Hop-Based Localization, 130 Point in Triangle (PIT), 131 Summary, 132 d Exercises, 133		
9		Sensing Tech	niques		135
		9.2 Sensin 9.3 High-I 9.4 Specia 9.5 Actuat 9.6 Sensor 9.7 Detect Sensing Tech	of Sensors, 135 g Coverage, 136 Level Sensors, 137 l Case: The Human As a Sensor, 138 ors, 138 Calibration, 139 ing Errors, 140 niques: Summary, 141 d Exercises, 141		
	10	10.1 Early 10.1.1 10.1.2	MSN Deployments, 143 Murphy Loves Potatoes, 144 Great Duck Island, 144		143
		10.2.1 10.2.2 10.2.3	Node Problems, 145 Node Problems, 146 Link/Path Problems, 147 Global Problems, 148		
			Analyzing Lifetime and Energy Requirements, Analyzing Required Data, 153	153	

10.5	The Top	o-Down Design Process, 154
		The Network, 154
	10.5.2	The Node Neighborhood, 155
	10.5.3	The Node, 156
	10.5.4	Individual Components of the Node, 156
10.6	Bottom	-Up Implementation Process, 157
	10.6.1	Individual Node-Level Modules, 158
	10.6.2	The Node As an Entity, 159
	10.6.3	The Network As an Entity, 159
Desig	gning and	Deploying WSN Applications: Summary, 160
Furth	er Readi	ng, 160

163

Index

11 Summary and Outlook

167