

Contents

Part I Introduction to Wireless Sensor Networks and Topology Control

1	Wireless Sensor Networks	3
1.1	Introduction	3
1.2	Node and Network Architectures	4
1.2.1	Wireless Sensor Device Architecture	4
1.2.2	Network Architectures	6
1.3	Application Domains and Examples	7
1.4	Challenges and the Need for Energy Saving Mechanisms	7
2	The Physical Layer	11
2.1	Introduction	11
2.2	Wireless Propagation Models	11
2.2.1	The Free Space Propagation Model	12
2.2.2	The Two-Ray Ground Model	12
2.2.3	The Log-Distance Path Model	12
2.3	Energy Dissipation Model	14
2.4	Error Models	15
2.4.1	The Independent Error Model	15
2.4.2	The Two-State Markov Error Model	16
2.5	Sensing Models	18
2.5.1	The Binary Sensing Model	19
2.5.2	The Probabilistic Sensing Model	19
3	The Data Link Layer	21
3.1	Introduction	21
3.2	The Medium Access Control Sub-layer	21
3.2.1	Common MAC Protocols	23
3.2.2	MAC Protocols for WSNs	26
3.3	The Logical Link Control Sub-layer	30
3.3.1	Error Control	31

3.3.2	Performance Analysis of LLC Protocols	33
3.3.3	Energy Analysis of LLC Protocols	36
4	The Network Layer	41
4.1	Introduction	41
4.2	Routing Protocols for WSNs	42
4.2.1	Topology Aware Routing Protocols	42
4.2.2	Topology Unaware Routing Protocols	44
5	The Transport Layer	51
5.1	Introduction	51
5.2	Transport Layer Functions	52
5.3	Wireless Sensor Network Applications	52
5.3.1	Single Packet–Low Reliability Applications	53
5.3.2	Single Packet–High Reliability Applications	55
5.3.3	Multiple Packet–Low Reliability Applications	55
5.3.4	Multiple Packet–High Reliability Applications	56
5.4	Congestion Control in Wireless Sensor Networks	57
5.5	The Use of TCP and UDP in Wireless Sensor Networks	58
6	Topology Control	61
6.1	Introduction	61
6.2	Motivations for Topology Control	62
6.2.1	Energy Conservation	62
6.2.2	Collision Avoidance	63
6.2.3	Increased Network Capacity	64
6.3	Challenges in Topology Control	65
6.4	Design Guidelines	65
6.5	Definition of Topology Control	66
6.6	Topology Control and the Communications Protocol Stack	68
6.7	Topology Control Taxonomy and Road Map	68

Part II Topology Construction

7	Controlling the Transmission Power	73
7.1	Introduction	73
7.2	Centralized Topology Construction: The Critical Transmission Range (CTR) Problem	73
7.3	Centralized Topology Construction: The Range Assignment (RA) Problem	80
7.4	Algorithms from Computational Geometry	82
7.5	Distributed Topology Construction for Homogeneous Networks	84
7.5.1	Location-Based Techniques	84
7.5.2	Direction-Based Techniques	88
7.5.3	Neighbor-Based Techniques	93

7.5.4	Routing-Based Techniques	98
7.6	Heterogeneous Topology Construction	99
8	Building Hierarchical Topologies	105
8.1	Introduction	105
8.2	Backbone-Based Techniques	106
8.2.1	Growing a Tree	107
8.2.2	Connecting Independent Sets	109
8.2.3	Pruning-Based Techniques	112
8.3	Cluster-Based Techniques	113
8.4	Adaptive Techniques	116
9	Hybrid Approaches	119
9.1	Introduction	119
9.2	Hybrid Techniques	119

Part III Topology Maintenance

10	Introduction	125
10.1	Introduction	125
10.2	Definition of Topology Maintenance	125
10.2.1	When Are the Reduced Topologies Built?	126
10.2.2	Scope of Topology Maintenance	126
10.2.3	Triggering Criteria	127
10.3	Design Issues	128
10.4	Synchronizing Radios	129
10.5	Performance Evaluation	131
11	Topology Maintenance Static Techniques	133
11.1	Introduction	133
11.2	Performance Evaluation of Static Global Topology Maintenance Techniques	134
11.2.1	Sparse Networks	135
11.2.2	Dense Networks	137
11.3	Other Static Techniques	138
12	Topology Maintenance Dynamic Techniques	141
12.1	Introduction	141
12.2	Performance Evaluation of Dynamic Global Topology Maintenance Techniques	142
12.2.1	Sparse Networks	142
12.2.2	Dense Networks	143
12.2.3	Other Dynamic Global Techniques	145
12.3	Performance Evaluation of Dynamic Local Topology Maintenance Techniques	145

12.3.1	Sparse Networks	147
12.3.2	Dense Networks	148
12.3.3	Other Dynamic Local Technique	149
13	Topology Maintenance Hybrid Techniques	153
13.1	Introduction	153
13.2	Performance Evaluation of a Hybrid Global Topology Maintenance Technique	153
13.2.1	Sparse Networks	154
13.2.2	Dense Networks	155
13.3	Comparison of Topology Maintenance Techniques	155
13.4	Sensitivity Analysis	158
13.4.1	Time-Based Analysis	158
13.4.2	Energy-Based Analysis	160
13.4.3	Density-Based Analysis	161
A	The Atarraya Simulator	165
A.1	Introduction	165
A.2	Description of Atarraya's Internal Structure	166
A.2.1	Abstract Design and Functional Components	166
A.2.2	Atarraya's Class Tree	169
A.3	Protocol Structure and Design – The <i>EventHandler</i> Class	171
A.3.1	Simulation Events	171
A.3.2	State Labels	173
A.3.3	Communication with the <i>atarraya_frame</i> Class	174
A.3.4	Interaction with Other Protocols	174
A.3.5	Initialization of Nodes and the Initial Events – The <i>init_nodes</i> and the <i>initial_event</i> Methods	174
A.3.6	The <i>HandleEvent</i> Method	175
A.3.7	SimpleTree: An Example of a Topology Construction Protocol	181
A.4	How to Use Atarraya	183
A.4.1	Selection of the Protocols	183
A.4.2	Type of Experiments	187
A.4.3	Structure of a Topology	188
A.4.4	Structure of the Nodes	189
A.4.5	Simulation Results	192
A.5	Future of Atarraya	197
	References	199
	Index	207