

Contents

About the Series Editors	xi
List of Figures	xiii
List of Tables	xvii
Preface	xix
Part I WPANS and 802.15.4	1
1 Prologue: Wireless Personal Area Networks	3
1.1 Wireless Ad Hoc Networks	3
1.2 Design Goals for the MAC Protocol	4
1.3 Classification of MAC Protocols for Ad Hoc Networks	6
1.4 Contention-Based MAC Protocols	9
1.5 New Kinds of Ad Hoc Networks	12
1.6 Sensor Networks	12
2 Operation of the IEEE 802.15.4 Network	17
2.1 Physical Layer Characteristics	17
2.2 Star Topology and Beacon Enabled Operation	20
2.3 Slotted CSMA-CA Medium Access	22
2.4 Acknowledging Successful Transmissions	24
2.5 Downlink Communication in Beacon Enabled Mode	25
2.6 Guaranteed Time Slots	28
2.7 Peer-to-Peer Topology and Non-Beacon Enabled Operation	29
2.8 Device Functionality and Cluster Formation	31
2.9 Format of the PHY and MAC frames	35
Part II Single-Cluster Networks	39
3 Cluster with Uplink Traffic	41
3.1 The System Model – Preliminaries	41
3.2 Superframe with an Active Period Only	44

3.3	Superframe with Both Active and Inactive Periods	51
3.4	Probability Distribution of the Packet Service Time	57
3.5	Probability Distribution of the Queue Length	59
3.6	Access Delay	61
3.7	Performance Results	65
4	Cluster with Uplink and Downlink Traffic	71
4.1	The System Model	71
4.2	Modeling the Behavior of the Medium	84
4.3	Probability Distribution for the Packet Service Time	86
4.4	Performance of the Cluster with Bidirectional Traffic	91
5	MAC Layer Performance Limitations	95
5.1	Congestion of Packets Deferred to the Next Superframe	95
5.2	Congestion after the Inactive Period	98
5.3	Congestion of Uplink Data Requests	99
5.4	Blocking of Uplink Data and Data Requests	100
5.5	Possible Remedies	102
6	Activity Management through Bernoulli Scheduling	111
6.1	The Need for Activity Management	111
6.2	Analysis of Activity Management	112
6.3	Analysis of the Impact of MAC and PHY Layers	116
6.4	Controlling the Event Sensing Reliability	121
6.5	Activity Management Policy	123
7	Admission Control Issues	131
7.1	The Need for Admission Control	131
7.2	Performance under Asymmetric Packet Arrival Rates	133
7.3	Calculating the Admission Condition	135
7.4	Performance of Admission Control	139
	Part II Summary and Further Reading	143
	Part III Multi-cluster Networks	145
8	Cluster Interconnection with Master-Slave Bridges	147
8.1	Analysis of Bridge Operation	149
8.2	Markov Chain Model for a Single Node	158
8.3	Performance of the Network	165
8.4	Network with a Single Source Cluster/Bridge	166
8.5	Network with Two Source Clusters/Bridges	173
8.6	Modeling the Transmission Medium and Packet Service Times	179
9	Equalization of Cluster Lifetimes	187
9.1	Modeling the Clusters	187

9.2 Distributed Activity Management 190

9.3 Energy Consumption in Interconnected Clusters 194

9.4 Performance of Activity Management 198

10 Cluster Interconnection with Slave-Slave Bridges 203

10.1 Operation of the SS Bridge 205

10.2 Markov Chain Model for the SS Bridge 217

10.3 Markov Chain for Non-Bridge Nodes 224

10.4 Performance Evaluation 230

10.5 To Acknowledge or Not To Acknowledge: The CSMA-CA Bridge 231

10.6 Thou Shalt Not Acknowledge: The GTS Bridge 234

10.7 Modeling the Transmission Medium and Packet Service Times 240

Part III Summary and Further Reading 251

Part IV Security 253

11 Security in 802.15.4 Specification 255

11.1 Security Services 256

11.2 Auxiliary Security Header 257

11.3 Securing and Unsecuring Frames 258

11.4 Attacks 260

12 The Cost of Secure and Reliable Sensing 265

12.1 Analytical Model of a Generic Key Update Algorithm 267

12.2 Analysis of the Node Buffer 273

12.3 Success Probabilities 276

12.4 Key Update in a Multi-Cluster Network 278

12.5 Cluster Lifetime 280

12.6 Evaluation of Lifetimes and Populations 283

Part IV Summary and Further Reading 287

Appendices 289

Appendix A An Overview of ZigBee 291

A.1 ZigBee Functionality 291

A.2 Device Roles 292

A.3 Network Topologies and Routing 293

A.4 Security 295

Appendix B Probability Generating Functions and Laplace Transforms 301

Bibliography 302

Index 311

