

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
<b>2</b>	<b>Problem Domain</b>	<b>5</b>
2.1	Motivation: The HelioMesh Project . . . . .	5
2.1.1	Wireless Communication in Solar Power Plants . . . . .	5
2.1.2	Objectives . . . . .	6
2.1.3	Use Cases . . . . .	7
2.1.4	Start from Scratch . . . . .	8
2.2	Communication in LD-WMN . . . . .	10
2.2.1	Definition . . . . .	10
2.2.2	Requirements . . . . .	11
2.2.3	Goals of the Dissertation . . . . .	12
2.3	Background and Terminology . . . . .	13
2.3.1	Network Model . . . . .	13
2.3.2	Connected Dominating Sets . . . . .	14
2.3.3	Self-Stabilization . . . . .	14
2.3.4	Metrics . . . . .	15
2.3.5	Statistics . . . . .	16
<b>3</b>	<b>Programming and Simulation Environment</b>	<b>19</b>
3.1	Current Approaches . . . . .	19
3.1.1	Languages and Operating Systems . . . . .	19
3.1.2	Simulation Tools . . . . .	20
3.2	OMNeT++ Network Simulator . . . . .	21
3.2.1	General . . . . .	21
3.2.2	Channel, Physical, and MAC Model . . . . .	23
3.2.3	Topologies . . . . .	26
3.2.4	Simulation Performance . . . . .	28
3.3	CometOS . . . . .	29
3.3.1	Motivation . . . . .	29
3.3.2	Concept . . . . .	30
3.3.3	Message Passing Interface . . . . .	31
3.3.4	MAC Abstraction Layer & Airframes . . . . .	33
3.3.5	Cross-Layer Support . . . . .	33
3.3.6	Configuration and Initialization . . . . .	34

3.3.7	Remote Method Invocation . . . . .	35
3.3.8	Platform Abstraction Layer and Porting . . . . .	36
3.3.9	Quality Assurance . . . . .	36
3.3.10	Evaluation . . . . .	37
3.4	Hybrid Testbed . . . . .	38
3.4.1	Use Cases . . . . .	39
3.4.2	Realization . . . . .	39
3.4.3	Discussion . . . . .	41
3.5	Concepts and Utilities for Wireless Communication . . . . .	42
3.5.1	Framework for State-Exchange and Self-stabilization . . . . .	42
3.5.2	Density Estimation and Adaptive Beaconing . . . . .	44
3.5.3	Ensuring Bidirectional Communication . . . . .	46
3.5.4	Quality of Service . . . . .	46
3.5.5	Security . . . . .	47
3.5.6	Graph Generator and Graph Simulator . . . . .	47
<b>4</b>	<b>Decomposition Paradigms</b> . . . . .	<b>49</b>
4.1	Analysis of Communication in Flat Networks . . . . .	49
4.1.1	Channel Utilization . . . . .	49
4.1.2	Memory Demand . . . . .	51
4.1.3	Expenditure of Time . . . . .	52
4.1.4	Connectivity in Dense Networks . . . . .	52
4.2	Multi-Channel Communication . . . . .	53
4.2.1	IEEE 802.15.4 Communication in the 2.4 GHz ISM Band . . . . .	53
4.2.2	Recent Approaches . . . . .	54
4.2.3	Random Channel Assignment . . . . .	55
4.2.4	Channel Reassignment and Load-Balancing . . . . .	56
4.3	Multi-Gateway and Transmit Power Adaptation . . . . .	59
4.3.1	State of the Art . . . . .	59
4.3.2	Throughput Maximization by Range Adaptation . . . . .	60
4.4	Clustering and Connected Dominating Sets . . . . .	63
4.4.1	Related Work . . . . .	63
4.4.2	Self-Stabilizing Algorithm . . . . .	64
4.4.3	Efficient Implementation . . . . .	69
4.4.4	Estimation of Complexity . . . . .	73
4.4.5	Experimental Validation . . . . .	74
4.4.6	Simulation . . . . .	75
4.5	Combined Approach . . . . .	78
4.5.1	Concept . . . . .	78
4.5.2	Construction Heuristic . . . . .	79
4.5.3	Framework for Network Decomposition . . . . .	79
4.5.4	Evaluation . . . . .	80
4.5.5	Further Concepts - Aggregation and Compression . . . . .	82

<b>5</b>	<b>Broadcasts and Information Dissemination</b>	<b>85</b>
5.1	Paradigms and Limitations	85
5.1.1	Broadcast Storm	85
5.1.2	General Broadcasting Techniques	86
5.1.3	Reliable Broadcasting Techniques	87
5.2	Reliable CDS-Based Broadcasting	87
5.2.1	Algorithm	88
5.2.2	Reachability	90
5.3	Evaluation	94
5.3.1	Simulation Environment and Setup	94
5.3.2	Simulation of R-CDS	95
5.3.3	Comparison of Flooding Algorithms	97
<b>6</b>	<b>Routing</b>	<b>101</b>
6.1	Towards Routing	101
6.1.1	Classification	101
6.1.2	Routing Protocols	103
6.1.3	Limitations of Current Routing Protocols	106
6.2	CDS-Based Routing	108
6.2.1	Wrapping Arbitrary Routing Protocols	108
6.2.2	MIAO-DV Routing	109
6.2.3	Source-Tree Routing	111
6.2.4	Scalable Source Routing in a CDS	111
6.2.5	Hierarchical Routing	113
6.3	Proposals for Routing in Dense Networks	115
6.3.1	Source-Tree Routing with Signal Power Adaptation	115
6.3.2	Sector-Based Greedy Routing	116
6.4	Evaluation	118
6.4.1	Towards Scalable Source Routing	118
6.4.2	Simulation Environment	120
6.4.3	Flooding	121
6.4.4	Distance-Vector Routing	122
6.4.5	Location-Based Routing	124
6.4.6	Tree-Based Routing	125
6.4.7	CDS-Based Routing	127
6.4.8	Summary	128
<b>7</b>	<b>Communication in Heliostat Fields: A Case Study</b>	<b>129</b>
7.1	Testbed Deployment	129
7.1.1	Hardware & Software	129
7.1.2	Deployment	131
7.1.3	Execution	131
7.1.4	Performance of Routing and Broadcasting	133

7.2	Emergency Shutdown . . . . .	135
7.2.1	Signaling an Emergency Shutdown . . . . .	136
7.2.2	Design Space and Goals . . . . .	137
7.2.3	Evaluation . . . . .	139
7.3	Over-The-Air-Programming . . . . .	140
7.3.1	Architecture . . . . .	141
7.3.2	Firmware Deployment . . . . .	143
7.3.3	Bootloader and Recovery . . . . .	146
7.3.4	Evaluation . . . . .	148
8	Conclusion and Outlook	153
	Bibliography	159
	List of Symbols & Abbreviations	169
	Author's Publications	171
	Curriculum Vitae	173