

Bang Wang

# Coverage Control in Sensor Networks

# Contents

## Part I Introduction

- 1 Introduction . . . . . 3**
  - 1.1 Sensors . . . . . 3
  - 1.2 Sensor Nodes . . . . . 5
  - 1.3 Sensor Networks . . . . . 9
    - 1.3.1 Sensor Network Scenarios . . . . . 9
    - 1.3.2 Sensor Network Applications . . . . . 12
  - 1.4 Challenges and Issues . . . . . 14
    - 1.4.1 Sensor Network Challenges . . . . . 14
    - 1.4.2 Key Research Issues . . . . . 15
  - References . . . . . 17
  
- 2 Sensor Coverage Model . . . . . 19**
  - 2.1 Motivations . . . . . 19
  - 2.2 Sensor Coverage Models . . . . . 21
    - 2.2.1 Boolean Sector Coverage Models . . . . . 22
    - 2.2.2 Boolean Disk Coverage Models . . . . . 23
    - 2.2.3 Attenuated Disk Coverage Models . . . . . 25
    - 2.2.4 Truncated Attenuated Disk Models . . . . . 26
    - 2.2.5 Detection Coverage Models . . . . . 27
    - 2.2.6 Estimation Coverage Models . . . . . 30
  - References . . . . . 32
  
- 3 Network Coverage Control . . . . . 35**
  - 3.1 Motivations and Objectives . . . . . 35
    - 3.1.1 Notes and Comments . . . . . 37
  - 3.2 Coverage Control in the Protocol Architecture . . . . . 38
    - 3.2.1 Notes and Comments . . . . . 40
  - 3.3 Design Issues of Network Coverage Control . . . . . 41
  - 3.4 A Taxonomy for Network Coverage Problems . . . . . 44
  - References . . . . . 48

**Part II Target Coverage Problems**

**4 Node Placement Optimization . . . . . 51**

4.1 Node Placement as the Set-Covering Problem . . . . . 51

4.2 Optimal Sensor Placement Problems . . . . . 55

4.2.1 Modeling Node Placement . . . . . 56

4.2.2 Approximation Algorithms . . . . . 57

4.2.3 Other Placement Problems . . . . . 59

References . . . . . 62

**5 Coverage Lifetime Maximization . . . . . 65**

5.1 Maximizing Target Coverage Lifetime . . . . . 65

5.1.1 Disjoint Set Cover . . . . . 69

5.1.2 Nondisjoint Set Cover . . . . . 77

5.1.3 Notes and Comments . . . . . 83

5.2 Maximizing Connected Target Coverage Lifetime . . . . . 84

5.2.1 Notes and Comments . . . . . 92

References . . . . . 93

**Part III Area Coverage Problems**

**6 Critical Sensor Density . . . . . 99**

6.1 Deterministic Node Placement . . . . . 99

6.1.1 Node Placement in Two-Dimensional Field . . . . . 99

6.1.2 Node Placement in Three-Dimensional Space . . . . . 103

6.1.3 Notes and Comments . . . . . 106

6.2 Random Node Deployment . . . . . 106

6.2.1 Vacancy Analysis . . . . . 106

6.2.2 Numerical Example . . . . . 114

6.2.3 Notes and Comments . . . . . 116

References . . . . . 118

**7 Sensor Activity Scheduling . . . . . 121**

7.1 Assumptions and Objectives . . . . . 121

7.2 Preserving Complete Area Coverage . . . . . 123

7.2.1 Redundancy Check Methods . . . . . 123

7.2.2 Activity Scheduling Procedures . . . . . 127

7.2.3 Example Scheduling Protocols . . . . . 129

7.2.4 Notes and Comments . . . . . 133

7.3 Preserving Partial Area Coverage . . . . . 134

7.3.1 Random Independent Sleeping . . . . . 134

7.3.2 Neighbor Based Scheduling . . . . . 136

7.3.3 Example Scheduling Protocols . . . . . 140

7.3.4 Notes and Comments . . . . . 145

- 7.4 Preserving Area Coverage and Network Connectivity . . . . . 147
  - 7.4.1 Relation Between Area Coverage and Network Connectivity . . . . . 147
  - 7.4.2 Connected Coverage Scheduling . . . . . 148
  - 7.4.3 Notes and Comments . . . . . 150
  - References . . . . . 150
- 8 Node Movement Strategy . . . . . 155
  - 8.1 Healing Coverage Hole . . . . . 155
  - 8.2 Optimizing Area Coverage . . . . . 159
    - 8.2.1 Coverage Pattern Based Movement . . . . . 160
    - 8.2.2 Virtual Force Based Movement . . . . . 162
    - 8.2.3 Grid Quorum Based Movement . . . . . 164
  - 8.3 Improving Event Coverage . . . . . 168
  - References . . . . . 170
- Part IV Barrier Coverage Problems
- 9 Build Intrusion Barriers . . . . . 175
  - 9.1 Sensor Barrier for Intrusion Detection . . . . . 175
  - 9.2 Sensor Scheduling for Barrier Construction . . . . . 180
  - 9.3 Sensor Barrier with Mobile Nodes . . . . . 183
  - References . . . . . 185
- 10 Find Penetration Paths . . . . . 187
  - 10.1 Maximal Breach Path . . . . . 187
  - 10.2 Maximal Support Path . . . . . 190
  - 10.3 Exposure Path . . . . . 192
  - 10.4 Detection Path . . . . . 194
  - 10.5 Analysis for Path Characteristics . . . . . 198
  - References . . . . . 199
- A Voronoi Diagram and Delaunay Triangulation . . . . . 201
  - A.1 Voronoi Diagram . . . . . 201
  - A.2 Delaunay Triangulation . . . . . 203
  - References . . . . . 203
- Index . . . . . 205
- Color Plates . . . . . 207