

Contents

Contents	ix
List of Figures	xiii
List of Tables	xviii
1. Introduction	1
1.1. Motivation	2
1.2. Scope and Definition	3
1.3. Problems Addressed	5
1.4. State of Art in Multipath Assisted Passive Localization	7
1.5. Summary of Contribution	10
1.6. Thesis Outline	14
 I. Fundamentals of RF Emitter Position with Ray-tracing Multipath Exploitation	 17
2. RF Emitter Position Framework	19
2.1. Motivation and Related Work	20
2.2. Data-Model for Localization using TDOA	23
2.3. Algorithms for localization using TDoA	27
2.3.1. Nonlinear Algorithms	28
2.3.2. Linear Algorithms	30
2.3.3. Comparison of Localization Algorithms	33
2.4. Practical Aspects in TDoA Systems	35
2.4.1. Synchronization Requirements in TDoA	37
2.4.2. Accuracy in TDOA Measurements	39
2.4.3. Signal Processing for TDoA Extraction	42
2.4.4. Quality and Power Measurements in TDOA Estimation	45
2.4.5. Effect of NLOS in TDOA Estimation	47
2.5. Concluding Remarks	50

ix

3. RF Channel Estimation for Localization	53
3.1. Motivation and Related Work	54
3.2. Channel Model	56
3.3. Multipath Estimation using Complex Baseband (CBB) Signals from each Sensor	60
3.4. Blind Estimation using SIMO FIR	67
3.5. Multipath Extraction using Volume Cross-correlation	73
3.6. Concluding Remarks	78
 4. Multipath Exploitation with Ray Tracing	 81
4.1. Motivation and Related Work	82
4.2. Ray Tracing Techniques	85
4.2.1. Shooting and Bouncing Ray Technique	87
4.2.2. Method of Images	88
4.2.3. Hybrid Method	88
4.2.4. Visibility Tree in Ray Tracing (RT)	90
4.3. Modeling of Ray Interaction in RT	91
4.4. Limitations of RT Tools in Channel Impulse Response (CIR) Estimations	98
4.5. Multipath Fingerprints with RT	100
4.5.1. Multipath Fingerprints SIMO approach with RT	103
4.5.2. Multipath Fingerprints Volume Cross-Correlation (VCC) approach with RT	104
4.6. Concluding Remarks	106
 5. Machine Learning in Localization Problems	 107
5.1. Motivation and Related Work	107
5.2. General Framework of Machine Learning	110
5.3. Multipath Fingerprint Datasets	115
5.4. Decision Tree in Machine Learning Models	117
5.5. Formulation of Random Forests	119
5.5.1. Regression using Random Forest	122
5.5.2. Classification using Random Forest	125
5.6. Evaluation of Multipath Fingerprints using Random Forest Models	128
5.7. Noise and Mismatching Effects in the Prediction	132
5.8. Random Forest Implementation	135
5.9. Concluding Remarks	137

II. Multipath Position Fingerprints	139
6. Contributions for Multipath Exploitation in RF Outdoor Localization	141
6.1. Enhancement Approaches for Localization	142
6.1.1. RT Multipath Database Exploitation	144
6.1.2. Matching Real Measurements with RT Multipath	148
6.1.3. Multipath Fingerprints using Regression NN	149
6.1.4. RT Multipath Fingerprints using Random Forest	153
6.2. Processing the Datasets for Multipath Fingerprints	154
6.2.1. RT datasets	155
6.2.2. Reference Points Dataset	157
6.3. Multipath Fingerprints Dataset Enhancement with Reference Emitters	158
6.4. Concluding Remarks	160
7. Performance Evaluation	161
7.1. Experimental Scenario Configuration	162
7.2. Generation of the Multipath Fingerprints using RT	163
7.2.1. Emitter Configuration	167
7.2.2. TDoA System Setup	171
7.3. Multipath Fingerprints Enhancement in TDoA Localization	176
7.3.1. Multipath RT Fingerprints Database	178
7.3.2. Random Forest Multipath Fingerprints with VCC	182
7.3.3. Random Forest Multipath Fingerprints with SIMO FIR	188
7.4. Analysis of the Results	192
7.5. Concluding Remarks	194
8. Conclusions and Outlook	197
8.1. Key Points and Contributions	197
8.2. Future Works	199
8.3. Other Fields of Application	201
8.4. Final Remarks	202
Appendix A. Performance Criteria in Localization Systems	205
A.1. Cramer Rao Lower Bound	206
A.2. Confidence Error Ellipse	207
A.3. Circular Error Probability (CEP)	209

Contents

A.4. Empirical Cumulative Distribution	211
Appendix B. Machine Learning Terminology	213
Appendix C. Fusion Estimation in Localization Problems	217
Bibliography	221
Abbreviations, Symbols and Notation	241
Abbreviations	241
Symbols and Notation	245