

Contents

Kurzfassung	V
Abstract	VII
Nomenclature	XIII
List of Symbols	XIX
1 Introduction	1
1.1 Motivation and Area of Application	3
1.1.1 Vehicular Communication	3
1.1.2 Robotic Systems	5
1.2 Problem Statement	6
1.3 Solution Approach and Key Contributions	7
1.4 Outline of this Work	9
2 State-of-the-Art, Related Work and Basics in Research and Technology	11
2.1 Cellular Communication	12
2.1.1 Decentralized Cellular Communication	12
2.2 Sidelink Communication	13
2.2.1 Cellular Device-to-Device Communication	15
2.2.2 Cellular Vehicle-to-Everything Communication	21
2.3 Channel Model for Vehicular Communication	29
2.3.1 Path Loss Channel Models	29
2.3.2 Multipath Propagation Channel Models	32
2.4 Additional Basics	34
2.4.1 Software-Defined Radio	34
2.4.2 Software Virtualization	34
2.4.3 Radio-based Position Estimation	35
2.4.4 Communication Traffic Generators	37
3 Performance Evaluation Methods	39
3.1 Performance Metrics	40
3.2 Simulation	41
3.2.1 Discrete Event Simulation	41
3.2.2 Numerical Simulation	42
3.2.3 Simulation Scenarios	42

3.3	Experiments	44
3.3.1	tinyLTE - A Decentralized Cellular Communication Platform . .	44
3.3.2	SDR-based C-V2X Traffic Generator	50
3.4	Key Contributions	54
4	Evaluation of Decentralized Cellular Communication	57
4.1	Experimental Performance Analysis of Decentralized Cellular Communi- cation	58
4.1.1	Laboratory Setup	58
4.1.2	Field Tests in Automotive Scenarios	59
4.1.3	Field Tests in Maritime and UAV Scenarios	67
4.2	Key Contributions	74
5	Evaluation of Cellular Device-to-Device Communication	77
5.1	Simulative Performance Analysis of Cellular D2D communication . . .	78
5.1.1	D2D Communication Configuration	78
5.1.2	Simulation Setup	79
5.1.3	Evaluation Results	81
5.2	Key Contributions	95
6	Evaluation of Cellular Vehicle-to-Everything Communication	97
6.1	Simulative Performance Analysis of C-V2X	99
6.1.1	Simulation Design	99
6.1.2	Evaluation Results	100
6.2	Experimental Performance Analysis of an C-V2X Traffic Generator . . .	107
6.2.1	Experimental Setup	107
6.2.2	Evaluation Results	108
6.2.3	Comparison to C-V2X Evaluation Results	112
6.3	Validation of CAM position information using C-V2X	114
6.3.1	Range Estimation and Validation using C-V2X	115
6.3.2	Simulation Design	118
6.3.3	Validation Results	122
6.4	Key Contributions	129
7	Summary and Outlook	131
7.1	Conclusions	132
7.2	Outlook	133
7.2.1	Experimental Validation of Additional C-V2X Communication Use Cases	134
7.2.2	Performance Evaluation of Upcoming Cellular Communication Standards for Vehicular Communication	134
7.2.3	C-V2X Communication for Emergency Scenarios	135

A	Appendix	137
A.1	Additional Decentralized Cellular Communication Field Tests	137
A.2	Additional D2D Simulation Results	140
A.2.1	Scalability	140
A.2.2	Packet Inter-Reception	141
A.3	Additional C-V2X Simulation Results	143
A.4	Additional CAM Position Information Validation Results	144
	List of Figures	145
	List of Tables	151
	Publications	153
	Supervised Student Theses	153
	Bibliography	154

Inhalt

Was vor Ashoka war	7
Prinz Ashoka	13
Krieg gegen Kalinga	65
Ashoka der Große	93
Epilog	226
Nachwort	227
Zeittafel	236
Bibliografie	239
Bildnachweis	243