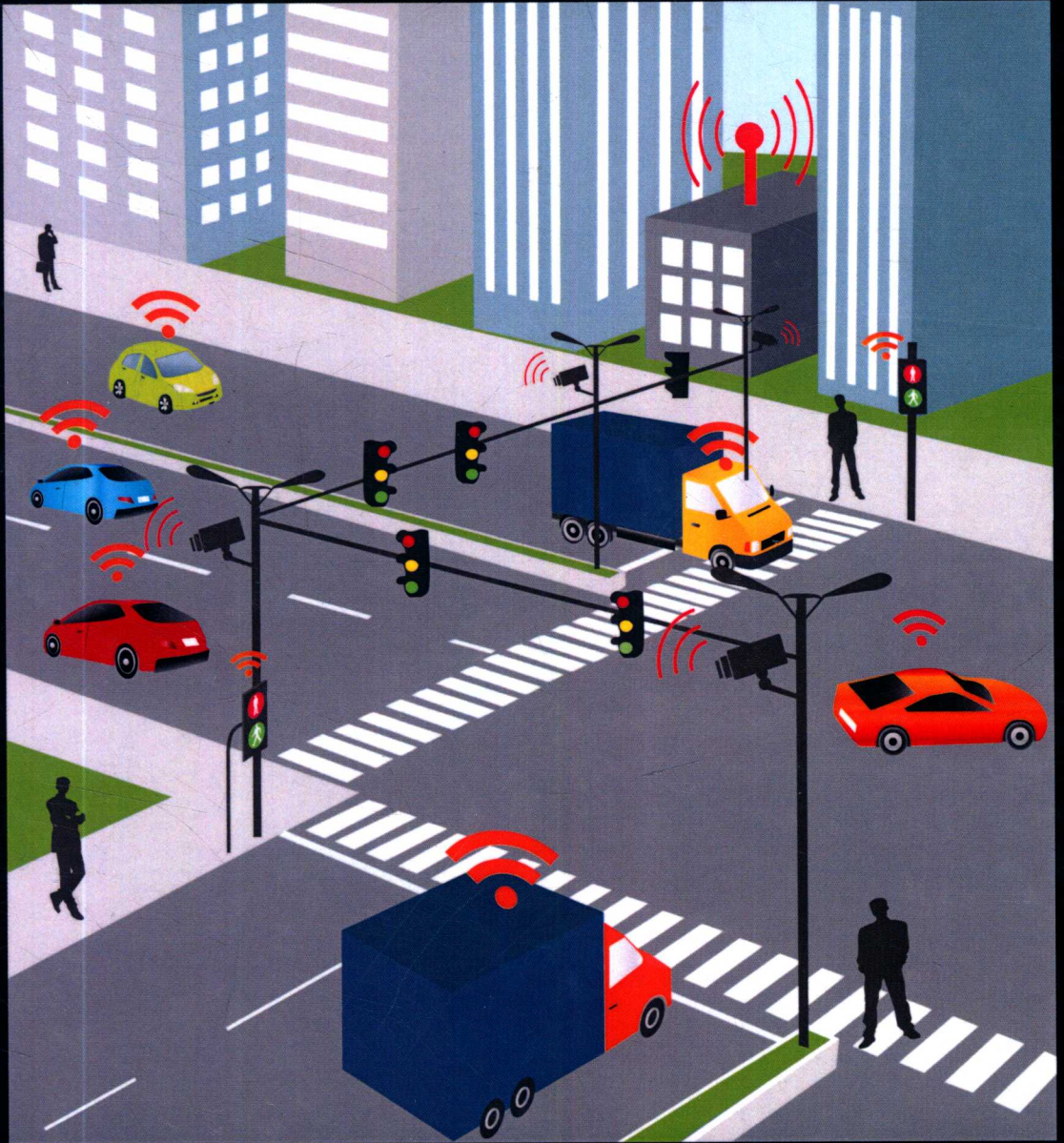


Connected Vehicle Systems

Communications, Data, and Control



Edited by Yunpeng Wang • Daxin Tian
Zhengguo Sheng • Jian Wang

MATLAB[®] is a trademark of The MathWorks, Inc. and is used with permission. The MathWorks does not warrant the accuracy of the text or exercises in this book. This book's use or discussion of MATLAB[®] software or related products does not constitute endorsement or sponsorship by The MathWorks of a particular pedagogical approach or particular use of the MATLAB[®] software.

CRC Press

Taylor & Francis Group

6000 Broken Sound Parkway NW, Suite 300

Boca Raton, FL 33487-2742

© 2017 by Taylor & Francis Group, LLC

CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works

International Standard Book Number-13: 978-1-138-03587-4 (Hardback)

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Visit the Taylor & Francis Web site at

<http://www.taylorandfrancis.com>

and the CRC Press Web site at

<http://www.crcpress.com>



Printed and bound in Great Britain by
TJ International Ltd, Padstow, Cornwall

Connected Vehicle Systems

Yunpeng Wang, Daxin Tian, Zhengguo Sheng, and Jian Wang

Connected Vehicle Systems: Communications, Data, and Control



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

List of Tables

1.1	Comparisons of Functional Classes	6
1.2	Comparison of Automotive Protocols	11
2.1	Parameters Used for Performance Analysis	28
2.2	Parameters Used for Performance Analysis	28
3.1	Original and Proposed Values of Contention Window (CW) as a Function of Backoff Procedure Event Counter (BPC) and Priorities	49
3.2	Summary of Differences	50
3.3	Minimum and Maximum Intermessage Times in the Regular and Proposed Real-Time HomePlug GP	51
4.1	Parameters	66
5.1	Network Conditions Settings	88
5.2	Applications Settings	88
5.3	Model Settings	89
5.4	Settings on the Weights	89
6.1	Parameters	104
8.1	Parameters of IEEE 802.11p	136
8.2	Procedure 1: The DOAs, $\hat{\theta}^i$, Estimation	149
8.3	Parameters Setting	149
8.4	$\hat{\eta}^{opt}$ in Different SNRs ($M = 10, N = 10, K = 4$)	150
8.5	DOA Estimation Based on MT-BCS and MSE Values	151
8.6	DOA Estimation Based on MT-BCS ($K = 4$) and MSE values	153
9.1	CV-IMM-KF and GPS Error Comparison	167
10.1	Parameters and Values	197
12.1	Parameters	235

List of Figures

1.1	Class A application zone.	5
1.2	Class B multiplex application.	5
1.3	Class C applications.	6
1.4	Automotive network architecture.	10
1.5	A roadmap of automotive communication development.	12
1.6	Block diagram of the architecture of the automotive network test bed platform.	13
1.7	An implementation of a minimum viable test bed for automotive communication using Raspberry Pi and Arduino boards.	14
1.8	Distribution of data bit rate on the Ethernet connection over the period of testing.	16
1.9	Partitioning of total data throughput on the Ethernet connection into overhead and data traffic.	16
1.10	Proportion of the traffic on the Ethernet link used by overhead bits as well as data bits transmission.	17
1.11	Graph showing the average latency in signal transmission over the Ethernet link of the test bed.	17
1.12	Graph showing the traffic over the Wi-Fi connection between the onboard unit and RSU of the test bed.	18
1.13	Graph showing proportion of traffic used by overhead in the Wi-Fi connection of the test bed.	18
1.14	Pie chart showing the proportion of traffic that comes from transmission of overhead bits.	18
1.15	Graph showing the average RTT over the Wi-Fi connection.	19
2.1	Magnitude of $S_{21}(f)$ for different connections from HEV VCU to potential communication nodes [222], where VCU is Vehicle Control Unit, ESS is Energy Storage System, TMDMOC is Traction Motor Digital Module Controller, and DC/DC stands for DC-to-DC converter unit of the vehicle. . . .	24
2.2	View of a single transmission cycle.	26
2.3	Illustration of the collision resolution algorithm performed on each channel.	27
2.4	Channel selection probabilities when $M = 10$ channels are available for multiple choices of β	30
2.5	Block diagram of a robust sensing module.	32

2.6	ECDF of the received signal before and after preprocessing.	33
2.7	Illustration of the protocol operation with imperfect sensing.	34
2.8	Success probability versus number of contending nodes for different values of γ , $N = 50$, $k = 6$, $M = 2$	36
2.9	Average success probability versus number of channels for different number of time slots (k), $N = 50$, $\gamma = 0.6$	37
2.10	ρ_1 versus number of channels for different number of time slots (k), $N = 50$, $\gamma = 0.6$	37
2.11	Average success probability versus total number of nodes connected to the harness (N), $\gamma = 0.6$	38
2.12	Probability mass function of the number of transmission cycles required to transmit the first packet (a) all packets (b) when there are 25 contenders, $N = 50$, $\gamma = 0.6$, $k = 4$, $M = 3$	39
2.13	Probability mass function of the number of transmission cycles needed to transmit the first packet (a) all packets (b) when there are five contenders, $N = 50$, $\gamma = 0.6$, $k = 4$, $M = 3$	40
2.14	Success probability of the proposed protocol, and CDR versus number of contending nodes, $M = 3$, $N = 50$, $\gamma = 0.6$	41
2.15	Throughput ρ_1 of the proposed protocol and CDR versus number of contending nodes, $M = 3$, $N = 50$, $\gamma = 0.6$	42
2.16	Average success probability versus threshold λ of the energy detector, $N = 50$, $\gamma = 0.6$, $k = 6$, $M = 2$, $u = 10$	42
2.17	Success probability versus number of contending nodes for multiple values of r , where the good channel is indexed 1, $k = 6$, $M = 2$, $N = 50$, $\gamma = 0.6$	43
2.18	Success probability versus number of contending nodes for multiple values of r , where the bad channel is indexed 1, $k = 6$, $M = 2$, $N = 50$, $\gamma = 0.6$	43
2.19	Success probability versus number of contending nodes for multiple values of r , where channels are equally good, $k = 6$, $M = 3$, $N = 50$, $\gamma = 0.6$	44
2.20	Success probability versus number of contending nodes for multiple values of r , where channels are equally bad, $k = 6$, $M = 5$, $N = 50$, $\gamma = 0.6$	44
3.1	Frame structure of the proposed MAC protocol	50
3.2	Topology of extended HomePlug Green PHY network	51
3.3	Average delay for the regular HomePlug GP messages	52
3.4	Average delay for the proposed HomePlug GP messages	52
3.5	Percentage of collisions in the regular HomePlug	53
3.6	Percentage of collisions in the modified HomePlug	54
4.1	Dynamic spectrum access taxonomy.	60
4.2	Overlay system model of three secondary users.	63
4.3	State probabilities of channel occupancy in overlay.	67
4.4	Secondary system throughput comparison between two and three secondary users.	67
4.5	Throughput comparison between two and three secondary users in overlay scheme.	68
5.1	WAVE stack.	71
5.2	Channel access mechanisms.	72
5.3	V2V communication system architecture with DSRC devices.	74
5.4	The V2V communication system model.	75
5.5	Varying activity α in simulations.	80

5.6	Evaluation of the impact of random noise variability on the dynamics system.	81
5.7	The handover decision framework based on the extended attractor selection model.	82
5.8	The variation of the adopted sigmoid function with different parameter settings.	84
5.9	The real testing scenario.	85
5.10	Performance comparison: Transmission delay versus relative distance. . . .	86
5.11	Performance comparison: Packet loss rate versus relative distance.	86
5.12	A simulation scenario.	87
5.13	The variation of the decision vector states of the different applications: (a) the voice application, (b) one video application, and (c) another video application.	90
5.14	The simulation results under different vehicular terminals: (a) the results of the activity α and (b) the results of the fairness.	91
5.15	The simulation results under different initial velocities: (a) the results of the activity α and (b) the results of the fairness.	92
6.1	Relation between the probability of sending packet p_0 and packet transmission delay T_{delay}	100
6.2	Relation between F_{value} and n	102
6.3	Flow diagram of the decision-making process.	104
6.4	Relation between the number of multicast n and S under different vehicle densities.	105
6.5	Relation between the number of multicast n and E_{decide} under different vehicle densities.	105
6.6	Relation between the number of muticast n and S under different multicast ranges r	106
6.7	Relation between the number of multicast n and E_{decide} under different multicast ranges r	107
6.8	Relation between the number of multicast n and S under different packet's lengths L_p	108
6.9	Relation between the number of multicast n and E_{decide} under different packet's lengths L_p	108
6.10	Relation between the number of multicast n and S under different transmission data rates R_d	109
6.11	Relation between the number of multicast n and E_{decide} under different transmission data rates R_d	109
6.12	Relation between the number of multicast n and S under different vehicle speeds v	110
6.13	Relation between the number of multicast n and E_{decide} under different vehicle speeds v	110
7.1	Ideal partitioning.	118
7.2	Definition of distance.	119
7.3	Potential problem.	120
7.4	Map generated by data and OSM map.	122
7.5	Merged map.	123
7.6	Borders and centerline of the roads.	125
7.7	Nearest point on the road for each node.	126

7.8	Fitting result of LS-SVM and B-spline.	127
7.9	Leftmost marked part.	128
7.10	Middle marked part.	128
7.11	Rightmost marked part.	129
7.12	Deviation of lines fitted by the two methods and the original lines.	129
7.13	Final fitting centerlines of the test area	130
8.1	The hybrid TOA/DOA method.	135
8.2	Maximum throughputs and TUL of 802.11p.	137
8.3	Minimum delays and DLL of 802.11p.	138
8.4	Negotiated deceleration rates used by communication vehicles.	139
8.5	Highway capacity with varied PLRs at different speeds (delay = DLL, payload size = 1000 bytes).	140
8.6	Details of highway capacity with varied PLRs at different speeds (delay = DLL, payload size = 1000 bytes).	140
8.7	Highway capacity with varied bitrates at different speeds (payload size = 1000 bytes, PLR = 0).	141
8.8	Details of highway capacity with varied bitrates at different speeds (payload size = 1000 bytes, PLR = 0).	141
8.9	Highway capacity with varied PLRs at different speeds (delay = 50 ms, payload size = 1000 bytes).	142
8.10	Details of highway capacity with varied PLRs at different speeds (delay = 50 ms, payload size = 1000 bytes).	142
8.11	The mobility of multiple vehicles in different traffic scenarios.	143
8.12	DSRC test bed and its performance evaluation system.	144
8.13	The evaluation results at different speeds and distances.	145
8.14	Problem definition and the initial idea for the solution.	146
8.15	Impinging signals on uniform linear antenna array and the hybrid TOA/DOA positioning method.	147
8.16	Angular scope discretization.	149
8.17	Plots of the number of received signals ($d = /2$; $K = 2$): (a) $M \in [5:5:25]$, $N \in [10:10:100]$; (b) $M \in [5:5:25]$, $SNR \in [0:5:20]$ dB; (c) $N \in [10:10:100]$, $SNR \in [0:5:20]$ dB.	152
8.18	MT-BCSbased DOAs.	153
8.19	Actual and estimated DOAs.	154
8.20	Multiple snapshots DOA estimation ($M = 10$; $N = 10$; $d = /2$; $K = 2$) Plots of \overline{RMSE} when $SNR[0:5:20]$	155
8.21	RMSE of hybrid TOA/DOA-based location estimation.	156
8.22	CDF of the location error (CRB for TOA/DOA for one single RSU).	156
8.23	The absolute position error related to the two simulated cars obtained by comparison methods.	157
9.1	Vehicular positioning system with information fusion of the DFS and GPS measurements from both itself and the other neighboring vehicles.	164
9.2	Initial scenario.	166
9.3	CV-IMM-KF and GPS performance in positioning error.	168
9.4	Positioning enhanced by the DFS and the RSSI measurements.	168
9.5	The schematic of the proposed vehicular cooperative localization method.	172
9.6	One trial demo of vehicular positioning estimation with both the DFS and the RSSI measurements.	182

9.7	The performance of the GPS and the proposed method, and the fundamental limits bounded by the R.SPEB and the R.mSPEB.	182
9.8	The enhancements for different CV penetrations—DFS only.	183
9.9	The neighbors number and achieved performance—DFS only.	183
9.10	The enhancements for different CV penetrations—RSSI only.	184
9.11	The neighbors' number and achieved performance—RSSI only.	184
9.12	The enhancements for the DFS and the RSSI measurements combination, and for the DFS measurements only.	185
10.1	The communication scenario.	189
10.2	Effect of the information security strength on the node utility and the optimal transmit power.	197
10.3	Effect of the relative density of eavesdropper nodes on the node utility and the optimal transmit power, where $\alpha = 0.8$	198
10.4	Effect of the total node density on the node utility and the optimal transmit power, where $\alpha = 0.8$	198
10.5	Effect of the transmit power of other nodes on the node utility and the optimal transmit power, where $\alpha = 0.8$	199
10.6	Effect of the wireless channel bandwidth on the node utility and the optimal transmit power, where $\alpha = 0.8$	200
10.7	Effect of the key length on the node utility and the optimal transmit power, where $n = 1.63 \times 10^{1053}$ times/ μ s.	200
10.8	Effect of the attacker's capability on the node utility and the optimal transmit power, where (a) $\lambda = 128$ bits, (b) $\lambda = 192$ bits, and (c) $\lambda = 256$ bits. . . .	201
11.1	Cyberspace and physical space.	206
11.2	Hyper simulator platform system architecture and modulated components. V2V, vehicle-to-vehicle; V2I, vehicle-to-infrastructure.	211
12.1	The interplay range of vehicle i	216
12.2	Bump function with different parameters.	218
12.3	The variation of the potential functions with different parameter settings. . .	220
12.4	The interaction range.	228
12.5	Sigmoid function with different parameters.	229
12.6	The traveling trajectory of vehicles.	233
12.7	The road situation for the simulation.	234
12.8	The mobility of multiple vehicles in different traffic scenarios.	236
12.9	The results of P_o and P_v under different initial velocity settings.	240
12.10	The results of P_o and P_v under different vehicle numbers.	241
12.11	The collision probability in different traffic scenarios.	242
12.12	The results of flow rate.	244
12.13	Flow rate.	245

Preface

In recent years, connected vehicles have attracted the interest of the research community; e.g., wireless communications, intelligent vehicle technology, intelligent transportation systems, mobile computing, sensors, multimedia, etc. The vehicular systems can help improve the efficiency and safety of a system. Some potential applications include emergency warning system for vehicles, automatic driving assistance systems, fleet management, smart road, and dynamic traffic light, just to name a few. These applications have been recognized by governmental organizations and vehicle manufacturers. The U.S. Federal Communications Commission has allocated 75 MHz of spectrum band around 5.9 GHz for Dedicated Short-Range Communications (DSRC), which is used for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications to support vehicular networking applications. Besides standardization efforts such as VSCC in North America, Car-2-Car consortium in Europe, and IEEE 802.11p working group, a number of research projects including NoW, CVIS, Fleetnet, SafeSpot, and SEVE-COM have addressed vehicular telematics research around the world. Therefore, there is much interest in better understanding the properties of the related system and developing new application systems.

Connected Vehicle Systems: Communications, Data, and Control is the book to present and discuss the recent advances in theory and practice in connected vehicle systems; it will cover emerging research that aims at dealing with the challenges in designing the essential functional components of connected vehicles. The major topics will cover intra- and intervehicle communications, trace and position data analysis, security and privacy, and mobility control. It starts with (Chapter 1) a summary of automotive applications and provides an outline of the main standards used in the automotive industry, in particular, the networks and their protocols. In-vehicle communications are emerging to play an important role in the continued development of reliable and efficient x-by-wire applications in new vehicles. Chapter 2 presents the advancement of power line communications, which can provide a very low-cost and virtually free platform for in-vehicle communications. The latest Home Plug Green PHY (HPGP) has been promoted by major automotive manufacturers for communications with electric vehicles; Chapter 3 gives the results of its hard delay performance in supporting mission-critical in-vehicle applications. Vehicular ad hoc networks (VANETs) physical channel suffers from serious multipath fading and Doppler spreading; the physical channel behaviors are discussed in Chapter 4. Safety-related applications are geared primarily toward avoiding the risk of car accidents; they include cooperative collision warning, precrash sensing, lane-change warnings, and traffic violation warning—these applications all have real-time constraints. Chapter 5 discusses the short-range communications. Because of the special features of vehicular networks

such as mobility, high speed, and self organization, V2V multihop broadcast has become a hot topic in recent years. A high-speed and efficient way to transmit data is discussed in Chapter 6. With the large-scale popularization of GPS equipment, the massive amount of vehicle trajectory data has become an important source for location service, digital map building, and moving trace monitoring. Chapter 7 focuses on road recognition; Chapters 8 and 9 present the DSRC positioning and enhancement methods. VANETs differ from the wired networks and behave in a highly dynamic context; e.g., frequently changing signal-to-noise ratio (SNR) and security risks, which undoubtedly affects the suffered security risk. Chapter 10 presents a lightweight and adaptive security mechanism. Chapter 11 demonstrates a prototype of social-network-enabled transportation system that enables communication between vehicles, monitoring, information gathering, assistant driving, and traffic flow control. Chapter 12 proposes a mobility model to describe the self-organized behavior of the vehicle swarm in VANETs.

MATLAB[®] is a registered trademark of The MathWorks, Inc. For product information, please contact:

The MathWorks, Inc.
3 Apple Hill Drive
Natick, MA 01760-2098 USA
Tel: 508-647-7000
Fax: 508-647-7001
E-mail: info@mathworks.com
Web: www.mathworks.com

Contributors

Falah Ali

University of Sussex
Brighton, United Kingdom

Roberto P. Antonioli

Federal University of Ceará
Fortaleza, Brazil

Min Chen

Huazhong University of Science and
Technology
Wuhan, People's Republic of China

Xuting Duan

Beihang University
Beijing, People's Republic of China

Amir Kenarsari-Anhari

University of British Columbia
Vancouver, British Columbia, Canada

Jia-Liang Lu

Shanghai Jiaotong University
Shanghai, People's Republic of China

Yingrong Lu

Beihang University
Beijing, People's Republic of China

Xiaolei Ma

Beihang University
Beijing, People's Republic of China

Victor Ocheri

University of Sussex
Brighton, United Kingdom

Morgan Roff

Queen's University
Kingston, Ontario, Canada

Zhengguo Sheng

University of Sussex
Brighton, United Kingdom

Wei Shu

University of New Mexico
Albuquerque, New Mexico

Nima Taherinejad

Technical University of Vienna
Vienna, Austria

Daxin Tian

Beihang University
Beijing, People's Republic of China

Jian Wang

Jilin University
Changchun, People's Republic of China

Yunpeng Wang

Beihang University
Beijing, People's Republic of China

Min-You Wu

Shanghai Jiaotong University
Shanghai, People's Republic of China

Yue Yang

Beihang University
Beijing, People's Republic of China

Guohui Zhang

University of Hawaii
Honolulu, Hawaii

Xuejun Zhang

Beihang University
Beijing, People's Republic of China

Jianshan Zhou

Beihang University
Beijing, People's Republic of China

Keyi Zhu

Beihang University
Beijing, People's Republic of China

Contents

List of Figures	vii
List of Tables	xiii
Preface	xv
Contributors	xvii
PART I: INTRAVEHICLE COMMUNICATIONS	1
1 A Survey of Automotive Networking Applications and Protocols	3
<i>Victor Ocheri, Zhengguo Sheng, and Falah Ali</i>	
2 CAN-Based Media Access Control Protocol	21
<i>Zhengguo Sheng, Amir Kenarsari-Anhari, Nima Taherinejad, and Yunpeng Wang</i>	
3 Worst-Delay Analysis of Intravehicle Communication Buses Using HomePlug GP	47
<i>Zhengguo Sheng, Roberto P. Antonioli, Morgan Roff, and Yunpeng Wang</i>	
PART II: INTERVEHICLE COMMUNICATIONS	57
4 Physical Channel Modeling and Sharing	59
<i>Jian Wang and Yunlei Zhang</i>	
5 Short-Range Communication Technology in the Internet of Vehicles	69
<i>Daxin Tian, Jianshan Zhou, Yingrong Lu, Yunpeng Wang, and Zhengguo Sheng</i>	
6 Cross-Layer Multihop Broadcasting	95
<i>Jian Wang and Fangqi Liu</i>	

PART III: VEHICULAR DATA APPLICATION AND MOBILITY CONTROL	113
7 Road Recognition from Trajectories Collected by Freight Vehicles Based on Least Squares Support Vector Machine Fitting	115
<i>Daxin Tian, Yue Yang, Xiaolei Ma, Yunpeng Wang, and Zhengguo Sheng</i>	
8 DSRC for Vehicular Positioning	131
<i>Yunpeng Wang, Xuting Duan, Daxin Tian, Xuejun Zhang, and Yingrong Lu</i>	
9 Vehicular Positioning Enhancement	159
<i>Yunpeng Wang, Xuting Duan, Daxin Tian, Xuejun Zhang, and Min Chen</i>	
10 A Lightweight, Adaptive Security Mechanism	187
<i>Jian Wang and Zemin Sun</i>	
11 A Social-Network-Enabled Green Transportation System Framework Driven by Connected Vehicle Innovations	203
<i>Wei Shu, Guohui Zhang, Min-You Wu, and Jia-Liang Lu</i>	
12 A Mobility Model for Connected Vehicles Induced by the Fish School	213
<i>Daxin Tian, Keyi Zhu, Jianshan Zhou, and Yunpeng Wang</i>	
References	247
Index	269

INTRAVEHICLE COMMUNICATIONS

I