

# Contents

<b>Preface . . . . .</b>	xiii
Léo MENDIBOURE	
<b>Part 1. Introduction to Cooperative Intelligent Transport Systems . . . . .</b>	1
<b>Chapter 1. Local Interactions for Cooperative ITS: Opportunities and Constraints . . . . .</b>	3
Jean-Marie BONNIN and Christophe COUTURIER	
1.1. Introduction . . . . .	3
1.2. Ephemeral local interactions: concept and examples . . . . .	5
1.2.1. Examples of services using ephemeral local interactions . . . . .	5
1.2.2. Characteristics of ephemeral local interactions . . . . .	6
1.2.3. Advantages of ephemeral local interactions . . . . .	8
1.2.4. Suitability of communication technologies for this type of interaction . . . . .	10
1.3. Local interactions serving cooperative ITS . . . . .	13
1.3.1. Cooperative ITS services . . . . .	13
1.3.2. Benefit of ephemeral local interactions for cooperative ITS . . . . .	14
1.3.3. V2X communication technologies . . . . .	16
1.3.4. Properties of C-ITS services built on local interactions . . . . .	18
1.3.5. Limitations and constraints of implementing services built on local interactions . . . . .	22
1.4. Role of infrastructure in cooperative ITS services . . . . .	26
1.4.1. Infrastructures dedicated to cooperative ITS . . . . .	26
1.4.2. Towards an active infrastructure . . . . .	28
1.5. Conclusion and prospects . . . . .	29
1.6. References . . . . .	30

<b>Chapter 2. Evolution of Use Cases for Intelligent Transport Systems . . . . .</b>	<b>33</b>
Sassi MAALOUL, Hasnaâ ANISS, Marion BERBINEAU and Léo MENDIBOURE	
2.1. Introduction . . . . .	33
2.2. Vehicular communication technologies . . . . .	34
2.2.1. ITS-G5/IEEE 802.11p technology . . . . .	35
2.2.2. The 3GPP standard: C-V2X . . . . .	36
2.2.3. Deployment of ITS technologies . . . . .	37
2.3. Evolution of use cases . . . . .	37
2.3.1. Classification of use cases . . . . .	38
2.3.2. Required performance . . . . .	40
2.3.3. Example of use cases . . . . .	41
2.4. Challenges and future services of V2X . . . . .	48
2.5. Conclusion . . . . .	49
2.6. References . . . . .	49
<b>Part 2. Optimization of Data Transmission for Cooperative Intelligent Transport Systems . . . . .</b>	<b>51</b>
<b>Chapter 3. Towards an Optimization of Data Transmission in Cooperative Intelligent Transport Systems . . . . .</b>	<b>53</b>
Mohamed BENZAGOUTA, Ramzi BOUTAHALA, Secil ERCAN, Sassi MAALOUL, Hasnaâ ANISS, Léo MENDIBOURE, Marwane AYADA and Hacène FOUCHAL	
3.1. Introduction . . . . .	53
3.2. Context . . . . .	55
3.2.1. C-ITS Services . . . . .	55
3.2.2. Communication standards . . . . .	56
3.3. Experimental evaluation of the performance of the C-ITS message broadcasting system . . . . .	58
3.3.1. C-Roads France project and COOPITS application . . . . .	58
3.3.2. Experimental environment and measurements . . . . .	60
3.3.3. Analysis of results . . . . .	61
3.4. Discussion of the main causes . . . . .	65
3.4.1. Absence of adaptation to actual conditions . . . . .	66
3.4.2. Duplication of non-scalable information . . . . .	66
3.4.3. Broadcasting of information in wide geographical areas . . . . .	66
3.4.4. High level of security in relation to the risks involved . . . . .	67
3.5. Recommendations and research avenues . . . . .	70
3.5.1. Differentiation by traffic conditions . . . . .	70
3.5.2. Smart broadcasting of constant messages . . . . .	70
3.5.3. Smart definition of message broadcast areas . . . . .	70
3.5.4. Security-level optimization . . . . .	71
3.6. Conclusion . . . . .	71

---

3.7. Acknowledgments . . . . .	72
3.8. References . . . . .	72
<b>Chapter 4. Efficient Hybridization of C-ITS Communication Technologies . . . . .</b>	<b>75</b>
Badreddine Yacine YACHEUR, Toufik AHMED and Mohamed MOSBAH	
4.1. Introduction . . . . .	75
4.2. Related works . . . . .	77
4.3. Definition of a heterogeneous network architecture and design of a protocol stack . . . . .	79
4.4. RL for selecting the mode of communication . . . . .	81
4.4.1. Deep reinforcement learning. . . . .	82
4.4.2. Correspondence with key elements of reinforcement learning . . . . .	82
4.5. Performance evaluation . . . . .	87
4.5.1. Simulation framework and scenario. . . . .	87
4.5.2. DDQL algorithm parameters. . . . .	89
4.5.3. Simulation results . . . . .	90
4.6. Conclusion . . . . .	93
4.7. References . . . . .	93
<b>Chapter 5. Using SDN Technology to Control C-ITS: Towards Decentralized Approaches . . . . .</b>	<b>97</b>
Romain DULOUT, Lylia ALOUACHE, Tidiane SYLLA, Léo MENDIBOURE, Hasnaâ ANISS, Virginie DENIAU and Yannis POUSSET	
5.1. Introduction . . . . .	97
5.2. Context . . . . .	99
5.2.1. SDN-controlled C-ITS architectures (SDVN) . . . . .	99
5.2.2. Blockchain technology . . . . .	101
5.3. Application of Blockchain to SDVN architectures . . . . .	103
5.4. Optimization of Blockchain technology for SDVN architectures . . . . .	106
5.4.1. New architectures. . . . .	107
5.4.2. New mechanisms . . . . .	108
5.5. Future research avenues. . . . .	109
5.5.1. Optimal positioning of Blockchain nodes. . . . .	109
5.5.2. Energy consumption reduction . . . . .	109
5.5.3. Integration of AI and Blockchain . . . . .	110
5.5.4. A more complete integration between SDN and Blockchain . . . . .	110
5.6. Conclusion . . . . .	111
5.7. References . . . . .	112

<b>Chapter 6. Application of Network Slicing in C-ITS Systems . . . . .</b>	<b>115</b>
Abdenour RACHEDI, Toufik AHMED and Mohamed MOSBAH	
6.1. Introduction . . . . .	115
6.2. Vehicle-to-everything (V2X) communications . . . . .	116
6.3. Presentation of V2X technologies . . . . .	118
6.3.1. ITS-G5 . . . . .	119
6.3.2. LTE-V2X . . . . .	121
6.3.3. 5G-V2X . . . . .	123
6.4. Network slicing for 5G-V2X . . . . .	125
6.4.1. Network slicing for C-V2X . . . . .	126
6.4.2. ITS-G5 network slicing. . . . .	128
6.5. Conclusion . . . . .	138
6.6. References . . . . .	138
<b>Part 3. New Approaches to Data Processing in Cooperative Intelligent Transport Systems . . . . .</b>	<b>141</b>
<b>Chapter 7. A Novel Cloud Approach for Connected Vehicles . . . . .</b>	<b>143</b>
Geoffrey WILHEM, Marwane AYADA and Hacène FOUCHAL	
7.1. Introduction . . . . .	143
7.2. State of the art . . . . .	144
7.2.1. ETSI standards for C-ITSS . . . . .	145
7.2.2. Vehicular cloud computing . . . . .	146
7.2.3. Information-centric networking . . . . .	147
7.3. The GeoVCDN approach . . . . .	150
7.3.1. A centralized context-cloud architecture . . . . .	150
7.3.2. Geographic routing ICN protocol . . . . .	153
7.3.3. Discussion . . . . .	160
7.4. Analytical model. . . . .	160
7.4.1. Description of the model . . . . .	161
7.4.2. Network modeling . . . . .	161
7.4.3. Communication environment modeling. . . . .	164
7.4.4. Message dissemination modeling . . . . .	165
7.4.5. Approaches . . . . .	173
7.4.6. Discussion . . . . .	179
7.5. Evaluation . . . . .	180
7.5.1. Simulator description . . . . .	180
7.5.2. Simulation results for network load . . . . .	182
7.6. Simulation results for data utility. . . . .	186
7.6.1. Simulation results for data validity . . . . .	186
7.6.2. Simulation results for data freshness . . . . .	187
7.6.3. Discussion of the simulation . . . . .	191

---

7.7. Use case study . . . . .	191
7.7.1. Scenario . . . . .	192
7.7.2. Discussion . . . . .	194
7.8. Conclusion . . . . .	195
7.9. Acknowledgment . . . . .	196
7.10. References . . . . .	196
<b>Chapter 8. Optimal Placement of Edge Servers in C-ITS Systems . . . . .</b>	<b>199</b>
Sabri KHAMARI, Toufik AHMED and Mohamed MOSBAH	
8.1. Introduction . . . . .	199
8.2. Context . . . . .	201
8.2.1. Vehicular applications . . . . .	201
8.2.2. Multi-access edge computing (MEC) . . . . .	201
8.2.3. Deployment of MEC systems . . . . .	201
8.3. State of the art . . . . .	202
8.4. OptPlacement: efficient edge server placement . . . . .	203
8.4.1. System modeling . . . . .	204
8.4.2. Methodology and simulation . . . . .	208
8.4.3. Performance evaluation . . . . .	213
8.5. Conclusion . . . . .	218
8.6. References . . . . .	219
<b>Chapter 9. Risk Estimation: A Necessity for the Connected Autonomous Vehicle . . . . .</b>	<b>223</b>
Dominique GRUYER, Sio-Song IENG, Sébastien GLASER, Sébastien DEMMEL, Charles TATKEU and Sabrine BELMEKKI	
9.1. Context and objectives . . . . .	223
9.2. Estimation of risk local to the ego-vehicle: some existing metrics . . . . .	226
9.3. Development of communication strategy to extend risk: CBL and CBL-G . . . . .	232
9.4. Computation of cooperative risks: extended local risk and global risk . . . . .	234
9.5. Impact of global risk and anticipation of risky situations . . . . .	236
9.6. Discussion . . . . .	242
9.7. Conclusion and prospects . . . . .	246
9.8. References . . . . .	247
<b>Chapter 10. Resilience of Collective Perception in C-ITS – Deep Multi-Agent Reinforcement Learning . . . . .</b>	<b>251</b>
Imed GHNAYA, Hasnaâ ANISS, Marion BERBINEAU, Mohamed MOSBAH and Toufik AHMED	
10.1. Introduction . . . . .	252
10.1.1. Background and issue . . . . .	252
10.1.2. Motivation and contribution . . . . .	253

---

10.2. State of the art . . . . .	255
10.2.1. Standardization of collective perception by ETSI . . . . .	256
10.2.2. Perception data selection and exchange techniques . . . . .	257
10.3. Mathematical modeling of the cooperative driving environment . . . . .	258
10.3.1. Awareness and perception data exchange . . . . .	259
10.3.2. Utility of perception data in the driving environment . . . . .	260
10.4. Multi-agent learning with DRL for selection and exchange of perception data . . . . .	261
10.4.1. System design . . . . .	262
10.4.2. Learning algorithm . . . . .	263
10.5. Simulations, results and evaluations . . . . .	265
10.5.1. Simulation tools, scenarios and parameters . . . . .	265
10.5.2. Results and evaluations . . . . .	266
10.6. Conclusion . . . . .	269
10.7. References . . . . .	270
<b>Part 4. Securing Cooperative Intelligent Transport Systems . . . . .</b>	<b>273</b>
<b>Chapter 11. Distance-Bounding Protocols . . . . .</b>	<b>275</b>
David GÉRAULT, Pascal LAFOURCADE and Léo ROBERT	
11.1. Introduction . . . . .	276
11.2. Relations between threats for DB protocols . . . . .	278
11.2.1. Threat models . . . . .	278
11.2.2. Relation between different threat models . . . . .	281
11.3. Overview of existing protocols . . . . .	283
11.3.1. Improvement of attacks . . . . .	284
11.3.2. Comparison of DB protocols . . . . .	287
11.4. References . . . . .	288
<b>Chapter 12. Context-Aware Security and Privacy as a Service for the Connected and Autonomous Vehicle . . . . .</b>	<b>295</b>
Tidiane SYLLA, Mohamed Aymen CHALOUF, Léo MENDIBOURE and Francine KRIEF	
12.1. Introduction . . . . .	295
12.2. Security, privacy and trust of connected and autonomous vehicle applications. . . . .	297
12.2.1. Main applications of the connected and autonomous vehicle . . . . .	297
12.2.2. Security, privacy and trust services for the connected and autonomous vehicle . . . . .	300
12.3. Security and privacy architecture . . . . .	303
12.3.1. Context-aware security and privacy . . . . .	303
12.3.2. Gaps in existing solutions. . . . .	305

---

12.3.3. Proposed solution . . . . .	306
12.4. Self-adaptive selection of network access technologies. . . . .	312
12.4.1. Infrastructure edge computing . . . . .	313
12.4.2. Orchestration and placement of services . . . . .	315
12.5. Main research works to be conducted . . . . .	317
12.6. Conclusion . . . . .	318
12.7. References . . . . .	319
<b>Chapter 13. Vehicular Wireless Communications: Risks and Detection of Attacks . . . . .</b>	<b>321</b>
Jonathan VILLAIN, Virginie DENIAU and Christophe GRANSART	
13.1. Introduction . . . . .	321
13.2. General characteristics of wireless communications for connected vehicles . . . . .	322
13.2.1. Challenges related to the connected vehicle . . . . .	322
13.2.2. V2V communications . . . . .	323
13.2.3. V2I communications . . . . .	324
13.3. Characteristics of wireless communications . . . . .	325
13.3.1. Principle of wireless communications . . . . .	325
13.3.2. Long-range communications . . . . .	325
13.3.3. Short-range communications . . . . .	326
13.3.4. Advent of 5G. . . . .	326
13.4. Susceptibility of communications and risks incurred . . . . .	327
13.4.1. Principle of attacks targeting layers 1 and 2 of communication systems . . . . .	327
13.4.2. Sybil attack . . . . .	328
13.4.3. Deauthentication frame attack . . . . .	328
13.4.4. Black-hole attack . . . . .	329
13.4.5. Jamming attack . . . . .	330
13.4.6. Flooding attack . . . . .	331
13.4.7. Risks and performance indicators . . . . .	331
13.5. Attack detection . . . . .	332
13.5.1. Need for a detection system . . . . .	332
13.5.2. Detection method . . . . .	333
13.5.3. AI for detection . . . . .	335
13.6. Conclusion . . . . .	338
13.7. References . . . . .	338
<b>List of Authors . . . . .</b>	<b>341</b>
<b>Index. . . . .</b>	<b>345</b>

---