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Advanced Technologies for Intelligent Transportation Systems

Springer

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We cannot teach people anything; we can only help them discover it within themselves.

Galileo Galilei

The beginning of all science is wondering why things are the way they are.

Aristotele

To my parents and all the people that supported me during these years

Marco Picone

To all who have loved me, to all whom I have loved

Stefano Busanelli

To my parents and Annalisa, for their endless support

Michele Amoretti

To Niccolò and Rita, my only wealth

Francesco Zanichelli

To Sofia, Viola, and Anna, the north stars of my sky

Gianluigi Ferrari

Foreword

Intelligent Transportation Systems (ITS) have lately earned center stage as some of the most relevant technologies to academia, industries, and the society in general. Their strong suit is *transversality*, as the development of ITS straddles several different research fields (e.g., from communication to logistics), and has a dramatic impact on many real-world aspects.

Applications supported by ITS range from safety to entertainment, and all of them will lead to tangible improvements of our daily life. Among such applications, those that aim at reducing energy consumption and carbon footprint deserve special mention, as they make ITS one of the green technologies that will define an eco-friendly society.

It is therefore evident that introductory and teaching material on ITS, as well as in-depth studies in this field, are precious resources for students, engineers, researchers, and anyone who would like to enhance her knowledge on the world we live in.

This book, *Advanced Technologies for Intelligent Transportation Systems*, is the work of one of the most renowned groups of experts in the field. It first presents the fundamental aspects of ITS in a tutorial manner, then it moves toward more advanced topics. It successfully covers a vast range of technical aspects such as communication, networking, security, applications. Additionally, the book provides an insightful overview of the major analytical and experimental methodologies for the study of ITS, which is one of its most unique merits.

This book thus represents the definitive guide to ITS: an excellent reference for students as well as for researchers working in the field. I am certain that all readers will enjoy it.

Turin, May 2014 Carla Fabiana Chiasserini

Preface

This books is by no means a treatise on all aspects of Intelligent Transportation Systems (ITSs). Rather, it attempts to present a unified perspective on ITS, encompassing a few advanced technologies which we came in touch with during part of our research activity in the last years. In particular, one of the peculiarities of this book is the presentation of possible solutions at various communication layers, encompassing both computer science-oriented (high layers) and telecommunication-oriented (low layers) perspectives. Along the way, we describe, in a coherent fashion, a number of interwoven innovative technologies. The approach is thus inherently cross-layer, in the sense that we cover different wireless communication protocols, but we also take into account application-level services. The intended audience is academic and industrial professionals, with good technical skills in information and communication technologies. To ease reading, we have limited as much as possible the mathematical details, which are mostly reported in the appendices of the book.

The contents of the book flow from a preliminary regulatory overview to more technical issues. The synopsis can be summarized as follows. The *first chapter* presents ITS principles and a brief standardization history, comparing European and US visions. Emerging worldwide ITS architectures are also illustrated, together with the most relevant envisioned ITS applications. The *second chapter* goes more deeply into the analysis of the communication paradigms and technologies that enable ITSs. Key challenges in vehicular networks are discussed, taking into account Vehicle-to-X (V2X) communications. A survey of the literature on centralized client/server and decentralized Peer-to-Peer (P2P) vehicular networks is proposed. This chapter terminates with the presentation of the most important enabling communication technologies for future ITSs, namely: cellular networks, WiFi, IEEE 802.11p, WAVE and ETSI ITS. The *third chapter* is fully devoted to wireless communications for Vehicular Ad hoc NETworks (VANETs). We first investigate probabilistic broadcast protocols with silencing, a recursive analytical performance evaluation framework and simulations. Then, we analyze the performance of VANETs as distributed wireless sensor networks. The *fourth chapter* presents X-NETAD, a hierarchical architecture for "cross-network" ITS

communications. Experimental results are illustrated and discussed. The *fifth chapter* focuses on application-level distributed algorithms for ITS. In particular, the Distributed Geographic Table (DGT) P2P overlay scheme is presented, and its performance is evaluated, relying on both analytical and simulation results. The DGT for Vehicular Networks (D4V) architecture, supporting a number of ITS applications, is finally presented.

We remark that the specific protocols and architectures considered in this book are "representative," as opposed to "optimal." In other words, we set to write this book mainly to provide the reader with our (limited) view on the subject. Our hope is that this book will be interpreted as a starting point and a useful comparative reference. Some of the tools used in the book (for example, the simulator DEUS) are open-source and available to the interested reader.

It is our pleasure to thank all the collaborators and students who were with us during the years of research which have led to this book, collaborating with our two groups at the Department of Information Engineering of the University of Parma: the Wireless Ad hoc and Sensor Networks (WASN) Lab and the Distributed Sytems Group (DSG). We cannot thank them one by one, but their contributions were instrumental to get here. Finally, we express our sincere gratitude to Springer for giving us the opportunity to complete this project. In particular, we are indebted to Dr. Cristoph Bauman, who believed in this project from the very beginning, and to Mrs. Janet Sterritt-Brunner, our production project coordinator, who was very kind and (above all) very patient.

Parma, June 2014

Marco Picone
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Acronyms

ABC	Always Best Connected
AC	Access Class
ACK	Acknowledgment
AIFS	Arbitration Inter-Frame Space
AP	Access Point
AS	Application Server
ASV	Advanced Safety Vehicle
BA	Basic Access
BC	Backoff Counter
BPAB	Binary Partition Assisted Protocol
BPSK	Binary Phase Shift Keying
BS	Base Station
BSS	Basic Service Set
BTP	Basic Transport Protocol
C2C-CC	Car 2 Car Communications Consortium
CALM	Communications Access for Land Mobiles
CAM	Cooperative Awareness Message
CCK	Complementary Code Keying
CCP	Cluster Confirmation Packet
CDF	Cumulative Distribution Function
CHE-IF	Cluster-Head Election IF
CIP	Cluster Initialization Packet
C-ITS	Cooperative ITS
COTS	Commercial Off-The-Shelf
CP	Coverage Percentage
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
D2D	Device-to-Device
D4V	DGT for VSN
DCF	Distributed Coordination Function
DENM	Decentralized Environmental Notification Message

DFE	Distance From Event
DGT	Distributed Geographic Table
DHT	Distributed Hash Table
DIFS	Distributed InterFrame Space
DK	DGT Kernel
DMH	DGT Message Handler/Dispacher
DSRC	Dedicated Short-Range Communications
DSSS	Direct Sequence Spread Spectrum
EC	European Commission
ECDA	Enhanced Distributed Channel Access
ECU	Engine Control Unit
EG	Event Generator
EIFS	Extended IFS
EMDV	Emergency Message for Vehicular Environments
ERP	Extended Rate PHY
ETSI	European Telecommunications Standards Institute
EU	European Union
FCC	Federal Communications Commission
FCS	Frame Control Sequence
FHSS	Frequency Hopping Spread Spectrum
FHWA	Federal Highway Administration
FNTP	Fast Networking and Transport Layer protocol
FSAP	Fast Service Advertisement Protocol
FTM	Fluid Traffic Model
GB	GeoBucket
GDP	Gross Domestic Product
GM	Geo-Bucket Manager
GP	Global Position
GPA	Global Positioning System
HCCA	HCF Controlled Channel Access
HCF	Hybrid Coordination Function
HR/DSSS	High Rate Direct Sequence Spread Spectrum
I2V	Infrastructure-to-Vehicle
IBSS	Independent BSS
ICT	Information Communication Technologies
IDM-LC	Intelligent Driver Motion with Lane Changes
IF	Irresponsible Forwarding
ITS	Intelligent Transportation System
ITSC	ITS Communication
IVC	Inter-Vehicular Communication
IVCES	In-Vehicle Communications and Entertainment System
LM	Location Manager
LocHNESs	Localizing and Handling Network Event System
LTE-A	LTE Advanced
M2M	Machine-to-Machine

MAC	Medium Access Control
MAF	Mass Air Flow
MANET	Mobile Ad-hoc NETworks
MBMS	Multimedia Broadcast Multicast Service
MCDS	Minimum Connected Dominant Set
MIMO	Multiple-Input Multiple-Output
ML	Map Loader
MM	Mobility Model
NHTSA	National Highway Traffic Safety Administration
NPE	Node Position Error
OBU	On-Board Unit
OFDM	Orthogonal Frequency Division Multiplexing
OIS	On-board Infotainment System
P2P	Peer-to-Peer
PAF	Probability Assignment Function
PATH	Partners for Advanced Transportation TecHnology
PCF	Point Coordination Function
PDF	Probability Density Function
PER	Packet Error Rate
PMF	Probability Mass Function
PP	Probe Packet
PU	Primary User
QoS	Quality of Service
RB	Resource Block
RE	REachability
RITA	Research and Innovative Technology Administration
RSU	Road Side Unit
RTD	Round-Trip Delay
RTS/CTS	Ready-To-Send/Clear-To-Send
RTSM	Real-Time Simulation Monitoring
SB	Smart Broadcast
SDO	Standards Development Organizations
SIFS	Short Inter Frame Space
SL	Sip2Peer Layer
SM	Subscription Manager
SNR	Signal to Noise Ratio
SS	Switch Station
SSWE	Switch Station Web Editor
TD	Transmission Domain
TE	Transmission Efficiency
TSF	Timing Synchronization Function
TTL	Time To Live
TXOP	Transmission Opportunity
UDP	User Data Protocol
UI	User Interface

UMB	Urban Multihop Broadcast
USA	United States of America
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-X
VSN	Vehicular Sensor Network
WAVE	Wireless Access in Vehicular Environments
WLAN	Wireless Local Area Network
WPA	WiFi Protected Access
WSA	WAVE Service Advertisement
WSMP	WAVE Short Message Protocol
X-NETAD	Cross-Network Effective Traffic Alert Dissemination