Preface

The automotive industry is undergoing a continuous transformation; vehicles are no longer thermo mechanical systems with some electronic components used to start engines and lighting. Today's vehicles are complex systems, with networks of computers controlling their most important functions. Increasing fuel costs, as well as increasing awareness of vehicular pollution and noise affecting large human agglomerations and unacceptable numbers of traffic accidents and road congestion are exerting much pressure for change on the automotive industry. What kind of change is expected?

Within a short period, mobile communications have changed our lifestyles allowing us to exchange information, almost anywhere at anytime. The introduction of such mobile communications systems in motor vehicles should be therefore only a matter of time. This should bring a new paradigm, that of sharing information amongst vehicles and infrastructure, and lead to numerous applications for safety, traffic efficiency as well as infotainment.

The main purpose of this book is to provide an overview of the information and communications technologies that are to be deployed in the new generations of vehicles – to provide valuable insights into the technologies for vehicular networks and data exchange, from both theoretical and practical perspectives. We hope that the contents can be used in graduate level courses as a reference and by the automotive industry as training material. The book should provide a concise background and a good foundation to students entering the field of automotive information and communications technologies. We also hope that it would serve as a reference to researchers/scientists and practitioners by enabling them to offer exciting and novel technologies and applications that would, in the future, transform our land transportation systems.

Information technology is the driving force behind innovations in the automotive industry. In the past years, control systems of cars have moved from the analog to the digital domain. In particular, x-by-wire systems began to appear, and have driven research efforts of the whole automotive industry in the last decade. Networked Electronic Control Units (ECUs) are increasingly being deployed in cars to realize diverse functions such as engine management, air-bag deployment, and even in intelligent brake systems. At the same time, emerging vehicular networks in the forms of intra-vehicle, vehicle-to-vehicle and vehicle-to-infrastructure communications are fast becoming a reality. They will enable a variety of applications for safety, traffic efficiency, driver assistance, as well as infotainment to be incorporated into modern automobile designs.

This book introduces the advanced information technologies that shape the ultra-modern automotive industry today. Contributions to this publication are made by professors, researchers, scientists and practitioners throughout the world, bringing together their rich expertise and results of their current endeavors. The authors have several years of expertise in their respective domains, and have good publication records.

As can be seen from the table of contents, the book comprises of 15 chapters. It spreads across many technical areas with car communications as the central theme. The first chapter is an introductory chapter on the emerging area of vehicular networks in the forms of Intra-Vehicle (InV), Vehicle-to-Vehicle (V2V), and Vehicle-to-Infrastructure (V2I) communications. Chapters II to III and a large part of Chapter V cover the technologies related to InV networks. The rest of Chapter V and Chapters VI to XII present the technologies related to V2V and V2I communications which will enable a variety of applications for safety, traffic efficiency, driver assistance and infotainment. Privacy, security, and reliability as key requirements in deploying VANETs (Vehicular Ad Hoc Networks) are addresses in Chapter XIII. Chapter XIV discusses simulation architectures, models used for representing the communication among vehicles, vehicle mobility features, and ways to implement simulation tools with the aim to improve traffic safety and control. Chapter XV describes in-vehicle network architectures for the next-generation vehicles. Chapter-wise details are presented bellow.

The introductory chapter presents the emerging area of vehicular networks in the forms of Intra-Vehicle (InV), Vehicle-to-Vehicle (V2V), and Vehicle-to-Infrastructure (V2I) communications. This will enable a variety of applications for safety, traffic efficiency, driver assistance, as well as infotainment, to be incorporated into modern automotive designs. Critical data is being exchanged within a vehicle and with outside the vehicle via vehicular networks. Thus, this chapter first introduces car communications, potential vehicular applications and wireless technologies, as well as specially designed technologies DSRC (Dedicated Short Range Communications) standards and communication stack for data exchange. As the emerging area of vehicular networks is attracting widespread interest from research groups around the world, this chapter next introduces the consortiums and initiatives working on advanced automotive technologies in Europe, the United States, Japan, and Singapore. Finally, in the future trend, vehicular networks still plays a vital role in enhancing the automotive industry for safety, security and entertainment.

Chapter II presents the impact of drive by wire systems on vehicle safety and performance. An overview of the drive-by-wire technology is presented along with in-depth coverage of salient drive by systems such as throttle-by-wire, brake-by-wire, and steer-by-wire systems, and hybrid-electric propulsion. This is followed by in-depth coverage of technological challenges and the current state-of-the-art solutions to these technological hurdles. For example, an analytical redundancy/model-based fault-tolerant control can not only reduce the overall system cost by reducing the total number of redundant components, but also further improve overall reliability of the system through the usage of a diverse array of sensory information. Future trends in the drive-by-wire systems include various drive-by-wire systems in the same vehicle sharing a diversity of sensors and actuators via data fusion methodologies, integrated control of various drive by wire systems and future communication bus for x-by-wire systems, for example FlexRay,

Chapter III provides a basic overview of the electromagnetic compatibility (EMC) issues affecting automotive communications. As the number of electronic systems in automobiles rises, the potential for electromagnetic interference increases. Designing for electromagnetic compatibility is important to devote proper attention to electromagnetic compatibility at every stage of an automobile's development. Problems discovered late in the design cycle can seriously impact development schedules and product cost. This chapter provides basic information of electromagnetic compatibility issues affecting automotive communications for non-EMC engineers and engineering managers who work with automotive networks.

Chapter IV introduces the most widely used automotive networks like LIN (Local Interconnect Network), CAN (Controller Area Network), MOST (Media-Oriented Systems Transport), and FlexRay. To fulfill the increasing demand of intra-vehicle communications, a new technique based on power line communication (PLC) is then proposed. This allows the transmission of both power and messages without functional barriers. On the other hand, there are several infotainment applications (like mobile phones, laptop computers) pushing for the adoption of intra-vehicle wireless communications. Thus, some potential wireless technologies used in the automotive domain, namely Bluetooth, IEEE 802.11 b/g wireless technology – WiFi, and Zigbee are covered here. Finally, the chapter highlights the challenges of these wired or wireless alternative solutions in automotive networks.

Chapter V elaborates one of the most popular in-vehicle networking technologies called Controller Area Network (CAN). The chapter begins with an overview of the basis and the general technology of CAN in automotive industry and the deployment of in-vehicle CAN networks. It then presents the various existing and future potential applications that make use of the CAN data, and the related technical challenges in achieving secure remote monitoring and control of vehicles via CAN. Furthermore, the chapter elaborates two key components in achieving remote vehicle monitoring and control, namely, the wireless communication component and data security component. It stresses the importance of secure data and information flow between vehicles and an application server. Finally, the chapter presents an overall architecture for secure wireless real-time vehicle monitoring and control environment. In future rends, the author foresees the area of real-time monitoring and control being a fertile ground for future automotive innovations and services.

Chapter VI describes the current medium access control (MAC) and routing protocols for vehicular networks, and the various factors that affect their design and performance. The mobility and speed of the communicating nodes in vehicular networks add extra dimensions to the challenges faced by the MAC protocols, in addition to the existing requirements of reliability and efficiency. This chapter reviews some of the existing MAC protocols for vehicular network. For example, basic MAC protocols, the IEEE 802.11 MAC Extension for Vehicular Networks, and other MAC Protocols for Vehicular Networks (ADHOC-MAC, the Directional MAC (D-MAC) protocol). Future Intelligent Transportation Systems require fast and reliable communication between cars (vehicle-to-vehicle) or between a car and a road side unit (vehicle-to-infrastructure). Ad hoc unicast routing schemes can be divided into two categories: topology-based routing and position-based routing. Topology-based schemes use a variety of *proactive* routing schemes (DSDV ((Destination Sequenced Distance Vector routing), Optimized Link State Routing (OLSR), Fisheye State Routing (FSR)) or *reactive* approaches (AODV (Ad Hoc On-Demand Distance Vector Routing), DSR ((Dynamic Source Routing), Temporally Ordered Routing Algorithm (TORA), Associativity Based Routing Algorithm (ABR), or *hierarchical* protocols (Cluster Based Routing Protocol (CBRP), Core Extraction Distributed Ad-hoc Routing (CEDAR) and Zone Routing Protocol (ZRP)) to create routes.

Popular location services in position-based routing protocols are Distance Routing Effect Algorithm for Mobility (DREAM) and Grid Location Service (GLS). Context Assisted Routing (CAR) and Spatially Aware Routing (SAR) are proposed routing algorithms to overcome the problem of topology holes in position-based routing. Current multicast protocols that can be used in V2V networks include: Position-based Multicast (LBM), GeoGRID, Unicast Routing with Area Delivery and Inter-Vehicle Geocast. Overall, routing of communications for vehicular safety applications remains a challenging topic.

Chapter VII presents a new reactive algorithm based on location information in the context of vehicular ad-hoc networks. It proposes a Location Routing Algorithm with Cluster-Based Flooding (LORA-CBF), which is formed with one cluster head, zero or more members in every cluster, and one or more gateways to communicate with other cluster heads. It first validates the model at one, two, and three hops by comparing the results of the test bed with the results of the model developed in OPNET. For more than three hops, it validates the model by comparing with two non-position-based routing algorithms (AODV and DSR) and one position-based routing algorithm (GPSR (Greedy Perimeter

Stateless Routing)). Results show that mobility and network size affects the performance of AODV and DSR more significantly than LORA_CBF and GPSR. It is also observed that GPSR and LORA-CBF behave similarly in terms of the end-to-end delay, and LORA_CBF is more robust in terms of delivery ratio, routing overhead, route discovery time, and routing load compared with GPSR.

Chapter VIII presents the role of communications in cyber-physical vehicle applications. Cyber-physical systems use sensing, communications and computing to control the operation of physical devices. The embedded computers and sensors both within the vehicles and in the infrastructure will be networked into cyber-physical systems to reduce accidents, improve fuel efficiency, increase the capacity of the transportation infrastructure, and reduce commute time. Communications between nearby vehicles will enable cooperative control paradigms that reduce accidents more than computing and sensors alone, and communications between vehicles and the infrastructure will improve the scheduling of traffic signals and route planning. The chapter describes applications that improve the operation of automobiles, control traffic lights and distribute the load on roadways. The requirements on the communications protocols that implement the applications are determined and a new communications paradigm, neighborcast, is described. Neighborcast communicates between nearby entities, and is particularly well suited to transportation applications.

Chapter IX incorporates the characteristics of traffic flow into the interference issue at the communication layer of VANETs. There are several fundamental issues, such as connectivity, reachability, interference and capacity, with respect to information propagation in VANETs. This chapter mainly addresses the issue of interference, by incorporating the characteristics of traffic into this issue at the communication layer of VANETs. High node mobility and dynamic traffic features make the interference problem in VANETs quite different. As compared with previous efforts to solve this problem which only considered static network topologies, this work is (to the best of our knowledge), the first to demonstrate the interference features in VANETs by incorporating realistic traffic flow characteristics based on a validated simulation model. Analytical expressions are developed to evaluate the interference in VANETs taking account of both the macroscopic and the microscopic traffic flow characteristics. These analytical expressions are validated within the simulation framework. The results show that the analytical characterization performs very well to capture the interference in VANETs. The results from this work can facilitate the development of better algorithms for maximizing throughput in VANETs, and the research efforts bridging the features of both the communication layer and the transportation layer will help to build more efficient systems.

Chapter X first captures the state-of-the-art in the area of traffic control with the assistance of VANETs in terms of vehicular traffic models, vehicular traffic theories, flow control strategies, and performance measurement methodologies. It surveys traffic control strategies for optimizing traffic flow on highways, with a focus on more adaptive and flexible strategies facilitated by current advancements in sensor-enabled cars and VANETs. It provides an overview of new ideas and approaches in the area of traffic flow control with the assistance of VANETs. This chapter then presents new research into proactive traffic merging strategies and the potential benefits of applying sensor-enabled cars. It shows how sensor-enabled cars can assist in improving merging algorithms, and compares proactive merging algorithms against a conventional merging strategy: priority-based merging. Assisted by advanced sensing and communication technologies, traffic control strategies and merging algorithms will lead to more efficient use of the current road networks and ultimately help to alleviate traffic congestion. It has shown that the significant improvement in traffic flow and the decrease in travel time mainly result from the decoupling of the merging point and the decision point, and multilane optimizations, such as pre-lane-changing. Proactive merging strategies can significantly improve traffic flow by increasing it by up to 100% and reduce overall travel delay by 30%.

Chapter XI presents the localization problem in cooperative vehicle applications by focusing on the constraints imposed by the need for precise vehicle localization estimates. Such accurate estimates are a pre-requisite to deploying vehicles with adequate communications capabilities in real traffic conditions. V2V and V2I safety applications are complex, and the problem does not limit to communications capabilities. It involves spatial information with respect to the vehicles' locations relative to each other and the infrastructure. Thus, V2V and V2I applications are considered as a spatio-temporal problem. The tenet is that information can be shared only if this is time stamped and related to a spatial description of the information sources. The chapter formulates the spatio-temporal problem having as constraint the precision of the pose estimates of the vehicles involved. It formulates the localization problem and accuracy of digital road maps as a combined issue that needs to be addressed for the successful deployment of cooperative vehicle applications. The problem formulation is completed by two case studies, the use of V2V or V2I communications to traverse safely an intersection and an overtaking manoeuvre. The chapter concludes by including comments and recommendations on the precision limits of the vehicle pose estimations and the potential uncertainties that need to be considered when designing V2V and V2I applications.

Chapter XII reviews the problem of estimating (in real-time) the position of a vehicle for use in land navigation systems. After describing the application context and giving a definition of the problem, it looks at the mathematical framework and technologies involved in the design of positioning systems. Through a review of some of the various sensor fusion techniques usually encountered in such systems, it compares the performance of some of the most popular data fusion approaches, and provides some insights on their limitations and capabilities. The extended Kalman filter (EKF) in data fusion centralized architectures remains a design of choice for most applications. The chapter then describes how to make positioning systems more robust and adaptive by detecting and identifying sensor faults. Finally, it explores possible architectures for collaborative positioning systems, where many vehicles are interacting and exchanging data to improve their own position estimate using a collaborative and geometric data fusion approach. One major trend seen in the field of dense sensor networks is in the use of multilateration techniques for location accuracy. Despite significant errors in range estimates between sensors, multilateration is able to render more accurate location estimates, thus making it suitable for use in vehicle navigation. With the current evolution of automotive technologies, all vehicles are becoming networked and equipped with wireless communication capabilities, thus allowing the use of distributed and collaborative techniques for navigation and positioning. Wireless communications networks are becoming attractive to localize vehicles using various radio-based range technologies such as received signal strength indicators (RSSI), power signal attenuation or time-of-arrival (TOA) techniques.

Privacy, security, and reliability as key requirements in deploying VANETs are addressed in Chapter XIII. Without these strengths, the VANET technology will not be suitable for market diffusion. This chapter concerns with how to fulfill these requirements by using pseudonym-based authentication, and designing security schemes that do not endanger transport safety while maintaining low overhead. At the same time, the design improves system usability by allowing nodes to self-generate their own pseudonyms. It manages security credentials in VANET through self-generation and self-certification of pseudonyms, which greatly simplifies the security management and makes a step towards a usable system. It employs group signatures to generate certificates which satisfy the requirements of anonymity and liability attribution, and results show that the computational cost and the overhead are comparable to the baseline approach. Next, it analyzes the costs imposed by security on the transportation systems by analyzing data link performance to obtain packet reception probability curves for the pseudonym-based security systems, and analyzing the impact of safety messaging, security and privacy-enabling technologies on transportation safety to show that secure communication schemes achieve safety levels comparable to those with no security at all. This chapter performs a detailed investigation of pseudonym-based authentication by analyzing several system issues and showing how these security mechanisms can be applied in practice.

Chapter XIV systematically presents actual issues faced by developers and engineers in the simulation of VANET applications, some of which are related to the challenges in developing VANET simulators. It discusses simulation architectures, models used for representing the communication among vehicles, vehicles mobility features, and simulation tools implementation methods. The focus is on the new trends in communication protocols and traffic models, and on new facilities incorporated in simulation tools. Advances in VANET technology and protocols support the adoption and use of more complex mobility models and of more flexible and adaptable traffic controls. VANETs' rapid topology changes or the changes in the vehicles mobility as reaction to traffic changes are captured by the simulation models, which become more or less complicated and include more elements that constrain vehicle mobility: maps, real traffic conditions (congestion), driver behavior, fuel consumption, pollutant emissions, and so forth. It also includes a critical analysis of the solutions adopted in some well-known actual simulators. Other issues related to the use of simulation in the evaluation of applications that aim at improving traffic safety and control are discussed. Representative city and highway application scenarios are analyzed, and results obtained by simulation, along with ways these results can be exploited by VANET developers and users, are highlighted. Future trends in the development of simulators that produce more accurate results, and their use for the evaluation of more sophisticated traffic control solutions, are also included.

Chapter XV takes a more futuristic look at various types of topologies and protocols that could be used specifically in in-vehicle networks. Varying functionalities of vehicles will require different types of communication networks and networking protocols. As the size and complexity of the network grows, integration, maintenance and troubleshooting will become a major challenge. To facilitate integration and troubleshooting of various nodes and networks, it would be desirable that networks of future vehicles be partitioned, and the partitions be interconnected by a hierarchical or multi-layer physical network. These partitions must be appropriately interconnected to handle functional dependencies and for better diagnostics. A number of network topologies have been presented and analyzed for cost, bandwidth and message latencies. This chapter describes a number of ways using which the networks of future vehicles could be designed and implemented in a cost-effective manner. Since future vehicles will also be communicating with external entities for various reasons, the chapter also addresses the issues of security, safety and privacy which should be taken into consideration at the time of designing the in-vehicle network components. Finally, some ideas have been presented in developing simulation models to analyze various types of networks which will ultimately help in selecting the most appropriate network topology and various network components for a given set of requirements and specifications.

Thus, we have walked through the world of new information and communication technologies being developed for vehicular systems. We hope that the book is of interest to academia and industry. We earnestly hope that the insights provided by this book, on the specific information and communication technologies used in vehicles, will help inspire and spawn a multitude of novel applications and innovations.

This book is dedicated to my parents Lanying Guo and Tianfu Guo.

Huaqun Guo
Singapore, October 2008