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Introduction

1.1 Basic Principles and Challenges

The basic concept of VANET is straightforward: take the widely adopted and inexpensive wireless local area network (WLAN) technology that connects notebook computers to each other and the Internet, and, with a few tweaks, install it on vehicles. Of course, if it were truly that straightforward, the active VANET research community would likely never have formed and this book would never have been written. As the reader likely understands (especially if they continue reading), the vehicular environment creates unique opportunities, challenges, and requirements. This book documents the early years and the current state of the art of this exploration.

First, consider the opportunities. If vehicles can directly communicate with each other and with infrastructure, an entirely new paradigm for vehicle safety applications can be created. Even other non-safety applications can greatly enhance road and vehicle efficiency. Second, new challenges are created by high vehicle speeds and highly dynamic operating environments. Third, new requirements, necessitated by new safety-of-life applications, include new expectations for high packet delivery rates and low packet latency. Further, customer acceptance and governmental oversight bring very high expectations of privacy and security.

Even today, vehicles generate and analyze large amounts of data, although typically this data is self-contained within a single vehicle. With a VANET, the 'horizon of awareness' for the vehicle or driver drastically increases. The VANET communication can be either done directly between vehicles as 'one-hop' communication, or vehicles can retransmit messages, thereby enabling 'multihop' communication. To increase coverage or robustness of communication, relays at the roadside can

be deployed. Roadside infrastructure can also be used as a gateway to the Internet and, thus, data and context information can be collected, stored and processed 'somewhere', e.g., in upcoming Cloud infrastructures.

It warrants repeating that the interest in vehicular inter-networks is strongly motivated by the wealth of applications that could be enabled. First of all, active safety applications, i.e., accident prevention applications, would benefit from this most direct form of communication. Second, by collecting traffic status data from a wider area, traffic flow could be improved, travel times could be reduced as well as emissions from the vehicles. As it was concisely stated as the tenet of the Intelligent Transportation System World Congress in 2008: save time, save lives.

The application classes 'Safety' and 'Efficiency' can be used to classify applications based on their primary purpose. However, the aspects of safety and efficiency cannot be seen as completely disjoint sets of features. Obviously, vehicle crashes can lead to traffic jams.[1] A message reporting an accident can be seen as a safety message from the perspective of near-by vehicles. The same message can be seen by further-away vehicles as an input to calculate an alternative route within a transport efficiency application. Figure 1.1 schematically illustrates the aspects of hazard warning and traffic information.

While being conceptually straightforward, design and deployment of VANET is a technically and economically challenging endeavour. As described in the following chapters, key technical challenges include the following issues:

- Inherent characteristics of the radio channel. VANET present scenarios with unfavorable characteristics for developing wireless communications, i.e., multiple reflecting objects able to degrade the strength and quality of the received signal. Additionally, owing to the mobility of the surrounding objects and/or the sender and receiver themselves, fading effects have to be taken into account.

- Lack of an online centralized management and coordination entity. The fair and efficient use of the available bandwidth of the wireless channel is a hard task in a totally decentralized and self-organizing network. The lack of an entity able to synchronize and manage the transmission events of the different nodes might result in a less efficient usage of the channel and in a large number of packet collisions.

- High mobility, scalability requirements, and the wide variety of environmental conditions. The challenges of a decentralized self-organizing network are particularly stressed by the high speeds that nodes in VANET can experience. Their high mobility presents a challenge to most iterative optimization algorithms aimed at making better use of the channel bandwidth or the use of predefined routes to forward information.

- Security and privacy needs and concerns. There is a challenge in balancing security and privacy needs. On the one hand, the receivers want to make sure that they can trust the source of information. On the other hand, the availability of such trust might contradict the privacy requirements of a sender.

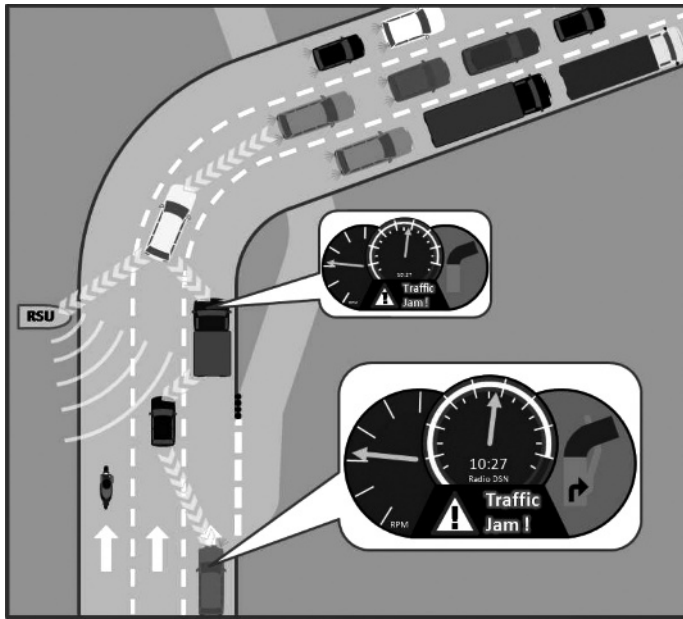[1]The IntelliDrive™ initiative reports that about 25% of all traffic jams are due to crashes.

Figure 1.1   By using vehicle-to-vehicle and vehicle-to-roadside communication, accidents can be avoided (e.g., by not colliding with a traffic jam) and traffic efficiency can be increased (e.g., by taking alternative routes). (Source: Hartenstein and Laberteaux, 2008, reproduced by Permission of © 2008 IEEE.)

- Standardization versus flexibility. Without any doubt, there is a need for standardizing communications to allow VANET to work across the various makes and brands of original equipment manufacturers (OEMs). Yet, it is likely that OEMs will want to create some product differentiation with their VANET assets. These goals are somewhat in tension.

From an application and socio-economic perspective, key challenges are as follows:

- Analyzing and quantifying the benefit of VANET for traffic safety and transport efficiency. So far, relatively little work has been done to assess the impact of VANET as a new source of information on driving behavior. Clearly, the associated challenge in addressing the issue of impact assessment is the modelling of the related human factor aspects.

- Analyzing and quantifying the cost–benefit relationship of VANET. Because of the lack of studies on the benefits of VANET, a cost–benefit analysis can hardly be done.

- Designing deployment strategies for this type of VANET that are not based on a single infrastructure and/or service provider. Owing to the 'network effect', there is the challenge of convincing early adopters to buy VANET equipment when they will rarely find a communication partner.

- Embedding VANET in intelligent transportation systems architectures. VANET will be a part of an intelligent transportation system where other elements are given by traffic-light control or variable message signs. Also public and individual transportation have to be taken into account in a joint fashion. Therefore, truly cooperative systems need to be developed.

As can be seen from the above lists of technical, application, and socio-economic aspects, the field of vehicular application and inter-networking technologies is based on an interdisciplinary effort in the cross section of communication and networking, automotive electronics, road operation and management, and information and service provisioning. VANET can therefore be seen as a vital part of intelligent transportation systems (ITS).

While various projects discussed deployment strategies for VANET, research activities have primarily addressed the technical challenges. Currently, we observe a shift from this classical 'bottom-up' approach to a more 'top-down'-based thinking. Ideally, both approaches will be followed and will finally meet each other: what is identified as a requirement for beneficial deployment can be served by the technological advances. This book is intended to define the current position of the state of the art in VANET research and development.

In Section 1.2 we outline the history of inter-vehicle communications. In Section 1.3 we present an overview of Chapters 2 to 10 and their main contributions.

1.2   Past and Ongoing VANET Activities

The history of the use of radio and infrared communication for vehicle-to-roadside and vehicle-to-vehicle communication is strongly tied to the evolution of intelligent transportation systems. As referenced in Shladover (1989) and in Lasky and Ravani (1993), the basic concepts of roadway automation, i.e., the use of communication and control techniques to make road traffic safe, efficient, and environmentally friendly, were exhibited at the 1939 World Fair. The exhibit, called 'Futurama' by its creator, General Motors, envisioned a peek 20 years into the future, showing both concepts and technology forecasts.[2]

Later, since at least the late 1960s, actual radio-based 'roadway automation' systems were developed and demonstrated. Since this time, one can observe the following facts:

- While safety, efficiency, and environmental friendliness are the key themes, the emphasis consistently changed over time. For example, in the early days route-guidance systems were investigated. Later, for example, tolling systems or research into automatic driving became popular.

- Research and development in various regions, primarily in the USA, in Japan, and in Europe, but also in other parts of the world, were influencing each other.

- The topic has been addressed with a different focus by the automotive and the transportation communities.

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[2]At the time of writing, video of the 1939 Futurama exhibit can easily be found online.

- A consistent theme over time is 'funding – who will pay?'. Frequently, communication-based tolling and congestion pricing are offered as solutions, although scepticism persists. For example, as cited in Jurgen (1991), Kan Chen and Robert Ervin described the 'chicken and egg standoff' in 1990 as follows: on the one hand, automotive and electronics industries doubt whether the public infrastructure for Intelligent Vehicle-Highway Systems (IVHS) will ever materialize. On the other, highway agencies doubt whether IVHS technologies will deliver practical solutions to real highway problems.

In this section, we present a selection of what we consider important milestone activities with respect to VANET. Owing to the wealth of research and development done in the field of intelligent transportation systems, our overview will be non-exhaustive.

1.2.1   From the beginning to the mid 1990s

In the USA, an Electronic Route-Guidance System (ERGS) was proposed in Rosen et al. (1970):

> 'The system is destination-oriented. The driver enters a code word, representing his intended destination, into the vehicle equipment. Then as the vehicle approaches each instrumented intersection, the destination code is transmitted to the roadside where it is decoded, according to a stored program, and a routing instruction is transmitted back to the vehicle.'

The corresponding communication system was operating at 170 kHz using loop antennas installed at intersections and mounted under the rear of the vehicles. Data transmission rate is reported as 2000 bits per second. According to French (1986, 1987) the ERGS efforts were terminated owing to the expensive roadside infrastructure.

In Japan, the Comprehensive Automobile Traffic Control System (CACS) project was carried out from 1973 to 1979 by the Agency of Industrial Science and Technology of the Ministry of International Trade and Industry (MITI). The objectives of CACS as presented in Kawashima (1990) are still valid after more than 30 years:

- reduction of road traffic congestion

- reduction of exhaust fumes caused by traffic congestion

- prevention of accidents

- enhancement of public and social role of automobiles.

In order to attain this goal, four technical objectives were established:

- to guide drivers along most appropriate routes in order to avoid congestion and air pollution

- to provide useful information in order to assist safe driving

   • to give priority of road to public or emergency vehicles

   • to provide information promptly to drivers in case of emergency.

The CACS project also carried out a pilot operation with 98 units of roadside equipment and 330 test vehicles (Nakahara and Yumoto 1997). For roadside-to-vehicle communication, loop antennas were used for the roadside units and ferrite core antennas for the vehicle units. The transmission speed is reported as 4.8 kbps.

   In Europe, the PROMETHEUS (Programme for European Traffic with Highest Efficiency and Unprecedented Safety) framework initiated in 1986 and launched in 1988 significantly stimulated research and development activities in the area of information technology and mobile communications for motor vehicles and the roads they drive on. PROMETHEUS was supported by 19 European countries and the Commission of the European Communities (Walker 1992; Williams 1988). As for example outlined in Gillan (1989), PROMETHEUS was organized in various sub-programmes including:

   • PRO-CAR: driver assistance by electronic systems.

   • PRO-NET: vehicle-to-vehicle communications.

   • PRO-ROAD: vehicle-to-environment communications.

   In PROMETHEUS, vehicle-to-vehicle communication played a prominent role: the report of Dabbous and Huitema (1988) can still be regarded as up to date in many aspects. Dabbous and Huitema analyzed the communication requirements based on typical scenarios, for example for a lane-change maneuver. Assuming a periodic broadcast strategy and collision distance accuracy requirements, they show that a conservative estimate of the transmission rate of the status messages each vehicle sends out periodically might lead to 20 transmissions per second per vehicle. Dabbous and Huitema also indicate that relaxing the requirements on the accuracy of collision distance and introducing prediction methods can significantly reduce the number of transmissions required. Focus was typically on systems operating in the 60 GHz frequency band (see, e.g., Fischer 1991).

   Interest in vehicle-to-vehicle communication continued in Japan and the USA. The survey in Kawashima (1990) cites two technical reports by JSK (the Association of Electronic Technology for Automobile Traffic and Driving) published in 1986 and 1988, respectively, on experimental results of vehicle-to-vehicle communication. For the USA, as outlined in Shladover et al. (1991), a main driver appeared to be automatic driving and vehicle platoons. In Sachs and Varaiya (1993), requirements and specifications for vehicle-to-vehicle and roadside-to-vehicle communication for automated vehicles are presented.

   An excellent 'snapshot' summarizing project activities of this epoch in the USA, Europe, and Japan as well as looking ahead towards Intelligent Vehicle-Highway Systems is given by Jurgen (1991).

1.2.2   From the mid 1990s to the present

The second half of the 1990s provided remarkable milestones and some major paradigm shifts. Impressive results on cooperative autonomous driving were demonstrated at the San Diego demo of the California Partners for Advanced Transit and Highways (PATH) in 1997, at the Advanced Safety Vehicle (ASV) Phase 2 Demo in 2000 in Tsukuba city, Japan, and within the PROMOTE CHAUFFEUR European project. The focus then shifted from cooperative autonomous driving to cooperative driver assistance systems. In the USA the Intelligent Vehicle Initiative (IVI) in the years 1998 to 2005 (Hartman and Strasser 2005) focused on cooperative active safety. In Europe, the CarTalk and FleetNet projects (Franz et al. 2005) investigated technologies and applications for cooperative driver assistance. In Japan, Phase 3 of the Advanced Safety Vehicle project also acknowledged the role of inter-vehicle communications for cooperative driver assistance.

A game changer: 5.9 GHz DSRC

The concept of VANET has been significantly impacted by the advances in technology and standardization since the mid 1990s. In 1999 a 'game changer' occurred when the US Federal Communication Commission allocated 75 MHz bandwidth of the 5.9 GHz band to Dedicated Short-Range Communication (DSRC). The term 'dedicated short-range communication' was used as a technology-neutral term for short-range wireless communication between vehicles and infrastructure.

   A year later, ASTM International established a working group to develop requirements for corresponding DSRC standards. In 2001, the Standards Committee 17.51 of the ASTM selected IEEE 802.11a as the underlying radio technology for DSRC. The corresponding standard was released in 2002 (ASTM E2213-02 2003) and revised in 2003 (ASTM E2213-03 2003). The pressure to make use of the assigned channels and the availability of the IEEE 802.11a technology and standard significantly increased research and development activities. In particular, the mobile networking community's interest in the topic of vehicular networks was revitalized. In 2004, the IEEE started the work on the 802.11p amendment and Wireless Access in Vehicular Environments (WAVE) standards based on the ASTM standard (Jiang and Delgrossi 2008). The Vehicle Safety Communications (VSC) project – backed by the Crash Avoidance Metrics Partnership (CAMP), the US Federal Highway Administration (FHWA), and the US National Highway Traffic Safety Administration (NHTSA) – investigated emerging 5.9 GHz DSRC technology in the years 2002 to 2004 and concluded that the approach based on IEEE 802.11a would be able to support most of the safety applications that VSC had selected. The VSC final report (VSC 2006), however, also explicitly points to challenges of low-latency communication and high availability of the radio channel as well as of general channel capacity-related issues. In 2004, the first ACM International Workshop on Vehicular Ad Hoc Networks took place in Philadelphia, for which the term 'VANET' was coined. The editors of this book served key leadership roles in the early years of this workshop (Ken Laberteaux, General Co-Chair 2004–05; Hannes Hartenstein General Co-Chair 2005, Technical Program Co-Chair 2006).

Current projects and activities

In the following paragraphs we will provide a non-exhaustive overview on ongoing VANET projects and activities in Europe, Japan, and the US.[3] The overview indicates the high level of activity in the field of VANET research and development and demonstrates that the wireless communication technologies covered in this book form the basis of most VANET activities worldwide (see Figure 1.2).
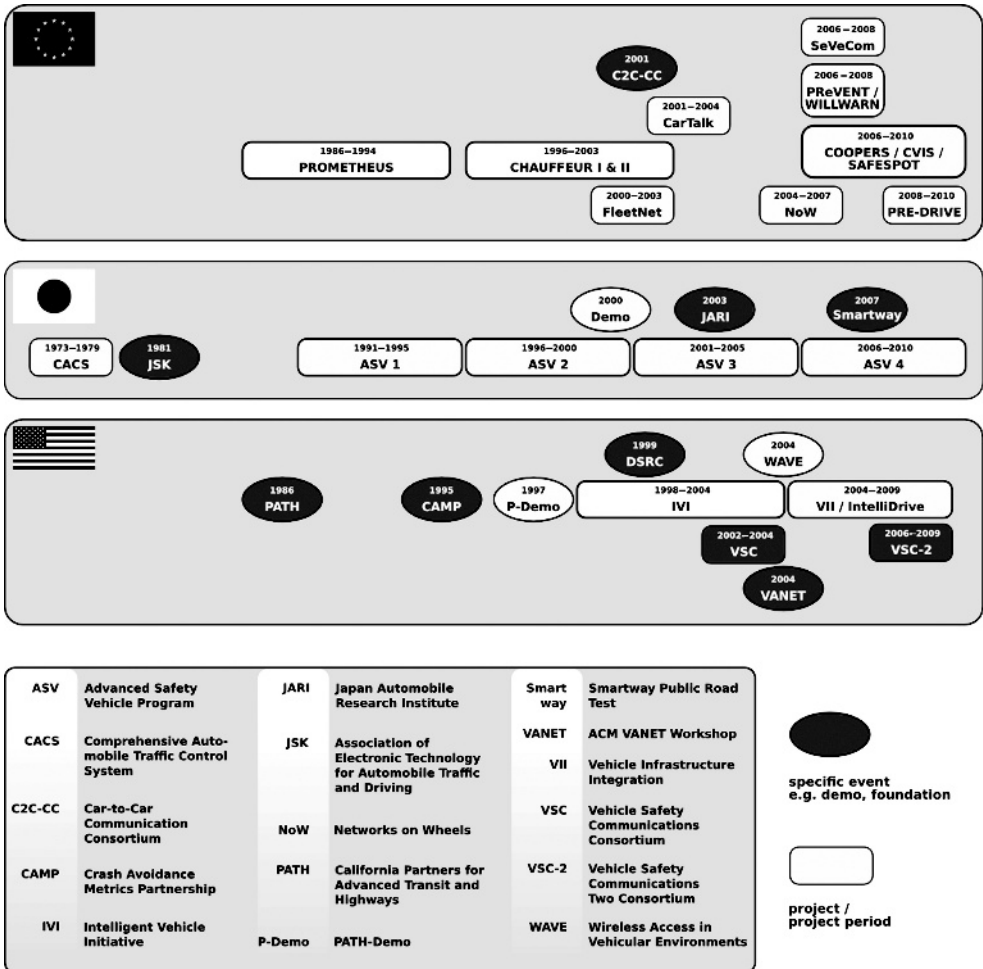

Figure 1.2   A nonexhaustive overview of pioneering VANET activities and milestones as described in this section.

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[3]We will not provide references to websites featuring those projects and activities since those pages (both content and addresses) change frequently.

Within the Framework Programme 6 of the EU, four integrated projects were started in areas that touch the field of VANET: COOPERS, CVIS, PReVENT, and SAFESPOT. The project Co-operative Systems for Intelligent Road Safety (COOPERS, 2006–10) focuses on innovative telematics applications for cooperative traffic management. From a communication perspective, it therefore primarily addresses vehicle-to-roadside communications and makes use of CALM standards like the CALM infrared communication interface. CALM is the ISO TC 204 (ITS) Working Group 16 (Communication) on 'Continuous Air interface for Long and Medium distance'. CALM aims to support continuous communications for vehicles by making use of various media and communication interfaces. The project Co-operative Vehicle-Infrastructure Systems (CVIS, 2006–10) has a main focus on development and testing of vehicle-to-infrastructure communication and also follows the CALM standards. CVIS makes use of the IEEE 802.11 WAVE-related interface that is denoted as M5 interface (for 'Microwave 5 GHz') within the CALM framework. Project SAFESPOT (2006–10) aims to design cooperative systems for road safety based on vehicle-to-vehicle and vehicle-to-infrastructure communication. The communication technology used in project SAFESPOT is IEEE 802.11a/p. Project PReVENT (2006–08) addressed development of preventive safety applications and technologies. Within the PReVENT Integrated Project, the subproject WILLWARN (Wireless Local Danger Warning) focused on the topic of vehicle-to-vehicle and vehicle-to-infrastructure communication. The WILLWARN system is based on IEEE 802.11a/p and made use of the communication platform developed in the German Network on Wheels (NOW) project. In addition, the project Secure Vehicular Communication (SeVeCom, 2006 to 2008) was dedicated to identifying threats and specifying methods and architecture for securing wireless vehicular communication. Currently, under Framework Programme 7, activities towards field operational tests are funded, in particular the project PRE-DRIVE-C2X that is preparing the building blocks required for successful field operational tests of VANET in Europe.

In Japan, a standard for vehicle-to-infrastructure communication was published in 2001 and denoted as 'Dedicated Short-Range Communication System' (ARIB 2001). The specified system operates in the 5.8 GHz frequency band, is based on time division multiple access (TDMA) and targets a range of about 30 m. The primary use of the system was seen in electronic toll collection but the system was generalized to support various other services (ARIB 2004). In 2008, more than 20 million on-board units for electronic toll collection were deployed in Japan. Based on the success on this 5.8 GHz DSRC system and on infrared-based vehicle-to-infrastructure communication, various ITS projects and activities are currently joining forces to demonstrate and enhance vehicle-to-infrastructure and vehicle-to-vehicle communication under the umbrella of Japan's national ITS Safety 2010 initiative. The Advanced Vehicle Safety initiative, now in its phase 4, is addressing vehicle-to-vehicle communication by a carrier sense multiple access (CSMA) based extension of ARIB STD T-75. The Advanced Cruise-Assist Highway System initiative builds on the 5.8 GHz DSRC system as well as the Driving Safety Support System (DSSS) that is also making use of infrared technology for vehicle-to-roadside communication. The Smartway activity focuses on the ITS services and a common service platform offered on top of the existing networks. In June 2007, it

was announced that a 10 MHz channel in the 700 MHz frequency channel will be allocated for safety-related inter-vehicle communication in Japan in 2012.

There are several industry/government projects in the USA ongoing as this book goes to press. Two representative projects are described below. These are chosen for their availability of information and technical scopes that closely track topics in this book. The first, Vehicle Infrastructure Integration (VII), which has been rebranded as IntelliDrive, has recently completed a large proof of concept demonstration. The second, the Vehicle Safety Communication-Applications project, is scheduled to end in late 2009, but several interesting details have been publicly presented, and will be discussed below. Both efforts are substantially funded by the US Department of Transportation and have active participation from several automotive manufacturers and suppliers.

In addition, two other projects deserve a brief mention: an ongoing Integrated Vehicle-Based Safety Systems project explores human-machine interface issues when several safety applications, with potentially overlapping or contradictory advisories, are operated simultaneously (University of Michigan Transportation Research Institute 2007).

A second project, the Cooperative Intersection Collision Avoidance System project, had three components (McHale 2007): a Violation Warning project (demonstrated in Michigan), a Stop Sign Assist project (demonstrated in Minnesota), and a Signalized Left Turn Assist project (demonstrated in California). As equipped vehicles approached a CICAS-V intersection, the vehicles received signal phase and timing information from the intersection light (over DSRC). Each vehicle would then predict the likelihood that it would be in the intersection in violation of a red light, and if appropriate, warn the driver (Maile 2008a). This project was planned to test with naive drivers (Maile 2008a), although the US Department of Transportation has made no such announcement.

1.2.3   Examples of current project results

Vehicle Infrastructure Integration

In 2005, the US Department of Transportation initiated a proof of concept (POC) demonstration. The majority of this testing environment was implemented in the northwest suburbs of Detroit, MI. This system comprised 55 road side equipment (RSE) stations within 45 square miles (see Figure 1.3) and employed 27 vehicles (Kandarpa 2009).

Seven applications were developed and tested:

- In-Vehicle Signage: RSEs trigger displays of advisory messages within the vehicle.

- Probe Data Collection: Vehicles provide historical data on their location/state and share with the RSE, which is then centrally compiled and analyzed.

- Electronic Payments – Tolling.
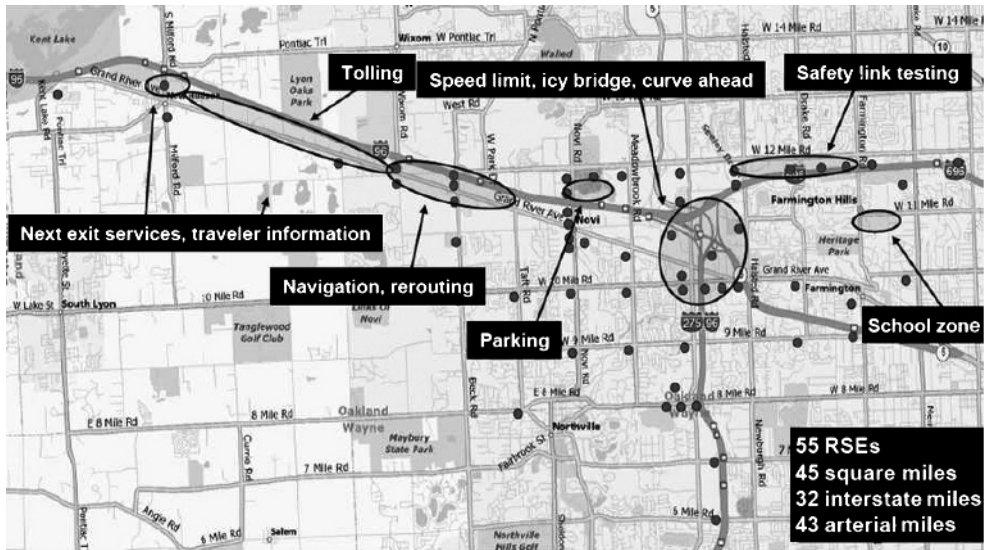
- Electronic Payments – Parking.

Figure 1.3 VII Proof of Concept Testbed in Michigan. Road Side Equipment locations are shown. Source: Schagrin and Briggs (2008).

- Traveler Information/Off-Board Navigation.

- Heartbeat: RSEs collect periodic (e.g. 100 msec) status messages from vehicles including vehicle speed and location.

- Traffic Signal Indication: Broadcasts traffic light state.

Some key findings (Andrews and Cops 2009; Kandarpa 2009):

- Packet error rates were a strong function of line of sight. When line of sight was maintained, packet error rates remained low even at distances of 100s of meters (e.g. between an RSE with a tall antenna and vehicle). When line of site was lost, error rates increased rapidly.

- IPv6 performed well.

- Low-cost GPS receivers, as used in the POC, did not consistently provide lane-level accuracy.

- End-to-end encryption of packets was successfully demonstrated.

- Heartbeat application worked well for vehicles within approximately 100 m of the RSEs (depending on line of sight).

- Security systems were shown to work, but remained brittle. Also, large-scale tests were not performed.

- Management of network communications resources for multiple simultaneous applications is more complex than expected.

- Installing, configuring and maintaining the RSE was more complex and difficult than expected.

As this phase of the VII program ended, the US Department of Transportation has repositioned and rebranded the VII program (Row et al. 2008). Its new name is *IntelliDrive*. It will emphasize wireless technology in the service of safety applications. Quoting 'The Future of VII' (Row et al. 2008):

> The new VII program will focus research activities in the following areas:
>
> - technology scanning and research to identify and study a wide range of potential technology solutions
> - research, demonstration, and evaluation of technology-enabled safety applications
> - establishment of test beds to support operational tests and demonstrations for public and private sector use
> - development of architecture and standards to provide an open platform for wireless communications to and from the vehicle
> - study of non-technical issues such as privacy, liability and application of regulation
> - research on ancillary benefits to mobility and the environment.

As an initial step, the Safe Trip-21 project launched in 2008 and has established Connected Traveler test sites in California. Safe Trip-21 'is designed to improve safety and reduce congestion by identifying and harnessing existing technology and adapting it for transportation needs,' and 'will demonstrate that significant advances in solving transportation problems do not have to require large infrastructure investments.' (Safe Trip-21 2008).

No national-scale deployments of VII have been announced in the USA.

Vehicle Safety Communications-Applications

The Vehicle Safety Communications-Applications (VSC-A) is a three year project between five auto makers (Daimler/Mercedes-Benz, Ford, GM, Honda, and Toyota) and the US Department of Transportation. This project is a follow-up to the first Vehicle Safety Communications project (2002–04), and focuses on vehicle communications and relative positioning with the goal of enabling interoperable safety applications (Ahmed-Zaid 2009).

The VSC-A project identified eight crash scenarios as having a 'Top Composite Ranking', based on US Government statistics on crash frequency, cost, and functional years lost. Based on this, VSC-A identified seven safety applications to address these crash scenarios. Those applications are (Maile 2008b):

- Emergency Electronic Brake Lights (EEBL): Warns of sudden braking of vehicles in the forward path.

Table 1.1 Mapping of VSC-A safety applications to crash scenarios of greatest concern (Maile 2008b).

Crash scenarios	V2V safety applications						
	EEBL	FCW	BSW	LCW	DNPW	IMA	CLW
1 lead vehicle stopped		✓					
2 control loss without prior vehicle action							✓
3 vehicle(s) turning at non-signalized junctions						✓	
4 straight crossing paths at non-signalized junctions						✓	
5 lead vehicle decelerating	✓	✓					
6 vehicle(s) not making a maneuver – opposite direction					✓		
7 vehicle(s) changing lanes – same direction			✓	✓			
8 LTAP/OD at non-signalized junctions						✓	

- Forward Collision Warning (FCW): Warns of impending rear-end collision with forward vehicle.

- Blind Spot Warning (BSW)/Lane Change Warning (LCW): Warns during a lane-change attempt if there is another vehicle moving the same direction in (or soon will be in) the blind spot. Secondary advisory whenever there is a vehicle in the blind spot.

- Intersection Movement Assist (IMA): Warns when it is not safe to enter intersection.

- Do Not Pass Warning (DNP): Warns when oncoming vehicle poses collision threat if a lane change is attempted.

- Control Loss Warning (CLW): Self-generated warning when vehicle loses control. Other vehicles will be warned depending on the threat.

The mapping of the eight crash scenarios to the seven VSC-A safety applications is shown in Table 1.1 (Maile 2008b).

In the communications area, the focus is on (Caminiti 2009):

- message composition

- power testing

- message dissemination

- multi-channel operation

- standards coordination and validation.

The message composition subtask has defined a basic safety message which supports all safety applications (Caminiti 2009). This work is strongly influencing the nearly completed negotiations of the SAE J2735 working group. A final standard/recommended practice is expected near the end of 2009.

The power testing work explores whether high power (> 20 dBm) increases safety application performance, and low power (< 20 dBm) addresses congestion control. Comparing packet error rate (PER) around a non-line-of-sight 'closed intersection', the project has shown significantly longer-range low-error communication when using 33 dBm transmission power (over the nominal 20 dBm) (Caminiti 2009). This provides an interesting path for exploration, especially in light of the challenges posed by non-line-of-sight communications reported in the VIIC Report (Kandarpa 2009).

The VSC-A has been actively participating in various DSRC standards, including IEEE 802.11p, IEEE 1609, and SAE J2735 (Caminiti 2009). These standards will be further discussed in Chapter 10. Note that the author of Chapter 10 currently serves as the technical leader for VSC-A in this area.

The message dissemination work will investigate the use of power, rate, and other controls to mitigate network congestion and improve message delivery (Caminiti 2009). The multi-channel operation subtask is investigating channel switching and multi-radio usage (Caminiti 2009). Final results from these subtasks have not been disclosed at the time of this writing. However, results should become available shortly after the completion of the VSC-A project in November 2009.

In addition, VSC-A has a task focused on the security of vehicle-to-vehicle messages. They wish to avoid dedicated security hardware. The project is evaluating elliptic curve digital signature algorithm (ECDSA) (Accredited Standards Committee 2005), timed efficient stream loss-tolerant authentication (TESLA) (Perrig et al. 2002), and several modified versions of the same. Evaluations will be based both on extensive network simulations and on testing of the project's final test-bed of vehicles (Bai 2009). Note that the first-author of Chapter 9 is the technical lead of security work for VSC-A.

1.3   Chapter Outlines

The material contained in this book is organized as follows. Chapters 2–4 identify applications and communication requirements and approaches. Chapter 5 focuses on the mobility models for vehicular traffic, which in turn motivates several aspects and tunings of the protocols described in later chapters. Chapter 6–9 describe the four technical aspects which are most affected by VANET considerations: physical layer, medium access control, middleware, and security. Chapter 10 gives an overview of standards efforts and further describes protocols in the VANET stack.

Cooperative Vehicular Safety Applications (Chapter 2)

This chapter first discusses the enabling technologies for cooperative driving systems. Subsequently, a layered software architecture for cooperative driving systems is described. Following the discussion on cooperative driving architectures, environment mapping, which is the principle architectural component for cooperative safety, is discussed in detail. The stress in this section is on various existing techniques for vehicular path prediction. In the final section of this chapter, several cooperative vehicular safety applications are detailed and illustrated. Each of these applications underlines a particular advantage of vehicle ad-hoc networks (VANET), which is unavailable through other sensing technologies.

Information Dissemination in VANET (Chapter 3)

Vehicles can be seen as probes that locally detect traffic status. Various applications that target transport efficiency could make use of the vast information collected by the vehicles; however, this collection of information needs to be transported over larger distances, for example, city-wide or region-wide. For this purpose, various information dissemination approaches were proposed in the literature and are surveyed in this chapter. The information dissemination 'lifecycle' is structured in four phases: obtaining information, transport of information, summarization of measurements, and aggregation of information. Summarization refers to the process of appropriately combining the measurements of the same observed event of different observers. Aggregation refers to the process of an appropriate reduction of information to deal with the limited capacity of the wireless network.

VANET Convenience and Efficiency Applications (Chapter 4)

VANET convenience and efficiency applications comprise Internet access, service announcements, infotainment, payment services, and most notably collaborative traffic information services. This chapter discusses the suitability of VANET to support this application class. The discussion addresses communication capacity and connectivity limitations as well as the role of competing technologies. In addition, solutions based on centralized client–server systems, on peer-to-peer systems, and on pure vehicle-to-vehicle communications are compared. As the technical basis, data aggregation schemes, as outlined in the previous chapter, are applied to the case of collaborative traffic information systems. Simulation results of these approaches for a city-wide scenario are presented that also indicate the benefit of supporting roadside units.

Vehicular Mobility Modeling for VANET Simulations (Chapter 5)

Since mobility influences the performance of VANET, and the purpose of VANET is to influence mobility, mobility modeling represents a key resource to understand this influencing factor as well as the target domain of VANET research. This chapter surveys various flow and traffic models and presents how these models and corresponding simulators can be used together with communication network

simulators. In addition, a design framework for realistic vehicular mobility models is presented that can help researchers and developers to select the right building blocks and the appropriate level of detail depending on their simulation needs. In the chapter, open issues are discussed with respect to the sufficient degree of the level of detail of models as well as on combining mobility and traffic simulators with communication network simulators.

Physical Layer Considerations for Vehicular Communications (Chapter 6)

This chapter begins with an overview of the proposed DSRC standard and the specific parameters of the orthogonal frequency division multiplexing (OFDM) architecture it employs. This is followed by a development of wireless communications channel theory, along with an examination of common metrics used to quantify the performance of wireless channels. The remainder of the chapter describes extensive DSRC channel measurement experiments. The measurement methods are described in detail, followed by a summary and analysis of the results. This shows that the current DSRC standard appears to be sufficient, but not necessarily optimal, for its intended environment.

MAC Layer and Scalability Aspects of Vehicular Communication Networks (Chapter 7)

The vehicles will share a radio channel to exchange safety and control messages without a centralized coordinator for access to the channel. Efficient and effective medium access control (MAC), therefore, represents an essential building block determining the quality of the communication system and its scalability. This chapter first provides an overview of the challenges of medium access control for VANET and surveys the existing fundamental approaches. Then, the carrier sense multiple access based MAC, the IEEE 802.11p draft of standard, is presented. A performance evaluation of IEEE 802.11p for the case of active safety applications is given together with insights into the modeling and simulation methodology. An empirical model for the probability of packet reception is derived from a large number of simulation runs. Finally, various approaches to controling the load on the radio channel are discussed with a special emphasis on the use of transmit power control.

Efficient Application Level Message Coding and Composition (Chapter 8)

This chapter focuses on message contents for safety applications. The goals are to improve channel utilization by recognizing similarities in transmitted data, and to separate message construction and communication from the application functionality. The chapter begins with an overview of the wireless inter-vehicle communication environment and highlights some desirable features which a system architecture in this environment should possess. Then, the chapter turns to a solution: the message dispatcher (which has subsequently become known as the message handler). This message dispatcher concept is demonstrated by considering some example applications and the resulting message composition. Next, the

concept of efficiency is extended by including linear predictive coding to further reduce bandwidth consumption. The chapter concludes with an examination of the message dispatcher in light of the criteria set out at the beginning of the chapter.

Data Security in Vehicular Communications Networks (Chapter 9)

This chapter begins by presenting the challenges of providing data security in VANET, including attacker and application models. This is followed by an exploration of required supporting infrastructure, including the management and handling of a public key infrastructure (PKI). Protocols for providing secure communication, secure positioning, as well as identification of misbehaving nodes is presented next. This is followed by a detailed exploration of privacy in the VANET context. The chapter concludes with a discussion of implementation aspects, including appropriate key lengths, physical security, organizational aspects, and software updates in the field.

Standards and Regulations (Chapter 10)

This chapter begins with a description of the general protocol stack for DSRC, as well as a description of DSRC regulations in the USA and Europe. The remainder of the chapter describes the most relevant standards activities for VANET, specifically IEEE 802.11p, IEEE 1609, and SAE J2735. The description begins with the lower PHY and MAC/LLC layers, as standardized in IEEE 802.11p. Next, the middle layers, as defined by IEEE 1609 are presented, including multi-channel functioning (IEEE 1609.4) and security services (IEEE 1609.2). While the top-layer applications are described in other chapters, the so-called message sublayer, which provides a message-composition service to other applications, and is defined by SAE J2735, forms the final discussion of this chapter.

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