Chapter 1

Introduction to Vehicular Networks

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Contents

Intervehicle communication (IVC) is attracting considerable attention from the research community and the automotive industry, where it is beneficial in providing intelligent transportation system (ITS) as well as drivers and passengers' assistant services. In this context, vehicular ad hoc networks (VANETs) are emerging as a new class of wireless network, spontaneously formed between moving vehicles equipped with wireless interfaces that could have similar or different radio interface technologies, employing short-range to medium-range communication systems. A VANET is a form of mobile ad hoc network, providing communications among nearby vehicles and between vehicles and nearby fixed equipment on the roadside.

This chapter gives an overview of vehicular networks (also known as VANETs), showing their potential architectures and possible deployment scenarios. Vehicular network, benefits and real-life applications are presented from a network operator's view, giving potential service examples. A number of technical challenges in vehicular network deployment are discussed; most of these challenges are detailed in the following chapters. Moreover, the role of the involved actors (networks operators, car manufacturers, service providers, and governemental authorities) is shown, as well as the related standardization activities. Finally, some related projects are highlighted.

1.1 Vehicular Network Definition, Architectures, and Deployment Scenarios

1.1.1 What Are Vehicular Networks?

Vehicular networks are a novel class of wireless networks that have emerged thanks to advances in wireless technologies and the automotive industry. Vehicular networks are spontaneously formed between moving vehicles equipped with wireless interfaces that could be of homogeneous or heterogeneous technologies. These networks, also known as VANETs, are considered as one of the ad hoc network real-life application enabling communications among nearby vehicles as well as between vehicles and nearby fixed equipment, usually described as roadside equipment. Vehicles can be either private, belonging to individuals or private companies, or public transportation means (e.g., buses and public service vehicles such as police cars). Fixed equipment can belong to the government or private network operators or service providers.

Indeed, vehicular networks are promising in allowing diverse communication services to drivers and passengers. These networks are attracting considerable attention from the research community as well as the automotive industry. High interest for these networks is also shown from governmental authorities and standardization organizations. In this context, dedicated short-range communications (DSRC) system has emerged in North America, where 75 MHz of spectrum was approved by the U.S. FCC (Federal Communication Commission) in 2003 for such type of communication that mainly targets vehicular networks. On the other hand, the Car-to-Car Communication Consortium (C2C-CC) has been initiated in Europe by car manufacturers and automotive OEMs (original equipment manufacturers), with the main objective of increasing road traffic safety and efficiency by means of intervehicle communication. IEEE is also advancing within the IEEE 1609 family of standards for wireless access in vehicular environments (WAVE).

1.1.2 Vehicular Network Architectures

Vehicular network can be deployed by network operators and service providers or through integration between operators, providers, and a governmental authority. Recent advances in wireless technologies and the current and advancing trends in ad hoc network scenarios allow a number of deployment architectures for vehicular networks, in highway, rural, and city environments. Such architectures should allow communication among nearby vehicles and between vehicles and nearby fixed roadside equipment. Three alternatives include (i) a pure wireless vehicle-to-vehicle ad hoc network (V2V) allowing standalone vehicular communication with no infrastructure support, (ii) a wired backbone with wireless last hops that can be seen as a WLAN-like vehicular networks, (iii) and a hybrid vehicle-to-road (V2R) architecture that does not rely on a fixed infrastructure in a constant manner, but can exploit it for improved performance and service access when it is available. In this latter case, vehicles can communicate with the infrastructure either in a single hop or multihop fashion according to the vehicles' positions with respect to the point of attachment with the infrastructure. Actually the V2R architecture implicitly includes V2V communication.

A reference architecture for vehicular networks is proposed within the C2C-CC, distinguishing between three domains: in-vehicle, ad hoc, and infrastructure domain [1]. Figure 1.1 illustrates this reference architecture. The in-vehicle domain refers to a local network inside each vehicle logically composed of two types of units: (i) an on-board unit (OBU) and (ii) one or more application unit(s) (AUs). An OBU is a device in the vehicle having

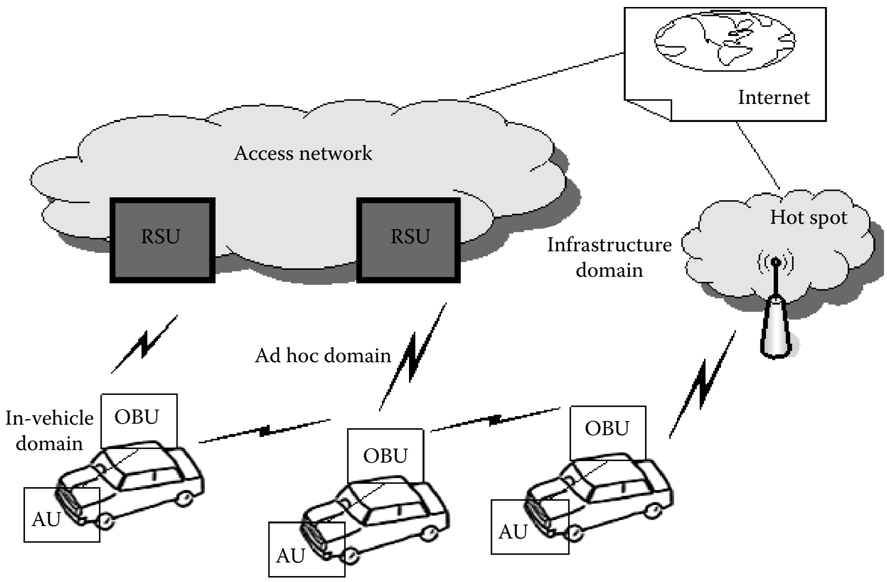

Figure 1.1 C2C-CC reference architecture.

communication capabilities (wireless and/or wired), while an AU is a device executing a single or a set of applications while making use of the OBU's communication capabilities. Indeed, an AU can be an integrated part of a vehicle and be permanently connected to an OBU. It can also be a portable device such as a laptop or PDA that can dynamically attach to (and detach from) an OBU. The AU and OBU are usually connected with a wired connection, while wireless connection is also possible (using, e.g., Bluetooth, WUSB, or UWB). This distinction between AU and OBU is logical, and they can also reside in a single physical unit.

The ad hoc domain is a network composed of vehicles equipped with OBUs and road side units (RSUs) that are stationary along the road. OBUs of different vehicles form a mobile ad hoc network (MANET), where an OBU is equipped with communication devices, including at least a short-range wireless communication device dedicated for road safety. OBUs and RSUs can be seen as nodes of an ad hoc network, respectively, mobile and static nodes. An RSU can be attached to an infrastructure network, which in turn can be connected to the Internet. RSUs can also communicate to each other directly or via multihop, and their primary role is the improvement of road safety, by executing special applications and by sending, receiving, or forwarding data in the ad hoc domain.

Two types of infrastructure domain access exist: RSU and hot spot. RSUs may allow OBUs to access the infrastructure, and consequently to be connected to the Internet. OBUs may also communicate with Internet via public, commercial, or private hot spots (Wi-Fi hot spots). In the absence of RSUs and hot spots, OBUs can utilize communication capabilities of cellular radio networks (GSM, GPRS, UMTS, WiMax, and 4G) if they are integrated in the OBU.

1.1.3 Possible Deployment Scenarios for Vehicular Networks

Regarding the C2C-CC reference architecture together with the advances in heterogeneous communication technologies, vehicular networks potentially have two main types of communication scenarios: car-to-car (C2C) communication scenario and car-to-infrastructure (C2I) communication scenario.

These types of communication scenarios allow a number of deployment options for vehicular networks. Vehicular network deployment can be integrated into wireless hot spots along the road. Such hot spots can be operated individually at home or at office, or by wireless Internet service providers or an integrated operator. On the other hand, vehicular network deployment can be integrated into the existing cellular systems. Vehicles can even communicate with other vehicles directly without a communication infrastructure, where vehicles can cooperate and forward information on behalf of each other. We notice that combination of these deployment cases is also possible.

Moreover, future architecture for intelligent transportation systems (ITS) considers vehicles as active nodes that are responsible for collecting and forwarding critical information. Consequently, vehicular network coexistence with sensor network would potentially take place, where vehicles would be able to collect and process information by means of intelligent sensors and to exchange information with other nodes (fixed or mobile) in a global communication system.

1.2 Special Characteristics of Vehicular Networks

Vehicular networks have special behavior and characteristics, distinguishing them from other types of mobile networks. In comparison to other communication networks, vehicular networks come with unique attractive features, as follows [2]:

- Unlimited transmission power: Mobile device power issues are usually not a significant constraint in vehicular networks as in the case of classical ad hoc or sensor networks, since the node (vehicle) itself can provide continuous power to computing and communication devices.
- Higher computational capability: Indeed, operating vehicles can afford significant computing, communication, and sensing capabilities.

- Predictable mobility: Unlike classic mobile ad hoc networks, where it is hard to predict the nodes' mobility, vehicles tend to have very predictable movements that are (usually) limited to roadways. Roadway information is often available from positioning systems and map-based technologies such as GPS. Given the average speed, current speed, and road trajectory, the future position of a vehicle can be predicted.

However, to bring its potency to fruition, vehicular networks have to cope with some challenging characteristics [3], which include

- Potentially large scale: Unlike most ad hoc networks studied in the literature that usually assume a limited network size, vehicular networks can in principle extend over the entire road network and so include many participants.
- High mobility: The environment in which vehicular networks operate is extremely dynamic, and includes extreme configurations: on highways, relative speeds of up to 300 km/h may occur, while density of nodes may be 1–2 vehicles 1 km on low busy roads. On the other hand, in the city, relative speeds can reach up to 60 km/h and nodes' density can be very high, especially during rush hour.
- Partitioned network: Vehicular networks will be frequently partitioned. The dynamic nature of traffic may result in large intervehicle gaps in sparsely populated scenarios, and hence in several isolated clusters of nodes.
- Network topology and connectivity: Vehicular network scenarios are very different from classic ad hoc networks. Since vehicles are moving and changing their position constantly, scenarios are very dynamic. Therefore the network topology changes frequently as the links between nodes connect and disconnect very often. Indeed, the degree to which the network is connected is highly dependent on two factors: the range of wireless links and the fraction of participant vehicles, where only a fraction of vehicles on the road could be equipped with wireless interfaces.

1.3 Vehicular Network Potential Applications and Services

Vehicular network applications range from road safety applications oriented to the vehicle or to the driver, to entertainment and commercial applications for passengers, making use of a plethora of cooperating technologies.

The primary vision of vehicular networks includes real-time and safety applications for drivers and passengers, providing safety for the latter and giving essential tools to decide the best path along the way. These applications thus aim to minimize accidents and improve traffic conditions by providing drivers and passengers with useful information including collision warnings, road sign alarms, and in-place traffic view.

Nowadays, vehicular networks are promising in a number of useful driver- and passenger-oriented services, which include Internet connections facility exploiting an available infrastructure in an "on-demand" fashion, electronic tolling system, and a variety of multimedia services. As well as, a variety of communication networks, such as 2-3G, WLANs IEEE 802.11a/b/g/p, and WiMAX, can be exploited to enable new services designed for passengers apart from the safety applications, such as infomobility and entertainment applications, which can rely on the vehicular network itself.

Regarding the discussed applications' potential, vehicular networks open new business opportunities for car manufacturers, automotive OEMs, network operators, service providers, and integrated operators in terms of infrastructure deployment as well as service provision and commercialization. For safety-related applications, the network operator can assure the authentication of each participant through playing the role of a trusted third party that authenticates the participating nodes, or even having the role of a certification authority issuing a certificate to each participant in order to prove the authenticity of them later during the communication. On the other hand, in nonsafety-related applications, network operators and/or service providers, besides network access and services' provision, can have the role of authorizing services' access and billing users for the consumed services. However, one should notice that ad hoc systems still require a certain level of penetration and necessitate high vehicle density for more reliable communication. Also, the investment cost for new communication infrastructure for vehicular networks is high, where as on the other hand cellular communication systems offer a high coverage along roads and have a reliable authentication and security mechanism. Consequently number of technical challenges needs to be resolved in order to help the evolution of vehicular networks for wide-scale deployment. The following section discusses some of these challenges.

1.4 Technical Challenges

Vehicular networks' special behavior and characteristics create some challenges for vehicular communication, which can greatly impact the future deployment of these networks. A number of technical challenges need to be resolved in order to deploy vehicular networks and to provide useful services for drivers and passengers in such networks. Generally speaking, scalability and interoperability are two important issues that should be satisfied, and the employed protocols and mechanisms should be scalable to numerous vehicles and interoperable with different wireless technologies. The following subsections discuss a number of these challenges, more details are given in the following chapters.

1.4.1 Reliable Communication and MAC Protocols

Similar to ad hoc networks, vehicular networks experience multihop communication, which can potentially extend the network operator fixed infrastructure and thus provide virtual infrastructure among the moving vehicles. Indeed, multihop wireless communication represents a major challenge on the reliability of communication. Consequently, efficient MAC (medium access control) protocols need to be in place, while adapting to the highly dynamic environment of vehicular networks, and considering messages priority of some applications (e.g., accident warnings). In spite of the dynamic topology and the high mobility, fast association and low communication latency should be satisfied between communicating vehicles in order to guarantee (i) service reliability for safety-related applications while taking into consideration the time-sensitivity during message transfer, and (ii) the quality and continuity of service for nonsafety applications. Moreover, MAC protocols should take into consideration the heterogeneous communication that is liable to take place between different wireless technologies (e.g., Wi-Fi and GSM) in vehicular networks.

1.4.2 Routing and Dissemination

Vehicular networks differ from conventional ad hoc wireless networks by not only experiencing rapid changes in wireless link connections, but also having to deal with different types of network densities [4]. For example, vehicular networks on freeways or urban areas are more likely to form highly dense networks during rush hour traffic, while vehicular networks are expected to experience frequent network fragmentation in sparsely populated rural freeways or during late night hours. Moreover, vehicular networks are expected to handle a wide range of applications ranging from safety to leisure. Consequently, routing and dissemination algorithms should be efficient and should adapt to vehicular network characteristics and applications, permitting different transmission priorities according to the application type (safety-related or not). Until now, most of vehicular network research has focused on analyzing routing algorithms to handle the broadcast storm problem in a highly dense network topology [5,6], under the oversimplified assumption that a typical vehicular network is a well-connected network in nature. So far, the penetration of vehicular network technology is somewhat weak, and hence these networks should rely on an existing infrastructure support for wide-scale deployment. However, in the future, these networks are expected to observe high penetration with lesser infrastructure support, and hence it is important in this case to consider the disconnected network problem which is a crucial research challenge for developing a reliable and efficient routing protocol that can support highly diverse network topologies.

As for message dissemination, the dissemination algorithms should depend on the network density as well as the application type. For example, message dissemination in safety-related applications should be mostly broadcast-like, in a way to assure the message propagation to the required cluster of vehicles without causing a broadcast storm. In nonsafety-related applications, message transfer through unicast or multicast transmission is more suitable.

1.4.3 Security

Vehicular communication security is a major challenge, having a great impact on the future deployment and application of vehicular networks. Indeed, security and privacy are major concerns in the development and acceptance of services and should not be compromised by ease-of-use of service discovery protocols. As the demand for service discovery is growing, passengers may use services in foreign networks and create immense security problems for themselves and for other network users. Consequently, it is important to propose innovative solutions for secure communication between participants as well as authorized and secure service access. To enhance the vehicular network access ubiquity, these solutions should take advantage of (i) the ad hoc multihop authentication and communication concepts, which on one hand allow secure communication and on the other hand extend the infrastructure coverage with the minimum deployment cost for the network operator, and (ii) the distributed-based authentication. Appropriate security architectures should be in place providing communication between vehicles and allowing different service access. As well as, a set of security mechanisms suitable for any vehicular network environment should be developed, providing trust, authentication, access control, and authorized and secure service access. In this context, authentication optimization is important to be studied for both infrastructure-based and infrastructure-less communications, aiming to facilitate the reauthentication process that may need to take place during the vehicle mobility.

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Moreover, node behavior is an important issue that can threaten the security of communication and service delivery in vehicular networks, and hence is worth consideration. Due to the open and dynamic environment of vehicular networks, nodes cooperation is an important aspect that should be satisfied for allowing successful communication between vehicles. We notice that nodes may behave selfishly by not forwarding messages for others in order to save power and bandwidth or just because of security and privacy concerns. Consequently, appropriate mechanisms should be developed to detect selfishness and enforce node cooperation in vehicular network environment.

1.4.4 IP Configuration and Mobility Management

The potential vehicle-to-infrastructure architecture is promising in allowing vehicular Internet access as well as provision of Internet-related services to drivers and passengers. However, two technical challenges exist under this issue: IP address configuration and mobility management. These challenges can threaten the service quality and the service continuity. Regarding the vehicular network characteristics, IP address configuration should be carried out in an automatic and distributed manner. So far, there is no standard for IP autoconfiguration in ad hoc networks, and hence the problem becomes complex for vehicular networks. We notice a considerable work in progress by a number of standardization bodies aiming to resolve this problem. Besides the IETF efforts through the Autoconf WG for developing IPv6 solutions for ad hoc networks including vehicular network scenarios, all of the international committees defining architectures for vehicular communication have included a native IPv6 stack in their protocol stacks, namely, IEEE 1609, ISO TC 204 (CALM), C2C-CC, and the newly formed ETSI TC ITS.

As for mobility management, this is a crucial problem for nonsafety applications, where messages dissemination is not broadcast-based. Indeed, the absence of mobility management mechanism threatens service commercialization in vehicular networks, and loses the benefit of the vehicle-to-infrastructure architecture since all Internet-related services would guarantee neither service quality nor their continuity.

1.4.5 Application Distribution

From a general view, we can notice that building distributed applications involving passengers in different vehicles requires new distributed algorithms. As a consequence, a distributed algorithmic layer is required for managing the group of participants and ensuring data sharing among distributed programs. Such algorithms could assimilate the neighborhood instability to a kind of fault. However, the lack of communication reliability necessitates employing fault-tolerant techniques. An important requirement, in this context, is allowing mobile participants in vehicular networks to have service access with an acceptable quality level while facilitating the message exchange between vehicles.

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1.4.6 Business Models

Business models represent an important challenge for service commercialization in vehicular networks. As a matter of opening a new business opportunity, business models should be rentable for telecom operators and service provides aiming to promoting services and attracting clients. It is also important that business models be affordable and attractive to clients, taking into account the cooperation between mobile clients in vehicular networks, where nodes can be compensated (rewarded) according to their participation. Special payment strategies could be proposed, in this context, for encouraging the cooperation between mobile nodes, where a sort of remuneration can be done for each participant according to his contribution. Consequently, special accounting mechanisms and tailored billing systems are needed, which also assure interdomain accounting. However, processing delay constraints should be considered as well as the need for authentication and integrity, where the operator could assure the authentication, authorization, and secure communication between clients in a way that protects the clients' data and allows for billing the used services.

1.5 Vehicular Network Evolution and Progress

1.5.1 Main Actors

Vehicular networks present a highly active field of research, development, standardization, and field trials. Throughout the world, there are many national and international projects in governments, industry, and academia devoted to such networks. These include the consortia like Vehicle Safety Consortium—VSC (United States) [7], Collision Avoidance Metrics Partnership. CAMP (United States) [8], Car-2-Car Communication Consortium—C2C-CC (Europe) [9], Advanced Safety Vehicle—ASV Program (Japan) [10], a lot of standardization efforts as we will see in the following section, and field trials like the large-scale Vehicle Infrastructure Integration Consortium (VIIC) United States [11].

The Vehicle Infrastructure Integration initiative was first launched by the U.S. Department of Transportation (USDOT) during the ITS World Congress in 2003. Then the Vehicle Infrastructure Integration Consortium was formed in early 2005 by a group of light-duty vehicle manufacturers to actively engage in the design, testing, and evaluation of a deployable VII system for the United States. USDOT's VII program is divided into three phases: (i) Phase I—operational testing and demonstration, (ii) Phase II—research in the areas of enabling technology, institutional issues, and applications to support deployment, and (iii) Phase III—technology scanning to determine potential new technology horizons for VII. The first experimental results presented in the symposium IEEE Wivec2007 in Detroit show the strong viability of VII.

In Japan, we notice large initiatives and advanced ITS solutions such as VICS (Vehicle Information and Communication System), AHS (Advanced Cruise-Assist Highway System, since 1996), DSSS (Driving Safety Support Systems, since 2002), and ASV (Advanced Safety Vehicle, since 1991). In the milestones of ITS-Safety 2010 project, a large-scale verification testing on public roads is scheduled in 2008 and a nation-wide deployment in 2010.

We notice that the target applications in the United States include safety, traffic efficiency, electronic toll collect (ETC), and customer relationship management (CRM). On the other hand, in Europe, less roadside infrastructure is expected than in the United States and consequently the target applications are safety and traffic efficiency. In this context, the Car2Car Communication Consortium [9] is a nonprofit organization initiated by six European car manufacturers (Audi, BMW, DaimlerChrysler, Fiat, Renault, and Volkswagen) with the aim to develop an open industrial standard for intervehicle communication to ensure pan-European interoperability, using wireless LAN technology (WLAN IEEE 802.11 standards). More details are given in the following subsection.

Moreover, the telcos with their large existing infrastructures also give a special attention to the development of vehicular networks. Orange Labs, Telcom Italia, AT&T labs, or Deutsche Telekom all take part in the development of the technology via partnerships with industries, universities, and their own R&D teams. In fact, they see such networks as a natural evolution or extension of the current wireless systems, while representing a low-cost solution that improves the performance of telco networks by overcoming the limitations of using multihop technology and giving a potential of new business (develop customer loyalty, catch new customers).

Many industries, and companies, involved in the consortiums cited above, are investing enormous budget for the development of new ITS solutions. Some of them (such as, Dash, Google, and TomTom) are interested in particular in real-time infotainment and guidance of the travelers. They do more than only charting the roads; they also allow the drivers or passengers to receive real-time information about the traffic, to connect to the Internet, and to have other useful information (such as, nearest gas station, restaurants and cinemas) on the way. Other example is Microsoft, which proposed to carmakers and their suppliers a new version of its operating system capable of managing all the embedded systems within the car [12]. Being a technology always under development, vehicular networks belong to the main tendencies in research topics. Large number of conferences and workshops dealing with this is the proof. A set of universities and research institutes (UCLA, Karlsruhe University, Stanford University, INRETS, etc.) take part in the optimization of several challenges encountered in these networks, among which are routing and data dissemination, Phy/Mac, security, self-organization, and the like.

1.5.2 Main Standardization Activities

In 1999, the U.S. Federal Communication Commission allocated 75 MHz of dedicated short-range communication (DSRC) spectrum at 5.9 GHz (5.850–5.925 GHz) to be used exclusively for vehicle-to-vehicle and infrastructure-to-vehicle communications in North America. The primary purpose was to enable public safety applications that save lives and improve traffic flow. Private services are also permitted in order to lower cost and to encourage DSRC development and adoption. The DSRC spectrum is divided into seven 10-MHz wide channels. Channel 5885–5895-MHz is the control channel, which is generally restricted to safety communications only. The two channels at the edges of the spectrum are reserved for future advanced accident-avoidance applications and high-powered public safety usages. The rest are service channels and are available for both safety and non-safety usage.

On the other hand, in Japan, the allocated frequency bands, namely for DSRC, range from 5.770 to 5.850 GHz.

As for Europe, one obstacle to introduce VANETs for road safety was the lack of a dedicated frequency spectrum. Compared to North America and Japan, the process for frequency allocation is considerably complex and time consuming since all European countries and their national authorities are involved. Major steps taken after few years of work for frequency regulation and redeployment are analysis of spectrum requirements, request for the proposed spectrum, study of compatibility aspects, and recommendation of policies for harmonized spectrum usage. A decision by the European Commission to designate the spectrum has been carried out and the spectrum has been allocated in the middle of 2008 [13] and is in its way for implementation by the EU countries (at the time this book was written). Eventually, the frequency bands 5875–5905 MHz for road safety, additional 20 MHz above this band as future extension, and 5855–5875 MHz for nonsafety will be available. The allocated frequency of 50 MHz and optional the additional 20 MHz are similar to the 75 MHz ITS band in North America.

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1.5.2.1 IEEE

The DSRC radio technology is essentially IEEE 802.11a adjusted for low overhead operations in the DSRC spectrum and it is being standardized as IEEE 802.11p (at the time this book was written). The overall DSRC communication stack between the link layer and applications is being standardized by the IEEE1609 working group. Hence, IEEE 1609 is a higher-layer standard on which IEEE 802.11p is based. Indeed, the IEEE 1609 family of standards for wireless access in vehicular environments consists of four standards: (i) IEEE P1609.1—WAVE Resource Manager defines the basic application platform and includes application data read/write protocol between RSU and OBU, (ii) IEEE P1609.2—WAVE Security Services defines the 5.9-GHz DSRC Security, anonymity, authenticity, and confidentiality, (iii) IEEE P1609.3—WAVE Networking Services defines network and transport layer services, including addressing and routing, in support of secure WAVE data exchange, and (iv) IEEE P1609.4—WAVE Multichannel Operations provides DSRC frequency band coordination and management, where it manages lower-layer usage of the seven DSRC channels, and integrates tightly with IEEE 802.11p.

1.5.2.2 C2C-CC

A major driving force for vehicular communication based on WLAN technology in Europe is the C2C-CC [9], a consortium of car manufacturers, suppliers, and research institutes. The C2C-CC assimilates developments from various European R&D projects, creates system and protocol specifications, and provides a framework for system prototyping. In 2007, the C2C-CC took a substantial step forward and published its “manifesto” describing the main concepts of the system, covering system and protocol architecture, use cases, and communication protocols. A core concept of C2C-CC’s networking approach is based on wireless ad hoc and multihop communication utilizing geographical addressing and routing. The consortium is looking forward for allowing interoperability among cars from different car manufacturers and suppliers of on-board and roadside units. In this context, the C2C-CC is concerned with real-life demonstrations of safety applications for tangible ad hoc networks.

1.5.2.3 ETSI

The European Telecommunications Standards Institute (ETSI) has recently created a new technical committee TC ITS [14] in order to develop standards and specifications for ITS services. The TC ITS is organized in five working groups: WG1—User and Application Requirements, WG2—Architecture and Cross-Layer Issues, WG3—Transport and Network, WG4—Media and Related Issues, and WG5—Security. The working groups have already agreed on a number of work items for various aspects of vehicular communication including media, networking, and security and safety applications. In WG3, the current focus is on specification of ad hoc networking based on geographical addressing and routing. In order to allow for use of different media, the specification distinguishes between media-independent and media-dependent network functions. The specifications are backed by other work groups, which specifically address media and security issues, such as a European profile standard of IEEE 802.11 for ITS. The technical committee is developing a road map for standardization developments for the coming years in order to achieve a complete set of standards ranging from communication architecture to protocol specifications together with formal test procedures. ITS-related work within ETSI is led by ETSI ERM TG37 (Electromagnetic compatibility and Radio spectrum Matters), which works in close cooperation with other ETSI committees and with other SDOs, notably ISO TC204. ERM TG37 contributes to the development process standards of being led by ISO TC204 and will develop complementary ETSI standards as appropriate.

1.5.2.4 ISO

The worldwide ISO TC204/WG16 has produced a series of draft standards known as CALM (Continuous Air-interface, Long and Medium Range [15]). The goal of CALM is to develop a standardized networking terminal that is capable of connecting vehicles and roadside systems continuously and seamlessly. This would be accomplished through the use of wide range of communication media, such as the mobile, cellular, and wireless local area networks, and the shortrange microwave (DSRC) or infrared (IR). CALM provides universal access through a number of complimentary media and links them with modern Internet protocols, adaptation layers, and management entities. The CALM architecture separates service provision from medium provision via an IPv6 networking layer, with media handover, and will support services using 2G, 3G, 5 GHz, 60 GHz, MWB (802.16e, 802.20, and HC-SDMA). It will be able to include other technologies as they evolve by use of common service access protocols and the IPv6 networking.

The CALM [15] concept, that ETSI is also helping to develop, is now at the core of several major EU sixth framework research and development projects such as SAFESPOT [16] and CVIS [17], which will test CALM solutions. In the United States the VII initiative will be operating using IEEE 802.11p/1609 Standards at 5.9 GHz, which are expected to be aligned with CALM 5.9-GHz standards, although the IEEE standards do not have media handover.

1.5.3 Related Projects

The earliest research in intervehicular communications was conducted by JSK (Association of Electronic Technology for Automobile Traffic and Driving) of Japan in the early 1980s [18]. This work treated intervehicular communications primarily as traffic and driver information systems incorporated in ATMs (asynchronous transfer mode).

From the 1990s through 2000, American PATH [19] and European “Chaffeur” [20] projects investigated and deployed automated platooning systems through the transmission of data among vehicles.

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Recently, the promises of wireless communications to support vehicular safety applications have led to several national and international projects around the world. Since 2000, many European projects (CarTALK2000, FleetNet, etc.), supported by automobile manufacturers, private companies, and research institutes, have been proposed with the common goal to create a communication platform for intervehicle communication.

- The IST European project CarTALK2000 [21] was focused on new driver assistance systems which are based upon intervehicle communication. The main objectives were the development of cooperative driver assistance systems and the development of a self-organizing ad hoc network as a communication basis, with the aim of preparing a future standard.
- The FleetNet project in Germany [22], supported by six manufacturers and three universities from 2000 through 2003, produced important results in several research areas, including the experimental characterization of vehicular networks, the proposal of novel network protocols (MAC, routing), and the exploration of different wireless technologies.

1.5.3.1 Recent Projects

At the time this book was written, many activities in research and development of vehicular networks were ongoing. In Europe, major R&D projects were being initiated to constitute the basis of a Europe-wide intelligent transportation system, for example, NoW [23], CVIS [17], SAFESPOT [16], COOPERS [24], GeoNet [25], and GST [26].

- NoW [23].
  Network on Wheels (NoW) is a German project, successor of the project FleetNet-Internet on the Road [22], which mainly works on communication aspects for vehicle-to-vehicle and vehicle-to-roadside communication based on WLAN technology. The specific objective of the NoW project is the development of a communication system which integrates both safety [such as extended electronic break light (EEBL)] and nonsafety applications (such as car-to-home applications). Started in 2004, the final project presentation in May 2008 demonstrated a consolidated technical basis, which serves as reference for planned field. One of the main outcomes of the project is a prototype software platform for car-to-car and car-to-infrastructure communication (http://c2x-sdk.neclab.eu). This platform provides the protocol stack and an open API and offers a toolkit for application design, implementation, and testing.

- CVIS [17].
  Cooperative Vehicle Infrastructure Systems (CVIS) project aims at developing a communication system that is capable of using a wide range of wireless technologies, including cellular networks (GPRS, UMTS), wireless local area networks (WLAN), short-range microwave beacons (DSRC, and infrared. Access to these wireless technologies is based on the new international "CALM" standard [15], which allows future vehicular networking implementation to be integrated with the CVIS platform via standardized CALM service access points. A framework for open application management (FOAM) is defined that connects the in-vehicle systems, roadside infrastructure, and back-end infrastructure, which is necessary for cooperative transport management.
- SAFESPOT [16].
  SAFESPOT provides cooperative systems for road safety, referred to as smart vehicles on smart roads, to prevent road accidents by developing a safety margin assistant that detects potentially dangerous situations in advance and extends the drivers' awareness of the surrounding environment in space and time. This assistant represents an intelligent cooperative system utilizing vehicle-to-vehicle and vehicle-to infrastructure communication based on WLAN technology (IEEE 802.11p).
- COOPERS [24].
  Cooperative Systems for Intelligent Road Safety (COOPERS) project focuses on the development of innovative telematics applications on the road infrastructure with the long-term goal of a cooperative traffic management between vehicle and infrastructure. COOPERS attempts to improve road sensor infrastructure and traffic control applications, develops a communication concept and applications able to cope with the requirements for infrastructure-to-vehicle communication, and demonstrates results at major European motorways with high-density traffic.
- GeoNet [25].
  The EU project GeoNet (http://www.geonet-project.eu/) has started in February 2008 and implements a reference system for vehicular ad hoc networking using concepts for geographical addressing and routing. Particular focus lies on integration of geonetworking with IPv6 and solutions for IP mobility support. In GeoNet, a vehicle is regarded as a mobile network, where the NEMO protocol handles Internet connectivity of the nodes in the mobile network with intermittent access to roadside units. For wide deployment of the project results, it is planned to provide the GeoNet implementations to other R&D projects.

- GST [26].
  Global System for Telematics (GST) project creates an open and standardized end-to-end architecture for automotive telematics services. The project targets at infrastructure-oriented services typically provided by a network operator, such as emergency call services, enhanced floating car data services, safety warning, and information services.

1.6 Conclusion

Inter vehicular communication (IVC) is becoming a reality, driven by navigation safety requirements and by the investments of car manufacturers and public transport authorities. Its opportunities and areas of applications are growing rapidly, and include many kind of services with different goals and requirements. However, it does pose numerous unique and novel challenges from network evolution to event detection and dissemination, making research in this area very attractive. Consequently, IVC is attracting a considerable attention from the research community and the automotive industry, where it is beneficial in providing intelligent transportation system as well as driver and passenger assistant services. In this context, vehicular ad hoc networks are emerging as a new class of wireless networks, spontaneously formed between moving vehicles, and allowing for a number of useful services for drivers and passengers, ranging from road safety applications to entertainment applications. These networks are promising for network operators, service providers, and for a number of industrials and telecom companies in terms of opening new business opportunities.

However, the penetration of vehicular network technology is still weak, and hence there is a need for infrastructure support to help its penetration. At the same time, deploying new infrastructure for these networks necessitate a lot of investment and high cost. It is more economical to rely on the existing infrastructure (owned by network operators for instance) for accelerating the penetration of such technology with the least cost.

Although many standard organizations are involved in the study and standardization of IVC, vehicular ad hoc networks are considered as a technology under development that merits a lot of research and field trials. Besides the ongoing standardization activities, a number of technical challenges, as discussed in the following chapters, need to be resolved aiming for wide-scale deployment of these networks in the near future. Still, many topics in this field are currently under discussion, such as allocation of a protected frequency band for road safety in Europe, potential usage of the IEEE 802.11p/WAVE standard, integration of multiple wireless technologies, data security, congestion control, data transport, and others.

In addition to technical breakthroughs, the phase of market introduction is critical for the success of this new technology. Also, car manufactures like BMW, Mercedes, Fiat, Ford, Toyota, and Nissan, are currently prototyping vehicles equipped with Wi-Fi (802.11a/b/g) and DSRC technologies, which are expected to be on the road within the next 3–5 years.

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