

Inter-Vehicular Communication Systems, Protocols and Middleware

Imad Jawhar, Nader Mohamed, and Liren Zhang
College of Information Technology, UAE University, Alain, UAE
Email:{ijawhar, nader.m, lzhang}@uaeu.ac.ae

Abstract—Inter-vehicular communication is an important research area that is rapidly growing due to considerable advances in mobile and wireless communication technologies, as well as the growth of microprocessing capabilities inside today's cars, and other moving vehicles. A good amount of research has been done to exploit the different services that can be provided to enhance the safety and comfort of the driver. Additional functions provide the car electronics and the passengers with access to the Internet and other core network resources. This paper provides a survey of the latest advances in the area of inter-vehicular communication (IVC) including vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) functions and services. In addition, the paper presents the most important projects and protocols that are involved in IVC systems as well as the different issues and challenges that exist at each layer of the networking model.

Keywords: Wireless networks, mobile ad hoc networks (MANETs), wireless sensor networks (WSNs), inter-vehicular communication, middleware, routing.

I. INTRODUCTION

One of the applications that can make good and efficient use of wireless sensor networks is road-side networks that can be used to monitor vehicular activities along roads such as speeding cars, accidents, and more. Car and other vehicles can have communication capabilities with other fixed wireless access points and Internet gateways along the road sides which can alert them to potential problems ahead, traffic conditions, or provide useful and practical Internet access. In addition, this type of communication can give quick life-saving warnings to the vehicle control system to alert a sleepy or distracted driver in case the car is about to be driven off the road. In fact, vehicle controls can even take critical actions before the driver can respond in time. Consequently, some researchers have already proposed systems that are intended to make car driving safer by using V2V and V2I communications which allow moving vehicles to alert drivers of danger in crossing an intersection or detecting an emergency situation that can cause an imminent accident.

Inter-vehicular communication (IVC) is an important emerging field of research that takes advantage of the latest advances in microprocessing and electronic circuitry that are installed inside moving vehicles (MVs) as well as the increase in wireless communication capabilities of such devices with their environment. This field of research is expected to contribute considerably to driver and passenger safety, as well as

offer important means of communication that can provide a large number of services that maintain the connectivity of the individuals on the road to the Internet as well as to passengers in other vehicles and businesses in the same geographic area.

In [1], Franz et al. presents an overview of the FleetNet applications, services, technical challenges, communication protocols, routing, Internet integration, and standardization. The paper in [2] presents a survey of IVC systems which is focused on V2V communication. It discusses the proposed techniques at the physical, MAC, and Network layers. The paper also outlines some location awareness, security, and mobility issues. The survey does not discuss the vehicle to infrastructure applications, issues and challenges. In addition, the paper includes a discussion of the possible use of IEEE 802.11b, 3G cellular, and Bluetooth as platforms for IVC systems. A more detailed discussion of FleetNet and the other IVC projects is presented in later sections in this paper.

In [3], the author presents a survey of the network layer aspects for IVC communication. The survey briefly discusses the different routing mobile ad hoc network (MANET) protocols [4][5] including flat, hierarchical, location-based, geographical, and geographical multicast routing. In addition, an overview of the mobility management aspects of IVC systems is presented including location management, and handover mechanisms using mobile IP, cellular, and vehicular strategies. In [6], a survey of research in the area of information dissemination and assurance in IVC networks is presented. The paper discusses the different types of information exchanges that are possible in vehicular communication along with the different methods of information exchange. The paper also briefly addresses the proposed solutions for ensuring authenticity and integrity of information, location privacy, and eviction of misbehaving vehicles from the network. In [7], the authors present a survey of vehicular sensor network (VSN) developments. The paper discusses the issues of collection, storage and harvesting of sensor information using IVC systems including mobility-assisted dissemination, geographic storage, and using infrastructure. The authors conclude that system performance is impacted by wireless access methods (e.g. cellular 2/3G, WIMAX/802.16, and WiFi IEEE 802.11), mobility, user location and popularity of information.

The survey presented in this paper has the following contributions beyond the existing papers discussed earlier. It presents an overview of the different IVC projects; it also provides a discussion of the current research in IVC systems at the various layers of the networking stack. In addition, the

This work was supported in part by UAEU Research grant 04-03-9-11/09.

paper includes a discussion of middleware support for IVC systems as well as additional issues, challenges and research opportunities in this area. Such research involves designing architectures and protocols that take advantage of the linear nature of most IVC mobile ad hoc networks in order to further optimize the performance, scalability, congestion control and response time of the network.

The remainder of the paper is organized as follows. Section 2 presents a list of existing IVC projects. Section 3 discusses the latest IVC systems research at the various networking layers. Section 4 offers additional issues and challenges facing IVC systems. Finally, the last section concludes the paper.

II. IVC PROJECTS

As mentioned earlier, IVC systems involve two categories of communication [8][9][10]:

- **Vehicle-to-Vehicle (V2V) communication:** In V2V communication, vehicles communicate with each other in order to support different applications and services such as cooperative driver assistance and decentralized floating car data (e.g. traffic state monitoring information).
- **Vehicle-to-Infrastructure (V2I) communication:** In this type of communication, vehicles are able to communicate with fixed infrastructure along side of the road in order to provide user communication and information services such as hot-spot Internet access, mobile advertising, Inter-vehicle chat, and distributed games.

In this section, a list of the existing IVC projects and systems is provided along with a brief description of each one.

FleetNet: is an "Internet on the Road" project, which was set up by a consortium of six companies and three universities in order to promote the development of inter-vehicle communication systems. FleetNet was started in September 2000.

CarTALK 2000: is a 3-year project started in August 2001. The project focused on developing new driver assistance systems which are based on inter-vehicle communications for safe and comfortable driving. It has three application clusters: Information and warning functions (IWF), communication-based longitudinal control (CBC), and co-operative assistance systems (CODA).

Wireless Local Danger Warning (WILLWARN): is one of the sub-projects of the Integrated Project PReVENT which contributes to road safety by developing and demonstrating preventive safety application and technologies. WILLWARN is a 3-year project aimed at developing, integrating and validating a safety application that warns the driver whenever a safety-related critical situation is occurring beyond the driver's field of view. This project explores both V2V and V2I communication.

Car2Car: is a communication consortium, which was founded by six European car manufacturers. One of its main objectives is to create and establish an open European industry standard for Car2Car communication systems based on wireless LAN components and to guarantee European-wide inter-vehicle operability.

Network on Wheels (NOW): is a German research project started in 2004. The main objectives of NOW are to solve technical key questions on the communication protocols and data security for V2V communications and to submit the results to the standardization activities of the V2V communication consortium.

Dynamic Radio for IP-Services in Vehicular Environments (DRiVE): One of the main objectives of this project is to produce in-vehicle multimedia services that allow information to be easily accessible anywhere as well as provide support for education and entertainment.

Table I offers a summary of the IVC projects and systems that were discussed in this paper, along with additional projects which include Cooperative Vehicle-Infrastructure Systems (CVIS), SAFESPOT, and COOPERatie systEMs for intelligent Road safety (COOPER).

In addition to the projects that are summarized in Table I, the following projects mostly focus on coordination of research and development efforts between various IVC-related companies and organizations:

INVENT: is a research initiative, which consists of eight component projects. These projects deal with different investigations into issues concerning driver assistance systems for safer driving, traffic management systems to relieve traffic jams and traffic management in transport and logistics, using user-friendly technologies.

Advanced Driver Assistance Systems in Europe (ADASE): is a project with a mission of increasing the road and traffic safety in Europe by not only reducing accidents but also by avoiding collisions before they occur.

Communication and Mobility by Cellular Advanced Radio (COMCAR): is a project is centered around the conception and prototypical realization of an innovative mobile communication network. With its main focus on asymmetrical and interactive mobile IP-based services, one of the key issues it tackles is intra-vehicular and inter-vehicular communication.

CHAUFFEUR 2: is an extension of the CHAUFFEUR 1 project. This research project is based on platooning of vehicles whereby a leading vehicle which is physically steered by a driver electronically tows more than one vehicle behind it.

The Main Features and Services Offered by a Typical IVC System

In order to highlight the main features and services offered by IVC systems, this section focuses on FleetNet which is one of the leading projects among the ones listed earlier. This is a project that is funded by the German Ministry of Education and Research (BMBF) and Daimler Chrysler AG. It provides a V2V communication framework which uses ad hoc networking principles. The framework is used for different applications including cooperative driver assistance, decentralized floating vehicle data (e.g. traffic jam monitoring information, route weather forecast, etc), and user communications and information services (e.g. Internet access, mobile advertising, distributed games, etc). Routing of data packets

TABLE I
IVC PROJECTS AND SYSTEMS SUMMARY TABLE.

IVC Projects and Systems	Main Features	Protocols	V2V	V2I
FleetNet	Provides V2V Communication framework. Cooperative driving. Position-based forwarding.	IEEE 802.11	✓	✓
CarTALK 2000	Ad hoc V2V communication. Traffic safety, and comfort. Three application clusters (IWF, CBLIC, and CODA).	IEEE 802.11. Uses infrared sensors and GPS technology.	✓	✓
Wireless Local Danger Warning (WILL-WARN)	Consortium of six European car manufacturers. Create an open industry standard for wireless LAN Car2Car communication systems. Guarantee European-wide inter-vehicle operability. Ad hoc network with position-based routing that is adaptable to fast changing topology.	Uses sensor technology. IEEE 802.11	✓	✓
Car2Car	Consortium of six European car manufacturers. Create an open industry standard for wireless LAN Car2Car communication systems. Guarantee European-wide inter-vehicle operability. Ad hoc network with position-based routing that is adaptable to fast changing topology.	IEEE 802.11	✓	
Network on Wheels (NOW)	Ad hoc networking. Provide traffic safety, efficiency, security, and infotainment. Vehicle on-board unit (OBU) and application unit (AU) to provide interface to driver/passengers. Road Side Units (RSUs) installed on roads.	IEEE 802.11, and GPS.	✓	✓
Communication Radio for IP-Services in Vehicular Environments (DRiVE)	Project addresses the convergence of cellular and broadcast networks to provide cost-efficient provision of IP-based in-vehicular multimedia services for information, education, training, and entertainment. Achieve an optimized inter-working of different radio systems in a common dynamically allocated frequency range.	GSM, GPRS, UMTS, DAB, DVB-T		✓
Cooperative Vehicle-Infrastructure Systems (CVIS)	Allow seamless V2V and V2I communication between various protocols and standards. Addresses issues of interoperability, security, and public policy needs. Cooperative V2I systems. CVIS communication and networking (COMM). Uses CALM (Continuous Air Interface for Long and Medium range), a set of automotive ISO standards supporting universal interoperability. Provide seamless handover between media and applications.	IEEE 802.11, Infrared, Millimeter wave, GSM/UMTS.CALM M5 radio communication.	✓	✓
SAFESPOT	Ad hoc networking. Relative localization, integrate vehicles with intelligent systems that warn drivers of road hazards. Real time representation of surrounding vehicles and environment. Decentralized architecture. Information gathered by road side sensors and mobile sensors. Road intersection safety, safe overtaking, head-on collision and vulnerable road warning.	IEEE 802.11p, GPS.	✓	✓
COOPERative systEms for intelligent Road safety (COOPER)	Improve traffic management and safety. Collects traffic information by using vehicles as floating sensors. Project to test and analyze existing protocols and technologies to see which one is best suited for use. Built on existing equipment and network on the road infrastructure.	GSM/GPRS/UMTS, Microwave and Infrared	✓	✓

is done using a position-based forwarding strategy. This latter strategy is well suited for V2V communication. Nodes forward packets from the source by performing a *geocast* which consists of broadcasting a packet in a limited geographic area around the source node. Forwarding of the packets is done in a greedy fashion in the geographic direction of the destination based on the position of the source, destination and the intermediate node. Due to this forwarding strategy, no route discovery is needed before sending data packets, and no associated routing tables at intermediate nodes are necessary. This routing approach requires location awareness of the nodes through GPS or other positioning systems in addition to a system for sharing and management of position information in the corresponding ad hoc network.

The following are the main features of a typical IVC systems such as FleetNet:

- Wireless multihop ad hoc networking with provisioning for connectivity even in low traffic density situations.
- Use of unlicensed radio spectrum.
- Low data transmission delay which is necessary for cooperative driving and safety applications.
- Position-based vehicle addressing which allows position-based addressing and location-based services.
- V2V and V2I communication.
- Intended to be an open standard.
- Support for high bit rates and adaptability to relative high speeds.
- IEEE 802.11 standard is used in the development and

testing phase.

III. IVC SYSTEMS RESEARCH AT EACH ONE OF THE NETWORKING LAYERS

Table II offers a summary of IVC systems research at various layers of the networking stack. Due to space considerations, we will not expand the discussion of these layers beyond that mentioned in the table.

IV. OTHER ISSUES AND CHALLENGES IN IVC SYSTEMS

A. Security

In [20], Papadimitratos et al. consider the security issues in IVC systems. The authors provide an analysis of the different types of threats to which such systems can be susceptible from anti-social and criminal attackers. For example, an attacker might "contaminate" a large part of the network with false information: A vehicle can transmit false warnings, or messages in order to masquerade as an emergency vehicle to cause other vehicles to slow down and yield. In addition, messages transmitted from vehicles using IVC systems can be used to track down a vehicle's location and transactions which can lead to information about the driver and passengers. In order to protect IVC systems from such possible attacks, various security requirements should be implemented such as: message authentication and integrity, message non-repudiation, entity authentication, access control, accountability, and privacy protection. Furthermore, security measures must be taken in order to ensure secure beaconing,

TABLE II
SUMMARY OF IVC SYSTEMS RESEARCH AT VARIOUS LAYERS OF THE NETWORKING STACK.

Protocol/Sys.	Comm. Layer/Cat.	Description	Protocol/Spec.	V2V	V2I
Festag et al. [9]	Network/ routing	Position-based routing is compared with typical ad hoc network routing protocol such as DSR. Better results can be achieved by combining position-based and map-based strategies.	Position-based routing, IEEE 802.11b, and Linux-based FleetNet routers	✓	
Bechler et al. [8]	Application	MOCCA (Mobile CommuniCation Architecture) as an Internet integration approach for IVC systems. Interoperability with Internet protocols. IP-based applications in vehicles running on top of FleetNet Data link and Physical layers access the Internet via roadside Internet Gateways (IGWs) using predefined Global addresses.	IPv6-based proxy, Mobile IP, FleetNet Data link and Physical layers	✓	✓
Subramanian et al. [11]	Physical	Use of steerable beam directional antennas with IEEE 802.11b in V2V systems. GPS used for beam direction.	IEEE 802.11b	✓	
OISHI et al. [12]	Physical	A communication model for radio wave propagation for IVC systems in urban areas. Building density is proposed to be used for simpler and more accurate IVC system simulations.	2.2 GHz radio frequency	✓	
Khaled et al. [13]	Data link/MAC	Authors study the performance of IEEE 802.11b protocols in the IVC networking environment. With current protocol, slower data rates would have to be used. Adaptable transmission heuristics needed to improve performance in delay and data loss.	IEEE 802.11b	✓	
Fasolo et al. [14]	Network/ routing	Specialized broadcast algorithm for IVC systems. Relies on GPS information to increase message propagation speed and reduce redundancy	Smart Broadcast, IEEE 802.11, GPS	✓	
Choffnes et al. [15]	Network/ routing	Virtual Ferry Networking (VFN). Store and forward approach to routing messages in IVC systems. Not suitable for fast response services. Only suitable for delay-tolerant applications.	VFN	✓	
Tian et al. [16]	Network/ routing	Spatially aware packet routing for Inter-vehicular MANETs. Protocol uses geographic information to avoid predictable and permanent topology holes caused by road structures in IVC systems and improve routing performance over generic MANET protocols.	Spatially Aware Routing (SAR), Geographic Source Routes (GSR) and GSR-based forwarding	✓	
Kates et al. [17]	Application	Intelligent speed adaptation controller technology in vehicles to enhance traffic performance, increase effective highway capacity, reduce congestion, and increase safety.	ACC controller, BMW XFACE	✓	✓
Strang et al. [18]	Application	Railway Collision Avoidance System (RCAS). Uses Ad hoc networking components without the need for extension to railway infrastructure. Provide traffic alerts, or direct system intervention if collision possibility is detected.	GALILEO/GPS, Global Navigation Satellite System (GNSS)	✓	
Yang et al. [19]	Application	Vehicle Collision Warning Communication (VCWC) protocol to support V2V communication in emergency situations. Data traffic congestion control mechanism to prevent delays due to sudden abnormal events in vehicles.	DSRC (Dedicated Short Range Communications) services with IEEE 802.11 DCF, GPS	✓	
Papadimitratos et al. [20]	Security	Security issues in IVC systems. Types of threats from anti-social and criminal attackers. Security requirements and measures that should be implemented.	Position-based routing, Geocast, GPRS, TCP/IP	✓	✓
Dressler et al. [21]	Security	Outline challenges and objectives of different models of IVC systems including centralized and distributed ones. Propose some solutions to the different attack types.	GPS-based systems. Centralized and distributed Traffic Information System (TIS).	✓	✓
Jawhar et al. [22]	Application/ Routing	Architectural model taking advantage of the linear alignment of nodes in most IVC systems. Research to use this characteristic to optimize the performance of the different protocols at the various layers of the networking stack in IVC systems.	Linear ad hoc network routing protocols, IEEE 802.11, WIMAX, Zigbee, GPRS	✓	✓
Hughes et al. [23]	Application/ Middleware	Event-based middleware. Provide guaranteed real-time message propagation in IVC systems	RT-STREAM event-based middleware	✓	
Marques et al. [24]	Application/ Middleware	Publish-subscribe middleware. Developed to support heterogeneous vehicles including underwater, surface, and air autonomous vehicles. Support for acoustic modems. Use Real Time Publish and Subscribe (RTPS) network protocol.	Seaware, support UDP and HTTP transport.		✓
Liu et al. [25]	Application/ Middleware	MARCHES: a context-aware reflective middleware for adaptive real-time vehicle operations. Improve vehicle safety and traffic congestion.	MARCHES, XML.	✓	✓
Guo et al. [26]	Application/ Middleware	Mobile agent-based middleware architecture for distributed V2V coordination.	JNomad, Sun Microsystems Jini platform		✓
Manasseh et al. [27]	Application/ Middleware	Middleware architecture for traffic-related data and traffic operation and safety. Data collected from sensors in vehicles and intersections. Provide Geo-spatial query interface for locating sensors.	GPS, different distributed platforms (CORBA, Java RMI, etc.)	✓	✓

neighbor discovery, and geocasting processes which constitute important functional parts of IVC systems.

In [21], Dressler et al. outline security requirements and objectives for Traffic Information Systems (TIS) and provide some possible solutions for such systems. They discuss the issues related to centralized TIS, Floating Car Data (FCD), and distributed TIS. The latter model is also referred to as decentralized Self-Organizing Traffic Information System (SOTIS) [28]. The authors identify security objectives such as confidentiality, data integrity, availability, and access control. In addition, they provide different attacker models for IVC systems including insider versus outsider, malicious versus

rational, active versus passive, and global versus local. The paper proposes solutions related to confidentiality, message integrity/authentication, key management/security updates, secure positioning, and privacy.

B. The linear nature of most IVC systems

In addition to the above, the special characteristics of IVC systems provide further research opportunities [22]. For example, linear ad hoc and sensor networks is a new area of research which can contribute to the optimization of IVC systems and protocols. In such networks, the nodes are aligned in a linear formation which characterizes the node positions

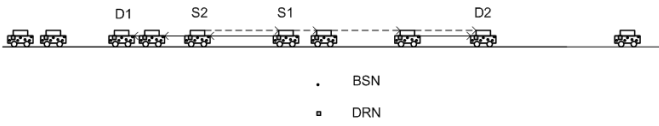


Fig. 1. A vehicular linear ad hoc network with V2V communication.

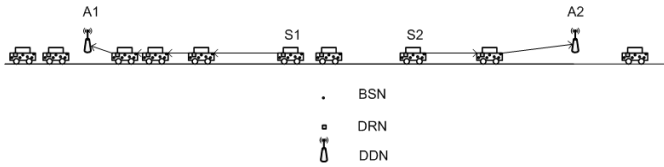


Fig. 2. A vehicular linear ad hoc network with V2I communication.

in IVC systems. Vehicles on a long highway constitute a good example of such an alignment. Figure 1 shows a vehicular linear ad hoc network that is not connected to roadside infrastructure. In the figure, vehicles S1 and S2 are sending data to vehicles D1 and D2 respectively. Both sessions are using the intermediate vehicles between them as routers. Figure 2 shows a vehicular linear network that is connected to roadside infrastructure nodes that serve as gateways to infrastructure networks including the Internet. In the figure, node S1 is communicating with access point A1, which is the closest one to it in number of hops. Similarly, node S2 is communicating with access point A2. As vehicles continue to move, they will continuously switch to the nearest access point using a hand over mechanism. The two figures also show the possibility of having three types of nodes: Basic Sensor Nodes (BSNs), Data Relay Nodes (DRNs), and Data Dissemination Nodes (DDNs). The function of the BSN nodes is to perform their designated and possibly diversified sensing operations. Then, they communicate their information to the DRN nodes. The DRN nodes are responsible for routing the information to the nearest DDN node. The DDN nodes are the gateway nodes which provide connectivity to the control center, the Internet, or any other backbone network depending on the application involved. More details about these types of nodes and the related framework can be found in [29]. The paper presents related research that has been done on Linear Sensor Networks (LSNs) and linear ad hoc networks, which, as indicated earlier, share a lot of common requirements and characteristics with IVC systems. The results of this research as well as future work to optimize and enhance the performance of such networks can be beneficial and useful to IVC systems design leading to increased network performance and reliability.

C. Middleware support for IVC systems

Middleware platforms offer many novel approaches and enhancements in developing and operating inter-vehicle applications. Middleware is defined as a software layer between applications and multiple distributed resources such as networked vehicles. It masks the heterogeneity and distribution of these underlying resources and provides advanced services for implementing and operating V2V applications. It simplifies

the communication among the distributed components of vehicle applications and provides a unified programming model to application developers. It can provide common services needed by different V2V applications. These services could be for interoperability support, real-time communication support, communication reliability enhancements, security enhancement and management, and efficient resource utilization and management. A number of middleware platforms and services were developed to provide support for both V2V and V2I communications and applications. Some research was done in the generic area of mobile ad hoc networks [30] where V2V communication is a special case. In this section, we will cover only the middleware platforms and architectures are specifically designed for inter-vehicle systems. These have been designed to respond to the dynamic nature of the environment they serve as well as fulfilling the need for real-time support for vehicle applications. An example of a middleware that provides real-time communication support is RT-STEAM [23]. RT-STEAM is an event-based middleware that provides guaranteed real-time message propagation for vehicular ad hoc networks. It supports hard real-time event delivery and filtering mechanism. The filtering can be based on subject, content, and proximity. Unlike other event middleware systems, there is no centralized event broker or look-up service. Another middleware example that provides real-time communication support in heterogeneous environments is Seaware [24]. Seaware is a publish-subscribe middleware that was developed to support heterogeneous vehicles including autonomous underwater vehicles, remotely operated vehicles, unmanned air vehicles, and autonomous surface vehicles. Seaware uses Real-Time Publish-Subscribe messaging (RTPS) and other transport protocols. RTPS is a standard protocol for communicating over lightweight unreliable network transport such as UDP. Seaware can support other heterogeneous transport vehicles such as acoustic modems for underwater communications, raw UDP transport, and HTTP transport. Another middleware that provides advanced real-time support is MARCHES [25]. MARCHES is a context-aware reflective middleware for adaptive real-time vehicle applications. This framework was created with the motivation to improve vehicle safety and reduce traffic congestion. The created context-aware reflective middleware can measure real-time contexts and accordingly reconfigure the behavior of supported applications. This is very important to improve the flexibility, adaptability, and affordability of the future vehicle safety systems. Unlike other context-aware reflective middleware, the suggested middleware can provide fast reconfiguration time to satisfy the strict real-time requirements of vehicle applications. Other types of middleware systems are designed to enable efficient V2V as well as V2I communication. Middleware can be used to improve communication reliability in dynamic environments. Resources such as bandwidth and error rates can change dynamically due to the ad hoc nature of V2V communication environments. Mobile agent-based middleware was used to support distributed coordination and communication in vehicle systems [26]. In addition, a middleware architecture for producing traffic related data for traffic operations and safety was developed [27]. This data can be collected from a mobile sensor network comprised of

vehicles and intersections. The developed architecture reduces the complexities of the heterogeneous communication layer and data sources by providing a uniform interface to collect data from the sensors. It also provides a geo-spatial query interface that allows locating the sensors.

V. CONCLUSIONS

IVC communication is rapidly becoming a very important area of research due to the considerable advancements in in-vehicle computing and processing capabilities as well as the significant improvement in the capacity of mobile and wireless communication systems. In this paper, a survey of IVC systems was presented. It included two categories of communication: V2V and V2I. The latest IVC projects were offered along with a description of the features and services that are supported by each one. In addition, a discussion of the current research in each layer of the networking stack was presented along with motivations to address some of the important open issues and future research challenges in this area. IVC systems are expected to play a powerful role in providing safer and more convenient driving as well as greatly contribute to reaching the goal of "computing anytime anywhere" of today's society. A good amount of research has been done in this field. However, a lot more is still needed to tackle the characteristic and distinctive challenges that IVC systems offer at each layer of the networking model.

REFERENCES

- [1] W. Franz, H. Hartenstein, and B. Bochow, "Internet on the road via inter-vehicle communications," *In Proc. GI/OCG Annual Conference: Workshop on Mobile Communications over Wireless LAN: Research and Applications*, Vienna, September 2001.
- [2] J. Luo and J.-P. Hubaux, "A survey of inter-vehicle communication," *Technical Report IC/2004/24, EPFL, Lausanne, Switzerland*, 2004.
- [3] A. Bohm, "State-of-the-art on network layer aspects for inter-vehicle communication," *Technical Report IDE0748, Halmstad University, Sweden*, June 2007.
- [4] I. Jawhar and J. Wu, "Qos support in tdma-based mobile ad hoc networks," *The Journal of Computer Science and Technology (JCST)*, Springer, vol. 20, no. 6, pp. 797–910, November 2005.
- [5] I. Jawhar and J. Wu, "Quality of service routing in mobile ad hoc networks," *Resource Management in Wireless Networking*, M. Cardei, I. Cardei, and D. -Z. Du (eds.), Springer, Network Theory and Applications, vol. 16, pp. 365–400, 2005.
- [6] P. Krishnamurthy, "Information dissemination and information assurance in vehicular networks: *Proc. iConference '08, Los Angeles*, February 2008.
- [7] L. Uichin and M. Gerla, "A survey of urban vehicular sensing platforms," *Computer Networks*, *In Press, Corrected Proof*, 2009.
- [8] M. Bechler, W.J. Fraz, and L. Wold, "Mobile internet access in FleetNet," *In 13. Fachtagung Kommunikation in verteilten Systemen*, 2001.
- [9] A. Festag, H. Fubler, H. Hartenstein, A. Sarma, and R. Schmitz, "FleetNet: Bringing car-to-car communication into the real world," *In Proc. ITS World Congress*, 2004.
- [10] "FleetNet inter-vehicular communication," <http://www.et2.tu-harburg.de/fleetnet/english/about.html>.
- [11] A. P. Subramanian, V. Navda, P. Deshpande, and S. R. Das, "A measurement study of inter-vehicular communication using steerable beam directional antenna," *Proc. ACM Int. Workshop on Vehicular Inter-Networking (VANET) San Francisco, CA*, September 2008.
- [12] J. OISHI, K. ASAKURA, and T. WATANABE, "A communication model for inter-vehicle communication simulation systems based on properties of urban areas," *IJCSNS International Journal of Computer Science and Network Security*, vol. 6, no. 10, October 2006.
- [13] Y. Khaled, B. Ducourthial, and M. Shawky, "Ieee 802.11 performances for inter-vehicle communication networks," *Vehicular Technology Conference, 2005. VTC 2005-Spring. 2005 IEEE 61st*, vol. 5, pp. 2925–2929, May 2005.
- [14] E. Fasolo, R. Furiato, and A. Zanella, "Smart broadcast algorithm for inter-vehicular communication," *IWS 2005 / WPMC'05 - Aalborg, Denmark*, pp. 1583–1587, September 2005.
- [15] D. Choffnes and F. E. Bustamante, "Exploiting emergent behavior for inter-vehicle communication," *In HotAC II: Hot Topics in Autonomic Computing on Hot Topics in Autonomic Computing, Berkeley, CA, USA, 2007. USENIX Association*.
- [16] J. Tian, L. Han, and K. Rothermel, "Spatially aware packet routing for mobile ad hoc inter-vehicle radio networks," *Intelligent Transportation Systems Proceedings. 2003 IEEE*, vol. 2, pp. 1546–1551, October 2003.
- [17] R. Kates, H. Belzner, A. Hochstaedter, and G. Lerner, "Flow stabilization and enhanced traffic performance using inter-vehicle communication and distributed intelligence," http://www.bmwgroup.com/bmwgroup_prod/publikationen/d/2003/pdf/ITS_London_VLA.en.2003.pdf.
- [18] Thomas Strang, Michael Meyer zu Hrste, and Xiaogang Gu, "A railway collision avoidance system exploiting ad-hoc inter-vehicle communications and galileo," *In: Proceedings, 13th World Congress and Exhibition on Intelligent Transportation Systems and Services (ITS 2006)*, London, UK, October 2006.
- [19] X. Yang, J. Liu, F. Zhao, and N. H. Vaidya, "A vehicle-to-vehicle communication protocol for cooperative collision warning," *Mobile and Ubiquitous Systems, the First Annual International Conference on In Mobile and Ubiquitous Systems: Networking and Services, 2004. MOBIQUITOUS 2004*, vol. 0, pp. 114–123, 2004.
- [20] P. Papadimitratos, L. Buttyan, T. Holczer, E. Schoch, J. Freudiger, M. Raya, Z. Ma, F. Kargl, A. Kung, and J.-P. Hubaux, "Secure vehicular communication systems: design and architecture," *IEEE Communications Magazine*, vol. 46, no. 11, pp. 100–109, 2008.
- [21] F. Dressler, C. Sommer, T. Gansen, and L. Wischhof, "Requirements and objectives for secure traffic information systems," *Proc. of the 5th IEEE Int. Conf. on Mobile Ad Hoc and Sensor Systems (MASS'08)*, 2008.
- [22] I. Jawhar and N. Mohamed, "A hierarchical and topological classification of linear sensor networks," *The Eighth Annual Wireless Telecommunications Symposium (WTS 2009), IEEE Communication Society, Prague, Czech Republic*, April 2009.
- [23] B. Hughes, R. Meier, R. Cunningham, and V. Cahill, "Towards real-time middleware for vehicular ad hoc networks," *Proceedings of the 1st ACM international workshop on Vehicular ad hoc networks*, pp. 95–96, 2004.
- [24] E. R. B. Marques, G. M. Goncalves, and J. B. Sousa, "Seaware: A publish/subscribe communications middleware for networked vehicle systems," *7th IFAC Conference on Manoeuvring and Control of Marine Craft (MCMC'06)*, 2006 2006.
- [25] S. Liu and L. Cheng, "A context-aware reflective middleware framework for adaptive real-time vehicle applications," *Technical Report LUCSE-09-001, Department of Computer Science and Engineering, Lehigh University*, 2009.
- [26] J. Guo and G. Xing, "Using mobile agent-based middleware to support distributed coordination for vehicle telematics," *21st International Conference on Advanced Information Networking and Applications Workshops (AINAW'07)*, 2006.
- [27] C. Manasseh and R. Sengupta, "Middleware for cooperative vehicle-infrastructure systems," *California PATH Research Report UCB-ITS-PRR-2008-2, Institute of Transportation Studies, University of California, Berkeley*, January 2008.
- [28] L. Wischhof, A. Ebner, H. Rohling, M. Lott, and R. Half-mann, "SOTIS: A self-organizing traffic information system," *(VTC2003-Spring)*, Jeju, South Korea, April 2003.
- [29] I. Jawhar, N. Mohamed, K. Shuaib, and N. Kesserwan, "An efficient framework and networking protocol for sensor networks," *The Ad Hoc & Sensor Wireless Networks Journal, Old City Publishing, London, Networks*, vol. 7, no. 1-2, 2009.
- [30] S. Hadim, J. Al-Jaroodi, and N. Mohamed, "Middleware issues in *proc. of IEEE Consumer Communications and Networking Conference (CCNC 2006)*, Las Vegas, Nevada, January 2006.