Vehicular Communications Networks: Current Trends and Challenges

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Chapter accepted to

Handbook of research on Next Generation Networks and Ubiquitous Computing

A book edited by:

Samuel PIERRE

ABSTRACT

Vehicular communications networks (VCNs) are created by vehicles equipped with short and medium range wireless communication technology. They include vehicular ad-hoc networks (VANETs), vehicle-to-vehicle and vehicle-to-infrastructure communications. VCNs enable a plethora of important applications and services, ranging from active safety or safety of life applications to traffic information, music/maps download and multi-hop internet connection.

Recently, the promises of wireless communications to support vehicular safety applications have led to several national/international projects around the world. These include the consortia like Vehicle Safety Consortium (US), Car-2-Car Communication Consortium (Europe) and Advanced Safety Vehicle Program (Japan), standardization efforts like IEEE 802.11p (WAVE), and field trials like the large-scale Vehicle Infrastructure Integration Program (VII) in the US. All these efforts have as a main goal to improve safety in vehicular environments by the use of wireless communications, but also consider transport efficiency, comfort and environment.

In comparison to other communication networks, VCNs come with unique attractive features: unlimited transmission power, predictable mobility and plethora of potential applications. However, to bring its potency to fruition, VCNs have to cope with formidable challenges that include: rapidly changing topology subject to frequent fragmentations and congestions, lack of connectivity redundancy, and the stringent application requirement on real-time and robust message delivery.

In this chapter, we present a detailed description of the state of the art of this fast-moving research area pointing to research, projects and standardization efforts that have been done. We explore the unique features and challenges that characterise these highly dynamic networks as well as their requirements with respect to applications, types of communication, self-organization and security. We discuss various forwarding and routing strategies focussing on position-based techniques including ‘anchor-based routing'. We survey various ‘intelligent flooding’ and information dissemination approaches. Scenarios for highways and cities are taken as example. We conclude by exploring future research directions in this field.

INTRODUCTION

Road safety has been an important concern in the world over the past few years since millions of people die every year because of car accidents and many more are injured. Current statistics show that road traffic accidents in the Member States of the European Union annually claim about 39000 lives and leave more than 1.7 million people injured, representing an estimated cost of 160 billion euros (http://europa.eu.int/comm/transport/care/index en.htm).

Automated highway systems and intelligent transportation systems (ITS) were introduced to accelerate the development and use of intelligent integrated safety systems that use information and communication technologies as an intelligent solution, in order to increase road safety and reduce the number of accidents in our future roads. In contrast, as mobile wireless devices became an essential part of our lives, and the ubiquitous 'anywhere, anytime' connectivity concept is gaining attraction, Internet access from vehicles is in great demand. The proliferation of cooperated system approach for ITS and the focus on information and communications technologies (ICT) services on one hand and the growing number of communication infrastructure-enabled vehicles on the other hand has opened up new business models and key market segments for many stakeholders in the ITS-market.

Vehicular Communication Networks (VCNs) are a cornerstone of the envisioned Intelligent Transportation Systems (ITS). By enabling vehicles to communicate with each other via Inter-Vehicle Communication (IVC) as well as with roadside base stations via Roadside-to-Vehicle Communication (RVC), vehicular networks could contribute to safer and more efficient roads.

The opportunities and areas of applications of VCNs are growing rapidly, with many vehicle manufacturers and private institutes actively supporting research and development in this field. The integration with on-board sensor systems, and the progressive diffusion of on-board localization systems (GPS) make VCNs suitable for the development of active safety applications, including collision and warning systems, driver assistant and intelligent traffic management systems. On the other hand, inter-vehicular communication (IVC) also fuels the vast opportunities in online vehicle entertainment (such as gaming or file sharing), and enables the integration with Internet services and applications (Nandan et all., 2004).

In this chapter, we present a detailed description of the state of the art of this fast-moving research area pointing to research, projects and standardization efforts that have been done. We explore the unique features and challenges that characterise these highly dynamic networks as well as their requirements, especially in terms of quality of service, market introduction and security. We discuss various forwarding and routing strategies focussing on position-based techniques including ‘anchor-based routing'. We survey various ‘intelligent flooding’ and information dissemination approaches. We conclude by exploring future research directions in this field.

STATE OF THE ART OF VCNS: HISTORY, RECENT PROJECTS & STANDARDIZATION EFFORTS

History

The earliest research into inter-vehicular communications was conducted by JSK (Association of Electronic Technology for Automobile Traffic and Driving) of Japan in the early 1980s (Tsugawa, 2005). This work treated inter-vehicular communications primarily as traffic and driver information systems incorporated in ATMS (Asynchronous Transfer Mode).

From the 1990s through 2000, American PATH (Hedrick et al., 1994) and European "Chaffeur" (Gehring et al., 1997) projects investigated and deployed automated platooning systems through the transmission of data among vehicles.

Recently, the promises of wireless communications to support vehicular safety applications have led to several national/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 inter-vehicle communication.

The IST European Project CarTALK2000 (www.cartalk2000.net) was focusing on new driver assistance systems which are based upon inter-vehicle communication. The main objectives were the development of co-operative driver assistance systems and the development of a self-organising ad-hoc radio network as a communication basis with the aim of preparing a future standard;

The FleetNet project in Germany (FleetNet project- Internet on the road, http://www.et2.tuharburg.de/fleetnet), supported by six manufacturers and three universities from the 2000 though 2003, produced important results on several research areas, including the experimental characterization of VANETs, the proposal of novel network protocols (MAC, routing) and the exploration of different wireless technologies.

Ongoing projects

Many activities in research, development and standardization of vehicular communication are currently ongoing:

In Europe, major R&D projects have been initiated to constitute the basis of a European-wide intelligent transportation system, for example Now, COMeSafety, CVIS, SafeSpot, COOPERS, GST and GeoNet.

- NoW (Network-on-Wheels, www.network-on-wheels.de) – Network on Wheels is a German project, successor of the project Fleetnet–Internet on the Road, 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 non-safety applications (such as car-to-home applications).

- CVIS (Cooperative Vehicle Infrastructure Systems, www.cvisproject.org/) aims at developing a communication system that is capable to use a wide range of wireless technologies, including cellular networks (GPRS, UMTS), wireless local area networks (WLAN), short-range microwave beacons (DSRC) and infra-red (IR). Access to these wireless technologies is based on the new international "CALM" standard that allows future vehicular networking implementation to be integrated to 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 that is necessary for co-operative transport management.

- SAFESPOT (Cooperative vehicles and road infrastructure for road safety, www.safespot-eu.org/) addresses co-operative systems for road safety, referred to as "smart vehicles on smart roads" to prevent road accidents 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 (Co-operative Systems for Intelligent Road Safety, www.coopers-ip.eu/) focuses on the development of innovative telematics applications on the road infrastructure with the long term goal of a "co-operative 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.

- GST (Global Systems for Telematics, www.gstforum.org/) 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.

- The EU project GeoNet (www.geonet-project.eu/), started in February 2008, 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.

Similar activities can be identified all over the world, such as the Vehicle-Infrastructure Initiative (VII) (www.vehicle-infrastructure.org/) in North America as well as Vehicle Information and Communication System (VICS) (www.vics.or.jp/) in Japan and ITSIndia (Intelligent Transport System India, www.itsindia.org/) in India.

- The Vehicle Infrastructure Integration (VII) (www.vehicle-infrastructure.org/) Initiative is a cooperative effort between Federal and State departments of transportation (DOT's) and automobile manufacturers. Together they are evaluating the technical, economic, and social/political feasibility of deploying a communication system that will be used primarily for improving the safety and efficiency of the nation's road transportation system. Additionally, VII will enable the deployment of a variety of applications that support private interests, including those of vehicle manufacturers. It is supported by a radio spectrum at 5.9 GHz, specifically allocated for DSRC (Dedicated Short Range Communications, www.leearmstrong.com/DSRC/DSRCHomeset.htm).

Standardization efforts

Standardization of vehicular communication is now being pushed by established work groups of major standardization bodies (IEEE, IETF, ETSI, ISO, SAE, ASTM) and consortia such as Vehicular Safety Consortium (VSC), Car-to-Car Communication Consortium (C2C-CC):

- The Car-to-Car Communication Consortium (C2C-CC, www.car-to-car.org) is an industry consortium, initiated by European car makers. It attempts to create and establish an open European industry standard for car-to-car and car-to-infrastructure communication based on wireless LAN components and to guarantee European-wide inter-vehicle operability. The C2C-CC specifies prototypes and demonstrates vehicular communication and pushes the harmonization of vehicular communication standards worldwide.

- Over the last years a working group of the IEEE is defining a new communication standard, which shall be used for future inter-vehicular communication. This so-called IEEE 802.11p or Wireless Access in Vehicular Environments (WAVE, http://grouper.ieee.org/groups/scc32/dsrc/index.html) standard focuses on physical and link layers to provide the required robustness for Vehicular communications and shall be finalized in the near future.

- The ISO Technical Committee 204, Work Group 16 (ISO TC204 WG16) develops a set of standards referred to as 'Continuous Air-interface for Long & Medium range telecommunications (CALM, www.calm.hu/). The CALM concept assumes that systems that future vehicles will be equipped with more than one wireless technology. CALM offers a set of protocol standards that will allow to route data over the most wireless technology that is available at that time, based upon knowledge of the QoS requirements for that application and the real-time performance of the available communications media.

MAIN CHARCACTERISTICS AND CHALLENGES OF VCNS

Characteristics of VCNs

In comparison to other communication networks, VCNs come with unique attractive features (Nekovee, 2005) :

Sufficient energy and storage. A common characteristic of nodes in vehicular networks is that nodes have ample energy and computing power (including both storage and processing), since nodes are cars instead of small handheld devices.

Higher computational capability. Operating vehicles can afford significant computing, communication and sensing capabilities.

Predictable mobility. Unlike general mobile ad hoc networks, where it is hard to predict the nodes' mobility, vehicles can have very predictable movement that is (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, VCNs have to cope with formidable challenges (Blum and al., 2004) that include:

Potentially large scale. Unlike most of the ad hoc networks studied in the literature that usually assume a limited area, VCNs can in principle extend over the entire road network and include many participants.

High mobility. The environment in which vehicular networks operate is extremely dynamic, and includes extreme configurations: in highways, relative speed of up to 300 km/h may occur, while density of nodes may be 1-2 vehicles per kilometer in low busy roads.

Highly dynamic topology. Due to high speed of movement between vehicles, the topology of vehicular networks is always changing. For example, assume that the wireless transmission range of each vehicle is 250 m, so that there is a link between two cars if the distance between them is less than 250 m. In the worst case, if two cars with the speed of 60 mph (25 m/sec) are driving in opposite directions, the link will last only for at most 10 sec.

Frequently disconnected network. Due to the same reason, the connectivity of the vehicular networks could also be changed frequently. Especially when the vehicle density is low, it has higher probability that the network is disconnected. In some applications, such as ubiquitous Internet access, the problem needs to be solved. However, one possible solution is to pre-deploy several relay nodes or access points along the road to keep the connectivity.

Various communications environments. Vehicular networks are usually operated in two typical communications environments. In highway traffic scenarios, the environment is relatively simple and straightforward (e.g., constrained one-dimensional movement); while in city conditions it becomes much more complex. The streets in a city are often separated by buildings, trees and other obstacles. Therefore, there isn't always a direct line of communications in the direction of intended data communication.

Main challenges of VCNs

VCNs enable a plethora of important applications and services, ranging from active safety or safety of life applications to traffic information, music/maps download and multi-hop internet connection. In spite of these numerous value-added application scenarios, VCNs come with their own set of requirements, especially in the aspects of quality of service, market introduction and security:

- **Quality of service**

Applications envisioned for vehicular networks require fast association and low communication latency between communicating vehicles in order to guarantee: i) service's reliability for safety-related applications while taking into consideration the time-sensitivity during messages' transfer, and ii) the quality and continuity of service for passenger's oriented applications.

- **Market introduction - Technology penetration**

Services and applications which are based on vehicle-to-vehicle communication and do not involve any infrastructure only provide value to the customer in case a sufficient penetration rate of equipped vehicles has been reached. For this reason, car manufacturers have to think about gradual market introduction strategies. Right from the start, car manufactures need to offer attractive infrastructure-based services (e.g. car-to-home data exchange, car-to-garage communications for remote diagnosis or Location Based Services) which provide clear customer benefit and motivate drivers to invest in additional wireless equipment for their vehicles. Eventually, after a longer period of time – it is expected that this process will take up to 10 years – high enough penetration rates can be reached to allow for purely ad-hoc vehicular communication services such as intersection collision warning, local danger warning, and the decentralized dissemination of real-time traffic flow information.

- **Security**

Security is a crucial aspect in VCNs in order to become a reliable and accepted system bringing safety on public roads (Hubaux et al., 2004). Vehicular communication and its services will only be a success and accepted by the customers if a high level of reliability and security can be provided. This includes authenticity, message integrity and source authentication, privacy, and robustness. A model of possible attacks on inter-vehicle communication systems is presented in (Aijaz et al., 2005); the threat model considers four groups of attacks (attacks on car to infrastructure applications, on cars to home applications, on car to car traffic applications, and on car to routing protocols), and defines a set of guidelines which have been used for the proposal of a novel security framework (called VaneSe) (Gerlach, 2005).

Technologically, many different aspects of vehicular communication still need ideas and results from research. They include high performance and efficient physical layer transmission schemes, fair and scalable medium access (MAC) schemes, efficient data dissemination protocols, routing protocols, to name the most critical ones. Some selected research aspects will be presented in the following section.

ROUTING AND INFORMATION DISSEMINATION: CHALLENGES AND SOLUTIONS

Fast and reliable communication between cars (vehicle-to-vehicle) and/or between a car and a road side unit (vehicle-to-infrastructure) are essential for future vehicle alert systems. From a network perspective, this means that messages have to be routed from the information source to one or several destinations without too much administrative overhead and delay.

The unique properties of vehicular networks that we discussed earlier have an impact on designing new network protocols for vehicular communication. In this section, we present the challenges and the most important proposed solutions on unicast routing and data dissemination.

Unicast Routing:

As we have shown in the previous section, VCNs are characterized by : (i) a dynamic, rapidly changing topology (due to high mobility); (ii) frequent network fragmentations into isolated clusters; (iii) constrained, largely one/two dimensional movement due to the static topology of streets within the city or highway environment.

These three characteristics significantly degrade the performance of conventional topology based routing protocols designed for mobile ad hoc networks: Neither proactive nor reactive protocols, currently exploited in a MANET environment, are suitable for the VCN, as reported in (Jaap et all., 2005). This is due to packet control overhead (route discovery, route maintenance, etc.) caused by the frequent update of routing information of the whole network, route failures and transient nature of links.

The frequently changing topology suggests that a local routing scheme without the need to keep track of global routing information scales better in VCNs and consumes lower wireless bandwidth. In addition, the popularity of the Global Positioning System (GPS) also makes position-based routing, which maintains only local information about the node's position, a popular routing strategy.

Recently, some position-based routing protocols specific to VCNs have been proposed. In the following, we present the most important ones: GSR, A-STAR, VADD, GVGrid , GYTAR and CAR:

- **'GSR'** (Lochert et all., 2003) (Geographic Source Routing) has been recently proposed as a promising routing strategy for vehicular ad hoc networks in city environments. It combines position-based routing with topological knowledge by computing the sequence of junctions that must be traversed by each packet to reach its destination; this information is then included in the packet in the form of geographic source routing.

- **'A-STAR'** (Seet et all, 2004) (Anchor-based Street and Traffic Aware Routing) is a position-based routing scheme designed specifically for vehicular ad hoc networks in city environments. It features the novel use of city bus route information to identify anchor paths of higher connectivity so that more packets can be delivered to their destinations successfully.

- **'GYTAR'** (Jerbi et all., 2007) (improved GreedY Traffic-Aware Routing) is also an intersection-based routing scheme. GyTAR consists of two modules: (i) dynamic selection of the junctions through which packets must pass to reach their destinations, and (ii) an improved greedy strategy used to forward packets between junctions.

- **'VADD'** (Zhao et all., 2006) (Vehicle-Assisted Data Delivery) is a recent example of vehicular routing that exploits the availability of map information. This routing protocol, aimed at sparsely connected vehicular networks, uses a store and forward technique and approaches the destination by selecting the direction with the lowest estimated delay to the destination. The forwarding algorithm selects the next hop by choosing either the neighbour that is nearest to the destination (which may lead to routing loops), or a neighbour that is approaching the target location.

- **'GVGrid'** (Sun et all., 2006) is a QoS based VANET routing protocol which exploits geographic information. It divides a geographical area into grids and forwards packets along the roads crossing different grids. Nodes toward the same direction are preferred.

- **'CAR'** (Naumov et all., 2007) Like other position-based vehicular routing protocols, the Connectivity-Aware Routing (CAR) protocol finds a route to a destination, but a unique characteristic of CAR is its ability to maintain a cache of successful routes between various source and destination pairs. This characteristic was prompted by observations of other position-based routing protocols and their inability to utilize information gathered about disconnected paths (due to unoccupied streets, for instance) after those disconnections are detected. CAR also predicts positions of destination vehicles, repairs routes as those positions change, and employs geographic marker messages.

Information Dissemination

When a message is disseminated to locations beyond the transmission range, multi-hopping is used. This is, however, a difficult task due to the highly dynamic nature of inter-vehicle networks which results in their frequent fragmentation into disconnected clusters [as mentioned in section 2]. Apart from interference, packet collisions, and hidden nodes which can stop the message dissemination during multi-hop broadcast. Moreover, multi-hop broadcast can consume significant amount of wireless resources because of unnecessary retransmissions. These facts make designing efficient and reliable multi-hop message dissemination a highly complicated task.

There has been considerable research in designing reliable and bandwidth efficient data dissemination protocols in VCNs. The following mechanisms represent general approaches for information dissemination in VCNs with regard to safety applications:

- **Vehicle-to-vehicle location-based broadcast (LBB)** (Xu et all., 2003) is a routing protocol for highway safety communication. It addresses the problem of message lifetime and repeated message broadcasts. The safety application has to assign a reasonable lifetime to a message. The message is only broadcasted during its lifetime and is dropped afterwards.

- **Cluster-based information propagation scheme** (Little et all., 2005) assumes that vehicles tend to travel in consecutive blocks that are separated by gaps. Thus, a directional propagation protocol (DPP) is suggested, which consists of three components: a custody transfer protocol (CTP), an inter-cluster routing protocol that controls communication within a cluster, and an intra-cluster routing protocol that controls the communication between clusters.

- **Optimized dissemination of alarm messages in vehicular ad hoc networks** (Benslimane, 2004) works by restricting rebroadcasts to certain vehicles. In addition, messages are only re-broadcasted in so called risk zones. The approach also suggests an algorithm for calculation of retransmission periods for the message originator that represents the danger (e.g. due to a vehicle breakdown).

The mechanisms below are specially designed for information dissemination in VCNs without special regard to safety applications:

- **UMB** (Korkmaz et al., 2004) is an IEEE 802.11 based Urban Multi-hop Broadcast protocol (UMB) for inter-vehicle communication. This is composed of directional and intersection broadcast. In the directional broadcast, a vehicle source node selects a furthest node on a road segment to be the forwarding vehicle node. This acknowledges in turn a packet received from the source to confirm its role as a next relay vehicle node. When vehicles arrive at an intersection, then intersection broadcast operates to send packets in each road segment constitutes this intersection.

- **SODAD** (Wischhof et al., 2005) is a method for scalable information dissemination in highly mobile VANETs. The method focuses on comfort applications like weather or traffic information systems. Although a variety of optimizations is possible, the basic idea of such a dissemination scheme is that every node maintains a knowledge base, where it stores known information, e. g., on road conditions or parking lot occupancies. The nodes periodically broadcast all or parts of their knowledge to their neighbors. Upon reception, the nodes integrate new or updated information into their knowledge base. Step by step a local overview of the total scenario emerges.

- **Abiding geocast** (Maihöfer et al., 2005) is a special geocast, where the packets need to delivered to all nodes that are sometime during the geocast lifetime (a certain period of time) inside the geocast destination region. The authors provided three solutions: (i) a server is used to store the geocast messages; (ii) an elected node inside the geocast region stores the messages; (iii) each node stores all geocast packets destined for its location and keeps the neighbor information.

CONCLUSION

Vehicular communication 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 kinds of service 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.

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. These solutions will be harmonized with other emerging worldwide standards that are related to the vehicular communications, such as IEEE 802.11, IEEE 1609, ISO TC 204 WG 16, selected IETF working groups and SAE.

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

REFERENCES

Aijaz A., Bochow, B. & alt (2005). Attacks on inter vehicle communication systems and analysis. Technical Report, NOW-Project.

Benslimane, A. (2004). Optimized Dissemination of Alarm Messages in Vehicular Ad-hoc Networks (VANET). *In Proceedings of the 7th IEEE International Conference*,Toulouse, France, June 2004.

Blum, J., Eskandarian, A. & Hoffmman, L. (2004) Challenges of intervehicle ad hoc networks, *IEEE Trans. Intelligent Transportation Systems*, Vol. 5, No 4, pp. 347-351.

Gehring, O., Fritz, H. (1997) Practical Results of a Longitudinal Control Concept for Truck Platooning with Vehicle to Vehicle Communication" *Proc. of the IEEE Conference on Intelligent Transportation Systems*, Boston, 1997.

Gerlach, M. (2005) VaneSe: an approach to VANET security", *in Proc. of V2VCOM 2005*, July 2005, San Diego, USA.

Hedrick, J., Tomizuka, M., and Varaiya, P. (1994) Control issues in automated highway systems, 1994.

Hubaux, J. P. et al. (2004) The security and privacy of smart vehicles, *IEEE Security & Privacy*, vol. 4, no. 3, pp. 49-55, May/June 2004.

Jaap, S., Bechler, M. and Woolf, L. (2005). Evaluation of Routing Protocols for Vehicular Ad Hoc Networks in City Trafic Scenarios", *in Proc. of EUNICE Open European Summer School on Networked Applications*, Colmenarejo, Spain, July 2005

Jerbi, M., Senouci, S., Meraihi,R. & Ghamri-Doudane, Y. (2007). An improved Vehicular Ad Hoc Routing Protocol for City Environments, *IEEE International Conference on Communications (ICC 07)*, Glasgow, Scotland, June 2007.

Korkmaz, G., Ekici, E., Özgüner, F. and Özgüner, Ü. (2004). Urban multihop broadcast protocol for inter-vehicle communication systems, *in VANET '04: Proceedings of the 1st ACM International Workshop on Vehicular Ad Hoc Networks.* Philadelphia, PA, USA: ACM Press, Sept. 2004, pp. 76–85.

Little, T.D.C. and Agarwal, A. (2005). An Information Propagation Scheme for VANETs. MCL Technical Report 07-01-2005, Department of Electrical and Computer Engineering, Boston University, Boston, USA, July 2005.

Lochert, C., Hartenstein, H., Tian, J., Herrmann, D., Füßler, H. & Mauve, M. (2003). A Routing Strategy for Vehicular Ad Hoc Networks in City Environments, *IEEE Intelligent Vehicles Symposium (IV2003*), pp. 156-161, Columbus, OH, USA, June 2003.

Maihöfer, C., Leinmüller, T., and Schoch, E. (2005) Abiding geocast: time-stable geocast for ad hoc networks," *in Proceedings of the 2nd ACM international workshop on Vehicular ad hoc networks (VANET '05)*, pp. 20–29, 2005.

Nandan A., Das S., Pau G., Mario Gerla, & Sanadidi, M.Y. (2004) Co-operative Downloading in Vehicular Ad-Hoc Wireless Networks, UCLA CS Technical Report October.

Naumov, V., and Gross , T. (2007) Connectivity-aware routing (car) in vehicular ad-hoc networks, *in INFOCOM 2007. 26th IEEE International Conference on Computer Communications*. IEEE. May 2007, pp. 1919–1927, IEEE.

Nekovee, M. (2005) Sensor networks on the road: the promises and challenges of vehicular adhoc networks and vehicular grids, *in Proc. of the Workshop on Ubiquitous Computing and e-Research*, Edinburgh, UK, May 2005.

Seet, B.-C., Liu, G., Lee, B.-S., Foh, C. H., Wong, K. J. & Lee, K.-K. (2004). A-STAR: A Mobile Ad Hoc Routing Strategy for Metropolis Vehicular Communications. *NETWORKING 2004*, 989-999.

Sun, W., Yamaguchi, H., Yukimasa, K. and Kusumoto, S. (2006). GVGrid: A QoS Routing Protocol for Vehicular Ad Hoc Networks. *Proc. of IEEE International Workshop on Quality of Service 2006*, 2006.

Tsugawa, S. (2005). Issues and recent trends in vehicle safety communication systems. IATSS. Research, *Journal of international association of traffic and safety sciences*, Vol.29 No.1 2005

Wischhof, L., Ebner, A. and Rohling, H. (2005). Information Dissemination in Self-organizing Intervehicle Networks. *IEEE Transactions on Intelligent Transportation Systems*, 6(1):90–101, March 2005.

Wu, H., Fujimoto, R., Guensler, R. and Hunter, M. (2004). Analytical models for information propagation in vehicle-to-vehicle networks, *Proc. IEEE VTC 2004*, Los Angles, USA, September 2004, pp. 4548-4552.

Xu, Q., Sengupta, R., and Jiang, D. (2003). Design and Analysis of Highway Safety Communication Protocol in 5.9 GHz Dedicated Short Range Communication Spectrum. *In Proceedings of the IEEE Vehicular Technology Conference (VTC 2003-Spring)*, volume 4, pages 2451– 2455, April 2003

Zhao, J. and Cao. G. (2006). VADD: Vehicle-assisted data delivery in vehicular ad hoc networks. *In Proceedings of the 25th Conference on Computer Communications (INFOCOM06)*, 2006.

KEY TERMS AND THEIR DEFINITIONS

1. **Vehicular Communication Network (VCN):** is a form of network created by vehicles equipped with short and medium range wireless communication technology. It includes vehicular ad-hoc networks (VANETs), vehicle-to-vehicle, vehicle-to-infrastructure and vehicle-to-pedestrian communications.
2. **Vehicular Ad-hoc Network (VANET)**: is a form of Mobile ad-hoc network (MANET), to provide communications among nearby vehicles.
3. **Mobile Ad-hoc Network (MANET)**: is a type of ad hoc network that can change locations and configure itself on the fly.
4. **Vehicle-to-vehicle communication (V2V)**: wireless communication between two vehicles equipped with short and medium range wireless communication capabilities (it is also termed as car-to-car communication).
5. **Vehicle-to-infrastructure communication (V2I)**: wireless communication between a vehicle and an infrastructure (also termed as vehicle-to-roadside).
6. **Wireless Local Area Network (WLAN)**: is one in which a mobile user can connect to a local area network (LAN) through a wireless (radio) connection.
7. The **IEEE 802.11:** is a group of standards that specify the technologies for wireless LANs
8. **Dedicated Short Range Communication (DSRC)**: is a short to medium range wireless protocol specifically designed for automotive use.
9. The **Intelligent Transportation Systems (ITS)** program: is a worldwide initiative to add information and communications technology to transport infrastructure and vehicles.