Proceedings of the 20th International Conference on Automation & Computing, Cranfield University, Bedfordshire, UK, 12-13 September 2014

Vehicular Ad Hoc Networks (VANETs): Current State, Challenges, Potentials and Way Forward

Elias C. Eze, Sijing Zhang and Enjie Liu
Centre for Wireless Research,
Institute for Research in Applicable Computing (IRAC),
Department of Computer Science and Technology, University of Bedfordshire,
Luton, LU1 3JU,
England
elias.eze@study.beds.ac.uk
{sijing.zhang, enjie.liu}@beds.ac.uk

Abstract*— *Recent advances in wireless communication technologies and auto-mobile industry have triggered a significant research interest in the field of VANETs over the past few years. VANET consists of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications supported by wireless access technologies such as IEEE 802.11p. This innovation in wireless communication has been envisaged to improve road safety and motor traffic efficiency in near future through the development of Intelligent Transport Systems (ITS). Hence, government, auto-mobile industries and academia are heavily partnering through several ongoing research projects to establish standards for VANETs. The typical set of VANET application areas, such as vehicle collision warning and traffic information dissemination have made VANET an interested field of wireless communication. This paper provides an overview on current research state, challenges, potentials of VANETs as well the way forward to achieving the long awaited ITS.

Keywords- Vehicular communication, V2V, V2I, ITS, IEEE 802.11p, WAVE, IEEE 1609

I. INTRODUCTION

Road accidents has been on an alarming increase despite the introduction of several innovative in-vehicle safety-oriented devices such as anti-locking braking system (ABS), seatbelts, airbags, rear-view cameras, electronic stability control (ESC). Several studies have maintained that 60% of the accidents that occur on motorways could be avoided if warning messages were provided to the drivers just few seconds prior to moment of crash [1] [2].

The possibility of direct exchange of kinematic data between vehicles over an ad hoc network environment called a vehicular ad hoc network (VANET) has been widely perceived by governments, car manufacturing industries and academia as a promising concept for future realization of intelligent transportation system (ITS) thereby achieving safety and efficiency in our nearly overcrowded motorways. The VANET is a sub-class of MANET where the mobile nodes are vehicles. When compared with MANET and other cellular systems, inter-vehicle communication (IVC) has four major advantages: broad coverage area, relatively low latency due to direct wireless communication, little or no power issue as well as no service fees.

In the recent years, car manufacturing industries, academia and government agencies have started putting much joint efforts together towards realizing the concept of vehicular communications in wide scale. Some frameworks are already worked out with the first landmark of standardization processes made by US Federal Communications Communication (FCC) through the allocation of 75 MHz of dedicated short range communication (DSRC) spectrum [3] basically to accommodate V2V and V2I communications for safety-related applications. Potentials envisaged in VANETs have led to numerous vehicular communications research with their associated standardization projects in many countries across the world. These projects include DSRC development by Vehicle Safety Communications Consortium (VSCC) [4] (USA), European automotive industry project co-funded by the European Communication Commission (ECC) to foster road safety through the development and demonstration of preventive safety-related applications/technologies called PReVENT project [5] [6] (Europe), Internet ITS Consortium [7] and Advanced Safety Vehicle project [8] (Japan), Car-2-Car Communications Consortium (C2C-CC) [9], Vehicle Infrastructure Integration program (VII) [10], Secure Vehicle Communication (SeVeCOM) [11], and Network on Wheels project [12] (Germany). IEEE and ASTM adopted DSRC standard (ASTM E 2213-03) [13] also called Wireless Access in Vehicular Environment (WAVE) in 2003 in order to provide wireless communications for vehicles at normal highway speeds within the range of 1000m.

The rest of this paper is organized as follows. Section II presents a brief overview of VANET. Application of VANET is presented in Section III while the current VANET open research challenges and certain ideas on possible solutions are presented in Section IV. Final conclusion of this paper is presented in Section V.

II. OVERVIEW OF VANETS

In VANETs, participating vehicles are equipped with set of wireless sensors and On Board Units (OBUs) to allow for possibility of wireless communication between the vehicles and their environs. These devices make each vehicle function as packet sender, receiver and router which enable the vehicles send and receive messages to other vehicles or road side units (RSUs) within their reach via wireless medium. These sets of wireless sensors, OBUs or some typical radio interfaces enable vehicles form short-range wireless ad hoc networks to broadcast kinematic data to vehicular networks or transportation authorities/agencies which process and use the data to foster traffic efficiency and safety on the motorways [14]. VANET-enabled vehicles are fitted with the appropriate hardware which allows for acquisition and processing of location (or position) data such as those from global positioning system (GPS) or differential global positioning system (DGPS) receiver [15]. The fixed RSUs are connected to the backbone network and situated at strategic positions across the roads to aid effective, reliable and timely vehicular communications. RSUs are equipped with network devices to support dedicated short-range wireless communication using IEEE 802.11p radio technology. The possible vehicular communication configurations in intelligent transportation system (ITS) include vehicle-to-vehicle (or inter-vehicle), vehicle-to-infrastructure and routing-based (RB) communication (see Figure 1).

Vehicles can directly establish communication wirelessly with one another forming V2V communication or with fixed RSUs forming V2I communications. These vehicular communication configurations rely heavily on acquisition of accurate and up-to-date kinematic data of both the vehicles and the surrounding environment with the aid of positioning systems and intelligent wireless communication protocols and access technologies for reliable, efficient and timely information exchange. Considering the network environment of VANETs with unreliable, shared communication medium and limited bandwidth [16], smart cross-layer communication protocols are required to guarantee reliable and efficient delivery of data packets to all vehicles and infrastructures (RSUs) within the vehicles' radio signal transmission coverage.

III. VANET APPLICATIONS

The concept of equipping future vehicles with sets of wireless sensors, on-board units, GPS or DGPS receivers and network interfaces presents an ample opportunity to achieve intelligent transportation systems with wireless-enabled vehicles capable of sending and receiving kinematic data on the road. VANET is the bedrock upon which vehicles will be able to gather, process and distribute information both for safety-related and non-safety-related purposes on our motorways. Extensive areas of potential VANET applications have been listed and evaluated by several researchers through different projects and consortia. Typically, these applications are classified into either safety-related or non-safety-related applications.

A. Safety-Related VANET Applications

Safety-related VANET applications are classified into three basic categories, namely: driver assistance (co-operative collision avoidance, road navigation and lane changing), alert information (work zone and speed limit alert information) and warning alert (road obstacle, post-crash and other life-threatening traffic condition warning).The vehicular safety communications consortium has listed eight (8) potential safety-related applications [17]:pre-crash sensing, curve speed, lane-change, traffic signal violation, emergency electronic brake light and co-operative forward collision alert, stop sign movement and left turn assistant. Safety-related messages from these applications normally require direct communication owing to their stringent delay requirement. For instance, in the case of a sudden hard breaking or accident, the vehicles following those ones involved in accident as well as those in opposite direction will be sent a notification message.

Major road safety applications are the primary measures taken to reduce (or eliminate) the probability of traffic accidents and loss of life in our motorways [8] [18] [19]. The traffic accidents that occur annually across the globe are as a result of intersection, rear-end, head-on and lateral mobile vehicle collisions. The necessary precautionary measures (or traffic warning systems) required to implement and deploy this road safety applications alongside their required use-case, mode of communication, minimum transmission frequency and latency are summarized in Table I. These active road safety-related applications offer assistance to drivers through the provision of time-sensitive, life-saving traffic information which enables drivers avoid collisions with other vehicles on the road. This is achieved through the timely and reliable exchange of kinematic information amongst vehicles via V2V and amongst vehicles and other road infrastructures via V2I, which is processed to predict traffic accidents and collisions. This kinematic information contains the vehicle's current location, intersection position, speed, acceleration and direction of movement, to create the awareness of the presence of other vehicles on the road. Moreover, most of these life-critical messages in vehicular communications are broadcast-oriented, time-sensitive, life-saving, safety-related messages which must have deep penetration across the entire network and must be reliably delivered to the intended recipients within a short time.

TABLE I. DESCRIPTION OF SELECTED USE-CASES AND CORRESPONDING TECHNICAL REQUIREMENTS OF ROAD SAFETY-RELATED APPLICATIONS.

Use-case	***Mode of communication***	***Minimum transmission frequency***	***Required latency***
Intersection collision warning.	Periodic message broadcasting	Minimum frequency: 10Hz	Less than 100ms
Lane change Assistance	Co-operation awareness between vehicles	Minimum frequency: 10Hz	Less than 100ms
Overtaking vehicle warning	Broadcast of overtaking state	Minimum frequency: 10Hz	Less than 100ms
Head on collision warning	Broadcasting Messages	Minimum frequency: 10Hz	Less than 100ms
Co-operative forward collision warning	Co-operation awareness between vehicles associated to unicast	Minimum frequency: 10Hz	Less than 100ms
Emergency	Periodic	Minimum	Less than

vehicle warning	permanent message broadcasting	frequency: 10Hz	100ms
Co-operative merging assistance	Co-operation awareness between vehicles associated to unicast	Minimum frequency: 10Hz	Less than 100ms
Collision risk warning	Time limited periodic messages on event	Minimum frequency: 10Hz	Less than 100ms

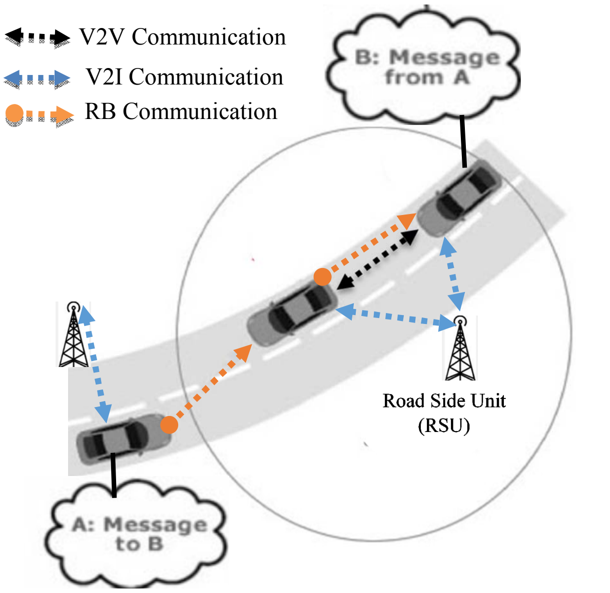

Figure 1. Possible Vehicular Communication Configurations in Intelligent Transportation Systems (ITS)

B. *Non-Safety-Related VANET Applications*

The non-safety-related applications of VANETs are also referred to as comfort or commercial applications. Typically, these applications aim to improve traffic efficiency, passenger comfort and commercial platforms in terms of advertisements and electronic toll collection (ETC). These applications include provision of weather information, current traffic and the ability to locate various Points of Interest (PoI) such as nearest parking lots, gas stations, shopping malls, hotels, fast food restaurants, etc. The owners of these aforementioned businesses can install some stationary gateways to transmit marketing adverts for the mobile customers travelling via the VANET enabled vehicles. The compelling argument in allowing comfort and commercial VANET applications is that of distraction and interference with safety-related applications thereby defeating the aim of improving safety and traffic efficiency in our motorways. Consequently, a possible solution would be achieved by using separate physical network channels for safety and non-safety applications or by applying traffic prioritization where safety-related messages are accorded higher priority than non-safety-related messages.

IV. OPEN RESEARCH CHALLENGES AND POSSIBLE SOLUTIONS FOR VEHICULAR NETWORKS

The current key research challenge of VANETs is the lack of central communication co-ordinator associated with all the existing wireless access technologies earmarked for VANET set-up, implementation and deployment. Deploying wireless communication in vehicular environment effectively requires that some intrinsic issues ranging from technical application development and deployment up to economic concerns must be resolved. Though VANET is a form of MANET, its behaviour and characteristics are fundamentally different. Some of the basic VANET research challenges that must be addressed to achieve effective vehicular communication are briefly discussed below.

A. *Comparison of High-Speed Wireless Communication Technologies for Vehicular Networks*

Many high-speed wireless access technologies and standards have been suggested, recommended and considered for use in VANET connectivity by many researchers [15] [17]. Some of the technologies and air interface protocols capable of supporting high-speed communication in vehicular environment which are currently being considered for VANETs include:

- *Cellular technology – (2G, 2.5G ...4G):* The 2G and 2.5G technologies provide reliable security and wide communication coverage while 3G and 4G technologies which are swiftly taking over offer highly improved communication capacity and bandwidth. In USA, Europe and Japan, many fleet and telematics projects are already using different generations of cellular technology [15]. However, the apparent high cost coupled with its high latency rate and limited bandwidth discourages its possible use as future communication base for VANETs.

- *Draft IEEE 802.11p based standards*: ASTM and IEEE-adopted draft is a variation of IEEE 802.11 family meant to support wireless communication in vehicular environment. This air interface protocol is a work-in-progress by IEEE Working Group that would provide inter-vehicle communication (IVC) and vehicle-to-roadside communication at vehicular speed ranging from 200 to 300km/h covering communication range of 1000m. The medium access control (MAC) and physical (PHY) layers are based on IEEE 802.11a. IEEE 802.11p technology is heavily promoted by vehicle manufacturing industries across the globe especially in USA through VII and VSCC, Japan through Advanced Safety Vehicle project (ASV), Europe through C2C-CC and Germany through SeVeCOM. Due to substantial production volumes, the estimated deployment cost of IEEE 802.11p is predicted to be relatively low when compared with cellular technology. Hence, this nascent technology also called WAVE has an edge over cellular technologies and fairly more suitable for VANETs.

- *Unified wireless access*: The International Standards Organization- technical committee (ISO-TC 204 WG16) has performed the most significant unification efforts of the various existing wireless access technologies. The product of the unification process is a vehicular communication standard called the Continuous Air Interface for Long and Medium range (CALM M5) [17]. CALM M5 combined several related air interface protocols and parameters, building on top of IEEE 802.11p architecture with support for cellular technologies as discussed earlier. These standards combined into single, uniform standard are expected to provide improved vehicular network performance through increased capacity, flexibility and redundancy in packet transmission and reception.

B. Spectrum Allocation Issues in VANETs

The Federal Communication Commission (FCC) of US allocates a spectrum of 75MHz at 5.9GHz (5.850 – 5.925GHz) for vehicular communications (V2V and V2I). Most of the ongoing ITS Projects and Consortia (VII and VSC) have already adopted the derivative of IEEE 802.11 family of standards as the best suitable wireless access technology for communication systems using this spectrum [15]. Hence, the development of IEEE 802.11p and unification by ISO TC 204 WG16 as discussed in the sub-section above.

In Europe, the distributed short range communication (DSRC) band does not have a continuous spectrum of 75MHz as is the case in US. However, the C2C-CC of Europe has proposed an approach similar to US approach which allocates two 10MHz specifically for vehicular safety-related communications at 5.9GHz (5.875 – 5.925GHz). The allocation of this band in Europe provided a sort of global harmonization given that the same band is used in US as control channel. Use of supplementary spectrum could be supported by this technology for non-safety-related (comfort and commercial) applications in several other bands such as 5GHz RLAN or 5.8GHz IRM band [18].

At the moment, 5.9GHz band is allocated for stationary satellite services and military radar systems. However, the Short Range Device Maintenance Group (SRD/MG) of European Conference of Postal and Telecommunications Administrations (CEPT) and Electronic Communication Commission (ECC) has recommended the alignment of the first 10MHz control channel (5.885 – 5.895GHz) with the US FCC approach while the other half of the channel (10MHz) in ISM band range of 5.865GHz to 5.875GHz be used for radio location services below 5.85GHz [17].

C. Message Braodcasting in Vehicular Networks

The envisaged VANET applications require transmission, gathering and processing of large volume of electronic messages/data packets. Message broadcasting has been seen as an attractive alternative solution by automotive wireless networking researchers partly as a result of its low-cost and partly due to its support for vast potential volumes of data packets. Hence, several broadcasting techniques and mechanisms have been taken into consideration by many researchers. These techniques include restricted and unrestricted bandwidth digital service solutions as well as satellite broadcasting solution which has already incorporated real time traffic data services [20].

Broadcasting techniques are associated with *broadcast storm* problem. This problem could be reduced or eliminated by reducing the message broadcast range specifically to the site of interest thereby reducing the unnecessary network overhead. This concept is called location-aware broadcasting. Another approach that has emerged as a promising solution is *clustering* approach where neighbouring mobile vehicles form clusters, manageable groups which limit the message broadcasting range. Several cluster-based VANETs broadcasting protocols have been proposed as is the case in [21] [22] [23].

D. VANETs Routing Protocols

Much research has been carried out on the suitability of MANET routing protocols in VANETs as well as several other research surveys [24] [25] [26] [27]. Contrarily, the frequent network partitioning (intermittent network connectivity) due to extremely dynamic topology and high mobility in VANET render MANET protocols unsuitable for vehicular communications. Moreover, the assumptions in MANET routing that end-to-end network connectivity can be established at all times, and that intermediate nodes between source and destination can always be found cannot hold in VANET. Hence, where the aforementioned assumptions do not hold in VANET, the *carry and forward* approach was proposed in [28] for VANETs whereby a moving vehicle continuously carry a data packet until it is forwarded to another vehicle closer to the destination(s) in absence of any direct route.

The challenging issue of packet routing in VANETs could be resolved if the three main categories of VANETs routing algorithm such as geographic, opportunistic and trajectory-based forwarding [15] could be combined with the concept of carry and forward mentioned above to realize an optimum VANET routing solution in order to reduce the end-to-end delay as well as the total number of dropped data packets during routing. Future task could be to carry out an extensive experiments and simulations with more refined parameters and extension of existing routing protocols so as to overcome the problems of possible long end-to-end delay and high rate of packet drop during vehicular communications without drastic increment in network overhead.

E. Power Control and Adjustment

Power management in the sense of energy efficiency is not an issue in VANETs as is the case with other evolving wireless technologies such as LTE due to the existence of installed batteries in the vehicles. However, power management in term of transmission (TX) power is a challenging issue that must be resolved to achieve effective vehicular communication. In a dense vehicular network, high TX power could lead to disruption of an ongoing transmission with another transmission at a distant vehicle as a result of interferences. Hence, reduced TX power should be used in a denser network to achieve reliable and efficient transmission.

Efficient routing could as well be achieved through proper adjustment of the TX power to increase the overall throughput and reduce interference occurrences. So far, very few algorithms have been proposed in this regard. One such algorithm proposed in [29] adjusts the TX power to limit the total number of transmitting neighbours within the maximum and minimum TX thresholds.

F. Security, Privacy, Anonymity and Liability

Security is one of the challenges that demands careful attention prior to designing and deployments of VANETs in our motorways. Several potential threats to vehicular communication system exist, ranging from fake (or fraudulent) messages capable of disrupting traffic or even causing danger to driver's privacy invasion. Frameworks must be worked out to enable vehicles receiving data packets from other vehicles (or network nodes) to be able to establish trust on the entities transmitting the packets while the privacy of the drivers are protected using anonymous node identities. Though, the major challenge of security and privacy in VANET is how to develop a security solution capable of supporting the tradeoff between authentication, liability, and privacy given that every vehicular information (both safety and non-safety related information) must be disclosed to appropriate governmental agencies (transport authority) by the network. However, such security solution must make vehicle identification or tracking impossible especially for non-trusted parties. In line with the above line-of-thought, SeVeCOM, as presented in [30] has provided a security architecture that is used as input for security related European Telecommunications Standards Institute (ETSI) [17] ITS WG5 and ISO CALM standards.

G. Reliability and Cross-Layer Approach between Transport Layer and Network Layer

Vehicle to vehicle (or inter-vehicle) communication network is associated with the problem of incessant network route break-up leading to erroneous message transmission due to the wireless nature of the VANET environment. This issue gives rise to the challenge of reliability in vehicular communication networks. Several error recovery techniques have been proposed and implemented over the years to achieve reliable transfer of packets in wireless communications with respect to vehicular communication systems. Traditional techniques such as Automatic Repeat reQuest (ARQ) [31] and Forward Error Correction (FEC) [32] could not yield the desired results in vehicular communication yet. ARQ can only be used to ensure reliability in point-to-point unicast communication. Unlike FEC that works with readily awaiting streams of packets, each vehicle creates packet periodically or automatically in the face of emergency and broadcast to other vehicles. Hence, the issue of broadcast communication reliability remains an open research challenge in the design and deployment of VANET. Consequently, for reliable and efficient vehicular communication networks to be achieved on top of the inherently unreliable wireless network, effective and competent loss packets recovery schemes are required. Designing cross-layer medium access control (MAC) that will span across network (routing) layer and transport layer to support real-time services and multimedia applications can be of immense benefit in vehicular communication networks.

V. CONCLUSIONS

VANET is no longer a remote feasibility, given that heavy investments are already in the pipeline from several sectors including government agencies, auto-mobile industries, navigation safety and public transport authorities. VANET potentials, areas of application and prospects are growing rapidly including several kinds of services with multiple requirements and goals. However, several unique, novel open research challenges ranging from wireless network evolution, reliable message dissemination to event detection are making research in VANETs very attractive.

Many key important topics in vehicular communication are currently under intensive research and discussion. These topical issues include potential modification, refinement, enhancement and implementation of IEEE 802.11p, wireless access in vehicular environment standard (WAVE), allocation of protected frequency band for mobile vehicular safety communication, integration (or unification) of different wireless technologies, congestion control, data security and transport, reliability in V2V communication and so on. The final step would be the harmonization of these promising solutions with other emerging worldwide vehicular communication projects and standards.

Different appropriate governmental agencies are working closely with car manufacturers/industries such as Mercedes, Toyota, BMW, Fiat, Nissan, Ford, etc to put prototype of Wi-Fi (IEEE 802.11a/b/g/n) and DSRC (IEEE 802.11p) equipped vehicles and other wireless access technology enabled vehicles on our motorways within the nearest possible future. Besides the recent technical development, another critical and important phase that will drive this new technology to success is systematic commercial market introduction and public acceptance.

REFERENCES

[1] F. Bai and H. Krishnan, "Reliability Analysis of DSRC Wireless Communication for Vehicle Safety Applications," in *Intelligent Transportation Systems Conference, 2006. ITSC '06. IEEE*, Toronto, Ont., Sept. 2006.

[2] M. Moharrum and A. Al-Daraiseh, "Toward Secure Vehicular Ad-hoc Networks: A Survey," *IETE Technical Review (Medknow Publications & Media Pvt. Ltd.),* vol. 29, no. 1, pp. 80-89, Jan/Feb 2012.

[3] Y. Toor, P. Muhlethaler and A. Laouiti, "Vehicle Ad Hoc networks: applications and related technical issues," *Communications Surveys & Tutorials, IEEE,* vol. 10, no. 3, pp. 74 - 88, Third Quarter 2008.

[4] H. Krishnan, "Vehicle Safety Communications Project," 15 February 2006. [Online]. Available: http://www.sae.org /events/ads/krishnan.pdf. [Accessed 02 05 2014].

[5] A. Amditis, E. Bertolazzi, M. Bimpas, F. Biral, P. Bosetti, M. Da Lio,, L. Danielsson, A. Gallione, H. Lind, A. Saroldi and A. Sjo□gren, "A Holistic Approach to the Integration of Safety Applications: The INSAFES Subproject Within the European Framework Programme 6 Integrating Project PReVENT," *IEEE Transactions on Intelligent Transportation Systems,* vol. 11, no. 3, pp. 554-566, Sept. 2010.

[6] Y. Liu, J. Bi and J. Yang, "Research on Vehicular Ad Hoc Networks," in *Control and Decision Conference, 2009. CCDC '09. Chinese*, Guilin, 17-19 June 2009.

[7] "Initernet ITS Consortium," [Online]. Available: Initernet ITS Consortium. hp://www.internetits.org..

[8] A. Takahashi and N. Asanuma, "Introduction of Honda ASV-2 (advanced safety vehicle-phase 2)," in *Intelligent Vehicles Symposium, 2000. IV 2000. Proceedings of the IEEE*, Dearborn, MI, 2000.

[9] W. W. R. F. (WWRF), Technologies for the Wireless Future, vol. 3, K. David, Ed., Chichester, West Sussex: John Wiley & sons LTD, 2008.

[10] "Vehicle Infrastructure Integration (VII) program of US Federal and State departments of transportation (DOT's) and automobile manufacturers.," 7 January 2014. [Online]. Available: http://www.vehicle-infrastructure.org/, http://www.its.dot.gov/press_room.htm. [Accessed 5 April 2014].

[11] F. Kargl, P. Papadimitratos, L. Buttyan, M. Müter, B. Wiedersheim, E. Schoch, T.-V. Thong, G. Calandriello, A. Held, A. Kung and J.-P. Hubaux, "Secure Secure Vehicular Communications: Implementation, Performance, and Research Challenges," *IEEE Communications Magazine,* vol. 46, no. 11, pp. 110-118, November 2008.

[12] D. Abusch-Magder, P. Bosch, T.-E. Klein, P. A. Polakos, L. G. Samuel and H. Viswanathan, "911-NOW: A network on wheels for emergency response and disaster recovery operations," *Bell Labs Technical Journal,* vol. 11, no. 4, pp. 113-133, Winter 2007 (current version: April 2014).

[13] M. Alsabaan, W. Alasmary, A. Albasir and K. Naik, "Vehicular Networks for a Greener Environment:A Survey," *IEEE Communications Surveys & Tutorials,* vol. 15, no. 3, pp. 1372-1388, Third Quarter 2013.

[14] S. Zeadally, R. Hunt, Y.-S. Chen, A. Irwin and A. Hassan, "Vehicular ad hoc networks (VANETS): status, results, and challenges," *Telecommunication Systems,* vol. 50, no. 4, pp. 217-241, August 2012.

[15] J. Jakubiak and Y. Koucheryavy, "State of the Art and Research Challenges for VANETs," in *Consumer Communications and Networking Conference, 2008. CCNC 2008. 5th IEEE*, Las Vegas, NV, Jan. 2008.

[16] H. Hartenstein and K. P. Laberteaux, "A tutorial survey on vehicular ad hoc networks," *Communications Magazine,* vol. 46, no. 6, pp. 164-171, June 2008..

[17] G. Karagiannis, O. Altintas, E. Ekici, G. Heijenk, B. Jarupan, K. Lin and T. Weil, "Vehicular Networking: A Survey and Tutorial on Requirements, Architectures, Challenges, Standards and Solutions," *Communications Surveys & Tutorials,* vol. 13, no. 4, pp. 584-616, Fourth Quarter 2011.

[18] M. L. Sichitiu and M. Kihl, "Inter-Vehicle Communication Systems: A Survey," *Communications Surveys & Tutorials,* vol. 10, no. 2, pp. 88-105, 2008.

[19] *European Commission, DG INFSO, INFSO G4/JJ D(2006) 701311 Working Paper on Intelligent Co-operative Systems based on V2V and V2I Communications,* Jan. 2006.

[20] Y. Luo, W. Zhang and Y. Hu, "A New Cluster Based Routing Protocol for VANET," in *Networks Security Wireless Communications and Trusted Computing (NSWCTC), 2010 Second International Conference on Networks Security*, Wuhan, Hubei, April 2010.

[21] N. Maslekar, M. Boussedjra, J. Mouzna and L. Houda, "Direction based clustering algorithm for data dissemination in vehicular networks," in *Vehicular Networking Conference (VNC)*, Tokyo, Oct. 2009.

[22] Y. Fan, T. Yuliang and H. Lianfen, "A novel cooperative MAC for broadcasting in clustering VANETs," in *2013 International Conference on Connected Vehicles and Expo (ICCVE)*, Las Vegas, NV, Dec. 2013.

[23] B. K. Chaurasia, R. S. Tomar, S. Verma and G. S. Tomar, "Suitability of MANET Routing Protocols for Vehicular Ad Hoc Networks," in *2012 International Conference on Communication Systems and Network Technologies (CSNT)*, Rajkot, May 2012.

[24] S. N. Mohammad, M. J. Ashraf, S. Wasiq, S. Iqbal and N. Javaid, "Analysis and Modeling of Network Connectivity in Routing Protocols for MANETs and VANETs," in *2013 Eighth International Conference on Broadband and Wireless Computing, Communication and Applications (BWCCA)*, Compiegne, Oct. 2013.

[25] P. Singh, "Comparative study between unicast and Multicast Routing Protocols in different data rates using vanet," in *2014 International Conference on Issues and Challenges in Intelligent Computing Techniques (ICICT)*, Ghaziabad, Feb. 2014.

[26] H. L. Sharma, P. Agrawal and R. V. Kshirsagar, "Acute direction route node selection multipath routing for VANET: Design approach," in *2014 International Conference on Signal Processing and Integrated Networks (SPIN)*, Noida, Feb. 2014.

[27] Z. D. Chen, H. Kung and D. Vlah, "Ad Hoc Relay Wireless Networks over Moving Vehicles on Highways," in *MobiHoc '01 Proceedings of the 2nd ACM international symposium on Mobile ad hoc networking & computing*, New York, NY, USA, 2001.

[28] G. Caizzone, P. Giacomazzi, L. Musumeci and G. Verticale, "A power control algorithm with high channel availability for vehicular ad hoc networks," in *IEEE International Conference on Communications, ICC 2005*, May 2005.

[29] *SeVeCom, "Secure Vehicular Communications: Security Architecture and Mechanisms for V2V/V2I, Delivarable 2.1,* 2007–2008.

[30] J. F. Kurose and W. K. Ross, Computer Networking: A Top-Down Approach, 5 ed ed., USA: Addison Wesley, 2009.

[31] S. Tanenbaum, Computer Networks, Indianapolis, Indiana: Prentice Hall PTR, 2002.

[32] *Vehicle Safety Communications – Applications (VSC-A) Project, Final Report, DOT HS 811 073,* January 2009.