Vehicular Ad Hoc Networks: Architectures, Research Issues, Challenges and Trends

Wenshuang Liang[1], Zhuorong Li[1], Hongyang Zhang[1], Yunchuan Sun[2], and Rongfang Bie[1,⋆]

[1] College of Information Science and Technology, Beijing Normal University, China
[2] School of Economic and Business Administration, Beijing Normal University, China
{lws,lzr,hongyang}@mail.bnu.edu.cn, {yunchuan,rfbie}@bnu.edu.cn

Abstract. Vehicular Ad hoc Networks (VANETs) have been quite a hot research area in the last few years. Due to its unique characteristics such as high dynamic topology and predictable mobility, VANETs attract so much attention from both academic and industry. In this paper, we provide an overview of the main aspects of VANETs from a research perspective. This paper starts with the basic architecture of networks, then discusses two critical technologies: routing, as well as security and privacy, and ends up with the analysis on challenges and future trends of VANETs.

Keywords: Vehicular Ad hoc Networks, Routing, Security and Privacy, Challenges and Trends.

1 Introduction

Recently, with the development of vehicle industry and wireless communication technology, Vehicular Ad hoc Networks are becoming one of the most promising research fields.

VANETs which use vehicles as mobile nodes is a subclass of Mobile Ad hoc Network (MANET) to provide the communication among nearby vehicles and between vehicles and nearby roadside equipment [1], but apparently differs from other networks by its own characteristics. Specifically, the nodes (vehicles) in VANETs are limited to road topology while moving, so if the road information is available, we are able to predict the future position of a vehicle; what's more, vehicles can afford significant computing, communication and sensing capabilities as well as provide continuous transmission power themselves to support these functions [2].

However, VANETs also come with several challenging characteristics, such as potentially large scale and high mobility. Nodes in the vehicular environment are much more dynamic because most cars usually are at a very high speed and change their position constantly. The high mobility also leads to a dynamic network topology, while the links between nodes connect and disconnect very often. Besides, VANETs have a potentially large scale which can include many participants and extend over the entire road network [2].

⋆ Corresponding author.

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It is precisely because of both these unique attractive features and challenging characteristics that VANETs could draw the attention of both industry and academia.

Therefore, several articles have tried to summarize the issues about vehicular networks. For example, In [3][4],the authors discuss the research challenges of routing in VANETs, and summarize and compare the performance of routing protocols; While, Hartenstein,H et al. present an overview on the communication and networking aspects of VANETs and summarizes the current state-of-the-art at that time[5]; Maxim Raya et al. address the security of VANETs comprehensively, provides a set of security protocols as well[6]; in [7], the authors propose a taxonomy of a large range of mobility models available for vehicular ad hoc networks. These articles are all overview specific research areas in VANETs. In addition, others papers like [8] provide comprehensive overview of applications, architectures, protocols and challenges in VANETs, especially introduces VANETs projects and standardization efforts in different regions (i.e. USA, Japan and Europe); Saif et al. provide a detailed information for readers to understand the main aspects and challenges related to VANETs, including network architecture, wireless access technologies, characteristics, applications, and simulation tools[9].

Compared with these current articles, this paper adds the introduction of layered architecture for VANETs so that the summary of network architecture is more completely. Also, we organize the overview of the vehicular ad hoc networks in a novel way. That is we introduce the VANETs from the research perspective in the paper, including some current critical technologies, which do good to the progress of VANETs. Moreover, we provide a more comprehensive analysis on VANETS research challenges and future trends, beneficial for further systematic research on VANETs. In summary, this paper covers basic architecture, critical technologies of VANETs, and provides an overall reference on VANETs.

The rest of this paper is organized as follows. Section 2 first introduces the vehicular Ad Hoc networks architecture, including network components, communication types and layered network architecture. Then in Section 3, we discuss two aspects of VANETs research issues: routing, as well as security and privacy. Section 4 provides an analysis on VANETs research challenges and future trends. Finally, concludes the paper in Section 5.

2 Architecture

This part describes the system architecture of Vehicular Networks. We first introduce the main components of VANETs architecture from a domain view. Then, we explain their interaction and introduce the communication architecture. Besides, we provide a presentation of the layered architecture for VANETs.

2.1 Main Components

According to the IEEE 1471-2000 [10,11] and ISO/IEC 42010 [12] architecture standard guidelines, we are able to achieve the VANETs system by entities which can be divided into three domains: the mobile domain, the infrastructure domain and the generic domain[13].

As is shown in Fig. 1, the mobile domain consists of two parts: the vehicle domain and the mobile device domain. The vehicle domain comprises all kinds of vehicles such as cars and buses. The mobile device domain comprises all kinds of portable devices like personal navigation devices and smart phones.

Within the infrastructure domain, it includes two domain: the roadside infrastructure domain and The central infrastructure domain. The roadside infrastructure domain contains roadside unit entities instantiated like traffic lights. The central infrastructure domain contains infrastructure management centers such as traffic management centers (TMCs) and vehicle management centers[13].

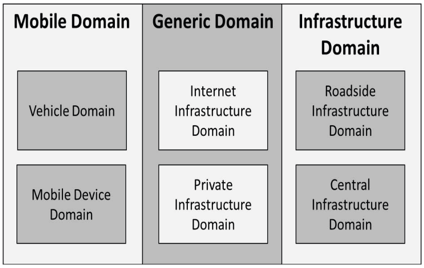

Fig. 1. VANETs System Domains

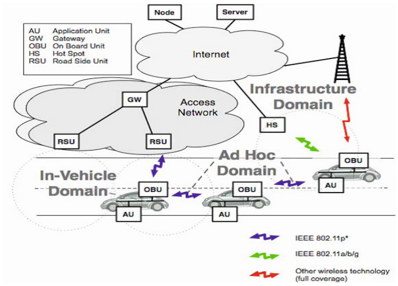

Fig. 2. C2C-CC reference architecture [15]

However, the development of VANETs architecture varies from region to region. In the CAR 2 X Communication System which is pursued by the CAR 2 CAR Communication Consortium, the reference architecture is a little different. CAR 2 CAR Communication Consortium (C2C-CC) is the major driving force for vehicular communication in Europe and published its "manifesto" in 2007. This system architecture comprises three domains:in-vehicle, ad hoc, and infrastructure domain.

As show in Fig. 2, the in-vehicle domain is composed of an on-board unit (OBU) and one or multiple application units (AUs). The connections between them are usually wired and sometimes wireless. While, the Ad-hoc domain is composed of vehicles equipped with OBUs and road-side units (RSU). An OBU can be seen as a mobile node of an Ad Hoc network, RSU is a static node likewise. An RSU can be connected to the Internet via the gateway; RSUs can communicate with each other directly or via multi-hop as well. There are two types of infrastructure domain access, RSU and hot spot (HS). OBUs may communicate with Internet via RSUs or hot spots. In the absence of RSUs and hot spots, OBUs can also communicate with each other by using cellular radio networks (GSM, GPRS, UMTS, WiMAX, and 4G) [2].

2.2 Communication Architecture

Communication types in VANETs can be categorized into four types. The category is closely related to VANETs components as described above. Fig. 3 describes the key functions of each communication type [16].

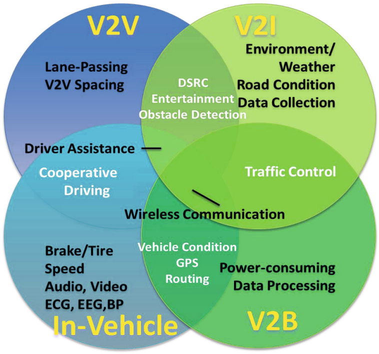

Fig. 3. Key functions of each communication type

In-Vehicle Communication, which is more and more necessary and important in VANETs research, refers to the in-vehicle domain. In-vehicle communication system can detect a vehicle's performance and especially a driver's fatigue and drowsiness, which is critical for driver and public safety.

Vehicle-to-Vehicle (V2V) Communication can provide a data exchange platform for the drivers to share information and warning messages, so as to expand driver assistance.

Vehicle-to-Road Infrastructure (V2I) Communication is another useful research field in VANETs. V2I communication enables real-time traffic/weather updates for the driver and provides environmental sensing and monitoring.

Vehicle-to-Broadband Cloud (V2B) Communication means that vehicles may communicate via wireless broad band mechanisms such as 3G/4G. As the broad band cloud may include more traffic information, monitoring data, as well as infotainment, this type of communication will be useful for active driver assistance and vehicle tracking.

2.3 Layered Architecture for VANETs

The Open Systems Interconnection (OSI) model is well-known to most readers, which groups similar communication functions into one of seven logical layers [17]. The session layer and presentation layer are omitted here, and a given layer can be further partitioned into sublayers in this architecture, as illustrated in Fig. 4[18].

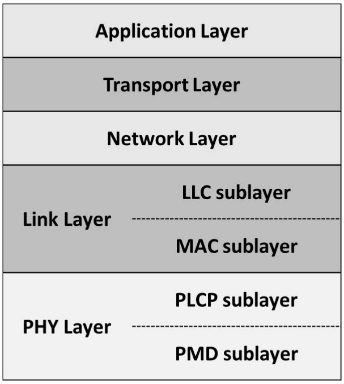

Fig. 4. OSI reference architecture

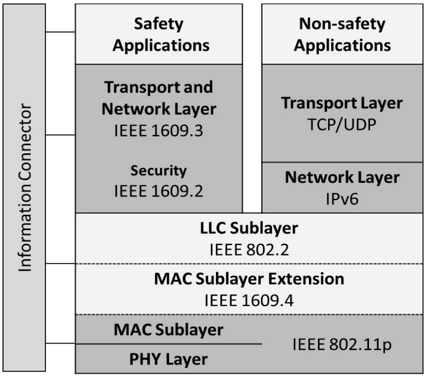

Fig. 5. Layered architecture for DSRC

VANETs architectures differ from region to region, thus the protocols and interfaces are also different among them. Fig. 5 illustrates the protocol stack for dedicated short-range communication (DSRC) in the US. DSRC is specifically designed for automotive use and a corresponding set of protocols and standards [18]. The US FCC has allocated 75MHz of spectrum for DSRC communication, from 5.850 GHz to 5.925 GHz [18]. Different protocols are designed to use at the various layers, some of them are still under active development now. The IEEE 802.11p, an approved amendment to the IEEE 802.11 standard to add wireless access in vehicular environments (WAVE), is focused primarily on the PHY layer and MAC sublayer of the stack. IEEE 1609 is a higher layer standard based on the IEEE 802.11p. IEEE 1609 represents a family of standards that function in the middle layers of the protocol stack to flexibly support safety applications in VANETs. While non-safety applications are supported through another set of protocols. In particular, network layer services and transport layer services for non-safety applications are provided by three quite stable protocols: IPv6, TCP and UDP [11,18,19].

3 Research Issues

This part is a brief introduction to two aspects of VANETs research issues: routing, as well as security and privacy. Firstly, we discuss the classification of routing protocols. then the state of the art security and privacy are discussed.

3.1 Routing

In VANETs, wireless communication has been a critical technology to support the achievement of many applications and services. However, due to the characteristics of VANETs such as high dynamic topology and intermittent connectivity, these existing routing algorithms in MANETs are not available for most application scenarios in VANETs. Thus researchers spare no effort to improve existing algorithms as well as design new ones, so that the communication reliability can be ensured. Depending on the number of senders and receivers involved, routing approaches can be divided into three types: geocast/broadcast, multicast, and unicast approaches.

- **Geocast/broadcast:** With the requirement of distributing messages to unknown/unspecified destinations, the geocast/broadcast protocols are necessary in VANETs. In [21], the authors review the current message broadcast protocols on vehicular networks, such as a spatially aware packet routing algorithm, SADV, FROV and a multi-hop broadcast protocol. Likewise, Omprakash et al. present an overview on Geocast Routing(GR) and categorize GR into two groups namely urban and highway based on traffic environment, such as CAGR, VDLA, FPBR and IPSA.[22].
- **Multicast:** Multicast is necessary to communications among a group of vehicles in some vehicular situations, such as intersections, road blocks, high traffic density, accidents and dangerous road surface conditions. In [21], the authors categorize the multicast protocols into two main types. One is topology-based approaches, such as ODMRP, MAODV and GHM. The other is location-based approaches, such as PBM, SPBM, LBM, as well as RBM and IVG. Besides, Dr.Parminder Singh evaluates the performance of some Multicast routing protocols like ODMRP and ADMR [46].
- **Unicast:** Researchers investigate the unicast communication protocols for VANETs in three ways: (1) greedy: nodes forward the packets to their farthest neighbors towards the destination, like Improved Greedy Traffic-Aware Routing (GyTAR), (2) opportunistic: nodes employ the carry-toward technique in order to opportunistically deliver the data to the destination, like Topology-assist Geo-Opportunistic Routing, and (3) trajectory based: nodes calculate possible paths to the destination and deliver the data through nodes along one or more of those paths, like Trajectory-Based Data Forwarding (TBD) [23].

3.2 Security and Privacy

Nowadays more and more intelligent onboard applications may store lots of personal information and vehicular tracks are available electronically, the problem of security and privacy has become an emerging hot research field in VANETs. Security and privacy are two of the critical fundamental problems which have to be solved before vehicular network communications among vehicles or between vehicles and infrastructures can be deployed. Otherwise, the reliability, dependability and user acceptance of the VANETs system is likely to be low, because attackers may manipulate messages or track the itineraries of vehicles[25,26]. In addition, in [47], the authors analyze some possible attacks in VANETs, such as data trust attack and replay attack.

There has been significant interest and progress in the field of security and privacy over the last few years. The majority of researchers have been focusing on the vehicular communication system, which is a promising approach to facilitate road safety, traffic management, and message dissemination for drivers and passengers[20]. In general, security architecture and vehicular communication are receiving increasing attentions from academia and industry. In [29], the authors describe the security architecture using different viewpoints, such as the functional layer view, the organizational/component view, the reference model view and the information centric view. In [30], the authors present a novel security architecture focusing primarily on securing the operation of the wireless part of the vehicular communication system and on enhancing the privacy of its users. Security vehicular communication draws more attention relative to architecture, such as secure communication schemes and algorithms[26,31]. Raya et al. present a communication scheme, which entities would like to establish a share session key if they need to securely communication for a long time. This scheme pays much attention on safety-related applications, but the non-safety-related applications are neglected [6,33]. In [31], the authors present an advanced secure communication scheme based Raya and Hubaux's scheme, which extends its session key to be using in non-safety-related applications. In [32], the authors discuss many security solutions that have been proposed in detail, such as VPKI, CA and the group signature.

4 Challenges and Future Trends

Based on the previous discussion of VANETs, we can see that VANETs is a fantastic self-organizing network for the future intelligent transportation system (ITS). Although researchers have achieved much great progress on VANETs study, there are still some challenges that need to be overcome and some issues that need to be further investigated, e.g., communication, security, applications, stimulation, verification, and services, etc.[16,34].

4.1 Top Challenges

Compared with Mobile Ad Hoc Network (MANET), the specific features of VANETs require different communication paradigms, approaches to security and privacy, and wireless communication system [35]. For example, network connections may not be stable for a long time period. In order to improve the performance of communication, researchers have investigated the efficient use of available infrastructure, such as road side units and cellular networks. Although, many specific challenges of VANETs have been overcome, we believe that many key research challenges have only partially been solved [35].Thus, researchers need to do deeper work to solve these challenges.In the following discussion we will summarize the key challenges.

– **Fundament Limits and Opportunities.** Surprisingly little is known about the fundamental limitations and opportunities of VANETs communication from a more theoretical perspective [36]. We believe that avoiding accidents and minimizing resource usage are both important theoretical research challenges.

- **Standards.** The original IEEE802.11 standard cannot well meet the requirement of robust network connectivity, and the current MAC parameters of the IEEE802.11p protocol are not efficiently configured for a potential large number of vehicles [16]. Thus, researchers may do more work about standards.
- **Routing Protocols.** Although researchers have been presented many effective routing protocols and algorithms such as CMV (Cognitive MAC for VANET) and GyTAR (Greedy Traffic Aware Routing), the critical challenge is to design good routing protocols for VANETs communication with high mobility of vehicles and high dynamic topology [34].
- **Connectivity.** The management and control of Network connections among vehicles and between vehicles and network infrastructure is the most important issue of VANETs communication [37]. Primary challenge in designing vehicular communication is to provide good delay performance under the constraints of vehicular speeds, high dynamic topology, and channel bandwidths [38].
- **Cross-layer.** In order to support real-time and multimedia applications, an available solution is to design cross-layer among original layers [38]. In general, cross-layer protocols that operate in multiple layers are used to provide priorities among different flows and applications. In [35,40], the authors address the importance of cross-layer design in VANETs after analyzing the performance metrics.
- **Cooperative Communication.** In [37], the authors consider the VANETs as a type of cloud called Mobile Computing Cloud (MCC), and in [16], the authors present a broadband cloud in vehicular communication. Thus, the cooperation between vehicular clouds and the Internet clouds in the context of vehicular management applications has become a critical challenge to researchers.
- **Mobility.** Mobility that is the norm for vehicular networks makes the topology change quickly. Besides, the mobility patterns of vehicles on the same road will exhibit strong correlations [40]. In [33], the authors address that mobility plays a key role in vehicular protocol design and modeling.
- **Security and Privacy.** Frank et al. present many solutions that come at significant drawbacks and the mainstream solution still relies on 'key-pair / certificate / signature'[41]. For example, key distribution is a key solution for security protocols, but key distribution poses several challenges, such as different manufacturing companies and violating driver privacy [40]. Besides, tradeoff the security and privacy is the biggest challenge under the requirement of efficiency.
- **Validation.** It is not only necessary to assess the performance of VANETs in a real scenario but also to discover previously unknown and critical system properties. Besides, validation has become more and more difficult under the wider range of scenarios, Onur Altintas et al. present can use Field Operational Tests (FOTs) to solve this problem, but conducting meaning FOTs is a challenge like a large and complex system with technology components [37].

Thus, considering the characteristics of high mobility and high dynamic topology, these challenges discussed above are still needed to do more research work to solve them.

4.2 Future Trends

As the society is more and more intelligent, the potential value of VANETs is unpredictable with safety and entertainment applications. New vehicle applications have recently emerged in several areas ranging from navigation safety to location aware content distribution, commerce and games [37]. Thus, the VANETs need to continue to explore and study, and we believe that there must be more applications and research results in the future. For instance, we consider the routing protocols and algorithms in VANETs. The DSRC technology is proposed to provide a communication link between vehicles and road side beacons [42], and the evolution of DSRC is also discuss in [43], the trends of DSRC are better channel interleaving and channel coding, more flexibility in channelization, and better MAC congestion control protocols. It is advanced to apply such DSRC to VANETs. We now discuss some possible future trends of VANETs in three aspects including architecture, algorithm and application, which we called 3A.

Architecture: In the future, a main research issue of vehicular networks focuses on designing an integrated system architecture that can make use of multiple different technologies (e.g. IEEE 802.11p DSRC, WAVE, ITS G5, Wi-Fi, or 3G/4G) and heterogeneous vehicular networks [37]. Besides, in order to the deployment of the FOT mentioned above, researchers need to design a large scale and complex system architecture which should cooperate with different partners and manufacturers [13]. Thus, the reliable and flexible system architecture is one of the main research trends.

Algorithm: Although these existing algorithms have been provided some solutions with these data dissemination problems in VANETs, it is still difficult to examine their performance and security because of these features of VANETs mentioned above. For example, due to the non-persistent network connections, the end-to-end communication path may not exist. In [44], the authors present that the opportunistic routing algorithm can solve this problem with the carry-forwarding pattern. So the advanced algorithms should be designed with the low communication delay, the low communication overhead and the low time complexity.

Application: Due to requiring continuous awareness of the road ahead, safety applications is still the key research trend in the mobile vehicular environment. Moreover, the authors find no applications followed these VANETs application guidelines after studying the most popular vehicular applications in the Android marketplace [45]. So, researchers should do more work about applications'standards and security, and investigate the question "how to use model checking to automatically explore whether these applications meet the standards".

5 Conclusion

In this paper, we first introduce the vehicular networks architecture, including network components, communication types and layered network architecture. Then we discuss two critical technologies in VANETs research issues: routing, as well as security and privacy. Finally, we provide an analysis on VANETs research challenges and future trends.

This paper introduces the vehicular ad hoc networks from the research perspective, covers basic architecture, critical technologies of VANETs, and provides a comprehensive reference on vehicular Ad Hoc networks.

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References

1. Sivasakthi, M., Suresh, S.R.: Research on vehicular ad hoc networks (VANETs): An Overview. Journal of Applied Sciences and Engineering Research 2(1), 23–27 (2013)
2. Moustafa, H., Zhang, Y.: Vehicular networks: techniques, standards, and applications. CRC Press (2009)
3. Li, F., Wang, Y.: Routing in Vehicular Ad Hoc Networks: A Survey. Vehicular Technology Magazine, 12–22 (2007)
4. Su, X.: A Comparative Survey of Routing Protocol for Vehicular Sensor Networks. In: 2010 IEEE International Conference onWireless Communications, Networking and Information Security (WCNIS), pp. 311–316 (2010)
5. Hartenstein, H., Laberteaux, K.P.: A Tutorial Survey on Vehicular Ad Hoc Networks. IEEE Communications Magazine, 164–171 (2008)
6. Raya, M., Hubaux, J.-P.: Securing vehicular ad hoc networks. Journal of Computer Security 15(1/2007), 39–68 (2006)
7. Harri, J., Filali, F., Bonnet, C.: Mobility Models for Vehicular Ad Hoc Networks: A Survey and Taxonomy. IEEE Communications Surveys & Tutorials 11(4), 19–41 (2009)
8. Karagiannis, G., Altintas, O., Ekici, E., Heijenk, G., Jarupan, B., Lin, K., Weil, T.: Vehicular Networking: A Survey and Tutorial on Requirements, Architectures, Challenges, Standards and Solutions. IEEE Communications Survey & Tutorials 13(4), 584–616 (2011)
9. Al-Sultan, S., Al-Doori, M.M., AlBayatti, A.H., Zedan, H.: A comprehensive survey on vehicular Ad Hoc network. Journal of Network and Computer Applications 37, 380–392 (2013)
10. Maier, M.W., Emery, D., Hilliard, R.: Software architecture: Introducing IEEE standard 1471. IEEE Computer 34(4) (2001)
11. Maier, M.W., Emery, D., Hilliard, R.: ANSI/IEEE 1471 and systems engineering. Systems Engineering 7(3) (2004)

12. Emery, D., Hilliard, R.: Every architecture description needs a framework: Expressing architecture frameworks using ISO/IEC 42010. In: Proc. Joint Working IEEE/IFIP Conference on Software Architecture and European Conference on Software Architecture, WICSA/ECSA (2010)
13. Kosch, T., Schroth, C., Strassberger, M., Bechler, M.: Automotive Internet-working (2012)
14. Lysaker, N.: Vehicular Networks: Techniques, Standards, and Applications. Auerbach Publications (2009)
15. CAR 2 CAR Communication Consortium Manifesto (2007), http://elib.dlr.de/48380/1/C2C-CC_manifesto_v1.1.pdf
16. Faezipour, M., Nourani, M., Saeed, A., Addepalli, S.: Progress and challenges in intelligent vehicle area networks. Communications of the ACM 55(2) (2012)
17. http://en.wikipedia.org/wiki/OSI_model
18. Hartenstein, H., Laberteaux, K.: VANET-Vehicular Applications and Inter-Networking Technologies. Wiley (2010)
19. http://en.wikipedia.org/wiki/IEEE_802.11p
20. Emmelmann, M., Bochow, B., Kellum, C.: Vehicular Networking Automotive Applications and Beyond. Wiley (2010)
21. Yang, J., Fei, Z.: Broadcasting with Prediction and Selective Forwarding in Vehicular Networks. International Journal of Distributed Sensor Networks (2013)
22. Kaiwartya, O., Kumar, S.: Geocast Routing: Recent Advances and Future Challenges in Vehicular Ad Hoc Networks. In: Internation Conference on Signal Processing and Integrated Networks (SPIN), pp. 291–296 (2014)
23. Wahid, A., Yoo, H., Kim, D.: Unicast geographic routing protocolsfor inter-vehicle communications: a survey. In: Proceedings of the 5th ACM Workshop on Performance Monitoring and Measurement of Heterogeneous Wireless and Wired Networks, PM2HW2N 2010, pp. 17–24. ACM, New York (2010)
24. Kim, D., Cano, J.C., Wang, W., De Rango, F., Hua, K.: Data Disseminations in Vehicular Environments. International Journal of Distributed Sensor Networks (2013)
25. Dötzer, F.: Privacy Issues in Vehicular Ad Hoc Networks. In: Danezis, G., Martin, D. (eds.) PET 2005. LNCS, vol. 3856, pp. 197–209. Springer, Heidelberg (2006)
26. de Fuentes, J.M., Gonzlez-Tablas, A.I., Ribagorda, A.: Overview of security issues in Vehicular Ad-hoc Networks (2010)
27. Sivasakthi, M., Suresh, S.R.: Research on vehicular ad hoc networks (VANETs): An Overview. Journal of Applied Sciences and Engineering Research 2(1), 23–27 (2013)
28. Lin, X., Lu, R., Zhang, C., Zhu, H., Ho, P.-H., Shen, X(S.): Security in Vehicular Ad Hoc Networks. IEEE Communications Magazine (2008)
29. Gerlach, M., Festag, A., Leinmuller, T., Goldacker, G., Harsch, C.: Security Architecture for Vehicular Communication
30. Papadimitratos, P., Buttyan, L., Holczer, T., Schoch, E., Freudiger, J., Raya, M., Ma, Z., Kargl, F., Kung, A., Hubaux, J.-P.: Secure Vehicular Communication Systems: Design and Architecture. IEEE Communications Magazine (2008)
31. Wang, N.-W., Huang, Y.-M., Chen, W.-M.: A novel secure communication scheme in vehicular ad hoc networks. Journal of Computer Communications 31(12), 2827–2837 (2008)
32. Samara, G., Al-Salihy, W.A.H., Sures, R.: Security Issues and Challenges of Vehicular Ad Hoc Networks (VANETs). In: 4th International Conference on New Trends in Information Science and Service Science (NISS), pp. 393–398 (2010)

33. Raya, M., Hubaux, J.P.: The Security of Vehicular Ad Hoc Networks. In: Proceedings of the 3rd ACM Workshop on Security of Ad hoc and Sensor Networks, pp. 11–21 (2005)
34. Zeadally, S., Hunt, R., Chen, Y.-S., Irwin, A., Hassan, A.: Vehicular ad hoc networks (VANETS) status, results, and challenges (2012)
35. Dressler, F., Kargl, F., Ott, J., Tonguz, O.K., Wischhof, L.: Research Challenges in Inter-Vehicular. Karlsruhe Institute of Technology (2010)
36. Hartenstein, H., Heijenk, G., Mauve, M., Scheuermann, B., Wolf, L.: Working Group on Fundamental Limits and Opportunities. Karlsruhe Institute of Technology (2010)
37. Altintas, O., Dressler, F., Hartenstein, H., Tonguz, O.K.: Inter-Vehicular Communication - Quo Vadis, vol. 3(9), pp. 190–213. Karlsruhe Institute of Technology, KIT, Dagstuhl Reports (2014)
38. Karagiannis, G., Altintas, O., Ekici, E., Heijenk, G., Jarupan, B., Lin, K., Weil, T.: A Survey and Tutorial on Requirements, Architectures, Challenges. In: Gerla, M., Kleinrock, L. (eds.) Vehicular Networks and the Future of the Mobile Internet, Computer Networks (2011)
39. Sommer, C., Tonguz, O.K., Dressler, F.: Adaptive Beaconing for Delay-Sensitive and Congestion-Aware Traffic Information Systems. In: 2nd IEEE Vehicular Networking Conference (VNC 2010), pp. 1–8. IEEE, Jersey City (2010)
40. Parno, B., Perrig, A.: Challenges in Securing Vehicular Networks (2009)
41. Kargl, F., Buttyan, L., Eckhoff, D., Schoch, E.: Working Group on Security and Privacy. Karlsruhe Institute of Technology, KIT (2011)
42. Cseh, C.: Architecture of the Dedicated Short-Range Communications (DSRC) Protocol (1998)
43. Wu, X., Subramanian, S., Guha, R., White, R.G., Li, J., Lu, K.W., Bucceri, A., Zhang, T.: Vehicular Communications Using DSRC Challenges, Enhancements, and Evolution. IEEE Journal on Selected Areas in Communications/Supplement 31(9), 399–408 (2013)
44. Wang, S., Liu, M., Cheng, X., Li, Z., Huang, J., Chen, B.: Opportunistic Routing in Intermittently Connected Mobile P2P Networks. IEEE Journal on Selected Areas in Communications, 369–378 (2013)
45. Lee, K., Flinn, J., Giuli, T.J., Noble, B., Peplin, C.: AMC: Verifying User Interface Properties for Vehicular Applications. In: Proceeding of the 11th Annual International Conference on Mobile Systems, Applications, and Services, pp.1–12 (2013)
46. Singh, P.: Comparative study between Unicast and Multicast Routing Protocols in Different Data Rates Using VANET. In: International Conference on Issues and Challenges in Intelligent Computing Techniques(ICICT), pp. 278–284 (2014)
47. Kim, Y.K., Kim, I.: Security Issues in Vehicular Networks. In: International Conference on Infromation Networking (ICON), pp. 468–472 (2013)