ORIGINAL RESEARCH PAPER | Engineering | Volume - 7 | Issue - 3 | March - 2017 | ISSN - 2249-555X | IF : 4.894 | IC Value : 79.96

VANET: Research Methodologies, Challenges and Applications

KEYWORDS: vehicular ad-hoc networks, wireless ad-hoc networks, vehicular communications, dynamic topology, mobility.

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ABSTRACT A Vehicular Ad-Hoc Network or VANET is a sub form of Mobile Ad-Hoc Network or MANET that provides communication between vehicles and between vehicles and road-side base stations with an aim of providing efficient and safe transportation. The Vehicular Networks can provide wide variety of services, range from safety-related warning systems to improved navigation mechanisms as well as information and entertainment applications. So lot of research work is being conducted to study the problems related to the vehicular communications including network architecture, protocols, routing algorithms, as well as security issues. In order to stimulate the 'beginners in research', here we present a paper on an overview of Vehicular Ad-hoc Networks. VANETs comprise vehicle-to-vehicle and vehicle-to-infrastructure communications based on wireless local area network technologies. The distinctive set of candidate applications, resources, and the environment make the VANET a unique area of wireless communication. Due to their unique characteristics such as high dynamic topology and predictable mobility, VANETs attract so much attention of both academia 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 research issues and general research methods, and ends up with the analysis on challenges and applications of VANETs.

I. INTRODUCTION

The recent adoption of the various 802.11 wireless standards has caused a dramatic increase in the number of wireless data networks. Today, wireless LANs are highly deployed and the cost for wireless equipment is continuing to drop in price. Currently, an 802.11 adapters or access point (AP) can be purchased for next to nothing. As a result of the high acceptance of the 802.11 standards, academia and the commercial sector are looking for other applicable solutions for these wireless technologies. Mobile ad-hoc networks (MANET) are one area that has recently received considerable attention. One promising application of mobile ad-hoc networks is the development of vehicular ad-hoc networks (VANET). A MANET is a self forming network, which can function without the need of any centralized control. Each node in an ad-hoc network acts as both a data terminal and a router. The nodes in the network then use the wireless medium to communicate with other nodes in their radio range. A VANET is effectively a subset of MANETs. The following figure-1 shows the hierarchy of wireless ad-hoc networks.

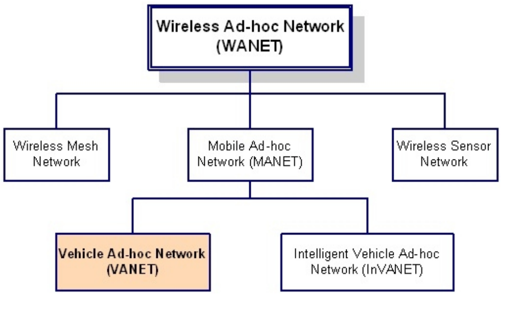

Fig. 1: Hierarchy of wireless ad-hoc networks

The benefit of using ad-hoc networks is it is possible to deploy these networks in areas where it isn't feasible to install the needed infrastructure. The concept of leveraging wireless communication in vehicles has fascinated researchers since the 1980s [1]. In the last few years, we have witnessed a large increase in research and development in this area. Several factors have led to this development, including the wide adoption (and subsequent drop in cost) of IEEE 802.11 technologies; the embrace of vehicle manufactures of information technology to address the safety, environmental, and comfort issues of their vehicles; and the commitment of large national and regional governments to allocate wireless spectrum for vehicular wireless communication [19]. Although cellular networks enable convenient voice communication and simple infotainment services to drivers and passengers, they are not well-suited for certain direct vehicle-to-vehicle or vehicle-to-infrastructure communications. However, vehicular ad-hoc networks (VANETs), which offer direct communication between vehicles and to and from roadside units (RSUs), can send and receive hazard warnings or information on the current traffic situation with minimal latency. With the availability since the late 1990s of low-cost, global-positioning system (GPS) receivers and wireless local area network (WLAN) transceivers, research in the field of inter-vehicular communication gained considerable momentum (e.g., [2]). The major goals of these activities are to increase road safety and transportation efficiency, as well as to reduce the impact of transportation on the environment. These classes of applications of VANET technology are not completely orthogonal: for example, reducing the number of accidents can in turn reduce the number of traffic jams, which could reduce the level of environmental impact. Due to the importance of these goals for both the individual and the nation, various projects are underway, or recently were completed, and several consortia were set up to explore the potential of VANETs. These consortia projects involve several constituencies, including the automotive industry, the road operators, tolling agencies, and other service providers. These projects are funded substantially by national governments. National governments also contribute licensed spectrum, generally in the 5.8/5.9-GHz band and at least in Japan, the 700-MHz band. The term VANET was originally adopted to reflect the ad-hoc nature of these highly dynamic networks. In this article we present an overview on the communication and networking aspects of vehicular ad-hoc networks. We first look more closely at the network architecture and characteristics. Then, we present research issues. After the sections we concentrate on the research methodologies. We also address research challenges and applications of VANETs. Finally, we summarize the current state-of-the-art and discuss important issues.

II. NETWORK ARCHITECTURES AND CHARACTERISTICS

MANETs generally do not rely on fixed infrastructure for communication and dissemination of information. VANETs follow the same principle and apply it to the highly dynamic environment of surface transportation.

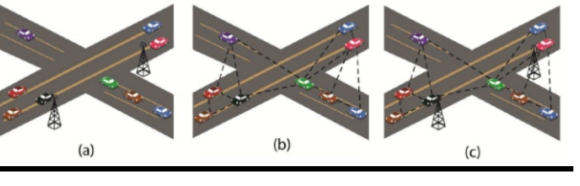

Fig. 2: Three possible network architectures for VANETs.

As shown in Figure 2, the architecture of VANETs falls within three categories: pure cellular/WLAN, pure ad-hoc, and hybrid. VANETs may use fixed cellular gateways and WLAN access points at traffic intersections to connect to the Internet, gather traffic information or for routing purposes. The network architecture under this scenario is a pure cellular or WLAN structure as shown in Figure 2(a). VANETs can combine both cellular network and WLAN to form the networks so that a WLAN is used where an access point is available and a 3G connection otherwise. Stationary or fixed gateways around the sides of roads could provide connectivity to mobile nodes [20] but are eventually unfeasible considering the infrastructure costs involved. In such a scenario, all vehicles and roadside wireless devices can form a mobile ad-hoc network (Figure 2(b)) to perform vehicle-to-vehicle communications and achieve certain goals, such as blind crossing (a crossing without light control). Hybrid architecture (Figure 2(c)) of combining cellular, WLAN and ad-hoc networks together has also been a possible solution for VANETs. Namboodiri *et al.* [5] proposed such a hybrid architecture which uses some vehicles with both WLAN and cellular capabilities as the gateways and mobile network routers so that vehicles with only WLAN capability can communicate with them through multi-hop links to remain connected to the world. VANETs comprise of radio-enabled vehicles which act as mobile nodes as well as routers for other nodes. In addition to the similarities to ad-hoc networks, such as short radio transmission range, self-organization and self management, and low bandwidth, VANETs can be distinguished from other kinds of ad-hoc networks as follows:

▪**Highly dynamic topology:** Due to high speed of movement between vehicles, the topology of VANETs 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*.

▪ **Real-time processing & self-organizing:** VANET communication requires fast processing of information that does not take time in order to correctly exchange information. Furthermore, since nodes are mobile, the network is organized in different 'topologies' each time. The following figure 3 shows the dynamic nature of VANETs.

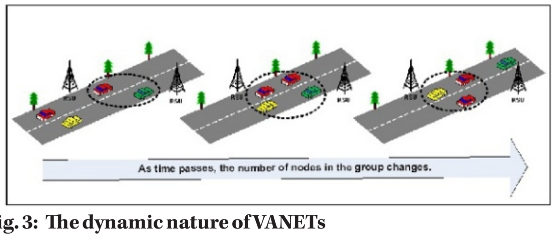

Fig. 3: The dynamic nature of VANETs

▪ **Frequently disconnected network:** Due to the same reason, the connectivity of the VANETs 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.

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

▪ **Geographical type of communication:** Compared to other networks that use uni-cast or multicast where the communication end points are defined by ID or group ID, the VANETs often have a new type of communication which addresses geographical areas where packets need to be forwarded (*e.g.*, in safety driving applications).

▪ **Mobility modeling and predication:** Due to highly mobile node [22] movement and dynamic topology, mobility model and predication play an important role in network protocol design for VANETs. Moreover, vehicular [21] nodes are usually constrained by prebuilt highways, roads and streets, so given the speed and the street map, the future position of the vehicle can be predicated.

▪ **Various communications environments:** VANETs 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.

▪ **Hard delay constraints:** In some VANETs applications, the network does not require high data rates but has hard delay constraints. For example, in an automatic highway system, when brake event happens, the message should be transferred and arrived in a certain time to avoid car crash. In this kind of applications, instead of average delay, the maximum delay will be crucial.

▪ **Interaction with on-board sensors:** It is assumed that the nodes are equipped with on-board sensors to provide information which can be used to form communication inks and for routing purposes. For example, GPS receivers are increasingly becoming common in cars which help to provide location information for routing purposes. It is assumed that the nodes are equipped with on-board sensors to provide information which can be used to form communication links and for routing purposes. For example, GPS receivers are increasingly becoming common in cars which help to provide location information for routing purposes.

III. RESEARCH ISSUES

VANETs introduce a new challenging environment for developers and communication engineers. There are many different hot topics to be studied by researchers as follows:

A. Mobility modeling: Traditional ad-hoc networks typically assume limited node mobility, where nodes are usually handheld devices carried by users like laptops, PDAs, smart cell phones, etc. For VANETs, mobility is typical, and it is measured in miles, not meters, per hour. Also, there is a strong relationship among vehicles mobility patterns on the same road as they travel by following the same traffic rules and regulations. Furthermore, since two vehicles remain within their communication range for a matter of seconds, it is an open research issue to develop rich topology model [4] for VANET that will differ from traditional network topologies which require significant interaction between the sender and receiver.

B. Routing protocols: Routing plays an important role in VANET applications but the traditional network routing protocols are inappropriate with this unique vehicular environment as the vehicles move in high-speed resulting rapid change in network topology and not to establish end-to-end connectivity between source and destination nodes [6]. This has prompted researchers and developers to establish rich and robust routing algorithms to deal with the VANET environment that will be able to provide high throughput and better packet delivery ratio.

C. Scalability issues: One of the main challenges inherent to the deployment of VANETs is operability, both in very light and in highly overloaded networks [22]. It is always expected that VANET must work in very low density areas such as roads and highways, as well as in situations with very high traffic density areas, such as cities, urban

Volume - 7 | Issue - 3 | March - 2017 | ISSN - 2249-555X | IF : 4.894 | IC Value : 79.96

areas where traffic jams are high and major intersections exist on road. The number of active nodes (vehicles) and scalable protocol design may be a great issue both for researchers and developers.

D. Security frameworks: Vehicular networks rely on distributed untrustworthy nodes which should cooperate with each other and with RSU [5]. Security issues are a major concern in the VANET environment as nodes communicate with each other through wireless communication. Any change in the network information by a fraud node may cause the great harm for the vehicle drivers and passengers, as well as partition the network and decrease the performance of the whole network. So it can be an essential research issue to develop a robust security [7] solution for the VANET network that will meet the diverse needs of the applications reliably with minimum involvement of un-trusted nodes.

E. Quality of Service (QoS): QoS support over VANETs remains a challenge when current routing paths become no longer available as a result of changes in node velocity, node positioning, network topology or distance between vehicular nodes [23]. It may be a challenging issue both for network engineers and researchers to utilize the available bandwidth allocated for VANET to improve delivery of messages as well as to develop adaptive QoS routing protocols that will establish new routes quickly and efficiently.

F. Broadcasting: Broadcasting continues to be a strong research area of focus by VANET researchers because a significant number of messages transmitted in VANETs are broadcast messages [23]. Effective and co-operative broadcasting algorithms are of concern for the researchers and developers to circulate safety and routing information both in the low density car areas and in the congested city areas where large number of private cars are plying on.

II. RESEARCH METHODOLOGIES

In order to evaluate the performance of different architecture [18] approaches, protocols, algorithms, and applications, an effective research methodology is required in VANETs. Such methods enable researchers and developers to check the drawbacks as well as ensure the availability of new proposed approaches to the above-mentioned aspects. Since VANETs have a potentially large scale, the introduction of a new technology into VANETs requires long development and the experimental implement is very expensive. In general, there are two important and necessary steps before the market introduction: (1) analysis and evaluation by simulations and (2) analysis and verification by field operational testing [13]. In this section, we first introduce the different models which are the essential basis for setting up respective methodologies, and then the simulations and field operational testing are discussed in the following contents.

A) VANETs Models: VANETs are a large and complex overall system model, which consists of four sub models for the different aspects: driver and vehicle model, traffic flow model, communication model, and application model [13].

(i) *Driver and Vehicle Model*: This model aims to reflect the behavior of a single vehicle. This behavior needs to consider two main factors: different driving styles and the vehicle characteristics, such as an aggressive or passive driver and a sports car.

(ii) *Traffic Flow Model*: This model aims to reflect interactions between vehicles, drivers, and infrastructures and develop an optimal road network. In [15], according to various criteria (level of detail, etc.), the authors discuss three classes of traffic flow models: microscopic, mesoscopic, and macroscopic.

(iii) *Communication Model:* This model is a pretty important part of research methodologies to address the data exchange among the road users. Thanks to the constraints of many factors (the performance of the different communication layers, communication environment, and the routing strategies), communication model plays an important role in the research. The authors in [14] give a detailed overview in the research field.

(iv) *Application Model*: This model is very useful for the market introduction because it can address the behavior and quality of cooperative VANETs applications. This kind of model is necessary for two main reasons: (1) different functionality and visualizations for cooperative applications are provided by different vehicle manufacturers and (2) a prioritization of the information and warnings is needed among the simultaneous existence of several cooperative applications [13].

B) Simulation Methods: Simulation is no doubt an essential step before the implement of new technologies in VANETs. The simulation of VANETs requires two different components: a traffic simulator and a network simulator.

(i) *Traffic Simulators:* In order to analyze vehicular ad-hoc network characteristics and protocol performances, traffic simulators are needed to generate position and movement information of a single vehicle in VANETs environment. In [13], the authors list some existing traffic simulators in detail, like SUMO (simulation of urban mobility) and VISSIM (simulation of the position and movement for vehicles as well as city and highway traffic).

(ii) *Network Simulators:* To model and analyze the functionality of VANETs, a good network simulator should possess some features including a comprehensive mode, efficient routing protocols, and communication standards. Martinez et al. do a comparative study of network simulators, such as GloMoSim (global mobile information simulation) and NS-2 (the most popular simulator for IP-based wired and wireless networks) [16].

C) Field Operational Testing: Although the simulation method makes great contributions to the investigation of the VANETs, it does not reflect the real vehicular world. In order to overcome these issues, field operational testing (FOT) has attracted the attention of researchers, which aims to test and evaluate these applications at scale and covers a much wider range of real-world scenarios. Such testing can make the VANETs system closer to the market and generate economic value. Due to the high financial costs and the number of partners, FOT still depends on the reliable results of simulations. On the contrary, the data from the FOT can make the network models more reasonable and improve the performance of protocols. Finally, FOT has four important characteristics: (1) real system components, (2) real vehicles and traffic, (3) including all stakeholders, and (4) large and heterogeneous fleet [13].

V. RESEARCH CHALLENGES IN VANET

Based on the previous discussion of VANETs, we can see that VANETs are a fantastic self-organizing network for the future intelligent transportation system(ITS). Although researchers have achieved much great progress on VANETs [23] 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, services, etc.) [23,24]. Compared with MANETs, the specific features of VANETs require different communication paradigms, approaches to security and privacy, and wireless communication systems [8]. 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 roadside units and cellular networks. Although some specific challenges of VANETs have been overcome, many key research challenges have only partially been solved [8]. Thus, researchers need to do deeper work to solve these challenges. In the following discussion, we will summarize the key challenges [24].

(i) *Fundament Limits and Opportunities:* Surprisingly little is known about the fundamental [9] limitations and opportunities of VANETs communication from a more theoretical perspective. We believe that avoiding accidents and minimizing resource usage are both important theoretical research challenges.

(ii) *Standards*: The original IEEE 802.11 [3] standard cannot well meet the requirement of robust network connectivity, and the current MAC parameters of the IEEE 802.11p protocol are not efficiently configured for a potential large number of vehicles [23]. Thus, researchers must do more work about standards.

(iii) *Routing Protocols*: Although researchers have been presenting 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 [24].

(iv) *Connectivity*: The management and control of network connections among vehicles and between vehicles and network infrastructures is the most important issue of VANETs communication [10]. Primary challenge in designing vehicular communication is to provide good delay performance under the constraints of vehicular speeds, high dynamic topology, and channel bandwidths [11].

(v) *Cross-Layer*: In order to support real-time and multimedia applications, an available solution is to design cross-layer among original layers [11]. In general, cross-layer protocols that operate in multiple layers are used to provide priorities among different flows and applications. In [8, 12], the authors address the importance of cross-layer design in VANETs after analyzing the performance metrics.

(vi)*Cooperative Communication*: In [10], the authors consider the VANETs as a type of cloud called mobile computing cloud (MCC), and in [23] 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.

(vii) *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 [12]. In [17], the authors address the idea that mobility plays a key role in vehicular protocol design and modeling.

(viii) *Security and Privacy:* Reference [17] presents many solutions that come at significant drawbacks and the mainstream solution still relies on "key pair/certificate/ signature." 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 [12]. Besides, tradeoff of the security and privacy is the biggest challenge under the requirement of efficiency.

(ix) *Validation*: It is necessary not only 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, and 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 [10].

Thus, considering the characteristics of high mobility and high dynamic topology, researchers still need to study further and find solutions to the challenges we discussed above.

VI. APPLICATIONS OF VANETS

The prospective applications of Vehicular ad-hoc networks (VANET) are categorized into three major groups as comfort oriented applications, convenience-oriented applications and safety oriented applications. Safety oriented related applications look for the increasing safety of passengers by exchanging relevant information via vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). And comfort and convenience applications [6] improve passenger's comfort and traffic efficiency.

A) Safety-oriented applications: These types of applications help the driver to avoid potential dangers via the exchange of information among vehicles. They are the most important applications because they serve to avoid accidents. The following figure 4 shows Safety applications provided by VANETs.

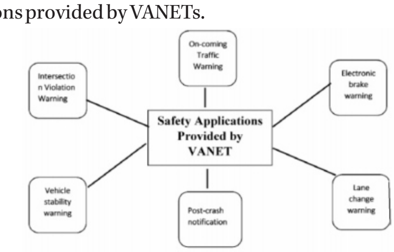

Fig.4: Safety Applications provided by VANETs

They can take control of the vehicle in case of dangerous situations, as in the case of the automatic braking, or only send warning messages to drivers. Some safety oriented application shown in Table I.

Table I: Examples of Safety-Oriented Applications

Name	Description
Intersection violation warning	It warns drivers when they are going to pass over a red light
On-coming traffic warning	It helps the driver during overtaking manoeuvres
Electronic brake warning	It reports to the driver that a preceding vehicle has performed a sudden braking
Vehicle stability warning	It alerts drivers that they should activate the vehicle stability control system.
Post-crash notification	A vehicle involved in an accident sends warning messages in broadcast to approaching vehicles
Traffic signal violation warning	A roadside unit sends messages in broadcast to warn drivers of potential violations of traffic signals
Lane change warning	It helps drivers to perform a safe lane change

B) Convenience-oriented applications: These types of applications improve the efficiency of the roads and to save drivers time and money. The following figure 5 shows Convenience oriented application provided by VANETs. Some Convenience oriented application [6] shown in Table II

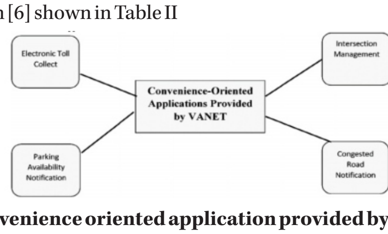

Fig. 5: Convenience oriented application provided by VANETs

Table II: Examples of Convenience-Oriented Applications

Name	Description
Intersection management	V2V and V2R communications allow a better intersections management
Limited access and detour warning	A roadside unit sends information in broadcast about limited access areas or possible detours.

Electronic toll collect	A vehicle establishes uni-cast communication with a toll gate roadside unit and pays the toll without stopping.
Parking availability notification	A vehicle asks to a roadside unit for a list of available parking spaces, and the roadside unit sends the list to the vehicle
Congested road notification	A vehicle in a congested road sends information in broadcast to other vehicles

C) Commercial-Oriented Applications: These types of applications serve to make the travelling more comfortable and productive, for example, by means of the internet connection. Some Commercial oriented application shown in Table III.

Table III: Examples of Commercial-Oriented Applications

Name	Description
Remote diagnosis	The driver can start a wireless connection with the dealer in order to upload the vehicle diagnostics information to detect possible problems
Media or map download	A vehicle can start a wireless connection with the home network or a hot-spot to download maps and multimedia contents
Service announceme nt	Restaurants and other businesses can use a roadside unit to send promotional messages to the drivers of the vehicles that are in their communication range.

VII. CONCLUSION

In this paper, we first introduce the VANETs architecture. Then we discuss VANETs research issues as well as applications. We also focus on VANETs research methodologies. Finally, we provide an analysis on VANETs research challenges. This paper introduces the vehicular ad hoc networks from the research perspective, covers basic architecture, critical research issues, and general research methods of VANETs, and provides a comprehensive reference on vehicular ad hoc networks.

Many VANET applications do not use traditional forms of communication, but require broadcast communication and more advanced information dissemination schemes. The prospective applications of Vehicular ad-hoc networks (VANET) are categorized in to three major groups as comfort oriented applications, convenience-oriented applications and safety oriented applications. Safety oriented related applications look for the increasing safety of passengers by exchanging relevant information via vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). And comfort and convenience applications improve passenger's comfort and traffic efficiency. Moreover, VANETs differ notably from other types of ad-hoc networks, such as wireless sensor networks or mobile ad-hoc networks, because of node heterogeneity and dynamics. In this paper briefly described wide variety of VANET applications into logical groups to get a more concise picture of the applications. In addition, node and network characteristics clarify influences on the design of mechanisms.

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