Vehicular Ad Hoc Networks (VANETs): Challenges and Perspectives

Saleh Yousefi[1], Mahmoud Siadat Mousavi[2], Mahmood Fathy[1]
1. Iran University of Science and Technology
{syousefi, mahfathy}@iust.ac.ir
2. ITS Persia Institute
{siadat@itspersia.com}

***Abstract*- Vehicular Ad hoc Network (VANET), a subclass of mobile *Ad Hoc* networks (MANETs), is a promising approach for future intelligent transportation system (ITS). These networks have no fixed infrastructure and instead rely on the vehicles themselves to provide network functionality. However, due to mobility constraints, driver behavior, and high mobility, VANETs exhibit characteristics that are dramatically different from many generic MANETs. This article provides a comprehensive study of challenges in these networks, which we concentrate on the problems and proposed solutions. Then we outline current state of the research and future perspectives. With this article, readers can have a more thorough understanding of vehicle ad hoc networking and the research trends in this area.**

I. INTRODUCTION

The integration of communication technology in state-of the-art vehicles has begun years ago: Car phones and Internet access based on cellular technologies as well as Bluetooth adapters for the integration of mobile devices are popular examples. However, the direct communication between vehicles using an Ad Hoc network, referred to as inter-vehicle communication (IVC) or vehicle ad hoc networks (VANETs), is a relatively new approach. Compared to a cellular system, IVC has three key advantages: lower latency due to direct communication, broader coverage and having no service fee.

Recently, the promises of wireless communications to support vehicular safety applications have led to several research projects around world: the Vehicle Safety Communications Consortium [1] developing the DSRC technology [2] (USA), the Internet ITS Consortium [3] (Japan), the PReVENT project [4] (Europe) or the 'Network on Wheels' project (Germany) [5] are some samples.

To cater to the emerging wireless communication needs with regard to vehicles, in July 2003 ASTM and IEEE adopted the Dedicated Short Range Communication (DSRC) standard (ASTM E 2213-03) [6]. The aim of this standard is to provide wireless communications capabilities for transportation applications within a 1000 m range at typical highway speeds. It provides seven 10 MHz channels at the 5.9 GHz licensed band for ITS applications, with different channels designated for different applications, including one specifically reserved for vehicle-to-vehicle communications.

The specific properties of VANETs allow the development of attractive new services. Some currently discussed examples in the two most relevant areas safety and comfort are as follows [7].

1) Comfort Applications: This type of application improves passenger comfort and traffic efficiency and/or optimizes the route to a destination. Examples for this category are: traffic-information system, weather information, gas station or restaurant location and price information, and interactive communication such as Internet access or music download.

2) Safety Applications: Applications of this category increase the safety of passengers by exchanging safety relevant information via IVC. The information is either presented to the driver or used to activate an actuator of an active safety system. Example applications of this class are: emergency warning system, lane-changing assistant, intersection coordination, traffic sign/signal violation warning, and road-condition warning. Applications of this class usually demand direct vehicle-to-vehicle communication due to the stringent delay requirements.

Although much effort is needed until these applications come to reality, dissemination of various messages is the most important challenge. In this paper we focus on networking problems which should be addressed for message exchanging between vehicles in VANETs.

Since VANETs are new topic of interest in scientific and industry community, we strongly believe a comprehensive survey study about the topic is needed. In the previous work [8] the authors had a review of works in various protocol stack layers. However we will concentrate on the mechanisms instead of protocol stack layers, and then describe each mechanism which can be implemented in different layers.

In this work we first classify the challenges as shown in fig. 1, and then describe networking strategies which should be considered.

The rest of this paper is organized as follows: We clarify distinctive networking properties of VANETs in section 3. In section 4 the literature about safety applications has been reviewed and in section 5 we will bring to debate previous works about comfort applications. In the section 6 we briefly introduce efforts going on for simulation of VANETs and mobility modeling. Finally in sections 7, 8 we conclude our survey and outline some open problems for future works.

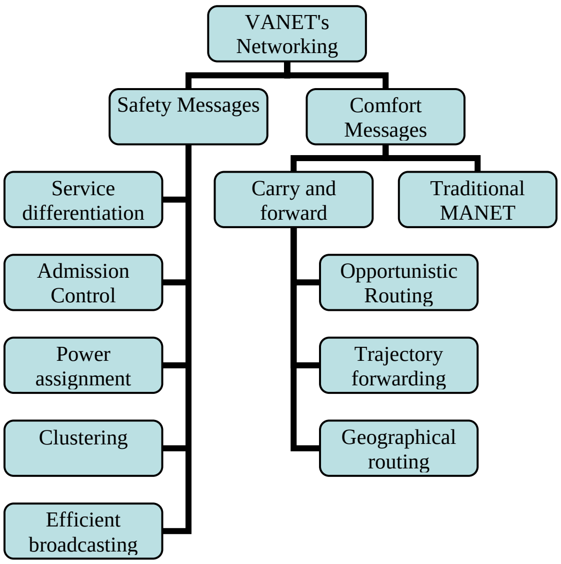

Figure1. Networking challenges in VANETs

II. NETWORKING PROPERTIES OF VANETS

VANETs are an instantiation of a mobile Ad Hoc networks (MANETs). MANETs have no fixed infrastructure and instead rely on ordinary nodes to perform routing of messages and network management functions. However, Vehicle Ad Hoc networks behave in fundamentally different ways than the models that predominated MANET research. Driver behavior, constraints on mobility, and high speeds create unique Characteristics in IVC networks. These characteristics have important implications for design decisions in these networks. The major differences are as follows.

a) Rapid changes in the VANETs topology are difficult to manage. Due to high relative speed between cars network's topology changes very fast. In [9], [10] authors tried to find the approximation of link's lifetime and [11] tried to find trajectory duration for a typical highway scenario through simulation. Although their results could be useful, they are valuable just for considered scenarios.

b) The IVC network is subject to frequent fragmentation, even at a high rate of IVC deployment. Although the connectivity characteristic of MANETs has been studied broadly, there is few research which tries to tackle this problem. It is mostly because VANET's connectivity depends on the scenario. In [12][13] authors tries to captures some relationships between the model of vehicular mobility and connectivity of the networks, but since the results are from simulation they are specific-purpose. Of course being connective for VANETs is not important for emergency safety messages since while the network is not connected there is no problem in safety point of view.

c) The IVC network has small effective network diameter. Rapid changes in link's connectivity cause many paths to disconnect before they can be utilized. In [14] authors studied the effective network diameter in a typical VANETs. This characteristic is important for mostly comfort application as they need to establish unicast and multicast routes (e.g., to the internet gateway).

d) No significant power constraints, unlike sensor and other types of mobile networks where limited battery life is a major concern.

e) Potentially large-scale: In a city center or highways at the entrance of big cities the network could be quite large scale.

f) Variable Network density: the network's density depends on vehicular density which is highly variable. In traffic jam situations the network can be categorized in very dense networks whilst in suburban traffics it could be a sparse network.

g) The topology of the network could be affected by driver's behavior due to his/her reaction to the messages. In other words the content of messages can change network's topology.

III. SAFETY APPLICATIONS

Examples of vehicle-to-vehicle safety communication may include collision warning, road obstacle warning, cooperative driving, intersection collision warning, and lane change assistance [15].

There are two types of safety messages circulate in the control channel (e.g., of DSRC) and can be classified depending on how they are generated: event driven and periodic. The first ones are the result of the detection of an unsafe situation, (e.g., a car crash, the proximity of vehicles at high speed, etc). Periodic messages instead can be seen as preventive messages in terms of safety, and their information can also be used by other (non-safety) applications (e.g., traffic monitoring) or protocols (e.g., routing). Periodic message exchange (also called beaconing) is needed to make vehicles aware of their environment. Thus, they will be able to avoid emergency or unsafe situations even before they appear. Therefore beacon messages essentially contain the state of the sending vehicle, i.e., position, direction, speed, etc., and also aggregated data regarding the state of their neighbors.

It is reasonable to assume that these periodic messages will be sent in a broadcast fashion since the messages' content can be beneficial for all vehicles around. In the following we come to debate the previous related works attempting to providing safety applications.

MAC Layer Issues: As mentioned before, event driven messages should have higher priority than periodic and comfort messages. Thus some mechanisms for service differentiation and admission control are needed. In the other words, we could define three levels of priority: event driven safety messages, beaconing safety messages and comfort messages, in decreasing order.

These mechanisms are highly depended on MAC layer policy. Therefore in the first step the research and industry community should standardized a standard for MAC layer in VANETs. There are some promising MAC techniques for future VANETs [16]. Currently IEEE 802.11a is chosen by ASTM (American Society for Testing and Materials) to be basis for its standard of DSRC [2] and IEEE P1609 Working Group is proposing DSRC as IEEE 802.11p standard [15]. However MAC layers based on UTRA TDD [17] , promoted by CarTALK can be another alternative. Also still some efforts are running on Time Division Multiple Access (TDMA) [18].

Message Dissemination: Due to specific characteristics of safety messages, broadcasting could be the only possible way for message exchange. So it could be possible to get complete coverage to all relevant vehicles.

Message forwarding can help warning message reach vehicles beyond the radio transmission range. In [15], the authors propose a multi-hop broadcast protocol based on slotreservationMAC. Considering the scenario that not all vehicles will be equipped with wireless transceivers, emergency message forwarding in sparsely connected ad hoc network consisting of highly mobile vehicles is studied in [19]. Motion properties of vehicles are exploited in [20] to help with message relay. Two protocols to reduce the amount of forwarding messages were proposed in [21].

In [22] authors presented several context-aware packet forwarding protocols for intra-platoon scenarios. Also in [23] some other algorithms have been proposed which can help vehicles to limit the effects of broadcast storm problem.

Clustering: Clustering neighbor vehicles into manageable units, is crucial to achieve efficient and reliable safety communications. Without boundaries among vehicles:

• Too many vehicles can interfere with each other in contention for radio bandwidth for transmissions.

• All messages may propagate everywhere, flooding the system with messages.

Although many clustering algorithms are proposed in the literature [24], in a vehicle network, where nodes may be densely populated and lined on roadways, the conventional clustering strategies may not be effective to form efficient groups and organize vehicles in clusters. More efficient organizing methods need to be derived with consideration of the vehicular environment. In [25] authors proposed a novel grouping (clustering) method for vehicle ad hoc networks called Local Peer Groups (LPGs). Two alternatives for the proposed grouping are: static and dynamic LPGs. Also application level clustering has been discussed in [26] which considers the problem of group managing in application layer.

Power assignment:

Independently of the type of MAC, mobile nodes exchange information with their neighbors and form a network topology. The topology varies with time as users move, radio channel characteristics vary and users may join or leave the network. Offered traffic, that is, the density of active users per unit area, greatly affects topology. It is well known that when user density is low, a high percentage of nodes may be isolated or form isolated clusters. It is possible to cope with this problem by increasing transmission power, in order to let nodes communicate even if the network is lightly populated. On the other hand, if the user density is too high, nodes compete for radio transmission resources and the average amount of radio capacity per user may be excessively small. This problem can be approached by reducing transmission power so that, in a given area, fewer nodes compete for the radio channel.

The key system parameter involved in this problem is transmission power. If nodes transmit at fixed power, they will find few neighbors if traffic is low or an excessive number of neighbors if offered traffic is high. By adjusting transmission power adaptively, that is, by increasing power when the number of neighbors is small and by decreasing power when the number of neighbors is large, a node jointly copes with the isolation problem at low load and with the limited system capacity at high load.

Although Channel capacity and power control are broadly studied concepts in ad hoc networks and large number of studies tried to optimize the channel throughput or capacity adjusting the transmission power.

Up to now, The particularity of having safety as main goal brings to VANETs new constraints not considered before. Most of the studies address unicast environments and try to improve the spatial reuse minimizing the interference or energy consumption. These studies find the path to the destination that minimizes energy consumption and/or maximizes the overall throughput. In the category of ‘energy concerned protocols’ would fit most of the topology control proposals such as [27] that propose adaptive algorithms that make use of only local information to adjust their power. Although we can find related issues and methodologies in all these works we have to remember that energy efficiency is not an issue in VANETs where nodes have unlimited power supply. In addition, another common goal of these approaches is to keep the network connected for unicast flows, which is a totally different approach than the one in VANETs.

the most related piece of work to our special case is as follows: Li et al. in two steps [28] and [29] propose, first, an analytical model able to find a transmission power that maximizes 1-hop broadcast coverage and, second, an adaptive algorithm that converges to the beforehand fixed transmission power. Although they focus on a pure broadcast environment their assumptions make their approach infeasible for VANETs: a) all nodes are static and b) all nodes use the same transmission power.

In [30] authors proposed a power assignment algorithm called FPAV the goal is to make sure that nodes close to the sender will receive its messages with high probability while ensuring fairness in the overall system.

Authors in [31] discus an important characteristic of VANETs: dependency of network density on the characteristics of vehicle traffic flow. Thus they found a method for estimating density of vehicles without any message exchanging by using traffic flow theory. By using this estimation each vehicle can set its transmission range for better network performance.

In other work G. Caizzone at el., proposed a power control algorithm which is based only on local information and no exchange of power-related signaling among nodes is required [32]. This target is obtained by controlling transmission power, so that the number of neighbors of each node is always within a minimum and maximum threshold.

IV. Comfort Applications

Generally, four services that have immediate application for comfort issues are unicast, multicast, anycast and scan.

To illustrate an application using these services, consider a vehicle (or a traffic signal controller) wishing to obtain information concerning some remote region. The vehicle/controller needing the information first queries its own proximity (*multicast*) to determine if a near-by vehicle happens to have this information. Any vehicle having such information can respond (*unicast with approximate/precise location*). If no one replies within a certain amount of time, the vehicle/controller sends a query to any vehicle in the remote region (*anycast*). Receivers in the remote region with this information can respond. The response can be disseminated as *unicast with approximate/precise location,* or *multicast* if caching is desired.

Another application is mobile Internet access. Fixed location Internet gateways may be placed along roads. A vehicle wishing to access the Internet first propagates a query through a region for gateways (*scan*). Gateways receiving the query can respond to the requesting vehicle (*unicast with approximate location*). The requesting vehicle picks one responder and begins to interact with it. The communication from the vehicle to the gateway is *unicast with exact location* while the reverse direction is *unicast with approximate location*.

Because of distinctive networking characteristics of VANETs as described before in this paper, data dissemination, especially, comfort messages comes on the shadow of a class of routing strategies which discuss the problem in sparse networks. In the following we briefly introduce these algorithms and investigate their applicability to VANETs.

Data delivery in ad-hoc network heavily relies on the routing protocol, which has been extensively studied for many years. However, most protocols assume that intermediate nodes can be found to setup an end-to-end connection; otherwise, the packet will be dropped. Since the network diameter in VANETs is relatively small, there should be other strategies for data delivery in vehicle networks and traditional algorithms are not applicable. To deal with disconnections in sparse ad hoc networks, researchers [33] adopt the idea of *carry and forward*, where nodes carry the packet when routes do not exist, and forward the packet to the new receiver that moves into its vicinity. There exist three important categories of data delivery protocols which can be used in companion with carry and forward mechanism in VANETs: Geographical forwarding, Trajectory based forwarding, Opportunistic forwarding, which have been discussed briefly in following. In addition recently some algorithms have been presented which use the combination of two or three of the mentioned mechanisms[34] [35]

Geographic Forwarding: Geographic routing uses nodes' locations as their addresses, and forwards packets (when possible) in a greedy manner towards the destination. The most widely known proposal is GFG/GPSR [36]. One of the key challenges in geographic routing is how to deal with dead-ends, where greedy routing fails because a node has no neighbor closer to the destination; a variety of methods (such as perimeter routing in GPSR/GFG) have been proposed for this. More recently, GOAFR+[37] proposes a method for routing around voids that is both asymptotically worst case optimal as well as average case efficient. Geographic routing is scalable, as nodes only keep state for their neighbors, and supports a fully general any-to-any communication pattern without explicit route establishment. This forwarding strategy can be used in vehicular ad hoc networks for both unicasting and multicasting [38].

Trajectory Forwarding: This mechanism [39] directs messages along predefined trajectories. It was presented to work well in a dense network. Despite their sparseness, V2V networks should be a natural application of trajectory based forwarding because messages are moving along the road graph. Trajectory forwarding can help limit data propagation along specific paths and thus reduce message overhead.

A forwarding trajectory is specified as a path extending from the source to the destination region. The road network can be abstracted as a directed graph with nodes representing intersections and edges representing road segments. Geographical forwarding attempts to move the message geographically closer to the destination. For an ad-hoc network deployed in a two-dimensional area, geographical distance is often defined as Cartesian distance [40].However, in V2V networks, geographical distance has to be defined as graph distance [41].

Opportunistic forwarding: This mechanism as suggested in [42], targets networks where an end-to-end path cannot be assumed to exist. Messages are stored and forwarded as opportunities present themselves. When a message is forwarded to another node, a copy may remain with the original and be forwarded again later to improve reliability. Some simple implementations, e.g., two nodes exchange data whenever they can communicate [43], work well if the data needs to be propagated to everybody. But they are inefficient if a message is to be delivered to some specific receivers, e.g., those in a certain region. In this case, it is more efficient to forward messages in a way that they migrate closer to the eventual destination, and not to others. In VANETs, since vehicles are moving in roads, it is possible their opportunistic meet for exchanging information. In [44] authors describe an analytical description of message dissemination which is based on opportunistic forwarding.

In [34] authors proposed a data dissemination technique called vehicle-assisted data delivery (VADD) which is based on the idea of carry and forward. This method makes use of the predicable mobility, which is limited by the traffic pattern and road layout. Another sample in this category is MDDV [35]. It exploit vehicle mobility for data dissemination, and combines the idea of opportunistic forwarding, trajectory based forwarding and geographical forwarding.

V. Mobility Modeling and Simulation

For Classical MANETs studies, researchers often adopt a common set of simulation parameters, such as:

• The number of nodes is small (i.e., <100m).

• Nodes move in an open field.

• Nodes move according to a random waypoint model or the Manhattan mobility mode with arbitrary pause times and often with arbitrarily uniform speed distributions between 0 and 20m/s.

• Nodes transmit signals that propagate without error to other nodes within a radius of 250m.

Such parameter settings are clearly inadequate for many MANETs, and particularly for VANETs. For example, in [45], the authors have shown that the relationship between distance and signal reception between two nodes is, at best, weakly correlated over large distances. Further, besides settings such as conventions in large conference halls, it is difficult to imagine many scenarios where nodes will move in an open field and/or in a way that can be accurately modeled by random waypoints. Specifically in VANETs, the number of nodes is generally large, the mobility of these nodes is constrained by roads and their velocities must be adjusted according to traffic control mechanisms (e.g. stop signs and traffic lights), speed limits and the level of congestion in the vehicular network.

The ad-hoc research community is increasingly aware of the limitations resulting from some of these simplifying assumptions [45]. In the context of VANETs, various research groups are designing experiments that better model real vehicular traffic scenarios. For example [46] uses CORSIM, a proprietary vehicular traffic simulator, to provide mobility traces for the simulation. Also in [47] a new mobility model call STRAW which incorporates a simple car-following model with traffic control to introduce vehicular congestion, which models real traffic conditions.

There is another trend toward coupling between network simulators (e.g., NS, GloMoSim) with Vehicle traffic simulators (e.g., CORSIM, VISSIM). So co-simulation of network traffic and vehicle traffic can be conducted [48]. Another advantage of this approach is that the effects of driver behavior can be simulated [49].

VI. Conclusions and Future Perspectives

This paper presents a state of the art survey in networking challenges in vehicular ad hoc network which is a promising technology for intelligent transportation system (ITS).

Although many problems are not yet solved, the general feeling is that vehicles could benefit from spontaneous wireless communications in a near future, making VANETs (Vehicular Ad-Hoc Networks) a reality. In this way we classified the problems into several aspects and surveyed each issue briefly.

In the following we summarize the paper and present some proposals for the future works.

1. For being practical, it is needed that research and industry community come to agreement about a MAC technology. The trend is toward an extension of IEEE 802.11 called DSRC.
2. Because of the emergency of safety messages and their strict QOS requirement, there is a severe need to optimum methodologies for service differentiation and admission control.
3. Due to limited bandwidth of channel, there is a need for some techniques for controlling the amount of data sent to the network. This problem addressed in [15] as congestion control.
4. Efficient broadcasting for safety messages for getting full coverage and low latency should be addressed increasingly.
5. There are some comfort applications which will have very good business market (e.g., in-vehicle internet access). For providing these applications many problems related to routing in partitioned ad hoc networks should be solved.
6. General characteristics of VANETs (i.e., connectivity, coverage) are deeply related to the traffic flow, which is variable both in time and space. It is strong belief that these characteristics should be captured in a way to design reliable and high performance protocols and application. There are some works in this area [31] [50] but much effort is needed.
7. Since the mobility of VANETs can not be captured by general mobility models of MANETs, special mobility models by making use of traffic flow theory should be proposed. So the simulation results could be trustable.
8. Since experimental evaluation of VANETs is expensive, simulation technique should be improved. There are some works attempting to conduct co-simulation. In this case two or three simulators, simulate network and traffic characteristics and driver behavior.

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