Vehicular Ad Hoc Network (VANET): A Survey, Challenges, and Applications

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Vehicular Ad Hoc Network (VANET): A Survey, Challenges, and Applications

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Abstract An ad hoc network consisting of vehicles has emerged as an interesting but challenging domain where a lot of new application may find their place. Though research in this field is on since last two decades, large-scale practical implementation still require some time. In this paper, a survey of current challenges and potential applications, incorporating medium access control schemes, routing approaches, hardware and spectrum issues, and security and privacy issues for VANETs, is presented.

Keywords VANETs · Challenges · Applications

1 Introduction

Vehicular ad hoc network (VANET) is a challenging network environment that pursues the concept of ubiquitous computing for future. Vehicles equipped with wireless communication technologies and acting like computers will be on our roads soon, and this will revolutionize our concept of traveling. VANETs bring lot of possibilities for new range of applications which will make our travel not only safer, but also fun.

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The concept of VANETs is quite simple: By incorporating the wireless communication and data sharing capabilities, the vehicles can be turned into a network providing similar services to the ones we are used to in our office or at home networks.

VANET is considered an offshoot of mobile ad hoc networks (MANET). In many ways, VANETs are similar to MANETs. For example, both networks are multi-hop mobile networks having dynamic topology. There is no central entity, and nodes themselves route data across the network. Both MANETs and VANETs are rapidly deployable without the need of an infrastructure.

VANETs have some distinguishing characteristics in many ways [1]. Both MANET and VANET are mobile networks; however, the mobility pattern of VANET nodes follows geometrical patterns. MANETs are often characterized by limited storage capacity, low battery, and processing power. VANETs, on the other hand, do not have such limitations.

In VANETs, any node may move at high relative velocity. This makes the lifetime of communication links between nodes quite short. Node density is also unpredictable; during rush hours, the roads are crowded with vehicles. Similarly some roads have more traffic than other roads.

Specialized and mixed node deployment patterns and versatile mobility have made the problem more complicated. These network topologies which are highly fluent in nature also involve large variations in node densities and relative node velocities. Scalability considerations of futuristic networks may require support for several thousands of nodes spanned in very large areas. Quality-of-service (QoS) requirements for such multidimensional and complicated networks pose another challenging dimension.

In addition to this, there are many new and unique applications emerging for VANETs, such as traffic management, emergency response services, infotainment, theft detection, law enforcement, military and commercial fleet, and convoy management [2].

Although many different solutions have been presented by research community to answer the problems, consensus has developed on four major approaches, which are given as:

- Software-defined hardware to adapt according to available resources.
- Provision of efficient MAC scheme for maximum utilization of physical resources.
- Selection of best possible route incorporating runtime changes.
- Designing of network efficient applications.

On the one hand, efficient MAC and hardware will provision maximum physical layer resources for upper layer's data, to provide best QoS. On the other hand, efficient applications and routing will try to use minimum network resources. These two pronged and mutually complimentary strategies, known as cross-layer architecture, have opened up new dimensions and possibilities for researchers. Several academic and industrial projects have been initiated to address these challenges [3].

The rest of this paper is organized as follows: Sect. 2 presents VANET applications and their requirements; Sect. 3 discusses current challenges for VANET, and Sect. 3 concludes the paper.

2 Challenges

Though, initially it was considered that VANET is a subclass of MANET, most of the research and designs related to MANET were applied to VANET. However, subsequent progress showed significant difference among both classes of networks. VANET paradigm design for communication, privacy, and provisioning coupled with security cannot be compared directly with MANET.

To highlight the peculiar VANET issues, a lot of research has already been done [4, 5]. However, many challenges are still open to researchers for the optimum solution due to non-implementation of VANET at large scale. In subsequent discussion, key challenges of the VANET are highlighted.

2.1 VANET Architecture

Architecture definition was considered as a prime problem by many standardization organizations, such as IEEE and ISO [3]. The work on formulation of four main standards started in parallel, lacking major collaboration and coordination. These standards include WAVE, C2C, CALM, and ARIB. Different regional agencies, political forces, and car manufacturers backed different standards without focusing a global harmony.

2.1.1 CALM

International Standard Organization (ISO) started its own standard named as CALM (Communications, Air-interface, and Long and Medium range). This standard is although quite complex focused on seamless inter-node and intra-node communication. The concept of CALM architecture is a heterogeneous cooperative communication framework. CALM was the first one to introduce any available interface at MAC layer. However, seamless handshake of different MAC interfaces is still open to researchers.

2.1.2 C2C

European automobile industry backed a VANET standard under the label of GEoNEt through Car-2-Car Communication Consortium (C2C-CC). It is a comprehensive architecture, mainly aiming at active safety applications. It is significantly different from Internet architecture. However, it supports many available interfaces at MAC and PHY layers.

2.1.3 WAVE

IEEE started its work under the label of WAVE (Wireless Access in Vehicular Environment). Though WAVE is a complete protocol stack labeled as 1609 protocol family and is based on current Internet model, so far no major large-scale implementation is available other than test laboratories and small-scale projects [2]. Moreover, WAVE only allows IEEE 802.11p MAC for all kinds of communication, which is considered as a bottleneck by many researchers.

2.1.4 ARIB

Japanese Standardization Agency: The Association of Radio Industries and Businesses (ARIB) defined multiple VANET architectures. Although mainly relying on WAVE, first ARIB standard named as ARIB-2001 uses only single MAC layer at 700 MHz band. Later, ARIB-2004 introduced use of 5.8 GHz band. ARIB-2008 introduced use of infrared for toll payment. Like WAVE, ARIB only focuses on emergency VANET messages. Currently, JAPAN is the most VANET compliant country in the world.

2.2 Transmission Capacity Limits

According to researchers, fundamental communication limit for mobile networks is extremely difficult [6, 7]. Researchers have defined transmission capacity as the number of successful simultaneous transmissions within a unit region [8]. Shannon in 1948 gave the formula for the capacity of the link-based networks [6]. Researchers showed that in mobile ad hoc networks, where peer-to-peer communication, interference, and mobility play an important role, Shannon's framework is not applicable [8, 9]. Andrews et al. [8] showed that the researchers have yet not been able to find a framework which can be used to find the fundamental capacity of an ad hoc network.

Interference, noise, and back-off delays are major concerns for any MAC protocol. Out of these, interference is the most limiting factor for VANETs. Interference must be mitigated to meet minimum signal-to-interference-plus-noise ratio (SINR) threshold. Current MAC protocols use techniques such as carrier sensing, random back-offs, spread spectrum and guard zone-based inhibition, to mitigate interference. Under a dense VANET environment, such as traffic jam and parking areas, the number of nodes, hence the interference, will increase overwhelmingly. There are a lot of researchers who have evaluated different MAC schemes. However, no significant work is done to check the transmission capacity under VANET architectures. Presence of hundreds of nodes will cause severe MAC issues, which will increase manifolds in case of an emergency.

2.3 Routing Techniques

Routing techniques and protocols are one of the most researched topics in VANET [1]. However, the main challenge to design a VANET routing protocols which is suitable to all scenarios and conditions is still open. More or less, researchers have consensus that static or single routing scheme cannot satisfy varying VANET network conditions. Summary of a few surveys on routing in VANET [1] is given below:

- Before determining routes, varying real traffic state is generally not considered by many protocols.
- All real-life traffic conditions cannot be met through current VANET routing protocols.
- Under rapidly changing VANET topologies, topology-based routing lacks efficiency.
- Delay tolerant networks, such as disconnected nodes, cannot be covered using vehicle-to-vehicle communication design.
- Use of non-delay tolerant routing protocols face degradation during disconnected scenarios.
- Though periodic or proactive routing approaches provide low latency, network resources are generally underutilized due to unused paths.
- Though on-demand or reactive routing protocols provide better resource utilization, latency in route determination is major limitation.
- Though geographical information is considered very helpful for VANET, mapping of geographical regions as per road layout is a big problem.
- Network partitioning and availability of accurate and updated location information causes significant network resource wastage.
- Geographical routing can form routing loops or a packet can travel longer route due to network partitioning.
- Under high-speed movement, inherent latency of GPS [10] may cause inaccurate emergency alerts, e.g., accident alert.

Efficient routing focuses on three main goals, i.e., efficiently finding most suitable route from source to destination, updating the new route at run time on availability of a better one, and lastly maintaining the route in the case of route failure. Most of the current research covers the first and third goals, whereas the second goal is generally considered as the logical outcome of the first one [1].

To find a route between two nodes, routing algorithms currently focus on three basic questions.

- What information (metrics) should be shared for determination of route?
- How and when the selected information should be shared within the network?
- How route should be determined using the shared metric?

To answer the metric issue, many different metrics for route finding have been identified by the researchers. Subsequently, hundreds of protocols have been proposed using a single or a combination of metrics. Metrics can be grouped as localized, end-to-end, and cross-layer [1].

Second issue of how to disseminate the routing information is generally simpler, and researchers have considered mainly three types:

- Through sharing of repeated/automated topology beacons regardless of situation change.
- Through sharing of topology updates, either for new route determination or on link breakage.
- Derivatives of above two approaches.

For dissemination of selected metric information from a single node perspective, choices restrict to first two only. The decision for sharing the metric to next hop is determined by the role of said node, i.e., source node or transit node. Decision for both of the roles is generally preconfigured without any significant runtime intelligence.

In the absence of any deployed VANET architecture, early research on VANET routing was based on the simulation scenarios. The main goal of this research was to provide safety information to nearby vehicles. With the advancement in research, the need emerged to incorporate roadside servers and Internet. Such requirement demanded multi-hop communication and more robust routing schemes based on realistic traffic and mobility and communication constraints.

Current routing research is primarily focused on routing algorithms with stationary route update policy, using off-time configurations only. Adaptation in routing has also been proposed by researchers through different approaches [1, 11]. The requirement of route update in the lifetime of previous route requires updated information of network conditions. Analysis of different situations shows that the route update mechanism in the current routing approaches is more or less fixed and predefined in the protocol, instead of being based on runtime network conditions.

To answer the routing challenges of dynamic networks, e.g., VANET, having range of node densities with rapid topology changes due to high mobility and scalability, there is a need of new, more flexible and adaptive route update and maintenance strategies. These new route update strategies must work efficiently, supporting a variety of realistic node deployment patterns, mobility scenarios, and QoS requirements.

2.4 Security and Privacy

Though most of the VANET security issues are same as MANETs, privacy issues are more complicated in VANETs. Security concerns are more complex due to the scalability, frequent topology changes, high mobility, and variety of applications. In addition to this, there is a compromise among authentication and non-repudiation against driver/vehicle privacy. Figure 1 enlists some of the security concerns related to the VANET.

After deployment of VANET, intelligent on-board applications may keep record of large amount of vehicle movement data and personal information. Theft or misuse of such information can lead to serious privacy and general security issues. There is a dire need to overcome these concerns before large-scale deployment of VANET.

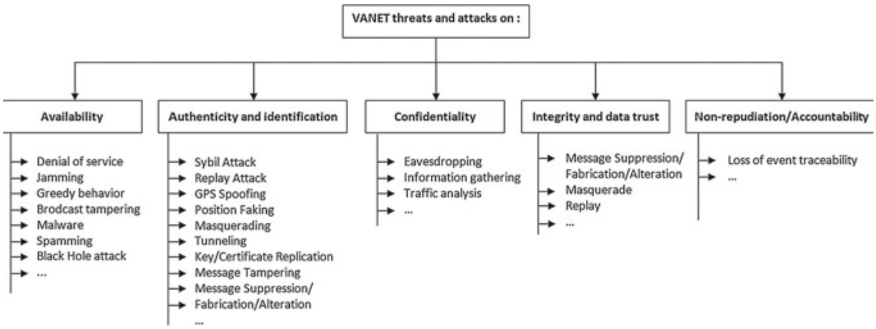

Fig. 1 Categorization of VANET Attacks

Though researchers are already doing efforts to address the security problems in VANETs, a comprehensive strategy to answer the issue is still open considering the unique characteristics of heterogeneous vehicular networks. Some characteristics of VANETs pose challenges to meet security requirements, such as low overhead, time sensitivity, minimum hops, use of stored information, and optimized data dissemination solutions.

Another major issue is to prevent attackers from interfering with both the integrity of the exchanged messages and the availability of the system. Tracking a target is a fundamental functionality in VANETs for communication protocols and also for applications and services. Tracking requires creating a mechanism to identify the path a node follows in the network and predict the next positions if necessary.

2.5 Verification and Validation

Most of the research is validated through theoretical modeling against simulative studies. Such methodology provides definition for upper and lower practical bounds prior to implementation. However, most of the research for MAC and routing strategies is based on routing scenarios defined in well-known and especially open-source simulators [11]. A survey on network simulators [12] identifies many significant limitations in scenarios, environments, and protocol patch implementations.

The fact of simulation limitations is also evident from different results even for same scenario and using same simulator. The large variations among graphs for different metrics, e.g., node density, velocity, delay, and throughput, under same environment demand clear definition and usage of simulative scenarios as well as metrics for final evaluation. Lack of such definitions leads to many questions on viability of results. The major limitations can be identified as:-

- The term of ‘highly scalable’ has gone beyond the scope of few hundred nodes. Traffic jams and parking areas may have thousands of nodes, heavily packed.

- The term velocity or speed cannot be compared with relative mobility. Two nodes moving in same direction even at the speed of fighter aircraft can be considered static with respect to each other.
- The active node density can be compared neither with simple node density nor with scalability, especially for networks such as VANETs. There can be scenarios with very high node density, but with very limited number of nodes practically participating in active communication.
- There can be different types of data behaviors experienced at MAC layers. Variations to single hop to multiple hop communication and versatile QoS support cannot be guaranteed in all scenarios of same network.

Accordingly, there is a need to verify and validate any VANET protocol or approach incorporating following conditions.

- Driver and vehicle model
- Traffic flow model
- Communication model
- Application model
- Driver behavior model

2.6 Software-Defined Hardware

A significant increase in VANET deployment will flood VANET applications. Such increase will be more visible in urban regions. Resultantly, large number of nodes will exhaust communication resources and may lead decrease in efficiency for safety applications. At the same time, use of bandwidth hungry infotainment applications, such as multimedia applications and information systems, can lead to spectrum scarcity.

Under congested circumstances, use of cognitive or software-defined hardware can provide efficiency in VANETs. This can enable efficient radio spectrum usage and overall vehicular communication efficiency.

As in many countries, spectrum regulators are utilizing unused license bands for unlicensed services over different space and time. Unused licensed spectrum bands include television and broadcasting. Such allocation makes software-defined hardware an attractive choice for VANET. Resultantly, cognitive radios and dynamic spectrum allocation is an open research topic to enhance the spatiotemporal efficiency of VANET PHY and MAC.

3 Applications

The most targeted and ultimate goal was to ensure safer travel by generating early warnings and timely response to the situations. However, to increase the market penetration, other classes of applications such as traffic control and provision of

Fig. 2 Categorization of VANET Applications

infotainment are also being considered [2]. Different VANET architectures support multi-channel operation for safety- and non-safety-related applications on a different channel. Based on the primary purposes, VANET applications are typically classified into two major categories [13–15] (Fig. 2):

- Safety-oriented applications
- Non-safety applications

3.1 Safety-Oriented Applications

The aim of safety applications was to ensure safer travel by generating early warnings and timely response to the situations. These applications are used to avoid the risk of road accidents by distributing information about hazards and obstacles. Safety applications can play an important role in avoiding accidents or minimizing the impact of accidents. According to a study, if the driver gets a warning half a second before the collision, more than half of the accidents can be avoided [16].

On the road, there are many considerations for a driver, such as attention toward traffic lights, pedestrians, and other vehicles as well as following GPS directions. This is impossible for a driver to focus their full attention on all of these events at once. For example, a driver getting ready to make a right turn might easily overlook a pedestrian crossing on the left side of the street. Therefore, the number of accidents can also be reduced with the help of early warning system. Some other kinds of warning systems can also be deployed to avoid the accidents, e.g., work zone warning, stopped vehicle warning, and low bridge warning for trucks.

Some safety applications can also be helpful after accident such as to send emergency notifications to nearby emergency responders. Such applications also manage traffic flows and identify alternative routes.

Besides warning messages, safety applications are also used to provide assistance to a drive about lane change, navigation and to avoid collisions by applying automatic emergency breaks. Safety applications also guide the driver about speed limit to avoid collisions.

Safety applications demand strict time delay bounds. Even a fraction of a second is important in decision making. Thus, the requirement of hard deadline posed by the safety applications requires special handling at lower layers. As network layer is concerned, not much routing is involved in safety applications, because the target audiences for the messages are usually in the neighborhood. Therefore, the messages need not to be sent to nodes more than one hop away.

3.2 Non-safety Applications

Although the main purpose of VANET is to provide safety, however, some non-safety applications are also being considered to increase the market penetration such as traffic efficiency, control management, and some infotainment applications [2].

3.2.1 Traffic Control and Management Applications

The main purpose of traffic control and management applications is to optimize traffic flows and to minimize the travel time by avoiding traffic congestions or assist the driver about best route with updated road conditions. This can involve the use of some roadside equipment, e.g., intelligent traffic signals and e-sign boards. Information about the road congestions ahead can definitely help in reducing the congestion and improving the capacity of roads.

Some other applications can also be envisioned such as automated call to emergency services, enroute, and pre-trip traffic assistance. An interesting application is eToll plaza, where vehicles do not need to stop to pay toll fee. Vehicles can communicate with the roadside infrastructure, where it can be recognized and a fee can be charged against its account.

Congestion at road intersections can be handled in an efficient manner using intelligent traffic signals. These traffic signals can adjust themselves in response to the traffic conditions at intersection and can even communicate the status to neighboring intersections. Neighboring intersections can thus display this information on the e-sign boards and adjust their traffic signals accordingly.

Traffic management applications extensively use the roadside infrastructure. Some infrastructure may be available to be used by any user while some will need subscription. For example, eToll infrastructure will require a subscription to offer its services. For these applications, the infrastructure needs to be managed and updated. For these applications to work, the infrastructure with relevant information needs to be managed and controlled. Comfort and Infotainment Applications be managed and controlled.

3.2.2 Comfort and Infotainment Applications

Besides road safety applications, comfort and entertainment applications are also envisioned for VANETs. These applications aim to provide comfort and entertainment to travelers. Such applications can be further categorized into three types: infotainment, mobile e-commerce, and city leisure information.

The passengers in a vehicle can enjoy the facility of Internet connectivity where other traditional wireless Internet connectivity options (Wi-Fi, Wi-MAX, etc.) are not available. Even in the presence of such options, a node connected to Internet through these options can share its connectivity with other vehicles through VANET. Peer-to-peer applications can also find their place in VANETs, e.g., gaming, chatting, file sharing, and Web browsing.

Different companies use VANET for advertisements or announcements of location-based sales information; for example, gas stations can announce updated prices or different restaurant can highlight different deals to attract travelers. Beside this, some VANET applications make it easy for travelers to see the nearest service shops or restaurant, etc. The messages sent by such type of applications usually need to be delivered over multiple hops; hence, routing will be involved.

Infotainment applications in VANET can be grouped as peer-2-peer and Internet-based applications. These applications are very much useful to provide services such as sharing multimedia files, movies, and songs among the vehicles in the network. People can connect with the Internet all the time, thereby VANET provides the constant connectivity of the Internet to the users. These applications provide comfort for travelers such as advanced traveler information systems and general entertainment.

4 Conclusion

This paper presents VANETs by highlighting current challenges and applications. The applications envisioned are likely to find their place in inter-vehicular communication, hence making the widespread VANET deployment possible in near future. Although significant research has already been done, many key factors for their success are still open. There is lack of profound performance evaluation of different schemes and versatile and comprehensive real-life scenarios in VANET context. The few studies that are currently available are not only limited in scope, but also restricted to a specific scenario. Hence, some upcoming challenges are still open to researchers.

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