Data Communication in VANETs: A Survey, Challenges and Applications

Felipe Domingos da Cunha, Azzedine Boukerche, Leandro Villas, Aline Viana, Antonio A. F. Loureiro

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Abstract: VANETs have emerged as an exciting research and application area. Increasingly vehicles are being equipped with embedded sensors, processing and wireless communication capabilities opening a myriad of possibilities for powerful and potential life changing applications on safety, efficiency, comfort, public collaboration and participation while they are on the road. Although, considered a special case of a Mobile Ad Hoc Networks, VANETS hold a vital feature - the possibility to affect people's life or death decisions. Due to the particular characteristics, from highly dynamic topology to intermittent connectivity, VANETs have great challenges lie ahead, to mention a few: different application QoS requirements, and conflicting privacy and safety issues. In this paper, a view of VANETs is presented from the communication and application challenges perspective.

Key-words: Vehicular Networks, Ad-hoc Networks, Survey

RESEARCH CENTRE
SACLAY – ÎLE-DE-FRANCE

1 rue Honoré d'Estienne d'Orves
Bâtiment Alan Turing
Campus de l'École Polytechnique
91120 Palaiseau

Communication des données: Une sondage, défis et applications

Résumé : Réseaux de Véhicules sont apparus comme un domaine de recherche et d'application passionnants. De plus en plus, les véhicules sont équipés avec des capteurs embarqués et ont des capacités de traitement et de communication sans fil, qui ouvrent une infinité de possibilités d'applications puissantes qui peuvent changer notre vie quotidienne en terme de sécurité, d'efficacité, de confort, et de la collaboration et participation public sur la route. Bien que considéré comme un cas particulier de réseaux ad hoc mobiles, les réseaux de véhicules maintient une fonction vitale - la possibilité d'influer sur la vie ou sur les décisions liées à la mort. En raison des caractéristiques particulières, de la topologie très dynamique avec de connectivité intermittente, les réseaux de véhicules ont de grands défis à relever, pour ne citer que quelques-uns: de différentes demandes de qualité de service de l'application, et les questions de confidentialité et de sécurité conflictuelle. Dans cet article, le réseau de véhicules est présenté par rapport a ses défis de communication et d'application.

Mots-clés : Réseaux Ad-Hoc, Réseaux Voitures, Survey

1 Introduction

Information and communication technology are the driving force behind some of the most important innovations in the automotive industry and in our society. In the last two decades, mobile communications have changed our lifestyles allowing us to exchange information, anywhere at any time. The use of such mobile communications systems in vehicles is expected to be a reality in the next years. This new paradigm of sharing information among vehicles and infrastructure will enable a variety of applications for safety, traffic efficiency, driver assistance, infotainment, and urban sensing, to be incorporated into modern vehicle designs. These applications will be a reality once emerging vehicular networks in the forms of intra-vehicle, vehicle-to-vehicle and vehicle-to-infrastructure communications are widely available. This is expected to be the case since industry, telecom and network operators, academia, and governments worldwide are devoting expressive resources on the deployment of vehicular networks to have a more secure transportation infrastructure. This can be certified by different national and international projects in government, industry, and academia devoted to vehicular networks [**?**, **?**].

Given the advances in information technology and communication, the concept of a networked vehicle has received immense attention all over the world. A current trend is to provide vehicles and roads with capabilities to make the transportation infrastructure more secure, more efficient, urban aware, and to make passengers' time on the road more enjoyable. In this context, a transportation infrastructure more secure means to provide information about traffic jams, accidents, hazardous road conditions, possible detours, weather conditions, and location of facilities (e.g., gas stations and restaurants); more efficient means an increased road network capacity, reduced congestion and pollution, shorter and more predictable journey times, lower vehicle operating costs, more efficient logistics, improved management and control of the road network, and increased efficiency of the public transport systems. Vehicles can also be used to collect, analyze and share knowledge of and Area of Interest (AoI) [**?**] in applications such as civilian surveillance (photo shots of violence scenes in progress sent to public authorities via infrastructure), pollution control, roads and traffic planning and innumerable others urban aware applications. Finally, more enjoyable means to provide Internet access, tourist/advertising information, social media on the road, guidance for people to follow each other on the road, games, file downloads, and social applications (e.g., microblogs and chats). These applications are typical examples of what we call an Intelligent Transportation System (ITS), whose goal is to improve security, efficiency, urban awareness and enjoyment in transportation systems through the use of new technologies for information and communication.

An important component of an ITS is the vehicular communication network (VANET) that enables information exchange among vehicles. A VANET is a special case of a Mobile Ad Hoc Network (MANET) in which vehicles equipped with wireless and processing capabilities can create a spontaneous network while moving along roads. Direct wireless communication from vehicle to vehicle make it possible to exchange data even where there is no communication infrastructure, such as base stations of cellular phones or access points of wireless networks.

VANETs and MANETs present some similar characteristics such as low bandwidth, short range of transmission and omnidirectional broadcast. However, VANETs have some unique characteristics such as:

- *Highly dynamic topology*: vehicles move at different directions and/or speed and, as a result the topology changes constantly;
- *Frequently disconnected network*: the highly dynamic topology results in frequent changes in its connectivity, thus the link between two vehicles can quickly disappear while they are transmitting information;

- *Geographical type of communication*: vehicles to be reached typically depend on their geographical location. This differs from other networks where the target node or a group of target nodes are defined by an ID or a group ID;

- *Constrained mobility and prediction*: VANETs present highly dynamic topology but vehicles usually follow a certain mobility pattern constrained by roads, streets and highways, traffic lights, speed limit, traffic conditions, and drivers' driving behaviors. Thus, given the mobility pattern, the future position of the vehicle is more feasible to be predicted;

- *Propagation model*: typically, VANETs operate in tree environments: highway, rural and city. In a highway, the propagation model is usually assumed to be free-space, but the signal can suffers interference by the reflection with the walls around the roads. In a city, its surroundings can be complex and more difficult to communication due to variable node density and the presence of buildings, trees and other objects that act as obstacles to the communication signal and cause shadowing, multipath and fading effects. Usually, the propagation model is assumed to be not free-space due to those characteristics of the communication environment. In the rural environments, due to the complex topographic forms (fields, hills, climbs, dense forests, etc.), it is important to consider the signal reflection and the attenuation on the signal propagation. Thus, in this scenario the free-space model is not appropriate. As in any other network, the propagation model in a VANET must consider the effects of potential interference of wireless communication from other vehicles and the existence of largely deployed access points.

A VANET will be a major step toward the realization of intelligent transportation systems. Nowadays, a large number of car manufacturers are supplying vehicles with onboard computing and wireless communication devices, in-car sensors, and navigation systems (e.g., GPS and Galileo) in preparation for the deployment of large-scale vehicular networks. By using different sensors (e.g., road and weather conditions, state of the vehicle, radar and others), cameras, computing and communication capabilities, vehicles can collect and interpret information with the purpose of helping the driver to make a decision, particularly in driver assistance systems. In this case, there is a strong support from the industry, academia, and standardization agencies to develop standards and prototypes for vehicular networks.

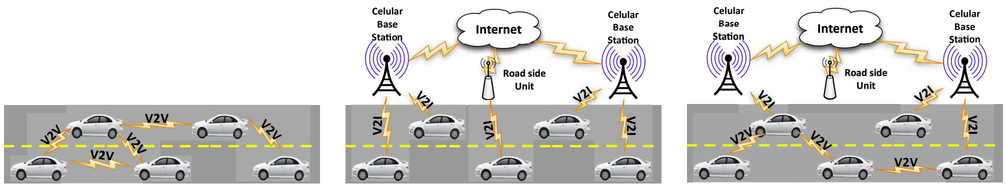
In the literature, there are several studies addressing different aspects of a VANET, such as: applications [?, ?], communication [?, ?, ?, ?, ?], security [?] , routing protocols [?, ?, ?, ?], cloud computing in VANETs [?], and generalize aspects [?]. However, this survey provides an in depth discussion about the architectures of vehicular networks, including the protocol stack and their protocols, classified according to the each layer. It also presents a comprehensive overview of the current state of the art of applications and data communication. In addition, some challenges and future perspectives for vehicular networks are discussed in order to guide new researches.

This work is organized as follows. Section 2 examines the VANET architectures. Section 3 presents the protocol stack for VANETs. Section 4 discusses existing and future applications for vehicular networks. Section 5 debates some communication challenges for VANETs. Finally, Section 6 concludes this work and presents some future directions.

2 Data Architecture and Communication in VANETs

The advances in mobile communications and the current trends in ad hoc networks allow different deployment architectures for vehicular networks in highways, urban and rural environments to support different applications with different QoS requirements. The goal of VANET architectures is to allow the communication among nearby vehicles and between vehicles and fixed roadside equipment leading to the following three possibilities (as shown in Figure 1):

- *Vehicle-to-Vehicle (V2V) ad hoc network*: allows the direct vehicular communication without relying on a fixed infrastructure support and can be mainly employed for safety, security, and dissemination applications;
- *Vehicle-to-Infrastructure (V2I) network*: allows a vehicle to communicate with the roadside infrastructure mainly for information and data gathering applications;
- *Hybrid architecture*: combines both Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I). In this scenario, a vehicle can communicate with the roadside infrastructure either in a single hop or multi-hop fashion, depending to the distance, i.e., if it can or not access directly the roadside unit. It enables the long distance connection to Internet or to vehicles that are so far.



(a) Vehicle-to-Vehicle Ad Hoc Network (b) Vehicle-to-Infrastructure Network (c) Hybrid Architecture

Figure 1: VANET Architectures

A vehicular network is highly dynamic due to two reasons: speed of the vehicles and characteristics of radio propagation. Vehicles have high relative velocities in the order of 50 km/h in urban environments to more than 100 km/h in highways. So, the vehicles can quickly join or leave the network in a very short period of time, leading to frequent and fast topology changes. Another issue to be treated is network clustering that can often appear, mainly when a V2V solution is used. Communication solutions must take into account this spatio-temporal constraint since connectivity is one of the key parameters. The heterogeneity of nodes in terms of speed and mobility is a fact to consider in the development of algorithms and protocols for vehicle networks. For instance, consider cars and trucks versus buses and trams: cars and trucks have different speeds and tend to follow an unpredictable mobility model, whereas buses and trams have a regular, slower speed and a predictable mobility model.

VANET architecture can also be characterized by its geographical area, i.e., whether it provides communication over a wide, larger area, or a local, more restricted area. Broadly speaking, vehicular networks support two main categories of applications: driver assistance and information dissemination. Driver assistance encompasses applications that support drivers in their driving to make it more secure and more efficient as explained above. Information dissemination applications focus on providing information to both drivers and passengers, and even vehicles. This information might be adapted to the context of the users. Information dissemination VANET applications range from entertainment to safety-critical operations. Therefore, the Quality of Service (QoS) required by these applications categories varies from non-real-time to soft real-time. In the later, a timing failure might compromise the service quality, but the failure is not critical, up to hard real-time where a timing failure can put lives and property at risk. In non-real-time applications not exist time requirements and the failure is acceptable.

A key application in a vehicle network is accident prevention and road safety. In this scenario, the communication types will focus on message multicast/broadcast from a given source to recipients mainly located in the origin's neighborhood or direction. Vehicles will broadcast data that is probably valuable for multiple surrounding vehicles. This means that the vehicles to be reached, using normally unidirectional communication, depend on their geographical location and their interest to the reported event.

3 Protocol Stack for VANETs

The protocol stack for vehicular networks has to deal with communication among nearby vehicles, and between vehicles and fixed roadside equipment considering their distinct characteristics. Because there is no coordination or configuration prior to setup of a VANET, there are several challenges in the protocol design. In the following, we discuss the protocols for VANETs according to each layer of the protocol stack.

Physical layer The protocols for the physical layer have to consider multipath fading and Doppler frequency shifts caused by the movements of the nodes.

Experimental vehicle-to-vehicle communications have used radio and infrared waves [?]. Very high frequency, micro, and millimeter waves are examples of radio waves used for V2V communications. Both infrared and millimeter waves are suitable only for line-of-sight communications, whereas VHF and microwaves provide broadcast communications. In particular, VHF supports long-range links at low speeds and, because of that, the trend is to use microwaves.

Dedicated Short-Range Communication (DSRC) is a short to medium range communication technology that operates in the 5.9 GHz band for the use of public safety and private applications [?]. In the United States, Federal Communications Commission (FCC) allocated 75 MHz in the 5.850–5.925 GHz band for DSRC, while the European Telecommunications Standards Institute (ETSI) allocated 30 MHz in the 5.875–5.905 GHz band. DSRC supports a vehicle speed up to 200 km/h, nominal transmission range of 300 m (up to 1000 m), and default data rate of 6 Mbps (up to 27 Mbps).

This frequency band is divided into six service channels (SCH) and one control channel (CCH) with equal bandwidth of 10 MHz each. The CCH is dedicated to safety applications (exchange of security messages) and control messages, and SCHs are used to data dissemination, which can transmit different types of service data. In DSRC, the entire spectrum is divided into time slots of 50 ms and messages have two different priorities: low for data dissemination messages transmitted on the SCH channels, or high for safety or control messages transmitted on the CCH channel. All vehicles monitor these messages. If the CCH channel is active, all nodes are bound to stop their communication during the CCH time frame to receive and transmit security messages on the CCH channel. DSRC is proposed to support communication between vehicles and roadside units.

Within IEEE 802.11 technical committee, DSRC is known as IEEE 802.11p WAVE (Wireless Access in Vehicular Environments) [?]. The WAVE protocol proposes amendments to the physical (PHY) and medium access control (MAC) layers of the existing IEEE 802.11 wireless standards to support ITS applications. This includes data exchanges between high-speed vehicles and between vehicles and the roadside infrastructure in the 5.9 GHz band. The ultimate goal is to have WAVE as an international standard applicable worldwide.

MAC layer The MAC layer has to provide a reliable, fair and efficient channel access. MAC protocols should consider the different kinds of applications for which the transmission will occur.

For instance, messages related to safety applications must be sent quickly and with very low failure rates. This calls for an efficient medium sharing, which is even more difficult in VANETs due to high node mobility and fast topology changes.

MAC protocols for VANETs [?] have also to solve the hidden station problem, which frequently shows up in scenarios where vehicles form long rows causing a decrease on the data transfer. This is especially important since there is a trend to make available multimedia applications for passengers in vehicular networks that will demand a higher data rate. Furthermore, in a VANET the bandwidth has to be shared among the communicating vehicles.

In the following, we briefly discuss the IEEE 802.11p, ADHOC MAC and directional antenna-based MAC protocols, which are MAC protocols for VANETs [?]. The IEEE 802.11p WAVE protocol [?] is an amendment to the IEEE 802.11 protocol suite. Its goal is to fulfill the requirements present in V2V and V2I communications, where high reliability and low latency are extremely important. For example, in the United States the Vehicle Infrastructure Integration (VII) initiative proposed that information about an accident should be communicated through a VANET within half a second to all equipped vehicles in a 500 m range [?]. WAVE uses CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) as the basic medium access technique for link sharing.

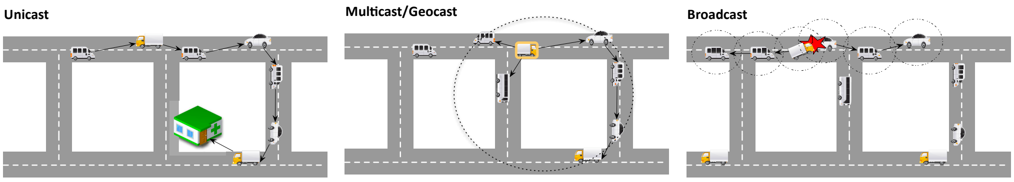
ADHOC MAC [?] uses the Reliable Reservation ALOHA (RR-ALOHA) protocol, a distributed reservation protocol that creates a reliable single-hop broadcast channel, the Basic Channel (BCH). Each BCH carries signaling information to solve both the hidden and exposed terminal problems, and to provide an efficient implementation of a network broadcast service. The basic idea is to have each terminal periodically transmitting the frame information (FI), i.e., the status of slots in the previous period (frame). New terminals to get access to the network use this information. ADHOC MAC works independently from the physical layer, and its main disadvantage is that the medium is not used efficiently, and the number of vehicles that can communicate in a given region is not greater than the number of the time slots in the frame time.

With a directional antenna, terminals can transmit in a particular direction with the goal of reducing the transmission collisions and increasing the channel reuse capability. The use of directional antenna is a very promising communication solution in VANETs, in particular for MAC protocols, since the movement of a vehicle is restricted to roads and driving rules. A directional antenna can also potentially reduce interference and collisions with transmissions ongoing over parallel neighboring vehicular traffic. Directional MAC (D-MAC) [?] is a MAC protocol based on directional antenna. It assumes that each terminal knows its geographic position and those of its neighbors and that the directional gain equals the omnidirectional gain. D-MAC proposes two different schemes that are similar to IEEE 802.11 in some ways: an ACK is sent immediately after a DATA, and if a given terminal is aware of an ongoing transmission between some other two terminals, the former terminal does not participate in a transfer itself. D-MAC scheme 1 uses directional RTS frames, and D-MAC scheme 2 uses both directional RTS and omnidirectional RTS frames. The basic principle of D-MAC is that in case a directional antenna at some terminal is blocked, other directional antennas at the same terminal may not be blocked, allowing transmission using those unblocked antennas. In summary, by using directional antennas, transmission collisions can be reduced, and the channel transmission reuse increased. Table 1 compares these two MAC protocols for VANETs.

Network layer In the network layer, the routing protocol has to implement strategies that provide a reliable communication and do not disrupt the communication. Vehicular networks supported different communication paradigms as shown Figure 2. These can be categorized as

Protocol	Main Feature	Medium Access	Advantage	Drawbacks
IEEE 802.11p	A draft amendment to the IEEE 802.11 standard.	CSMA/CA	Design provides reliability and low latency requirements.	Lacks QoS and is not suitable for real-time traffic.
ADHOC MAC	Guarantees a good QoS.	RR-ALOHA	Overcomes the hidden terminal problem and reduces transmission collisions.	Number of slots is fixed.
DMAC	Use directional antennas.	CSMA based.	Improve the performance and reduce collisions.	It assumes that each terminal is aware of the geographic position.

Table 1: Comparison among MAC protocols



(a) Unicast (b) Multicast/Geocast (c) Broadcast

Figure 2: Different communication scenarios in VANETs

follows:

- *Unicast communication*: the main goal is to perform data communication from a source node to a target node in the network via multi-hop wireless communication. The target node may be at either a precise known location or an approximate location within a specified range. Despite the unicast communication to be a useful mode in VANETs, multicast is more suitable for applications that require dissemination of messages to different nodes in the network.

- *Multicast/Geocast communication*: the main goal is to perform data communication from a source node to a group of target nodes. Geocast is a specialized form of multicast addressing, in which a message is sent to a group of target nodes in a particular geographic position, usually relative to the source of the message.

- *Broadcast communication*: has as the main feature of having a source node sending the information to all neighbors' nodes at once. The neighbors' nodes that receive the broadcast message forward it through a new broadcast in order to deliver message to the target nodes. Broadcast is also used at routing discovery phase in unicast communication paradigm to find an efficient route from the source node to the target node.

Two basic strategies for data forwarding commonly adopted in multi-hop wireless networks are topology-based and position-based routing [**?**, **?**, **?**, **?**, **?**]. Topology-based protocols use information about communication paths for packet transmission. In this case, every node maintains a routing table, which is the case of routing protocols for MANETs. Topology-based protocols can be further divided into proactive (table-driven) and reactive (on-demand). Position-based protocols assume that the locations of the origin, its neighborhood and destination are known. Position-based protocols can also be further divided into delay tolerant, non-delay tolerant, and hybrid. Delay tolerant geographic routing protocols consider intermittent connectivity whereas non-delay tolerant protocols do not and are only useful in densely populated VANETs. Hybrid approaches take advantage of partial network connectivity.

In principle, we could try to apply routing protocols developed for MANETs, such as AODV [?] and DSR [?], to VANETs since a vehicular network is a type of mobile ad hoc network with some distinct characteristics. However, those protocols do not present good performance in VANETs because of fast vehicle movement and relatively high speed of mobile nodes [?]. On the other side, due to continuous movements of vehicles, position-based routing seems to be more suitable for VANETs. With the increasing availability of navigation systems in vehicles, and improved position accuracy up to a few feet, this is a very reasonable assumption. Furthermore, position-based protocols do not exchange nor maintain link state information (as opposed to proactive and reactive topology-based protocols) and are more robust and promising to the highly dynamic environments like VANETs.

GPSR [?] is a well-known position-based routing protocol for MANETs based on a greedy forwarding mechanism. This protocol has a route discovery process that leads to significant delays in vehicular networks. In addition, with the rapid movement of vehicles, routing loops can be introduced while in the perimeter mode of GPSR. GPCR [?] and GPSRJ+ [?] are position-based protocols, based on GPSR, designed to improve the route discovery process in vehicular networks. Since they are position-based protocols they do not have a global view of the network paths. D-Greedy/D-MinCost [?] and VADD [?] are also position-based protocols designed to consider errors in the route discovery process of GPSR. Basically, those protocols decide whether to forward packets or to store them until a better forwarding node is found. They are also able to reduce packet delays and estimate path delays based on vehicle speed and number of intersections. Nevertheless, those protocols do not consider more relevant information like packet traffic congestion. A-STAR [?] and CAR [?] use traffic awareness for efficient packet delivery. Both protocols deal mainly with network connectivity issues and are not designed to address delay sensitive applications. PROMPT [?] is a cross-layer position-based delay-aware communication protocol that improves end-to-end delay using path information gathered by vehicles while propagating beacon messages.

The performance of routing protocols depends on different factors such as vehicular mobility model, data traffic, and road layouts. Data dissemination can significantly improve the data delivery ratio if, for instance, data buffers are located at road intersections [?]. There are also some protocols based on link and traffic metrics proposed for VANETs such as Multi-hop Routing protocol for Urban VANET (MURU) [?] and improved greedy traffic aware routing protocol (GyTAR) [?]. In contrast, we still need to further investigate the routing performance when physical, MAC, and network characteristics are all considered together [?].

When we consider the routing type geocast, some protocols can be enumerated. Two approaches to disseminate the message to group are presented in [?, ?]. In this scenario a message is designate for a specific set of vehicles according to an interest. The base of the routing protocols in this situation is the position of the vehicles. Through of them it is possible to determine that the message will be useful to others vehicles. Sometimes in a street or highway can happen an accident or can exist an obstacle, and the vehicles around them needs to be notified. Thus, the first approach [?] sends the message to vehicles inside in a zone-of-relevance. This zone considers an area that vehicles are to define that the message will be relevant. The other approach, the protocol IVG [?], determines this area according to the driving direction, speed and the position of the vehicle.

Routing Protocol	Communication Paradigm	Forwarding Strategy	Architecture	Scenario	Application	Drawbacks
GPSR	Unicast	Greedy Forwarding	V2V	Real City Traces	CBR Traffic	Greedy forwarding is often restricted to a city scenario, because the direct communication typically does not exist.
GPCR	Unicast	Packet Forwarding	V2V	Real City Traces	–	It is not indicated to low density scenarios.
GPRSJ+	Unicast	Greedy Forwarding	V2V	Real City Traces	CBR Traffic	It needs more simulations in more complex and realistic trajectories.
D-Greedy/ D-MinCost	Unicast	Data Muling and Multihop Forwarding	Hybrid	Real City Traces	–	Protocols do not consider local information in the routing decision but only the global information.
VADD	Unicast	Packet Forwarding w/ Prediction	V2V	Real City Traces	CBR Traffic	It is difficult to select an outgoing edge freely.
A-STAR	Unicast	Packet Forwarding w/ Traffic Info	V2V	Grid City Traces	CBR Traffic	More appropriate for a city environment.
CAR	Unicast	Packet Forwarding	V2V	Real City Traces	CBR Traffic	The model depends on historical information about the traffic density and average velocity.
PROMPT	Unicast	Packet Forwarding w/ Position Based	V2I	Grid City Traces	Variable Traffic	A simulation w/ realistic model traffic to improve the performance evaluation of the protocol.
MURU	Unicast	Expected Disconnection Heuristic	V2V	Grid City Traces	CBR Traffic	Overhead in the update of EDD metric that is the basis for the routing.
GyTAR	Unicast	Packet Forwarding w/ Street Awareness	V2V	Real City Traces	CBR Traffic	Greedy approach designed to city environments.
Direct Message	Geocast	Packet Forwarding	V2V	Road Traces w/ Accident	–	Simple protocol that uses only a maximal-hop-number threshold limit in a forwarding decision.
IVG	Geocast	Packet Forwarding	V2V	Urban and Rural Road Traces	–	Simple solution that depends on a GPS equipment.
Caching Geocast	Geocast	Packet Forwarding w/ caching	V2V	Random Traces	–	In some scenarios, this approach can be affected by the network partition.
BROADCOMM	Broadcast	Packet Forwarding w/ Virtual Cells	V2V	Fixed Traces	Simple Broadcast	Naive performance evaluation.
UMB	Broadcast	Packet Forwarding	Hybrid	Urban Traces	CBR Traffic	Solution has a best performance only in a dense scenario.
V-TRADE/ HV-TRADE	Broadcast	Packet Forwarding w/ Vector Distance	V2V	Urban and Rural Traces	CBR Traffic	The selection of forwarding nodes in every hop causes an overhead.

Table 2: Comparisons of Routing Protocols in VANETs

Other principle to use in a geocast routing is a caching [?], that combines the dissemination in a specific area with store the message to reach a good performance in delivery. This approach is based on the main idea of adding a cache layer to hold the packets and only to do the forward when a newly node is discovered. Thus, simulation results show that with this greedy routing the delivery success ratio can improve significantly.

In the other hand, some task in VANETs is necessary to use the broadcast pattern. The focus is sending a message to all neighbors, and some protocols uses this pattern to established and organizes the routing structure. BROADCOMM [?] is a protocol designed to emergency environment that uses a hierarchy scheme to broadcast the message. The goal is use this hierarchy structure to guarantees different polices and improve the QoS features in a broadcast communication. Other strategy, the protocol UMB [?], is designed to address broadcast storm, hidden node, and reliability problems of multi-hop broadcast in urban areas [?]. This protocol allows achieving an efficient use of the channel and a high success rate in delivering a message.

The work presented in [?] proposes two strategies to perform a broadcast in a VANET. The first one (V-TRADE) uses a vector distance and GPS information to broadcast the message. The second one (HV-TRADE) uses the position history to guarantee the maximal reachability in the broadcast. Table 2 summarizes the main characteristics of the protocols mentioned above.

Transport layer As mentioned above, vehicular networks are characterized by intermittent connectivity and rapid topology changes. In contrast with other ad hoc networks, VANETs also have more predictable mobility patterns. In these scenarios, vehicles connecting to an access point at higher speed have few seconds to download information in an environment with high losses that highly decreases the performance of both TCP and UDP protocols [**?**].

In VANETs, many unicast applications require a similar service as provided by TCP, i.e., a reliable and in-order data delivery. Unfortunately, TCP presents a poor performance in wireless networks that have a high degree of mobility and frequent topology changes [**?**]. Vehicular Transport Protocol (VTP) [**?**] is a transport protocol for unicast applications in VANETs that probes the network and uses statistical data to improve the performance when a connection is disrupted. Its design is based on the path characteristics that are relevant for a transport protocol for vehicular networks. Mobile Control Transport Protocol (MCTP) [**?**] is based on similar principles of the Ad Hoc TCP protocol [**?**]. Its main goal is to provide end-to-end QoS between a vehicle and an Internet host via a roadside infrastructure.

These transport protocols for VANETs are designed for applications that require unicast routing. However, many envisioned VANET applications require multicast communication, which requires new approaches not based on traditional transport protocols. The design of a reliable transport protocol for multicasting communication is a challenging design problem, since multicast protocols are usually stateless.

Application layer In the application layer, protocols should minimize the end-to-end communication delay, which is important when providing emergency information and in delay sensitive applications. In the former case, depending on the location that generated an emergency event and the location and velocity of the vehicle interested in receiving it, the application protocol may have to comply with real-time deadlines to guarantee that the vehicle's driver will be notified on time about this event. In the latter case, vehicular networks should have small end-to-end delay for making infotainment applications involving real-time multimedia available to users.

Application protocols may also be designed to develop marketing tools for businesses. For instance, restaurants, hotels, parks and gas stations can broadcast their information in VANETs and interested drivers or passengers can send a query to receive more information. Application protocols may also be used in business transactions. Again, such applications require delay-efficient and reliable networks.

Vehicular Information Transfer Protocol (VITP) [**?**] is an application-layer communication protocol designed to support the establishment of a distributed, ad hoc service infrastructure in VANETs. It is based on a location-aware stateless (similar to HTTP) transport protocol for V2I communication.

4 Applications for VANETs and Data Communication

Efficiency and safety are two important requirements that can be used to classify VANET applications based on their primary purpose. However, efficiency and safety are not completely separated from each other. On the contrary, those aspects and others should be considered together whenever designing applications for VANETs. For instance, an engine failure or an accident involving two or more vehicles can lead to a traffic jam. A message reporting this event conveys a safety warning for nearby drivers who use it to increase their awareness. The same message may trigger the computation of an alternative route for a vehicle that planned to pass through the accident location, but it is not close to that point yet. In this case, the goal is to increase the transport efficiency for individual vehicles. Furthermore, depending on different factors such as the importance of the accident location, the transport system may compute and suggest alternative routes to a large set of vehicles considering a broader view of the traffic demands in order to diminish the impact of this event to regions not close to the accident. In this case, the goal is to increase the overall transport efficiency. Note that in both cases, an early event notification can help a driver or a passenger to decide to take a different route, use a different means of transport or even stay at the current location in case of a serious traffic problem. In this case, an additional goal is to provide a person with useful information in the planning of an activity related to the transport system.

This section briefly discusses existing and future application domains for vehicular networks, which are broadly divided into driver assistance and information dissemination.

4.1 Basic Applications

A current trend is to provide vehicles and roads with services and applications to make the transportation infrastructure more secure and more efficient. There are two basic networking issues required to achieve these goals: data gathering and data communication.

VANET applications will monitor different types of data such as the vehicle conditions, surrounding roads, approaching vehicles, surface of the road and weather conditions to make the infrastructure more secure and more efficient. Once this data is available vehicles will communicate via wireless communication networks with other vehicles and the road infrastructure, and exchange data and information relevant for different purposes.

A vehicular network can be seen as a network paradigm for urban monitoring and for sharing and disseminating data of common interest. This is particularly true in urban areas, where we can expect to have a high concentration of vehicles equipped with onboard sensors. Vehicular networks can be used for effective monitoring of environmental conditions and social activities in urban areas, playing an important role in urban sensing [?, ?]. Urban sensing applications can be further potentialized when smartphone capabilities taken onboard can be used complementarily with VANET sensors [?, ?].

The design of a Vehicular Sensor Network (VSN) introduces novel and challenging issues, which are considerably different from traditional wireless sensor networks, thus requiring innovative solutions. This is a promising research area since vehicles are not affected by energy constraints and other restrictions. Vehicles can be equipped with powerful processing units, different wireless communication devices, navigation systems, and a plethora of sensing devices such as chemical detectors, vibration/acoustic sensors, and still/video cameras. The combination of vehicular and sensor networks presents a tremendous opportunity for different large-scale applications in VANETs ranging from traffic routing and relief to environmental monitoring, distributed surveillance and mobile social networks.

Wireless networks form the basis of data communication in vehicular networks. These networks will be completely mobile, require little or no infrastructure, and support applications in a scenario with a dynamic, random, and multihop topology. Vehicles will be connected via continuous wireless communication with other vehicles and the road infrastructure, exchange data and information relevant for different purposes, increase the overall road safety, and enable cooperative traffic management. An important requirement for VANETs is the capacity of vehicles to exchange important messages immediately and efficiently mainly for safety reason. Therefore, communication protocols, mainly in the lower levels of the protocol stack, should avoid collision and corruption of emergency messages. The problem is that current protocols for wireless networks mostly handle data without time constraints and provide no real QoS or real-time traffic support.

4.2 Driver Assistance

The ultimate goal of safety applications in a VANET is to avoid and decrease the number of road accidents. There is a wide range of potential applications in this category, some of the scenarios in which safety applications can be useful are:

- Accidents: In case a collision occurs, there are two factors to be to monitored: the approaching vehicles and the accident location itself. Simple applications like sending emergency notifications to a call center that transfers the notification to emergency responders already exist, such as the GM's OnStar system [**?**]. Whenever an accident happens, an event (e.g., the release of an airbag) triggers a notification system to send emergency messages to nearby emergency responders. These notifications may carry the position provided by a GPS-enabled device. For future applications, depending on the distance to the accident that occurred further along the road, this application must warn the driver or even automatically break the vehicle (e.g., emergency breaking) when the distance decreases under a certain limit. It is also highly desirable to obtain emergency video streaming to help emergency responders (paramedics, fire fighters, and other rescue personnel). They could know before arriving on the scene the geographic location of the vehicle and traffic conditions at the site, in order to respond more strategically to the incident. This video information can be obtained from vehicles equipped with video cameras, and with capabilities to store and forward the images. The application could also monitor the post-collision scenario, taking appropriate actions and executing them promptly. Once an accident has occurred, the application should manage vehicle flows and identify alternative routes to either individual or large set of vehicles, according to the accident location, time of the day and other factors. Of course, a safety application should be designed to act proactively providing drivers with early warnings and prevent an accident from happening in the first place.

- Intersections: Traffic control and management is an important research area that can benefit from VANETs. For instance, vehicles passing near and through intersections should drive carefully since two or more traffic flows converge, and the possibility of collision increases. In this scenario, it can be design virtual traffic lights to control and manage the traffic flow at intersections. It can also design a safety application to warn the driver of an impending collision, who can take proper actions to prevent it. In both applications, i.e., virtual traffic lights and safety, there are stringent requirements to achieve mainly related to real-time constraints and distributed processing.

- Road congestion: A road congestion application can provide drivers with the best routes to their destinations and also determine the best time schedules for traffic lights along the overall routes. The goal is to decrease congestion on the involved roads and maintain a smooth traffic flow. This can potentially increase the road capacity and prevent traffic jams.

4.3 Information Dissemination

Applications for information dissemination aim to distribute and deliver information to drivers, passengers, and vehicles. Ideally, the information should be tailored to the users' context. The challenge is how to keep this context information up-to-date, considering the dynamics and mobility of vehicles and people in a VANET. This is a fundamental research problem in vehicular networks.

Some possible information types that can be disseminated in a VANET are:

- *Infomobility:* such type of information group comprises: weather information, warnings for environmental hazards such as ice on the pavement, gas station or restaurant location, city leisure information, tourist information, traffic and road conditions (e.g., congestion or construction sites), information on the available parking lot at a parking place, international service handover, road charging, route navigation (e.g., estimated journey time, recommended information based on the user's context, automatic road map update, civilian surveillance);
- *Mobile e-commerce:* this information type contains: advertisements or announcements of location-based sales information, e.g., drivers and passengers can have the opportunity to find real-time context-aware service like gas station listings with update prices, nearby service shops with highlighted deals;
- *Infotainment:* such type of information consists in: Internet access, distributed games, microblogs, chats, music downloads, web browsing, chatting, file sharing, video-on-demand, home control, etc. In future generation applications, passengers will have the opportunity to interact with passengers of nearby vehicles or with people anywhere in the world through instant messaging services, games, and even videoconference.

Some of the scenarios in which dissemination applications can be useful are:

- Notification services: This application provides all sorts of information to users and vehicles through a wireless network. After an entity subscribes to a given service, it should be notified whenever an up-to-date information is available, e.g., service shops can send alerts showing the parts of the vehicle that need to be replaced, their prices and how long the service would take;
- Platooning: This allows vehicles to travel closely and safely in an efficient way. This can lead to a reduction in the space used by vehicles on the road infrastructure, which, in turn, allows more vehicles to use the highway without causing traffic congestion. Moreover, platooning can take advantage of aerodynamics to reduce fuel consumption.
- Vehicle tracking: This service allows trusted parties such as car manufacturers and logistic companies to remotely monitor the vehicle's whereabouts and statistics.

In Table 3, in order to summarize its main characteristics, we categorize applications according to features, communication requirements, existing protocol solutions, pull-based $\times$ push-based.

5 Challenges and Future Perspectives

Given the challenges and characteristics of VANETs, some future perspectives should be considered to design new efficient communication approaches, as follows:

Highly heterogeneous vehicular networks: many non-interoperable wireless networking technologies have emerged with the rapid development and availability of mobile computing systems and environments. As a consequence, the provision of seamless connectivity across different wireless networking technologies under a time-varying network topology is very complex in terms of node addressing, quality of service, routing, security and billing. Thus, it is expected that the next generation of intelligent transportation systems reflect a more holistic approach to network solutions. This would require support to the coexistence of multiple different co-located wireless networks to provide ubiquitous and universal access to broadband services [?].

Data management and storage: As outlined in previous sections, we can expect to have large scale vehicular networks with millions of vehicles, which will generate huge amounts of distributed data that must be stored in some fashion and distributed across the VANETs. Due to this feature, as pointed out in [**?**, **?**], the massive scale, both in the size of network and amount of produced data, as well as the inherent dynamic properties of VANETs, pose new and unique challenges to data management in this setting.

Localization systems: Critical safety applications in VANETs require more reliable and high accurate localization systems. A natural solution of a localization system for VANETs is to embed a GPS receiver in each vehicle. But satellite-based positioning systems (e.g., GPS, Galileo, GLONASS) present some undesired problems such as not always being available (e.g., GPS reception problems on bridges or in tunnels). Furthermore, satellite-based positioning systems are vulnerable to several types of attacks such as spoofing and blocking. In addition, it has a localization error of 10 to 30 m, which does not satisfy the requirements of critical applications for VANETs and implies the need for other localization techniques. A number of localization techniques has been proposed for computing the position of mobile nodes [**?**], namely Map Matching, Dead Reckoning, Cellular Localization, Image/Video Processing, Localization Services, Differential GPS technique, and Relative Distributed Ad Hoc Localization. All these techniques have advantages and disadvantages, but no single technique can satisfy all the requirements of critical applications at the same time, such as availability anywhere and anytime, with highly accurate and reliable position computation. A reliable and ubiquitous localization system to be used by vehicles in a VANET for critical safety and emergency applications will likely be provided by a combination of different techniques and data fusion.

Security and privacy: Several network security issues resemble those of traditional wireless networks. However, security challenges in VANETs are intrinsic and unique due to the size of the network, frequent topology changes, high mobility, and the different classes of applications and services, with conflicting requirements that will be offered to such networks. Besides those challenges, such as the trade-off between authentication and non-repudiation versus privacy [**?**]. Another major issue is to prevent attackers from interfering with both the integrity of the exchanged messages and the availability of the system. Some characteristics of VANETs pose challenges to meet security requirements, which demand novel protocol solutions with some of the following characteristics [**?**, **?**, **?**]: low overhead due to time sensitivity, minimum hops communication among nodes, pre-stored information about the participating routing nodes and optimized data dissemination solutions. Despite the valuable existing results addressing the problem of security in VANETs, new secure communication protocols must be investigated taking into consideration the unique characteristics of heterogeneous vehicular networks.

Disruptive tolerant communications: Current problems, such as higher delay and lower reliability delivery, are more constant in sparse networks. To increase the delivery reliability, some solutions make use of Carry-and-Forward technique, which further increases the information delivery time. These problems may be solved/minimized exploring new data communication approaches for Heterogeneous Vehicular Networks. As another alternative, the driver's behavior can be considered to improve the carry-and-forward method and reduce the information delivery time.

Geographical addressing: The physical position of a vehicle or its geographic region is necessary for many applications to perform data communication, which requires a geographical address. Three geographical addressing families are presented in [**?**, **?**, **?**]: application layer solutions, GPS-multicast solution and Unicast IP routing extended to deal with GPS addresses. Thus, given the vehicles' mobility pattern and drivers' behavior of drivers, tracking and managing geographical addresses to predict the future position of a vehicle is a problem extremely challenging.

Tracking a target: Communication is a fundamental aspect in any network and, in VANETs, depends on the physical location of vehicles. Therefore, tracking a target is a fundamental functionality in VANETs for communication protocols and also for applications and services that can benefit from this type of information [**?**]. Tracking requires creating a mechanism to identify the path a node follows in the network and predict the next positions if necessary. As pointed out before, privacy issues have to be observed in the devised solutions.

Standardization of protocols: VANETs can be comprised of different types of vehicles such as trucks, cars, trams, buses, taxis motorbikes and bicycles. In this scenario, it is important that all of them are able to communicate among themselves using the same protocol. This can only be achieved in case there is an standardization effort involving industry, government and academia [**?**].

Cooperation with other networks: People in VANETs are expected to interact with other people, applications, and services in other networks. This cooperation can be useful to provide a good service to the user, like information about traffic conditions, weather, and routes. This information can be obtained through interactions with sensor networks, Internet, LANs and WANs.

Variable network density: In urban scenarios, the VANET topology can have hundreds of vehicles in a relatively small region. In this case, it is necessary to design protocols for medium access control to avoid collision and transmission errors. However, in highway scenarios the topology is sparser and the connectivity is more intermittent. This scenario suggests the need of protocols aware of these disconnections. Also, vehicles that travel in both scenarios need to adapt their behavior to these network density variations in order to provide a good data transfer.

Network fragmentation: Network fragmentation is a challenge for network designers since it causes some of the nodes to become unreachable. Network fragmentation may occur in scenarios of light traffic or rural areas. Also, it is expected that the initial deployment of VANET radios, in which only a small percentage of vehicles will be equipped with transceivers, will lead to frequent fragmentation of the network [**?**]. Traditional protocol solutions such as those relying on topology information in a node are not suitable for VANETs and new approaches are required.

6 Conclusion

Wireless vehicular networking is a key enabling technology for future intelligent transportation systems, smart vehicles, and smart infrastructure. The advent of vehicular networks comprised of vehicles equipped with the ability to establish wireless communications and self-organize into a collaborative mesh, opens a countless of applications that can make road travel safer (by avoiding collisions), more efficient (by decreasing travel time, avoiding traffic congestion, and increasing road capacity), and more pleasant to the users. In fact, VANETs are likely to become the most important realization of mobile ad hoc networks.

The distinct characteristics of VANETs lead to specific networking problems, demanding the design of fully distributed protocols. VANETs introduce additional challenges for protocol designers, besides those already present in mobile ad hoc networks. In particular, the mobility of vehicles results in a dynamic scenario with substantial rate of link changes and, consequently, very short lifetime for multihop paths. In this case, protocols that need to know the state of the system (even if only local) are inefficient due to the frequent network changes. In addition, VANET applications may require (or may benefit from) a different protocol stack.

There are many exciting research challenges in different areas yet to be solved that need to be incorporated into real deployment since innovation heavily depends on acceptance of technology.

During the last decade, there were significant advances in VANET research and the associated technology, which have sparked a lot of interest in different research communities such as transportation, wireless communication, and networking. Several automotive companies, research institutions, and government organizations are currently involved in evaluating, proposing, creating, and engineering future VANET systems, which will come from opportunities and synergies of interconnected vehicles and infrastructures. A common and fundamental aspect in all aspects of vehicular networks is the different type of algorithms employed in VANETs.

This paper brought discussions on the main characteristics of vehicular networks, architecture details, constraints of layers, protocols, applications and future perspectives. We hope the insight discussed here will help protocols' designers and applications engineers to improve the services provide in this type of network, and to help the drivers to make secure trips.

Application Class	Characteristic to consider	Architecture	Location Awareness	Time Awareness	Communication Technology	Desirable properties of protocols	Challenges	Application Examples
Safety	Delay	V2V–V2I	Yes	Yes	DSRC/RFID/ Bluetooth/Wi-Fi	Reliability	Reduce the latency	Collision alert; Intersection collision; pedestrian crossing warning; bike/motorbike lane changing.
Efficiency	Availability	V2V–V2I	Yes	Yes	DSRC	Real-time and reliability	Availability Of services	Traffic flow; road condition; dangers on the road.
Comfort	Reliability	V2I	Yes	No	WiMAX/Wi-Fi/ 3G/4G/LTE	Real time	Support on-demand applications	Free parking space; Music Downloads; Play videos.
Interactive Entertainment	Connectivity and availability	V2V–V2I	No	Yes	3G/LTE/Wi-Fi/ WiMAX	Unicast Communication	Keep synchronization	Games; synchronous activities and other Internet activities.
Non Interactive Entertainment	Tolerant of delay	I2V	No	No	3G/LTE/Wi-Fi/ WiMAX	Data dissemination	Appropriate throughput	Video downloads; asynchronous activities.
Urban Sensing	Mobility	V2V–V2I	Yes	Yes	DSRC/3G/LTE/ Wi-Fi/WiMAX	Data collection	Security in data communication	Photographs, road conditions, etc.

Table 3: Categorization of VANETs Applications.

RESEARCH CENTRE
SACLAY – ÎLE-DE-FRANCE

1 rue Honoré d'Estienne d'Orves
Bâtiment Alan Turing
Campus de l'École Polytechnique
91120 Palaiseau

Publisher
Inria
Domaine de Voluceau - Rocquencourt
BP 105 - 78153 Le Chesnay Cedex
inria.fr

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