On Developing Smart Applications for VANETs: Where are we now? Some Insights on Technical Issues and Open Problems

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***Abstract*—The advances in research on ad hoc networks, the availability of cheap radio interfaces (e.g. WiFi) and the increasing amount of electronic devices installed in vehicles have set the path for vehicular ad hoc networks. In the past few years, vehicular ad hoc network (VANET) research has addressed all layers, trying to optimize from the physical layer to the application layer to support the design of new possible application scenarios. It is often difficult to find a comprehensive approach to VANETs, due to their complexity. It is also often difficult to realize how far, technically, is the implementation of VANET-based application scenarios. We here propose to take one step in such direction, partially reviewing the research in this space and finding out how well can applications such as peer-to-peer file sharing and gaming can be supported. Our final scope is to provide an understanding of how far ahead in time, from the technological point of view, is the implementation of the cited scenarios on a distributed vehicular ad hoc network.**

I. Introduction

The idea of seeing vehicles as elements of a telecommunication network dates back to the first smart navigation tests carried out in the seventies, when transportation engineers were testing the effects of traffic information dissemination on vehicular traffic. In the same years, independently, research on ad hoc networks begun with the purpose of enhancing military communications. The ideas and technologies thought for ad hoc networks and designed for the battlefield, have been ported to the vehicular space. Although, solutions that are found for small to medium scale networks with pedestrian mobility hardly map to large scale networks with challenging mobility patterns. Vehicular networks introduce new challenges compared to mobile ad hoc network (MANETs) technologies, mainly because of their highly dynamic mobility patterns. The application scenarios are also very different. MANETs are designed to interconnect swarms of soldiers, tanks and aircrafts and therefore require, for example, robust and reliable multicast protocols to enable the interaction and coordination of these entities. Applications running on VANETs can be less demanding in terms of quality of service, especially in those scenarios that do not require real-time communication patterns, but usually have to deal with more challenging propagation and mobility conditions.

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The majority of work on vehicular networks aims at finding optimizations that solve very narrow problems. Optimizations for routing protocols have been introduced considering the peculiarities of urban or freeway settings, while optimizations for information distribution protocols have been engineered considering speeds, topologies and inter-contact probabilities. We observe that the successful design and implementation of an application depends on a correct interpretation of the key elements underlying the behavior of the network it runs on. In the case of vehicular networks, we cannot avoid seeing that mobility and locality represent the key performance drivers for any application.

Mobility has been at first modelled using simplistic approaches such as random waypoint [8] or group mobility models [9]. It has soon been realized that the realism of simulation results for VANETs heavily depends on the used mobility models which should match as close as possible real mobility scenarios [6]. Typical settings present two different types of difficulties depending on the location. In the country side and less densely populated areas, the sparseness of the network represents a barrier to the implementation and deployment of most applications. Delay tolerant [4], [5] paradigms have been designed and studied to answer such type of problems. In densely populated areas, most routing protocols fail because the amount of overhead traffic that is produced (e.g. broadcast storms [11]) overwhelms the communication network. Authors of [6] decompose reactive protocols into building blocks to expose the mechanisms which are more sensitive to mobility. A possible solution to the broadcast storm problem which we will further discuss in this paper has been proposed in [12], this is a simple but effective modification that could benefit any protocol's discovery mechanism. Authors in [7] point out the importance of relying on the existing wireless access point (AP) infrastructure in urban areas, showing that this can greatly improve the scalability of vehicular networks and alleviate the disruption due to high dense networks. The results published in [28], [29] highlight the importance of

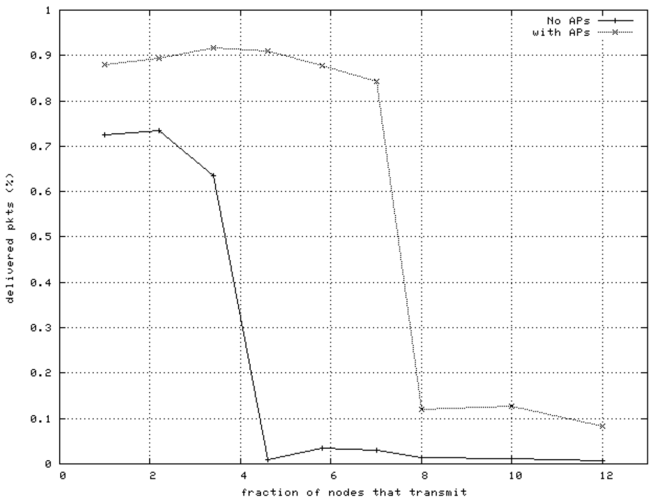

Fig. 1. We can see here the delivered packet ratio, as the number of connected vehicles increases. The use of an AP infrastructure visibly improves performance.

such idea, implementing in simulation a realistic scenario in terms of both traffic flows and existing AP infrastructure and showing the performance improvements that derive from the use of an opportunistically exploited AP infrastructure.

We here present a partial survey of our and our colleague's work on vehicular networks. We begin reviewing the impact of mobility on ad hoc network protocols, highlighting the problems connected to the high density of vehicles in an urban setting and seeing in what measure can an AP infrastructure alleviate them. We then review two approaches to network congestion problems, a broadcast optimization algorithm [12] and a flow fairness enforcement scheme. In Section III we cover distributed applications designed to run on or with the aid of a VANET. CarTorrent [15], a BitTorrent-like [2] protocol for file sharing, has been specifically designed to exploit the availability of chunks of data that are contained in neighboring cars when far from AP coverage. The role of fairness in vehicular game applications is described in Section III-B. We finally observe in Section III-C how a VANET could also help the implementation of health related applications, increasing the connectivity area and lowering the costs of data transmission to health care centers.

II. Mobility Models, Issues and Possible Solutions

In [28], [29] authors analyze the feasibility of implementing a VANET in downtown Portland, Oregon. The most important contribution of this work is the use of very realistic mobility traces, produced with TRANSIMS [22], at the Los Alamos National Laboratories [16]. The traces have been engineered by first building an activity location model for Portland in order to reflect the expected traffic flows and directions at a given time. In fact, in the morning, traffic flows from suburban areas towards downtown, as in many western cities. Moreover, an additional degree of reality is introduced in the simulated urban setting in [28]. The open APs reported in [23], available at that time in Portland, are used as an infrastructure in simulations. APs are more dense in the downtown area, at intersections, thus providing a free and available infrastructure to WiFi enabled vehicles. This information and these models are used to derive what bit-rates and what level of connectivity can be reached by a vehicular network. To understand the role such type of free infrastructure could gain, second generation commercial navigation systems such as Dash [21] provide the opportunity of connecting to an open AP to receive free traffic information updates.

For the details of the simulation settings please refer to [28], [29]. In Figure 1 we plot the delivery ratio, using the AODV [30] routing protocol, with and without the use of the AP infrastructure. The greatest cause of performance disruption that has been observed in the simulations is route reply (RREP) collisions which occur during the discovery phase, when a path from a sender to a receiver is being set. When an infrastructure is used, packets are routed through the closest AP when the wireless distance travelled flowing through APs is less than the wireless distance travelled without the use of the infrastructure. In practice, as we see from Figure 1, the capacity of the network doubles using an open AP infrastructure. It is also interesting to observe that from the results of [28], the AP placement is far from optimal. In fact, using a random AP placement the average number of hops from each vehicle to an AP reduces by half, from about 14 to 7 hops on average.

We have seen that the major challenge in the case of urban vehicular networks, which can only partially be solved by the use of an AP infrastructure, is network traffic congestion. Traffic jams, in fact, can cause network jams, which origin from broadcast storms in routing discovery processes and data traffic congestion when streaming between end hosts. Broadcast optimization and topology control algorithms represent different approaches to this type of problems. In the following we will provide an overview of a simple but effective broadcast optimization algorithm.

A. Broadcast Optimization

We have seen a case where the broadcast storm problem can be particularly severe. An approach to this issue is described in [12]. The algorithm dynamically estimates the transmission range of each node and uses this information to choose the best forwarding node. More in detail, the scheme is composed of two algorithms, a dynamic transmission range estimation scheme and an adaptive broadcast algorithm. Based on the distance from the source node and the maximum transmission range, each node sets a different contention windows value, so that the node that guarantees the best wireless coverage properties ends transmitting the packet. The scheme is implemented in a totally distributed fashion, each node infers its forwarding priority without any overhead or control traffic. Nodes (vehicles) that hear that a broadcast message has already been forwarded avoid re-transmitting the same message.

In Figure 2 we can see the effect of using the appropriate transmission range measure as opposed to erroneously estimated transmission ranges. Simulations were performed using highly dense straight-street scenarios, in the worst case

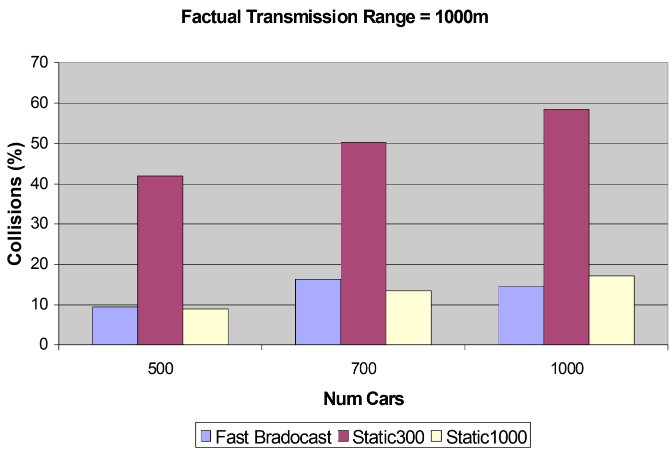

Fig. 2. We can here observe the percentage of collisions over total transmitted packets, as the number of vehicles in simulation increase. Fast broadcast is the algorithm described in [12], while Static300 and Static1000 are instances of the same algorithm where the maximum transmission range is set to 300m and 1000m, respectively. As expected, an error in estimation which results in a lower transmission range estimate, increases the number of collisions.

each vehicle can count about 120 neighbors. As we can see, when the transmission range is over-estimated, the collision ratio can reach over 60% of transmitted packets. This is an unacceptable condition. For this reason, to support discovery processes of routing protocols and data dissemination of particular applications we need an efficient and distributed broadcast algorithm capable of minimizing the waste of the wireless resource.

B. Fairness and Admission Control

In the vehicular network space, broadcast storms are unfortunately not the only problem that should be taken care of. Due to the wireless access schemes based on carrier sensing-collision avoidance multiple access (CSMA/CA), unfairness between short and long lived flows can be observed. A solution to this problem comes from the implementation of fairness and admission control schemes that guarantee quality of service in terms of bandwidth share and delay. We present two algorithms in [17], [18], one for flow fairness enforcement and one for flow admission control, the former derives from the definition of an optimization model where the objective is to minimize the number of lost packets. These algorithms are designed to serve streaming traffic over ad hoc networks. The peculiarity of our fairness model, which for such reason we believe can suite the requirements of a vehicular network, is that it is implemented in a totally distributed fashion. The cost of running such algorithm is the maintenance of flow state information in each node (i.e. vehicle), which in turn brings the advantage that no end-to-end control on flows is required.

The intuition behind FairCast is very simple, assuming it is run in a collaborative network, a node advertises its one-hop neighbors, sending a control message, when a flow that traverses it is suffering from contention. Neighbors (vehicles) which are unfairly capturing the wireless medium and delivering more than the required packets of the flows that traverse them react dropping packets. The basic idea, which dates back to [10], was originally implemented to enforce fairness on competing TCP flows. Authors of [17] port such idea to unicast and multicast streaming scenarios, enriching it of an analytic justification. An admission control scheme is then added in [18] to lead FairCast to operate close to an acceptable equilibrium and far from a disruptive situation where flows oscillate, breaking each other's performance in rounds.

In a highly dynamic and disruptive scenario such as a vehicular network, the idea of implementing fairness and admission control schemes has been rarely considered. In Section III-B, we show a case where a simple and local (i.e. requires only AP modifications) fairness scheme can greatly benefit the quality of streaming traffic and therefore the gaming experience from a vehicle.

III. Peer-to-Peer Applications

Although cellular networks are at the moment capable to provide the bandwidth required by most wireless applications, vehicular networks represent a convenient alternative in terms of costs. In the near future, as the number of users of bandwidth demanding applications increases, IP-connected vehicles could extend the Internet infrastructure more conveniently than increasing cellular coverage and bandwidth. Moreover, VANETs provide two significative advantages: (a) penetration rate in urban areas and, (b) robustness to power grid failures. In emergency settings where on-field triage applications are deployed, VANETs can run independently, without suffering from power blackouts. In typical cases, without looking at extreme situations, VANETs can still play an important role. Applications such as traffic information dissemination and file sharing require a large number of users and a high density, for this reason these could be particularly successful in urban areas.

A. CarTorrent

CarTorrent [15] is one of the first examples of peer-to-peer file sharing systems specifically designed for vehicular networks. Briefly, CarTorrent combines a chunk swarming mechanism (i.e. a parallel download mechanism from multiple hosts typically used in BitTorrent based peer-to-peer systems) and a chunk selection strategy to improve file dissemination performance in a VANET.

In Section II we have seen that an AP infrastructure can benefit a VANET's performance in an urban setting. In CarTorrent, in a dual manner, authors show that the exploitation of the buffers of vehicular neighbors can reduce a file's download time, compared to only using connections which flow through an AP. Very simply, when out of an AP's range, vehicles explore the availability of missing chunks in neighboring car's data buffers. To this scope, authors implement three different piece selection strategies: first-available, rarest-first and rarest-closest. Given the wireless setting and the use of TCP as a transport protocol, the rarest-closest first algorithm results as the most efficient. In fact, TCP poorly performs on multi-hop connections in ad hoc network scenarios and limit the search

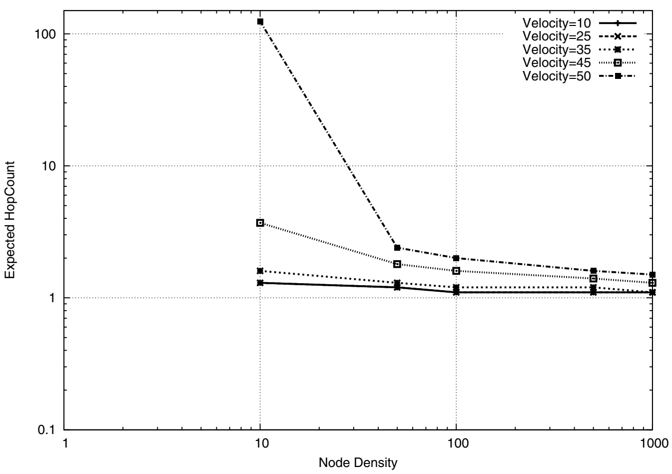

Fig. 3. Hop-count as a function of vehicle density and speed. As the density increases, the hop-count decreases, as expected, even under high speed.

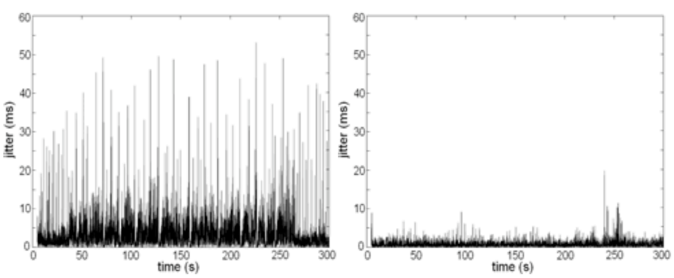

Fig. 4. In the left figure we can see the effects of competing TCP traffic on UDP flows, the delay jitter (i.e. end-to-end time variance) is very high. In the right figure the effect of implementing the SAP-LAW algorithm [14] to TCP flows, the delay jitter of UDP flows decreases.

space to the close neighborhood boosts results in an increased download bit-rate.

In Figure 3 we can appreciate an opposite effect of density, compared to what we have seen in Section II. A greater density, in fact, reduces the required hop count to find a new piece of a missing file. As density increases, even with a high speed, the expected hop count required to find a useful piece tends to one. As a result the time required to download a file decreases.

B. Entertainment

Authors in [14], [20] expose the problem of providing event consistency to vehicular players (i.e. players taking part in a networked game from a vehicle). The problem of consistency, very well known in the Internet massive multiplayer online game arena (MMOG) (a possible solution based on a P2P infrastructure is described in [13]), is particularly dramatic in a vehicular scenario. MAC layer re-transmissions generate a high delay jitter and, consequently, an incorrect reordering of game events. Inconsistent ordering of events ends up creating unfairness among players, jeopardizing the final result of a game.

Interestingly, authors of [14] show how fairness enforcement between flows can result in fairness between players. This work builds up on observing that competing TCP flows can deteriorate the behavior of gaming applications that rely on UDP streams. Since all of flows may be delivered to a vehicular network through an AP infrastructure, where this is available, it is important to balance the the bandwidth share that TCP based applications receive compared to UDP gaming applications. The flow balancing algorithm is totally distributed and solely implemented in the APs, thus following the idea of implementing a totally distributed solution, clearly more flexible in a highly dynamic network scenario. We can observe in Figure 4 the result of implementing the algorithm proposed in [14], the end-to-end jitter of UDP flows decreases dramatically (i.e. bounded within few tens of milliseconds), thus enabling users to play games while sitting in the rear seats of a car.

C. Health Applications

Vehicular networks can become a convenient data mule for any type of information. In [19] authors think of using vehicles as a transport infrastructure for patient health data, useful whenever patients leave primary care centers and therefore an AP coverage.

Each patient is equipped with a set of sensors, a processing gateway and an on-body terminal. Vehicles periodically send advertisement messages that can be received by the on-body terminal. These messages contain the vehicle's position and IP information. When the on-body terminal receives this information, it decides to initiate or not a connection depending on the availability of data. We can see how the amount of data that is transferred increases when deploying more cars (Figures 5 and 6). More vehicles directly translate in a higher connection time, we then see one more time how higher densities can benefit those applications that implement one hop dissemination algorithms.

Due to the delay tolerance involved in using such system, this can clearly play a role when the recorded information is not of vital nature, in those cases where information can be delivered with a delay, therefore avoiding the cost of using a cellular infrastructure. In case an emergency situation occurs, although, the importance of being able to rely on a backup infrastructure is key. Such architecture, therefore, could also be used when the power grid fails, the infrastructure is not available and a triage system is put in place.

IV. Conclusion

In this paper we briefly review some relevant work on VANETs. We begin seeing the role of mobility and the main challenges introduced by urban mobility patterns. We then discuss some possible solutions and describe a few application proposals that could benefit from such solutions and be successful in the VANET space.

The high penetration ratio of radio enabled vehicles is an opportunity and a challenge. An opportunity since, as we have seen, the possibility of easily disseminating data using file-sharing techniques rapidly increases. A challenge because the amount of overhead and data traffic increases as well and there is no comprehensive approach, to the best of our knowledge,

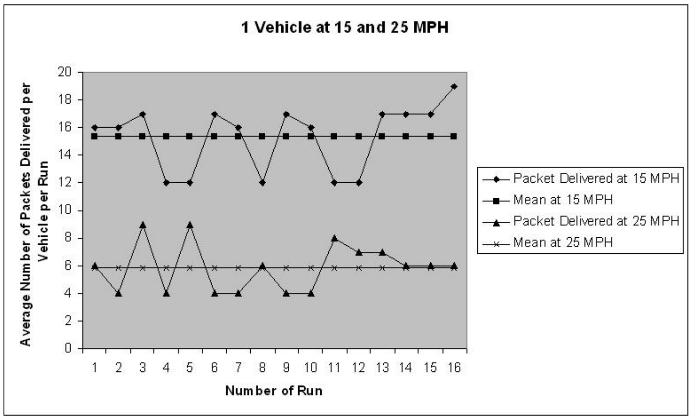

Fig. 5. Number of exchanged packets, between a patient and a car, at each round. As expected a higher speed, and therefore a smallar contact time, reduces the number of exchanged packets.

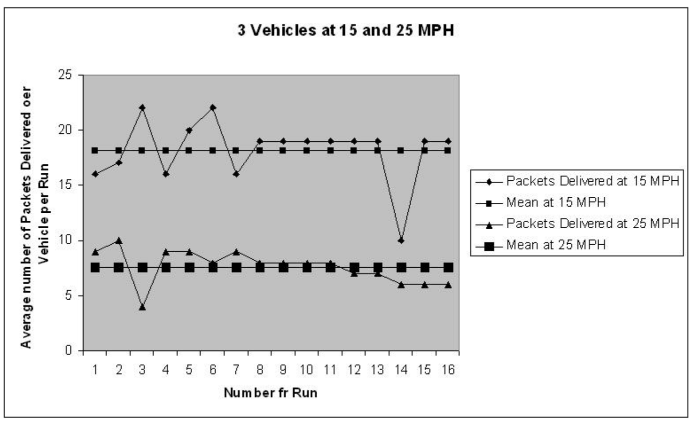

Fig. 6. We can see here that the number of transmitted packets increases as the use of more cars increases the wireless coverage.

that considers the joint optimization of network protocols, AP infrastructure and application requirements.

Local and sub-optimal solutions should be preferred to global and optimal solutions, since it is hard to find a steady state behavior of traffic, especially in urban areas. Very often traffic states in urban areas are regarded as successive transient states. It is then difficult to engineer an approach based on the common steady state assumption hypothesis. It is important then, at any protocol layer, to be able to adapt and scale with the number of flows and neighbors.

We believe the cellular infrastructure won't step down to less important roles, because of its ability to provide bandwidth everywhere, although at a high cost. A VANET can complement a cellular infrastructure and reach all those users that today do not benefit from a wireless Internet connection because of its cost. Moreover, a VANET can provide a penetration ratio in urban areas that competes with 3G coverage. This opportunity is in fact being explored by a number of services that already provide a high quality connection, through 3G, and a low quality connection, through APs (e.g. Dash).

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