Optimized IPv6 Internet access from vehicles in multi-hop and heterogeneous environments

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***Abstract*—In order to provide efficient Internet connectivity from vehicles, three fundamental functionalities are needed: IP address autoconfiguration, enhanced routing and mobility support. This extended abstract provides a brief view of the work done so far in this research work, that aims at providing a solution for these three open issues. An analytical model for an address autoconfiguration mechanism and a routing protocol have been already proposed, with accepted contributions. A third line analyzing mobility aspects is currently being developed. Another accepted contribution is a statistical framework for studying the interarrival time between vehicles, that has been elaborated using real traffic measurements.**

I. Introduction

In the last few years a considerable number of applications have been proposed for Vehicular Ad-hoc networks (VANETs), spreading from safety applications to traffic management and even content distribution. Working groups and standardization bodies such as IEEE 1609, ISO TC204, ETSI TC ITS or the Car to Car communication consortium (C2C-CC) are currently working on providing vehicles with connectivity, both among them and to the Internet. Also the IEEE has approved the 802.11p amendment for wireless access in vehicular environments. If we exclude safety applications, that have unique requirements of delay and priority over standard traffic and are generally broadcast-based, the other applications need a way to communicate among vehicles or from a vehicle to a the infrastructure, using possibly a multi-hop path.

Among all the open issues that are present in the vehicular networks environment, this research work focuses on the problem of Internet access from vehicles, hence on how to bring IP connectivity in a vehicular network. Bringing IP connectivity to VANETs means joining them with the Internet and fulfilling all the requirements that are typically asked to mobile networks. Three main functionalities are needed: *a)* the capability of vehicles to autoconfigure an IP address, *b)* mechanisms for an efficient routing of IP datagrams from/to the vehicular network, and *c)* IP mobility mechanisms suited for vehicular scenarios.

This research work proposes solutions for each of the functionalities that have been considered: GeoSAC (sect. III), an IP address autoconfiguration mechanism; TREBOL (sect. IV), a tree based routing protocol for VANETs and the ongoing work on mobility (sect. VI). Furthermore, an interarrival time between vehicles analysis based on real traces (sect. V) is used in order to validate the effectiveness of the proposed solutions (either by means of simulation and implementation).

II. Related Work

Providing support for IP based applications in VANETs is a complex problem that raises a large number of heterogeneous issues. As already stated in section I, there are three main functionalities that have to be carried out: address autoconfiguration, routing and mobility management. Despite the common goal of these three research fields, they can be tackled somehow independently, as each one is considering a different piece of the problem. Many of the already proposed solutions are inspired by Mobile Ad-hoc network (MANET) solutions, with modifications in order to deal with VANETs characteristics (nodes high mobility, connectivity patterns difficult to predict).

The multi-hop nature of VANETs typically makes the use of standard IPv6 autoconfiguration protocols, both stateless (SLAAC) and stateful (DHCPv6) unfeasible. Several proposals in the literature [1], [2] introduce modified versions of DHCP, adapted to work in VANETs environments. Using a stateless mechanism like IPv6 SLAAC offers advantages in terms of scalability as it does not rely on a central entity (or a federation of delegates). This architecture is studied in [3], [4]. The solution proposed in [3] is the basis of the work further described in section III.

Using MANET routing protocols in vehicular scenarios is not suitable, due to VANETs high dynamics and the possibly very short link lifetimes. The common assumption that vehicles are equipped with a positioning device like GPS, has led to the adoption of geographic based solution as a common choice for routing in vehicular networks. Numerous solutions [5],[6] base their operation on additional VANET-related information such as position of gateways, traffic statistics or trajectory estimation. These extra information are however difficult to gather and expensive (in terms of

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overhead) to keep up-to-date. The work defined in section IV consists in a routing algorithm for V2I communications that exploits the geographic knowledge of the node, without using additional information.

Deploying a Wireless LAN based access network for vehicular environments is a difficult task. As the wireless radio coverage can be extremely short outdoors, the connectivity map to the gateways will likely be not homogeneous and odd. Giannoulis [7] already proposed mechanisms to efficiently handoff between Access Points, but without a full wireless coverage seamless connectivity is impossible to achieve. With the use of a 3GPP LTE device, vehicles can have an "always on" connectivity. Nevertheless, taking advantage of fixed Wireless LAN gateways provides advantages in terms of bandwidth and 3G network offloading [8]. The ongoing work outlined in section VI aims at design a mobility mechanism for efficiently exploiting Wireless LANs when available, using 3GPP LTE otherwise.

III. GeoSAC: an IP address autoconfiguration mechanism

GeoSAC [3] is an adaptation to VANETs of the standard IPv6 SLAAC (Stateless Address Autoconfiguration) mechanism, built on top of the ETSI TC ITS system architecture. GeoSAC supports geographic addressing and networking, by extending the concept of an IPv6 link to a specific geographic area associated with a point-of-attachment. The network is intended as composed by vehicles (that carry On Board Unit - OBU) and Road Side Units (RSU) that form a self organizing wireless network.

In GeoSAC, a sub-IP layer (ETSI TC ITS NET) deals with ad-hoc routing by using geographic location information, and presents to the IPv6 layer a flat network topology. Consequently, the link seen by the IPv6 layer includes nodes that are not directly reachable but are portrayed as such by the sub-IP layer. This layer provides IPv6 with a multicast link which includes a non-overlapping partition of the VANET formed by all nodes within a certain geographical area. The RSU sends out standard IPv6 Router Advertisement (RA) messages which reach the nodes currently located within a well-defined area, and the nodes can then generate IPv6 addresses appending their network identifier derived from the MAC address to the received IPv6 prefix. Due to the fact that the concept of an IPv6 link is associated to a specific geographic area, each vehicle has to stop using its old IP address and configure a new one every time it changes area. This reconfiguration involves a time during which the vehicle cannot communicate, until a valid IP address is configured and becomes usable.

The goal of [9] was to design an improvement to GeoSAC based on RA caching and an analytical model to evaluate the configuration time. In GeoSAC, the vehicular network is logically partitioned in non-overlapping areas by selectively filtering received RAs. However, a vehicle within radio range of others in a neighbouring area also receives the messages they sent. Therefore, the performance of GeoSAC (in terms of reduction of its configuration time and/or signaling overhead) can be improved by vehicles caching the RAs sent by other vehicles in adjacent areas and reusing them when crossing the area border, without waiting for the reception of the next RA (vehicles are considered to be equipped with positioning devices). Simulations and implementations using COTS devices show that using the proposed optimization the configuration time can be pulled down to zero under most traffic conditions and different RA configurations, obtaining a potentially seamless IP address configuration.

IV. TREBOL: Tree-based routing and addressing for VANETs

The RSU is the network entity acting as gateway to the Internet, hence V2I traffic is always routed through it. TREBOL [10] (Tree-Based Routing for Vehicle-to-Internet Communications) is a tree-based and configurable routing protocol which benefits from the inherent tree-shaped nature of vehicle-to-Internet traffic to reduce the signaling overhead while dealing efficiently with the vehicular dynamics.

TREBOL builds the upstream routing tree by slightly modifying the Router Advertisement messages sent by the RSUs with some additional information required to construct the tree piggybacked into them. Once the tree has been built, every node has a parent node that is used as next hop for upstream (V2I) traffic. This upstream tree is updated periodically by means of some lightweight signaling sent by the RSU. For downstream (I2V) traffic, nodes keep soft-state about routes for currently used destinations. Furthermore, the protocol could also be used to allow nodes to autoconfigure IPv6 addresses when used in conjunction with [9], reducing even more the overall control overhead required by routing and address autoconguration functions. Another remarkable feature of the proposed protocol is the wide range of deployment scenarios, mostly defined by the size of the TREBOL area where it may operate, making it suitable for both urban and highways scenarios.

The protocol is validated using a real trace driven simulator and the results show that TREBOL outperforms a well known geographic routing protocol, providing better traffic delivery ratio and allowing at the same time a significant saving of control overhead, aspect considered as critical in wireless VANETs networks, as it does not introduce any beaconing mechanism.

V. Trace based vehicular interarrival time analysis

The research developed in [9] led to the need for a procedure to validate the proposed analitycal model. Initially the distribution used for modeling the interarrival time between two consecutive vehicles was an exponential distribution, as already used in many papers in the literature. This model was firstly proposed in [11] and more recently extended by [12]. Later, we used real vehicular traffic measurements collected at different locations in several highways of the city of Madrid to feed the simulators used in [9] and [10]. We performed an analysis of the traces, checking if they matched the exponential based model.

While in some traces the model fits adequately the traces, in others the experimental data largely deviates from the negative exponential random variable. We wanted to go beyond this first approximation, aiming at a more refined distribution for the interarrival time between vehicles. As the set of data comprised speeds as well, we found a noticeable correlation between them (especially at highways with dense traffic) that can be in some cases particularly high for consecutive cars. With this hint we divided vehicles into two groups, the "burst" vehicles (the ones traveling at similar speeds, close to each other) and the "isolated" vehicles (with no relation between the speed of two consecutive ones).

We modeled the first group as a gaussian distribution and the latter as an exponential distribution. Using statistical tools like the expectation-maximization (EM) algorithm we could build a weighted mixture model of the two components. After comparing the maximum likelihood of our model with other distribution proposed in the literature (lognormal and exponential) we found that it is the best suited to mimic the behavior observed in a highway lane and furthermore provides some insights on drivers' behavior, like the dependence between consecutive arrivals, that gives a meaning to raw data. This work has been published in [13].

VI. Ongoing Work

The missing point of the three functionalities mentioned in section (I) is an IP mobility solution especially tailored for VANETs. Our work already considered this issue, especially in [9] where each well defined area is represented by an IPv6 prefix. Traveling vehicles traverse many areas during a trip, thus changing IPv6 prefix and point of attachment to the network. We are currently working on a mobility mechanism that allows to seamlessly handover between different RSUs via a multi-hop wireless access. However, the knowledge coming from previous work shown us that this could be sometimes infeasible, due to a lack of multi-hop connectivity. Although using a WLAN interface is desirable because it can provide higher bandwidth, the possibly lack of multi-hop connectivity suggests its opportunistic use. Hence, an IP mobility solution for VANETs should also consider the possibility of using a 3GPP LTE interface as default option, conveniently offloading some selected IP flows as soon as a multi-hop link to a RSU becomes available.

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