Transport Protocol for Vehicular Environments: Challenges and Trends

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***Abstract* – So far, in most vehicular applications, navigation and communication are viewed as separate capabilities with little or no relationship between each other. Although much work has already been done related to the enhancement of vehicular communication protocols, they do not consider the leveraging of rich data sets provided by GPS receivers, such as position information, roadmap geometry, and traffic conditions, which would improve the utilization of the wireless medium and provide higher quality of service for a wide range of applications. With this goal in mind, we shall seek for opportunities to use GPS data at every layer of the communications protocol stack. The work presented in this paper aims to present the issues and provide solutions for a transport protocol for vehicular networks by using cross-layer optimization and geographic data to improve vehicular communications.**

***Keywords* – Vehicular Networks, VANET, Transport Protocol.**

I. INTRODUCTION

Transport protocols are responsible for encapsulating the application (session) data blocks into datagrams, enabling them to be transferred over a certain network protocol; these protocols fall into the scope of the transport layer, in both the OSI and TCP/IP models.

Beyond encapsulating information, transport protocols perform at least two important functions in a network: flow and congestion control. By flow control we mean the act of controlling the transmission rate on the sender, so that it does not outrun a slow receiver. This is fundamental in a network, since, generally, devices cannot send/receive data at the same speed; thus, these differences lead to bandwidth wasting due to high ratios of packet loss, if no flow control exists.

Congestion control is related to avoiding congestion in a network to reach a state where the network would collapse. There are several congestion control mechanisms either based on windows, as TCP, or other kinds of metrics, such as end-to-end delay.

TCP is nowadays the dominant reliable transport protocol in most networks, however, it should be noticed that there are certain applications for which it is not appropriate, leading to poor performance. Nevertheless, TCP is many times used for these applications in order to maintain compatibility between different technologies; for instance, TCP is not the best choice for wireless communications, such as Wi-Fi, due to their moderate to high bit error probability, but it is used in order to maintain compatibility with wired networks, where it performs well.

A. Vehicular Ad-Hoc Networks

Vehicular Ad-Hoc Networks (VANET) are networks established between moving vehicles, mainly cars, motorcycles and buses. This type of networks can be very useful in a near future, since it can promote improved road safety, interesting content delivery and infotainment applications.

The fact that the vehicles are moving at moderate to high speed turns it difficult to have a stable wireless connection for much time; therefore, these brief moments during which the connection is stable must be effectively used: there is no time for unnecessary operations and the necessary ones must be performed in the least possible time, in order to maximize the goodput.

B. TCP and VANETs

VANETs are an example of the unsuitability of TCP for some applications. Whereas in traditional Wi-Fi networks the problems of TCP can be accommodated and sometimes circumvented, the unique characteristics of VANETs discourage its utilization.

One of the major problems of TCP in vehicular environments is its congestion control algorithm. TCP uses a window system based on the acknowledgements received, in which the transmission window increases according to two phases (exponential and linear increase) and it is reduced when three duplicate acknowledgements are received, or a timeout has been achieved. The issue with all the wireless networks and especially with vehicular networks is that the medium over which the signals are being transmitted is not trustworthy and, consequently, the information is subject to bit errors which may completely disrupt it. What happens with TCP is that it may understand bit errors as congestion in the network, since the packets are disrupted, and reduce the congestion window, thus reducing the throughput, when all that was needed was to resend that packet and keep sending at the maximum transmission rate. As a consequence of the TCP slow start imposed by the congestion control mechanism, the transmission starts at a very low transmission rate, which is only increased with the reception of acknowledgements; this prevents the utilization of the entire bandwidth for the whole connection duration. In Fig. 1, we can identify the slow-start behavior of TCP, which leads it to take more than 10 round-trip times to achieve the maximum transmission rate, as well as the reduction in the congestion window when a congestion situation is detected.

As the vehicular environment is extremely prone to errors and the transmission rate must be the highest all the time, using TCP as the transport protocol for VANETs is not the best choice.

Considering all the problems of the existing solutions, our approach consists in building a new protocol from scratch,

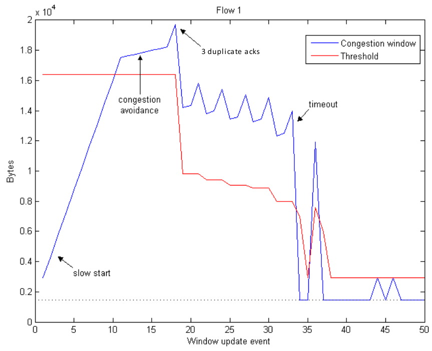

Fig. 1 - Events in a TCP connection.

taking advantage of cross-layer information, mainly from the MAC layer, as well as GPS coordinates. In order to do that, we had to evaluate the most promising MAC protocols and determine which of them would be appropriate for a VANET, in order to determine which useful information could be retrieved from them. After studying the state of the art MAC protocols, we focused our attention in the transport protocols, so that we could determine which features would be useful for our own protocol.

The rest of the paper is organized as follows. Section II presents the state of the art and related work, Section III delineates the requirements of a transport protocol for VANETs, as well as lower layer requirements, necessary to perform the design of a new protocol. Finally, Section IV draws the conclusions and Section V exposes the future work.

II. STATE OF THE ART AND RELATED WORK

IEEE 802.11 is believed to be a promising technology for VANETs, but needs to be adapted in order to fit the necessary requirements [1] [2]. IEEE 802.11p is intended to address all these issues [3], but although great achievements have been made in this draft amendment, several questions are still open. High load scenarios are a good example of that [4]. Since 802.11p relates many times to safety applications, the transmission delays must be bounded and well known; CSMA, which is traditionally used by IEEE 802.11 cannot guarantee this, so new MAC methods, such as STDMA must be developed [5]. There are also problems with the IEEE 802.11 backoff windows due to the variations in the number of transmitting devices. On the one hand, an adaptive backoff window mechanism can be a solution for this, as proposed in [6] and [7]; on the other hand, the operation method of the protocol can be radically changed to impose that data transmission can only be initiated by the user. Message redundancy is also an issue that must be solved in this type of networks, since redundant messages can prevent users from receiving important information [8]. Since the number of communicating vehicles can, sometimes, be huge, this type of networks may not scale well, so data must be prioritized according to its relevance [9].

In [10], Choi et al. present a MAC protocol that enables stations to receive data only upon request. Although it is an interesting way of seeing the problem, the overhead might be too high for vehicular applications. The GeoMAC protocol, introduced by Kaul and Onishi in [11], takes advantage of GPS coordinates by calculating the distance to each possible forwarder and decides which is the best one based on those calculations. In [5], Bilstrup et al. evaluate the possibility of using an existing slot allocation MAC method, which is able to grant service to everyone within a determined area, by reallocating slots from the farther nodes. A virtual collision MAC method is suggested in [12]. Though it is able to decrease collisions, it increases contention times, which is not good for vehicular networks. The priority based MAC scheme shown in [13] aims to increase reliability by sending out repeated messages, according to their importance; although it obviously increases the reliability, because messages are sent more than once, it will also increase the number of collisions. This way, it may be feasible for 40 nodes, but not for 400 or more, as we expect to have in VANETs.

As shown by [14], vehicle-to-vehicle communication is not enough to achieve satisfactory information dissemination. Roadside stations are imperative to assure connectivity between car clusters [15] and, consequently, correct information propagation. It makes sense that the rate of information update varies according to speed, so [16] proposes an adaptive information diffusion mechanism. Ensuring that no malicious people will interfere with communications or even disseminate erroneous information is also vital. A way to guarantee this is, for example, a two-directional verification method, as proposed by [17]. In order to evaluate all these improvements in the protocol, new models and simulation platforms must be developed. In [18] various models are evaluated and it is concluded that the attenuation due to obstacles can be parameterized through real world measurements.

[19] is an analysis of the path characteristics of the VANET environment. The authors establish limits for the connectivity and disruption times of connections in a VANET, based in analytical results and simulation.

Concerning transport protocols, in [20], Monks et al., exhibit the general limitations of TCP-like approaches for Ad-Hoc congestion control and, particularly the limitations of TCP-ELNF. In [21], Arthur et al. demonstrate that TCP reordering has a non-negligible effect in today's networks and this applies to Ad-Hoc / Vehicular networks.

ATCP, presented in [22], is a protocol that inserts a layer between the transport and network layers, respectively TCP and IP. By using the TCP persist mode and explicit congestion notification (ECN), this protocol can improve traditional TCP connections throughput up to 3 times in high bit error rate scenarios. In [23], Bechler et al. propose a modified version of ATCP, intended for vehicular scenarios. There are slight modifications to the original protocol, but an interesting idea of separating the Internet from the VANET by using proxy servers is exposed. This approach turns out to be promising, since this way optimized protocols can be deployed in the VANET regardless of the compatibility with the outside world, which this way is provided by the proxy server.

In [24], Sundaresan explores the possibility of using a completely different transport protocol for the Ad-Hoc environment. After concluding that the major part of the losses in Ad-Hoc networks with mobility occurred due to link failures and that TCP took too much time to achieve the highest transmission rate, the author decided to use lower layer metrics to calculate the initial rate and progressively adapt it through feedback content included in the packet headers. The congestion control and reliability functions are decoupled, in order to adapt the protocol to the VANET environment.

Finally, HOP [25] is a block-switched network transport protocol, which uses reliable per-hop block transfer. The interest on this proposal resides in the fact that the information can still crawl towards its destination even if there is no end-to-end connection, since the protocol operates in a hop-by-hop style. Congestion control is performed by backpressure, a concept that might prove to perform well in VANETs, as explained later in this work.

III. REQUIREMENTS OF A TRANSPORT PROTOCOL FOR VANETS

After evaluating some of the TCP-like and non-TCP-like approaches, as well as several studies accounting for the TCP performance in Ad-Hoc environments, we decided to develop a new protocol from scratch, considering all the improvements that each protocol we analyzed could bring to VANETs.

Before starting the design of the protocol, we had to focus on lower layer aspects that influence the transport protocol, such as the connection disruptions and node addressing, and define a set of assumptions over which we started developing the protocol.

A. Connection and Disruption Times

One of the major problems of the VANET environment for the transport protocol are the frequent connection disruptions that can occur due to a plethora of situations, such as the existence of buildings, trees, vehicles in the middle, etc...

The analysis of the path characteristics in a VANET presented in [19] estimates connection periods of 10s followed by disconnection periods up to 3s, as depicted in Fig. 2.

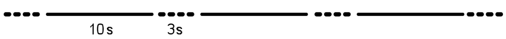

Fig. 2 - Connection shape in VANETs.

Fig. 3 allows us to evaluate the disconnection times for two communication distances: 500m and 2000m. For the 500m analytical results, which is also the situation considered in Figure 2, 91% of the connections remain uninterrupted for at least 10s. The simulation shows a slight decrease in these values, but it must be taken into account that the simulation is performed using the traditional IEEE 802.11 MAC and as we are expecting the MAC layer for VANETs to be improved, these results will probably get closer to the analytical analysis. For 2000m we can see that only 40% of the connections are not interrupted after 10s; although there is a large decrease, these results are not too important, since 2000m is a big distance and probably two cars at this distance will use relay nodes to communicate rather than performing direct communication.

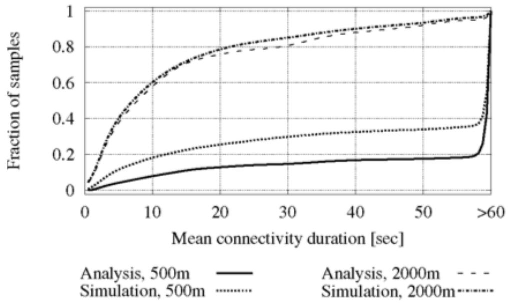

Fig. 3 - CDF of connectivity duration for analysis and simulation [19]

B. Node Addressing

Although addressing is not a competence of the transport layer, we found it useful to know what type of addresses would we be dealing with in a VANET, since this will be a determinant factor for the duration of the configuration times, especially the address configuration time, as well as the periodicity of these configurations. Having considered a lot of existing approaches for this problem, where either MAC addresses, IP addresses or even GPS coordinates were proposed as identifiers, we decided to evaluate the possibility of using GPS coordinates together with an unique identifier.

By reducing the sensibility of a GPS coordinate, we can create broadcast domains in the same way as in wired networks; inside these broadcast domains, each device can be identified by a unique address (such as the MAC address), that will distinguish one from another. At a first sight, this seems to bring a lot of issues, such as address updates and node location, however, by reducing the sensitivity or, by other words, increasing the granularity of the GPS coordinates, we create areas where a node can have place and allow the address updates to be performed within reasonable times. Below we present some calculations based on [26] that show that this alternative addressing method is feasible.

In order to allow some disruption time in connections, we have to ensure that a vehicle does not move to another broadcast domain within the disruption time allowed. Fig. 4 depicts the size of the broadcast domain for the disruption time allowed, so that a connection is not lost due to this and also, an extra address update is not needed. Speed and inter-vehicle spacing values have been extracted from the observations performed in [26] for a road in the USA and are presented in Table I and Table II.

TABLE I
SPEED VALUES

Time of the day	S (m/s)
01:00 - 03:00	30.93
10:00 - 12:00	29.15
15:00 - 17:00	10.73

TABLE II
INTER-VEHICLE SPACING

Time of the day	D (m)
01:00 - 03:00	55
10:00 - 12:00	22
15:00 - 17:00	11

Using the speed and the allowed disruption times, the granularity G of the GPS coordinate can be calculated according to (1).

$$G = T_d \times V, \quad (1)$$

where T_d represents the disruption time in seconds and S the speed in meters per second.

Now that we have the extension of each broadcast domain, we can calculate the number of vehicles inside each one, N by (2).

$$N = G \times R \times L, \quad (2)$$

where R stands for the number of roads and L for the number of lanes in each road.

Using these simple calculations, we can generate the plots presented in Fig. 4 and Fig. 5.

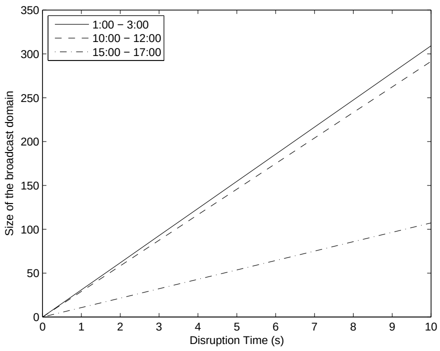

Fig. 4 - Size of the broadcast domain and allowed disruption time

As we can see, for disruption times up to 6 seconds, which is a conservative estimation, a size 200m should be enough for each broadcast domain. Now the question is how many cars/nodes can be in a 200m circle around a GPS coordinate. Once again, based in [26], the values presented in Fig. 5 were calculated.

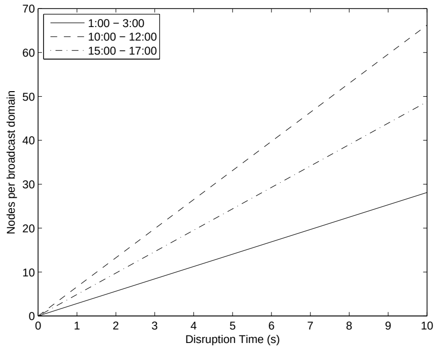

Fig. 5 - Number of nodes in each broadcast domain

According to the traffic observation, we can see that for 6 second disruption times, we would have about 40 nodes per broadcast domain in the worst case.

Considering these values, this approach seems to be reasonable and preferable, when compared to the other addressing methods, since it avoids most of the configuration: GPS coordinates do not need to be assigned by any entity.

C. Transport Protocol Functionalities

After evaluating the pros and cons of several state of the art protocols, we started sketching the requirements of the transport protocol. Fig. 6 is a very high level sketch of the protocol, in which we emphasize the existence of 3 main modes, as explained next.

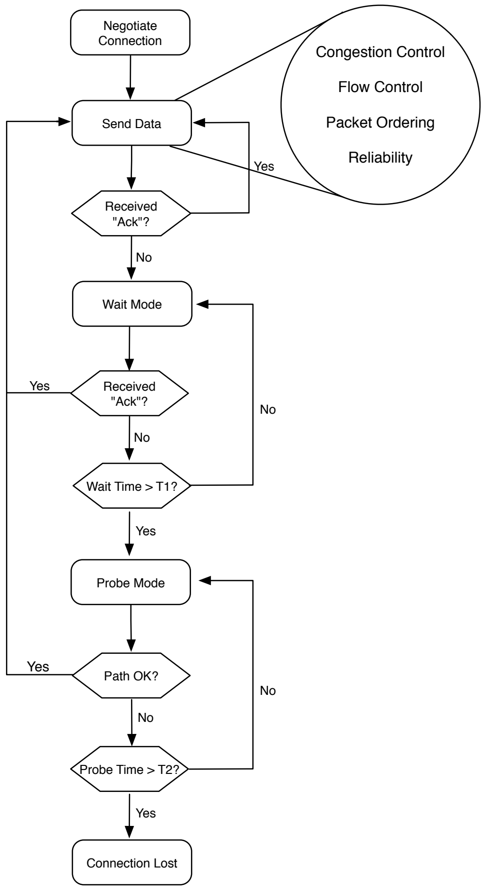

Fig. 6 - Sketch of the protocol functionalities.

After the connection is established, the data starts to be sent at the same time as the congestion control, flow control, packet re-ordering and reliability mechanisms operate. Although there is a received "ACK" box in the diagram, we are still studying which type of acknowledgement will be used; that is why we also include reliability in the big circle.

Congestion control and flow control will probably be coupled in the optimized protocol, since besides being different mechanisms, they share some properties. This way, by evaluating the best congestion control mechanism we will also account for the best way to perform flow control. Packet ordering is extremely necessary in VANETs, because of the vast amount of paths that information will be able to take and, consequently, the different order in which the packets will arrive at the receiver. Reliability in packet delivery must be assured, since the VANET will also be used to deliver safety-critical information, thus it must be certified that all the packets properly arrive at their destination.

The protocol includes three operation states: send data, wait mode and probe mode. If, for any reason, when data is being sent the respective acknowledgements are not received, the wait mode is entered. In this mode, the receiver does nothing more than waiting for the missing acknowledgements; this allows the sender to tolerate the disruption times mentioned in Section III-A. If after T1 the acknowledgements are not received, the probe mode is entered. In this mode, the sender sends out probe packets to determine when the connection is available again and to collect low level metrics that allow him to estimate the maximum transmission rate over the path. If after T2 the connection is not reestablished, it is assumed to be lost.

Due to the characteristics of the network, T1 and T2 must be accurately determined, so we need to consider an adaptive approach, in which these values are determined for each specific connection.

D. Congestion Control

Due to the characteristics of the vehicular environment – poor medium quality and high bit error rate –, congestion control algorithms must be accurately chosen. As we have already stated, the traditional TCP congestion control mechanism does not perform well in vehicular environments, so new hypotheses must be studied. We are currently building a simulator to isolate the congestion control mechanism from most of the other mechanisms and evaluate two possibilities that appeared to be the most promising ones: backpressure and distributed congestion control.

The backpressure mechanism, represented in Fig. 7, performs congestion control by preventing nodes from accepting more data to be retransmitted than what they can send out. Referring to Fig. 7, node A will only accept as many packets as it can send out through its neighbors, thus preventing congestion to occur due to the bad conditions of the link after node C, for example. The estimation of the amount of packets that can be sent out is based on the difference between the number of packets that has been received and reliably transmitted over time; the starting point is 1, which may be a drawback of this method because the maximum transmission rate is not used from the beginning.

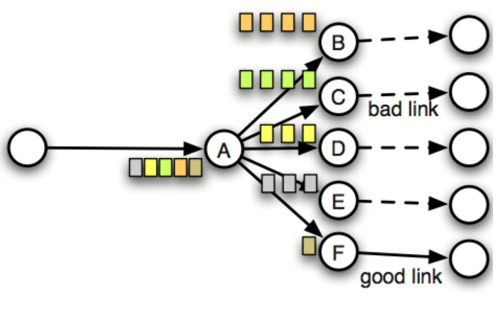

Fig. 7 - Backpressure congestion control [25].

On the other hand, there is the distributed congestion control mechanism. In this approach, some metrics are collected from every node along the path in order to determine which is the highest transmission rate allowed. The path is sensed at the beginning of a connection, using specific probe packets, and then the metrics are periodically updated though a header field included in every packet to ensure that the maximum transmission rate is not exceeded. One possible drawback of this implementation is the variance of the end-to-end metrics over time in the vehicular environment, but we believe that this can be circumvented using adaptive feedback update intervals.

Both approaches are possible, so we are building a simulator to account for their behavior in the VANET environment and decide which one is more appropriate.

IV. CONCLUSIONS

We have presented a general overview of the state of the art in vehicular networks and then particularized into the transport protocols.

After studying some protocols and gathering information about the improvements each protocol would bring to a protocol operating in vehicular environments, we started evaluating each choices to account for its feasibility.

An addressing scheme for VANETs has been identified and we are now developing a simulator to account for the pros and cons of two congestion control mechanisms.

V. FUTURE WORK

We will continue the development of the simulator for the congestion control mechanism and after proving which is the most appropriate one, we move on to the next functions of the transport protocol. By accurately determining which features should each part of the transport protocol have, we expect to build a very optimized protocol for vehicular environments that enables nodes to communicate easily.

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