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Analysing Impact of Mobility Dynamics on Multicast Routing in Vehicular Networks

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Abstract—Enabling Internet to Vehicular multicast communication is fraught with challenges due to the heterogeneous nature of the two networks. While the conventional multicasting in the Internet relies on "structured" multicast routing, it is not clear how robust can be such routing structure in vehicular networks. We study the robustness of the multicast routing structure in vehicular networks for data flow from the Internet to a set of vehicles. In this paper, we investigate the impact of the urban traffic dynamics on the link stability of the multicast tree. Our study shows that in an intersection scenario, the link can be sufficiently stable without depending much on the relative direction of the vehicles, while on straight roads, the link stability is largely affected by the relative direction.

Keywords—Multicast routing; vehicular networks; urban traffic dynamics; link stability

I. INTRODUCTION

A number of Intelligent Transportation System (ITS) applications, including the vehicular fleet management and publish/subscribe geo-scoped services, requires multicast communications from the Internet to Vehicular networks. Enabling such application is challenging due to the hybrid communications path (the Internet and wireless media) and the highly mobile nature of the destination nodes, which are the members of the multicast group.

The conventional multicast routing in the Internet is based on protocols such as Protocol Independent Multicast (PIM) [1], which relies on a tree structure to deliver packets from the source to the destinations. Thanks to the fixed topology of the Internet, the size of the multicast tree can be very large. On the other hand, due to the highly mobile nature of vehicular networks, it can be difficult to maintain a large tree in vehicular networks. Indeed, there is tendency to prefer structureless routing, e.g., opportunistic routing, for vehicular communications. However, it is not clear how such a structureless routing can be used for multicasting and how it can be combined with the structured multicast routing, which is used for the Internet, for Internet-to-Vehicular multicast communications.

To the best of our knowledge, very few studies are made on pure multicasting for Internet to vehicular communications

for different road environments. The analysis made by [2] shows that multicasting is preferable to broadcasting when the number of nodes in the network or the size of the area increases. Most of the existing works on multicasting for vehicular networks including [3] assume that the multicast members are all the nodes that belong to a specific geographic area and tackle the problems of geographic broadcasting (geocast) among the vehicles. On the other hand, some other works focus on vehicular group clustering organization and management. Although promising solutions are proposed (e.g., [4]), the proposals lack a deeper analysis of the impact of realistic road traffic on the communication between vehicles.

In this paper, we study multicasting for vehicular networks for data flow between Internet and vehicles. Since the tree-based multicast routing is the *de-facto* scheme in the Internet, we first investigate the stability and robustness of the tree structure in realistic road environments. This paper reports our preliminary analysis, which is carried out using the SUMO traffic simulator [5] targeting a realistic intersection road scenario. The simulations show the impact of the relative direction on straight road and the feasibility of stable link at the intersection.

This paper proceeds as follows. The related works are introduced in Section II. In Section III, we present our preliminary study concerning the impact of traffic dynamics on neighbor link stability. Finally, we conclude the paper in Section IV.

II. RELATED WORK

A number of efforts made for multicasting in ad hoc networks. The authors of [6] showed the feasibility of maintaining a multicast delivery tree for vehicular ad hoc networks (VANET) in straight roads environments. The scheme identifies the set of vehicles, which are concerned by the message, and builds a delay-constrained minimum Steiner tree by using a cost function. Unlike our work, the intersection road scenarios, which create more complex traffic dynamics, are not considered in this study. [4] proposes a multicast mechanism to enable communication in architecture which integrates the Long Term Evolution (LTE) technology and the IEEE 802.11p in VANET. In what they call "low-level multicasting" (group

communication in a cluster), they build a two-hops sharing tree to disseminate the message from the Cluster Head to the members of the group. In their analysis, the authors claim that a use of multicast tree provides efficiency and low control overhead. However, the author didn't justify the chosen size of the tree and they did not analyse the effects of the vehicular traffic characteristics on its stability.

In [7], the authors propose an approach to deliver multicast packets from the Internet to the vehicles which are located in a specific geographical area. In this approach, the packets are first forwarded to the access router, whose IP address is matched with the destination geographic area, and then the access router broadcasts the packets over one or more number of hops. [3] presents a broadcasting protocol named DV-CAST that addresses the problem of dealing with the extreme situations of dense and sparse vehicular traffic. The design of the protocol strongly relies on the one-hop neighborhood informations and shows a certain reliability in each road traffic situation. Although the approaches based on geobroadcast ensure robustness in some situations, it is not clear yet how efficient and scalable they are, especially in situations when the density is high or when the multicast group size is small as read in [2].

In [8], a study of the impact of the spatio-temporal traffic density variation in highway scenario is presented. The authors use in their study both empirical and analytical data to analyze and report the impact of different traffic situations on the communication performance. Although this work is similar to ours, it considers only simple dissemination mechanisms based on multi-hop geocast and single-hop broadcast.

III. IMPACT OF TRAFFIC DYNAMICS ON NEIGHBOR LINK STABILITY

In our simulations, we consider an urban area with an intersection as illustrated in Fig. 1. The size of the overall area is $4000m \times 4000m$. Each road has a single forward and backward lanes. Vehicles are generated at the edge of each lane (the points A, B, C and D in Fig. 1) following the poisson process at the average rate λ Hz (car/second). The maximum speed, acceleration and deceleration are 50 km/h, $0.8 m/s^2$ and $4.5 m/s^2$ respectively. The minimum inter-vehicle distance is 2.5 m. The velocity of the vehicles is limited to 50 Km/h. Their acceleration ability is set to $0.8 m/s^2$ and their deceleration ability is set to $4.5 m/s^2$. The minimum inter-vehicle distance is set to 2.5 m. The intersection is equipped with traffic lights and so that, the vehicles stop at the intersection if necessary. At the intersection, vehicles select randomly their destination and follow the route to their destination. Consequently, vehicles dynamically control their mobility following the traffic rule as well as to avoid collisions. The total simulation time is 15 minutes.

The aim of the simulations is to evaluate the number of K-hops neighbors of randomly chosen ego nodes (vehicles), the neighborhood lifetime, the relative directions and velocities. We define a node as a neighbor of the ego node, if the distance between the node and the ego is less than the communication range R . R is set to 300 m, with the IEEE 802.11p technology [ref], in mind. The neighborhood lifetime is the period of time during which the nodes stay as neighbors. The relative

direction is the angle difference between the moving directions of the neighbors.

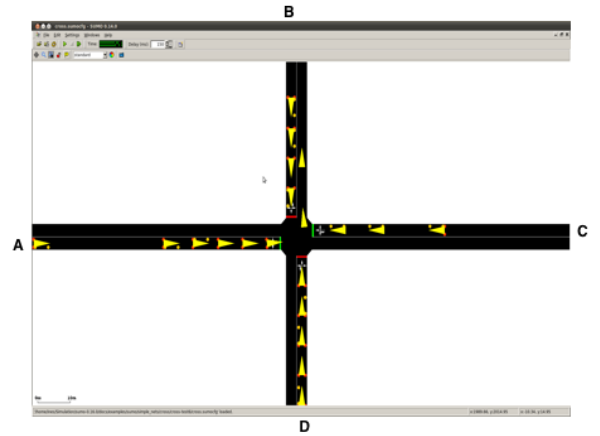


Fig. 1: Intersection scenario set up

Fig. 2 illustrates the maximum, the minimum and the average values of lifetimes for 10 randomly chosen ego vehicles. The horizontal axis is the road density, more specifically λ (the average vehicle generation rate). For each simulation, we change the value of the density, λ . As shown is the figure, the neighborhood lifetime linearly increases with the increase of the density. When the vehicular density on the road is low ($\lambda=0.04$ Hz), the maximum lifetime that we obtain is about 150 seconds, resulting in shorter neighborhood lifetimes with individual neighbors compared to those when density is higher (e.g., 650 seconds expressed by $\lambda=0.2$ Hz). The minimum neighborhood lifetime remains the same for all densities. This value is obtained when both the ego vehicle and its neighbors are moving at the maximum velocity and in opposite directions. As in the scenario, assuming that the maximum velocity is 50 km/h and the range R is 300 meters, the minimum neighborhood lifetime value can be obtained in this scenario as following:

$$\Delta t = \frac{R}{|v_{ego} - v_{neighbor}|} = \frac{0,3km}{100km/h} = 10,79sec$$

The average neighborhood lifetime drops notably compared to the maximum value of the neighborhood lifetime. The range of the average neighborhood lifetime varies from 30 seconds for a density λ of 0.04 Hz to 170 seconds for a density λ of 0.2 Hz. Those values explain that only few neighbors are kept for a long period (maximum lifetime) and that most of the contacts' durations belong to the interval [30sec,170sec]. Thus, vehicles are able to share common links with their neighbors during relatively long period of time (i.e., neighborhood lifetime) in intersection scenarios.

In the following, Fig. 3, Fig. 4 and Fig. 5 show respectively the number of the neighbors, the relative direction and the relative velocity measured (w.r.t ego node) when λ is 0.1 Hz. The horizontal axis of Fig. 3 and Fig. 4 (corresponding to the vertical axis of Fig. 5) is the normalized neighborhood lifetime. Based on our analysis, we used different markers; both rectangular and cross markers correspond to the results obtained

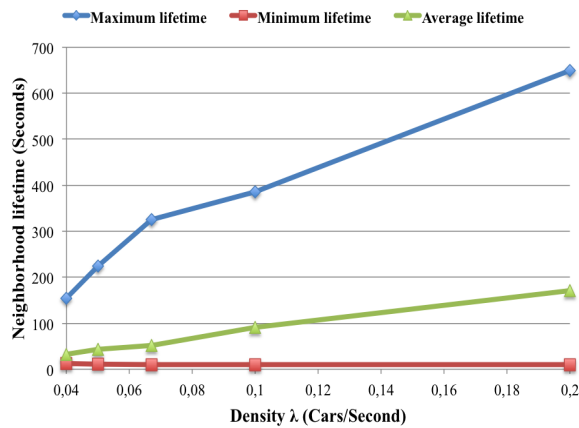


Fig. 2: Variation of the maximum neighborhood lifetime with the road density

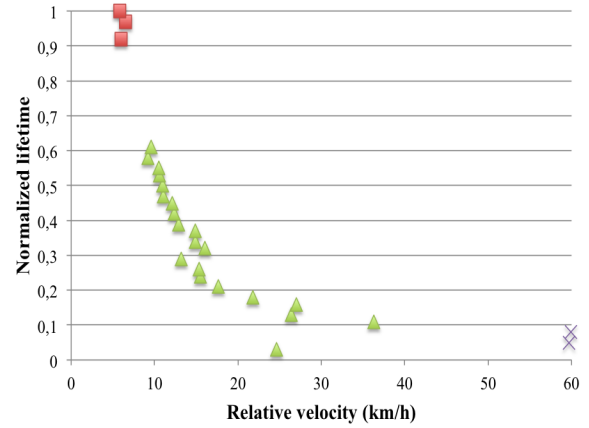


Fig. 5: Neighbors' relative velocity w.r.t the ego vehicle

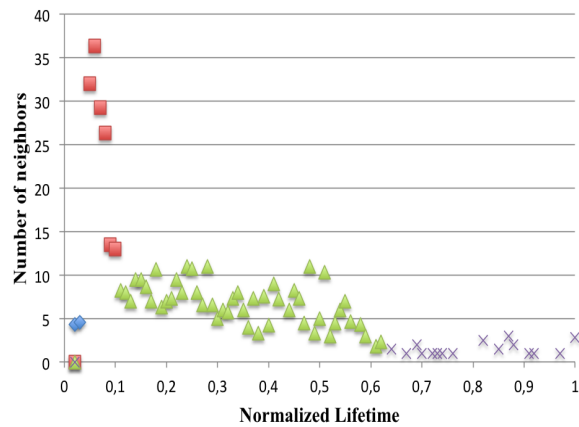


Fig. 3: Average number of neighbors

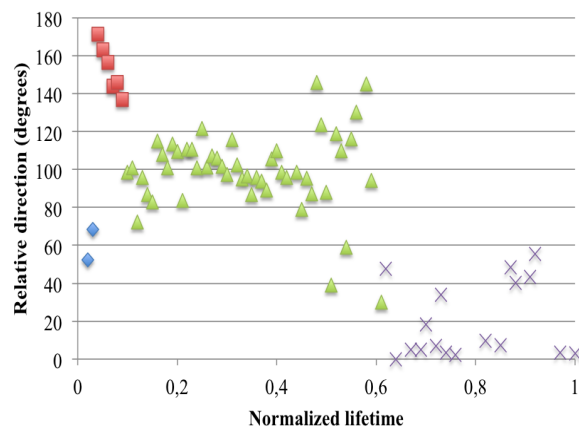


Fig. 4: Neighbors' relative direction w.r.t the ego vehicle.

for straight roads whereas triangular markers correspond to the results obtained in the intersection area.

Fig. 3 shows that a great number of neighbors, between 35

and 15 (expressed with rectangular markers), kept less than 0.07 of the lifetime (more precisely between 4% and 7% of the total lifetime). This explains why the average lifetime is much lower compared to the maximum lifetime in Fig. 2. The relative direction of these neighbors, as shown in Fig. 4 is as high as close to 180 degrees (i.e., opposite direction with the ego vehicle). Fig. 3 also shows that the lifetime of very few neighbors (1 to 3 neighbors) is longer than 50% of the maximum neighborhood lifetime and the corresponding relative direction is at most 40 degrees (expressed with cross markers in the figures).

Our investigation shows that such extremely short or long lifetime values reflect the situations where the ego vehicle is driving on the straight road. This implies that on the straight road, the relative direction provides a major impact on the link stability. While the ego node meets a larger number nodes, which are moving to the opposite direction, the neighborhood lifetime can be short and thus unreliable. On the other hand, while the number can be few, the neighbors, which are following the same direction as the ego node even after the intersection area, can provide stable links, and the lifetime can be especially long. Those situations correspond to a normalized lifetime of 1.

Furthermore, for the neighbors which start their journey on the same road segment as the ego node but take a different direction at the intersection, gives slightly shorter lifetime (between 0.5 to 0.8) and the relative direction is higher than 0. The lifetime in the range of [0.05, 0.08] (expressed with rectangular markers in the figures) corresponds to the neighbors which meet the ego node at the intersection. The relative directions of those nodes are relatively high; 80 to 160. It is interesting to observe that for those neighbors, the relative direction takes a high value for a long lifetime. Specifically, the neighbor with the relative direction [80, 120] had the neighborhood lifetime of [0.1, 0.3], whereas the neighbors with the relative direction 160 has neighborhood lifetime of 0.47. Finally, attention should be made to the case of lifetime neighborhood of less than 0.02 (expressed with diamond marker) that corresponds to the neighbors, which did not stop at the intersection and with whom the ego meets at the intersection. Because the neighborhood lifetime of such nodes

is even shorter than those of the neighbors, which move on the opposite direction at the straight road), such nodes should be distinguished from nodes which stop at the intersection.

As a consequence, it should be mentioned that we could not find a clear relationship between the neighborhood lifetime and the direction. For this reason, we investigated the impact of the velocity (Fig. 5) on the neighborhood lifetime duration of an ego vehicle.

Fig. 5 illustrates the variation of the neighborhood lifetime with the neighbors' relative velocity. From the figure, we can notice that long neighborhood lifetimes (almost 100% of the lifetime) are obtained when the relative velocity is low (i.e., between 0 to 10 km/h). In contrast, it is almost less than 10% of the neighborhood lifetime when the relative velocity is 60 km/h. Those situations correspond to the scenarios where vehicles are either driving on the same direction or on opposite direction but in the same road. On the other hand, the lifetime considerably decreases and becomes almost constant for the highest relative velocity which reflects the situation where the neighborhood contact duration is low when the vehicles are moving in opposite directions. Following the observation of Fig. 5 and Fig. 4, it seems that keeping relatively long neighborhood lifetime does not depend much on the moving direction but more on the relative velocity. indeed, as can be seen from Fig. 4, at intersection, while vehicles can have large relative direction, the lifetime can be low.

Consequently, our current investigation of the parameters that may have impacts on the neighborhood lifetime duration in the intersection scenario leads to the conclusion that the velocity seems to have the major influence on the neighborhood link duration. Our next step will be the investigation of such parameter in n hop neighborhood.

IV. CONCLUSION AND FUTURE WORK

We study the traffic road impact on the stability of multicast routing for data flows from Internet to Vehicular networks. In this paper, we reported our preliminary study of the traffic dynamics impact on link stability for a realistic intersection road scenario. The study is carried out using the SUMO traffic simulator under different road traffic settings. Simulation results show that in an intersection scenario, the link can be sufficiently stable without depending much on the relative direction of vehicles. On the other hand, on straight roads, the link stability is largely affected by the relative direction. Specifically, for the target scenario, only 2 neighbors are kept for more than 80% of the total ego trip time, whereas 35 neighbors keep a link with the ego for 5% of the total travel time. The study of the impact of the relative velocity shows clearly the correlation between the neighborhood lifetime and the relative velocity of neighbors and emphasizes the fact that this lifetime does not depend much on the relative direction.

As a future work, we study the impact of vehicles' velocity and density on the neighborhood lifetime for K-hop neighbors under more complex urban scenarios. Based on our studies, we plan to seek a multicast routing approach that is more adapted to Internet to vehicular communications scenarios.

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