Geo-localized Virtual Infrastructure for Urban Vehicular Networks

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Abstract— **Supporting future large-scale vehicular networks is expected to require a combination of fixed roadside infrastructure (e.g. Road Side Units, RSU) and mobile in-vehicle technologies (e.g. On Board Units, OBU). The need for an infrastructure, however, considerably decreases the deployment area of VANET applications. In this paper, we propose a self-organizing mechanism to emulate a geo-localized virtual infrastructure (GVI). This latter is emulated by a bounded-size subset of vehicles currently populating the geographic region where the virtual infrastructure is to be deployed. The GVI is designed in order to help the efficient support of dissemination-based applications. It can also be very useful in several ITS applications. Simulation results show that the proposed GVI mechanism can periodically disseminate the data within an intersection area, efficiently utilize the limited bandwidth and ensure a high delivery ratio.**

Keywords- Vehicular networks, Virtual infrastructure, Dissemination, Performance evaluation.

I. INTRODUCTION

Vehicular Communication Networks (VCNs) have emerged as the cornerstone of the envisioned Intelligent Transportation Systems (ITS). By enabling vehicles to communicate with each other via Inter-Vehicle Communication (IVC) as well as with roadside base stations via Roadside-to-Vehicle Communication (RVC), vehicular networks could contribute to safer and more efficient roads.

The opportunities and areas of applications of VCNs are growing rapidly, with many vehicle manufacturers and private institutes actively supporting research and development in this field. The integration with on-board sensor systems and the progressive diffusion of on-board localization systems (GPS) make VCNs suitable for the development of active safety applications, including collision and warning systems, driver assistance applications and intelligent traffic management systems. On the other hand, VCNs also fuels the vast opportunities in online vehicle entertainment (such as gaming or file sharing), and enables the integration with Internet services and applications [1]. Many of these applications rely on distributing data, e. g., on the current traffic situation, or on free parking lots. Often, data needs to be distributed over long distances, for example to allow a driver to choose between different arterial roads when driving into the city center. Typically, such applications are based on some form of proactive information dissemination in an ad hoc manner - i.e. by forming Vehicular Ad hoc Networks (VANETs).

Proactive information dissemination is, however, a difficult task due to the highly dynamic nature of VANETs. Indeed, VANETs are characterized by their frequent fragmentation into disconnected clusters that merge and disintegrate dynamically [2]. In addition, the results presented in [3] clearly show that during the rollout of VANET technology, some kind of support is needed. Otherwise, many envisioned applications are unlikely to work until a large fraction of vehicles participate.

One of the largely accepted solutions towards efficient data dissemination in VCNs is by exploiting a combination of fixed roadside infrastructure (e.g. Road Side Units, RSU) and mobile in-vehicle technologies (e.g. On Board Units, OBU). For example, in [4], roadside base stations are used to bridge network partitions in vehicular networks. A car already informed of an accident forwards the alert when passing by a roadside base station. Subsequently, the base-station forwards the message to other base-stations located in the alert zone. Each of the informed stations periodically broadcasts the alert to inform passing vehicles. Another recent example of broadcasting protocol specifically designed for vehicular networks with infrastructure support is the Urban Multi-hop Broadcast (UMB) protocol presented in [5]. UMB gives insightful results in terms of successful delivery rate. However, this is obtained with the help of repeaters at the road intersections. The need for an infrastructure considerably decreases the deployment area of UMB-based networks as UMB fails to handle intersections without a repeater. So, while such infrastructure-based approaches may work well, they may prove costly as they require the installation of new infrastructures on road network, especially if the area to be covered is large.

Thus, we propose in this paper a self-organizing mechanism to emulate a geo-localized virtual infrastructure (GVI) by a bounded-size subset of vehicles populating the concerned geographic regions.

This is realized in an attempt to both approaching the performance of a real infrastructure while avoiding the cost of installing it. A vehicle that enters the geographic region of a GVI attempts to participate in the mechanism; a vehicle that leaves the geographic region ceases to emulate the GVI. If all the vehicles leave a GVI's region, then the GVI fails; if vehicles return, then the GVI restarts.

A critical question that arises is where to position the GVI, in order to allow for a best-possible support of VANETs. This depends on in which environment the GVI will perform and for which application. As we are dealing with the city environment, an intersection sounds suitable as geographic region because of its better line-of-sight and also because it is a high traffic density area. Hence, the proposed GVI mechanism can periodically disseminate the data within a signalized (traffic lights) intersection area, controlled in fixed-time and operated in a range of conditions extending from under-saturated to highly saturated. Thus, it can be used to keep information alive around specific geographical areas (nearby accident warnings, advertisements and announcements, available parking lot at a parking place, etc.). It can also be used as a solution for the infrastructure dependence problem of some existing dissemination protocols like UMB [5]. One should also note that the GVI mechanism can be preferably instantiated in intersections with an acceptable level of car density (like in downtowns and highly used roads). In intersections implying low car densities, we can either decide deploying GVI or a static repeater. These situations being rare in metropolitan areas, the implied consequences remain reduced.

The rest of this paper is organized as follows. Section II describes the GVI scheme. Section III describes simulation setting and results followed by a discussion of relevant applications of the system in Section IV. Finally, Section V concludes the paper depicting future research directions.

II. GEO-LOCALIZED VIRTUAL INFRASTRUCTURE

The geo-localized virtual infrastructure mechanism consists on electing vehicles that will perpetuate information broadcasting within the intersection area. So, the GVI mechanism is composed of two phases: (i) the first phase is selecting vehicles able to reach the broadcast area[1]. (ii) in the second phase, only one among the selected vehicles is elected as the local broadcaster. It will perform a local / single hop broadcast once it reaches the broadcast area.

Note that GVI considers that each vehicle participating in the mechanism knows its own geographic position and speed using a Global Position System (GPS). Furthermore, we consider that such vehicles can determine the position of urban intersections through pre-loaded digital maps.

A. Selecting vehicles candidates

Among the vehicles which are around the intersection, only those which are within the notification area could participate to the GVI mechanism. They are selected as candidates only if they are able to reach the intersection center. The considered notification area is a region around the intersection starting at TR/2 before and extending to TR/2 beyond the intersection where TR is the transmission range of a vehicle. Figure 1 illustrates the candidate vehicles selection where vehicles {A, B, C, D, E, F, G, H} could participate to the GVI mechanism since they are located within the notification area and only vehicles {A, B, D, F} are selected as candidates because they are moving towards the broadcast area.

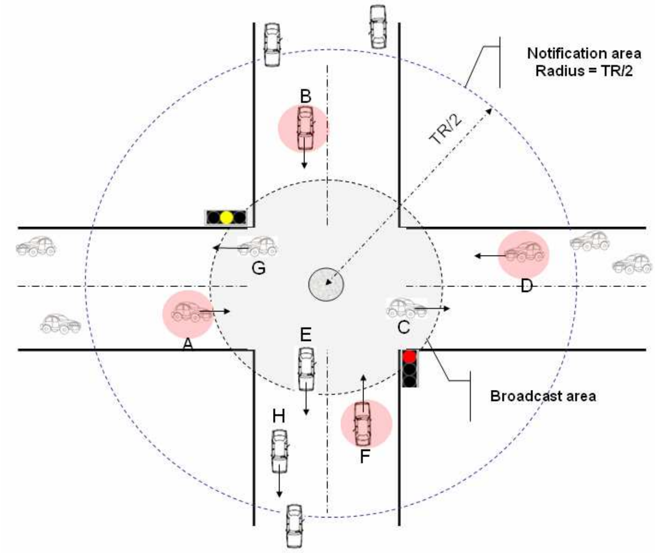

Figure 1 *– Selecting vehicles candidates in GVI mechanism.*

B. Electing local broadcaster vehicle

Each vehicle selected as candidate starts by computing the time period Δt needed to reach the center of the intersection considering its geographical location, direction and speed. According to this time period Δt, it computes a weight *P*(Δt). This one has to be maximal when the expected time period Δt matches the desirable GVI broadcast cycle time *T* and it decreases when we are far from *T*. One possible function for computing the weight is given by equation (1) (See figure 2). Note that other forms for this function (e.g. triangle) can also be considered.

$$P(\Delta t) = \frac{1}{\sigma.\sqrt{2\Pi}} \times \exp\left(-1/2\left(\frac{\Delta t - T}{\sigma}\right)^2\right) \quad (1)$$

where σ is a constant defining the width of the bell curve.

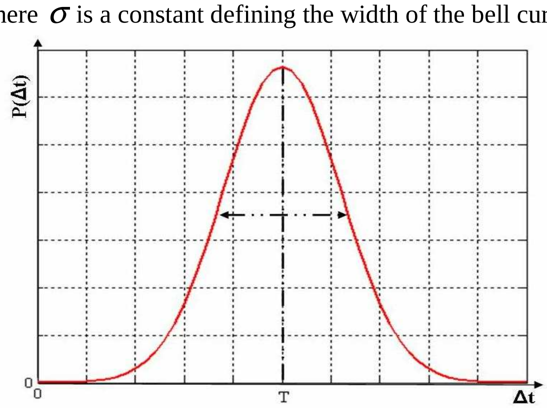

Figure 2 *– Calculating the weight P corresponding to the time period Δt that a vehicle needs to reach the broadcast area.*

[1] a small area around the center of the intersection, where an elected vehicle could perform a local broadcast.

Based on the computed value of *P*, each candidate vehicle will be assigned a waiting time determined through the following formula:

$$WT(P) = MaxWT\left(1 - \frac{P}{P_{max}}\right), \quad (2)$$

Thus, the candidate vehicle with the highest weight P will have the shortest waiting time WT to broadcast a short informative message telling other candidate vehicles that it has been elected as the local broadcaster within the corresponding GVI area. One should also note that, the probability of having a collision between two of these informative messages is small. This is due to two reasons, the length of these messages and the number of vehicles that may compute similar weight *P*. In the unlikely event of a collision among two broadcasted messages, the GVI will have multiple elected nodes for the corresponding time interval. All these elected nodes will perform the local broadcast while arriving at the intersection center instead of one. So, such collisions will not break the GVI.

The reason to choose the notification area starting at TR/2 before the intersection is that the elected vehicle has to inform the other candidate vehicles. So, its transmission range should cover the points within the proposed borders. In the worst case, the elected vehicle is TR/2 away from intersection and it can cover the points up to TR/2 away at the other side of the intersection.

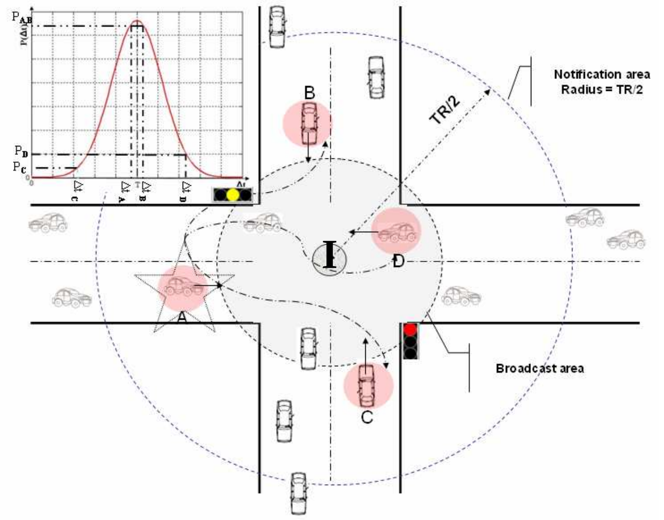

Figure 3 *– Electing the local broadcaster in GVI mechanism.*

An example of vehicle election is illustrated in Figure 3. Having been selected as candidate nodes, vehicles A, B and C start by computing the time period Δt to reach I (the center of the intersection) considering their position, direction and speed. We assume that vehicle B will have a long time period Δt_B since it is stopped at the traffic light. Vehicle C has a very short time period Δt_C since it is very close to I. Vehicle A requires a time period Δt_A very close to the broadcast cycle time T. Consequently, A will have the highest value of P as shown in the bell curve and at the same time, will have the shortest WT(P). Thus, vehicle A will be the first to send a message to vehicles B and C informing them that it has been elected to perform the local broadcast once it reaches the broadcast area around the center of intersection I.

Thus, the proposed mechanism described in phase 1 and 2 ensures that among all vehicles which are around the intersection, only one vehicle will be selected to perform a single broadcast when it reaches the center of the intersection. This is to avoid collision and interference problems.

Once vehicles within the transmission range of the elected vehicle receive the broadcasted message, they will participate in the election of the next local broadcaster following phase 1 and 2. Note that the elected vehicle has always the closest time duration to T. Hence, we can ensure that our GVI will perform a periodic local broadcast. Figure 4 illustrates the whole process of vehicle election in the GVI mechanism.

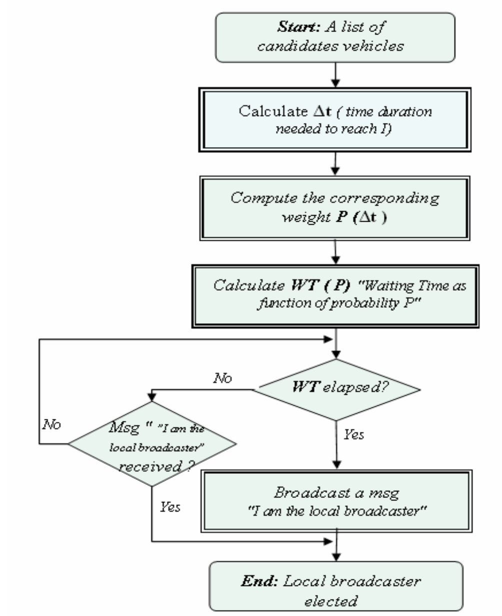

Figure 4 *– Electing the local broadcaster in GVI mechanism.*

III. Simulation & Results

In this section, we present the performance evaluation of the GVI mechanism. We built our own simulator based on queuing theory and realistic vehicular mobility model. Indeed, the model of the queue length and of the vehicles intersection stay is crucial in the study of the performance of the GVI mechanism. The main objective of this simulation study is to discuss whether or not GVI mechanism can ensure a good reachability (in terms of number of informed vehicles within the destination region[2]) and a low overhead (in terms of average number average number of copies of the same message received by every informed vehicle during its stay within the destination region). Note that GVI mechanism is designed to solve the infrastructure dependence problem of some existing

[2] an area around the center of the intersection whose radius is equal to the vehicles' transmission range.

dissemination protocols; and, to the best of our knowledge, is not really explored in literature. For these reasons, GVI is not compared to other dissemination protocols.

A. Simulation model

The simulation is based on a signalized, two direction intersection without turning movement (Figure 5), where vehicle arrival follows Poisson distribution with parameter λ. The arrival rate and departure rate (saturation flow rate) of the North-South (N-S) direction are λ1 and ν1, those of the East-West (E-W) direction are λ2 and ν2.

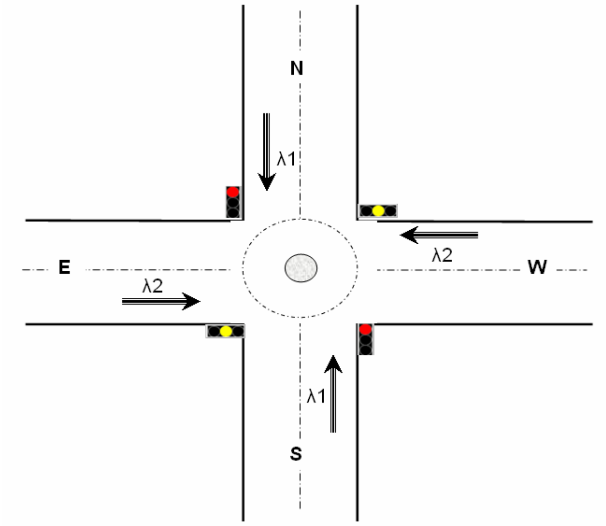

Figure 5 *- Simulation scenario –*

We consider vehicles arriving at a traffic signal TS_i on a one-lane approach. The cycle time C_i of the signal consists of red and green periods of length *Tr* and *Tg* respectively. Vehicles will form queues due to the presence of the traffic signals. The service time of a traffic signal is considered as constant *S*, it corresponds to the necessary time to go through the crossroad. By the above consideration, we can express the departure rate ν_i as

$$\nu_i = {}^{1}\!/_{S} \cdot \frac{T_g}{T_g + T_r}, \qquad (3)$$

Hence, in order to characterize the vehicular traffic within a traffic signal, we can compute the corresponding traffic load ρ, expressed as the ratio between the arrival rate and the departure rate:

$$\rho_i = \lambda_i . S \frac{T_g + T_r}{T_g} \quad , \qquad (4)$$

Most experiment parameters are listed in table 1.

Table 1 Simulation setup.

SIMULATION / SCENARIO	
Simulation Time	1.000.000s
Cycle Time (C=Tg+Tr)	80s
Red & Green Interval (Tg,Tr)	(40s,40s)
Service Time	2 s
Transmission Range (TR)	200m
Broadcast Area	340 m²
Intersection Region: (π.(TR/2)²)	31400 m²
Destination region : (π.TR²)	125600 m²
Broadcast Cycle Time	5 – 40 s
Vehicle velocity (city)	30-50±5 Km/h

B. Simulation results and analysis

Using the above setting, two sets of scenarios were conducted:

<u>Case1: Symmetric intersection with equal arrival rates</u>

In this case, the departure flow rates of two directions ($\nu_1$and ν_2) are equal to 0.25 veh/s, the arrival rates of two directions (λ_1 and λ_2) are equal, range from 0.1 veh/sec to 0.2 veh/s.

Figure 6 shows the relation between the broadcast cycle and the percentage of vehicles which fail to receive the data time under various vehicle traffic loads. It can be easily noticed that under the same vehicle traffic load, the increase in the broadcast cycle time leads to an increase in the packet loss. This is expected since if the broadcast cycle time is too long, vehicles pass the intersection before one cycle finishes and then fail to receive the data. Consequently, when the broadcast cycle time is smaller than 20 seconds; almost all vehicles get the data since even the fastest vehicle takes more than 20 seconds to move across the intersection.

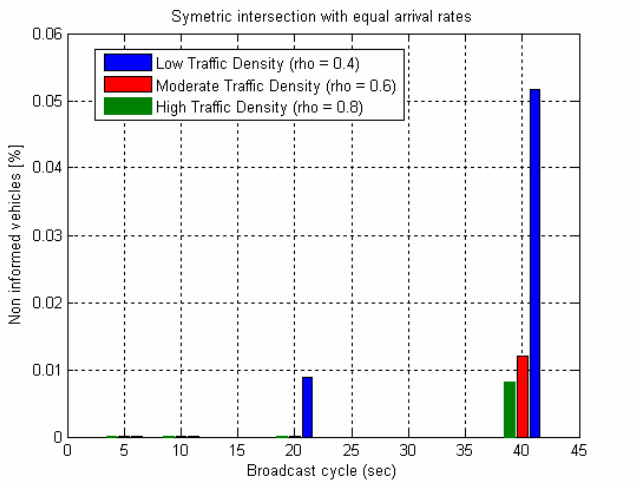

Figure 6 *– Non informed vehicles vs. broadcast cycle time (case 1).*

Another observation is that under the same broadcast cycle time, more vehicles fail to receive the data as the vehicle traffic density decreases. This also can be explained by vehicles intersection stay: when increasing vehicular traffic density, speed of vehicles decreases [6], which in turn increases the intersection stay. While under low vehicle traffic load, vehicles move faster and then may pass the intersection without getting data.

Figure 7 reports the average number of copies of the same message per informed vehicle as a function of the broadcast cycle time and for different vehicle traffic loads. Obviously, the obtained curves show that the higher the broadcast cycle time is, the smaller the number of copies is. Interestingly, the figure shows also that when the broadcast cycle time is high (40s), the average number of copies is almost the same under different vehicle traffic densities. This is because the broadcast cycle time is so high that the increase in vehicles intersection stay due to vehicular traffic density variation does not has a great impact on the number of copies the same message is received by a vehicle. In fact, the mean number of reception of the broadcast message is approximately equal to the mean sojourn time divided by the broadcast cycle time *T*.

The two figures show the kind of trade-off that can be achieved by changing the value of the broadcast cycle time between the number of copies of the same message (that is a measure of cost to provide the service) and the probability to inform a vehicle (that is a measure of quality of service). Clearly, in order to guarantee high probability of informing nodes, large redundancy in terms of number of copies of the same message is needed. It can be easily noticed also that for the simulated scenario, a broadcast cycle time of 20 seconds is an example of a good trade-off since it guarantees the information delivery in the intersection area and decreases the generated traffic.

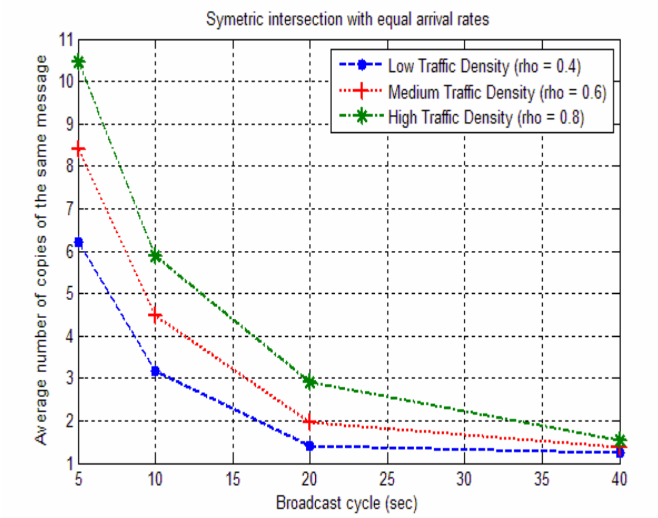

Figure 7 *- Average number of copies of the same message received by every informed vehicle (case 1).*

<u>Case2: Symmetric intersection with different arrival rates</u>

In this case, the arrival flow rates of two directions are different in order to simulate an intersection between a main road and a crossing road, the load (ρ1) of the N-S direction ranges from 0.9 to 0.6 while ρ2, the load of the E-W direction, increases from 0.3 to 0.6. The shape of the curves in this case (Figure 8 and Figure 9) is very similar to the first one.

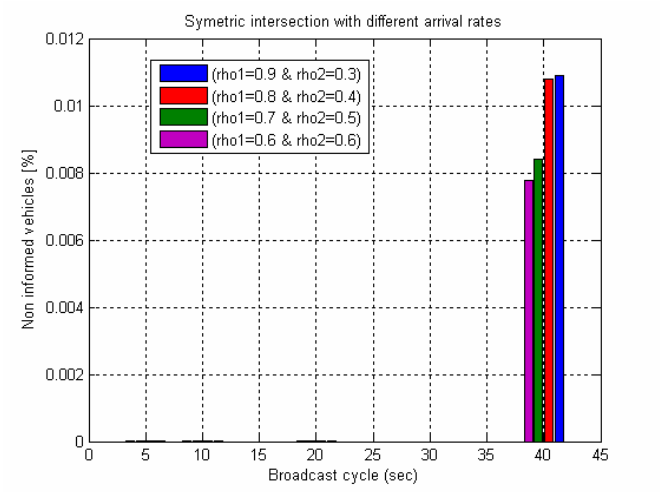

Figure 8 *– Non informed vehicles vs. broadcast cycle time (case 2).*

From the results we can conclude that no matter the saturation flow rates and arrival rates of the two directions are symmetric or not, the probability to inform a vehicle increases for low broadcast cycle time while the number of copies of the same message decreases for high values of broadcast cycle time.

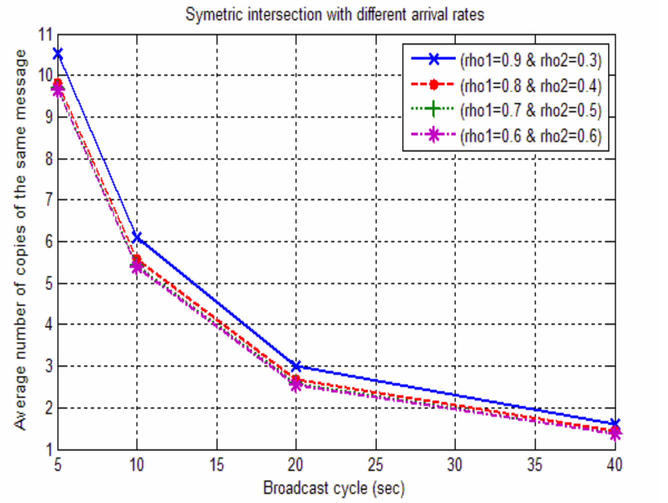

Figure 9 *- Average number of copies of the same message received by every informed vehicle (case 2).*

IV. Discussion

Before we begin to discuss what kind of services could profit from the GVI mechanism, we have to define what semantics a solution should have. In other words, we have to define what is the information the vehicles have to broadcast periodically, where do they get it from, for how long a message should be kept alive, etc. However, we know from other group communication research that it is not trivial or even impossible to define semantics suitable for most or all applications. In the following, we will describe two location-based services with their semantics:

- In [7], we presented a completely decentralized mechanism, IFTIS, for the estimation of traffic density in a city-road traffic network. The traffic information is collected using a data packet relayed between groups of vehicles following a unicast path until it reaches the destination intersection. Then, we simply elect the first GVI local broadcaster as the first vehicle who receives the message inside the intersection and switches from unicast to broadcast. Such information is important for drivers to optimize their travel, to alleviate traffic congestion, or to avoid wasteful driving. So, the GVI mechanism is suitable to keep this information about congestion alive within an intersection area. Thus, all the vehicles passing by the corresponding area will be kept informed.

- In [8, 9], the authors presented several approaches for disseminating a warning message to all reachable cars on the highway within the nearby accident area. However, their focus is on instantaneous delivery of the alert within the vicnity of the accident area. It is also important to keep such alert alive around entries such that other vehicles entering the highway could receive the message and then take precautions or change their travel path to avoid the condition. In such scenario, the GVI play the role of an accident warning sign within a highway entry. The initial sender of the message is the crashed vehicle. It uses a unicast geographic routing protocol to deliver the message to the GVI area.

Note that the GVI mechanism provides a best effort service without guarantees. In other words, our approach does not try to achieve reliability and is not suitable form some critical safety services like an Urban Intersection Collision Warning (UICW) [10]. Therefore, reliability mechanisms are not discussed in this paper.

Finally, one should note that the GVI mechanism is also suitable as a solution for the infrastructure dependence problem of some existing dissemination protocols like UMB [5].

V. Conclusion and Future Work

In this work, we presented an elegant solution for building a Geo-localized Virtual Infrastructure using inter-vehicle ad-hoc networks. The proposed mechanism has various potential applications ranging from safety to convenience applications, solving by the way the infrastructure dependence problem of some existing dissemination protocols. Simulation results show that the proposed GVI mechanism can periodically disseminate the data within an intersection area, efficiently utilize the limited bandwidth and ensure high delivery ratio.

We are currently studying analytic models to provide guidelines on choosing the system parameters, such as the best broadcasting period T, according to the road traffic parameters. We are also working on designing a new dissemination protocol based on the GVI mechanism.

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