Assessing the VANET's Local Information Storage Capability under Different Traffic Mobility

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***Abstract*—Wireless networking enabled vehicles can form vehicular ad hoc mesh networks (VMesh). By cooperative communication among VMeshes, a local transient information could be "retained" within a given geographic region for a certain period of time, without any infrastructure help. In this paper, we study this "storage capability" of VMesh. We analyze the scenarios of highway traffic (both one-way and two-way highway free flow traffic), and vehicular traffic in a city environment. For highway traffic, we study different properties of the "VMesh storage", using a simulation tool that accurately models the freeway vehicular mobility. For city traffic, we first perform simulations based on real traffic trace of San Francisco Yellow Cabs. Then we compare the results with the scenario where a general Random Way Point (RWP) mobility model is used. Our results show that transmission range has high impact on the storage lifetime for one-way highway traffic, and the size of the region in which we want the information stored has high impacts for two-way highway traffic. For city-wide traffic, the storage's lifetime generated using San Francisco Yellow Cabs' trace is shorter than that obtained using the RWP mobility model. This arises due to the regular movement of the cabs as compared to the random vehicle movement in the RWP mobility model.**

I. INTRODUCTION

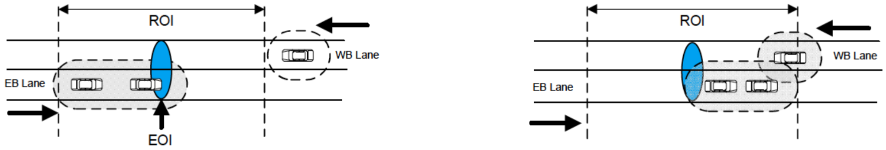
Vehicular Ad-hoc Networks (VANETs) are mobile wireless networks formed by vehicles with Dedicated Short Range Communication (DSRC)/Wireless Access in Vehicular Environment (WAVE) [1] and positioning capabilities. Enhancing VANET nodes with processing and storage capability enables the formation of a new computing and transportation infrastructure that can support new vehicular traffic control and safety applications [2]. Our focus is on vehicular wireless mesh networks, which are the transient mobile wireless ad hoc networks formed by vehicles in a VANET. Within these vehicular mesh networks, each vehicle serves as a node capable of broadcasting and relaying messages. With the help of vehicular mesh networks, it is possible to disseminate information among vehicles with no or minimal need for alternative fixed roadside infrastructure based approaches such as WiFi or cellular based data networks.

In traditional wireless mesh networks [8], all nodes are static. However, in vehicular mesh networks, the vehicle mobility results in a change in the topology of the mesh. Furthermore, the topology and size of the mesh can change due to vehicles leaving and/or new vehicles joining the mesh. As a result, the geographic region covered by one particular mesh is constantly changing. While vehicle mobility may cause problems such as inefficient hand-offs [14] and performance issues [18][19][17], regular and directed mobility of vehicular nodes such as in freeways may help in scenarios such as directed multi-hop routing [16]. We examine the scenario in which multiple vehicular mesh networks cooperatively retain certain transient information within a particular geographic region for a certain period of time. By holding and cooperatively passing the transient information of interest among themselves, the information can be considered "stored" in a certain geographical region of interest. We call this the "storage" capability of vehicular mesh networks. Possible applications of such storage include zero-infrastructure traffic warning system, ad hoc road condition monitoring, casual car-pooling, location-based commercial advertisements, among others.

In this paper, we study the storage capability of vehicular mesh networks for different traffic scenarios: 1) highway traffic (including one-way and two-way traffic flows), and 2) city-wide traffic. We are interested in the time for which the transient information can be maintained within a region of interest around the point where the transient event occurred. We define this time as the mean time to information loss (MTTIL). For highway traffic, we study the impact of different parameters such as vehicular traffic density, wireless transmission range, and the size of the region of interest on MTTIL. For city-wide traffic, we examine the MTTIL through simulation using real vehicle mobility traces of San Francisco Yellow Cabs [3] and compare the results against the simulation results obtained by using a general Random Way Point (RWP) mobility model.

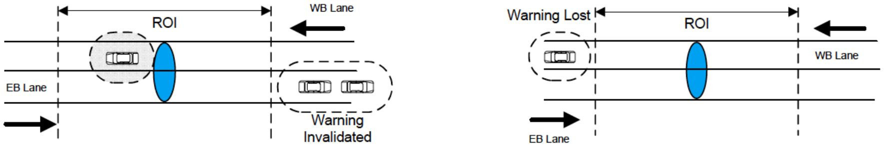
The remainder of the paper is organized as follows. Section II gives some background and a motivating example of the problem. It gives an illustrative example to show how storage works and what are the interesting attributes of the vehicular mesh storage that we analyze in this paper. Section III presents the problem formulation and the assumptions we have made for analyzing the VANET's storage capability. Section IV describes the simulation setup and results for the highway traffic. Section V presents the extension of the problem to the two-dimension city-wide traffic. Finally, Section VI concludes the paper.

This research is funded in part by the National Science Foundation under the grant number CMMI *0700383. The authors are solely responsible for the contents of this paper.



(a) EOI captured by a VMesh

(b) Capturing VMesh meets another VMesh



(c) Original Vmesh travels out of ROI, but EOI information still within ROI

(d) EOI information lost

Fig. 1. An illustrative example.

II. Background and Motivating Examples

VANET has been envisioned to have many potential applications in areas such as road condition monitoring, vehicular traffic control, and location-based commercial applications. Many of these applications require a location based information to be passed to nearby vehicles within a given region and for a specific period of time. While it is possible to implement these applications using current infrastructure based networks and systems (traditional ITS systems, road side WiFi [15], and centralized cellular based data networks [11], etc.), the distributed, infrastructure-less solutions enabled by local communication among vehicles could be more agile and can result in lower cost and shorter feedback control loop. As a motivating example, consider a hazardous road condition warning system. Suppose a hazardous road condition appears on the highway, such as a heavy item (e.g. ladder, furniture) that has dropped off of a vehicle, or a dangerous unnoticeable pothole created due to heavy rain. The normal practice nowadays requires drivers to inform related authorities to clear the condition or setup warning zones. However, this entire process could take as long as over ten minutes [5], during which time, drivers in the affected region are vulnerable. However, with the help of local communications among vehicles, a warning message about the hazardous condition could be passed to vehicles entering the road system within a certain region around the scene. This message could be generated by the first unlucky vehicle that discovers the hazardous condition. It is desirable that even when the first vehicle travels out of the warning region, the message still remains within that region, until the problem is solved. In this case, the ad hoc communication solution is complementary to the infrastructure based solutions.

In our proposed system, the task of "storing" the information within the region of interest (region of geographic relevance) is achieved through local communication and cooperation among vehicles. In this paper, we study the general properties of this local "storage capability" of VANETs.

Figure 1 illustrates how vehicular mesh networks can help retain a transient information within a given region for a certain period of time under a regular two-way traffic. Figure 1a shows the scenario that there are two cars forming a mesh network travelling on the East Bound (EB) lane. We consider that a transient event occurs (e.g. the first car hits the pothole) and is captured by the first vehicle in the mesh. This information can be relayed to the other car in the same mesh. Vehicles with the information can decide what to do about the event (e.g. moving out of lane or slowing down, etc.). More importantly, it is desirable that the transient information be passed to other cars/meshes within a certain region D of where the information occurred.

The vehicular mesh in Figure 1a (the original mesh) is considered having stored the transient information. If that mesh travels out of D, without being able to pass the information to other meshes, the information it holds will be considered lost. Figure 1b, shows the scenario in which before it travels out of D, the original mesh is able to transfer the information to another mesh in West Bound (WB) lane. When the two meshes ”meet”, the information can be relayed to all the vehicles in WB lane. As Figure 1c shows, even if the original EB mesh travels out of the region D, there is still the new mesh holding the information within D. This process can continue as meshes of different lanes passing EOI among themselves.

Depending on the intensity of the vehicles in the lanes, the above process may stop. When the only mesh within D travels out of D without meeting another mesh in the other direction, the information will be lost forever (depicted in Figure 1d). Similar scenario could also be considered in a city-wide traffic environment.

We are interested in for how long this information can be stored within D, i.e., the duration between the time when the information is captured until the time when the information is lost. This depends on various parameters including how many cars/meshes are on the road, the size of D, transmission range of cars, among others.

III. Problem Definition and Assumptions

For ease of discussion, we define the following terms:

- **VMesh:** A contiguous sequence of vehicles which form a wireless mesh, in which each vehicle is within the transmission range of at least another vehicle. If one vehicle in a VMesh holds any information, it is assumed that all other vehicles in the same VMesh can receive the information through broadcast or multi-hop relay.

- **Transient Event of Interest (EOI):** A transient event that can occur along or on the road. The information about the transient event is of interest to vehicles within a certain region. It is assumed that the EOI only has a location and does not occupy a physical space. An EOI could be "picked up" by a VMesh if the EOI's location is within the coverage of that VMesh. Also, it is assumed that this EOI is transient in nature; if the EOI is not picked up by any meshes when it appears, it immediately disappears, and the EOI will be considered lost. In real applications, the last assumption may not always be necessary. However, we want to conduct a baseline study of the property of the VMesh storage based on this assumption, since this assumption gives the most strict requirement for the lifetime of the VMesh storage.
- **Region of Interest (ROI):** ROI defines a physical region within which we want the EOI information to be stored.

Given the definition of the terms, we define the problem studied in this paper as follows. An EOI appears on the road. With a certain probability, this EOI is picked up by a VMesh. Then, this EOI information can remain in the ROI for a certain period of time, with the help of VMeshes cooperatively holding and passing it among themselves. Given the traffic density, the vehicle speed information, and the size of the ROI, we would like to examine the duration for which the information is stored within the ROI, i.e., the life time of the VMesh storage.

For the purposes of modelling and analysis of the highway traffic, which is more regular and tractable, we make the following assumptions:

1) **Poisson Arrivals:** We assume that vehicle inter-arrival times (temporal headways) is negative exponentially distributed with rates which may be different for each lane. This is a standard assumption that is made for free flow traffic in transportation research [10].
2) **Free Flow Traffic:** In order to make the analysis tractable, we assume that all vehicles are moving at the same free flow speed without speeding up or slowing down, i.e., there is no congestion or random slow downs. In Section IV we will examine the impact of this assumption.
3) **Directed Lines as Highways and Points as Cars:** In the analysis, we model a one-way highway a directed line, and each vehicle on that lane is modelled as a point moving along the line, following the direction of the lane. This assumption will also be examined in Section IV.
4) **EOI appears randomly along the road:** We assume the EOI's position is uniformly distributed along the road/within the region.

We are interested the Mean Time to Information Loss (MTTIL), which is defined as the time from the moment the EOI is captured by a VMesh, until the moment when no vehicle in the ROI holds the EOI anymore.

IV. RESULTS AND DISCUSSIONS FOR HIGHWAY TRAFFIC

Based on the above assumptions, we developed an analytical model for one-way highway traffic and an approximation model for two-way highway traffic. The details of the models can be found in [9]. In this section, we study VMesh storage's properties with realistic simulations.

A. Simulation Setup

In the analysis of the one-way and two-way highway traffic, the following assumptions need to be examined: 1) all vehicles travel at a constant speed, 2) each vehicle takes no physical space, and 3) EOI information can be relayed to all vehicles within a VMesh instantaneously.

In order to examine the impact of the above assumptions, we used VGSim [12] to simulate the VMesh storage for both one-way and two-way cases. VGSim is an integrated VANET simulation platform with realistic microscopic vehicular traffic mobility model and full stack network protocol simulation support. In VGSim, each vehicle takes physical space, and moves according to the Nagel-Schreckenberg(N-S) car following model [13]. N-S model is a Cellula-Automata (CA) model widely used in transportation research to generate synthesized vehicular traffic that resembles the data observed in the real-world [13]. Therefore, movements of vehicles in VGSim include random slowdown and speedup, which will result in varying headways between vehicles. VGSim also supports detailed wireless network simulation with full protocol support, so that the propagation/relay of EOI messages among vehicles can be simulated. Details of VGSim is documented in [12].

In VGSim, we have the following simulation parameters: vehicle arrival rate (λ) for each lane, vehicle speed (v) for each lane, vehicle transmission range (T_x), size of the ROI (D) that covers the EOI, and simulation duration. We simulate a stretch of the highway that is ten times the length of the ROI. The simulation duration is set to 108000 seconds (three hours). We mount a radio antenna on each vehicle which enables wireless communication among the vehicles.

At the start of the simulation, the lane generates vehicles according to the specified arrival rates, and the vehicles moves along the road as simulation time progresses. After the entire lane is populated by vehicles, an EOI will be generated uniformly along the stretch of the road. If the EOI is captured by a VMesh, that VMesh will be marked as carrying the information, and it broadcasts the EOI message to all vehicles within its transmission range. Each recipient of the EOI will forward it to all its neighbors after a small retransmission time. This process continues until all vehicles in a VMesh receives the EOI, and the vehicles stop retransmitting the EOI when they travel out of the ROI. All message transfers are based on UDP over 802.11b. We measure the Mean Time To Information Loss (MTTIL) which is the average time when the first vehicle picks up the EOI until the last vehicle that receives the EOI travels out of ROI.

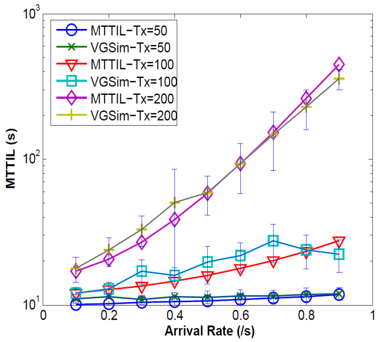


Fig. 2. One-way highway traffic MTTIL as a function of the arrival rate for different transmission range T_x, ($D = 500$).

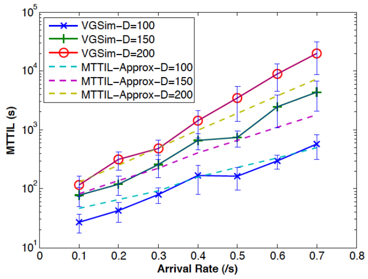


Fig. 3. Two-way highway traffic MTTIL as a function of the arrival rate for different ROI (D), ($T_x = 200m$). Results from simulation and approximate analysis

B. Results

1) ***One-way Highway Traffic:*** Figure 2 presents the analytical and simulation results of MTTIL for the one-way case for different system parameters. The bars around each data point of VGSim's data represent the 95% confidence interval of the simulation results. In general, in all cases, as the arrival rate (λ) increases, the MTTIL also increases. For T_x, Figure 2 shows that MTTIL increases exponentially with T_x. This confirms the analytical results in [9]. Notice that although typical transmission range for 802.11b is within 100 meters, the DSRC/WAVE standard specifies transmission range up to one kilometers for vehicular communication [7]. Therefore, transmission range over 100 meters in vehicular environment is reasonable.

The analytical models in [9] are based on some unrealistic assumptions. With VGSim's ability to reproduce realistic vehicular traffic and conduct detailed wireless communication simulation, we can study MTTILs using realistic vehicle mobility, and compare it against the results from the analytical model . From Figure 2 we can see that, the model and the VGSim results are close to each other. Most of the analytical results fall within the 95% confidence interval of the VGSim simulation results. Therefore, in general, the model and simulation with realistic vehicle mobility fit with each other; although there are some differences between the two results due to the random changes of the headways between vehicles.

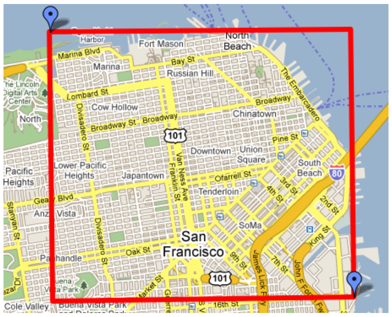


Fig. 4. Marked square represents the focus region within which we generates EOIs.

2) ***Two-way Highway Traffic:*** Figure 3 shows the impacts of D on the MTTILs of the two-way highway traffic. As we can see, as D increases, so do the MTTILs. In addition, two-way traffic result in significantly longer MTTILs than one-way traffic even with smaller D and T_x (as compared with Figure 2). This is because for two-way traffic, the key factor in determining the MTTIL is the number of times the captured EOI is passed between VMeshes moving in opposite directions. This number is highly related to D. Intuitively, the larger the size of the ROI, the higher the chance that a vehicle can pass the EOI to a vehicle from the other direction, before it travels out of the ROI.

Figure 3 also shows the results of approximate analysis for two-way highway traffic in [9], compared with simulation results obtained using VGSim. In the figure, the dashed line near each plot of the VGSim's data represents MTTIL obtained using the approximate analysis, calculated with the corresponding parameters. In general, the approximation yields results that follow the trend of MTTIL of two-way traffic obtained using realistic traffic.

V. CITY-WIDE TRAFFIC

In this section, we examine the VANET's storage capability for city-wide traffic scenarios through a detailed simulation study. First, we examine the MTTILs using real vehicle traffic traces generated by San Francisco Yellow Cabs (SF Cab). Then we examine the MTTILs for the traffic with Random Way Point (RWP) mobility model, and compare it against the results generated by SF Cab.

A. Simulation Setup

We performed simulation of VMesh storage in city environment, using the mobility trace of San Francisco Yellow Cabs provided by Cabspotting [3]. Cabspotting traces San Francisco's taxi cabs as they travel throughout the Bay Area. Once every minute or so, each cab reports its GPS location to the central dispatch [3]. The particular dataset that we used in our simulation is obtained from CRAWDAD project from Dartmouth College [4]. It contains GPS coordinates of approximately 500 cabs during the period 08-05-17 to 08-06-10. The cabs in this trace travel around the Bay Area, but we considered a rectangular region around San Francisco

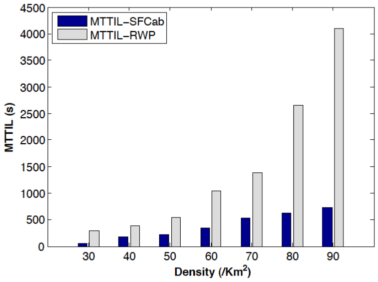


Fig. 5. Average MTTIL for SF Cab trace compared with RWP model, for fixed EOI, for different Local Density ($D = 200m, T_x = 300m$)

downtown area, which showcases a typical city-wide road network. It is shown by the marked square in Figure 4. We simulate a scenario where EOIs are generated at a location where there are more traffic (Chinatown area in downtown San Francisco). If the EOI is captured by any vehicle, the EOI is rebroadcasted. Vehicles that receive the EOI and are within the ROI will rebroadcast it until travelling out of the ROI. This process continues until the last vehicle with EOI travels out of ROI, and cannot pass the EOI to any vehicle in the ROI anymore. We measure and record all Time To Information Loss (TTIL) for all EOIs that are captured, and calculate the MTTILs.

We also implemented our simulation with the Random Way Point (RWP) mobility model. The density of the nodes are set the same as the average density of the SF Cab trace. The maximum vehicle speed is set to 20 m/s, which is similar to traffic speed limit in city environment. After the simulation starts, vehicles are populated randomly in the field, and move according to the RWP model. We measure, record and calculate MTTILs in the same manner as in SF Cab case.

B. Results

The transmission range (T_x) of each vehicle is set to 300 meters and the radius of ROI (D) is 200 meters.

MTTILs for both SF Cab trace and RWP model are shown in Figure 5. The x-axis represents the local densities, which were calculated as the time-averaged number of vehicles within the ROI over the area of the ROI. In general, Figure 5 shows that as the local density increases, so does the MTTIL for both the SF Cab trace and the RWP model. Furthermore, it shows that RWP model produces much longer MTTILs than the SF Cab trace. From the visual inspection of the simulation, this is because at the microscopic level of serval hundred meters, SF Cab traffic is restricted to roads, and thus is more regular. Vehicles can only enter/leave the ROI from several specific roads, while as in RWP model, nodes can enter/leave the ROI from anywhere. This results in higher MTTILs for the RWP model.

VI. Conclusion

With the help of inter-vehicle communication capability, vehicles on the road can form wireless ad hoc mesh networks. In this paper, we evaluate how these vehicular meshes can help to retain certain transient information in a specific region for a period of time, by cooperatively passing the information among themselves. We term this the VANET "storage" problem. We analyze both highway traffic, and city traffic. For the one-way highway traffic, we study different properties of the VMesh storage, and validate our model's assumptions through simulation using VGSim, which can generate realistic freeway vehicular traffic. For the two-dimensional city-wide traffic, we first conduct simulation using San Francisco Yellow Cab's mobility trace, and then compare the results with simulation using Random Way Point (RWP) mobility model. The results show that for one-way highway traffic, transmission range has high impact on MTTIL, while the size of the ROI has high impact on MTTIL for two-way highway traffic. It also shows that two-way traffic can greatly increase MTTIL compared with the one-way case. For the simulation using SF Cab trace, the results show that vehicle's regular movement in the SF Cab trace results in shorter MTTIL than the RWP model.

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