Realistic Mobility Models for Vehicular Ad hoc Network (VANET) Simulations

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***Abstract*— Vehicular Ad-Hoc Network (VANET) is surging in popularity, in which vehicles constitute the mobile nodes in the network. Due to the prohibitive cost of deploying and implementing such a system in real world, most research in VANET relies on simulations for evaluation. A key component for VANET simulations is a realistic vehicular mobility model that ensures that conclusions drawn from simulation experiments will carry through to real deployments. In this work, we first introduce a tool MOVE that allows users to rapidly generate realistic mobility models for VANET simulations. MOVE is built on top of an open source micro-traffic simulator SUMO. The output of MOVE is a realistic mobility model and can be immediately used by popular network simulators such as ns-2 and qualnet. We evaluate the effects of details of mobility models in three case studies of VANET simulations (specifically, the existence of traffic lights, driver route choice and car overtaking behavior) and show that selecting sufficient level of details in the simulation is critical for VANET protocol design.**

I. Introduction

Vehicular Ad-Hoc Network (VANET) communication has recently become an increasingly popular research topic in the area of wireless networking as well as the automotive industries. The goal of VANET research is to develop a vehicular communication system to enable quick and cost-efficient distribution of data for the benefit of passengers' safety and comfort.

While it is crucial to test and evaluate protocol implementations in a real world environment, simulations are still commonly used as a first step in the protocol development for VANET research. Several communication networking simulation tools already exist to provide a platform to test and evaluate network protocols, such ns-2 [1], OPNET [2] and Qualnet [3]. However, these tool are designed to provide generic simulation scenarios without being particularly tailored for applications in the transportation environment. On the other hand, in the transportation arena, simulations have also played an important role. A variety of simulation tools such as PARAMICS [4], CORSIM [5], VISSIM [6] etc have been developed to analyze transportation scenarios at the micro- and macro-scale levels.

One of the most important parameters in simulating ad-hoc networks is the node mobility. It is important to use a realistic mobility model so that results from the simulation correctly reflect the real-world performance of a VANET. A realistic mobility model should consist of a realistic topological map which reflect different densities of roads and different categories of streets with various speed limits. Another important parameter should be modeled is the obstacles. In addition, each vehicle needs to decide a turning direction at the intersection (e.g. turn left, turn right or go straight). Such a turning model could have an effect on the congestion of the road as well as the clustering of the vehicles. Furthermore, a smooth deceleration and acceleration model should be considered since vehicles do not abruptly break and move. Some prior studies [7], [8] have shown that a realistic model is critical for accurate network simulation results.

Selecting appropriate level of details in the mobility model for a VANET simulation is a critical decision. Unrealistic mobility model can produce simulations that are misleading or incorrect. on the other hand, adding details requires time to implement and debug, it might increase simulation complexity and slow down simulation, and it can distract form the research problem at hand. We previously developed a tool MOVE (MObility model generator for VEhicular networks) to facilitate users to rapidly generate realistic mobility models for VANET simulations [9]. MOVE provides an environment that allows the user to quickly pinpoint incorrect details and manage details overhead. Our tool is built on top of an open source micro-traffic simulator SUMO [10]. The output of MOVE is a mobility trace file that contains information about realistic vehicle movements which can be immediately used by popular simulation tools such as ns-2 or qualnet. MOVE allows users to rapidly generate realistic VANET mobility models in two aspects:- by interfacing with real world map databases such as [11], MOVE allows user to conveniently incorporate realistic road maps into the simulation. In addition, by providing a set of Graphical User Interfaces that automate the simulation script generation, MOVE allows the user to quickly generate realistic simulation scenarios without the hassle of writing simulation scripts as well as learning about the internal details of the simulator. The architecture of MOVE is shown in shown in Figure 1.

In this paper, we first briefly describe the architecture and implementation of MOVE (Section II). We then show that a realistic mobility model is critical for VANET simulations. We present three case studies that consider three different scenarios including the existence of traffic and driver route choice at the intersection and car overtaking behavior. We

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discuss how these details affect the network topology and resultingly the performance of VANET in the simulation (Section III).

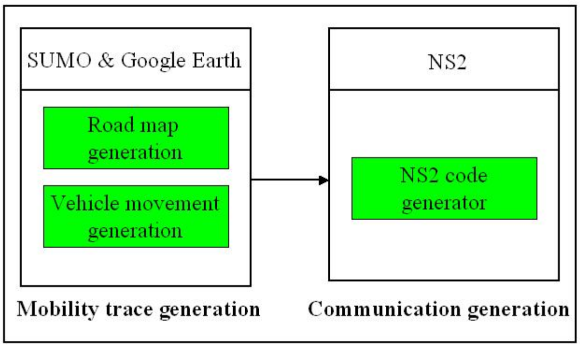

Fig. 1. The architecture of MOVE

II. Architecture

MOVE is currently implemented in Java and runs atop an open-source micro-traffic simulator SUMO. MOVE consists of two main components: the Map Editor and the Vehicle Movement Editor.

The Map Editor is used to create the road topology. Currently our implementation provides three different ways to create the road map – the map can be manually created by the user, generated automatically, or imported from existing real world maps such as publicly available TIGER (Topologically Integrated GEographic Encoding and Referencing) database from U.S. Census Bureau [11], as shown in Figure 2. We have also integrated Google Earth into MOVE to facilitate the creation of nodes in a realistic setting. Google Earth is a tool that enables its user to view the satellite image map of any place on earth. One of the functionality that Google Earth provides is called "placemark" which allows the user to put a mark on any location of the Google Earth map. Each placemark contains the longitude and latitude information of the selected locations and can be saved into a file in KML format [12]. Hence, one can define the *node* location on the Google map and then extract the node information by processing the saved KML file. This allows MOVE users to generate a map for any real-world road on earth for their simulations.

The Vehicle Movement Editor allows the user to specify the trips of vehicles and the route that each vehicle will take for one particular trip. We currently support three different methods to define the vehicle movements – the vehicle movement patterns can be manually created by the user, generated automatically, or specified based on a bus time table to simulate the movements of public transport. The information users input in the Map Editor and the Vehicle Movement Editor is then fed into SUMO to generate a mobility trace which can be immediately used by a simulation tool such as ns-2 or qualnet to simulate realistic vehicle movements.

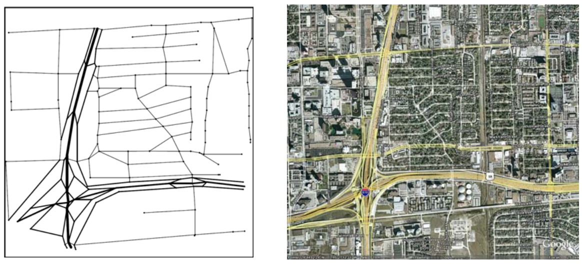

Fig. 2. Generating realistic mobility model by MOVE

III. Evaluation

Mobility models play an important role in VANET simulations. Nodes location, density, and direction etc. affect VANET performance directly. The objective of MOVE is to inject as much detail as possible into the simulation in order to provide a more "realistic" mobility model. However, a "truely realistic" simulation is very challenging since human behavior (e.g. mood, sex, age, etc.) and unexpected road accidents are difficult to model while all of them have strong effects on vehicle movement patterns. In this section, we evaluate the impact of mobility models generated by MOVE on the performance of ad-hoc routing protocols. The road topology generated by MOVE is based on the TIGER database data. The propagation model employed in our simulation is the TwoRayGround model. All nodes use 802.11 MAC operating at 2Mbps. The transmission range is 250m. The routing protocol is AODV [13].

we evaluate the effects of details of mobility models in three case studies. Specifically, we set out to understand how the existence of traffic lights, driver route choice and car overtaking behavior affect the VANET simulation results. The number of nodes in our simulations is 300 and the simulation time lasts for 1000 seconds. The roads created in the simulation have two lanes.

A. Existence of traffic lights

In real world, traffic lights are used to regulate traffic flow moving in different directions. The existence of traffic lights tends to create a "clustering" effect. In other words, places where there is a traffic light are likely to have a higher node density since vehicles are forced to stop at the traffic light to wait for the light to turn green. Intuitively, a high node density might improve the network connectivity. On the other hand, a higher node density might also suggest a higher chance for packet collision since more nodes might be transmitting at the same time. In addition, the distance between two adjacent traffic lights can have a significant effect on the network connectivity. Specifically, the network can be "fragmented" by the traffic lights when the radio transmission range is smaller than the distance between two adjacent clusters. In other words, a link breakage can happen when the inter-cluster distance is larger than the radio coverage.

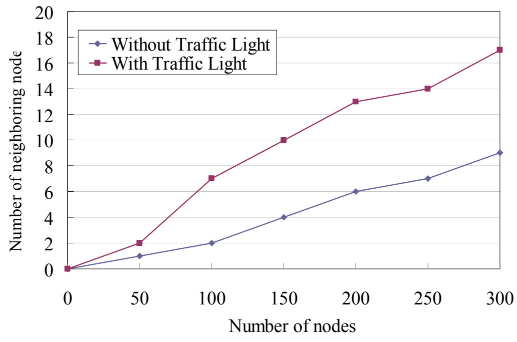

Fig. 3. Clustering effect due to the traffic light

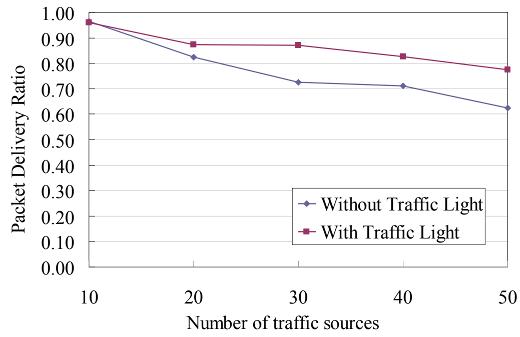

Fig. 4. Effect of traffic light

Figure 3 shows the distribution of the number of neighboring nodes when ten traffic lights are included in the simulations. Our results show that each node has twice the number of neighboring nodes when traffic lights are simulated, as compared to the case when traffic lights are not simulated. Here we define a "neighboring node" as the node which is within the radio range of a vehicle. Having a larger number of neighboring nodes typically suggests a better network connectivity.

As shown in Figure 4, the packet delivery ratio is improved when the traffic lights are simulated. Note that in this simulation the distance between two adjacent traffic lights is shorter than the given radio range. In addition, we observe that the number of packet collisions increases as we increase the number of traffic sources. As a result, the packet delivery ratio decrease when there are more traffic sources.

To understand the effect of inter-cluster distance on the simulations results, we increase the distance between two adjacent traffic lights (from 200m to 400m) so that the inter-cluster distance is larger than the effective radio distance. As shown in Figure 5, in this scenario we observe frequent link breakage between two adjacent clusters which significant degrades the network performance. The effective radio range is around 250m in this experiment.

Finally, we find that the traffic light cycle can also have a significant impact on the network performance. As shown in Figure 6, we observe from simulations that the packet delivery ratio decrease as we increase the traffic light cycle duration. While the increased traffic light cycle increases the cluster size, it also introduce more link breakage between clusters and results in more packet losses.

B. Driver route choice

In real world, a driver normally has to decide his moving direction at an intersection. He can choose to either go straight, turn left, or turn right. MOVE allows s user to define the turning probability of different directions at each intersection (e.g. 0.5 to turn left,0.3 to go straight and 0.2 to turn right) in the Vehicle Movement Editor. As shown in Figure 7, we find that different choices of route directions can significantly change the simulation results (the x-y-z notation in Figure 7 means that the car has x% of chance to turn left, y% to go straight and z% to turn right).

C. Overtaking behavior

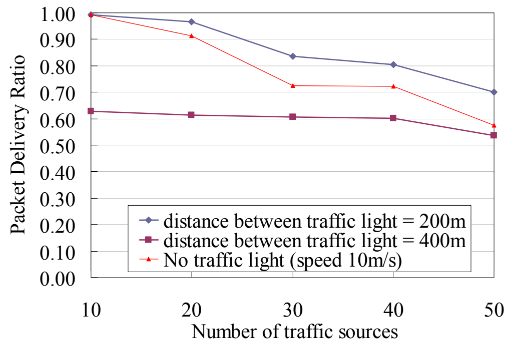

Fig. 5. Effect of inter-traffic-light distance

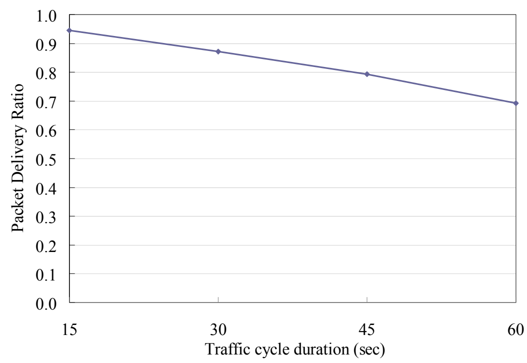

Fig. 6. Effect of traffic cycle duration

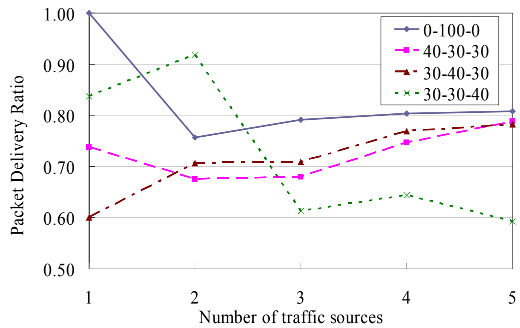

Fig. 7. Effect of driver route choice

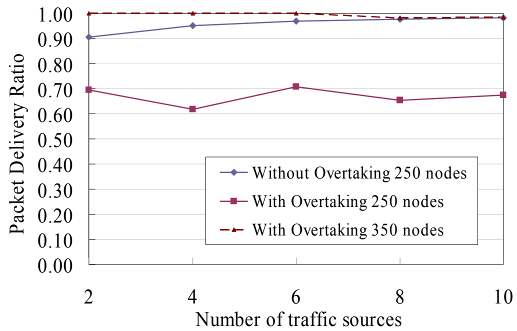

Fig. 8. Effect of car overtaking behavior

In real world, a faster vehicle can overtake some other slower ones when overtaking is allowed on a multi-lane road. Overtaking behavior can have a great effect on the network topology and should be considered. Specifically, when overtaking behavior is not allowed, it usually results in a chain-like topology and a shorter and uniform inter-vehicle distance (the uniform distance is due to the that the vehicle needs to maintain a safe distance from the adjacent cars), which often suggests a better network connectivity. As shown in Figure 8, we observe a dramatic impact on the network performance when the overtaking behavior is allowed. In addition, we find that the effect of overtaking behavior is less significant when the network density is higher. As shown in Figure 8, the packet delivery ratios in overtaking-allowed scenario is close to results of no-overtaking scenario when we increase the number of nodes from 250 to 350.

In summary, we show that details of mobility models such as the existence of traffic lights, driver route choice and car overtaking behavior can have a drastic impact on the VANET simulation results. We argue that the faithfulness of simulation results is proportional to the realism of the parameters and the models used in the simulations. Therefore, selecting appropriate level of details in the mobility model for a VANET simulation is a very important yet challenging task.

IV. Related Work

Our work builds on prior work in MANET mobility models.

Random WayPoint (RWP) [14] is an earlier mobility model widely used in MANET simulation [15]–[18]. RWP assumes that nodes can move freely in a simulation area without considering any obstacle. However, in a VANET environment vehicles are typically restricted by streets, traffic lights and obstacles. Hong et al. [19] propose a Reference Point Group Mobility (RPGM) model to characterize the relationship between mobile hosts. Bettstetter et al. [20] present a Random Direction Model which introduces a stop-turn-and-go behavior which can mimic the vehicle behavior at the intersections. Camp et al. [21] survey different mobility models and divided them into two categories: entity models and group models. Saha et al. [7] proposed a macro mobility model based on TIGER map database. This work considers the use of Dijkstra shortest path algorithm to select the path from source to destination. Jardosh et al. [22] present an obstacle mobility model that considers the placement of obstacles in the simulation and discussed the effect of obstacles on the signal propagation. Stepanov et al. [23] described a spatial model that considered path selection and user movement dynamics (such as road congestion and car-following behavior). Japp et al. [24] present a city mobility model that is based IDM (Intelligent-Driver Model). Treiber et al. [25] discussed a model that support car turning at the intersections. Street RAndom Waypoint (STRAW) [26] model considered traffic light control and car following. It uses shortest path algorithm to calculate movement path. Mahajan et al. [27] discussed Stop Sign Model (SSM), Probabilistic Traffic Sign Model (PTSM), and Traffic Light Model (TLM) in the context of a traffic control system. In SSM, every vehicle stops at the stop sign for a fixed duration time. PTSM use a probability p to deice if the vehicle needs to stop at the intersection. In TLM, traffic from different directions are considered for adjusting traffic light cycle to minimize the road congestion. Finally, Baumann et al. [28] proposed two mobility models. One uses vectorized street information from the Swiss Geographic Information System (GIS). The other is based on a microscopic, multi-agent traffic simulator (MMTS) [29] to generate vehicle movement traces. In the GIS-based mobility model, the actual node movement is generated according to the random trip model [30] on the vectorized street map. MMTS models the behavior of people living in the area and the travel plan of each individual as well as road congestion situation are considered in the simulation. This trace-based model, while imitating reality closely, requires a high amount of computing power for generation of traces.

Complementary to these previous efforts, our work emphasizes on creating a tool that allows users to rapidly generate realistic mobility models for VANET simulations.

V. Conclusion and Future work

In this paper, we first briefly describe a tool MOVE which is based on an open source micro-traffic simulator SUMO. MOVE allows user to quickly generate realistic mobility models for vehicular network simulations. We show that the details of a mobility model such as the existence of traffic lights, driver route choice and car overtaking behavior can have a significant impact on the simulation results. Care should be taken if simple mobility models are used for evaluation of VANET as the results might not be as close to reality as expected.

We have made MOVE publicly available and can be downloaded via the following URL - http://lens1.csie.ncku.edu.tw/MOVE/. In our current implementation, the movements of vehicles are based on static configurations defined in the Vehicle Movement Editor. In other words, the mobility model is first generated off-line and then used by a network simulator like ns-2. In the next version of our software, we plan to build an interface to tightly integrate SUMO and ns-2. Such an interface will allow that vehicle state information (such as location, speed, direction, etc.) can be fed into ns-2 in real time. Hence, during the simulation, the vehicles can dynamically adjust their routes based on different traffic scenarios and communication techniques employed.

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