Review of Mobility Scenarios Generators for Vehicular Ad-Hoc Networks Simulators

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Abstract.

The most used technology for ITS (Intelligent Transportation System) is VANET (Vehicular Ad-hoc NETworks) which is a subclass of MANET (Mobile Ad-hoc NETworks). VANET enables wireless communication between vehicles as well as RSU (Road Side Units), by using the standard 802.11p channels bandwidth to transmit all sort of information to each vehicle, within the range of the communication, providing passengers with plethora of safety, comfort and traffic monitoring applications. These networks are characterized by the predictable motion nature of vehicles which allows to predict the future locations of the nodes. They are also known for their varying topology through time, due to the changing number of nodes and the lane-constrained mobility patterns and their reduced power consumption requirements. However, the implementation, deployment and testing of VANET implies significant cost and requires a huge experimental platform. Therefore, computer simulation seems to be one of the best alternatives to test VANET communication protocols, before their deployment. However, the correct simulation of these networks requires to have access to a large number of heterogeneous mobility and traffic scenarios. Several research works try to solve these issues by creating mobility models that tend to accurately generate trace-files, that reflect the true nature of road traffic motion. This paper reviews these existing solutions and the need to develop them into intelligent tools, capable of faithfully reflecting human driving behavior in computer simulation scenarios designed to accurately test VANETs.

Keywords — VANET, Network Simulation, Mobility generators, ITS

1. Introduction

The domain of VANET (Vehicular Ad-hoc NETworks) is expanding and the implementation of communication protocols in these kind of networks require an experimentation platform, which proves to be very effective and gives results faithful to the real performances of the protocols. Unfortunately, these platforms are expensive and do not allow to evaluate communication protocols on a very large scale. Thus, the simulation presents an unavoidable alternative, and makes it possible to obtain an acceptable evaluation of the communication protocols. To get accurate results, it is crucial and recommended that the simulated model is as realistic as possible, which led networks simulators to become essential tools at least for the initial states of the VANET engineering and modeling process, making it the main tool for research.

Simulation is a real-world modeling technique; it allows to represent the functioning of a system that we want to observe. It relies on mobility scenarios generated according to one or more models. These
models aim to closely represent the motion patterns of the nodes, because it can significantly affect the accuracy of simulation results.

VANETs [1] are a subclass of mobile ad-hoc networks specifically dedicated to enable wireless communication between vehicles on the road, without the need of intermediate network equipment. These networks are characterized by their high transmission range, unlimited calculation power, predictability, and high mobility which can extend to the entire road network. These attributes make them highly salable, but due to their mobility and speed characteristics they often suffer from network partitioning. They also suffer from the core nature of the transmission link which is sensitive and limited. VANETs have wide range applications, from road users’ comfort and security, to traffic optimization solutions; to enable the intelligent transportation systems for smart cities.

This paper is organized as follows; Section 2 briefly describes the architecture and operation of network simulators. Section 3 introduces vehicular mobility models and their importance for VANET simulation. Section 4 to 6 present the Intelligent Driver Model (IDM) and its importance to mimic driver’s behaviour during a computer simulation; followed by a brief review of existing mobility generators as described in the literature. Finally, some of the main factors affecting realism in generated computer mobility scenarios are introduced.

2. Network Simulators
A network simulator includes two large modules, the protocol simulator and the mobility simulator (see Fig. 1). These simulators are in close collaboration to represent the global behaviour of vehicles in terms of movement and communication such as the specified protocol. The role of the protocol simulator is to allow a representation of the behaviour of a protocol, for a better evaluation of the performance and validation of the different functions of the protocol.

![Figure 1. VANET Simulator structure](image)

The mobility simulator allows a better representation of the movement of vehicles in road traffic. It makes possible to generate node mobility scenarios in order to test the communication protocols under driving conditions that are close to reality. These scenarios can be deployed in the absence of a real experimental platform, but require huge financial resources and only work on a small scale, unlike what can be done on a computer. The movement of vehicles is produced according to predefined models.

A mobility generator is composed of two essential modules: The traffic generator, to give vehicle positions at any time on a pre-established route. The road platform, which represents the environment in which vehicles travel.

Figure 2 shows some of the main VANET simulators used in research to evaluate the performances of networking protocols.
In general, Network simulators act as middleware to link mobility and VANET simulators’ output files, while predicting the vehicular networking system behavior, by calculating the interaction between the various network components. The majority of networking simulators use a discrete-event simulation, where the state variables change at discrete moments over time. The choice of the right network simulator is critical as it directly affects the performance of the simulated model. The chosen software should minimize CPU and memory usage, while optimizing the computational time and handling of model scalability [3].

3. Vehicular Mobility Models

A mobility model defines the motions of mobile nodes (vehicles) during a simulation of a wireless mobile network in a given area (real map, road platform, etc.). We identify three main classes of mobility models. These models can define free or restricted movements by mobility constraints (limited speed, presence of obstacles, constraints of realism), these Models [4] are defined as follows.

- **Macro mobility**: Macroscopic models are used when one wants to study the volume of traffic. This type of model is concerned with the topology of the road (street, lane, intersections), traffic density, type of traffic, the initial distribution of vehicles on the various tracks, etc., as well as its structure (unidirectional, multi-directional, one or more channels, etc.). These models consider the existence of attractions such as schools, restaurants, supermarkets and industrial zones, at specific times of the day, which significantly influences the movement of vehicles on road structure. They are generally used to build tactical scenarios related to road traffic management. Macroscopic models allow for rapid results obtained from the rough traffic modeling; but they do not allow the description of the individual movement of each vehicle. A more detailed model was then put in place to remedy this anomaly, the microscopic model.

- **Micro mobility**: Micro mobility is used to study the movement of the vehicle as well as the interactions it may have with its environment, such as signaling, safety distance between vehicles, lane change, overtaking and the driving behavior at intersections.

- **Meso mobility**: Meso mobility is a hybrid solution and combines the two previous models. Not only does it consider the intrinsic characteristics of the vehicle, as well as its direct interaction with its surroundings, but it is also concerned with the movement of vehicle clusters as an ensemble. It perfectly mirrors the traffic flow.

Due to the specific characteristics of vehicular networks (high movement speeds, movement dependence on the road structure, predictable trajectories, no battery limitation, etc.), the Mobility models conceived...
for MANET can not be applied to VANET and may give inaccurate results. This is why it is important to create models that attempt to satisfy a prime criterion, which is ‘realism’ at a very high degree of detail; which is essential to reproduce road traffic with great fidelity. Thus, it becomes clear that the construction of realistic traffic scenarios, that include the essential elements for the management of traffic, is essential for the implementation of a mobility generator.

Vehicular mobility models (see Fig. 3) are studied in order to investigate VANET and enable intelligent transportation systems. They are classified upon the method used to generate the output traffic and mobility scenario. They are divided into two main components: (1) Trace-based mobility models, and (2) Dedicated traffic models.

Trace-based mobility models use data obtained from real-world or artificially generated traces in order to generate similar outputs for simulation purposes.

Dedicated traffic models try to mathematically model the traffic and mobility characteristics; then use these models as an engine to generate more accurate, realistic, mobility scenarios.

Figure 3. VANET Mobility model classification [5]

However, the generation of large-scale networking simulation scenarios raises a number of research challenges. Large data sets are hard to find and they are often not publicly available, which make difficult data-driven generation of traffic scenarios.

4. Intelligent driver model
Until now, microscopic traffic models have mainly been used to (approximately) describe the human driver for a realistic description of future mixed traffic. However, appropriate models for both human driving and automated driving [6] are needed. Car-following models, reacting only to the preceding vehicle were proposed to describe human drivers; they describe more closely the dynamics of the vehicles. IDM [7] is a time continuous car following model, used to simulate freeway and urban vehicular traffic. It describes the dynamics of both positions and speeds of the vehicles throughout the simulation. It is characterized by free road behaviour, behaviour at high approach rates and behaviour at small net distances [8]. However, it is intended to describe traffic dynamics in one lane only and leads, e.g. in lane-changing situations, to unrealistic driving behaviour, when the actual gap is significantly lower than the desired gap. For such
situations, an alternative heuristic, based on the assumption of constant acceleration; in order to prevent unnaturally strong braking reaction due to lane changes, has been formulated.

The Enhanced IDM [9][10] combines the well-proven properties of the original model with the constant-acceleration heuristic, resulting in a more relaxed driving behaviour, in situations which are typically not considered to be critical by human drivers.

5. Existing Mobility Generators
Software simulation tools need mobility generators to produce accurate and precise simulation results. These generators are used to create unique trace-files, mimicking and reflecting nodes motion throughout the network; creating specific mobility scenarios. Due to the nature and characteristics of Vehicular networks, special tools have been specifically designed and implemented to meet the needs of their simulation. Some of them are briefly introduced in the following subsections.

5.1. VanetMobiSim
VanetMobiSim [11] is a software generator of vehicular movement traces, used to simulate network telecommunication protocols. It is built upon a CANU Mobility Simulator, focusing and emphasizing on the realistic simulation of vehicular macroscopic and microscopic mobility models. For the large-scale or macroscopic level, the simulator either imports maps from TIGER Geo-databases (containing all needed information regarding roads, railroads, rivers, etc.), in the United States, or randomly generates maps using Voronoi tessellation. This simulator also implements multi-lane roads, isolates opposite directional flows, adds speed constraints and enables traffic signs at each road intersection.

For the microscopic level, the simulator implements mobility models such as the Intelligent Driving Model that contains Intersection Management and Lane Changing modules. It also includes an overtaking model such as MOBIL, which cooperate with the Intersection management module to handle lane changes, accelerations, as well as the slowing down of vehicles; providing realistic V2V and V2I communication and interactions.

5.2. Street Random Waypoint (STRAW)
Street Random Waypoint [12] is part of the C3 (V2V Cooperation) project. It generates precise simulation results by applying the vehicular mobility model on real cities located in the United States, based on the analysis of real road traffic data.

For a mobility model to be accurate and for the simulation to be realistic, the network simulator should receive as input the appropriate amount of features describing vehicle motion, as well as road structure. STRAW constrains vehicle movement to streets data gathered from the real map and limits their movements, following the road congestion and traffic control modules.

5.3. Simulation of Urban Mobility (SUMO)
SUMO [13] is a traffic simulation software built to manage large size vehicular networks. It is principally a microscopic simulator as it applies a microscopic vehicular mobility model. One of it’s main options is that it includes collision free vehicle motion. It also includes various other features such as a large set of vehicle types, multi-lane roads, with the lane changing option, single-vehicle routing and dynamic routing, different road hierarchy and junction types, implementing all traffic rules at intersections. This allows SUMO to handle big simulation environments, as it can receive in input from various network file formats [14] such as XML Descriptions, etc.
Figure 4. Route selection simulation in SUMO

By associating SUMO and an Internet based map generator [15], such as "openstreetmap.org", vehicular networks can be efficiently simulated in all the different regions of the globe. SUMO can make it easier to explore various research topics, such as route selection algorithms (Fig. 4), traffic light algorithms or even the simulation of inter-vehicular communication.

5.4. Mobility Model Generator for Vehicular Networks (MOVE)
The mobility model generator for vehicular networks [16] helps to create realistic mobility scenarios for VANET simulations. It is built on top of SUMO, producing mobility trace files that include all the data to recreate a realistic vehicle movement scenario, that is directly used by computer network simulators, for example ns-2 or GloMoSim. MOVE also contains a Graphical User Interface that permits the generation of the required simulation scenarios, without the need to master the writing process of the simulation scripts and without having to learn and fully-master the core functions of the targeted network simulator.

5.5. FreeSim
FreeSim [17] is both a macroscopic and a microscopic vehicular traffic simulator that helps to represent, load and simulate multiple freeway scenarios as graph data structures, where the edge weights are represented by the node speeds. FreeSim allows to create and run graph and traffic algorithms, for individual vehicles, as well as for an entire network. The simulator uses traffic data either generated by the user or converted from the real-time data; provided by the transportation system organization that monitors the traffic on the freeways. This makes it a great asset for Intelligent Transportation Systems simulation.

5.6. CityMob
CityMob [18] [19] is a vehicular mobility model generator that implements Simple, Manhattan and Downtown mobility models, to mimic a vehicle’s motion in an urban city environment. In the Downtown Model for example, the streets are ordered following the Manhattan grid model, where the formed blocks are uniform in size. To be realistic, generated scenarios should take into account parameters like human driving behavior as well. Usually the drivers can adjust the vehicle speed. They can determine the distance to the leading car, to adjust to a safe time gap, when preceded by slower vehicles and, also decide on when to safely overtake the vehicle located in front.

6. Factors Affecting Realism in Mobility Scenarios for VANET
There are several factors that affect whether a computer simulation scenario reflects the reality of road traffic. The mobility model should try to describe the behaviour of vehicles according to their environment
as closely as possible to what is actually happening on the road. Among all the factors affecting mobility we highlight the six most important ones being presented in the following subsections.

6.1. The Vehicles’ Motion Patterns
VANET communication and routing protocols such as route discovery, maintenance and reconstruction algorithms are highly affected by the vehicles’ motion pattern. For example, static and slow-moving vehicles tend to mitigate the frequent modification of the network’s topology. Therefore, it is best to choose them as relay nodes for transmitting packets transiting in the network to/from the adjacent vehicles of the network. Whereas, high-moving vehicles tend to increase the entropy of the system, causing frequent topology changes, network disconnection, route reconstruction and packet losses [20]. The chosen mobility model should take care of all this criteria to closely fit reality.

6.2. City Block Size
The number of intersections in a certain geographical area represent the size of a city block, hence it is possible to determine the frequency with which each vehicle brakes and stops during simulation. It also determines whether vehicles at neighboring intersections can establish wireless communication with each other. By setting a large block size, the network becomes more sensitive to clustering and the performance of the simulated scenario is degraded [21]. Vehicles will spend more time passing through intersections. Therefore, vehicles are more often mobile. This increased mobility scenario can create a weakened and unstable network connectivity, with a corresponding drop in quality of service.

6.3. Traffic Control Systems
Speed limitation, stop signs and traffic lights are among the most present traffic control systems on the roads especially at intersections. This results in the creation of clusters and increased vehicle traffic, leading to the reduction of the network’s average mobility; further resulting in more static vehicles and slower rates of network route changes. Network performance can be severely affected by cluster formation, leading to higher wireless channel contention and longer network partitions. Therefore, it is important that the VANET mobility model reflect this phenomena on a simulation when encountering such mechanisms on the road.

6.4. Interdependent Vehicle Motion
Every vehicle’s movement of is highly influenced and dependent on of its surrounding vehicles’ movement pattern. A car has to maintain a minimum safety distance from the preceding vehicle. This leads to an increase or decrease of its current speed. It is also possible to switch to another lane or overtake another vehicle. As a fully distributed system, the movements and actions of each vehicle in the network at \( t \), affects the actions of the surrounding neighbor nodes at \( t + 1 \).

6.5. Average Speed
Vehicle’s speed is determined by how quickly its position changes. Thus, the entire network’s average speed is directly affected by the speed limit of each road reflecting the network topology change rate. The average speed of vehicles is also directly affected by the road topology. If a given road map contains fewer intersections, vehicles are able to move with higher speeds compared to road maps containing more intersections or smaller block sizes. Determining the acceleration/deceleration rate of vehicles, leads to know, how often existing routes would be interrupted, in order to overcome common disconnection, creating new routes when necessary.

Furthermore, standstill vehicles do not suddenly change their velocities to high speeds, instead, they accelerate gradually until reaching the desired speed of motion. Conversely, vehicles tend to decelerate gradually when approaching a traffic jam, stop sign or red light.

6.6. Road Layouts
Roads force vehicles to confine their trajectories to well-defined routes. This constrained road structure influences and affects the geographic distribution of the vehicles and therefore, their connectivity. Roads are formed from single or multiple lanes, allowing either one-way or two-way traffic directions. For
example, during computer simulation, by finding the road type defined in the TIGER database [22], the number of lanes can be determined. During the simulation, if a vehicle has to either select a new road, cross or turn at an intersection, the lane with the minimum number of both mobile and stationary vehicles is elected.

Figure 5 shows the different existing methods for the road layout computer generation, for the purpose of simulation. These maps can be generated either from aerial road image parsing, or from existing digital maps. By combining data gathered from existing maps to create various combinations of potential maps, these interactively generated maps allow to test the full potential of traffic optimization and communication algorithms in various, different situations.

**Figure 5.** Urban City road layout modeling and generation [23]

**Conclusion**

The perfect deployment and evaluation of routing protocols for Vehicular Ad-Hoc Networks is related to how realistically mobility scenarios have been described and modeled. The mobility model is one of the most important factors that impacts the realism of mobility scenarios, but most of the existing models only target and address certain specific problems related to mobility. The realism of these models, has always been a problem to solve by the industry and research community.
In this article the existing mobility models and generators for VANET have been reviewed showing how mobility is affected by the different simulation parameters. Mobility in vehicular networks is a crucial parameter to evaluate emergency communication protocols. If modeled correctly, it allows to accurately test these protocols and prepare them to be implemented in real vehicles. It will in the future contribute to saving lives or simply offer a better and safer driving experience to road users.

In a future work, different fuzzy logic based potential solutions [24] [25] [26], will be considered for the mobility model. Our goal is to propose, implement, test and compare several solutions to the existing models; to address the problem of realism in mobility scenario generation for VANETs which can later be extended for the simulation of autonomous vehicles [27].

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