

# *A Realistic Mobility Model based on Social Networks for the Simulation of VANETs*

Ana Gainaru, Ciprian Dobre, Valentin Cristea

Computer Science Department  
University “Politehnica” of Bucharest  
Bucharest, Romania

anamch@gmail.com, {ciprian.dobre, valentin.cristea}@cs.pub.ro

**Abstract**—Validation of mobile ad hoc technologies relies almost exclusively on modeling and simulation. In this paper we present a novel mobility model based on social network theory. The mobility model is designed to accurately reflect the realistic mobility of the involved actors in various VANET simulation scenarios. This is much needed as, in order to have a high degree of confidence in the validation of various technologies using simulation, the mobility model (as well as the network model) must act very realistic. However, at present, most mobility models being used are very simplistic. The mobility model being presented is part of a VNSim, a generic VANET simulator designed to evaluate a wide range of VANET technologies. We present several results obtained using the presented mobility model. The results show that the presented mobility model offers a good approximation of real-world movement patterns.

**Keywords**—VANETs; modelling and simulation; mobility model; social networks

## I. INTRODUCTION

Vehicular Ad-Hoc Networks (VANETs) are a particular type of wireless ad-hoc networks. They are formed when equipping vehicles on the roads with short range wireless communication devices.

Validation of mobile ad hoc network protocols relies almost exclusively on simulation. In order to have a high value of confidence in the obtained simulation results, however, both components of a simulator (the movement pattern generator and the network model) must present realistic properties, as close as possible to the ones encountered in real-world daily situations. The mobility models in particular must present moving patterns similar to the real behavior of vehicular traffic in order to offer a great degree of confidence on the running conditions of a simulation experiment. However, at present, most models are very simplistic ([4]). The most widely used mobility models are based on simple random-pattern models that cannot describe vehicular mobility in a realistic way because they ignore the particular human behavior of the drivers involved. As a consequence, simulation results of protocols are often based on randomly generated movement patterns and, therefore, may differ considerably from those that can be obtained by deploying the system in real scenarios.

Vehicular traffic simulators can generally be classified into microscopic and macroscopic simulators. From a macroscopic point of view we are interested in traffic density, traffic flows

and initial vehicle distribution. In contrast, the microscopic simulators are in charge of calculating the movement of each vehicle that participates in the traffic. VNSim ([5]), a generic VANET traffic simulator, uses both the microscopic and macroscopic models in order to accurately evaluate the performance of a wide range of VANET technologies.

In this we present a novel macroscopic mobility model based on the social network theory. The presented mobility model creates movement patterns by taking into consideration the social relationship between individual drivers, social relationship that might change depending on the simulation time. The new mobility model allows the vehicular simulator to generate all the information pertaining to the microscopic, as well as the macroscopic levels, with results showing close resemblance to the real world movement of vehicles.

In order to test its performances we implemented the mobility model in VNSim. In this we also present its implementation details, together with results obtained in validating the presented model using the realistic vehicular traces designed at the ETH Zurich Institute ([1]).

This paper is organized as follows. Section 2 presents the VNSim simulator, highlighting its properties and characteristics. Section 3 presents the macroscopic mobility model being proposed in theory and then details more on its implementation. In section 4 we present several simulation results being obtained in order to validate the proposed mobility model. Section 5 provides examples of related mobility models. Finally, in section 6 we give conclusions and present future work.

## II. THE VNSIM SIMULATOR

VNSim ([5]) is a VANET simulator developed in a collaboration involving the University Politehnica of Bucharest, in Romania, and the Rutgers University, in USA. It is designed as a realistic simulator for evaluating the performances of a wide-range of VANET technologies, ranging from wireless networking protocols and dissemination strategies to applications being developed over VANETs.

The VNSim simulator, implemented in Java, is composed of two main models: a vehicular mobility model that considers the behavior of the drivers, and a wireless networking model, responsible with the simulation of the networking components

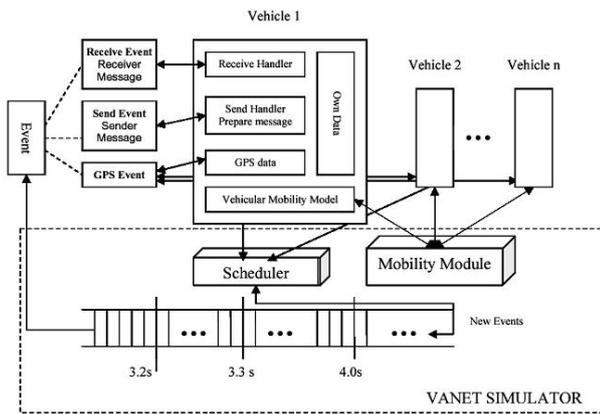


Figure 1. The architecture of VNSim.

and the communication protocols envisioned by a VANET system (see Figure 1).

VNSim uses a synthetic mobility model that integrates both microscopic and macroscopic motion. Its mobility model is in charge of importing the map topology and with building the dynamic of all vehicles.

From a microscopic point of view, the VNSim considers that drivers may be in one of the following four modes: free driving, approaching, following and braking. The decisions of the vehicles are influenced by the assumed model in which each vehicle is being driven, together with the model of the driver personality: calm, regular or aggressive. The mobility model also includes a lane-changing model for multi-lane roads and a traffic control system for intersections with traffic lights and for signed intersections. From this point of view the mobility model behaves very close to the real movements of vehicles.

From a macroscopic point of view, the VNSim reads entry and exit points for vehicles, and then, for each route between these points, the user specifies a flow of vehicles. This mobility model is useful in scenarios with a small number of vehicles. For example for an intersection scenario, this mobility model gives more freedom in choosing the directions of movement. Up until recently VNSim lacked a macroscopic mobility model for big scenarios where it would be very difficult to specify entry, exit points and routes for all vehicles.

The solution, being presented in this paper, consisted in the adoption of a novel mobility model that combines previous algorithms for macroscopic simulation of traffic design with elements from the social networking theory. This algorithm is presented next.

### III. THE DESIGN OF THE MOBILITY MODEL

The macroscopic mobility model is based on the social network theory. The mobility model automatically generates entry and exit points for all vehicles and then it calculates routes between all the points, routes that will be influenced by the strength of the social relationship between vehicles.

The model consists of four steps: importing the map, creating the groups of vehicles with the same destination, placing the vehicles in the topological space (one can envision this as finding the initial and final points for all vehicles) and moving all vehicles on the map between their initial and final points.

In order to build the map topology VNSim uses TIGER files, available in two formats: Record Type 1 and Record Type 2 (RT1 and RT2). These file formats allow us to build the road graph based on the road segments contained in the RT1 files, and the intermediary points for road segments needed to accurately represent curves that are available in the RT2 files. Additional information, like the number of lanes for a road or the traffic control system for intersections are added later in the simulation scenario generation (based on simple heuristics and the road class information included in the TIGER files).

After building the map topology VNSim automatically generate the movement of vehicles. For that we implemented two generators of synthetic social networks using two different models: the first one is Girvan-Newman algorithm and secondly we use the so-called Caveman Model proposed by Watts ([6]). Both algorithms are used to bundle together sets of vehicles having the same destination.

Within each run, each algorithm creates its own groups of vehicles, depending on the reconfiguration probability value presented as input by the user. The sets of vehicles formed by an algorithm considerably differ from the ones created by the other. In the morning the sets of vehicles with the same destination are generally represented by work colleagues and differ considerably from the sets of vehicles with the same destination in the afternoon, represented by family members. The two algorithms being used generate the sets of vehicles corresponding to the morning and afternoon conditions, as stated before. This is why we use the two algorithms consecutively, depending on the current state of the experiment.

Both algorithms start from  $K$  connected groups ( $K$  is an input for our model and it represents the initial number of groups). Then the algorithm rewires edges of the initial network to points from other groups with a certain probability  $p$ . Each vehicle is characterized by a Sociability Factor (SF), that is an indicator of its attitude towards interaction with other existing vehicles. The Sociability Factor of an individual  $i$  is obtained using the following formula:

$$SF_i = \frac{1}{z} \sum_{\substack{j=1..n \\ j \neq i \\ m > ct}} m_{ij}$$

where  $ct$  is the connection threshold and  $z$  represents the number of nodes.

A sociable vehicle is characterized by a value of SF close to 1 and a solitary one is then characterized by a SF value close to 0. The simulation scenario is established by mapping groups of hosts to certain areas in geographical space. After the definition of the social graph described above, groups, i.e., the highly connected set of nodes in the graph, need to be isolated.

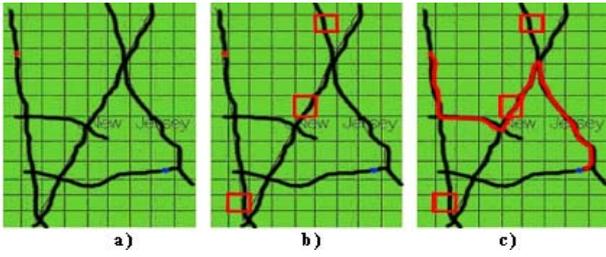


Figure 2. The social network route between entry (red point) and exit (blue point):  
a) the position of the entry and exit points.  
b) the squares on the map with the SF value greater than 0.  
c) the route that considers all intermediary points..

The groups of vehicles with the same destination are called groups with a high social relationship. After establishing these groups we need to map them in a topological space. In order to do this we apply a grid on the map imported from the TIGER files. The number of columns and rows for the grid are specified by the user and influences the density of the vehicles in the grid's cells.

Each group of vehicles is placed in a cell of the grid, more exactly on a road that is contained by that cell. The way the groups are placed on the map is done randomly or using probabilities (we can place groups of vehicles on the map with a higher probability for the cells that are in the middle of the grid or with higher probability for those that are at the edge of it).

In the last step we have all vehicles placed on the map and we know their entry and exit points. The VNSim's mobility model implements a module for choosing routes for each vehicle. The routes are dynamically chosen taking into consideration the social relation between the vehicles. The basic idea for this is that vehicles with a high social relationship have a higher probability to be geographically collocated most of the time.

The algorithm designates intermediary points for each vehicle and then creates the final route as the shortest path that intersects all of the checkpoints. The intermediary points are found as follows: for each vehicle, we search for the grid square that is geographically between the car's current position and the exit point and that has the highest social attraction. Then the algorithm places the vehicle on the above mentioned intermediary point and starts to designate another checkpoint using the same procedure. The social attraction that a square exerts over a vehicle is determined by the number of vehicles in the square that have a high social relationship for that particular vehicle. Following this algorithm, vehicles will move towards their exit points gradually.

The model also allows the user to specify the reconfiguration interval. This parameter represents the time interval after which the algorithm recalculates the entry and exit points and then the route between these new points. For example, vehicles having different trajectories in the morning and in the evening are based on different reconfiguration intervals.

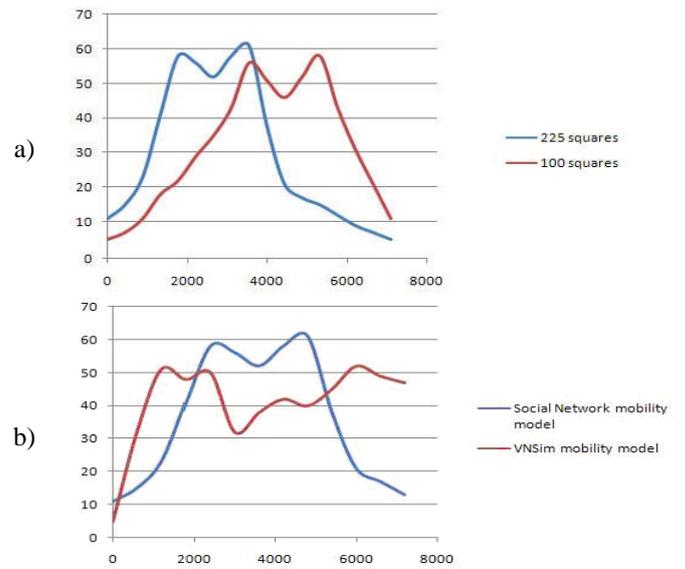


Figure 3. a) Distribution of the degree of connectivity; b) Distribution of the degree of connectivity for different densities of squares.

#### IV. EVALUATION

We evaluated the model in different mobile scenarios for a large topological space divided into a grid with different numbers of squares. The scenarios tested were composed of 100 hosts. The duration of the simulation is two hours and the reconfiguration interval 1 hour. We analyzed the behavior of our mobility model from three points of view: degree of connectivity, contact duration and inter-contact time.

The degree of connectivity is the number of contacts between vehicles in a particular moment. This parameter is important because it reveals the maximum number of vehicles that can be connected in a certain moment of time. This

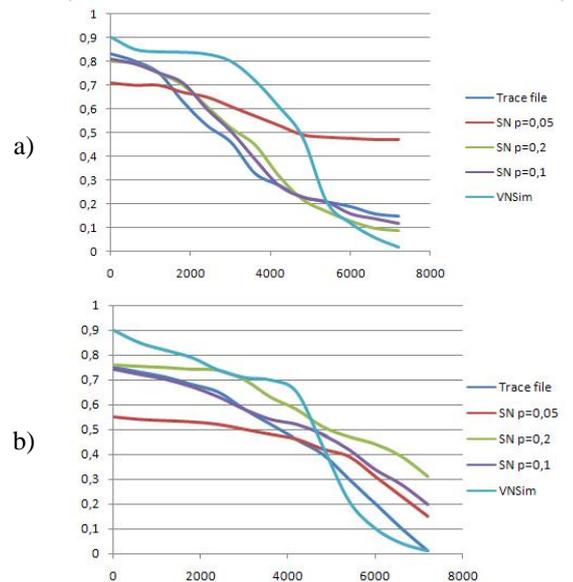


Figure 4. a) Comparison between the inter-contacts time; b) Comparison between the contact duration.

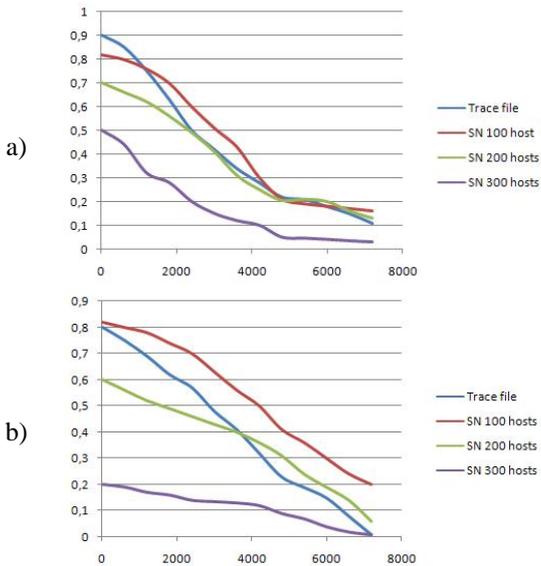


Figure 5. Influence of the density of population for a) inter-contact time and b) contact duration.

parameter affects the choice of bandwidth and the choice of priority algorithms. The contact duration represents the time interval for which two vehicles are able to communicate when they come into range. This parameter gives information about how much data can be transferred for each opportunity. The inter-contact time is the time interval between two contacts. Inter-contact time define the frequency and the probability of being in contact with the recipient of a packet or a potential carrier in a given time period. Inter-contact time affects the frequency with which packets can be transferred between networked devices.

We compared the results obtained using the proposed mobility model with the results obtained using a classic macroscopic mobility models (the one previously used in VNSim) and with results obtained using the ETH realistic vehicular traces ([1]). We also considered the implications of the work of ([2]) and ([3]) when designing the simulation experiments.

Figure 1 shows the results obtained in case of the distribution of the degree of connectivity when using the proposed mobility model. Figure 1.b shows the way the density of squares influences the distribution of the degree of connectivity. As presented, the peaks shift to the right as the density of the squares increases. This happens because, as the number of squares increases the density of vehicles per squares decreases, so the probability that vehicles have farther starting points is greater. Even if the peak shifts to the right the overall form of the graph remains the same and is very similar with the curve described by the traces imported from ETH. The VNSim mobility model instead shows an increase in the beginning and then an approximate constant behavior.

Figure 2 shows the comparison between the inter-contact time (figure 2a) and between contacts duration (figure 2b) for different rewiring probabilities. Our traces (especially the scenarios with a higher rewiring probability) show an approximate power law behavior for a large range of values

like those extracted from ETH Zurich data. A similar pattern is observed in the traces that we used starting from ([2]) and ([3]). The experiments presented in these two papers show similar behaviors, an approximate power law, as evidenced by the straightness of the curve. The distribution related to the original mobility model being used in VNSim, however, shows a typical exponential distribution.

In the end we were interested in the influence of the population density on the inter-contact time and contacts duration. For this we tested 3 different scenarios on our mobility model. We simulated scenarios composed of 100, 200 and 300 vehicles with a starting number of groups equal to 10, 20 and 30 and a rewiring probability of 0,2.

The impact of the density of the population in the described simulation scenario in presented in Figure 3. Also in these scenarios, the inter-contacts time and contacts duration distributions follow a similar pattern.

## V. RELATED WORK

There are several papers that use the social network theory in order to build a mobility model. The one that is the most related to ours is ([2]). In this paper the authors propose a synthetic mobility model that is based on the use of social networks. However their mobility model doesn't map the vehicles on a real topological space. This influences the choosing method for all entry and exit points and the way routes are build. Using our mobility model the vehicles know from the start their initial and final points. The routing track is then chosen taking into consideration the social relation between the vehicles but also considering the destination point. This means that vehicles move only between the initial and final point on courses chosen by the social relation strength between the vehicles. In ([3]), the mobility model proposed by the authors doesn't take into consideration roads and so the routing process doesn't follow strict points on a map. The vehicles move step by step according to social relation algorithms but without knowing their destination point.

In ([7]), a technique for the creation of a mobility models that include the presence of obstacles is presented. The specification of obstacles is based on the use of Voronoi graphs in order to derive the possible pathways in the simulation space.

Tuduce and Gross in ([8]) present a mobility model based on real data from the campus wireless LAN at ETH in Zurich. They use a simulation area divided into squares and derive the probability of transitions between adjacent squares from the data of the access points. Also in this case, the session duration data follow a power law distribution. Moreover, Tuduce and Gross' model represents the movements of the devices in an infrastructure-based network and not ad hoc settings.

We argue that, unlike previous existing work, our model describe more accurately the real-world behavior of vehicles in term of mobility patterns. Our mobility model considers more parameters than any of the simulators presented above. Our social mobility model creates initial and final positions for all vehicles, positions that are calculated considering different attraction and rejection points; it maps the points on a

geographical space and then creates movement patterns for all vehicles considering the social relationship between them.

## VI. CONCLUSIONS AND FUTURE WORK

In this we presented a novelty mobility model that takes into consideration the social relationship between vehicles. The mobility model generates automatically entry and exit points for all vehicles and then elaborates routes for all this points. This makes the model perfect for large city scenarios where there would be difficult to specify all these information manually.

The presented mobility model is part of VNSim, a generic VANET simulator designed to evaluate the performances of a wide range of wireless technologies. In order to accurately reflect the properties and characteristic of real-world mobility of vehicles in different scenarios, we augmented VNSim with the presented mobility model. The mobility model acts at a macroscopic level, as VNSim already benefited from a realistic microscopic mobility model. The two models combined make VNSim an ideal simulator that can cope with the realistic evaluation of VANET experiments under various real-world running conditions.

In this paper we presented the implementation details of the mobility model, together with several evaluation results designed to test its validity. The evaluation was conducted based on a comparison between the proposed social network mobility model, the macroscopic mobility model previously existing in VNSim, and the real vehicular traces from Zurich ETH ([1]). As presented, we showed that the social network mobility model generates mobility patterns very close to the movement of real vehicles in terms of degree of connectivity, contact duration and inter-contact time.

We intend to continue the work being presented in this paper in a number of directions. First we intend to add a module that allows users to select the attraction and rejection points for entry and exit. The presented mobility model

currently allows users to select different priorities for the center and the edge of the map. It would be useful if this selection could be done in more detail. This would allow users to select the exact scenario to simulate.

Another future work consists in the improvement of the interaction matrix generation module. In the social mobility model the matrix is symmetric since, to a first approximation, interactions can be viewed as being symmetric. It is probable that by performing psychological tests, the importance of a relationship, will be valued differently by the different individuals involved; in our model, this would lead to an asymmetric matrix. We plan to investigate this issue further in the future.

Finally we plan to add a module in the VNSim simulator that will monitor the traffic and will improve the routing algorithm using the gathered information.

## REFERENCES

- [1] Real Vehicular Traces - Zurich ETH <http://lst.inf.ethz.ch/ad-hoc/car-traces/>.
- [2] M. Musolesi, and Cecilia Mascolo, "A Community Based Mobility Model for Ad Hoc Network Research", Florence, Italy, May 2006.
- [3] A. Chaintreau, P. Hui, J. Crowcroft, C. Diot, R. Gass, and J. Scott, "Pocket Switched Networks: Real-world mobility and its consequences for opportunistic forwarding", February 2005.
- [4] J. Harri, F. Filali, and C. Bonnet, "Mobility Models for Vehicular Ad Hoc Networks: A Survey and Taxonomy", March 2007.
- [5] The VNSim's webpage: <http://cipsm.rogrid.pub.ro/vanet.htm>.
- [6] D. J. Watts, "Small Worlds The Dynamics of Networks between Order and Randomness", Princeton Studies on Complexity, Princeton University Press, 1999.
- [7] A. Jardosh, E. M. Belding-Royer, K. C. Almeroth, and S. Suri, "Real-world Environment Models for Mobile Ad hoc Networks", IEEE Journal on Special Areas in Communications, March 2005.
- [8] C. Tuduca and T. Gross, "A Mobility Model Based on WLAN Traces and its Validation", March 2005.