

Simulation of Mobility Models in Vehicular Ad hoc Networks *

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ABSTRACT

One of the emerging applications that belongs to ambient systems is to transparently and directly interconnect vehicles in roads, making an ad hoc network that enables a variety of applications through distributed softwares without the need of any fixed and dedicated infrastructure. The network as well as the embedded computers and sensors in the vehicle will be invisible to the driver, who will get the required services during his journey. The most important kind of services are the ones related to his safety. Before Proceeding to the real implementation of any software or communication protocol in vehicular ad hoc networks (VANETs) it is mandatory to first evaluate it through a comprehensive simulation study. Mobility is an essential parameter that features VANET, and should be carefully considered in the evaluation. To get faithful and correct results in a simulation study, the mobility model should be as realistic as possible. The earlier models used in general mobile ad hoc networks (MANETs), such as the random waypoint, are unsuitable for the VANET application, where the movements cannot take place freely in the open area. Indeed, vehicles move on the existing routes, constrained by many parameters (route intersections, stop and traffic light signals, the presence of other vehicles in front of the vehicle, etc.). Some new models taking into account these features have been recently proposed. In this paper we provide an overview of the mobility models newly proposed in literature, which can be used for simulating VANET. After that, we will present our mobility simulator that mimics many of the recent models. Finally, we use this simulator to illustrate the impact of the over-taking on mobility, a parameter ignored by all the previous simulation studies.

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1. INTRODUCTION

Ambient Systems represent a new important class of software-intensive systems that operate in extremely dynamic and distributed configurations, while aiming at greater user friendliness, and more efficient services support, which will enable the user to be continuously and transparently provided with the services it would need. A relevant example is the situation when the user is on the route in a vehicle. Through an ambient vehicular network, he can be provided with a variety of services, such as assisting his driving to increase his visibility and knowledge of the environment, prevent collisions, allow to take less crowded paths, allowing him to be connected to internet services if he is not a driver (or when he is in a bus), etc. These services are ensured thanks to the interconnection of his vehicle with other ones in a transparent, self-organized, distributed, and reliable way. A very exiting but challenging technology of vehicular networks is the ad hoc and infrastructureless interconnection. That is, vehicles are directly interconnecting to each other without relying on any fixed and dedicated base stations, and thus communicate in a multi-hop paradigm in which vehicles act as routers. Vehicular ad hoc network (VANET) is basically featured by the high mobility of nodes (vehicles) forming the network. It is mandatory before implementing any software to evaluate it by simulation, and thus the simulation is a very important step in the software design. The faithfulness of the simulation results is proportional to the realism of the parameters and models used in the simulation, particularly on the mobility model. Mobility model is the pattern that defines the movements of mobile nodes within the simulated area during a simulation. The earlier mobility models used to simulate general mobile ad hoc networks (MANET) assume the terrain to be with no obstacles, and nodes to be able to move freely in the whole rectangular stimulation area. This is realistic for some applications of pedestrians, but inappropriate for VANET. More recent studies propose new models constrained to routes and obstacles, and thus are more suitable for VANET. Earlier mobility models proposed for ad hoc networks have been largely studied and surveyed in literature [1, 2]. Nonetheless, the recent models of VANETs have not been surveyed yet. A state-of-the-art material of these solutions is then necessary. In this paper we present the most recent mobility models suitable for simulating vehicular ad hoc networks, as well as a simulator we developed enabling the simulation of many recent models.

We use this simulator to study the impact of the overtaking on the mobility. The rest of the paper is organized as follows: in the next section the related work will be presented, followed by a brief description of the basic mobility models. Section 4 illustrates the VANET's mobility models, followed by the introduction of our simulator and the presentation of the simulation study in section 5. Finally, section 6 concludes the paper and sketches the perspectives.

2. RELATED WORK

Mobility models used to evaluate ad hoc networks can be divided into two classes [1]: entity models and group models. In [1] Camp et al. discuss a variety of these models, and show by simulation how the choice of a mobility model significantly effects on the performance results. Except city section [3], all the other models presented in this survey are inappropriate for VANETs. In [4] and [2] the authors classify the models according to the randomness of speeds and directions, and divide them into i) trace-based (deterministic) models, ii) constrained topology based models iii) and statistical (fully random) models. Basing on this classification, [2] provides a more recent survey of MANET's mobility models, presenting some ones that consider obstacles in the simulated area. Still, these models are suitable to simulate pedestrian movements, but not vehicles. In [5], the authors provide a mathematical and simulation on some of the statistical (random) models, and combine them in the so-called random trip. Some recent research works focus on the vehicular ad hoc network application of MANET. [6] provides a general survey of VANET, and the existing challenges to overcome before the real deployment. In [7] the authors discuss the usefulness of VANET to ensure the vehicular traffic safety and facilities, as well as the advantages it provides compared to the other centralized technologies. Some specified applications have been proposed, such as the discovery of free parking places [8]. Regarding mobility models, some new ones have been specifically proposed for VANET, such as [9, 10, 11]. However, and as far as we know, there is no paper devoted to surveying these new models. In this manuscript, we will present and discuss these novel models, as well as those proposed for the general MANET that applies to VANET. But first, we sketch out the earlier MANET's models, since some concepts of these models are employed in the models we will present later.

3. MANET'S MOBILITY MODELS

In the following we briefly describe the earlier mobility models used to simulate MANET, more details could be found in [1]. In this paper the authors split the models up into two categories: entity and group models. All the models described in this section allow free movements within the simulation area, without any obstacles. They apply to networks where movements take place in open spaces, like in a public garden or a university campus, but not to VANET.

3.1 Entity Models

In this types of models, the movement of each node is defined separately and independently from the others. Each node moves by itself, following its own parameters. The number and the nature of these parameters, as well as the mobility algorithm change from a model to another. According to [12] the first mathematical model belonging to this category, namely the random mobility, was proposed by Einstein

in 1926. It defines a random mobility with no memory, using two variable parameters, the speed and the direction ($\theta \in [0, 2\pi]$), and two constant periods T_d and T_s . The mobile node moves continuously, its speed changes every T_s and its direction every T_d . Both the speed and the direction are picked randomly, following a uniform distribution. The most popular random mobility model is the random waypoint (RWP) [13]. It has been largely used for simulating ad hoc networks, and available in many network simulators (ns2, GloMoSim, etc.). This model defines the pause-time parameter, and thus each node has phases of movement and others of pause. At the beginning, the node selects randomly and uniformly a destination where it goes using a random speed, which is also selected following a uniform distribution. Once it reaches this destination, it remains there for the pause-time duration, then repeats the process. It has been illustrated that this model engenders, after a given simulation time, a spatial distribution of nodes concentrated around the center of the terrain, which is not uniform [4, 14]. To get over this problem, the smooth random model (SRM) [4] and the random direction model (RDM) [15] have been suggested. In RDM, a direction is used instead of a destination, then the node moves in the selected direction until reaching the terrain borders where it stays for the pause-time duration, before choosing another direction and speed and repeating the process. In addition to using a direction, SRM defines the acceleration parameter, along with the speed control and direction control random processes. In this model, a current speed does not change directly to a selected one, but it increases or decreases gradually, according to the value of the acceleration, which is more realistic. The same approach is adopted for the direction. The speeds and accelerations are managed by the speed control random process, and the directions by the direction random process. The last model we mention is the known as Gauss-Markov mobility model [1]. Specifically in this model, the values of speed and direction at a given time are calculated basing upon the values at the previous one. Contrary to RWP, this model does not suffer from the sharp change of the speeds and directions, as it allows past velocities (and directions) to influence future ones [1].

3.2 Group Models

Models belonging to this class mimic the mobility where nodes move in groups. This is realistic in many scenarios, such as in battlefields or tourist trips. Still, these models also assume the simulation terrain to be an open area without obstacles. The first model of this category we describe is the reference point group mobility model RPGM [16], which represents a random motion of a group of nodes as well as a random motion of each individual within the group. A logical center is defined for each group of nodes, defining the movement of the group according to a vector. The latter is used to set the speed, the direction, and the position of the center. The motion within the group is controlled using another vector derived from it. The nomadic community model [12] is very similar to RPGM, except that the motion of group members around the reference point are generated using one of the entity models presented previously (such as the random mobility model), but without distancing a lot from the reference point. First, the members follow the reference point whenever it changes the position, then they start moving around it individually. The parameters of the

employed entity model define the dispersal of nodes from the reference point. The column mobility model (CMM) [12] is very similar to RPGM, but the reference in this model is indeed a line (column), rather than a point. A typical example that can be represented by the previous models is a visit of a group of students to a museum. The museum guide who moves in the different parts of the museum represents the reference point. The students follow him during the visit, and may make some movements individually around him. The pursue mobility model (PMM) [12] is different from the previous ones. It attempts to represent a group of mobile nodes tracking a particular target, which may be either static or move following the random mobility model. For instance, this model can mimic the movement of police officers trying to catch an escaped criminal. In PMM the pursuers attempt to reach the target as directly as possible, but to simulate possible errors their mobility is slightly altered with a random speed/direction vector.

4. VANET'S MOBILITY MODELS

In this section we present the models that were either specifically proposed for simulating VANETs, or used in the general MANET context but usable in VANET. Basically, these models simulate movements in routes, contrary to the previous ones that assume an open area. As we will see, the considered parameters differ from a model to another. For instance, some models use traffic control mechanisms (stop signs or traffic lights) at route intersections, and others just assume continuous movement at these points. Some assume routes to be single-lane, some others support multi-lanes routes. Some define the security distance, while others just ignore this parameter.

4.1 Freeway

Freeway is a generated-map-based model, defined in [17]. The simulation area, represented by a generated map, includes many freeways, each side of which is composed of many lanes. No urban routes, thus no intersections are considered in this model. At the beginning of the simulation, the nodes are randomly placed in the lanes, and move using history-based speeds. The speed of each vehicle (node) follows this formula:

$$V(t+1) = V(t) + \text{random}() \times a(t).$$

Where $V(t)$ is the vehicle's speed at time t , $\text{random}()$ returns a random value in the interval $[-1, 1]$, and $a(t)$ is the acceleration of the vehicle at time t . A security distance should be maintained between two subsequent vehicles in a lane. If the distance between two vehicles is less than this required minimal distance, the second one decelerates ($a(t)$ is forced to be < 0) and let the forward vehicle moves away. The change of lanes is not allowed in this model. The vehicle moves in the lane it is placed in until reaching the simulation area limit, then it is placed again randomly in another position and repeats the process. This scenario is definitely unrealistic.

4.2 Manhattan

This is also a generated-map-based model, introduced in [17] to simulate an urban environment. Before starting a sim-

ulation, a map containing vertical and horizontal roads is generated. Each of these latter includes two lanes, allowing the motion in the two directions (north/south for the vertical roads and east/west for the horizontal ones). At the beginning of a simulation, vehicles are randomly put on the roads. They then move continuously according to history-based speeds (following the same formula like the freeway model). When reaching a crossroads, the vehicle randomly chooses a direction to follow. That is, continuing straightforward, turning left, or turning right. The probability of each decision are set by the authors respectively to 0.5, 0.25, 0.25. The security distance is also used in this model, and nodes follow the same strategy as in the freeway model to keep this distance. But contrary to the previous model, a vehicle can change a lane at a crossroads. Nonetheless, there is no control mechanism at these points (crossroads), where nodes continue their movements without stopping, which is unrealistic.

4.3 City Section Mobility (CSM)

CSM [3] can be viewed as a hybrid model between RWP and Manhattan, as it introduces the principle of RWP, especially the pause-time and random selection destination, within a generated-map-based area. At each step of the vehicle's movement a random point is selected from the generated road map, toward which it moves following the shortest path. After reaching that destination, it remains there for a pause-time, then repeats the process. The speed of nodes are constrained by the security distance, along with the maximum speed limit of the road.

4.4 Rice University Model (RUM)

Thus far, we have presented models based on virtual generated maps. RUM [11] is very similar to CSM, but indeed it uses real maps obtained from the TIGER/Lines database [11]. For each route segment¹, the coordinates are extracted and converted using the Mercator projection [11]. The extracted points are then presented by a graph, where the crossroads are presented by vertices, and routes by weighted arcs. The weight of each arc is dynamically calculated in such a way to mimic the estimated time required for a vehicle to move over the corresponding segment, which is proportional to its maximum authorized speed, its distance, and the number of vehicles it currently contains. Therefore, the lower the weight, more the vehicles move freely in the segment. Note that the maximum authorized speed of a route segment depends on its type. RUM has been compared to RWP, in the evaluation of DSR [13] in two different regions [11]. The first one contains a lot of roads of the same type, with a maximum speed limit set to 56km/h , while the second one has fewer roads, but of different types (which ranges the maximum speed from 56km/h to 120km/h). The two models engender almost the same results in the first region simulation. However, in the second region simulation (where the mobility is more constrained) the results were clearly different. We mention that like all the previous models, RUM defines no control mechanisms at crossroads.

4.5 Stop Sign Model (SSM)

SSM [9] is the first model we describe that integrates a traffic control mechanism. In every crossroads, a stop signal is

¹a part of the route lying between two crossroads

put, which obliges vehicles to slow down and make a pause there. This model is based on real maps of the TIGER/Lines database, but all roads are assigned a single lane in each direction. A vehicle should never overtake its successor (like in all the models presented before), and should tune its speed to keep the security distance. If many vehicles arrive at an intersection at the same time, they make a queue and then each one waits for its successor to traverse the crossroads. This results in gathering of nodes, and hugely affects the network connectivity as well as the vehicle mobility (average speeds). According to the authors [9], the problem with this model is the unrealistic disposition of the stop signals, since it is impossible to find a region with stop signals at each intersection. Therefore, they proposed TSM [9], described hereafter.

4.6 Traffic Sign Model (TSM)

In this model, stop signals are replaced by traffic lights. A vehicle stops at a crossroads when it encounters a red stop-light, otherwise it continues its movement. When the first vehicle reaches the intersection, the light is randomly turned red with probability p (thus turned green with probability $1-p$). If it turns red it remains so for a random delay (pause-time), forcing the vehicle to stop as well as the ones behind it. After the delay, it turns green then the nodes traverse the crossroads one after the other until the queue is empty. When the next vehicle arrives at the crossroads the process is repeated. TSM and SSM has been evaluated by simulation with ns2 [18]. The results show that the two models are not significantly influenced by the speed of nodes (maximum speeds). This is due to the traffic control models, which slow down the nodes and give more stability to the network [9]. When increasing the pause-time at the intersections, the authors remarked that the performances improved for both models, and that SSM gives better results than TSM when using the same pause-time. The authors argue this by the fact that in SSM nodes always stop at the intersections, unlike TSM. Nevertheless, in reality the pause-time of stop signals is shorter than the one of traffic lights, which makes TSM more stable indeed [9].

4.7 STRAW

STRAW [10] is also a model relying on real maps of TIGER/line. Like the other models (except freeway), the roads include one lane in each direction, and is divided into segments. The model is basically composed of three modules: intra-segment mobility manager, inter-segment mobility manager, and finally the route management and execution module. At the beginning of the simulation, the nodes are placed randomly one behind the other. Then they move using the car following model [10] such that they try to accelerate until reaching the maximum speed of the segment. The first module manages this movement until reaching an intersection. The security distance is maintained, and the overtaking is not allowed. At crossroads the vehicles always slow down, even when they change a segment and turn without a full stop, which is realistic. The second module defines the traffic control mechanism including both stop signals and traffic lights, put on crossroads according to the class of the intersected routes. In addition to this usual control form, the module makes sure that the next segment to take contains enough available space before moving the vehicle toward it. If it is fully busy, the vehicle waits at the crossroads (at

the end of the first segment). The last module selects the routes to be taken by each vehicle during the simulation. It implements two approaches: simple straw and straw OD. In the first one, the direction is randomly selected at each intersection. That is, when reaching an intersection, the vehicle randomly decides whether to continue straightforward, or to turn and change the route. On the other hand, in the second approach a destination is selected toward which the vehicle moves using the shortest path. The simulation study made by the authors [10] show that when using STRAW the reception ratio decreases from 43% up to 53% compared to movements in an open area. The results of this simulation also illustrate that the routes arrangement has an impact; scenarios with a high number of crossroads slow down the average speeds of nodes, which improves the reception ratio.

4.8 MOVE

MOVE [19] is a VANET's mobility model that uses as compiler SUMO [20], which is a realistic vehicular traffic simulation model. SUMO is an open-source application implemented with java integrating many realistic parameters such as realistic accelerations, the usage of real maps reflecting several types of routes (with multiple lanes), as well as traffic lights defining priorities between vehicles. Basically, MOVE is composed of two components; the road map editor and the vehicle movement editor. The former serves to manually and randomly generate a road map, either from TIGER/line files or Google earth files, whereas the latter allows to specify the properties of each vehicle, like the maximum speed, the acceleration, the probability of turning at crossroads, the path to take etc. The information collected by the two editors are sent to the SUMO compiler, then a trace file in ns-2 or Qualnet format is generated. MOVE has been compared by simulation to RWP using AODV. The results show that MOVE causes low reception rate.

4.9 Gorgorin et al model

In addition to all the realistic parameters of the previous models, this one [21] implements an overtaking mechanism within multi-lane segments. A vehicle always tries to move on the most right lane (the lowest rang), except in case of overtaking during which it moves left, and intersections in urban environment where it chooses the lane according to the next direction. A hierarchy of vehicle states is defined; free driving, approaching, following, and braking (in the order). When a vehicle is in another state than the free driving, it checks whether higher lanes allow it to pass to a higher state, and thus moves to the left lane to make an overtaking. Identically, a vehicle in a state different from braking checks whether the right lane allows it to at least stay in the same state and then moves right. Moreover, the model allows to specify the driver type, which affect many parameters of the vehicles (speed, acceleration, etc.). Finally, note that the model includes both traffic lights and stop signals at intersections. One of these two different control mechanisms is put at each intersections according to the types of the intersecting segments. The most important parameter added in this model is the overtaking mechanism. However, no study investigating this issue has been done yet.

5. NEW MOBILITY SIMULATOR

We developed a multi-platform vehicular mobility simulator with the Microsoft Visual studio .Net environment using

C# as the programming language. It allows to simulate movements of vehicles within a selected road map, visualize the movements in real time, and generate mobility trace file to be used by network simulators. The tool provides many visual facilities, and the mobility model implemented is parameterizable in such a way to including many of the models presented in the previous section. Through the simulator visual interface, many parameters related to both the mobility model and the scenario to be simulated are tunable. Hereafter, we illustrate the most important parameters.

5.1 Parameters related to the model

The tunable parameters enabling our mobility simulator to simulate several models are:

- The use of either the random method or the shortest path method to generate the route to follow: This allows to define the inter-segment mobility, also known as macro mobility.
- The possibility of overtaking: It could be either enabled or disabled
- The use of traffic light: For now, the implemented model includes only traffic lights, no stop signs. The employment of traffic light at intersections could be selected, and the user can define pause time duration when encountering red light for each type of segment intersections. A type of intersection is defined by the combination of the segments forming it. e.g i) intersection of three segments of type 1, two segments of type 1 and one of type 2, ii) three of type 2, etc. The segment type is proportional to the number of lanes it includes in each direction. Our simulator supports the commonest existing types (up to three-lane segments), but it is easily extendable to support four-lane and five-lane segments.
- the pause time after each movement

This way, many models can be simulated. For instance, when activating shortest path and traffic lights without overtaking we can get a TSM-like model. The RUM model can be fixed by deactivating traffic lights and set pause time to 0. In addition to the previous values, using a grill map allows to simulate Manhattan, and a map without intersections including only multi-lane segments to simulate freeway. But note that models that use stop signs, such as STRAW, are not supported thus far.

Parameter	Value
Simulation time	900s
Power-range	250m
Propagation model	Free-space
Simulation terrain	800 * 800m ²
Routing protocol	AODV
MAC protocol	IEEE802.11
Discretization time	100ms

Table 1: Simulation fixed parameters

5.2 Parameters related to scenarios

The other parameters related to the setting of a scenario are:

- Type of the map: The map to be used and its size can be either a real one, picked from Tiger/Line database, or a generic one. For the latter, it can be drawn using a drawing tool included in our simulator, which allows to stack a real map that can be obtained from google-earth and draw the road map to be used over it.
- Number of nodes
- Simulation time
- Maximum speed authorized on each type of segments
- Discretization time: the time unite that represents the interval between two events (node positions) in the simulator; it is trivial that the less the value, the more precession and realism we get, but this would require more time and resources.

Once the parameters are fixed, the simulation can be launched. The user can choose to visualize the simulation to see the movements of nodes, along with their Ids, speeds, and accelerations in the real time. This is helpful for tuning the value of some parameters, but requires a great deal of time. Once all the parameters are fixed, the user can choose to directly generate the mobility trace file without visualization. The user also has the possibility to specify the format of the output (trace) file. For the time being, the simulator supports GloMoSim and ns2 formats.

The fixed parameters of our scenarios are depicted in table 1. We just point out that in addition to 900 simulation time, in the mobility simulation phase we used an overheating period of 1000s, during which nodes move from their initial positions without taking any measurements.

We used our simulator together with GloMoSim to reveal the impact of the overtaking on the mobility. The simulation study consists of comparing two models a TSM-like model and a Gorgorin-like model, that integrates almost all the realistic features, and differs from TSM merely by the fact that it enables the overtaking. We measured the relative mobility, which represents the average changes in distances between nodes, instead of the changes from a fixed terrestrial point. This definition more accurately reflects the network topological, as it considers booth speeds and directions. It is given by the following formula [22]:

$$Mob = \sum_{i=1}^n \frac{M_i}{n}$$

$$M_x = \sum_{t=0}^{T-\Delta t} \frac{|A_x(t) - A_x(t + \Delta t)|}{T}$$

$$A_x(t) = \sum_{i=1}^n \frac{dist(n_x, n_i)}{n - 1}$$

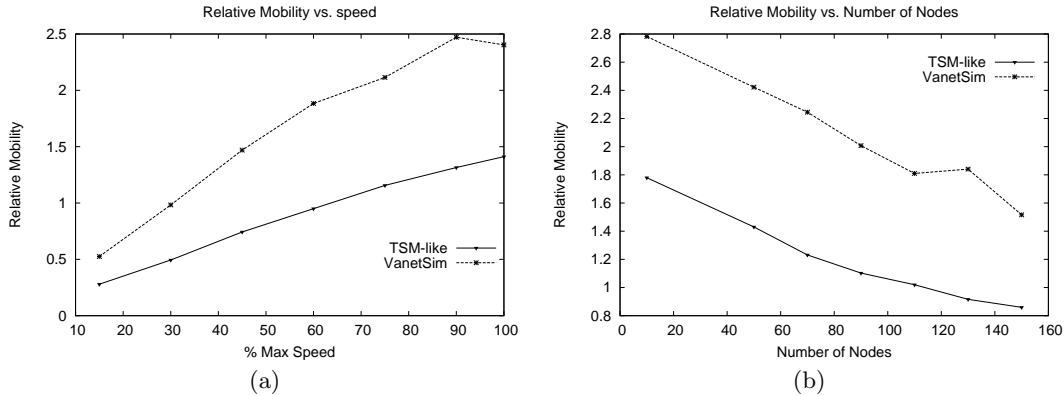


Figure 1: Relative Mobility

Feature \ Model	Freeway	Manhattan	CSM	RUM	SSM	TSM	STRAW	MOVE	Gorgorin
Real maps	no	no	no	yes	yes	yes	yes	yes	yes
# lanes/direction	many	one	one	one	one	one	one	many	many
Intersections	no	yes	yes	yes	yes	yes	yes	yes	yes
Changing lanes at intersections	no	yes	yes	yes	yes	yes	yes	yes	yes
Traffic control	no	no	no	no	stop signs	traffic lights	both	traffic lights +priority	both
Overtaking	no	no	no	no	no	no	no	no	yes
Security distance	yes	yes	yes	no	yes	yes	yes	yes	yes
Pause-time	no	no	yes	no	yes	yes	yes	yes	yes

Table 2: VANET’s mobility models features

where:

$dist(n_x, n_y)$: the distance between nodes x and y

n : number of nodes

$A_x(t)$: the average distance between node x and all the other nodes, at time t

M_x : the average relative mobility of node x regarding all other nodes, during the simulation time

T : simulation time

Δt : time period used in computation.

After each Δt , $A_x(t)$ is calculated, i.e it is calculated for: $t=0, t= \Delta t, t= 2\Delta t, \dots, t=T$.

Measuring this metric allows to show the effect of the model on the relative mobility, thus the network topology.

Figure 1(a) shows the relative mobility vs. the maximum speed used in the simulation, expressed as the rate of the maximum allowed speed at each segment. We used 130km/hr for 3 lanes segments, 90km/hr for segments of 2 lanes, and 50km/hr for single lanes segment. Hence, the maximum speed a vehicle can reach in our scenario is a ratio of these values, e.g for measurements of 15% the maximum speeds are respectively 19.5km/hr, 13.5km/hr, 7.5 km/hr. The plots of figure 1(a) clearly illustrate the difference in term of relative mobility between a model allowing the overtaking (VanetSim) and the one that does not allow this possibility (TSM-like). The difference between the models increases with the maximum speed, as well as the values of both models. The same metric vs. the number of nodes is depicted

in figure 1(b). We remark here that the mobility goes down while the nodes number goes up. This can be argued by the growing in node density. We can also see the huge difference between the two models. The two figures show clearly that the overtaking has a dramatic affect on the mobility.

6. CONCLUSION

VANET is a typical example of ambient systems enabling the user to transparently use different services while he is moving in his vehicle, and being assisted to increase his safety and comfort. Since the movement of vehicles does not happen in an open area but within a route network, earlier mobility models used to simulate general MANETs (described in section 3) are inappropriate for simulating VANETs. Map-based models, taking into account the constraints a vehicle faces during its movement, are more realistic and useful for simulating such networks. We dealt in this paper with mobility models that can be used to simulate vehicular ad hoc networks (VANETs), and provided an overview of them. Table 2 summarizes the characteristics of these models. The first three models we described, Freeway, Manhattan, and CSM, are based on unrealistic maps, and do not consider traffic control at intersections. The others are based on real maps, and particularly define control mechanisms at intersections (except RUM). The presence of such intersections where the traffic slows down is obviously realistic in urban areas. This issue has a great impact on the network connectivity and the average speed of vehicles. The traffic control of TSM/SSM and STRAW, as well as the one of Gorgorin et al. are the most realistic, as they involves both traffic

lights and stop signs, and further considers the place availability when changing a segment. The last model is the only one that considers the overtaking possibility. However, we remarked that the impact of this important parameter has not been investigated in any simulation study.

We developed a mobility simulator that integrates many realistic parameters of vehicular movements, that we used along with GloMoSim to illustrate the effect of overtaking on mobility. The results show that the employment of the overtaking in multi-lane route segments whenever possible has huge effects on the relative mobility.

In our perspectives, we plan to make more investigations into the impact of this parameter on the performance parameters, such as the end-to-end delay and the delivery ratio. Improving our simulator such that to integrate one way routes (for urban environment), and eight lanes (four in each direction) or even more like in some existing highways, as well as the extension to a parallel version and to other mobility trace file formats of other network simulators also represent possible perspectives to this work.

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