A Framework for Mobility Models Generation and its Application to Inter-Vehicular Networks

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Abstract

In this paper, we propose a novel concept map for mobility models and use it in a short survey of existing proposals. We then review necessary requirements, and define key components for the generation of mobility models adapted to vehicular ad hoc networks (VANETs). Based on this, we first adapt our concept map to vehicular motion, then present a framework for the generation of vehicular mobility models that include all parameters vehicles experience while moving, and finally propose two derived mobility models at the stage of research.

1. Introduction

In the past few years, we have seen the emergence of technologies providing network connectivity to mobile users. These technologies are based on a backbone of access points, which mobile devices can connect to. Examples of such systems are the cellular network or WiFi networks. Yet, a growing demand on increased bandwidth and improved communication quality made engineers choose to decrease the transmission range of mobile remote devices. Consequently, the backbone had to be re-designed with an increased number of access-points. Therefore, the infrastructure-based approach is not always most effective and is naturally supplemented by direct communication between terminals, also called ad-hoc communication.

One emerging new type of ad hoc networks is *vehicular ad hoc networks (VANETs)*, in which vehicles constitute the mobile nodes of the network. Enhancements in transportation technologies have to consider, besides traditional aspects such as security and driving conditions, the ability of vehicles to communicate. It also covers the internetworking of vehicles to the Internet. Connecting vehicles to the Internet provides users with the possibility to have an access to web services. However, offering this capability in an efficient way requires resolving several technical challenges going from gateways optimal placement on roadsides to the handover management between gateways. Besides, an increased motivation for the development of vehicular ad hoc routing protocols comes from particular vehicular capabilities such as the availability of GPS/GALILEO positioning and motion speed. These features actually occult certain traditional concerns with mobile nodes, like power efficiency.

In simulating mobile systems, it is important to use mobility models that reflect as close as possible the real behavior of mobile systems. Best would be to have a mobility model obtained after the analysis of a large measurement campaign. However, this kind of model does not exist in the open literature. Therefore, researchers often use random mobility models, and have to adapt them to specific environments such as vehicular ad hoc networks.

In this paper, we propose a novel concept map for mobility models and survey existing models that are or could be adapted to vehicular motion. We then identify basic properties that can be found in mobility models, and list missing features that should be considered for vehicular mobility models. Based on this, we adapt our concept map to vehicular motions and define a framework that vehicular mobility models should follow in order to correctly simulate real life vehicular motion. Finally, we propose two enhanced mobility models that are compliant with our framework.

The rest of this paper is organized as follows. In Section 2, we present a new concept map and survey existing mobility models, while in Section 3, we identify necessary components for a vehicular mobility model. Section 4 describes a vehicular-adapted concept map, then proposes a framework for a proper vehicular mobility model, and finally exposes two possible compliant mobility models. Last, in Section 5, we draw some concluding remarks and highlight key issues on vehicular motion.

2. Improved Concept Map and Short Survey of Existing Mobility Models

In this section, we first introduce an original concept map of mobility models, that besides being simple and easy to understand, is also able to categorize most recent mobility models. It should therefore be the basis for future development of more realistic mobility models. Then, using the criteria of our concept map, we briefly survey some of the common mobility models that can be found in the literature.

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[*] Institut Eurécom's research is partially supported by its industrial members: Bouygues Télécom, Fondation d'entreprise Groupe Cegetel, Fondation Hasler, France Télécom, Hitachi, Sharp, ST Microelectronics, Swisscom, Texas Instruments, Thales.

2.1. Bi-polar Concept Map for Mobility Models

The categories composing recent mobility models are distributed between two major components as depicted in Figure 1. Although being a simplified model compared to the model proposed in [4], our proposed concept map finds its originality in the bi-polarity between the *Domain* model and the *Node* model.

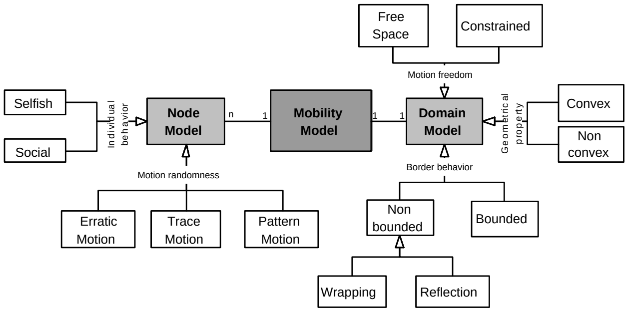

Figure 1. Concept map of actual mobility models

Bettstetter described in [4] a concept map where the two major components are the *Randomness Degree* and the *Level of Detail*. At the time [4] was written, a strong concern was set on macroscopic randomness. Nodes were randomly reacting to their environments and had no proactive actions. In real life, this is not generally the case, and in recent years, an increasing number of research papers have tried to model nodes mutual dependencies and non-random behaviors. A clearer picture can be drawn showing that mobility models are actually composed of two different components: a *Domain* model and a *Node* model. The *Domain* model describes the simulation domain along with its motion constraints, while the *Node* model depicts nodes motion patterns. Our original approach is quite logical in a sense that when developing a mobility model, one first models the domain, then nodes evolvement within that domain. This is particularly true when we want to model different classes of nodes.

While most of the contributions on mobility models have been performed on the *Domain* model, the *Node* one seems to have drawn an increasing attention only in recent years. Indeed, a growing interest is carried out on *Node motion* modeling, both in macroscopic and microscopic point of views. In the former case, we can observe real life pattern motions, such as preferred paths or social motions. In the latter case, a simple analysis of vehicular motions allows us to see that nodes individual behavior is correlated not only to their simulation domain, but also to other neighboring nodes. The approach taken in [4] is to consider neighboring nodes as being part of the simulation domain. We think that this should not be the case and motion correlation due to other nodes should be described separately. This approach is therefore able to clarify mobility models in order to better shape them to real behavior.

2.2. Survey of Existing Mobility Models with Regards to the Proposed Concept Map

Several surveys of models for mobility of nodes in a network has been presented in the past, including those from [7, 3, 6, 8]. We briefly summarize below some of the common mobility models.

The *Random Walk with Reflection* mobility model is a paradigm, where the domain model is bounded and non-constrained, while the node model is selfish and erratic. This mobility model was developed to mimic irregular movement in nature. A mobile node (MN) moves for a specified time from its current location to a new location by randomly choosing a direction and speed from particular speed and direction distributions. When this time ends, the whole process is repeated all over again. If it reaches a simulation boundary, it *bounces* off the simulation border with an angle determined by the incoming direction.

The *Random Walk with Wrapping* mobility model is similar to the standard Random Walk mobility model, with the difference that it is not bounded. This can be seen as a Random Walk on a torus simulation area. When mobile nodes hit the boundaries they are wrapped to the other side of the simulation area from where they continue their trip. A slightly different mobility model is the *Random Distance* mobility model, where nodes move until they reach a randomly chosen distance from the simulation boundary. This mobility model is therefore bounded by nature.

The most commonly used mobility model in the mobile ad hoc wireless research community is the *Random Waypoint* model [9]. Its domain model is usually convex and bounded, while its node model is erratic, although several declinations have appeared in recent years [8]. In this model, each node individually chooses a random destination within the simulated network boundary, and also determines a motion speed randomly chosen between a minimum and maximum limit. Based on this, it moves toward its destination at its determined velocity. Once the destination has been reached, each node stops for a randomly chosen time interval. After that pause time, it then repeats the process by choosing another random destination and a random speed. The characteristics and properties of this mobility model have recently been studied in detail in [1, 2]. Bettstetter [3] modified this model to reflect smooth transitions between waypoints.

Of all models described so far neither represent real motions. **Realistic motion** is a framework containing the **Social motion** subset from the *Node* model and the **Constrained Motion** subset from the *Domain* model. A model is considered realistic if it is compliant with *at least* one set contained in this framework. To the best of our knowledge, only one model, the *Weighted Waypoint* mobility model [16] includes both sets.

An example of **Social motions** is the *Reference Group* mobility model [10]. Nodes are gathered in groups in which mobile motions are not independent but governed by the motion of a reference point for the group. This reference point could be a leader, or simply a guideline. Nodes within those groups experience some degree of liberty but have to follow the group. Another social mobility model is the *Social Networks Based* mobility model [12]. This model allows collections of hosts to be grouped together in a way that is based on social relationships among the individuals.

Constrained motions use a different approach. Mobile nodes have limited choices for their destination, or for the path to their destination. For example, Jardosh et al. [11] proposed a *Space Graph* mobility model where the simulation area is composed of graph vertices, and where nodes are constrained to follow edges connecting these vertices. Consequently, a mobile node starts by randomly choosing an initial vertex and moves along the shortest path to another randomly chosen vertex.

The last kind of **Constrained** mobility models we list here are the *Manhattan* and the *City Section* [13] mobility models. While the former models a downtown urban area with horizontal and vertical streets, the City Section relaxes this horizontal and vertical shape to model all kind of roads. Saha and Johnson [14] even proposed to use real maps extracted from the US Census Bureau's TIGER (Topological Integrated Geographic Encoding and Referencing) database [15]. Actually, to the best of our knowledge, this is the first freely available work analyzing the characteristics of a realistic street mobility model.

We also have to mention that Lu et al. [5] proposed to create hybrid mobility models by mixing the Random Waypoint and the Manhattan model, for instance. The authors also defined *contractions* and *expansions*, which are particular points that attract or repulse mobile nodes. These proposed models cover scenarios in which nodes merge, scatter, or switch to different movement patterns over time. The interesting point here is that, although the domain model may be constrained or not (by using Manhattan or the Random Waypoint), the node model is also defined by *motion patterns*.

Finally, although all these proposals have tried to create realistic mobility models, they are all based on random mobility. Recently, some teams became interested in non-random patterns that can be experienced in real life. Among them, Hsu et al [16] proposed a *Weighted Waypoint* mobility model which captures preferences in choices of destinations of pedestrian mobility patterns in a campus environment. The authors estimated the parameters of this model using mobility survey data from the campus of the University of Southern California. Yet, this method is difficult to scale and a large amount of data is necessary to obtain satisfactory results. Nevertheless, their approach is promising since their *Weighted Waypoint*'s domain model is constrained by the campus structure, while the node model is based on real motion traces, and individual behaviors are described by social motions. This method is therefore the first mobility model that fits the closest to real pedestrian mobility.

3. Identification of Vehicular Mobility Models Components

Now that we have listed most known and used mobility models and shown an easier concept map for mobility models, let us discuss here particular requirements mobility models need to manage in order to accurately describe vehicular motions.

In the literature, vehicular mobility models are usually considered **microscopically** and **macroscopically** [17]. When focusing on a macroscopic point of view, we consider motion constraints such as roads, streets, crossroads, and traffic lights. We also assess traffic generation such as traffic density, traffic flows, and initial vehicles distributions. In contrast, in the microscopic approach, the movement of *each* individual vehicle and its behavior with respect to other vehicles is determined.

Yet, this micro-macro approach is more a way to analyze a mobility model than a formal description. As a matter of fact, a vehicular mobility model is composed of two blocks: **Motion Constraints** and **Traffic Generator**. The **Motion Constraints** part describes how each vehicle moves (its respective degree of freedom) and is usually obtained from a topological map. Macroscopically, motion constraints are streets or buildings, but microscopically, constraints are modeled by neighboring cars, pedestrians, or by limited roads diversities either due to the type of cars or to drivers habits. The **Traffic Generator**, on the other hand, generates different kind of cars, and deals with their interactions according to their environment. Macroscopically, it models traffic densities or traffic flows, while microscopically, the traffic generator deals with properties like inter-distances between cars, acceleration or braking.

All recent contributions to vehicular mobility models proposed to constrain vehicles mobility (see [3, 5, 12, 14]). A realistic mobility model should therefore include

- **True and accurate topological maps** including different categories of streets and assigned velocities.
- **Smooth deceleration and acceleration**.
- **Obstacles** including both mobility and wireless communication constraints.
- **Attraction points** including preferred roads depending on drivers habit.
- **Simulation time** performed on particular driving patterns such as *Morning and evening rush hours*, *Lunch Break*, or *Night life*.
- **Non-random distribution of vehicles** between homes, offices, or shopping malls; in other words: *center of interests*.
- **Traffic generator** controlling vehicles mutual interactions such as overtaking, traffic jam, preferred paths.

Finally, it might sound strange to be interested in **mobility predictions** for mobility models. Usually, mobility predictions are *extracted from* mobility models in order to obtain non-random motion patterns that would improve routing strategies. Yet, when we look deeper in the microscopic case, we see that mobility prediction is indeed of a particular interest. Positions, velocity information, as well as predictions can be used for example to regulate the inter-distance between vehicles, or decisions related to lane changing and overpassing.

4. Framework for Vehicular Mobility Model Generation

In this section, we first propose a concept map for mobility models adapted to vehicular motion. Then, we describe a framework for the generation of realistic vehicular mobility models. Finally, we present two derived models from our framework.

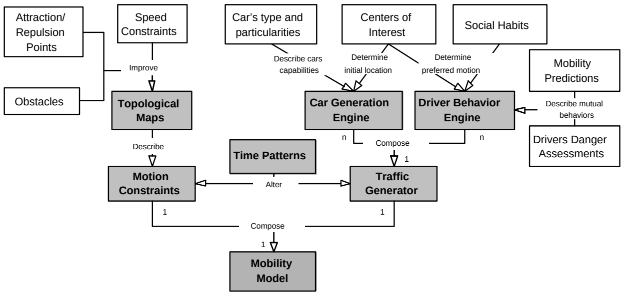

Figure 2. Proposed concept map of mobility model generation for inter-vehicle communications

4.1. Vehicles-Adapted Concept Map

Figure 2 illustrates the main needed components for mobility model generation: **Motion Constraints**, **Time Patterns**, and **Traffic Generator**. The **Motion Constraints** set includes all components needed to describe the simulation domain in which vehicles are moving. This set may be compared to the *Domain* model in Figure 1, but adapted to mobility constraints vehicles may experience. Usually, it is composed of a precise domain map extracted from a topological map and enhanced by obstacles, or attraction points, to name only a few. Similarly, the **Traffic Generator** set is a more specific case of the *Node Motion* model in Figure 1 also adapted to deal with erratic cars and drivers particularities. Finally, as the **Mobility Constraints** set describes determinism in *space domain* of a vehicular mobility model, the **Time Patterns** set represents determinism in *time domain*. Time patterns describe different configurations of a day or a week, when a particular motion pattern may be observed. The Time Patterns component also exists in the concept map of regular mobility models. However, for the sake of clarity, we did not include it on Figure 1 since to best of our knowledge, no actual mobility model uses it.

4.2. Framework General Description

As we mentioned in Section 3 and also could see in Figure 2, the two most important aspects of a mobility model are a **Topological Map** and a **Traffic Generator**. The main issue to obtain accurate **Topological Maps** is to be able to digitalize true maps in order to obtain an input for constrained traffic. To our knowledge, the only freely available solution at this time is the TIGER database from the US Census Bureau that unfortunately only contains maps of US cities. Yet, it is possible to use it as a starting point and work on new solutions for worldwide cities. Such maps should take into consideration:

- **Street heterogeneity** including multiple lanes as well as bi-directional and one-way roads.
- **Street capacity heterogeneity** including access limitations for particular classes of vehicles.
- **Speed heterogeneity** including speed limitations due to roads configurations and classes, or due to roads driving pitfalls.
- **Radio obstacle** including the blocking of signal transmissions by objects such as high-rise buildings in the city.

At this time, to the best of our knowledge, no actual mobility model includes all these features in its configuration. The *M-Grid [18]* mobility model includes some of them, but lacks by its rigorous squared modeling of streets, and true topological maps. The *City Section [14]*, on another hand, solves this problem but does not consider the rest of these requirements. Therefore, by grouping the main features of both approaches, we could obtain a good starting point for developing a realistic vehicular mobility model.

Traffic Generator may be an easier task to perform. Indeed, several models has been developed for microscopic traffic simulation such as the *Driver Behavior Model [19]*, the *Optimal-Velocity Model [20]*, the *Intelligent Driver Model [21]*, the *Intelligent Driver Model with Memory [23]*, or the *Human Driver Model [22]* to name only a few. A traffic generator should take into account

- **Cars characteristics heterogeneity**.
- **Lane changing and passing decisions** including inaccuracies and anticipations using mobility predictions.
- **Finite reaction time** including memory and frustration effects due to congested traffic.
- **Enroute diversion behavior** including familiarity with potential alternate routes, social habits, and drivers individual danger assessments.

4.3. Two Derived Models from the General Framework

4.3.1. A Simplified Architecture

If we do not have access to traffic generators or topological maps, we propose here a simplified architecture derived from a basic Stationary Random Waypoint Model proposed by Le Boudec et al. [8].

We initiate the model with time stationary distributions of locations within the simulation domain as proposed in Section $VI.B$ of [8]. We also want to include smooth transitions between speed changes. Therefore, similarly to [3], we define a node's targeted speed as V_{node}^{target}. A targeted speed is uniformly chosen in $[V_{min}, V_{max}]$. Then, the node samples an acceleration from an uniform distribution between $[0, \alpha_{max}]$. Then, each period of time Δt, the node's velocity increases according to

$$v(t) = v(t) + \alpha(t) \cdot \Delta t$$

until the node reaches V_{node}^{targ}. Then, the acceleration is set to 0 and the node moves with constant speed until the next speed change. A speed change occurs when approaching to a waypoint[1]. Consequently, a node follows the same procedure to smoothly decelerate before reaching the waypoint

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[1] A waypoint is considered here as any point where either speed or direction may be altered

and pausing, yet using an acceleration uniformly chosen in $[\alpha_{min}, 0]$. Our contribution here is that we also assume that at each waypoint, a node remains in the same trajectory with a probability $1 - p_t$ (and changes its trajectory with a probability p_t), and stops with probability p_p. This simulates vehicles behaviors when confronted to traffic signs and crossroads.

A graphical representation of the proposed mobility model is depicted in Figure 3. From a microscopic point of view, when approaching a waypoint, a node only changes its targeted speed with probability $1 - p_p$, or decelerates and stops with a probability p_p. In that case, it samples a pause time from a uniform density f_{pause}, on the expiration of which it accelerates again to reach a new target speed. This represents vehicles behavior when reaching a crossroad, a traffic light, or simply entering a street section where speed limitations change.

Yet, as it can be seen in the same Figure, from a macroscopic point of view, when a node keeps its trajectory (with a probability $1 - p_t$), the model switches to a Random Walk with Wrapping mobility model. Accordingly, rather than sampling a new destination, it keeps the same direction and samples a new targeted speed and a residual trip duration from an exponential distribution of parameter λ. When this time expires, we fall back again to the case where, first it chooses to pause with probability p_p, then with a probability $1 - p_t$, it samples a new residual time with the same direction, or changes its trajectory with probability p_t. If so, the model switches back to the Random Waypoint mobility model, the node samples a new destination and starts heading to it. If a trajectory makes a node reach the domain boundary, it is wrapped to the other side of the domain.

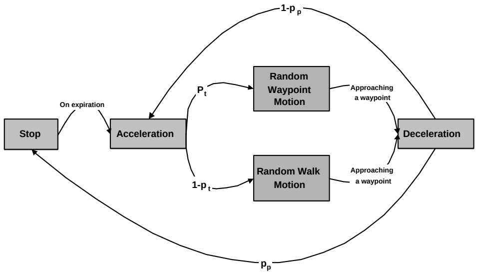

Figure 3. Graphical representation of the switches between the Random Walk and the Random Waypoint according to p_p and p_t

Therefore, the two macroscopic configuration probabilities p_t and p_p simulate virtual crossroads, the microscopic exponential distribution parameter λ describes road lengths, and the pause time density function f_{pause} represents traffic related mobility disturbances such as traffic lights, or traffic jams. Thanks to this, the model neither relies on any topological maps nor on traffic generators, yet it is able to keep a quite generic aspect.

4.3.2. A more detailed concept using maps and attraction points

The first consideration we will make here is that we assume in this model that drivers keep a constrained path from one repulsion point to an attraction point. At each intersection, they decelerate, and accelerate afterwards similarly to what we wrote in Section 4.3.2. Yet, V_{node}^{targ} is now uniformly chosen in $[V_{min}^{street}, V_{max}^{street}]$, where V_{max}^{street} is the maximum speed allowed on a particular street section. Along the path, drivers follow streets and traffic regulations allowed by the map. However, drivers danger assessment determines their behavior when confronted to traffic regulation signs. Then, after having reached an attraction point, drivers choose a new destination from a set of all attraction points and make a pause with a probability p_p.

As mentioned before, the proposed model includes topological maps obtained from the TIGER database. Yet, we add all proposed features from the M-Grid model. Thanks to the TIGER database, the topological maps straightforward include *street heterogeneity* and *speed heterogeneity*. We then add *attraction* and *repulsion points*. For example, Residential areas are considered as repulsion points in the morning but attraction points in the evening. Therefore, contrarily to the City Section, destinations are not randomly chosen, and drivers do not specifically choose shortest paths, since social habits are taken into accounts. Similarly, different from the M-Grid model, paths are not restricted to horizontal or vertical streets. As M-grid, we also include radio obstacles for non-LOS communications.

5. Conclusion

In this paper we proposed a framework for a realistic mobility model for Inter-Vehicular Networks. We reviewed actual mobility models, proposed an original concept map, and identified key features that should be included in a vehicular mobility model in order to obtain realistic motions. Such model should be *self-driven* from the moment we set the proper parameters. Randomness should be limited to jitters, traffic regulation liberty, or proactive routing. But vehicles distribution, paths, and destinations should have nothing to do with randomness.

We also described a general random limited mobility model that is fully compliant with our framework. Nevertheless, some parts of it are none-trivial tasks and either are not freely available or simply not feasible at this time. Consequently, we likewise presented a simplified fully random mobility model that is compliant with parts of our framework but which does not implement all features we described in this paper.

We finally proposed to use *Mobility Predictions* in order to obtain realistic inter-vehicular interactions, precise *Topological Maps* for accurate motion constraints, and *Points of Interests* as a way to better fit with social motions that can be experienced in metropolitan areas. Besides, such approaches were proposed for pedestrian mobility. Consequently, why couldn't that be the case also for the vehicular movement ?

References

[1] Christian Bettstetter, Hannes Hartenstein, and Xavier Perez-Costa. ”Stochastic properties of the random waypoint mobility model: Epoch length, direction distribution, and cell change rate”. In *Proc. of the Fifth ACM International Workshop on Modeling Analysis and Simulation of Wireless and Mobile Systems*, pp. 7-14, 2002.

[2] Christian Bettstetter and Christian Wagner. ”The spatial node distribution of the random waypoint mobility model”. In *Proc. of the First German Workshop on Mobile Ad Hoc Networks (WMAN)*, pp. 41-58, March 2002.

[3] Christian Bettstetter. ”Smooth is better than sharp: A random mobility model for simulation of wireless networks”, In *Proc. of the Fourth ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, pp. 19-27, 2001.

[4] Christian Bettstetter. ”Mobility Modeling in Wireless Networks: Categorization, Smooth Movement, and Border Effects”, In *ACM Mobile Computing and Communications Review*, vol. 5, no. 3, pp. 55-67, July 2001.

[5] Y. Lu, H. Lin, Y. Gu, A. Helmy, ”Toward Mobility-Rich Performance Analysis of Routing Protocols in Ad Hoc Networks: Using Contraction, Expansion and Hybrid Models”, In *IEEE International Conference on Communications (ICC)*, June 2004.

[6] F. Bai, A. Helmy, ”A Survey of Mobility Modeling and Analysis in Wireless Ad hoc Networks”, Book Chapter in the book on ”Wireless Ad Hoc and Sensor Networks”, Kluwer Academic Publishers, June 2004.

[7] T. Camp, J. Boleng, and V. Davies. ”A survey of mobility models for ad hoc network research”, In *Wireless Comm. and Mobile Computing (WCMC)*, vol. 2, no. 5, pp. 483-502, 2002.

[8] Jean-Yves Le Boudec and Milan Vojnovic, ”Perfect Simulation and Stationarity of a Class of Mobility Models”, In *Proc. of the Infocom’05*, USA, 2005.

[9] Josh Broch, David A. Maltz, David B. Johnson, Yih-Chun Hu, and Jorjeta G.Jetcheva. ” A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols”, In *Proc. of the Fourth Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom’98)*, pages 85-97. ACM/IEEE, October 1998.

[10] Xiaoyan Hong, Mario Gerla, Guangyu Pei, and Ching-Chuan Chiang, ”A group mobility model for ad hoc wireless networks”, In *Proc. of the Second ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, pp. 53-60, 1999.

[11] Amit Jardosh, Elizabeth M. Belding-Royer, Kevin C. Almeroth, and Subhash Suri. ”Toward realistic mobility models for mobile ad hoc networks”, In *Proc. of the Ninth Annual International Conference on Mobile Computing and Networking*, pp. 217-229, 2003.

[12] Mirco Musolesi, Stephen Hailes and Cecilia Mascolo, ”An Ad Hoc Mobility Model Founded on Social Network Theory”, In *Proc. of the 7th ACM/IEEE International Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM 2004)*, Venezia, Italy, October 2004.

[13] V. Davies, ”Evaluating mobility models within an ad hoc network”. In *Master’s thesis*, Colorado School of Mines, 2000.

[14] Amit Kumar Saha and David B. Johnson, ”Modeling Mobility for Vehicular Ad Hoc Networks”. *Appeared as a poster in the First ACM Workshop on Vehicular Ad Hoc Networks (VANET 2004)*, Philadelphia, Pennsylvania, October 2004.

[15] *www.census.gov/geo/www/tiger/tiger2003/tgr2003.html*

[16] W. Hsu, K. Merchant, H. Shu, C. Hsu, A. Helmy, ”Weighted Waypoint Mobility Model and its Impact on Ad Hoc Networks”, *Appeared as a poster to MobiCom 2004*, Philadelphia, September 2004.

[17] D. Helbing, ”Traffic and related self-driven many particle systems”, In *Rev. Modern Physics*, Vol. 73, pp. 1067-1141, 2001.

[18] K. J. Wong, B. S. Lee, B. C. Seet, G. Liu, and L. Zhu, ”BUS-Net: Model and Usage of Regular Traffic Patterns in Mobile Ad Hoc Networks for Inter-Vehicular Communications”, In *Proc. ICT 2003*, Thailand, April, 2003.

[19] T. Benz, L. Schäfers, C. Stiller, and D. Vollmer, ”Feasibility study on truck planning on european motorways”, Deliverable D08.1 of ITS project PROMOTE-CHAUFFEUR, 1999.

[20] M. Bando, K. Hasebe, K. Nakayama, A. Shibato, and Y. Sugiyama, ”Dynamical model for traffic congestion and numerical simulation”, In *Physical Review*, E 51, pp. 1035-1042, 1995.

[21] M. Treiber, A. Hennecke, and D. Helbing, ”Congested traffic states in empirical observations and microscopic simulations” In *Physical Review*, E 62, pp. 1805-1824, 2000.

[22] M. Treiber, A. Kesting, and D. Helbing, ”Delays, inaccuracies, and anticipation in microscopic traffic models”, submitted to *Physical Review* E, 2005.

[23] M. Treiber and D. Helbing, ”Memory effects in microscopic traffic models and wide scattering in flow-density data”, In *Physical Review* E 68, 2003.

[24] J.L. Adler, W.W. Recker, and M.G. McNally, ”Using Interactive Simulation to Model driver Behavior Under ATIS”, *Working Paper* University of California, Berkley, 1992.