Lisbon Mobility Simulations for Performance Evaluation of Mobile Networks

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Abstract— In this paper a novel realistic vehicular mobility model is introduced. It captures the moving-in-groups, conscious travelling, and introduces the concept of smart travelling while following drivers' social behavior extracted from inquiries and experimental traffic measurements. Under the model, a routing algorithm is considered. The routing algorithm minimizes the distance to a target on a step by step form, in every street crossing. This is done under a hierarchic street level structure that optimizes travel speed and quality. The mobility model was simulated for Lisbon case study and directional statistical results were compared with experimental measurements from Lisbon Municipality control center. The output shows a good correlation between simulated and experimental values.

Key words: Mobility Model, Hierarchic Road Networks, Mobility Patterns, Wireless Communications.

1. Introduction

The validity of the mobility model used to evaluate a cellular network determines the validity of the evaluation. In the literature, unrealistic assumptions of mobility are exercised for the sake of simplicity. In this paper we present a novel vehicular mobility model which is realistic in the sense that it captures the conscious travelling and introduces the concept of smart travelling. In the following, the model is applied to Lisbon case study.

Implementation of the autonomy of the subscribers is the crucial point of a mobility model. Each subscriber chooses his direction individually, as in real life. However, in real life one can observe that the direction of a subscriber is also dictated by the terrain. Although each person makes his decisions independent of the others, he cannot decide to drive over a building. If the street has a turn to the left, everyone on the street is supposed to turn to the left as long as they stay on the street. Thus, although the subscribers are autonomous, they drive or walk together on the streets and highways. This is called the moving-in-groups behavior of the society.

An autonomous subscriber updates his direction randomly, so that the subscribers exhibit stochastic mobility patterns. However, determining the new direction independent of the old one will result in a simulator where subscribers make unconscious moves, back and forth. A realistic mobility model should capture the conscious travelling feature of the subscribers where the subscribers tend to keep their directions towards a destination. The developed model works with origin-destination generations coupled with a routing algorithm that guides the subscriber in reaching its final destination.

In an European capital like Lisbon, not all vehicular subscribers have the same behavior. There are some that live in peripheral areas and migrate daily to the city center for working or leisure. There are others that live in the city and go to their work place nearby, and finally others that are also residents but go to work outside the city. We cannot forget the subscribers that use city's main axes to cross town and reach other remote locations. A correct mobility modeling must have the subscriber profile in mind, since it influences directly the simulation's accuracy.

When a driver starts some journey trying to reach a final destination, he normally chooses the course that minimizes the travel time. So he initially tries to pick the best (faster) axes (highways, speedways, main avenues, etc) to reach the vicinity of the target and only then he chooses local roads heading to final destination. It is also important to consider that drivers have memory, i.e., if in the pursuit for a target we reach to a dead-end, we drive back and we remember that error. This means we delete from our active set the road in a certain junction that led us to failure. In the following, we do not pick the same road but other according to our own routing algorithm. To this concept of optimized driving and learning with mistakes we will call it smart travelling and this will be applied in full in the developed model.

Finally, the underlying air interface should be considered since the signal propagation is determined by the coordinates of the mobile.

The subscriber's speed and directional pattern is also dependent on the mobility model and it influences directly radio channel simulations, mainly in the path loss, fading and Doppler effect integration. The speed variation and turns of the driver when he cruises the street database must be correctly modeled since it influences directly wireless networks performance.

The rest of the paper is organized as follows. In the next section, we discuss the previous work in the literature. Section 3 describes the mobility model including street database preparation, origin-destination generation and also routing algorithm strategy. Model validation is introduced in Section 4, followed by the conclusions in Section 5.

2. Previous Work

Most of the work in the literature on mobile networks assumes random walk [1], or cell change probability based on the side of the hexagon through which the subscriber leaves the cell [2]. Although these models simplify analysis, they rely on unrealistic assumptions and the mobility patterns produced do not resemble the human behavior in the real life.

In reference [3], Markoulidakis et al. have proposed a model with three levels: city area model, area zone model and street unit model, therefore the geographic area needs to be molded into these three levels.

Different kinds of mobility models have been proposed in publications on ad hoc networks [4,5]. However, since such networks are designed for disaster areas and military applications without any fixed ce11ular network, their mobility patterns differ from those in a ce11ular system.

ETSI has defined test scenarios for the indoor office, outdoor pedestrian and vehicular environments [6]. A Manhattan-style street structure is defined for the outdoor pedestrian environment and a random mobility model, without any street structure, for the vehicular environment. Furthermore, the speed of the cars is assumed to be fixed at 120 km/h.

In addition to the theoretic work, simulators like Opnet, NS-2 and GloMoSim also implement mobility models. However, Opnet and NS-2 have very simple mobility models.

In reference [7] Tugcu et al, introduces a mobility model that captures the moving-in-groups, and conscious travelling. The mobility and call patterns are determined according to the locus of the subscriber over a real map.

3. Mobility Model

In this section the mobility model is presented and divided into three stages: street database preparation, origin-destination (OD) generation and finally, routing algorithm implementation.

3.1. Street Database

The introduced mobility model was implemented using a MapInfo vectorial street database. Some background work was produced above the original database, mainly using graphs, or better digraphs (i.e., directed graphs).

Each record of the street database carries a line type Mapinfo object which is an oriented edge. The line objects are referenced geographically in the UTM coordinate system (Universal Transverse Mercator). The street database has associated a certain number of important properties which are: Segment Identifier (ID), street ID, street's name and type, edge's coordinates, orientation and allowed average speed, and edge level. This last property reveals the hierarchy level of the current edge.

3.2. Origin-Destination (OD) Generation

The model's OD analysis is the start and end point definition of vehicular subscribers included in the simulations.

The Lisbon vehicular subscribers have different behaviors. A correct mobility modeling must have the subscriber profile in mind, since it influences directly the simulations accuracy. In the following, four profiles are introduced. Dependent on the profile, the start and end points must be stochastically generated. The profiles are:

- Profile 1 – vehicular outsider2inside – Consists on the subscribers that live in peripheral areas and migrate daily to the city center for working or leisure. The origin will be the street database's first segment belonging to the main corridor used by the subscriber to reach Lisbon.
- Profile 2 – vehicular outsider2outside – subscribers that live in peripherical areas and use Lisbon main corridors to cross the city and reach other locations outside.
- Profile 3 – vehicular insider2inside – subscribers that live in the city and go to work or leisure nearby.

- Profile 4 – vehicular insider2outside –subscribers that are Lisbon residents and move to work or leisure outside Lisbon.

It was decided to concentrate the accesses to Lisbon into seven main entrances/exits which are:

- Restelo Corridor – NR 6 (national road)
- Cascais Corridor – H5 highway
- Sintra/Amadora Corridor – S19 speed-way plus NR 117
- West Corridor – H8 highway
- North Corridor – H1 highway
- Vasco da Gama bridge Corridor – S13 speed way plus NR10
- 25th April bridge Corridor – H2 highway

The OD analysis was implemented using statistical data [8] which was obtained by inquiries to Lisbon street users. The data was organized based on forty distinct analysis units (AU) that together fill all Lisbon area.

Figure 1 shows the spatial distribution of the AUs and the respective street segments on the Lisbon street database. The AUs are identified using the unit ID.

Figure 1. Lisbon AUs and street segment mapping.

The data associated with the referenced AUs allows us to determine which units have higher vehicle generation and attraction potential. The values considered in this study are in [8] weighted over the total unit area. This enables to calculate the generation and attraction potential per AU area, expressed in hectare. In the following approach, the morning busy hour was used (MBH).

Figure 2 presents the obtained results in terms of attraction potential considering individual transportation (IT), expressed in vehicle per hour per hectare. The presented individual grey-scale thematic map helps to focus on the distribution of attraction potential.

The highest attraction potential considering IT journeys exists on the Lisbon central corridor (Baixa, Marquês de Pombal, Avenidas Novas). Baixa and Avenidas Novas have similar attraction potentials, even if there are more trips to Avenidas Novas, considering absolute values. Campo Grande is the area with highest attraction potential.

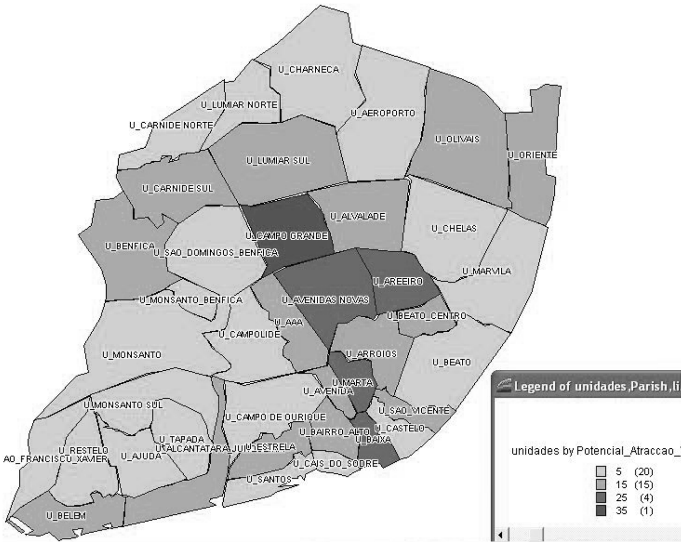

Figure 2. Attraction Potential per AU for IT (vehicle/h/ha).

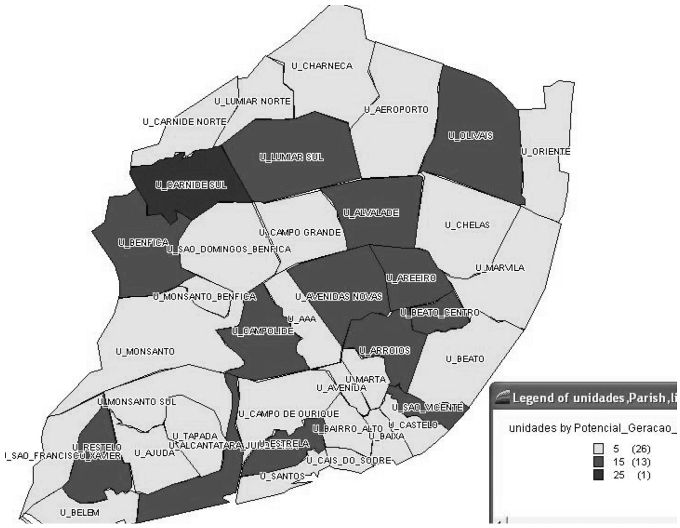

Figure 3. Generation Potential per AU for IT (in vehicle/h/ha).

Figure 3 presents the obtained results in terms of generation potential considering individual transportation (IT), expressed in vehicle per hour per hectare.

Carnide Sul assumes itself as the highest generating AU for IT. This fact can be explained by the intense medium to high class residential infrastructures, with greater economic potential which enables the massive IT usage.

Let $I_{out}(i)$ be the event of a vehicle departing from the ith start point and let $J_{in}(j)$ be the event of a vehicle arriving to the j^{th} destination point. *i* is the Lisbon entrance or origin AU index and *j* the Lisbon exit or destiny AU index, which depends on the profile that is being used. Hence,

$$P_{ij} = P(J_{in}(j) \mid I_{out}(i)) = \frac{P(J_{in}(j) \cap I_{out}(i))}{P(I_{out}(i))} \qquad (1)$$

where P_{ij} is the probability of a vehicle arriving to the jth destination point knowing that the departure was done from the ith start point. Additionally, $P(J_{in}(j) \cap I_{out}(i))$ will be modeled as,

$$P(J_{in}(j) \cap I_{out}(i)) = P_{cond}(i, j) P(J_{in}(j)) \tag{2}$$

where $P_{cond}(i, j)$ is a conductance probability dependent on the distance between start and exit points and based in vehicular traffic Gravity Model [9]. The well known model theoretically supports the statement that near destinations tend to be more attractive than far away ones. As an example, if profile 1 is considered, vehicles coming from outside Lisbon soon choose the corridor closest to its final destination. Hence, the highest share of vehicles will be for the closest AUs coming from the j^{th} corridor. Finally, P_{ij} will be given by

$$P_{ij} = P(J_{in}(j) \mid I_{out}(i)) = \frac{P_{cond}(i, j) P(J_{in}(j))}{P(I_{out}(i))} \tag{3}$$

$P(J_{in}(j))$ is the probability of a vehicle arriving to the j^{th} destination point, and can be calculated using the previously referenced attraction potential normalized to the total number of vehicles that arrive to all the AUs. $P(I_{out}(i))$ is the probability of a vehicle departing from the i^{th} start point and will be calculated using the vehicular traffic distributions extracted from [10] or with referenced generation potential, depending on the profiles.

Using this strategy, is possible to calculate probability distributions for all the profiles relating Lisbon main entrances/exits and focused AUs. Simulations are done looping over a *n* number of vehicles departing and arriving from stochastically chosen points in function of social behavior.

3.3. Routing Algorithm

After OD generation, next step is to define the routing algorithm strategy which will enable the driver to reach its final destination. The optimized routing along a digraph structure is a classic optimization problem already solved in [11]. If we assume that all the edges have the same properties, this leads to the problem of calculating the minimum distance between two points, over the aggregate distance of each possible combination of different paths from start to destination point. Although this is the optimal procedure to route the subscriber, in terms of minimizing the distance, it is too demanding from the computational point of view and not too realistic.

As a matter of fact, if we consider driver's daily routing strategy, they do not evaluate all the possible paths across the city. The decision is done step by step, the journey is started and after completing the first segment and reaching a street crossing, a decision has to be taken. Do we turn left? Do we turn right? Do we follow straightforward? We normally decide for the option that enables us to get closer to the final destination, i.e, to minimize the distance (or the travel time). The routing algorithm was implemented under this strategy, no different paths are evaluated a priori.

Using this realistic step by step procedure, deciding over the present, the driver will obviously be trapped on some dead-end situations, since some paths will lead to street segments that do not have any more neighboring relations in the direction of movement.

The problem is solved using the usual procedure from real life. To turn back, and remember that the decision previously taken led us to a dead-end. In the future, if for any chance the same scenario is encountered, that street segment will not be chosen, even that it leads to the shortest distance to target.

Additionally, when a driver starts some journey, he normally chooses the course that minimizes the travel time. He initially tries to pick the best (faster) axes (highways, speedways, main avenues, etc) and only then chooses secondary roads to the final destination. This suggests that a hierarchic street level has to be set in the database, in order to be used by the routing algorithm.

A three level hierarchic algorithm was implemented. The fundamental network (L1) includes arterial and principal ways. These guarantee the travelling connections of the arterial way to the diverse urban sectors and integrate the main avenues and urban roads. The main routes establish the connections between the city sectors. The secondary way (L2) has the role of distributing and collecting the traffic from the local to the fundamental network. The local network (L3) assures predominantly the local access to the urban functions and activities, which include streets with distinct utility and that mix vehicles and pedestrians.

Lisbon has a total of 1192 Km in what refers to street length. L1 covers 9,2 % of the total distance with an average speed of 34 km/h. Additionally, L3 with all secondary and residential roads has 77% of the total segment distance with an expected slower average speed of 17 km/h. L2 gets the remaining 14% with an intermediate average speed of 26 km/h.

Figure 4 shows the street level spatial distribution on the Lisbon database by means of an individual grey-scale thematic map. The street segment labeling into the three hierarchic levels was done manually, following the guidelines of [8] and also the technical and field experience of senior traffic engineers from TD/CML (Traffic Department – Lisbon Municipality).

In terms of routing algorithm, three decision regions were defined according to the distance to final destination, delimited with two thresholds, THR1 and THR2 (see Figure 5).

If the distance to target is higher or equal than THR1, then it is considered that the driver is far from its final destination, so, he will preferably cruise streets corresponding to L1 (active set is L1), mainly highways, speedways and fast avenues that will take the driver faster to destination. The L1 street segment to be chosen will be the one that minimizes distance to target.

Additionally, if the distance to target is between THR2 and THR1, then the driver is considered to be in an intermediate area, so he is allowed to use L2 and also L1. The L1 or L2 street segment to be chosen will be the one that minimizes distance to target (active set is L1 or L2).

Finally, if the remaining distance is lower than THR2, then the algorithm considers the driver already in the vicinity of its final destination and only in this area he will be allowed to choose L3.

Considering the focused active sets, note that the subscriber always upgrades street level when has as an option different and faster street segments, in order to maximize travel speed. Additionally, if the vehicle only has, at its disposal, street segments associated with lower levels which are not permitted considering the occupied region, then he will cruise these lower level segments until it has the chance to move to faster axes.

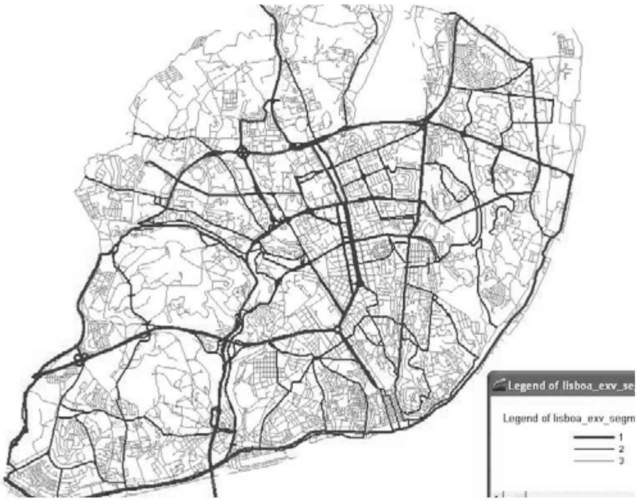

Figure 4. Lisbon Spatial Database Characterization by Street Level.

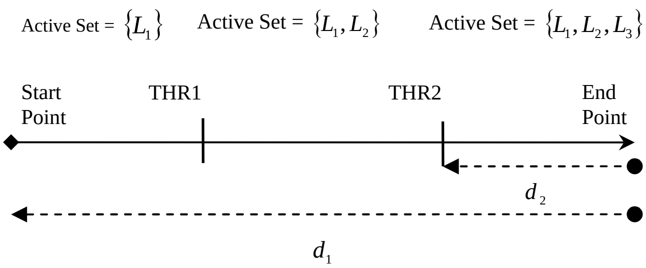

Figure 5. Routing algorithm's region definition.

For the Lisbon case, we have set threshold one (THR1) to 2000 m and threshold two (THR2) to 600 m [10]. Considering the possible application of the model to another city, the threshold values should be reviewed, since they are dependent on the city street structure and on the urban center area. In this section, the routing algorithm under the introduced mobility model, was presented. Essential to this model is the new concept of optimized driving with street level selection and also learning with mistakes (introducing memory), which we have call smart travelling.

4. Model Validation

The model validation was initiated comparing directional measurement statistics in [10] with corresponding values obtained by simulation. The focused case study considers vehicles that access the city using one of the seven main entrances, which corresponds to the aggregation of profile 1 and 2. Table 1 shows the vehicular traffic per entrance considered in the validation process [10] (MBH).

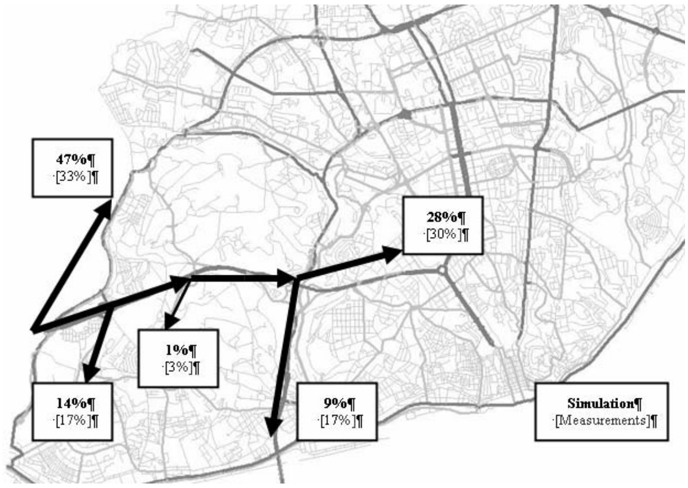

Figure 6. Directional Simulation Results for H5 entrance and considering profiles 1 and 2.

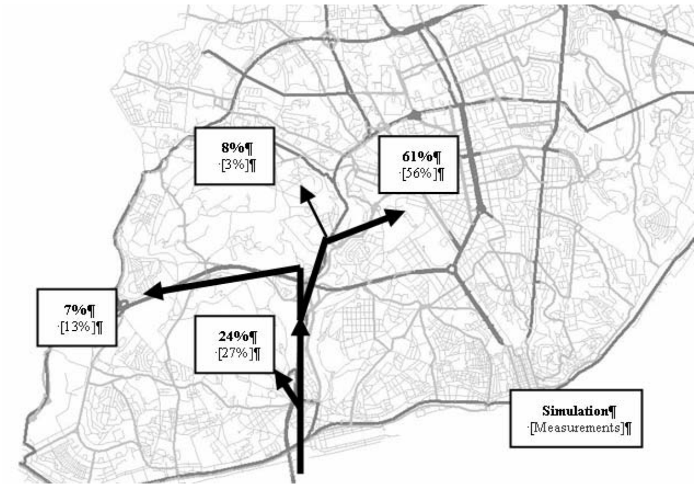

Figure 7. Directional Simulation Results for H2 entrance and considering profiles 1 and 2.

Table 1. Average vehicular traffic per Lisbon entrance at MBH [10].

Entrance	Profile 1 [veic.@MBH]	Profile 2 [veic.@MBH]	Total
NR6	1628	572	**2200**
H5	4144	1456	**5600**
S19	3340	2580	**5920**
H1	1857	1743	**3600**
PVGama	845	1575	**2420**
P25Abr	5402	1998	**7400**
H8	1908	792	**2700**
Total	**19124**	**10716**	**29840**

Simulations were done looping over a total of 2000 vehicles belonging to profiles 1 and 2 for each entrance. The distribution between profile 1 and 2 is based on Table 1. Figures 6 and 7 show vehicular directional statistics for the H5 and H2 main entrances. Besides the results from simulation, corresponding measurements in [10] are presented, for the main dispersion points. The simulation results reveal a good approximation to the vehicular traffic measurements, which partially validates the model. The correlation coefficient is around 92% in both scenarios.

5. Conclusions

In this paper a novel realistic vehicular mobility model is introduced. It captures the moving-in-groups, conscious travelling, and introduces the concept of smart travelling while respecting the social behavior of drivers based on inquiries and experimental traffic measurements.

After stochastically based OD generation, a routing algorithm is introduced. The routing algorithm minimizes the distance to a target on a step by step form, in every street crossing. This is done under a hierarchic street level structure that optimizes travel speed and quality. The preference for major axes leaving secondary axes to near to target distances follows street capacity issues, which are considered in real traffic network control.

The mobility model was simulated for Lisbon case study and directional simulation results were compared with experimental measurements. The output shows a good correlation (92%) between simulated and experimental values which validates the model's realism.

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