User Mobility Model based on Street Pattern

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***Abstract*— This paper presents a new statistical approach to user mobility characteristics. The object of research is focused on urban areas with low or normal traffic. The probability density function of the sojourn time for handover and new calls is estimated based on street pattern parameters. The parameters used are the average block area, the traffic parameter and the irregularity of the street pattern. It is proposed that these parameters provide all the information needed in order to estimate the statistical characteristics of the sojourn time for a random user.**

Keywords-sojourn time; mobility model; street pattern;

I. INTRODUCTION

A powerful tool for cell planning and system performance evaluation is the classical teletraffic analysis. A basic feature of this analysis is the statistical variation of the time that a user remains in a cell, called sojourn time (ST). The knowledge of the behavior of this stochastic variable is necessary for the rest of the analysis to be deployed. Due to many assumptions used for the ST calculation in the bibliography, the analytical approach has not been proven reliable. Therefore, the calculation of the statistical properties is based in statistic approaches like the Monte Carlo Simulation.

In [1], Hong and Rappaport present a simple analytical approach where the movement of the user is modeled as one step one direction movement which is a rather unrealistic model for urban areas. The results show that the ST follows an exponential-like distribution. In [2], a better approach is proposed. The user is supposed to move for a random distance and then turn to a random angle and continue this process until he exits the cell. In this case the statistical approximations suggest that the ST variable follows a gamma distribution. In [3], the previous model is refined using a more realistic approach. The movement is defined by a set of vectors. The vectors are generated with respect to street pattern characteristics. This statistical approach yields a gamma distribution as well. In all the above cases, a tool that calculates the ST statistic features is not available. Other previous works on this matter are [4],[5] and [6]. In [4] and [6], some parameters of road patterns and the implications in the sojourn time are studied. In [7], a useful overview on available mobility models is found, focused mainly on Mobile Adhoc NETworks (MANETs).

All the above models study vehicle movement in low or normal traffic. When the velocity is very low, either due to excessive traffic or when studying pedestrian movement, the number of handovers is greatly reduced and the whole analysis necessity is challenged.

In this context, the need for an elaborated model that connects the statistics of ST with the attributes of the road pattern is becoming clear. The target of this paper is to propose a model that can be applied in a specific road map and yield the ST statistical properties. The current version of the model is referred to urban environments with low or normal traffic and only for square pattern of streets. However, the model can be extended to cover any street pattern as well as more traffic scenarios. The parameters used in this model are the average block area, the irregularity factor of the blocks and the traffic parameter. All these parameters can be extracted from the knowledge of a specific urban area. It is suggested that these three parameters create a complete set able to determine the final characteristics of movement in the specific area.

The rest of this paper is organized as follows. In section II, the system model is presented, the methodology is explained in section III and the paper is concluded in section IV.

II. SYSTEM MODEL

A. Mobility Model

The cell is defined as a circular area with radius *CR*. The vehicle user moves through a series of vectors as in figure 1. For every step of the walk, two vectors are defined. The vector ***m*** that defines the path of the step and the vector ***r*** that defines the position relative to the center of the cell. The vector that gives the position of the user after *n* steps will be:

$$\bar{r}_n = \bar{r}_0 + \sum_{i=1}^{n} \bar{m}_i \quad (1)$$

The initial position $\mathbf{r_0}$ is defined by the polar variables r_0 and φ_0. For a new call and a handover call we set the initial values:

$$\begin{cases} r_0^{nc} = \dfrac{1}{CR}, [0, CR] \\ \varphi_0^{nc} = \dfrac{1}{2\pi}, [-\pi, \pi] \\ d_0^{nc} = \dfrac{1}{2\pi}, [-\pi, \pi] \end{cases} \quad \begin{cases} r_0^{hc} = CR \\ \varphi_0^{hc} = \dfrac{1}{2\pi}, [-\pi, \pi] \\ d_0^{hc} = \pi - \varphi_0^{nc} + \dfrac{1}{\pi}, [-\dfrac{\pi}{2}, \dfrac{\pi}{2}] \end{cases} \quad (2)$$

Where, d_0 is the initial direction of movement. The position of the user after i steps is found:

$$|\bar{r}_i| = \sqrt{\left[|\bar{r}_{i-1}|\cos\varphi_{i-1} + |\bar{m}_i|\cos(d_i+\varphi_{i-1})\right]^2 + \left[|\bar{r}_{i-1}|\sin\varphi_{i-1} + |\bar{m}_i|\sin(d_i+\varphi_{i-1})\right]^2} \quad (3)$$

$$arj(\bar{r}_i) = \tan^{-1}\left\{\frac{|\bar{r}_{i-1}|\sin\varphi_{i-1} + |\bar{m}_i|\sin(d_i+\varphi_{i-1})}{|\bar{r}_{i-1}|\cos\varphi_{i-1} + |\bar{m}_i|\cos(d_i+\varphi_{i-1})}\right\} \quad (4)$$

The starting point $\boldsymbol{r_0}(r_0,\varphi_0)$ is defined by a uniform distribution with characteristics given in (2). According to this r_0 can take any value in the cell whereas in reality it should be only in a street. For this reason, the street pattern is constructed around this starting point. This assumption conveniently solves this problem without loss of generality. In this case study, the parameter $|\boldsymbol{m_i}|$ is set to the acme of the assumed square block. The destination parameter d_i receives values from the set $\{0,\pi/2,-\pi/2,\pi\}$ with a binomial random procedure. Specifically, from statistical research, it has been shown that the order of maximum probability is going straight ahead (p_{0^o}), turning right (p_{-90^o}) and then turning left (p_{90^o}). The value of π is used with a minor probability as it is rather rare. Any other values are prohibited by the square structure. Table 1 provides the values for this binomial distribution.

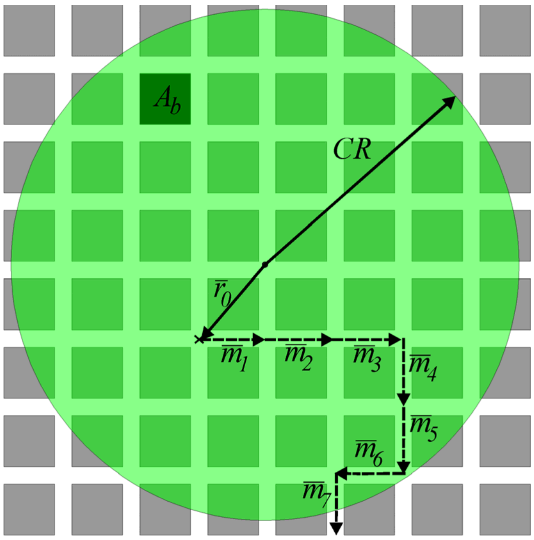

Figure 1. A representation of a new call scenario. In this scenario we have initial direction angle $d_0=0$.

TABLE I. SIMULATION VALUES FOR THE BINOMIAL DISTRIBUTION OF THE NEW STEP DIRECTION VARIABLE (DI).

	0^o	90^o (Left)	-90^o (Right)	180^o
probability values	0.7	0.135	0.164	0.001

Velocity is found in the literature to follow a mixed variation that can be modeled as a sum of normal and rician distribution. The first part corresponds to high speed roads and the latter to dense area roads [3]. In our model, free to drive roads are initially assumed where the velocity is modeled as normal (5). Then, a new stochastic variable is calculated which is the equivalent velocity due to a delay in a crossroad, (6). The final velocity v_i is the weighted sum of these two distributions. The resulting probability density function is tested against measurement data.

$$f_v(v) = \frac{1}{\sigma_v\sqrt{2\pi}}e^{-\frac{(v-\bar{v})^2}{2\sigma_v^2}} \quad (5)$$

$$u = \frac{\bar{d}}{\bar{\tau} + \frac{\bar{d}}{v}} \quad (6)$$

$$f_u(u) = \frac{\left(1+\frac{\bar{\tau}}{\bar{d}/u-\bar{\tau}}\right)^2}{\sigma_v\sqrt{2\pi}}e^{-\frac{\left(\frac{\bar{d}}{\bar{d}/u-\bar{\tau}}-\bar{v}\right)^2}{2\sigma_v^2}} \quad (7)$$

$$f_{v_i}(v_i) = p_{tr}f_v(v_i) + (1-p_{tr})f_u(v_i) \quad (8)$$

In figure 2, the result of (8) is showcased for several values of delay and road length.

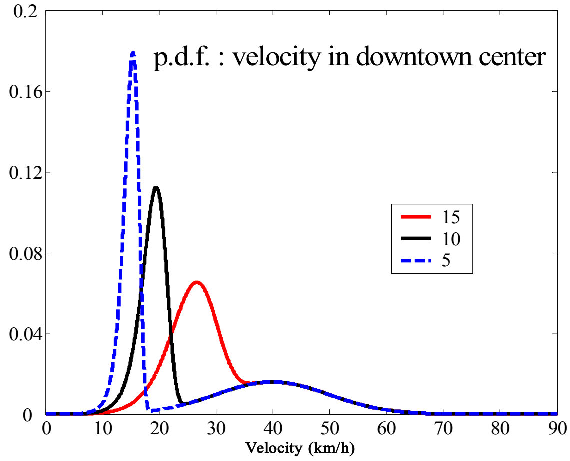

Figure 2. Velocity modelled using (8). $p_{tr}=0.6$ $\bar{d}=100m$ $\bar{\tau}=5,10,15\sec$.

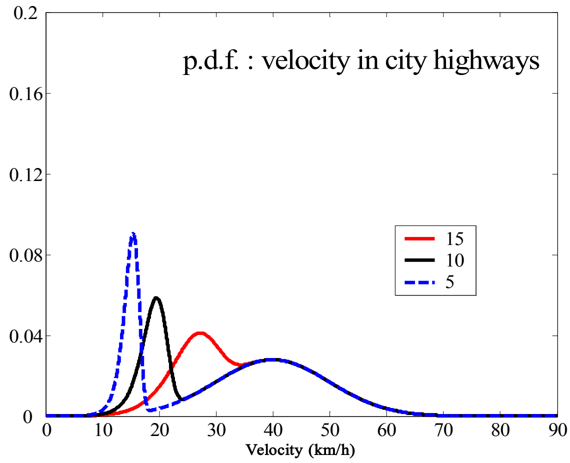

Figure 3. Velocity modelled using (8). $p_{tr}=0.3$ $\bar{d}=100m$ $\bar{\tau}=5,10,15\sec$.

As a result, this model makes an abstraction of several parameters like the velocity parameters σ_v, $\bar{v}$ and $\bar{\tau}$, the parameters of change of direction and the parameters characterizing the user (e.g. the car type and the driver ability). It is proposed, that the statistical movement in a real life city is not affected by these parameters. This model is based on the assumption that the movement of the vehicles is statistically defined by the structure of the city.

B. Statistical Approach

The parameter of street pattern irregularity in this case study is not usable as the structure is totally regular. The outcome of the model is expected to be a ST distribution depending on the other two parameters mentioned above, the average block area $A_b=a^2$ and traffic parameter p_{tr}. The traffic parameter p_{tr} represents the probability that a car will have to reduce speed at a crossroad. The calculation of the traffic parameter for a real scenario is explained in a following section. It is evident that both two parameters affect the velocity of the user and as a direct consequence the total ST.

With monte carlo simulation, statistical data are extracted for a wide range of A_b and p_{tr}. The data are fitted to a gamma distribution (9) and the fit is evaluated with a chi-square test of goodness of fit. Following the fitting, the α and b gamma parameters are yielded for a range of input parameters. Then the data are fitted to a model that uses a statistical regression and presented as functions $\alpha(A_b, p_{tr})$, $b(A_b, p_{tr})$. Figures 3-7 present these results.

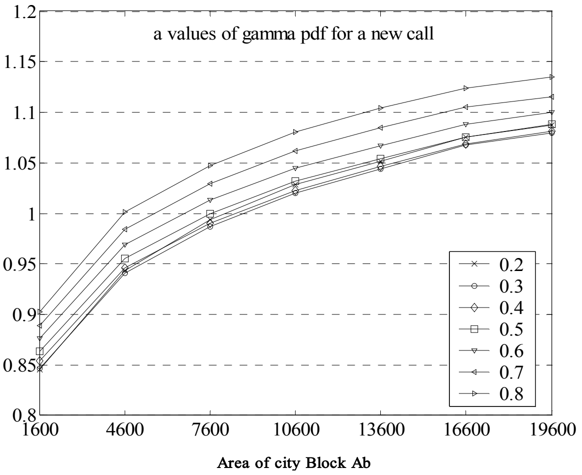

Figure 4. The parameter α of Gamma distribution as function of A_b and p_{tr}, for the new call scenario

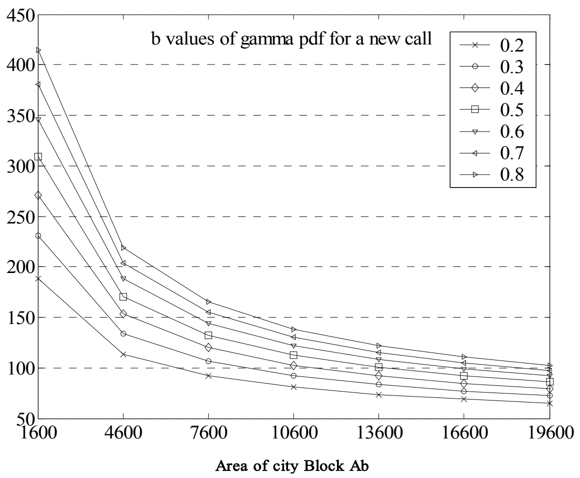

Figure 5. The parameter b of Gamma distribution as function of A_b and p_{tr}, for the new call scenario

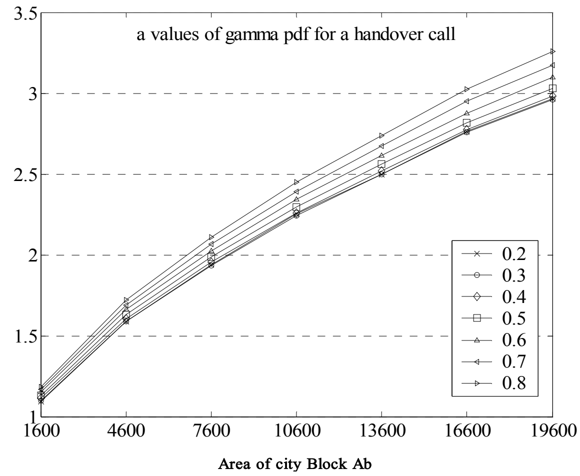

Figure 6. The parameter α of Gamma distribution as function of A_b and p_{tr}, for the handover call scenario

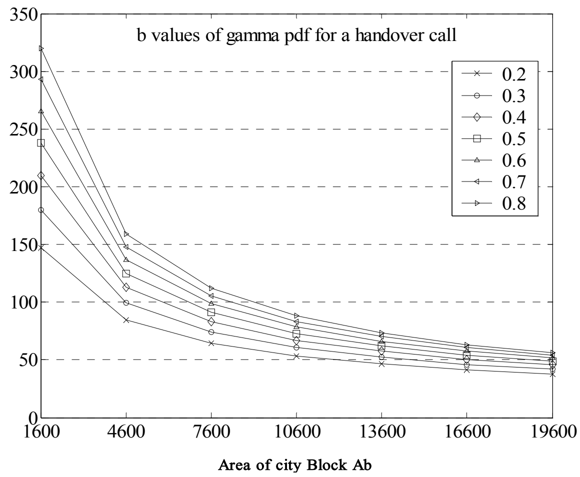

Figure 7. The parameter b of Gamma distribution as function of A_b and p_{tr}, for the handover call scenario

$$f_{gamma}(x)=\frac{x^{a-1}}{\Gamma(a)b^{a}}e^{-\frac{x}{b}} \quad (9)$$

Finally, the following empirical formulas are yielded:

$$a_{nc}=\begin{cases}1.1034-0.311e^{-0.0001428571\cdot A_b}, & p_{tr}\in[0.1,0.4)\\ 1.05374+0.1241525\cdot p_{tr}-0.311e^{-0.0001428571\cdot A_b}, & p_{tr}\in[0.4,0.9]\end{cases} \quad (10)$$

$$b_{nc}=53.60435+70.2435\cdot p_{tr}+(85.37414+495.558231\cdot p_{tr})e^{-0.0002740524\cdot A_b} \quad (11)$$

$$a_{hc}=4+0.54\cdot p_{tr}-(3.2+0.48\cdot p_{tr})e^{-\left(4.5\cdot 10^{-5}+1.3\cdot 10^{-5}\cdot p_{tr}\right)A_b} \quad (12)$$

$$b_{hc}=34+32\cdot p_{tr}+(82+400\cdot p_{tr})e^{-0.000261224\cdot A_b} \quad (13)$$

III. MOBILITY MODEL EVALUATION

The results in the previous section show a clear dependence of α, b values from A_b and p_{tr}. Moreover, the analytical formulas (10-13) are found to have less than 2% of fitting error at all cases. Using these formulas, the sojourn time distribution can be estimated for a known road pattern. A_b and p_{tr} can be extracted from a map.

A_b is estimated as the mean area of blocks. Two equivalent methods can be followed, always assuming that the blocks resemble a regular square shape. A number of random blocks can be measured and the median can be used, or an analogy can be drawn to an ideal case using the total area πCR^2 and the total number of crossings N_{total}. Since the reference cell radius is $500m$, the results should be scaled to the real cell radius.

p_{tr} can be estimated from two different concepts. Assuming that no traffic lights exist in a square block area, the probability of stopping in a crossing would be 0.5. If N_{tr} is the number of crossings with traffic lights, p_{tr} would be:

$$p_{tr} = 0.5 + 0.5 \frac{N_{tr}}{N_{total}} \quad (14)$$

Alternatively, p_{tr} can be estimated using the main roads. Given the fact that most vehicles use the main roads, the most cases simulated would be vehicle users that drive through a main road. As such, the extracted characteristics would mostly characterize the main roads. In this case, p_{tr} would be:

$$p_{tr} = \left(\frac{N_{tr}}{N_{total}} \right)_{mr} \quad (15)$$

Where, N_{tr} and N_{total} refer to the main roads this time. The optimum is to use both approaches using a weight function.

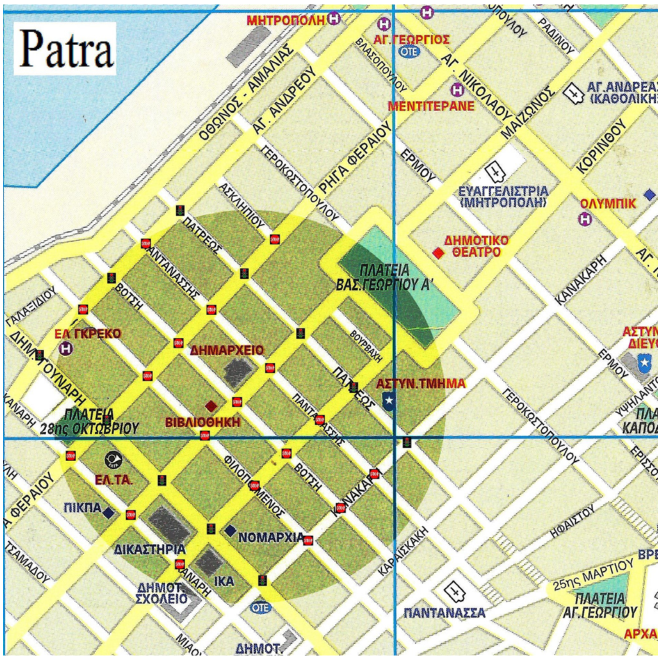

Figure 8. Map of Patra used to extract road pattern parameters. Traffic lights are marked on the map.

Using the example from figure 8, we calculate A_b=$9070m^2$ and p_{tr}=0.6476. From (10-13), we find α_{nc}=1.049, b_{nc}=132.9268, α_{hc}=2.1870 and b_{hc}=86.6261.

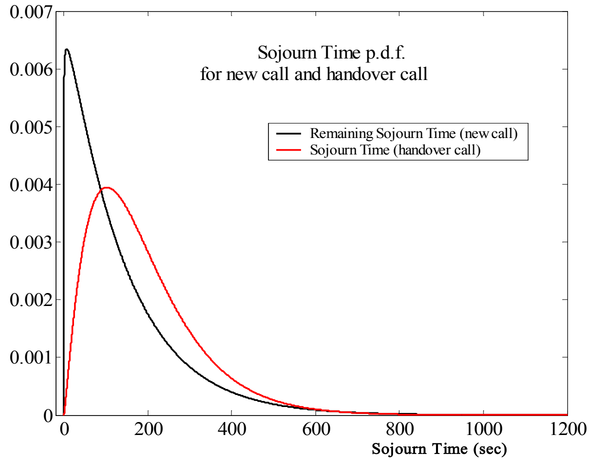

Figure 9. Probability Density Functions for Sojourn Time (handover calls) and Remaining Sojourn Time (new calls) for the scenario of a Patra center cell shown in figure 8.

The resulting probability density functions for new and handover calls are presented in figure 9

IV. CONCLUSION

A new approach to mobility for vehicle users in urban cells is proposed. Street pattern parameters are used as input to the model and the output is the statistical properties of the sojourn time (ST) probability density function. As part of the future work, the model can be enriched with irregular street patterns and more traffic scenarios. The proposed model is a powerful tool in the process of analyzing the teletraffic properties of a geographically specific urban cell.

One part of the future work will be to calibrate the model using city traffic measurements. Moreover, triangles and rectangles should be inserted in the model with the use of irregularity factor.

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