Location Management Based on the Mobility Patterns of Mobile Users

Ignacio Martinez-Arrue, Pablo Garcia-Escalle and Vicente Casares-Giner
GIRBA Group, Instituto ITACA, Universidad Politecnica de Valencia
Camino de Vera s/n, 46022 Valencia, Spain
E-mail: imartinez201j@cv.gva.es, pgarciae@upvnet.upv.es, vcasares@upvnet.upv.es

***Abstract*— In this paper, we propose a new mobility model as an extension of the random walk model. Our proposal gathers mobility patterns with several degrees of randomness, so that both random walk and totally directional mobility patterns are modeled. This model is used as an input to study and compare the location management cost of the distance-based and movement-based strategies as a function of the mobile terminal directional mobility patterns. To that end we make use of a general framework of the movement-based location update with selective paging strategy, proposed in a previous paper. Each time the mobile terminal revisits the last cell it had contact, its movement-counter is increased with probability p or it is frozen (stopped) with probability q or it is reset with probability r, ($p + q + r = 1$). We discuss the trade-off between the location update cost and the terminal paging cost, when selective paging is implemented, in terms of the set of parameters p, q and r.**

I. Introduction

Mobility models play an important role in the dimensioning of mobile access networks. In particular, mobility tracking are dependent of the mobility patterns of the Mobile Terminal (MT). One of the most extended mobility model used in the evaluation of mobility tracking procedures is the random walk mobility model, [1]. That model wase initially considered for macrocellular scenarios. However, in microcellular environments the mobility rate is higher and MTs may move according to directional mobility patterns such as the random way point (RWP) mobility model reflects, [2].

Motivated by those facts, in this paper we propose a new, quite simple and versatil mobility model that generalizes the conventional random walk mobility model. In our model, we define a directional movement parameter that features the directional movement characteristics [3], [4] to be considered in each scenario. Thus, both random mobility patterns (macrocellular scenarios) and directional mobility patterns (microcellular scenarios) are modeled. The main purpose is to see the influence of the users pattern mobility in some location management procedures.

The paper is organized as follows. Section II overviews the location update procedures. Section III describes the considered scenario and the proposed mobility model. In section IV, we use this model to compute the LU costs of several movement-based schemes. Section V concerns with the evaluation of the PG cost. Some numerical results related to these costs and their discussion are detailed in section VI. Finally, section VII reports some comments on the work presented in this paper.

II. Overview on Location Management

Location management is defined as the set of procedures that allow a MT being locatable at any time, any where, so that incoming calls may be delivered to that MT. These procedures are called location update (LU) and call delivery (CD). The LU process consists of maintaining the MT location information up to date in the system databases. The database entry of an MT is updated whenever the MT triggers an LU message or an incoming call is received. The CD procedure is decomposed into two steps: interrogation and terminal paging (PG). Firstly, in the interrogation step, the system databases are queried to obtain the registration area (RA) [5] where the MT sent an LU message by last time. Afterwards, by means of the PG procedure, the MT is searched by polling the set of cells of the RA.

There is a trade off between LU and PG procedures. As the number of delivered LU messages increases, the LU cost becomes higher but the PG cost decreases because the MT position is known more accurately. On the other hand, the lower is the number of LU messages, the lower is the LU cost; but the uncertainty of the MT position is higher and the PG cost increases.

The LU procedures can be classified into static or dynamic strategies. In static schemes, the whole coverage area is divided into several location areas (LAs). Each LA is a fixed set of neighboring cells, so that the MT delivers an LU message whenever it crosses an LA border. In the dynamic strategies, the RA borders depend on the cell where the MT position was updated by last time. In [6], [7], three dynamic LU schemes were proposed. LU messages are delivered according to the time elapsed, the number of movements performed or the distance traveled by the MT from the cell where it had its last contact. It is pointed out that the distance-based scheme outperforms both movement-based and time-based mechanisms. Besides, the movement-based strategy achieves a lower cost than the time-based scheme. However, the distance-based policy is more complex to be implemented because it requires to compute the distance traveled by the MT (measured in cells) using specific algorithms, [8]. Hence, the movement-based strategy may be more suitable for its simplicity. Moreover, some proposals such as [9] achieved enhanced versions of the movement-based scheme. Each time the MT revisits the last cell it had contact, its movement-counter is increased in one unit with probability p, or it is frozen (stopped) with probability q or it is reset with probability r ($p+q+r=1$).

Once an LU scheme has been chosen, the PG process can be carried out according to two different policies: non-selective or selective. In non-selective PG, hereinafter called one-step PG, all cells in the RA are polled simultaneously. It is obtained a high PG cost but a minimum delay on the CD. In selective PG strategies [10], [11], the RA is divided into several PG areas (PAs). The PAs are polled sequentially so that PAs where the called MT is more likely to be located are polled first. This policy yields a lower cost than one-step PG even though it is obtained a greater delay on the CD than one-step PG.

The performance of location management procedures are dependent of the mobility patterns of the MT.

III. Proposed mobility model

A regular cell layout scenario with all hexagonal cells with the same size has been chosen. An MT is roaming within a cell during a random time which is featured through a generalized gamma distribution [12], with probability density function (pdf) denoted by $f_c(t)$ and mean value equal to $1/\lambda_m$. λ_m is denoted as the mobility rate of the MT -the mean cell residential time-.

In the random walk model, when the MT leaves its current cell, it moves to one of its six neighboring cells with probability 1/6. In the proposed model a single parameter, α, will provide directionality to the MT. To that end, cells are labeled as it is shown in Fig. 1. Cells are divided into two sets. In the first set, there are cells that limit with three neighboring cells in their contiguous outer ring. Such cells are labeled as $(x,0)$, with $x \geq 1$. In the second set, cells are bordered by two neighboring cells in the outer ring. They are labeled as (x,i), with $x \geq 2$ and $1 \leq i \leq \lfloor \frac{x}{2} \rfloor$.

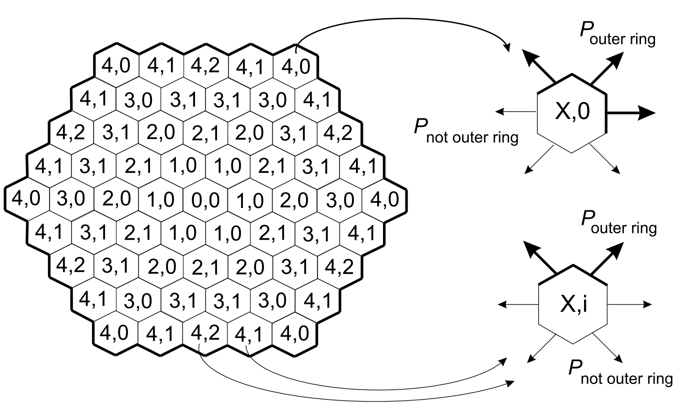

Fig. 1. Cell labeling and transition probabilities between two cells

The transition probabilities from one cell to another are defined according to the movement of a given MT that implies a movement to the outer ring ($P_{\text{outer ring}}$), a movement to the same ring ($P_{\text{same ring}}$) and a movement to the inner ring ($P_{\text{inner ring}}$).

Then, for cells of type $(x,0)$ with $x = 1,2,...$ we define

$$\begin{array}{ll} P_{\text{outer ring}} = \frac{\alpha}{3(1+\alpha)}; & \text{three edges per cell} \\ P_{\text{same ring}} = \frac{1}{3(1+\alpha)}; & \text{two edges per cell} \\ P_{\text{inner ring}} = \frac{1}{3(1+\alpha)}; & \text{one edge per cell} \end{array} \tag{1}$$

and for cells of type (x,i) with $x = 1,2,...$ and with $i = 1,2,...,\lfloor \frac{x}{2} \rfloor$ we define

$$\begin{array}{ll} P_{\text{outer ring}} = \frac{\alpha}{2(2+\alpha)}; & \text{two edges per cell} \\ P_{\text{same ring}} = \frac{1}{2(2+\alpha)}; & \text{two edges per cell} \\ P_{\text{inner ring}} = \frac{1}{2(2+\alpha)}; & \text{two edges per cell} \end{array} \tag{2}$$

Notice that the above probabilities fulfill the following conditions. Respectively we have

$$\begin{array}{rcl} 3P_{\text{outer ring}} + 2P_{\text{same ring}} + P_{\text{inner ring}} & = & 1 \\ 2P_{\text{outer ring}} + 2P_{\text{same ring}} + 2P_{\text{inner ring}} & = & 1 \end{array}$$

The parameter α is defined as a directional movement parameter [13], that may take values within $[0,\infty[$. When $\alpha = 1$ we get the random walk model. As α increases from 1 to infinity, movements towards the outer ring from the current one become more probable so that a more directional movement is modeled. In the limit case of α tending to infinity, all cell boundary crossings would imply a movement towards the outer ring. If α decreases from 1 to 0, the probability of the MT being roaming within the same ring or moving towards an inner ring from the current one is higher. If α is 0, that probability is equal to 1.

From the previous transition probabilities, a two-dimensional (2) Markov chain arises with states denoted by (x,i) (see Fig. 2). The label x represents the number of ring where the MT is roaming in, whereas the label i indicates the type of cells the MT is roaming in.

The 2D Markov chain of Fig. 2 is quite complex. To simplify the model, a one-dimensional (1D) Markov chain has been derived from the previous one. For this conversion, cells are grouped by rings, so that each state of the 1D Markov chain represents a single ring where the MT is roaming in. In the 1D Markov chain, we denote by $f^{(1)}_{m,n}$ the probability that the MT moves from ring m to ring n after a single cell boundary crossings. These one-step probabilities are given by, for ring $m = 0$:

$$f^{(1)}_{0,1} = 1; f^{(1)}_{0,0} = 0 \tag{3}$$

and for ring $m > 0$:

$$\begin{array}{rcl} f^{(1)}_{m,m+1} & = & \frac{1}{m}\left(\frac{\alpha}{(1+\alpha)}\right) + \frac{m-1}{m}\left(\frac{\alpha}{2+\alpha}\right) \\ f^{(1)}_{m,m} & = & \frac{1}{m}\left(\frac{2}{3(1+\alpha)}\right) + \frac{m-1}{m}\left(\frac{1}{2+\alpha}\right) \\ f^{(1)}_{m,m-1} & = & \frac{1}{m}\left(\frac{1}{3(1+\alpha)}\right) + \frac{m-1}{i}\left(\frac{1}{2+\alpha}\right) \end{array} \tag{4}$$

All the previous probabilities depend on α and they are used to compute the LU costs and the selective PG cost.

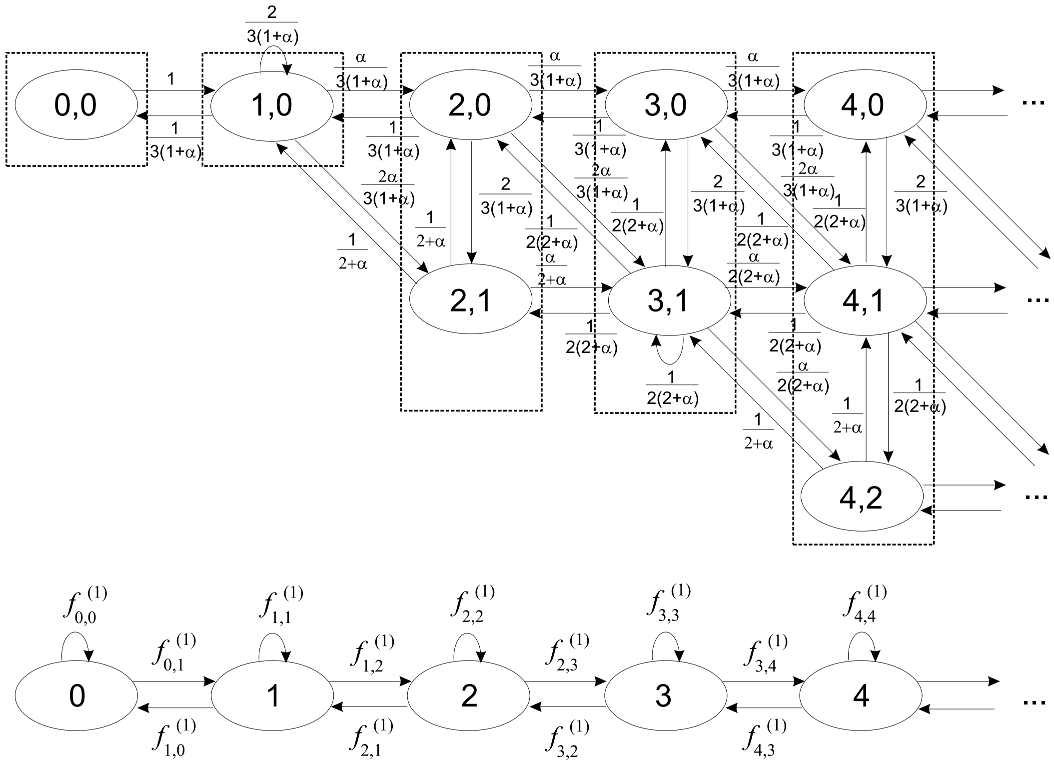

Fig. 2. Two-dimensional and one-dimensional Markov chains

IV. Location update procedure

A. Description

Our new mobility model has been used to evaluate the location update procedure of [9]. It is summarized in the next lines. Basically each MT will count for the number of visits to cells. When the movement counter reaches a predefined value D the MT will send an LU message to the fixed network (FN). However, each time the MT revisits the last cell it had contact with the FN, its movement-counter is increased in one unit with probability p, or it is frozen (stopped) with probability q or it is reset with probability r ($p+q+r=1$). Notice that the proposals of [11], $(p,q,r)=(1,0,0)$ and [14], $(p,q,r)=(0,0,1)$ are particular cases of our general scheme.

B. The analysis

Fig. 3 shows the 1D Markov chain, for the case of $D=5$, used in our analysis [9]; where the probability $P_{nab}(D)$ (nab= no absorption) plays a fundamental role. $P_{nab}(D)$ is the conditional probability that starting in state S_0 no absorption into state S_0 is produced after D movements, and it is given by

$$P_{nab}(D) = 1 - \sum_{n=1}^{D} f_{0,0}^{(n)} \tag{5}$$

In (5), $f_{i,j}^{(n)}$ denotes the conditional probability that state S_j is avoided at times $1,2,..,n-1$ and entered at time n, given that state S_i is occupied initially, –a taboo probability–. As a matter of fact, $f_{0,0}^{(n)}$ can be obtained in terms of $p_{0,0}^{(n)}$ by using the following convolution equation:

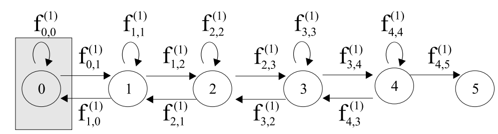

Fig. 3. 1-D Markov chain for $D=5$ with one absorbing state, S_5, and one state with three possible decisions, S_0.

$$p_{0,0}^{(n)} = \sum_{k=1}^{n} f_{0,0}^{(k)} p_{0,0}^{(n-k)} \tag{6}$$

In (6), $p_{i,j}^{(n)}$ denotes the conditional probability that starting in state S_i we enter state S_j at time n (not necessarily for the first time). Obviously $p_{i,j}^{(1)}=f_{i,j}^{(1)}$.

We denote by $M_s(z)$ as the expected number of LU triggered by the MT in z movements, given that state S_0 is occupied initially and the value of the counter of the MT is s, $s=1,2,..,D-1$. A recursive relationship was found for $M_s(z)$ –see expression (7) at the top of the next page–.

Assuming that calls arrive to the MT following a Poisson process with rate λ_c, the probability $\alpha(z)$ that there are z boundary crossing between two call arrivals is given by, (see [11]),

$$\alpha(z) = \begin{cases} 1-(1-a)/\theta; & z=0 \\ (1-a)^2 a^{z-1}/\theta; & z>0 \end{cases} \tag{8}$$

$$M_s(z) = \begin{cases} 0; & z < D-s \\ \sum_{n=1}^{D-s-1} f_{0,0}^{(n)}[pM_{n+s}(z-n) + qM_{n+s-1}(z-n) + rM_0(z-n)] + & \\ f_{0,0}^{(D-s)}[p + (p+r)M_0(z-D+s)) + qM_{D-1}(z-D+s)] + & \\ P_{nab}(D-s)[1 + M_0(z-D+s)]; & z \geq D-s \end{cases} \quad (7)$$

In (8), $a = f_c^*(\lambda_c)$ is the Laplace Transform $f_c^*(s)$ of the cell residential time of the MT evaluated at $s = \lambda_c$ – $a = f_c^*(\lambda_c)$ is the probability that the MT leaves its current cell before a new incoming call is received [5]–. The ratio between the call arrival rate, λ_c, and the mobility rate, λ_m is the so called call-to-mobility ratio (CMR) [11], denoted as $\theta = \lambda_c/\lambda_m$.

$\theta = \lambda_c/\lambda_m$ is the Call-to-Mobility Ratio, (CMR)

Therefore, the LU cost will be given by

$$C_{LU} = U \sum_{z=D}^{\infty} \alpha(z) M_0(z) = U \frac{(1-a)^2}{\theta a} M_0^*(a); \quad (9)$$

V. Terminal Paging Procedure

A. Description

For paging, we have considered a shortest-distance-first (SDF) partitioning scheme, [11]. Fig. 1 shows that each cell is surrounded by rings of cells. The innermost ring consists of only cell $(0,0)$. This is the cell where the MT had its last contact with the FN. Ring 0 is surrounded by ring 1, ring 1 is surrounded by ring 2, and so on. The number of cells in ring m, denoted by $g(m)$, is given by

$$g(m) = \begin{cases} 1; & m = 0 \\ 6m; & m > 0 \end{cases} \quad (10)$$

The residing area of the MT is partitioned into $l = \min(\eta, D)$ subareas, where η is the maximum allowable paging delay. Subarea j is denoted by A_j, where $0 \leq j < l$. Each subarea contains one or more rings of cells. Subarea A_j contains rings s_j to e_j where s_j and e_j are obtained as

$$s_j = \begin{cases} 0; & \text{for } j = 0 \\ \lfloor \frac{Dj}{l} \rfloor; & \text{otherwise} \end{cases} ; e_j = \lfloor \frac{D(j+1)}{l} \rfloor - 1; \quad (11)$$

Therefore, when an incoming call arrives to an MT, the network first determines the subareas for the called MT and then initiates the MT paging (PG) process. First, the network simultaneously polls all cells in subarea A_0. If the MT is found in subarea A_0 the PG process ends. Otherwise, the network polls the cells in subarea A_1, and so on.

B. The analysis

Let $\pi_{s,i}(z)$ $(s, i \in [0, D-1])$ denote the conditional probability that starting from ring 0 (state S_0) and the value of the movement-counter of the MT is s, the MT is located in a cell of ring i after z movements. Then, we can write the recursive relationship (12) –see the next page–.

Therefore, the probability that the MT is located in ring i when a call arrival occurs is given by $\pi_{s,i}$ evaluated at $s = 0$, where

$$\pi_{s,i} = \sum_{z=0}^{\infty} \alpha(z) \pi_{s,i}(z); \text{ for } 0 \leq s \leq D-1 \quad (13)$$

For a given SDF partitioning scheme, we compute the number of cells, $N(A_k)$, in subarea A_k and the number of cells polled before the MT is successfully located, w_k,

$$N(A_k) = \sum_{r_j \in A_k} g(j) \quad (14)$$

$$w_k = \sum_{m=0}^{k} N(A_m) \quad (15)$$

Therefore, using $\pi_{0,i}$, we can compute ρ_k, the probability that the MT is residing in partition A_k when a call arrival occurs

$$\rho_k = \sum_{r_i \in A_k} \pi_{0,i} \quad (16)$$

So the expected terminal PG cost per call arrival, denoted by C_{PG}, is

$$C_{PG} = V \sum_{k=0}^{l-1} \rho_k w_k = V \sum_{k=0}^{l-1} [\sum_{r_i \in A_k} \pi_{0,i} \sum_{m=0}^{k} \sum_{r_j \in A_m} g(j)] \quad (17)$$

where V is the cost for polling a cell.

VI. Some numerical results

The total cost $C_T = C_{LU} + C_{PG}$, i.e.the sum of (9) plus (17), has been evaluated for a set of parameters, with main emphasis in the mobility patterns parameter, α.

First, we have analyzed the influence of the three parameters, p, q and r in the total cost C_T. We report three 3D figures, Fig. 4, Fig. 5 and Fig. 6. All of them show that the minimal C_T is reached for $r = 1$ hence for $p = q = 0$.

Next, Fig. 7 and Fig. 8 plot the C_T in terns of D for $\alpha = 1$ –random walk–, 2 and 100 and for $(p, q, r) = (1, 0, 0)$ –movement strategy–, $(p, q, r) = (0, 1, 0)$ –frozen strategy– and $(p, q, r) = (0, 0, 1)$ –reset strategy–.

Finally, we have test the influence of the parameter α in the total cost, C_T, for the mentioned strategies: $(p, q, r) = (1, 0, 0)$ –movement strategy–, $(p, q, r) = (0, 1, 0)$ –frozen strategy–, $(p, q, r) = (0, 0, 1)$ –reset strategy– all compared

$$
\pi_{s,i}(z) = \begin{cases} p_{0,i}^{(z)}; & z < D-s \\ \displaystyle\sum_{n=1}^{D-s-1} f_{0,0}^{(n)} [p\pi_{s+n,i}(z-n) + q\pi_{s+n-1,i}(z-n) + r\pi_{0,i}(z-n)] + & \\ f_{0,0}^{(D-s)} [(p+r)\pi_{0,i}(z-D+s) + q\pi_{D-1,i}(z-D+s)] + & \\ P_{nab}(D-s)\pi_{0,i}(z-D+s); & z \geq D-s \end{cases} \tag{12}
$$

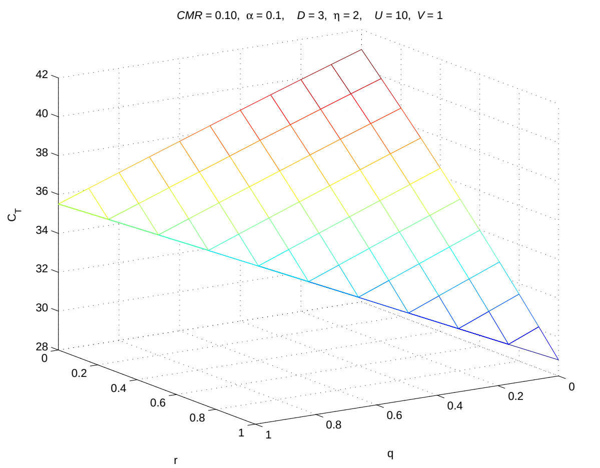

Fig. 4. Total cost= Location update + paging for $D = 2$, $\eta = 2$ –selective paging–, U=10, V=1 and for a CMR equal to $\theta = 0,10$ and $\alpha = 0,1$.

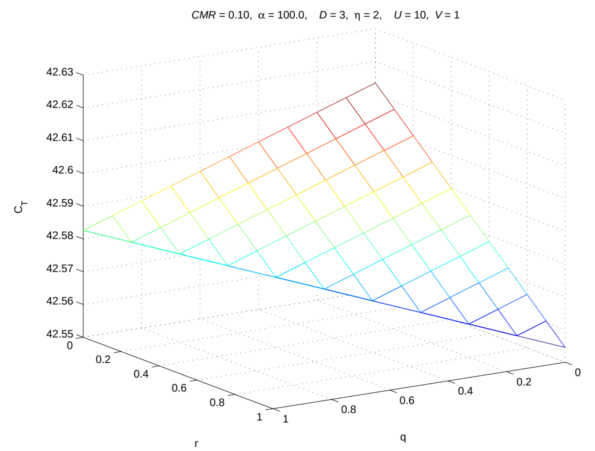

Fig. 6. Total cost= Location update + paging for $D = 2$, $\eta = 2$ –selective paging–, U=10, V=1 and for a CMR equal to $\theta = 0,10$ and $\alpha = 100$.

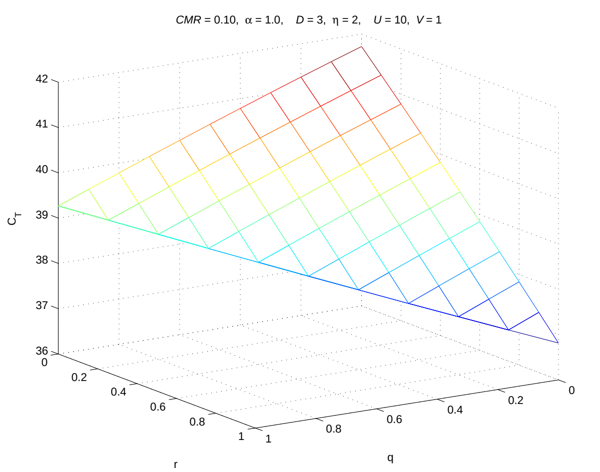

Fig. 5. Total cost= Location update + paging for $D = 2$, $\eta = 2$ –selective paging–, U=10, V=1 and for a CMR equal to $\theta = 0,10$ and $\alpha = 1$ –random walk– .

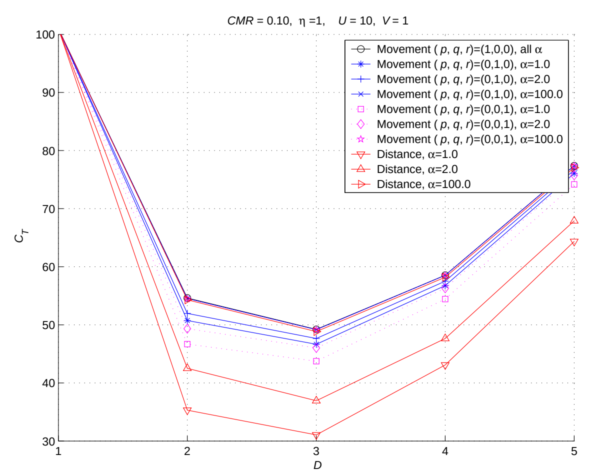

Fig. 7. Total cost= Location update + paging for a set of values of α, $\eta = 1$ –no selective paging–, U=10, V=1 and for a CMR equal to $\theta = 0,10$.

with the distance strategy. While Fig. 9 shows the case of no selective paging, Fig. 10 shows the case of a two steps selective paging. For both, clearly the best C_T is achieved for the distance strategy. Sorted from lower to higher C_T we can assert that $C_{T\text{distance}} < C_{T\text{reset}} < C_{T\text{frozen}} < C_{T\text{movement}}$. When α approach to ∞ all strategies perform equally, since the movement of a MT follows, roughly speaking, a strigh line. For values of α, say $\alpha \leq 10$ the differences between the $C_T's$ becomes significative.

VII. Conclusions

In this paper, a new mobility model has been presented. The model can be used in microcellular environments, where a more deterministic roaming of the MT could be expected. The new mobility model has been tested to evaluate several location managements schemes, in particular, four location update algorithms combined with selective paging. that among all the the movement-based type strategies, the $(p, q, r) = (0, 0, 1)$ (*reset*) strategy provides the best performance from

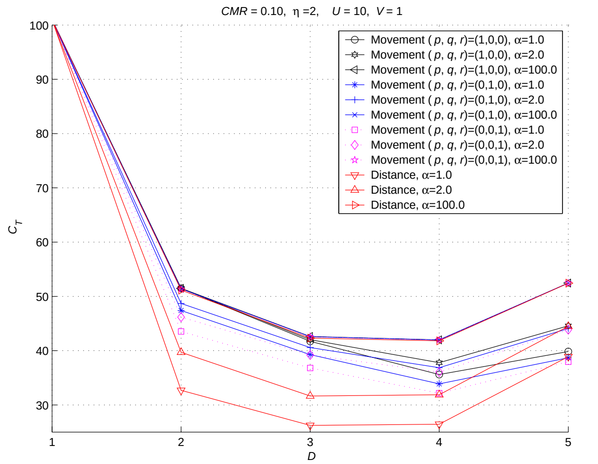

Fig. 8. Total cost= Location update + paging for a set of values of α, $\eta = 1$ –no selective paging–, U=10, V=1 and for a CMR equal to $\theta = 0, 10$.

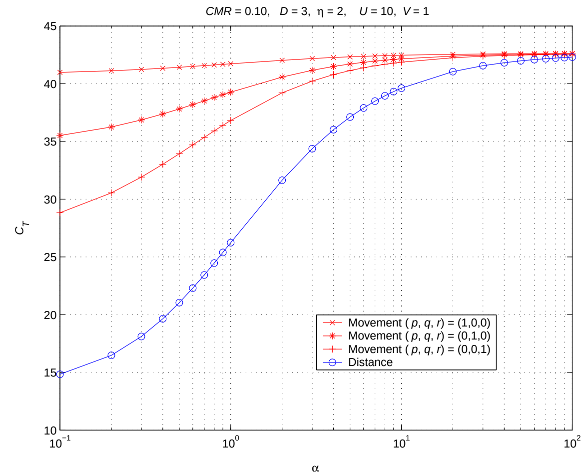

Fig. 10. Total cost= Location update + paging for $D = 3$, $\eta = 2$ –selective paging–, U=10, V=1 and for a CMR equal to $\theta = 0, 10$.

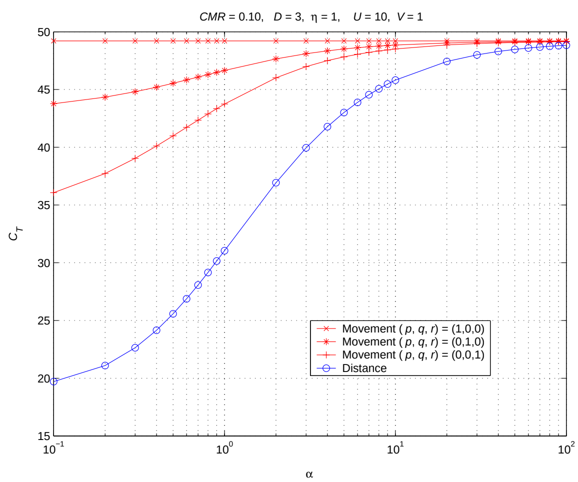

Fig. 9. Total cost= Location update + paging for $D = 3$, $\eta = 1$ –no selective paging–, U=10, V=1 and for a CMR equal to $\theta = 0, 10$.

the signaling load point of view. In addition to this results, we confirm the very well known fact that selective paging significantly reduces the paging signalling load on the common air interface. Therefore, in real cellular systems it is highly recommended the implementation of our proposal. We believe that its implementation in real cellular systems can be done in an easy manner.

Acknowledgments

This work has been financed by the *Ministerio de Educación y Ciencia (Spain)* under project numbers TEC2004-06437-C05-01 and TSI2007-66869-C02-02.

References

[1] T. Camp, J. Boleng, and V. Davies, "A survey of mobility models for ad hoc network research," *Wireless Communications and Mobile Computing*, vol. 2, pp. 483–502, August 2002.

[2] C. Bettsetter, H. Hartenstein, and X. Prez-Costa, "Stochsatic properties of the random waypoint mobility model," *Wireless Networks*, vol. 10, pp. 555–567, September 2004.

[3] A. Lombardo, S. Palazzo, and G. Schembra, "A comparison of adaptive location tracking schemes in personal communications networks," *International Journal of Wireless Information Networks*, vol. 7, no. 2, pp. 79–89, 2000.

[4] T. Tung and A. Jamalipour, "Adaptive location management strategy to the distance-based location update technique for cellular networks," in *Wireless Communications and Networking Conference*, vol. 1, pp. 172–176, March 2004.

[5] P. Garcia-Escalle, V. Casares-Giner, and J. Mataix-Oltra, "Reducing location update and paging costs in a PCS network," *IEEE Transactions on Wireless Communications*, vol. 1, pp. 200–209, January 2002.

[6] A. Bar-Noy, I. Kessler, and M. Sidi, "Mobile users: To update or not to update?," in *Proceedings of INFOCOM'94*, pp. 570–576, June 1994.

[7] A. Bar-Noy, I. Kessler, and M. Sidi, "Mobile users: to update or not to update?," *Wireless Communications Journal*, vol. 1, pp. 175–185, July 1995.

[8] R. Vidal, J. Paradells, and J. Casademont, "Labelling mechanism to support distance-based dynamic location updating in cellular networks," *IEE Electronics Letters*, vol. 39, October 2003.

[9] V. Casares-Giner and P. Garcia-Escalle, "On movement-based mobility tracking strategy- A general framework," in *Proceedings of the IEEE Wireless Communications and Networking Conference*, March 2004.

[10] J. S. M. Ho and I. F. Akyildiz, "Mobile user location update and paging under delay constraints," *Wireless Networks*, vol. 1, pp. 413–425, December 1995.

[11] I. F. Akyildiz, J. S. M. Ho, and Y.-B. Lin, "Movement-based location update and selective paging for PCS networks," *IEEE/ACM Transactions on Networking*, vol. 4, pp. 629–638, August 1996.

[12] M. M. Zonoozi and P. Dassanayake, "User mobility modeling and characterization of mobility patterns," *IEEE Journal on Selected Areas in Communications*, vol. 15, pp. 1239–1252, September 1997.

[13] I. Martinez-Arrue, P. Garcia-Escalle, and V. Casares-Giner, "Mobile user location management under a random-directional mobility pattern for PCS networks," in *Third International Working Conference on Performance Modelling and Evaluation of Heterogeneous Networks (HET-NET's)*, pp. P28/1–P28/10, July 2005.

[14] V. Casares-Giner and J. Mataix-Oltra, "On movement-based mobility tracking strategy - an enhanced version," *IEEE Communications Letters*, vol. 2, pp. 45–47, February 1998.