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Location Management Cost Reduction Using Adaptive Velocity-movement Based Scheme

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ABSTRAK

Rangkaian komunikasi peribadi tanpa wayar (PCN) terdiri daripada sebuah rangkaian tanpa wayar tetap dan sejumlah terminal bergerak. Terminal-terminal ini bebas untuk bergerak dalam kawasan PCN tersebut tanpa gangguan servis. Setiap terminal dengan tempoh tertentu akan melaporkan lokasi masing-masing kepada rangkaian melalui proses yang dipanggil kemas kini (atau pendaftaran) lokasi. Apabila panggilan tiba kepada sesuatu terminal bergerak, rangkaian akan menentukan lokasi sebenar terminal yang ditujukan melalui proses yang dipanggil pengeluian terminal. Satu masalah utama yang timbul dalam senario ini ialah kos yang bersangkutan dengan pengkeluian dan pendaftaran. Beberapa kertas kerja cuba mengurangkan kos tersebut melaui skema-skema baru bagi pengkeluian dan pendaftaran. Salah satu skema yang menarik telah dibentangkan oleh Wan dan Lin (1998) yang mempertimbangkan skema kelui dinamik berdasarkan pada informasi kelajuan masa-separa nyata bagi setiap pengguna bergerak. Ini membolehkan jangkaan yang lebih tepat dibuat terhadap lokasi pengguna apabila sesuatu panggilan diterima. Dalam kertas kerja ini, penulis mengubah skema yang dibentangkan oleh Wan dan Lin dengan mencipta sebuah jangka kelajuan mudah suai yang akan berubah mengikut kelajuan terminal bergerak dan menggunakan analisis yang sama kepada skema berdasarkan pergerakan. Kajian ini menunjukkan bahawa kaedah yang dicadangkan oleh Wan dan Lin memberikan keputusan yang lebih baik daripada yang dilaporkan, dan pendekatan yang dicadangkan penulis membantu mengurangkan jumlah kos secara drastik berbanding skema asal. Keputusan juga menunjukkan nilai ambang pergerakan dan unit kelajuan masa mudah suai, memberikan penjimatan kos yang signifikan bagi saiz-saiz sel yang berbeza pada kelajuan sama ada tinggi dan rendah.

ABSTRACT

Wireless personal communication networks (PCNs) consist of a fixed wireless network and a large number of mobile terminals. These terminals are free to travel within the PCN coverage area without service interruption. Each terminal periodically reports its location to the network by a process called location update (or registration). When a call arrives for a particular mobile terminal, the network will determine the exact location of the destination terminal by a process called terminal paging. One major problem that arises in this scenario is the cost associated with paging and registration. Several papers in the literature attempt to reduce the cost by devising new schemes for paging and registration. One of the many interesting schemes was presented by Wan and

Lin (1998) that considers a dynamic paging scheme based on the semi-real time velocity information of an individual mobile user, which allows a more accurate prediction of the user location when a call arrives. In this paper, we modified the scheme presented by Wan and Lin by creating an adaptive velocity timer that changes according to the speed of the mobile and applies the same analysis to the movement-based scheme. The investigation shows that the proposed approach of Wan and Lin has better results than what was reported therein and our new approach helps reduce the total cost drastically compared to the original scheme. Results also show that the movement threshold and the adaptive velocity time unit, when they are adaptive, provide significant savings of cost under different cell sizes and velocities in high and low mobility systems.

Keywords: Paging cost, registration cost, location management, velocity, movement

INTRODUCTION

Current cellular networks such as Global Special Communications (GSM) partition their coverage area into a number of location areas (LAs). Each LA consists of a group of cells and each terminal reports its location to the network whenever it enters an LA. This reporting process is called location update. When an incoming call arrives, the network locates the mobile terminal by simultaneously polling all cells within the LA. This polling process is called terminal paging. Both the location update and the terminal paging processes require a certain amount of wireless bandwidth in addition to power consumption. As a result, costs are associated with both the location update and the terminal paging processes. It is clear that if each LA consists of only one cell, the network knows exactly the location of each terminal. In this case the cost of terminal paging is minimal. However, the cost of location update will be very high, as the terminal has to report its location whenever it enters a cell. A trade-off, therefore, exists between the location update cost and the terminal paging policy that can minimise the total cost. In this paper, it is proposed that the mobile terminal velocity is estimated in terms of velocity classes as opposed to the actual speed. Velocity classes' estimation greatly simplifies the computations and provides important robustness against the change of velocity (Wan and Lin 1998). It is also proposed that the network estimates to which velocity classes each mobile terminal belongs each time it updates. When a mobile terminal receives a call, the network checks its velocity classes, estimates how far it could go, and pages the candidate cells.

Most of the research work performed on paging and registration algorithms can be categorised into two approaches. The first one, called the group mobility approach, builds the paging and registration schemes on top of the system users' collective mobility pattern. The pattern is typically derived from the summary of statistical data collected by the system over time. A good example of this approach is the location area scheme used in current PCN systems (Rose 1996). These algorithms essentially used the mobility information about a group of users to estimate an individual user's movement (Narayanan and Widom 1995; Kim *et al.* 1996; Vudali 1996). It is not surprising that these algorithms lack accuracy in their paging prediction and result in a rather large paging zone. The second approach, called the profile approach, recognizes the inherent problem with the group mobility approach and tries to use individual user profile to solve mobility (Silva and Brazio 1996; Rose and Yates 1997; Jannink *et al.* 1996). However it brings in significant management overhead into the system. These schemes require the collection of individual user movement statistics, user profile compilation, periodic profile update, and large profile storage. They are fairly complex to implement and put a great burden on system resources and system operators. The paging process relies on the location information provided by the registration process (Lin *et al.* 2000; Lin 1997; Akyildiz *et al.* 1996; Kim *et al.* 1996). The cost of paging also depends on the cooperating registration scheme. Generally, the more accurate location information the registration provides, the less cells the system needs to page. However, accurate location information does incur higher overhead in the form of registration cost. Therefore, a balance between the paging and registration schemes is necessary to achieve cost reduction. There are several registration methods such as location area registration, time based registration, distance based registration, movement based registration, predictive distance based update scheme, selective location update scheme and profile based scheme. The paging schemes are classified into two major types; delay bound and non-delay bound schemes. Delay constrained strategies are further classified as blanket polling and sequential group paging. Non-delay constrained strategies are sequential paging and shortest-distance-first. Examples of these paging methods are velocity-paging scheme, blanket polling paging scheme, location area paging, selective paging, shortest distance first scheme, sequential paging scheme, and velocity paging scheme.

BASIC VELOCITY PAGING AND VELOCITY CLASSES

The velocity paging approach is based on the method used in Wan and Lin (1998) and captures the semi-real time mobility characteristics of the individual mobile to provide more accurate prediction of the paging area. The scheme in Wan and Lin (1998) avoids the overhead of maintaining complex profiles for mobile terminals but still reduces paging cost significantly. Our scheme extends the velocity-movement based model and extends it by making the velocity information adaptive and a function of each mobile speed class instead of a fixed number for all. Similar proposals that minimise the paging and registration cost by utilising motion information to provide an optimal based solution have been reported in the literature (Rose 1995; 1996; Rose and Yates 1995; 1997). The objective of all these proposals is, due to the large number of users in a wireless system, to make computation for each registration/paging fairly simple. In addition, the procedures of the scheme should be easy enough to allow actual implementation. Therefore, our proposed approach focuses on the reduction of the computation intensity and the algorithm complexity.

In this section we will briefly discuss the velocity paging scheme with the movement based registration method and define the velocity classes and the relation between the velocity classes index and the adaptive velocity time unit based on velocity classes and the movement registration schemes.

Estimation of Mobile Velocity and Classes

Once in movement based registration schemes, only a counter is required to keep track of the number of movement made. The velocity classes then can be defined by the number of movements made during a predetermined time period, namely Velocity Time Unit (VTU). For a basic velocity-paging scheme, only the speed of a mobile terminal is considered. Paging prediction is sensitive to velocity changes or measurement errors. For example, if the VTU is 10 minutes, the movement threshold (given number of cells crossed by mobile before registering again), m, is 3, and a mobile terminal registers in time, t equals 15 minutes, with velocity class index, V_{CI} of 2 (Wan and Lin 1998) where

$$V_{CI} = (m/t) * VTU \tag{1}$$

In our modified scheme, we propose making the *VTU* timer adaptive and according to the velocity of the mobile itself. One way of doing this is as follows:

a) The parameter t is basically the interval between two successive registrations by the mobile and therefore, it relates directly to the velocity of the mobile as a function of the distance traveled regardless of the exact movement pattern that the mobile has followed. If t decreases, it indicates that the mobile has increased its velocity and therefore it crossed m cells in time t. Therefore, t is basically the ratio between the distance traveled in terms of cells and the mobile velocity as follows:

$$t = \frac{2rm}{V_i} \tag{2}$$

where r is the cell radius, m is the movement threshold and V_i is the mobile actual speed. Knowing t would allow us to determine the velocity of the mobile and therefore we can determine its velocity class using Eq. (1).

b) By predetermining the velocity classes of the mobiles and by replacing t in Eq. (1) by Eq. (2), the *VTU* timer can be made adaptive and specific to each mobile velocity. Therefore, *VTU* is found as follows:

$$VTU = \frac{2rV_{CI}}{V_i} \tag{3}$$

ALGORITHM

In a movement based registration scheme, each mobile terminal keeps a counter of movements and increases it every time it moves to another cell. The mobile terminal registers its current location with the serving Visitor Location Registration (VLR). In order to cooperate with the modified velocity-paging scheme proposed, the following attributes are needed in the mobile's VLR record:

1) Last known location
2) The velocity class index
3) Last registration time

Accordingly, the following additional steps should be performed in the movement based registration procedure:

a) Calçulate the time span, *t*, since the last registration.
b) When *t* is known, estimate the V_{cr}, V_i and VTU_i of the mobile terminal using Eq. (1), (2) and (3).
c) Record the estimated V_{cr}, V_i and VTU_i in the VLR record, and update the last known location and the registration time.

When a call arrives to a standby mobile, the system will invoke the modified velocity paging mechanism:

1) The system asks the VLR for the mobile's velocity class index, its estimated velocity, its velocity time unit, its last known location, and its last registration time.
2) Assuming the mobile terminal remains in the same velocity class, the system calculates the maximum distance the mobile terminal could have traveled since the last registration. A candidate cell should be within this distance from the mobile's last known location.
3) The system identifies all the cells in the circular area by checking a system cell map and pages them.

ANALYTICAL MODEL

To evaluate our system analytically and to produce relevant cost measures, it is necessary to evaluate another system as a benchmark and compare it with our system. The most commonly used system in current cellular networks is the Location Area (LA) scheme where the cellular network is divided into clusters known as *LA*s and are made of several tiers of hexagonal cells. An example of a two-tier system for our proposed scehme is shown in *Fig. 1.* Note that in the figure the size and the number of tiers in the network are determined adaptively. The movement threshold *m* in our system will decide the number of tiers and therefore the size of the location areas. Some necessary assumptions are needed in order to evaluate the two systems such as the following:

- All cells are hexagons and of the same size.
- Registrations are performed when a mobile terminal is powered up and powered down.
- Movement classes similar to those described in Tabbane (1995) and Lam *et al.* (1996) are used to describe the mobility characteristic of user groups. Each movement class consists of a normal distribution of velocity and the percentage of total users in the class as given in Table 1.

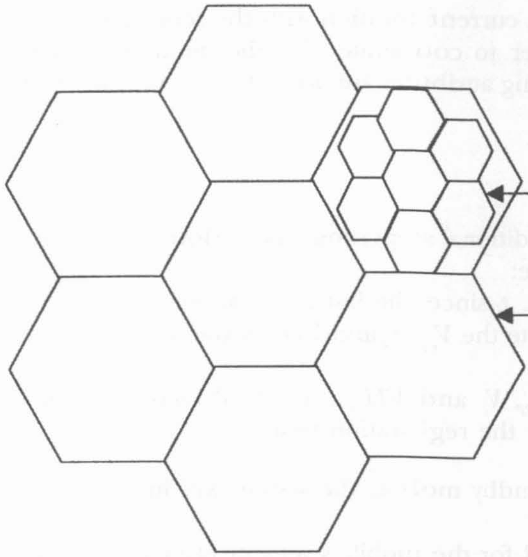

Fig. 1: Example of 2-tier model of the proposed modified velocity paging and restration scheme

TABLE 1
Movement classes for a high mobility system in confidence interval presentation

Movement Class	Velocity (km/hr) (95%CI)	User Percentage
MC_1	0 - 10	25%
MC_2	35 - 80	74%
MC_3	110 - 150	1%

Location Area Scheme (LA)

Now given N movement classes, MC_1, MC_2,.. MC_N, each movement class, MC_i has its normal distribution of velocity, $N(V_i, \delta_i)$, and its user percentage, PMC_i. Basically a circular area covers approximately m tiers of cells with radius R_m. It is easy to prove that the m^{th} tier contains $6m$ cells. Therefore, the number of cells within and including the m^{th} tier is (Tabbane 1995):

$$N_m = 3m(m+1)+1 \quad (4)$$

Let the number of moves necessary for mobile terminal to travel from one cell to another be m. Since the radius of equivalent circular area, which has the same area as the hexagonal cells, is (Tabbane 1995).

$$R_m = \sqrt{N_m r_{eq}} \quad (5)$$

Then the radius of an equivalent circle, which has the same area as a hexagonal cell of side length r, is (Tabbane 1995):

$$r_{eq} = \sqrt{\frac{3\sqrt{3}}{2\pi}r} \tag{6}$$

- Paging cost

  The total system paging cost is given by Wan and Lin (1998)

$$C_{pageTotal} = S\alpha N_m C_{page} \tag{7}$$

where

S is the total number of calls attempted per hour in the system
α is the percentage of mobile terminating calls
N_m is the average number of cells per location area
C_{page} is the paging unit cost for the LA scheme

- Registration cost

  The total registration cost is given by Wan and Lin (1998) which was derived from Tabbane (1995) and Thomas *et al.* (1998) is:

$$C_{regTotal} = N_{Sub}\left(\beta - \frac{S}{N_{Sub}}T_{call}\right)\frac{8\sum_{i=1}^{N}(V_i PMC_i)}{3\pi r\sqrt{N_m}}C_{reg} \tag{8}$$

where

S is the total number of calls attempted per hour in the system
N_{Sub} is the number of subscribers in the system
β is the power up probability for a mobile terminal
T_{call} is the average call duration
C_{reg} is the unit registration cost for the LA scheme

Modified velocity paging scheme (MVP)

- Paging cost of MVP

  The total system paging cost for the modified velocity-paging scheme is (Wan and Lin 1998)

$$C_{pageTotal} = C'_{page}\, S\alpha \sum_{i=1}^{N}\left(N_{E[d_i]} PMC_i\right) \tag{9}$$

where

α is the percentage of mobile terminating calls
PMC_i is the user percentage of mobility class i

C'_{page} is the paging unit cost for the *MPV* scheme
S is the total number of calls attempted per hour in the system
$N_{E[d_i]}$ is the average number of moves made by a mobile MC_i of class i, in time t_i, and is given by (Wan and Lin 1998)

$$N_{E[d_i]} = min\left(\frac{VTU_i\sqrt{12\frac{V_i^2+\delta_i^2}{r_{eq}^2}-3-3}}{6}\frac{t_i}{VTU_i}, m \right) \tag{10}$$

where
m is the movement threshold
VTU_i is the velocity time unit for mobile MC_i found using Eq. (3)
V_i and δ_i is the mean and variance of the normal distribution for MC_i, respectively

- Registration Cost
The total registration cost of the MPV scheme is (Lin *et al.* 2000):

$$C_{regTotal} = N_{Sub}\left(\beta - \frac{S}{N_{Sub}}T_{call}\right)C'_{reg}\frac{\sum_{i=1}^{N}\left(\frac{\sqrt{12\frac{V_i^2+\delta_i^2}{r_{eq}^2}PMC_i}}{6}\right)}{m} \tag{11}$$

where

C'_{reg} is the unit cost for registration in the *MPV* scheme.

NUMERICAL RESULTS

The velocity classes similar to those used in Wan and Lin (1998) are assumed for our results in order to facilitate comparison. The call arrivals are assumed to be Poisson processes and the registration activities will depend on the movements of the mobile terminals and the registration method used. Due to the extra computation incurred by the modified velocity-paging scheme, we used the conservative assumption of 10% cost increase for our scheme over the BVP and LA schemes as done in Wan and Lin (1998). Two systems, one with high mobility and the other with low mobility, were used in the study. The different mobility pattern in each system is modeled by a different set of movement classes. Tables 1 and 2 show the movement classes for the high and low mobility systems used in Wan and Lin (1998), respectively. The rest of the parameters are given in Table 3.

TABLE 2
Movement classes for a low mobility system
in confidence interval presentation

Movement class	Velocity (km/hr) (95%CI)	User percentage
MC1	0 - 10	50%
MC2	15 - 35	48%
MC3	40 - 80	2%

TABLE 3
Parameter values for performance comparison study

Parameter	Value	Comment
S	100000 calls per hour	Calls attempted in the system
α	30%	Mobile terminating call percentage
N_{Sub}	150,000	Number of subscribers
β	80%	Power up probability
T_{call}	2 minutes	Average call duration
VTU	10 minutes	Velocity time unite
C'_{page}	1	Unit paging cost for LA Scheme
C'_{reg}	2	Unit registration cost for LA Scheme
C_{page}	1.1	Unit paging cost for BVP Scheme
C_{reg}	2.2	Unit registration cost for BVP Scheme
m	3	Movement threshold

We have evaluated our modified velocity paging (*MVP*) scheme against the basic velocity paging (BVP) and LA schemes presented in Wan and Lin (1998). All the results of the combined costs of paging and registration for the two schemes are plotted against the cell radius (r) in km in *Figs. 2* and *3* for both mobility systems, high and low, respectively. It was highlighted in Wan and Lin (1998) that the *BVP* scheme tends to have a better performance compared to *LA* scheme except when 1.5 km < r < 2.4 km. This is actually not true as illustrated by our results in *Fig. 2*. In fact the *BVP* scheme has a better performance in terms of cost savings compared to *LA* scheme for any value of r > 2 km. These results are more accurate than those presented in Wan and Lin (1998) because the average paging zone size in the *BVP* scheme comes close to the average location area size in this range (r < 2 km). The reduction in paging zone size cannot compensate the assumed 10% increase in unit costs and, thus, results in higher cost for the BVP scheme. What is more interesting is that our *MVP* scheme has a better performance record compared to *LA* and *BVP* schemes even for a cell radius size of r > 1 km. As for the bigger paging zone sizes, our *MVP* scheme maintains the lowest total cost.

Our modified scheme concentrates on making the velocity time unit (*VTU*) timer adaptive and, thus as our analysis shows, the reduction is in the paging

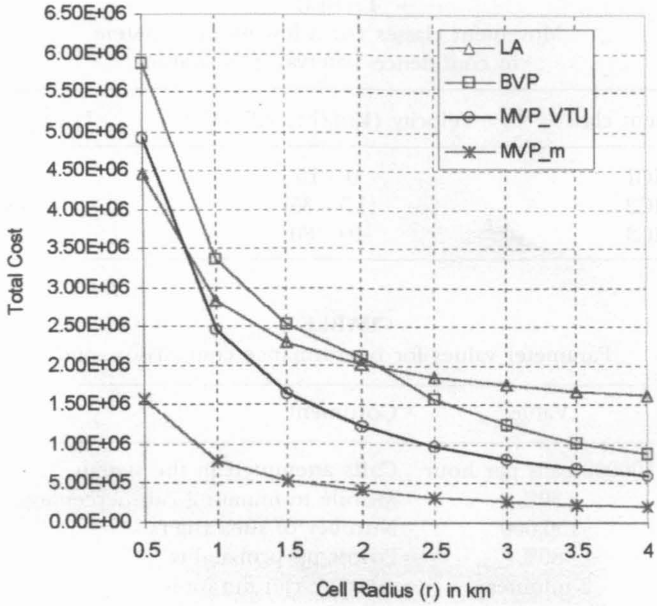

Fig. 2: Total system cost for high mobility class

cost only. Nevertheless, the improvement is very significant with no extra computational complexity on the implementation algorithm. The only difference between the *BVP* algorithm and the *MVP* algorithm is that with the *MVP*, the system will have to calculate the *VTU* parameter for every to-be-paged mobile, where as in the *BVP* scheme it considers a fixed value for the *VTU* parameter before it carries on the rest of the computations. Similar results are obtained for the low mobility system illustrated in *Fig. 3* although in this case, our *MVP* system outperforms both *LA* and *BVP* systems for any paging zone size.

To further improve our system, one should consider making the movement threshold, *m*, adaptive as well as a function of the mobile velocity. We carried out a simulation work based on our theoretical study to understand the effect of the movement threshold on the total cost of the system and the results are presented in *Fig. 4*. The figure depicts the results of the total cost of the *MVP* scheme for several movement thresholds, *m*. It is interesting to note that for low to average estimated mobile velocities, V_i, an $m = 4$ value tends to give the lowest total cost for the system. And for the higher velocities, an $m = 10$ value keeps the *MVP* scheme at low total cost range. Keeping this in mind, we made the assumption of making the movement threshold toggle between two values for low and high mobility ranges. Thus, $m = 4$ if 0 km/hr < V_i < 70 km/hr, and $m = 10$ for V_i >70km/hr. Then we evaluated our *MVP_VTU* system with the new adaptive movement threshold and the results are plotted again in Figs. 2 and 3 and named *MVP_m* system to differentiate between the *MVP_VTU* that assumes a fixed value of m =3 and the new *MVP_m* that uses both adaptive *VTU* and *m* values, for high and low mobility systems. The results illustrate the effect

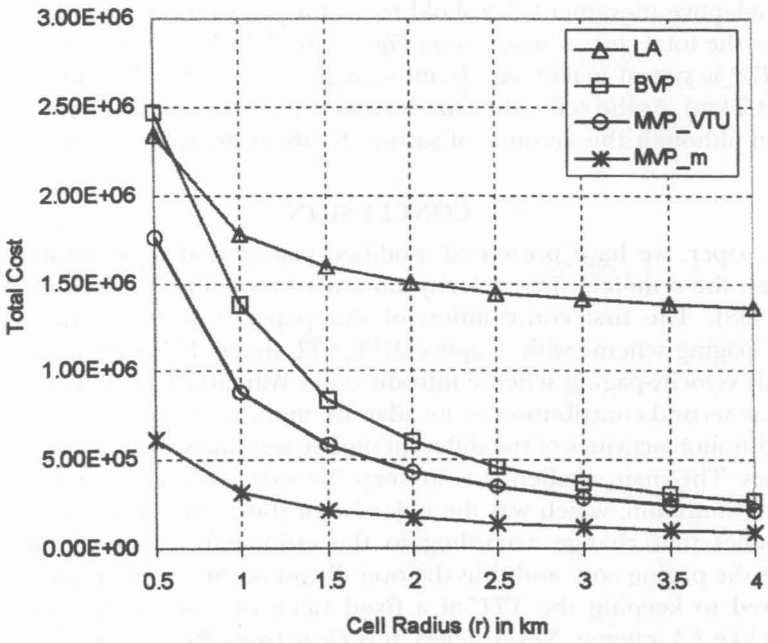

Fig. 3: Total system cost for low mobility class

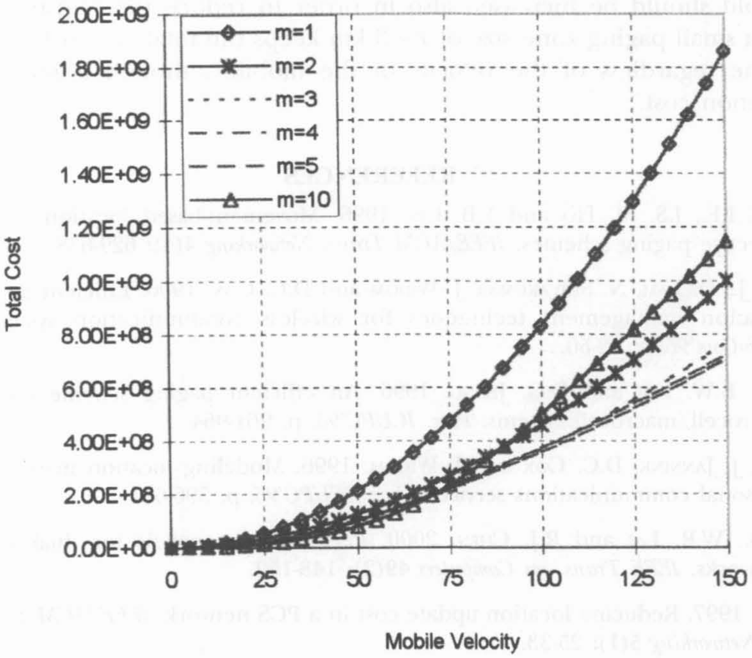

Fig. 4: Effect of movement threshold on total cost

of the adaptive movement threshold m on the registration cost (*MVP_m*) and, thus, on the total cost as apparent in *Figs. 2* and *3* for high and mobility systems. The *MVP_m* system makes significant savings for a paging zone radius of small size ($r < 2$ km). As the cell radius size increases, the total cost maintains the lowest position although the amount of savings tends to decrease as r increases.

CONCLUSION

In this paper, we have presented modified paging and registrations schemes based on the semi-real time velocity-movement model introduced in Wan and Lin (1998). The first contribution of this paper is the proposed modified velocity-paging scheme with adaptive *MPV_VTU* timer. This system outperforms the basic velocity-paging scheme introduced in Wan and Lin (1998) in terms of cost. The second contribution is the adaptive movement threshold that reduces the registration activities of the different mobile terminals roaming with different velocities. The main challenge is to keep the extra computation and network cost at a minimum, which was the objective of this paper. The use of adaptive *VTU* values that change according to the estimated velocity of the mobile reduces the paging cost, and thus the overall cost of the system, drastically when compared to keeping the *VTU* at a fixed value or when using conventional systems like *LA* scheme. Nevertheless, it is clear from the presented results that a small movement threshold tends to reduce the total cost for low mobile velocity regardless of the cell size. As the velocity increases, the movement threshold should be increased also in order to reduce the registration cost. Using a small paging zone size of $r = 3$ km keeps the total cost at low levels all the time regardless of the velocity of the mobile although it increases the registration cost.

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