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Adaptive profile strategy for tracking mobile users

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Abstract

Location management schemes have been proposed to reduce the signal cost for tracking users in a cellular network. The profile based strategies (PBS) have reduced significantly the cost of paging and updates under mobility assumptions. If these assumptions are not accomplished, the performance of these strategies may be very poor. A proposal of a dynamic PBS adaptable to uncertain users is presented. Which takes advantage of different behavior patterns (movement and incoming call), even when they are not fully respected by users.

Key words: location tracking, location management, update, paging, PBS.

Estrategia adaptativa basada en perfiles para el seguimiento de usuarios móviles

Resumen

El alto costo para el seguimiento de los usuarios en una red celular ha motivado la aparición de esquemas de gestión de ubicación muy diversos. Las estrategias basadas en perfiles (PBS por sus siglas en inglés) reducen el costo de ubicación y actualización de la posición, siempre y cuando se cumplan algunos supuestos. Desafortunadamente si estos supuestos no se cumplen el desempeño de estas estrategias es muy bajo. Este trabajo propone una estrategia PBS adaptativa para usuarios con perfil incierto. Dicha propuesta se aprovecha de distintos patrones de comportamiento (llamadas y movimiento) aun cuando éstos no sean completamente respetados por los usuarios.

Palabras clave: gestión de ubicación, actualización, localización, PBS.

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Introduction

User's mobility is inherent to cellular networks. In such context to find a user in the network and to deliver a call is a costly process. The traffic generated to complete this process is often bigger than the traffic generated for the voice calls themselves (Tabbane, 1997).

There exists two basic and mutually opposite strategies to track a user in a network: *update* and *paging*. Updating is the process executed by the Mobile Station (MS) to inform the network its location in the system. Once a MS is associated to a new Base Station (BS), it generates an update message to tell the system its new position. On the other hand, paging is the process executed by the network when it ignores the current location of a user and the system needs to place a call to him. At this moment, the system sends a polling signal to every BS in the system to locate the user. Between the two extremes (only-update and only-paging) there is a huge range of possibilities to minimize the cost of finding a user.

Today, the World assists to an explosion on the penetration of cell devices on the market. To deal with this increase on the number of devices to be serviced, operators have to reduce the cells' size in order to reuse frequencies and by that to continuous to increase number of customers. Keeping track of every active device in the network with smaller cells and a larger number of users becomes very expensive. In an update strategy the number of update messages becomes larger and larger; and in a paging strategy the number of BS to inquire increases dramatically also. Dense urban areas have been reported where the update rate is ten times the call rate (Tabbane, 1997). This situation is getting worse with the introduction of new services like SMS or new IP based services.

This article presents a new approach to alleviate the cost of locating a user in a cellular network. The proposal uses basic user profile information to adjust the strategy of implementation when tracking a user. Rather than using complex and difficult to obtain/calculate information, this strategy classifies users according to simple (easy to obtain or calculate) parameters. The strategy to locate or track a user changes based on the system's classification. We show that just by adjusting the selected strategy we can decrease the cost of locating a user, even if the actual user's behavior doesn't follow the expected behavior (category) (Dominguez, 2007).

This paper is organized as follow: first we review the location process in a GSM network and we present improvements found in related works to this process. Then we introduce our proposal followed by an analytical analysis and a simulation test to demonstrate its verification. Finally we present our conclusions.

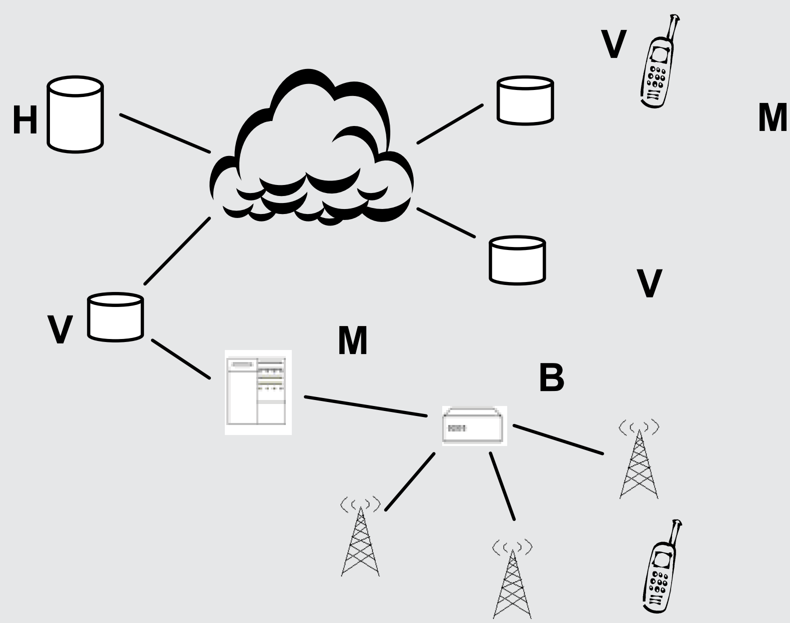
Location on GSM

GSM is the predominant cellular system in the world. Because of this predominance, its location tracking strategy is the basis for new proposals aiming to reduce the location associated costs.

The GSM architecture defines Location Areas (LA) to manage user tracking. LA is a group of adjacent cells, such as MS doesn't update its location on the system when moving around cells within LA. Only when a MS crosses a LA boundary, entering in a new LA, the MS performs a location update. When the network needs to locate a user, the system already knows its current LA, but it doesn't know on which BS the user is currently associated. To identify such BS, the system broadcast a paging message to all cells within the LA. This strategy reduces the number of updates (not at every BS change but only at LA change) and limits the number of cells to be broadcasted to those belonging to the current LA).

Figure 1 shows the GSM architecture. It uses a two level repository to support information location: there is a unique and centralized HLR (Home Location Register) and multiple VLRs (Visitor Location Register). The HLR stores the user's profile (subscription information) and it keeps the VLR where the user is currently registered. Each VLR keeps the profile of users in its zone and the LA where they are located. The MSC (Mobile Switching Center) performs switching functions and handles control functions. The BSC (Base Station Controller) controls the BSs handling the frequency reuse and handoff between cells. When the number of updates and paging increase in a network, so it does the signaling between these different components. For example, when placing a call between MSs on different VLRs, it is necessary to read the HLR to find the current destination VLR and then read this VLR to know the LA where the destination MS is located.

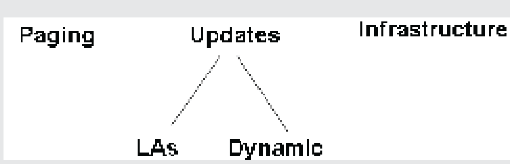
Figure 1. GSM Architecture



Related Works

To summarize the big number of undergoing research on location tracking, we classify these strategies as is shown in Figure 2.

Figure 2. Strategies classification



Paging strategies (Lee *et al*, 2004; Krishnamachari *et al*, 2004; Wang *et al*, 2001; Akildiz & Wang, 2004; Xiao, 2003; Mao, 2004) focus on how to locate a user in a specific area. Update strategies work on the fundamental question of when a MS must generate an update. Both strategies limit their scope to the MS. On the contrary, infrastructure strategies [Nar *et al*, 2002; Shivakumar *et al*., 1997; Khrisna, 1994; Jain & Lin, 1995; Pang *et al*, 2001 Jain & Lin, 1994; Wang & Huey, 2004) work on the GSM architecture itself and propose changes on the way the communication is achieved between components. Their goal is to reduce the signaling information between these components.

Update strategies may be also divided on those limited by LAs boundaries and those not limited by these restrictions. The first ones focus their work on optimization of the size and distribution of LAs [Tabbane, 1997; Krishnamachari *et al*, 2004; Varsamopouos & Gupta, 2004; Gondim, 1996), whereas in dynamic strategies the MS determines whether to generate a location update based on certain criteria, i.e. time, distance or movement. Amotz Bar-Noy *et al* [1994] show that using distance as the criteria to generate update exhibits the best performances but its implementation is very difficult when compared to time and movement methods. Naor [2003] proposes a practical implementation of a distance scheme.

Another axis to study these strategies is based on the use of the behavior pattern of users [Tabbane, 1997]. Profile Based Strategies (PBS) reduces significantly the number of updates and paging in a cellular network by using the repetitive patterns of user to predict their possible location. These strategies [Tabbane, 1995; Francois *et al*, 2004; Wang et al, 2000; Tung & Jamalipor, 2004; Pollini & Lin, 1997; Quintero, 2005] assign a probability of residence to each cell where a user is prone to be located. Then when the network needs to locate that user, it follows the order given by these probabilities. If a MS moves out its profile, it generates a location update and the new cells are included in the list of probable cells. The time of the last explicit update must be considered to adapt the strategy for short time events [Tabbane, 1995; Francois *et al*, 2004]. PBS can be combined with other strategies like the use of pointers to improve its performance. PBS has proved to be an efficient location tracking method; problems arise when users do not follow a deterministic behavior [Naor, 2003].

Another idea that has been explored to reduce the location tracking cost is to use the incoming call pattern of a user. However, its use is very limited (a probabilistic function) and we did not find attempts to include such criteria as part of a profile based strategy.

An adaptive profile based strategy

When starting this work we fixed some objectives:

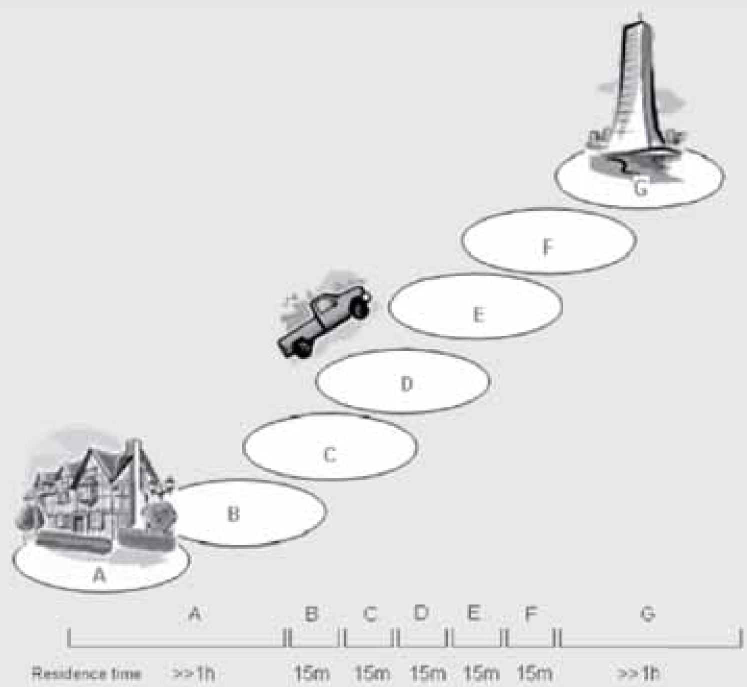
- It must reduce the number of paging and updates needed to locate a user in a cellular network.
- It must exploit user's repetitive pattern behavior. If the assumptions about user's mobility are correct, paging and update rates must be reduced. This is a profile based strategy.
- It must be realistic to implement. We want something as light as possible to increase their chances to be implemented. We discard complex algorithms and information difficult to obtain.
- As users change their mobility pattern, so the strategy must change. The solution must adapt its strategy when a user does not follow its expected behavior.

We classify users based on their mobility patterns in two categories: business people and taxi drivers. Business people are those with short travels between their two main points of residence: office and home. On the other hand, taxi drivers do not have a deterministic profile. This classification is different from that of Pollini [1997] because randomness is a Boolean issue for us: a user experiences a deterministic behavior or he does not; and this behavior may change with time. In a realistic scenario, users are not 100% business people, nor taxi drivers. Users may change their behavior depending on the hour of the day (taxi drivers sleep also).

Similarly to PBS, when a business users moves along its expected profile, he does not generate an update to the system. When the system needs to locate him, it pages the cells stored in his profile. Location updates are generated only when the user goes out his profile. As long as the user remains outside his profile, he will be considered like a taxi driver. Once he returns to a cell in his profile, he will generate a new location update message and he will be reclassified as a business people.

A known issue of PBS is the memory requirement to store the users' profiles. A typical profile maintains the expected entry time for each visited cell but ignores sequential between cells. As shown in Figure 3, when a user is moving between two points of interest (e.g. from home to work), the residence time is much more short at the cells on the path between the source cell and the destination cell that the residence time at the cells of interest.

Figure 3. Route PBS scheme



The cell where the residence time is significant is called camped. Otherwise is called on-route. Because the residence time in the on-route cells is very short, if a call delivery is in process the paging in the expected cell would be very imprecise. The profile must be saved based on the user routes instead cell per cell information. When the route is too long could be possible to generate an update if the paging cost is higher in the profile vs. the location update procedure (figures 4 and 5 illustrate the difference between the classical BPS strategy and our proposed scheme).

Figure 4. Classical PBS profile

idUser	*idCell*	ExpectedEntryTime
42648512369	A	7:30PM
42648512369	B	7:00AM
42648512369	C	7:15AM
42648512369	D	7:30AM
42648512369	E	7:45AM
42648512369	F	8:00AM
42648512369	G	8:15AM
42648512369	I	6:30PM
42648512369	J	7:00PM

Figure 5. Proposed PBS profile

idUser	*startCell*	*expectedExitTime*	*endCell*	*expectedEntryTime*	*Route*
42648512369	A	7:00AM	G	8:15AM	BCDEF
42648512369	G	6:00PM	A	7:30PM	FIJCB

For the on-route profile, the system uses profile information to compute the most appropriate cell to start paging. In the example, it can uses information on the table of Figure 4 to determine that at 8:10 it is wiser to start paging at cell F. If the user is not at cell F, the system should continuous paging around cell F, to other cells within the route (i.e. cells G and E, then cell D and C, and finally B and A before broadcasting).

Taxi drivers do not have a deterministic profile. They move all around a city with no camped cells. Because of this, it is very expensive to deliver a call to such users. The best approach in this case is to take into account the incoming pattern call to reduce the number of location update events while increasing the chance of knowing the current user's location when a call needs to be delivered. Taxi drivers generate a lot of location updates events because of their high mobility. We define an incoming calls pattern and limit these events to be generated only when the probability for this user to receive a call is high. The basic idea is to avoid updates when the probability to receive a call is below a threshold; and to avoid paging large areas when the probability to receive a call is high.

We classify users in three categories based on their incoming calls rate:

Receptor users: high incoming calls rate. The probability of needing a call delivery to this user is high. In this case it is cheaper to generate an update before the incoming call arrives than paging a large area to try to find the user among cells. Users classified as receptors generate location updates as they move along the cells. Explicit updates may be replaced by implicit updates every time the user place a call.

Apathetic users: very low incoming calls rate. The probability of receiving a call is low. For this kind of users it is better to eventually look up in a large number of cells than frequently updating its location to the system.

Uncertain users: they are not receptors, nor apathetic. They do not have clear incoming calls pattern.

The category assigned to a user varies on time and the call arrival probability is inspired on that of Akyldiz et al, [1995]: an incoming call counter is used to classify users. The counter is reset every period of time (periods may be of one hour, three hours or one day).

We propose a dynamic location update based on movements for taxi driver users. It is possible to use another kind of strategies [Naor, 2003], but we will show that the movement strategy is simple and good enough for our purpose. Rather than having a fixed number of movements, we will set up the threshold to launch the update based on the incoming call category for the user. Users classified as receptors will have the smallest value for this threshold. Users classified as apathetic will have the biggest threshold. Uncertain user will take a value in the middle. Once the MS has determined its category (a simple operation), what the MS has to do is to count the number of crossed cells, compare it with its threshold, and if greater, generate a location update.

If the user is reported in the system like a taxi driver, the system searches the user with an expanding ring search from the last reported cell.

Analytical model

The total cost of our strategy is based on the user's mobility and call rates, and it is given by [Lee & Chang, 2001; Quintero, 2005]:

$$C = \mu U + \lambda S$$

Where:

μ is average number of cell changes per unit time

λ is average number of calls to a MS per unit time

U is the cost of update procedure

S is the cost of searching procedure

And λ / μ is the CMR (Call Mobility Ratio)

The next nomenclature is used for explain costs:

P_{msc} : Cost of processing a message in the MSC

$M_{msc\text{-}vlr}$: Cost of send a message between the MSC and the VLR

$M_{vlr\text{-}hlr}$: Cost of send a message between the VLR and the HLR

$P_{msc\text{-}vlr}$: Cost of send the user profile between the MSC and the VLR

Q_{vlr} : Cost of query the VLR

Q_{hlr} : Cost of query the HLR

U_{vlr} : Cost of update the VLR

U_{hlr} : Cost of update the HLR

$Q_{profile}$: Cost of query the user profile

$S_{profile}$: Cost of a sequential search in the profile

S_{ers} : Cost of a expanding ring search

P_{cell} : Cost of page a cell

The search cost in our strategy depends on the user mobility classification. Let *p* be the probability that user has a business people behavior. Then 1-*p* is the probability of having a taxi driver behavior.

The search cost is: $S = pS_{bb} + (1-p)S_{tb}$,

Where:

S_{bb} is the search cost when the user has a business people behavior,

S_{tb} is the search cost for a taxi driver behavior.

The search cost is different if the MS is in the same served VLR. A one to one correspondence between the MSC and the VLR has been assumed for simplicity. Let *q* be the probability of finding the MS in the same VLR.

$$S_{bb} = qS_{bb1} + (1-q)S_{bb2}$$

$$S_{tb} = qS_{tb1} + (1-q)S_{tb2}$$

Where:

$$S_{bb1} = 2P_{msc} + 2M_{msc-vlr} + Q_{vlr} + Q_{profile} + S_{profile}$$

$$S_{bb2} = 3P_{msc} + 4M_{msc-vlr} + 2Q_{vlr} + Q_{hlr} + Q_{profile} + S_{profile}$$

$$S_{tb1} = 2P_{msc} + 2M_{msc-vlr} + Q_{vlr} + Q_{profile} + S_{ers}$$

$$S_{tb2} = 3P_{msc} + 4M_{msc-vlr} + 2Q_{vlr} + Q_{hlr} + Q_{profile} + S_{ers}$$

The search cost is:

$$S_{profile} = nP_{cell}$$

n is the number of cells in the profile paged to locate the user.

$$S_{ers} = P_{cell} \quad \text{for } n=1$$
$$= (6n-6)P_{cell} \quad \text{for } n>1$$

Where,

n is the number of rings to locate the user

The profile determination cost and the synchronization cost between the MS and the system are ignored.

$$U = qU_1 + (1-q)U_2$$

Where:

$$U_1 = P_{msc} + M_{msc-vlr} + Q_{vlr} + U_{profile}$$

$$U_2 = P_{msc} + M_{msc-vlr} + Q_{vlr} + M_{vlr-hlr} + U_{hlr} + P_{hlr-vlr} + U_{vlr} + U_{profile}$$

Simulation

The proposed scheme is evaluated in the Omnet ++ simulator. The proposed strategy is named Adaptative Profile (AdapProf) and it is comparable with standard strategies like full movement counter and location areas.

Parameters:

- Each cell has a ratio of 200 meters and has a normal user's distribution with a mean of 1500 and a standard deviation of 500.
- The simulation is done within a high mobility environment.
- We use six for the maximum range of on-route cells for business users.
- Speed (for taxi driver users):
- 60% use 6km/h, 20% use 20km/h, 20% use 40km/h.
- The threshold values for receptors, apathetic and uncertain users are respectively two, five and three. For simulation comparisons the selected movement counter is three and locations areas are made of nine cells.

All simulations were repeated several times and the obtained results were similar. The generated calls are 1'300.000 approximately.

Two opposite and basic strategies are implemented for strategy comparison. First, ideal strategies where all users have a business people behavior and always respect their profiles. This scenario is based only on the mobility profiles. The opposite scenario is when all the users have a taxis driver's behavior. This scenario uses only the incoming call pattern instead of the mobility profile. Figures 6 and 7 show the simulation result example of paging and updates for business people users. Similarly, Figures 8 and 9 show paging and updates for taxis drivers.

Figure 6. Number of cells paged for business people

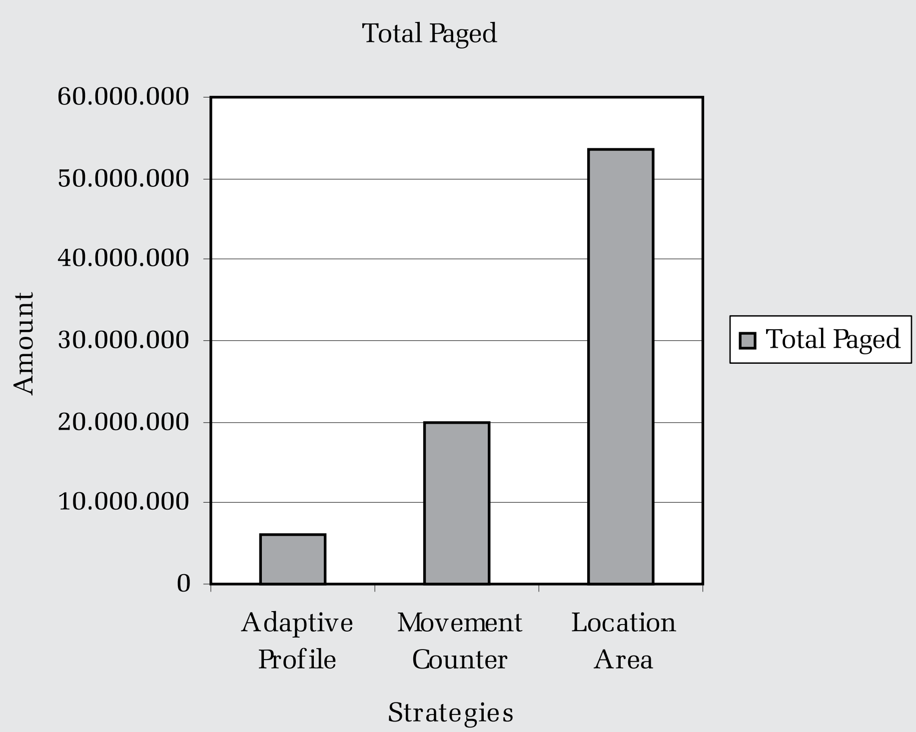


Figure 7. Number of updates for business people

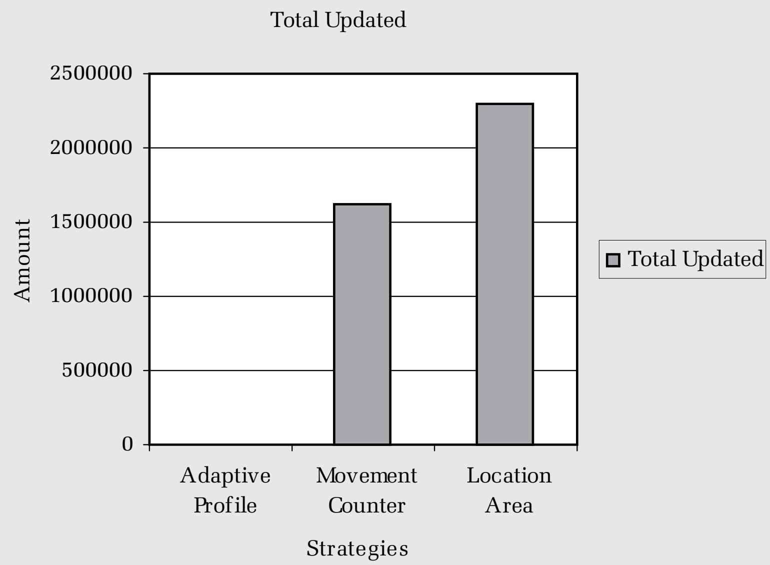


Figure 8. Number of cells paged for taxi drivers

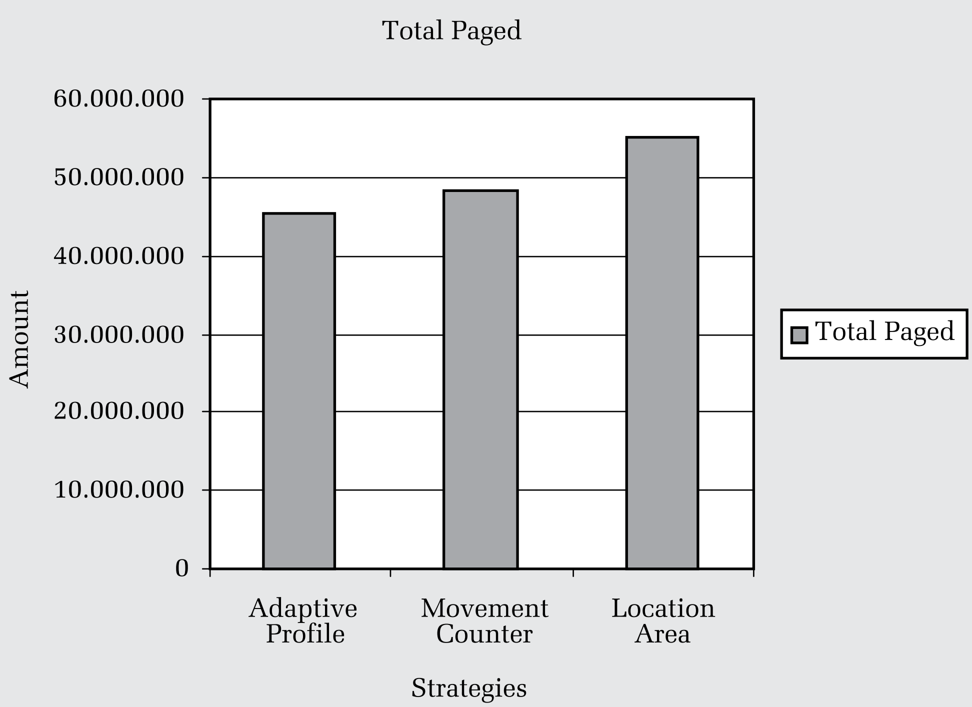
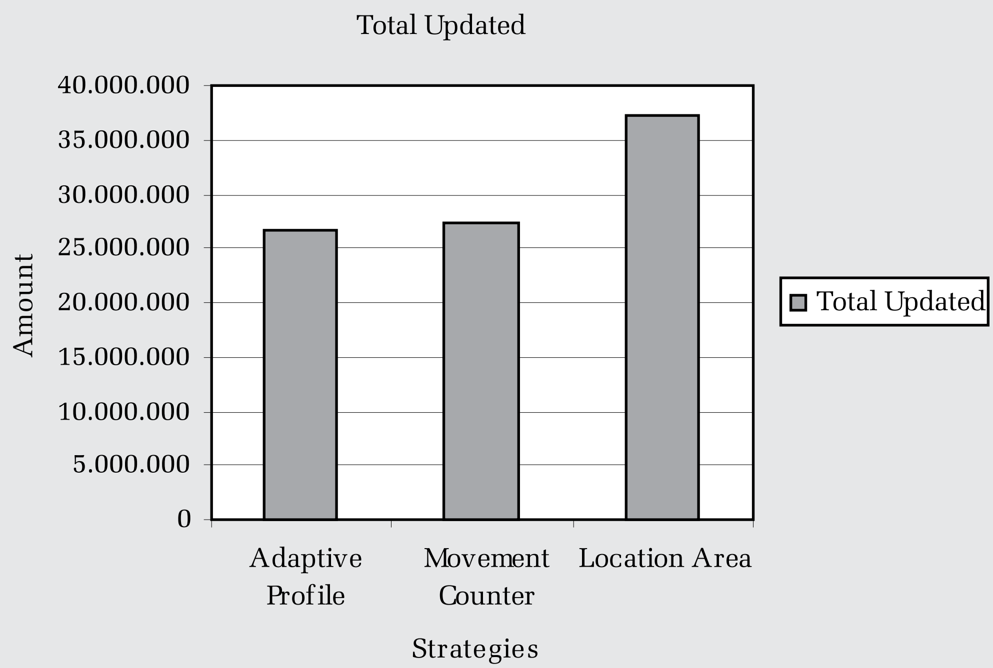


Figure 9. Number of updates for taxi drivers



The best performance is achieved when all users have a deterministic behavior (as expected in any PBS strategy). No updates are generated when all users have the business people behavior because they are always moving inside their profiles. On the contrary, the worst performance is presented when no mobility profile is identified (all user have a taxi drivers behavior). The performance in the latter case tends to be similar to the movement counter strategy. Nevertheless, the number of paging is reduced because it anticipates or delays the location update operation using the incoming call pattern (results showed up to 6% of reduction).

To study our proposal, we tested it using different proportions of business and taxi driver users and changing the rate of users who fulfill their profile. General results are shown in Figures 10 and 11. The *x* axis is the proportion of taxi driver users in the population. When the proportion of taxi driver users is zero, the proposed strategy is based only on movement profile. This scenario represents the ideal for a movement profile. In the simulation the proportion of business users who do not fulfill their profile varied. Strategy proposed has better performance if the business users fulfill their profiles at least 20% of time. Of course, the best performance is achieved when the business users always fulfill their profile. Another improvement can be achieved by dynamically adapting distance strategy to reduce the number of updates in the network.

Increasing the taxi driver proportion also increases the number of paging and updates in the system. This is inherent to the simulation because the taxi drivers do not have camped cells and they are continuously moving.

The strategy based in LAs had the worst performance in the simulation. If the LA size is shrunk to reduce the number of paging, the number of updates increases at the same rate. The opposite effect happens when the number of cells in the LA is increased.

Figure 10. Total paging

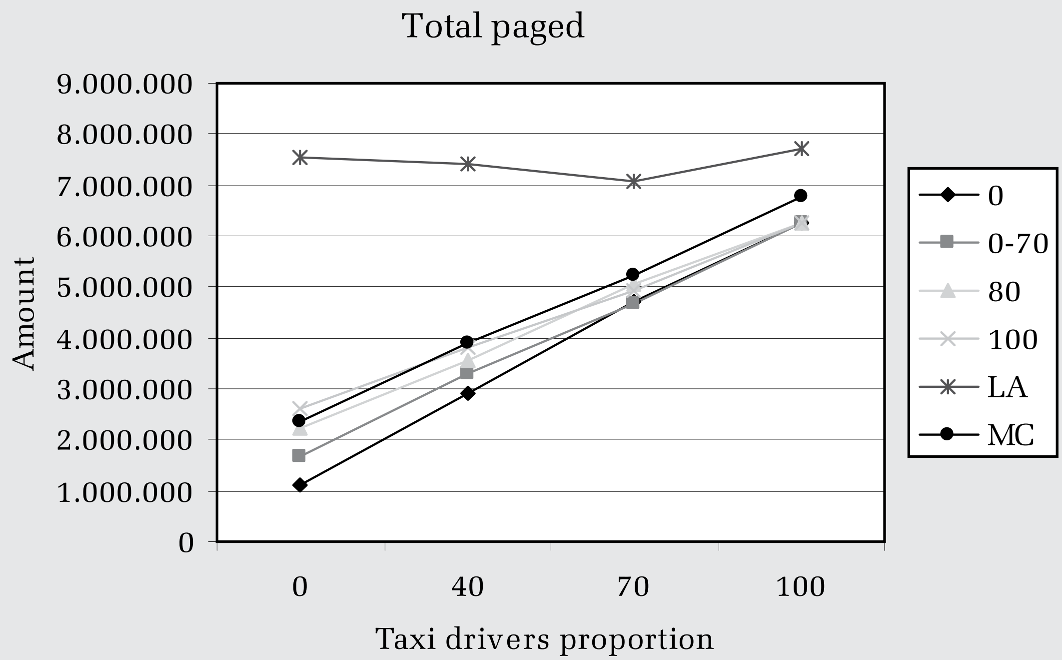
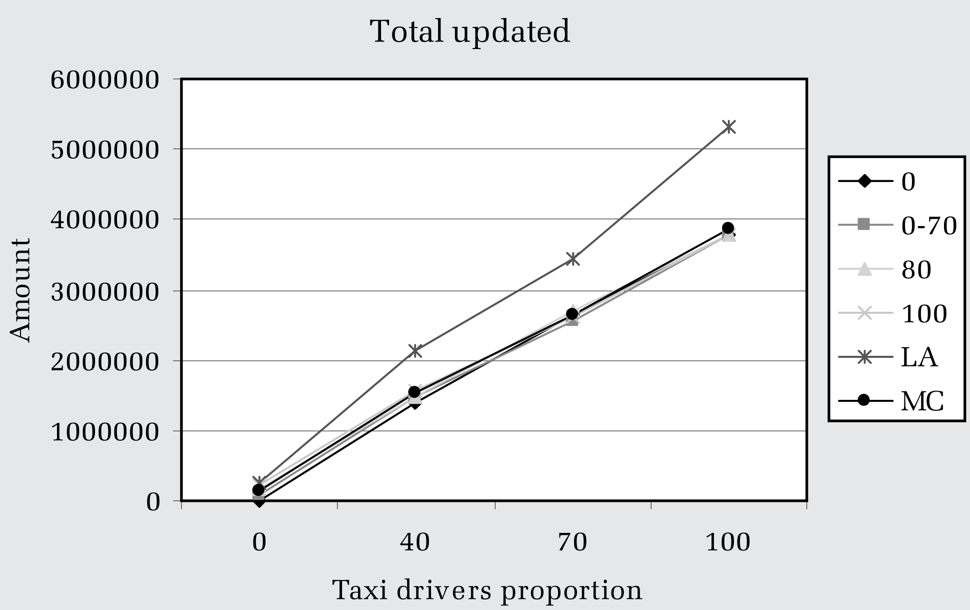


Figure 11. Total update



Conclusions

PBS reduce the cost of location tracking; these strategies must be adapted to take into account uncertain users by implementing compensatory mechanisms: users' routes must be considered to make profile storage more efficient and incoming call patterns may be used as this mechanism is easy to implement and may give accurate information about the timing to update information to the network.

We proposed an adaptive profile based strategy that it is easy to implement and that improves the location performance. It then may be part of a 3G system. It does not require patterns to be fully respected; however it takes advantage of existing patterns of behavior (mainly movement and incoming calls). Simulation results show that strategy proposed improves locations' costs even if patterns are followed only 20% of the time.

A final word on PBS is that their implementation must consider privacy issues. Many countries have established privacy acts that could limit the profile strategies when the user does not give his agreement explicitly.

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