Intelligent location tracking strategy in PCS

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Abstract: An alternative strategy (AS) for reducing location update signalling load has been proposed to improve the classical strategy (CS) used in the Global System for Mobile Communications (GSM). However, the AS is suitable only for long-term events and fixed movement tracks. Location tracking (paging) costs more when the mobile host (MH) changes movement habits or encounters short-term events. A novel method is proposed that aims to reduce signalling load resulting from location tracking in the above situations. The key idea is to take user recent movement information (called the paging information record) into account to determine which location area to page first. Performance evaluation has been conducted using a city area zone model that can model a realistic city area environment. Experimental results show that the method can reduce location management signalling costs by 14–55% and 6–39% compared to CS and AS, respectively. The overhead of the approach is the additional storage space required (for storing MH profiles and paging information records) and the additional processing time. However, the overhead is insignificant in terms of today's memory capacity and processor speed, and the reduction in signalling load makes more bandwidth available.

1 Introduction

Wireless communication is becoming cost-effective and is convenient for modern lifestyles. As a result, the population of mobile hosts (MH) has grown very rapidly in recent years. The location of an MH must be updated (registered) when the MH moves into a new coverage area so that the location management system can route a call to an MH at anytime. Third-generation mobile telecommunication systems [1], such as Universal Personal Telecommunications (UPT) and Universal Mobile Telecommunication Systems (UMTS), will come into service in the next century. However, this will bring very large MH populations and cause spectral congestion. To ease these problems, telecommunication systems need to employ small radio cells to reuse channels. However, this will cause a high rate of MH registration and is a heavy burden on the network.

In second generation mobile communication systems, such as the Global System for Mobile Communications (GSM) [2], location tracking (paging) [3] is achieved as follows. A network is divided into geographical areas, called 'location areas' (LA) and the location management system keeps track of the current LA of an MH. An LA may contain one or more cells. The location information is stored in the network database for location management. To maintain the consistency of location information, an update process is triggered whenever an MH crosses LA boundaries. When a call arrives, a query to the location database is conducted to obtain the location information of the called MH. Then the location management system pages all cells in the corresponding LA simultaneously.

In third generation mobile communication systems the same location management approaches may not be applicable. Owing to the fast growing population of MHs, the signalling load will become too heavy to handle location management, especially in densely populated areas. Several methods have been proposed for location management [4–6]. They are classified into two types. One type is based on algorithms and network architectures (memoryless), the other type is based on statistics to reflect the mobility behaviour of an MH (memory-based) [6]. The memory-based type relies on the information collection capability of the network. The proposed method belongs to the memory-based type. Based on the movement records of an MH during the last observation period, the location management system generates an LA list. When there is a call for the MH, the location management system takes the recent short-term events and the LA list into account to generate a new list called a 'paging list'. The LA list and the paging list are the two primary elements of the proposed location management method.

2 Existing methods

Existing location management strategies [9, 10] can be classified into two types, the memoryless and the memory-based. The main difference between these two types is that the memory-based type takes the MH movement history into account. History data of the MH is collected over several weeks [7]. The decisions to perform location update and location tracking are closely related to the mobility behaviour of an MH. The memoryless type is not concerned with MH movement history. In the following, we describe two representative location management methods, the classical strategy (CS) [7] and the alternative strategy (AS) [7, 8], one of each type.

2.1 Classical strategy (CS)

In CS [7] (used in such systems as GSM), the radio coverage area is partitioned into LAs, as shown in Fig. 1. Each LA consists of a group of cells (1, 2 or more cells). MH tracking is realised by updating the location whenever an MH leaves its current LA. The location management

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system always knows which LA an MH is in, and therefore when a call occurs for it, the system pages it over its current LA. The location area identifier (LAI) is recorded in a location pointer stored in a visitor location register (VLR). The address of the current VLR of an MH is kept in the home location register (HLR) of the MH. The major drawback of this method is the very high traffic generated by location updates for an MH that frequently changes its LA. If an MH receives very few calls, then the signalling traffic generated to track it is wasteful, and the ratio of the signalling cost to the number of processed calls is very high. This situation becomes severe with the growth of customer population and the very limited bandwidth capacity.

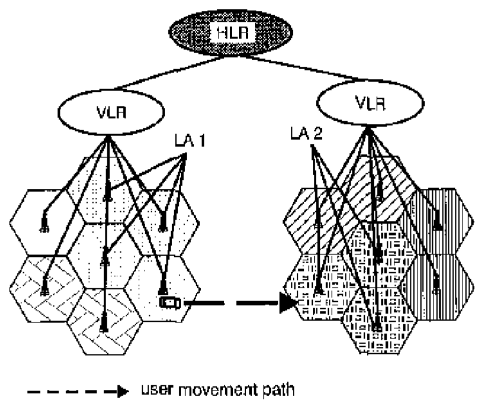

Fig. 1 *Classical strategy architecture*

2.2 Alternative strategy (AS)

The main goal of the AS [7, 8] is to reduce the location update (registration) cost by predicting users' movement patterns. It is based on user movement habits. Most people move along a 'usual' path. In this situation, an MH's movement path can be predicted to avoid most location updates. In this strategy, the system handles a profile for each user, where each user's mobility pattern is recorded. The structure and contents of this profile [7, 8] for an MH are as follows:

1. Over a period of time $[t_i, t_j]$, it crosses k LAs.

2. The profile consists of two elements: (a_f, p_f) with $1 \leq f \leq k$, where k is the number of LAs. a_f is the identifier of the fth LA that an MH can be located in and p_f is the residence probability that the MH is located in a_f, with $p_1 \geq p_2 \geq \ldots \geq p_k$.

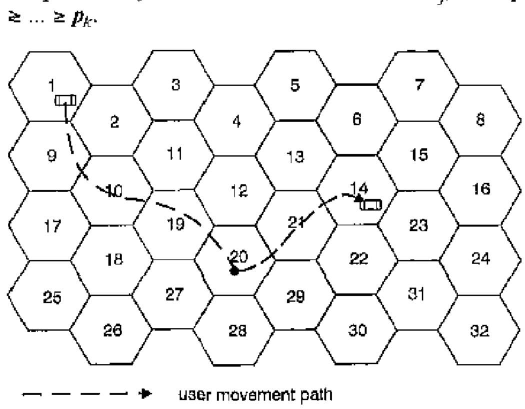

Fig. 2 *Alternative strategy*
Profile contains: {(1, 12/180), (9, 14/180), (10, 18/180), (19, 16/180), (20, 125/180), (21, 18/180), (14, 103/180)}
LA list: {20, 14, 21, 10, 19, 9, 1}

An MH needs to download its profile (and its LA list) at initial registration. When an MH updates its profile, the location management system generates a new LA list. The LA list is a set of LAs that appear in the profile and the LA sequence of the list is in descending order of the probability that an MH may reside in an LA. The profile of each user is stored in the HLR. If an MH is called, the system pages him/her over LA a_1. If he/she is not there, the system will page the MH over LA a_2 up to LA a_k (the last LA in the LA list). If an MH moves to an LA that is not in the LA list, the MH makes a registration to add a new LA to the profile and the LA list. As an example, in Fig. 2, an MH moves from LA 1 to LA 20, and then to LA 14. After the MH updates its profile, the system generates an LA list in the order of the MH residence probability. If there is a call for the MH, the system first pages LA 20.

The AS reduces the signalling load by decreasing the times of registration. An MH usually moves along the same track because the destination is the same (i.e. office, school, home etc.) and the route is usually the same. The cost of location management can be reduced by ensuring highly predictable mobility patterns. However, sometimes an MH may change its destination due to some short-term event. In this case we may have a different movement path and some new LAs which the MH has not visited in recent times. Under these conditions, the AS will consume more paging costs to locate the MH because it will page all the old LAs in the LA list before it pages the new LAs which are at the end of the LA list. To avoid consuming excessive network resources, a new method is proposed that takes short-term events into account.

3 Design approach

3.1 Short-term event scenarios

In the AS, when an MH is in an LA of the LA list, the location management system receives new location information only when the MH generates a call or after it is paged. An MH may not interact with the system very often because it does not make a call or because it receives very few calls. The system does not have enough information about the MH's short-term events. We describe two short-term event scenarios to illustrate the shortcomings of the AS as follows. First, consider the situation (scenario 1) in which MH is called and the time since the last connection is short. With this information, the probability that the MH stays in the same LA is high with the AS, the MH is paged from a_1 up to a_k in the LA list, wasting too much paging cost. In our approach, the MH is paged over the LA where the MH last appeared. Secondly, an MH may change its movement habit or move around some LAs (scenario 2). The LAs which the MH visits may not be frequently visited LAs (which are not in the first several LAs of the LA list). So the AS may need to page all the LAs in the LA list, again resulting in high paging costs.

For scenario 1, as shown in Fig. 3, when an MH in LA 14 has a call, the AS will page it according to the LA order in the LA list. That is, the local management system will page LA 20 first, then it pages the current LA (LA 14) where the MH resides. But if we take short-term events into account, the location management system may only need to page the last visited LA (LA 14) instead of LAs 20 and 14.

Now, we describe scenario 2 where an MH changes its usual movement habit, as shown in Fig. 4. After the MH moves to LA 20 it then moves to its destination (LA 13) which deviates from its usual movement path. In this situation, the MH will perform a location update when entering LAs 12 and 13 since these two new LAs are not in the original LA list. The system will add these two LAs to the end of the LA list. If there is a call for the MH in this situation, the AS will need to spend signalling cost and time paging all the LAs in the LA list to find the MH. But if we take short-term events into account, the system may only need to page LAs 12 and 13. Section 3.3 describes how short-term events are taken into account.

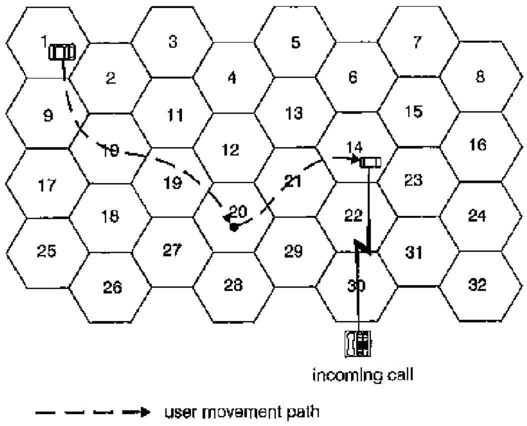

Fig. 3 *Last connection point: scenario 1*
LA list: {20, 14, 21, 10, 19, 9, 1}
LAs that must be paged in AS: {20, 14}

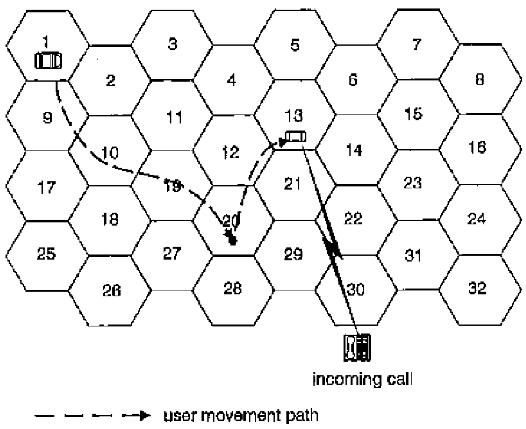

Fig. 4 *Last connection point: scenario 2*
Original LA list:
{20, 14, 21, 10, 19, 9, 1}
New LAs:
{12, 13}
LA list when MH is in LA 13:
{20, 14, 21, 10, 19, 9, 1, 12, 13}
LAs that must be paged in AS:
{20, 14, 21, 10, 19, 9, 1, 12, 13}

LAI	time	tag

Fig. 5 *Data structure of a paging information record*
LAI: location area identifier
time: start time of this connection
tag: a mark indicates if the LA has been paged successfully

3.2 Data structure definition

Before describing how our intelligent location tracking strategy works, the data structure of the paging information record must be defined first. A set of paging information records stores information about an MH communicating with the location management system. Fig. 5 shows the three fields of a paging information record, which are explained as follows:

(i) *LAI*: The location area identifier (LAI) identifies the LA in which an MH communicated with the location management system during the most recent time period. Communication events including the MH entering a new LA that is not in the LA list, the MH having a call to deliver, and a call for the MH, must be recorded.

(ii) *Time*: This is the start time (last connection time) when an MH had a connection with the location management system. This is an important factor in deciding which LA to page first for call delivery.

(iii) *Tag*: This is a mark (1: successful; 0: unsuccessful) to let us know if an LA has ever been successfully paged during the observation period before an MH updates the profile in the system. It is a factor to decide an offset (W). If there are i paging information records with 1 in the *Tag* field, the offset (W) is defined as:

$$W = i \times w$$

where w is a weighting parameter. W is an offset that the location management system should add to the p_fs of all LAs in the paging information records when it rearranges the LA sequence in the LA list. The purpose of W is to express the most recent history of the MH.

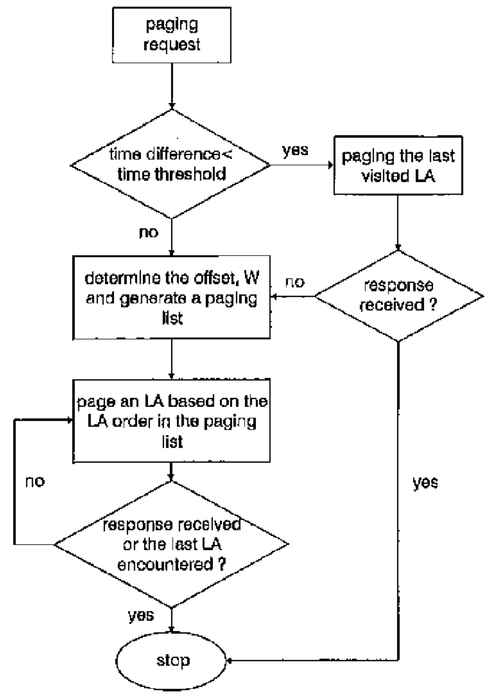

Fig. 6 *Flowchart of intelligent location tracking strategy*

3.3 Intelligent location tracking strategy

To reduce the paging cost under the two scenarios described in Section 3.1, we pay extra attention to short-term events. Based on the AS strategy, we add a new data item and store it in the HLR. The data item is called 'paging information records' (1, 2 or more records), described in the previous Section. The flow chart of the intelligent location tracking strategy is shown in Fig. 6. When an MH is called, using this strategy the MH is not paged according to the original LA sequence in the LA list. First, we determine the time difference between the time of the last call to or from the MH and the time of a new arrival call to the MH. If there is more than one record in the paging information records, we compute the time difference from the last record because this time difference will be the smallest. Then, we check if the time difference is smaller than the time threshold, which is defined as the maximum residence time that an MH is in an LA. If not, the system will rearrange the LA sequence in the LA list first by taking the paging information records into account. Those LAs that appear in the paging information records increase their residence probability by an offset, W. The system sorts the LA list and the sorted list is called a 'paging list'. The system then pages the LAs according to the new LA sequence in the paging list until paging is successful or the last LA is encountered. The offset is intended to reflect events that happened during this observation period. The larger the offset, the higher the probability that an MH is in the LAs of the paging information records.

This strategy can resolve the two short-term event scenarios which were shown in Figs. 3 and 4, and that result in high paging cost. In scenario 1, since the time difference is smaller than the time threshold, the last visited LA (LA 14) is paged first. As a result, the proposed method can reduce needless paging. In scenario 2, since the movement habit of the MH has changed, the AS needs to page all the LAs in the LA list. However, using the proposed strategy, the location update events that the MH moved to a new LA would be stored in the paging information records. When a call arrives, the new LAs 12 and 13 in the paging information records increase their residence probability by an offset W. Then the system will page an LA according to the LA order in the paging list. In this way, the paging costs can be reduced.

4 Evaluation

In this Section we describe a simulation model and use it to generate MH movement data. We first define some parameters (like MH groups, MH distribution, etc.) to simulate an environment which is close to the MH's movement in a real city. Then we compute the location update cost and the location tracking (paging) cost of the three approaches (CS, AS and our proposed approach) based on the simulation model.

4.1 Simulation model

The simulation model is based on a city zone area model [1, 11]. The city area is assumed to have a radius of 20km. There are four area types: the city centre, the urban area, the suburban area, and the rural area. This city model consists of 32 area zones (eight per area type), four circular highways, and four radial highways. Note that each area is covered by one base station, which corresponds to an LA. In the simulation we simulate a sample of 100 MHs roaming within city areas. There are three MH groups based on their mobility: high mobility users, working people, and housekeepers. Now we describe some environment parameters of this model.

Table 1: Distribution of MH groups

MH group	Probability
High mobility	15%
Working people	45%
Housekeepers	40%

MH groups based on their mobility: Table 1 shows the distribution of the three MH groups. Each MH group has its own mobility characteristics. An MH movement depends on which MH group that it belongs to. When an MH enters an LA, a residence time is assigned. The high mobility group has a short residence time in each LA on its way to a destination. An MH in this group will be assigned a new destination after it reaches the original destination. This process will be repeated during simulation. The working people group will be assigned a destination as its work place. When an MH in this group reaches its destination it will stay there for a long period of time. The housekeeper group is the same as the working people group except that it has low movement speed.

Movement attraction points: We assume each MH group has its own movement attraction points. Movement attraction points are places where the MH may reside for a period of time. They may be houses, workplaces, shopping centres, and parks. In each area zone, we define the probability that an MH may be attracted into this area [1], as shown in Table 2. An MH's destination is selected according to which MH group that it belongs to and the MH's movement attraction points, as shown in Tables 1 and 2.

Table 2: Distribution of movement attraction points

MH group	City centre	Urban area	Suburban area	Rural area
High mobility	39%	34%	20%	7%
Working people	40%	34%	16%	10%
Housekeepers	11%	30%	47%	12%

Time zones: The simulation time runs from 7:00 a.m. to 10:00 a.m. The total simulation time is three hours and our major goal is to simulate MHs moving from home to office. The simulations of MHs moving from office to home are similar. The difference is that destinations will be sources, and vice versa.

Mobility and traffic conditions: We follow the model in [11] to determine mobility conditions (average pedestrian speed and vehicle velocity). The movement algorithms and traffic conditions for high mobility users, working people and housekeepers (residential users) are also based on the model in [11].

Initial MH distribution over the city area: Since the distribution of MHs is an important factor in determining MH sources, we initialise the MH distribution over the city area by assuming that most of them live in the rural areas (45%), as shown in Table 3.

Table 3: Initial MH distribution over a city area

City centre	Urban area	Suburban area	Rural area
10%	22%	23%	45%

4.2 Simulation results

In the simulations we set $w = 20/180$ and *time threshold* = 20 minutes. These two values can be adjusted based on the history of the MH. Fig. 7 shows that the location update costs of the AS and the proposed method are much less than that of the CS with the variance of repeat probability. The repeat probability is the probability of the MH moving over the same path as in the last time period. If the repeat probability is 100%, this means that the MH is moving over the same path as in the last time period during simulations and the times of location update are zero. If the repeat probability is 0%, this means that the MH never moves over the same path as in the last time period during simulations. However, this does not mean that all the LAs on the movement path of the MH are completely different from the last period. That is, some LAs may be the same as in the last time period. As the repeat probability decreases, the location update cost increases. This is because the MH changes its movement path. It will stay in some LAs that didn't appear in the last time period.

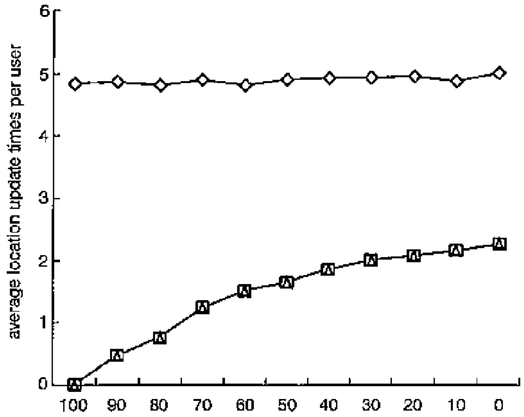

Fig. 7 *Location update cost among CS, AS and proposed method by simulation*
—◇— CS
—□— AS
—△— proposed

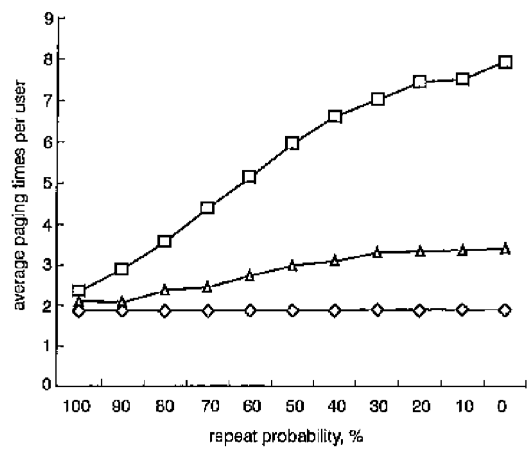

Fig. 8 *Location tracking cost among CS, AS and proposed method by simulation*
—◇— CS
—□— AS
—△— proposed

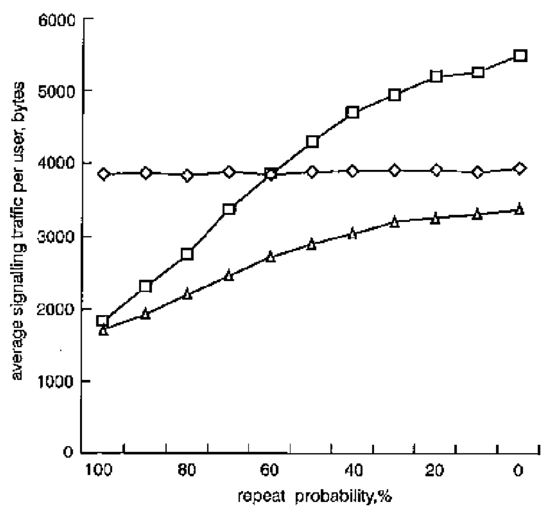

Fig. 9 *Total cost among CS, AS and proposed method by simulation*
—◇— CS
□ – AS
- ·△· · proposed

In Fig. 8 we can see that the proposed approach performs better than the AS on paging cost. When the repeat probability decreases, the paging cost of the AS increases faster than that of the proposed method. According to the SS7 MAP message size in GSM from [8], which is shown in Table 4, we can compare the total location management cost among these three strategies. Fig. 9 shows that our method can save 14–55% of location management's signalling cost compared to the CS, and save 6–39% signalling cost compared to the AS under different repeat probabilities. Our method performs significantly better than the AS when the repeat probability is low. Low repeat probability implies high occurrence probability of short-term events. The advantage of our method is due to the two short-term event scenarios mentioned before. Since the AS did not actually handle the short-term events, in these two scenar-

Table 4: SS7 MAP message size in GSM

Variable	Description	SS7 bytes
b_u	location update	461
b_{p1}	mobile terminated call	858
b_{p2}	mobile terminated without authentication	470

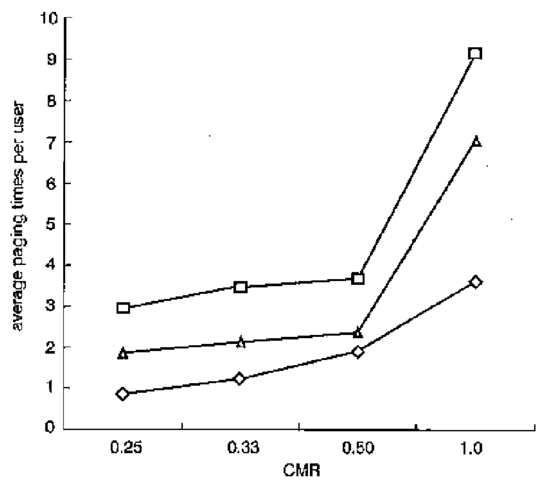

Fig. 10 *Location tracking cost among CS, AS and proposed method under different CMRs*
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—□— AS
—△— proposed

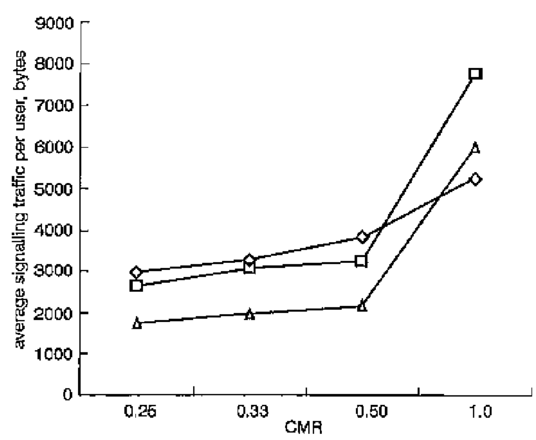

Fig. 11 *Total cost among CS, AS and proposed method under different CMRs*
—◇— CS
- -□- - AS
—△— proposed

ios, it may need to page almost all the LAs in the LA list before locating an MH. As shown in Fig. 10, we use the call-mobility ratio (CMR) as a variable to evaluate location tracking cost. CMR is the ratio of call incoming rate divided by LA crossing rate. The location tracking cost of our method is smaller than that of the AS under different CMRs. As expected, our method and the AS have more location tracking cost than the CS. In Fig. 11 it is shown that our method has the lowest total (location signalling) cost among the three methods except when CMR is close to 1.

5 Conclusions

The AS is suitable for situations of high mobility rate and small LA size because it significantly reduces the location update costs compared to the CS. Our approach further reduces location tracking costs in comparison with the AS, without increasing location update costs. It just needs extra storage space and some simple computations. Since the advances in memory capacity and processor speed are faster than improvements in the availability of radio channels, this overhead is not significant. Our method can reflect an MH's movement behaviour by generating a dynamic paging list. If an MH performs actions that it seldom or never did during the previous time period, our approach will increase an offset for each LA in the paging information records In this way, the proposed location management system can significantly reduce the total signalling cost by responding to the MH's behaviour quickly before an MH updates its profile.

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