A New Location Management Strategy Based on User Mobility Pattern for Wireless Networks *

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Abstract

For a wireless network to effectively deliver services to the mobile users, it must have an efficient way to track them. The location management fulfills this task through location registration and paging. Many location management strategies, such as profile-based scheme (PBS), have been proposed to reduce the signaling traffic caused by the location update and paging. In the PBS scheme, the system collects the user mobility history and stores the information in the user profile. If the user follows the pattern, no update is needed. When a call arrives, the user is paged in the location areas in the descending order of probabilities until the user is found. In this paper, we propose a new scheme–MPBS: mobility-pattern-based scheme, which incorporates both the mobility pattern and time information in the profile. The user location is determined by the system based on not only the distribution probability but also the system time. In the MPBS scheme, a mobile user can be in one of four identified states and different location update and paging strategies will be used for different states. Performance evaluation of the proposed scheme is carried out under various mobility-call patterns, paging cost and distribution probability. The results show that the MPBS scheme incurs significantly less signaling traffic and less paging delay than the PBS scheme.

1 Introduction

In the 3G and 4G wireless communication systems, both voice and data services will be supported. The core networks for 3G systems consist of both circuit-switching segments and packet-switching segments. It is anticipated that the core networks for 4G systems will be all packet-switched. In order to deliver packets to the moving users, the system must have an efficient way to locate them when call requests arrive. This is the concept of mobility management for wireless communication systems. Usually, in a wireless communication network, the covered service areas are partitioned into cells, and the cells are aggregated into groups geographically, which are called *location areas* (LAs). To deliver services to a user, all the cells in the LA covering that user will be paged to establish the radio link connection. To simplify the presentation, we use the term—*User Equipment* (UE) for the mobile terminal a user uses. In future generation systems, the LAs will become smaller. The smaller LA size can facilitate networks to trace users more efficiently and reduce transmission delay or packet loss significantly. For example, in the UMTS systems, the cells aggregate into *routing areas* (RAs). An RA is typically a subset of an LA, and the RAs can be further partitioned into smaller *UTRAN RAs* (URAs). The smaller size of location areas results more location update messages generated and sent to the *Home Location Register* (HLR). The radio spectrum in wireless communication system is the most scarce resource, large amount of update messages will consume a lot of bandwidth. As we mentioned before, data service will be provided in the next generation systems, then much more bandwidth will be occupied by the packet transmissions. All of these make the radio spectrum more valuable. The small size of cell groups can facilitate the system to provide users data service with required quality, while the location update messages sent by UEs increase with the reduction of registration area size. Since the radio spectrum is considered the most scarce resource, intensive research has been carried out to minimize the impact of the user location signaling traffic on the wireless systems ([3], [4]). In 3G/4G systems, the services should be user-oriented, namely, the networks can provide specific services for specific users. In order to provide user-oriented services, the system needs to store the user profile which records the necessary information. We can observe that many users follow some daily routines. If the system knows the routines in advance and uses the information to predict the user's

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location, then the registration traffic can be reduced. We define the daily routine of a user the *user mobility pattern* (UMP). As long as the user follows the pattern, no explicit registration is necessary and the network can organize the system resource more efficiently, thus we can reduce the spectrum consumption caused by the location updates ([5], [6]). On the other hand, a user may deviate his/her fixed route due to traffic or weather reasons. The system can make a prediction about the user's location with high accuracy according to the user information in the profile. Based on this observation, a profile-based location strategy (PBS) was proposed in [7], [8]. In the PBS scheme, the system maintains records of each user's most likely itinerary. If A_i is one of the location areas, a probability α_i is associated with it, which represents the probability of the user being in the location area A_i. The system will keep a list of (A_i, α_i) pairs for some time interval T. In the original PBS scheme, when a mobile user does not leave the location areas A_i on the list, no location update is necessary. When a call to the mobile arrives, the system will page the location areas on the list in the descending order of the probabilities α_i. However, the performance of the PBS was not well studied with respect to the *call-to-mobility ratio* (CMR). Our performance study also shows that the PBS scheme does not perform well with the increase of the unit paging cost. In this paper, we propose a new mobility management strategy—the *user mobility-pattern-based location scheme* (MPBS). In the MPBS scheme, the system maintains a list of 4-tuple $(A_i, t_i, T_i, \alpha_i)$ for each user. The t_i and T_i are the time the user enters location area A_i and the residence time in A_i, respectively. This 4-tuple incorporates both mobility pattern and time pattern. Based on this notation, we define four states, in which a mobile user or a UE will invoke different location update and paging schemes. Extensive simulation studies show that the proposed MPBS can achieve much better performance than the PBS strategy under various conditions.

The rest of the paper is organized as follows. In the next section, we describe the details of the PBS scheme and the new MPBS scheme. The simulation results are presented in section 3, and section 4 gives the conclusion.

2 PBS and MPBS strategies

In this section, we introduce the procedures of the PBS and MPBS schemes. Both schemes require the UMP information stored in the user profiles. If all the procedures, such as information collection and dissemination, are incorporated into the current distributed wireless communication database systems, the signaling and database retrieval traffic will overwhelm the system process capacity. The delay resulted from the heavy traffic load will degrade the whole system performance. In order to solve the problem, the *Virtual Management Network* (VMN) needs to be implemented [10]. VMN attempts to place *mobility agents* (MAs) in a distributed fashion so that each MA can be responsible for the management of mobility and resource in its charging area. In this way, signaling traffic resulted by mobility and resource management can be localized. The proposed MPBS can be implemented in this network architecture.

2.1 profile-based location scheme (PBS)

The profile-based location scheme (PBS) is studied in [7] and [8]. In this scheme, the system maintains records of each user's most likely itinerary. The probability distribution of a user's location is known already. If A_i is one of the location areas in the record list, the user's most likely itinerary can be defined as $\{A_i\}_{i=1}^k$, where k is the element number in the set. The system maintains a list of (A_i, α_i) pairs for some time interval T, where α_i is the probability the user could be found in A_i. If the user follows his/her daily itinerary strictly, namely, the user keeps roaming in $\{A_i\}_{i=1}^k$, no registration is needed. When the user leaves $\{A_i\}_{i=1}^k$, he/she will be required to manually register to the system. So the UE must keep a copy of the list. When a call arrives for a user, the system will page the location areas in the descending order of α_i until the user is found. Under this strategy, the database will know a user's exact location when he/she is out of $\{A_i\}_{i=1}^k$. The PBS can reduce the update cost at the expense of increasing paging cost or paging delay. In [8], the authors studied the paging delay and the radio link cost under different list length. The paging delay was derived, given three known probability distributions, by the expected location area numbers needed to be paged before the user can be found. In fact, it is intuitive that the total cost of the PBS scheme has a close relationship with the user's CMR. With small CMR, which means the user has relative higher moving rate than the call arrival rate, the PBS can significantly reduce update cost and the total cost. On the other hand, for the users with high CMR, the paging cost will be dominant and the total cost of PBS may exceed the basic IS-41 or GSM MAP scheme. We will study the PBS performance under various CMR in this paper.

2.2 mobility-pattern-based scheme (MPBS)

In this section, we present a new mobility management strategy—the *mobility-pattern-based scheme* (MPBS). The MPBS strategy can reduce the user update cost and try to limit the paging cost at the same time. In this scheme, only two more elements—the time a user enters A_i (t_i) and the residence time in A_i (T_i), are added in the user profile. An example of user profile in MPBS scheme can be seen in Fig.1. In Fig.1, the line represents time. In the profile, the user enters A_1 at t_1 and stay in A_1 for T_1, and then enter

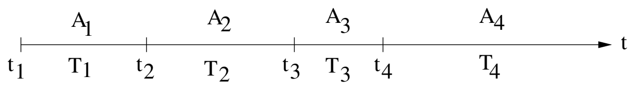

Figure 1. An example of user profile

A_2 at t_2 and stay for T_2 and so on. So a list of 4-tuple $(A_i, t_i, T_i, \alpha_i)$ is stored in the user's profile. We assume the cardinality is k. In the list, the tuples are not ordered according to α_i, but by t_i. For example, if a user's profile records all the location areas he/she will visit in 24 hours, the list is sorted by the time the user visits every location area. So for $i \neq j$, A_i and A_j may be same. In MPBS scheme, we define ω as the user out-of-pattern probability, which is given as $\omega = 1 - \sum_{i=1}^{k} \alpha_i$. In order to make the scheme clear, we need to define the user behaviors more precisely. In the MPBS scheme, when users follow the UMP, the location update traffic can be reduced. There are two kinds of patterns for users to follow in the MPBS scheme. When a user enters A_i at time t_i and the residence time in A_i is T_i, we say the user follows time-sequence pattern. If a user enters and exits location areas following the A_i order in the profile only, we say the user follows the sequence pattern. It is obvious that a user following the time-sequence pattern must follow the sequence pattern too, while a user following the sequence pattern may not follow the time-sequence pattern. However, users may deviate their daily routine because of weather or road traffic reasons. So we need some way to find out how close a user follows his/her mobility pattern. the UE for the next generation systems should incorporate more intelligent functions. When a user roams in the network service areas, we assume that the UE can record the location area id, location area entrance and exit time. We define the user's actual path information as the *User Actual Path* (UAP). The UAP can be used to update the UMP periodically. As the time elapses or user crosses location area boundary, the UE can tell whether the user is following any pattern or not by comparing the UAP with UMP. The UAP is in the same format as UMP. If we do not consider the time information, the UAP can be expressed as $\{B_i\}_{i=1}^{m}$, where m is the length of UAP. Without consideration of time, we can compare the similarity of UAP with UMP by edited distance [6]. We assume the regular movement of a mobile user can be modelled as an edited UAP by allowing the following legal operations:

- Inserting a location area L at position i of the UMP gives UAP: $A_1, A_2, \cdots, A_{i-1}, L, A_i, A_{i+1}, \cdots, A_k$,
- Deleting the location area A_i of the UMP gives UAP: $A_1, A_2, \cdots, A_{i-1}, A_{i+1}, \cdots, A_k$.
- Changing a location area A_i of the UMP to another location area L of the UMP gives UAP: $A_1, A_2. \cdots, A_{i-1}, L, A_{i+1}, \cdots, A_k$.

As a result, the edited distance between a UMP and a UAP becomes the sum of the weights of the editing operations. If the edited distance is less than a threshold, we say the user follows the sequence pattern. For large systems with complex network topologies, the calculation of the weights can be quite involved. How to assign and calculate the weight exactly is out of the scope of this paper. For simplicity and without loss of generality, we can define the weight as follows:

- The cost of inserting

$$W_I = \begin{cases} 1 & L \text{ is the adjacent location area of } A_i \\ \infty & \text{otherwise} \end{cases}$$

- The cost of deleting

$$W_D = \begin{cases} 0 & A_1, \cdots, A_{i-1} \text{ have already been deleted} \\ 1 & \text{otherwise} \end{cases}$$

- The cost of changing

$$W_C = \begin{cases} 1 & L \text{ is the adjacent location area of } A_i \\ \infty & \text{otherwise} \end{cases}$$

Based on the above notations, we can define user behaviors more precisely. When a user enters the location area A_i, the user is said to follow the time-sequence pattern if and only if the following requirements are met: (1) $A_i \in \{A_i\}$; (2) $|t_{i,actual} - t_i| < \Delta T$ and (3) $t - t_i - T_i < \Delta T$, where $t_{i,actual}$ is the actual time the user enters A_i, t is the current system time and ΔT is the time pattern threshold. The first condition constrains the user in the profile, the second and third conditions limit the user to enter and exit location area A_i within some time threshold. If we assume a UAP is $\{B_i\}_{i=1}^{m}$, the edited distance between UAP and UMP is $d(A_1, A_2, \cdots, A_m, B_1, B_2, \cdots, B_m)$ and the edited distance threshold is ΔD, we can say the user follows the sequence pattern if: (1) $A_i \in \{A_i\}$; (2) $|t_{i,actual} - t_i| > \Delta T$ or $t - t_i - T_i > \Delta T$ and (3) $d(A_1, A_2, \cdots, A_m, B_1, B_2, \cdots, B_m)/m < \Delta D$. In MPBS scheme, users can be in one of four states when enter a location area A:

State 1: If the user follows the time-sequence pattern, we define the user is in state 1.

State 2: if a user follows the sequence pattern, we define the user is in state 2.

State 3: if user does not follow any of the above two patterns but $A \in \{A_i\}$, the set of location areas in the user profile, we define the user is in state 3.

State 4: if $A \notin \{A_i\}$, we define the user is in state 4.

The purpose we define four states is that the system can invoke different paging mechanisms for users in different states. A user needs to register to the system when he/she switches states. In the MPBS scheme, we assume the user state information is included in the update message, so that the system can know the user current state every time the UE sends update message. When a user is in state 1, 2 or 3, no registration or state message needs to be sent if the user keeps the state unchanged. If the user is in state 4, the UE will update its location to the system every time the user enters a new location area. Then, only in state 4, the user needs to update the location every time he/she crosses a LA boundary. In state 1, state 2 and state 3, the user needs to send update message only when the states switch. If we can collect the user daily routine information well so that the user has large probability in state 1,2 or 3, the update cost can be saved. In the MPBS scheme, when a call arrives, the system can use different paging strategies based on the user's current state. If the user is in state 1, the system can decide which location area the user is in according to the current system time and page it. If the current time is t and the user is in state 1 when a call arrives, the system can retrieve the tuple matching $t_i \le t \le t_i + T_i$, then the user can be located in A_i. There is the probability that the user just moves out of the paged area and enters the next one. If the users does not change state, only the next location area needs to be paged. If the user is in state 2, the system knows the location areas the user is not in according to the last location update. Since the user follows the sequence pattern, the system knows the user must be in one of the location areas after the last updated one in the profile. Because there is no time information in state 2, all the location areas the user could be in will be paged in the descending order of the probabilities α_i. If the user is in state 3, the system knows that the user is in $\{A_i\}$ and all the location areas in $\{A_i\}$ will be paged according to the descending order of α_i until the user is found which is just like the PBS scheme. If the user is state 4, the system knows the user's exact location and page the respective location area. In fact, when the user is in the state 4, the MPBS scheme is exactly the same as IS-41/GSM scheme. The MPBS algorithm can be described by the pseudocode as follows:

```
MPBS_Update()
 {
   The user enters location area A_i;
   UE records location area id and time information in
   UAP;
   if(A_i ∈ {A_i})
    {
     if(|t_{i,actual} − t_i| < ΔT   &&   t − t_i − T_i < ΔT)
       User is in state 1;
     else
      {
       if(d(A_1, A_2, ···, A_m, B_1, B_2, ···, B_m)/m < ΔD)
         User is in state 2;
       else
         User is in state 3;
      }
     if(user state is changed)
       UE updates location and state to HLR;
    }
   else
    {
     User is in state 4;
     UE updates location and state to HLR;
    }
 }
```

```
MPBS_Paging()
 {
   A call arrives for the user;
   HLR checks user state information;
   if(user is in state 1 && t_i ≤ t ≤ t_i + T_i)
     Paging A_i or A_i and A_{i+1};
   if(user is in state 2 && user last location is A_i)
     Paging A_i, A_{i+1}, ···;
   if(user is in state 3)
     Paging {A_i};
   if(user is in state 4)
     Paging A_i;
 }
```

As we can see from the three schemes, the IS-41 will generate the most update messages and the PBS scheme generates the least ones. The MPBS is in the middle of them. Although the MPBS generates more update messages than the PBS, it reduces the paging cost dramatically than the PBS and achieves total cost saving. However, both the PBS and MPBS scheme will generate more paging cost than the IS-41/GSM scheme. In the next section, we carry out the performance evaluation of the MPBS and the PBS by simulations.

3 Simulation results and comparisons

The simulation system architecture is shown in Fig.2 [11]. The network consists of 16 RAs. Each RA has 4 neighboring RAs. At the initialization, a user is generated randomly in one RA and travels randomly in the network. The links between RAs are virtual links, which imply that the user can roam bidirectionally between the connected RAs. The links between RAs and HLR are signaling links. When the user enters an RA, depending on the

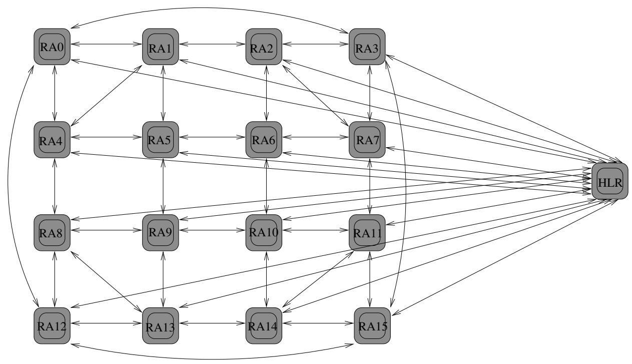

Figure 2. The simulated network architecture

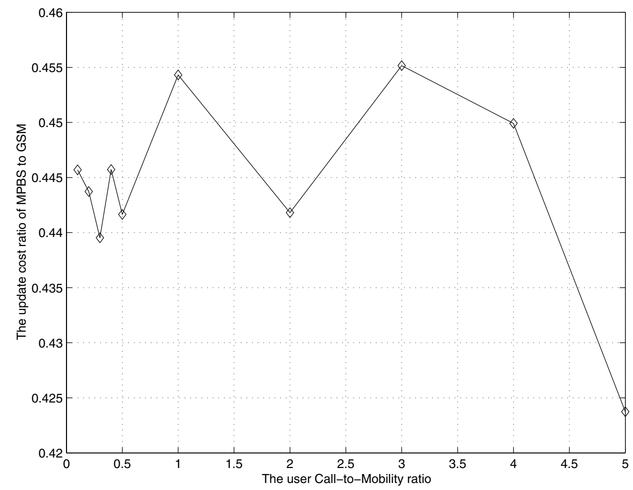

Figure 3. The location update cost ratio of the MPBS scheme to the IS-41/GSM

schemes currently adopted, an update message may be generated and sent to HLR. The user resides in an RA for some exponentially distributed time with predefined mean, then moves into the next RA. The calls for that user generated in HLR forms a Poisson process. For simplicity and clarity, we embed the VMN functions into the HLR node. The HLR node will record all the update and paging costs for different schemes at the end of the simulations. In the following performance analysis, we normalize the update cost $C_u = 1$. The paging cost is usually less than update cost, so we assume the paging cost for one location area is $0 < C_p \leq C_u$. We are interested in how the CMR, the paging cost C_p and the user distribution probability α_i affect the performance gain of the PBS and the MPBS. In the simulations, we assume there are three representative profile distribution [8]: uniform, linear and exponential. Denote the conditional probability of a user being in the ith location area in the list as $\beta_i = \alpha_i/(1-\omega)$, the definitions for the three kinds of distributions are given as below.

Uniform Distribution: when $\beta_1 = \beta_2 = \cdots = \beta_k = 1/k$, the profile is said to be uniformly distributed.

Linear Distribution: when $\beta_i = \frac{2(k+1-i)}{k(k+1)}$ for $i \in \{1, 2, \cdots, k\}$, the profile is said to be linearly distributed.

Exponential Distribution: when $\beta_i = \frac{e^{-bi}(1-e^{-b})}{e^{-b}-e^{-b(k+1)}}$ for $i \in \{i, 2, \cdots, k\}$, the profile is said to be exponentially distributed, where b is a constant.

In the simulations, we assume the update cost for every location area is same. At the time of initiation, a user is generated randomly in one location area and is set in state 1. The state 4 is different from the other states. In state 4, the user in fact does not follows any pattern. The system knows the user location information only by the registration messages sent by the UE when the user enters a new A_i. So when the user is in state 1, 2 or 3, we say the user is in-the-pattern, and the user is out-of-pattern when he/she is in state 4. We also assume 90 percent of the time, the user is in-the-pattern. The conditional probability of the user in state 1, state 2 and state 3 are 0.8, 0.15 and 0.05, respectively. All the simulations collect the user track information for 24 hours.

The MPBS scheme can reduce the update cost greatly against the IS-41 or the GSM scheme as shown in Fig.3. In this simulation, the out-of-pattern probability $\omega = 0.1$ and the probabilities of user in three different states are set as above. In Fig.3, the update cost of MPBS scheme is less than half of the IS-41/GSM, and the CMR does not affect the performance dramatically. The update cost is usually larger than the paging cost, that is why PBS and MPBS can achieve total saving by reducing the update cost at the expense of increasing the total paging cost. However, the MPBS can reduce the total cost without increasing the paging cost too much. In both PBS and MPBS schemes, the system usually pages more than one location areas in attempting to find the user's exact location. In other words, the MPBS and the PBS will introduce some delay during call delivery procedures. In Fig.4, we can see that the paging delay generated by the MPBS is much less than PBS. The reason is that, in the PBS scheme, all the location areas in the list need to be paged sequentially. Usually, the location areas are paged sequentially according to the user distribution probability. The delay can be different with different probability distribution. In Fig.4, we assume the user profile distribution is uniform. In the MPBS scheme, when the user is in-the-pattern, only if the user is in state 3, all location areas will be sequentially paged. If the user is in state 1, only one location area is paged most of the time; if in state 2, only part of the $\{A_i\}$ need to be paged. As

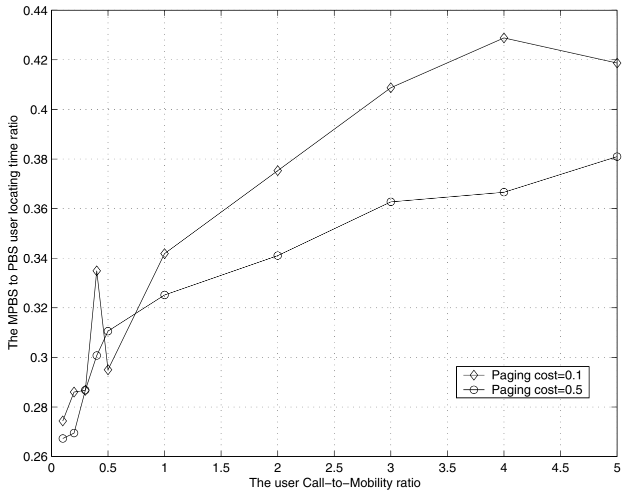

Figure 4. The comparison of the finding time for MPBS and PBS

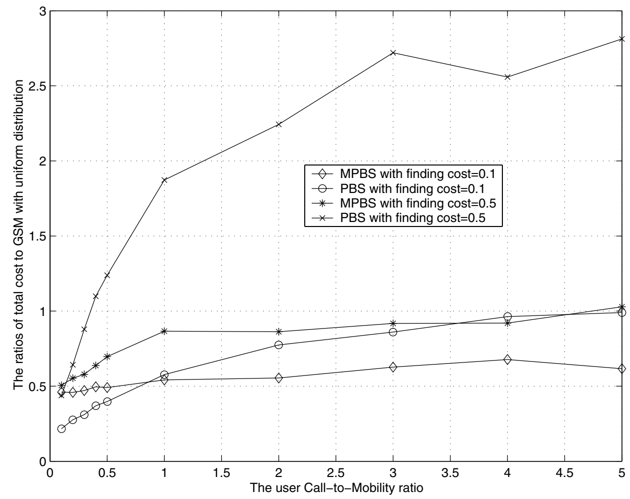

Figure 5. The total costs of MPBS and PBS to IS-41/GSM with uniform distribution

we can see, when the CMR is low, the paging delay for the MPBS scheme is 70% less than the PBS scheme. The reason is that when the CMR is low, the user has relative high moving probability, the PBS scheme needs to page more location areas to find the user, but the MPBS scheme is not affected by this factor. When the CMR is large, the user will stay in a location area for a relative long time, the PBS scheme can find out the user with less location area paging. However, the MPBS total paging cost is still 60% less than the PBS scheme.

Although the MPBS has less paging delay than the PBS, we need to find out the total costs for the two schemes and try to see whether these two schemes can achieve better performance than the conventional IS-41/GSM scheme. In Fig.5, Fig.6 and Fig.7, we plot both MPBS and PBS to IS-41/GSM total cost ratios with three different probability distributions and different paging costs. We can see from these figures, the costs of the PBS scheme increase very quickly with the increase of paging cost. When the paging cost is 0.5, the PBS scheme can have saving only when the CMR is very low. With the increase of CMR, the paging cost in PBS scheme plays a more important role, then the total cost increases fast. The MPBS total cost increases much slowly with the paging cost. This is the advantage of MPBS. Another advantage of MPBS is that the cost curves are flatter than PBS in a wide range of CMR. That means the MPBS scheme is applicable to different classes of users with different mobility patterns. In Fig.7, the total cost of the PBS scheme is a little less than MPBS scheme when the paging cost is small. The reason is that, for exponential distribution, the number of the paged location areas is fewer than that under other distributions. When the paging cost

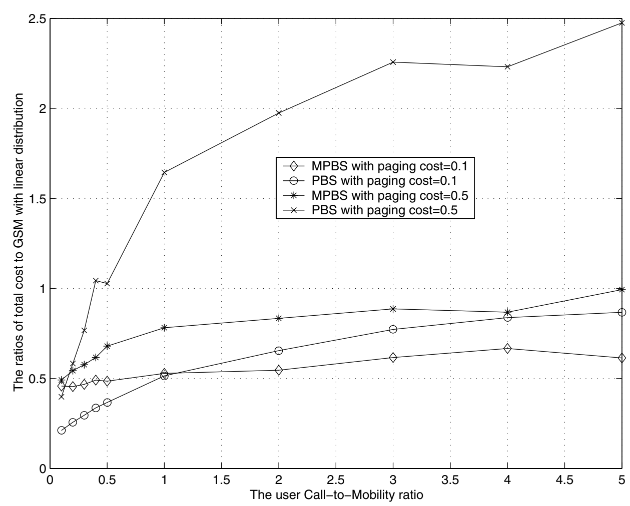

Figure 6. The total costs of MPBS and PBS to IS-41/GSM with linear distribution

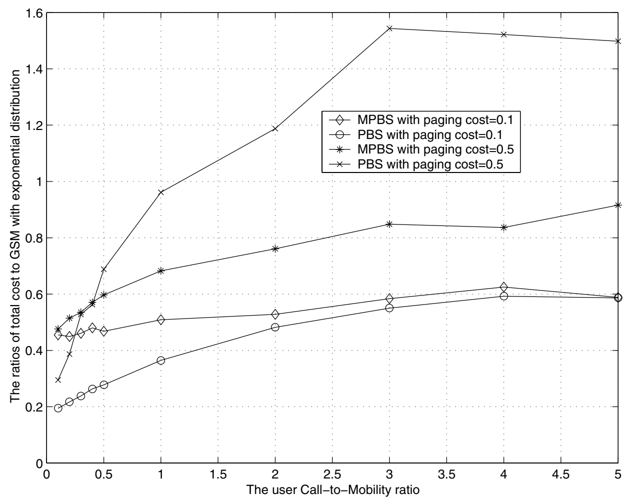

Figure 7. The total costs of MPBS and PBS to IS-41/GSM with exponential distribution

is small, the total cost may be small. But even with exponential distribution, the PBS total costs increase much faster than the MPBS scheme with the paging cost.

4 Conclusion

For the next generation wireless multimedia communication systems, the radio spectrum is the most scarce resource. In order to exploit the radio resource and provide users services more efficiently, the location areas become smaller. The result is that the user location update message will consume a lot of bandwidth. The PBS scheme is proposed in [7], [8] to solve the problem. We studied the PBS scheme performance under various conditions. In this paper, we also proposed a new user location scheme—the MPBS scheme. The simulation results suggest that, although the MPBS scheme generates more update messages than the PBS, the total cost of the MPBS is usually dramatically less than the PBS, and the MPBS scheme is not very sensitive to the increase of paging cost. The simulation results show that the paging delay of MPBS scheme is usually 60% less than that of the PBS scheme. Our results also shows that the MPBS scheme can work well for users with different CMR.

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