Spatial and Temporal Aware, Trajectory Mobility Profile Based Location Management for Mobile Computing

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Abstract

In this paper, we propose a new context-aware profile-based location management scheme. Besides temporal context that has been used in previous proposals, it considers spatial context of mobility profiles as well as recent travel trajectories. We present a conceptual framework for the cooperation between the Location Database Management System (LDMS) and the Mobile Host (MH) in keeping track of the mobility profiles for location management in mobile computing. Although extra overheads are put on both LDMS side and MH side, they are well justified in terms of reducing paging latency and paging traffic.

Introduction

Efficient and effective location management schemes to reduce wireless resource consumption is both theoretically and practically interesting. User mobility profile based location management researches in cellular network for personal communication and computing have drawn much attention in recent years (*Tabbane, 1995;* Pollini, 1997; Adly, 2000; Wu, 2001). Many of them propose to change candidate list of cells that MHs might be in for different time periods (slots), i.e., mobility profiles are temporal-aware. However, very few of them consider spatial context.

The key idea of our proposal is based on two observations. The first is that the cells which a MH is likely to visit in the candidate list are often spatially disjoint in a particular time slot while they might be overlapped over several time slots. Space can be also used to subset mobility profile. The second observation is that a MH usually follows its routine paths in many cases. We might be able to identify such routine paths based on the first several cells a MH has traveled. These kinds of information can be used to reduce the length of a candidate list and thus make it more accurate. Using a short candidate list as mobility profile will significantly reduce location update and paging costs.

The rest of this paper is arranged as follows: Section 2 reviews related work on profile based location management schemes. Section 3 presents our context aware, trajectory mobility profile based scheme. Section 4 performs analysis and discussion. Finally, section 5 is the conclusion and future work directions.

Related work and Motivation

There are several reviews and discussions on location management and mobility management in general. A list of 50+ references in this research area is presented in our website ([HREF 1]). We adopt the general architecture of wireless mobile network described in (Wong 2000). Based on this architecture, there are tradeoffs between location update and paging. The more frequent a MH performs location update, the more accurate the network knows where the MH currently is and thus the smaller paging area the network needs to page. Location management schemes, such as time-based, distance-based, movement-based, are proposed to minimize the total location management cost. These proposed schemes treat all MHs equally regardless of their mobility profiles.

Profile-based location management is originally proposed as an alternative strategy to schemes that treat all MHs equally. (*Tabbane, 1995*) presented a framework for a profile based scheme. The general idea of the scheme is to associate a candidate list of location areas in the decreasing order of the most likely places where each user is located within a set of predefined time slots as a MH's mobility profile. When a MH moves into a cell that is not in the list, it will perform a location update. Location areas in the list will be paged sequentially in the order indicated in the list when a call is initiated. The proposed scheme is temporal-aware in nature. The framework also allows using both fixed (or long-term) and dynamic (or short term) set of location areas by updating their weights in the candidate list. Although it proposes to give more weights for location areas that are within the possible distance since last update location, no details regarding to database operations are available. Furthermore, it is possible that even if cells are spatially close to each other, they might fall onto different paths that a MH seldom runs into during a short period of time (the starting cells of two opposite direction paths for example).

(Pollini, 1997) provided performance analysis for the basic profile based location management scheme. In addition to location update and paging costs that had been considered in (*Tabbane, 1995*), it also take list maintenance cost into consideration. The result showed that profile based strategy is much better than the fixed paging area strategy currently adopted by most PCS. (Adly, 2000) extended the work from (Tabbane, 1995). It proposed using hierarchal (tree-structured) location databases each of which stores a sub-profile for each user located in its sub-tree. Each sub-profile contains a list of the visited children nodes that the user could be located based on their respective associated probabilities. (Wu, 2001) provided a detailed implementation of profile-file based location management scheme which the authors called personal paging area design. It used data mining technologies to mine the moving behavior from a long-term collection of moving logs for each MH and then estimates their time-varying probabilities from the resultant moving behavior. Based on the information, the optimal paging areas of each time region of each MH can be derived. The method also proposed a protocol to update the candidate list. However, this scheme is only temporal aware without considering any movement information in maintaining the candidate list.

Proposed Framework

General Architecture and Process

The general scheme (Fig. 1) includes the MH part and the network part. The MH part has a profile list and a record for the recent trajectories of the active MHs. The network part has a Long-Term Profile Database (LTPD) and a Short-Term Profile Database (STPD) as well as a Special Event Database (SEDB). The network also may have three auxiliary databases namely geographical information database, activity knowledge database and user registration database to facilitate the generating initial profiles.

The process of the proposed location management scheme is as follows: The MH records its most recent movement trajectory and sends it back to network when mandate or voluntary location update is performed. The LDMS modifies its STPD based on the incoming trajectory data. Appropriate records to SEDB will be added if recent movements are significantly different from the current mobility profiles in the corresponding time slot. The LDMS computes the movement parameters based on the most recent trajectory and generate a new candidate list by querying the STPD and possibly the LTPD and the geographical information database if needed. The newly generated candidate list will be sent to the MH through air interface to update the old one. When there is a time-slot switch, the LDMS will update the LTPD based on the information stored in the STPD and update the STPD by retrieving new profile from the LTPD for the new time slot.

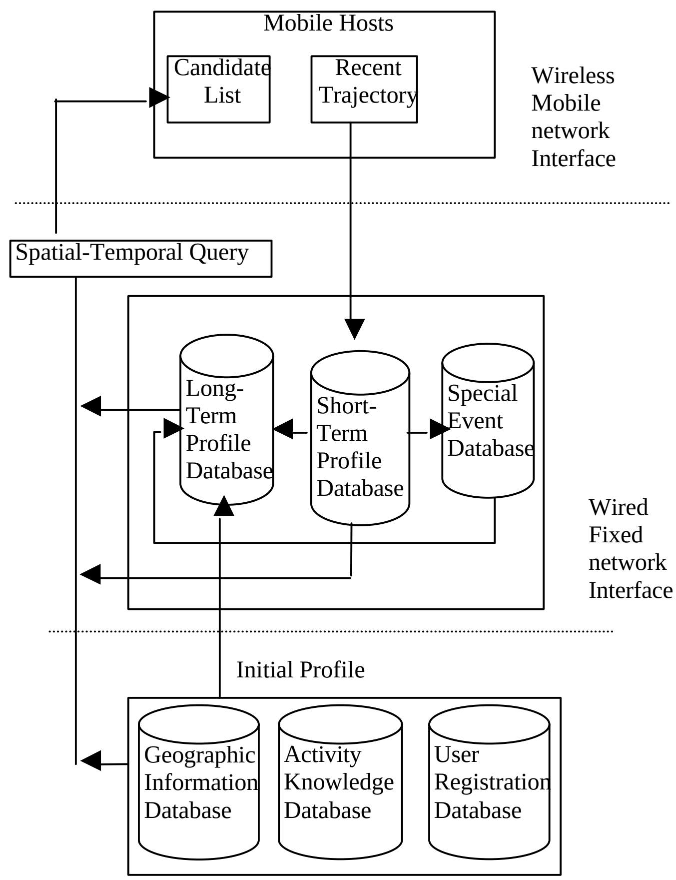

Fig. 1 General Architecture of the Proposed Location Management Scheme

Initial Profile Generation

User mobility profiles are often mined from a long term moving log as proposed in (Wu, 2001). There are some disadvantages in the existing approaches. First of all, data storage is huge. A 24-hour moving log in the bay area is 140M ([HREF 2]). Second, many data mining algorithms are not one-pass and assume all data can be fitted into memory which usually is not possible. Third, they have a huge computation overhead and thus yield an unacceptable delay if run in real time.

We propose to use initial profiles based on geographical information (such as census data), activity knowledge (traffic patterns) and user registration data (as much as available). If none of the registration information is available, we query all cell coverage areas against the census data to compute land use information. We give a higher priority to business/residential/entertainment areas and a low priority to rural areas. All users in this category will have the same set of initial frequently visited cells according to the order of popularity defined by the applications. If only residential location is in the registration data, then we can query the location against census data to find his/her community and set the average profile of the community as he/her initial profile. The possible mobility profiles that can be found by querying against geographical information database include the nearest grocery stores, shopping malls, kindergartens, cinemas, etc. The travel paths between them can also be generated in both two cases. If we further know the age, sex, marriage, work places, places that are often called by friends, etc., we can further adjust the frequencies that are assigned to the cells and travel paths to make the mobility profiles more accurate.

Mobility Profile Update

Given the huge amount of location update data, we cannot afford to store all of them in our LDMS. The huge volume of data not only wastes storage but also puts a heavy burden on query processing. Our proposal is to treat the location update data as a data stream and only record those that might be useful for updating mobility profiles while discarding the rest.

We assume a candidate list of cells that a MH might be located are transferred and stored at MH side. The list is associated with a time slot that is predefined by the LDMS. The distribution of time slots can be changed after enough evidence is gained. We further assume that a MH has a limited memory to record the sequence of its trajectory. The capacity of both the memory for the profile and the memory for the trajectory should fit the size of a packet to be sent to the network side to reduce bandwidth waste. When the cell where the MH is currently in is not in the candidate list or the trajectory memory set is full, the MH should perform location update. The LDMS will update its STPD and compute the moving speed and direction that will be used in sub-setting mobility profiles (discussed in the next sub-section). The visit frequencies newly transferred from the MH will be added to the frequencies of the corresponding cells in the STPD. New cell that the MH is visiting but not in its STPD records will be added to STPD.

Quite often a MH changes its moving patterns due to new activities, such as from home staying to driving and to working. In this case, we need to query the LTPD to update the STPD when the LDMS perceives the mobility pattern change besides time slot switch. The update of the LTPD from the STPD is very simple in our proposal: we only need to add the visit frequencies of cells in the STPD to the LTPD in the corresponding time slot.

It is also quite possible that a user might change his/her mobility patterns over time slots. For example, a user often goes to work at 7:30 on weekdays while going to work at 9:30 on Saturdays. In this case, if the cells visited by a MH are significantly different from the ones in the STPD fetched from the LTPD of the time slot then we will not update the LTPD for the time slot at the time of switch. Instead, we add special event records to the SEDB. The system will visit SEDB regularly to get evidence to decide whether to reorganize time slots (merge/split) as well as update other mobility profile components.

Spatially Sub-Setting Mobility Profile

We assume the network knows the geographical location (in the format of lat/log) of all the cells in the area and their topological (neighborhood) relationships. Based on the most recent trajectory transferred from the MH, the LDMS is able to compute the last cell that the MH is in, its average moving direction and speed and their deviations as well. These parameters will be used to subset the mobility profiles used in previous work (*Tabbane, 1995;* Pollini, 1997; Adly, 2000; Wu, 2001). Note that this is different from previous work (Wan 1999) that computes movement parameters at the MH side. Clearly, the LDMS has much more computation power and much less energy constraints. More importantly, the LDMS can perform spatial query against cell coordinates and other information in the geographical database to subset mobility profiles spatially which might be too computationally expensive to be performed at the MH side. The general process of spatially sub-setting (filtering) mobility profiles is briefly described as follows.

When a MH powers up, the direction it will follow and how fast it will move is not clear. In this case, we query cell location database (part of geographical information database) to get maximum number of cells the candidate list allows that are near to the power up cell whose visit frequencies are above a threshold within that particular time slot. In the initial period, it is highly like that the cell the MH is going to enter will soon be not in the candidate list and a location update is issued. At this time, the network is able to compute the movement parameters as discussed above. We first perform a range query against the cell location database with the current location as the center and possible moving distance (speed multiplied by a certain amount of time) as the radius. We call it the first step spatial filtering.

If the number of candidates or the uncertainty of the candidate list is greater than the predefined values, then we perform the second spatial filtering by selecting only those that are in the filtering area. In this step, based on the deviation of the moving speed and direction, the possible deviation angle of moving direction is estimated. The filtering area then can be determined based the current location, the deviation angle and the maximum distance. Clearly it is more expensive to query whether the cells fall in a part of a circle than simply comparing coordinates of the upper and lower points.

The third type filtering, which we call semantic spatial filtering, can be used either as an alternative method or as a refinement step in the second step. We first build a lookup table storing the major road network segments and the cells they run though by querying against cell locations and road network in the geographical information database. We can decide whether the sequence of cells a MH has traveled so far is part of a road segment. If the result if true, then the MH is following the road segment. We can give the rest cells along the road segment higher possibilities in the new candidate list. If the road segment is long and has no exits then we can make those cells the only cells in the candidate list and no location update is needed till the MH runs out of the road segment.

By spatially and temporally sub-setting user mobility profiles and using recent movement trajectory, we can provide much shorter and more accurate list of cells that will be associated with the user mobility profile under his/her mobility context. We will analyze our proposed scheme in the next section.

Analysis and discussion

The proposed scheme is an extension to the previous profile based location management studies. It can reduce location update costs compare to schemes that are currently used by popular cellular systems and other proposed schemes that do not make use of user mobility profile, such as time-based, distance-based or movement-based schemes.

The most important feature of the proposed scheme is that it can provide much fewer and more accurate cells in candidate list as mobility profile by exploring spatial and temporal mobility context as well as movement trajectory. This gives two advantages: the first is that the paging time is greatly reduced since the time needed for sequential paging is proportional to the length of the candidate list. Although parallel paging can also reduce paging time, it requires more network resources that we try to avoid. The second advantage is that the there is more reliability for a shorter list. According to the information entropy theory, under even possibility, the information entropy for N candidates is log(N). A smaller N means less entropy and more reliability. The conclusion is often true for uneven distribution. Another advantage is that the proposed scheme provides an online incremental profile generation mechanism. It does not need to store a huge amount of location update data and offline complex computation to generate profiles either.

The major disadvantage of the proposed scheme is that it needs greater network support. First, The network needs a geographical information database and functionalities to generate initial profile as well as look up tables. Second, user profiles which include both the short-term one and long term one, take much more space than those used in the standard Home Location Register (HLR)/ Visitor Location Register (VLR) scheme which only records the most recent cell ID. Third, Location updating costs, although roughly remains the same as in the other profile-based schemes, is much larger than used in the standard schemes. However, we argue that both spatial query and temporal clustering are on the network side. The shift of overheads from the MH side to the network side can improve the whole system performance under the current mobile computing environment due to the asymmetric configurations of the MH and network.

The overheads at the MH side include the storage of a candidate list and a trajectory. While the former is also required by other profile-based schemes, the later is specific to our proposal. However, these storage requirements are negligible (around tens of bytes for the candidate list and maximum size of a single packet for the trajectory). The communication overhead at the air interface is due to transferring the location update data and the trajectory data to the network. Since our scheme can provide much more accurate candidate list of mobility profiles, the amount of location updates necessary to keep track of the MHs is much smaller. The new candidate list sent from the network to the MH can be piggybacked into the acknowledgment data packet for location update for its small and constant size.

The proposed scheme heavily relies on efficient online mobility profile management at both the network and the MH side. At the MH side, it needs to compress its trajectory and keep the packet small and constant size for efficient location database update. At the network side, it needs to retrieve contextual (spatial and temporal) mobility profile from the LTPD when context switch is needed. The STPD in the proposed scheme actually servers as a cache between the MH and the LTPD, thus some cache management techniques, such as pre-fetching and replacement can be applied. The proposed scheme utilizes spatial and temporal query functionalities extensively in both real time contextual mobility profile (location and trajectory) and initial profile generation. The former is much more time critical. We are investigating indexing and query processing techniques for efficient context aware mobility profile access.

Conclusion and Future Work

In this paper, we provide a novel location management scheme using user mobility profiles that are spatial and temporal context aware. The unique feature is to subset mobility profiles under a given spatial and temporal mobility context. The reduction of the candidate list length of mobility profile and improvement of its accuracy will reduce paging cost and latency. We also propose a geography-based method to generate initial profiles and an incremental and streamed location update method for online profile updating while greatly reducing storage requirement. Our future work is to build a prototype to demonstrate the feasibility of the proposed scheme and analyze its performance. There are also several key techniques to implement, such as online spatial and temporal query for generating context aware mobility profiles, recognition of long-time mobility pattern change from the SEDB and the LTPD.

We recognize the overheads of the proposed scheme compared with the ones used by current commercial systems and other proposed profile-based location management schemes. However, the shift from wireless bandwidth consumption to computation power requirement in the fixed network is well justified under the current technology context. Furthermore, the ability of providing location-dependent services based on more accurate mobility profiles makes our scheme more preferable.

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[HREF 1] http://students.ou.edu/Z/Jianting.Zhang-1/Html/STAMobility.htm

[HREF 2] http://www-db.stanford.edu/sumatra/