Taxonomy and Survey of Location Management Systems

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Abstract

In wireless mobile computing, location management is introduced whenever users move from one place to another. In order to track a mobile user, the system must store information about their current location and report new locations to a home base station. Numerous techniques have been proposed to optimally manage the location of mobile hosts in mobile networks. This paper attempts to present a more structured and comprehensive analysis of the current location management techniques architectures and their technology enablers. We discuss some of the principal issues involved in location management and present a taxonomy and survey of location management strategies that have been proposed in the literature over the years for mobile computing systems.

Key words: Mobility management, location management (LM), location area (LA).

1. Introduction

Advancement in wireless technology (i.e., Cell-phone, bluetooth, personal digital assistant, GPS) and mobile devices (e.g., mobile phones and PDA's) have led to wireless mobile device management systems as shown in Figure 1.

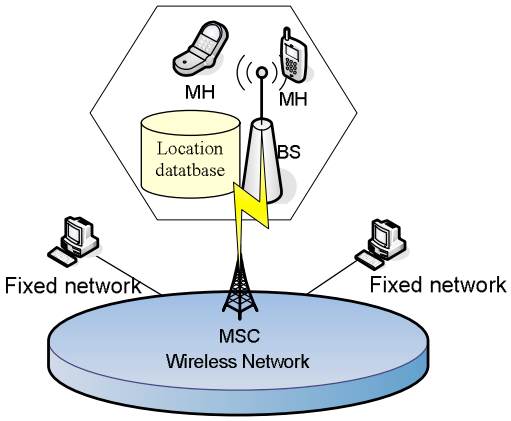

Figure 1: Wireless mobile system architecture.
MH: Mobile host, BS: Base station,
MSC: mobile switching centre.

Wireless mobile networks provide service to their subscribed mobile hosts (MH) in the coverage area called cells (a group of cells form a registration area (RA) that are managed by a mobile switching centre (MSC) connecting directly to the backbone public switched telephone networks (PSTN). In each cell there is a base station (BS), responsible for relaying communications to the underneath MHs over pre-assigned radio frequency. A BS also maintains location information database for managing MH locations such as home location register (HLR) and visiting location register (VLR). Mobility management (i.e., how to track the MHs that move from place to place) is one of the most important issues in wireless mobile networks. It is handled by location management (LM) system and hand-off management system. Every time a MH moves, its geographical location information is updated dynamically to the nearest base station. An automated hand-off registration process allows MH to switch between base stations to support mobility effectively and efficiently. Thus mobile LM systems must include properties such as scalability, availability, precision and efficiency. In this paper we focus on LM systems and present a taxonomy and survey of location management strategies for mobile computing systems.

The rest of the paper is organized as follows. We present taxonomy of LM systems in Section 2. In Section 3, we present classification of the update based schemes while Section 4 presents taxonomy of search based schemes. Finally Section 5 covers some concluding remarks.

2. Location management system

Existing LM system can be classified into four major sub-components such as design properties, structure, standards and operations as shown in Figure 2. The term schemes and algorithms in this paper are interchangeable.

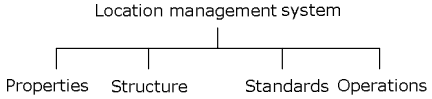

Figure 2: Location management schemes components.

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2.1. Design properties

Design properties are set of desirable factors used to measure the overall performance of LM system as well as schemes. We have classified LM system as well as LM scheme based on performance metrics as shown in Figure 3. We describe these properties in details in the following section.

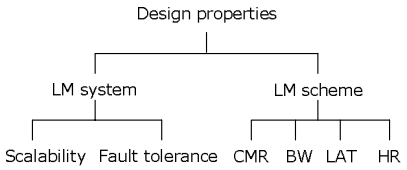

Figure 3: Performance metrics classification.

Scalability is described as the capability of a system to perform well with respect to increasing number of underneath mobile nodes in a network. A highly scalable system can ensure better performance with progressive growth of underneath network compared to a less scalable solution.

Fault tolerance can be well defined as level of system survival during expected as well as unexpected search and update error. A low tolerance system will result in low quality service under error prone situation. Whereas a comparatively higher fault tolerant system can provide better service.

Call to mobility ratio (CMR) can be denoted as relative ratio between a MHs' call and move operation over a certain time period. A small CMR value indicates that a user's mobility rate is comparatively higher than call arrival rate over a specific period of time and vice versa. Evaluating local call to mobility (LCMR) includes ratio between a called MH and origin of calls that is local or child to a hierarchically structured system. Regional call to mobility (RCMR) on the other hand can be described as the average call rate to a MH from a sub node where initial connection pointer was maintained, to average rate at which MH moves out of sub node that is rooted at the node to which the pointer is pointed. Numerical results have proven that, optimal RCMR value can further improve performance of LM solutions [1].

Bandwidth (BW) covers the concept of shared radio signals that gets generated as well as consumed while implementing any specific algorithm. A single cell managing a huge number of mobile nodes at a time will obviously handle more traffic than distributed systems. Signal load in such systems can be a major bottleneck which in terms can hinder overall performance.

Efficiency of a location management scheme can be evaluated based on overall latency (LAT). Few factors that contribute directly in generating signal latency are link speed, nodal data transfer rate etc. A scheme that introduces more latency is less preferable but not necessarily less efficient. Latency issues can be crucial when performing real time hand-off management procedures for MHs [2].

Hit ratio (HR) is a caching based LM scheme performance evaluation variable that is measured in percentage. It is defined as the ratio between the number of times a user is found in the RA pointed by the cache to the total number of cache inquiries related to that user. A higher hit ratio value demonstrates more efficient scheme. In some schemes these ratio can be higher but can yet be costly due to other factors [3].

2.2. Location management structure

Existing LM system could be classified as: centralized, distributed and hierarchically structured. In a centralized LM system, a single location database handles all location requests as well as the location registrations. Dependency among core modules has greater chance of single point of failure and can be overloaded with excessive database traffic resulting in connection latency and lacks overall scalability.

A distributed system consists of modules that can operate in stand-alone mode at anytime. In a partially distributed system, the location information can be distributed at some crucial part of the network. Where as, in a fully distributed scheme, the location information is distributed all over the network through location registers (LR) that replaces centralized VLRs and HLRs. These systems scale better than centralized system and reduce overall single point of failure rate as well. Overall cost of separate stand alone capability modules is a major draw back of such system [4].

Using two-tier hierarchical structure, the system contains HLR at level one and VLR at level two. Numerical analysis has shown that some two-tier systems do not scale well and might not be the best choice for future mobile applications due to lack of performance. Multi-tier schemes are classified by the number of multi-hops required in facilitating communication between two or more nodes. These systems have proven to scales better than two level and centralized schemes and shows improved performance using optimization [5].

2.3. Location management standards

Major LM standards can be classified in two major sub-categories such as non-IP based and IP-based standards. Under Non-IP standards we have two major multi-tier database hierarchy based standards: interim standard 41 (IS-41) and global system for mobile communications (GSM) mobile application parts (MAP). IS-41 is extensively used in advanced mobile

phone systems (AMPS). GSM on the other hand is used mostly in Europe for digital cellular systems-1800 and personal communication systems [6]. Modern concept such as general packet radio service (GPRS) is based on the concept of GSM architecture that performs better in a lower scale network.

The IP based schemes can be classified into two major sub categories such as: the mobile IP and cellular IP. Mobile IP offers the freedom of roaming in IP-based networks. In Mobile-IP based schemes, each MH uses a home agent (HA) at its home network to manage its temporary care-of-address (CoA) allocated through a foreign agent (FA) or dynamic host configuration protocol (DHCP) while visiting a foreign network to sustain service. Mobile-IP based schemes are widely used due to well scalability and performance factors [4]. In contrast, the cellular IP-based scheme operates based on the concept of micro-mobility. It also enables mobility management, passive connectivity and handoff control integrated with routing. It has been shown that, use of cellular-IP based schemes can lead to a simpler and low cost implementation solution for mobility management [7].

2.4. Location management operations

A LM system includes two major operations: update and search; and there are several LM schemes based on them as shown in Figure 4. An update occurs each time a MH notifies its location to a BS as well as during the registration process depending on the scheme behavior. A search operation is the process of looking up a MH to establish a connection.

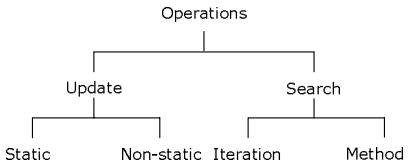

Figure 4: Classification of LM operations

3. Update operation

Update operation based schemes can be divided into two sub classes: static and non-static. The concept of static and non-static behavior can be defined by the factors that contribute in triggering an update event. In a static time-based location update scheme, a time-based registration method is used where a mobile node broadcasts its location update message periodically (using predefined timer) to the backbone system. The problem with such scheme based system is that, when a mobile node stays in the same network cell for a long time it constantly keeps updating same location information every time the timer restarts, resulting in a significant waste of wireless signal bandwidth [4]. Evaluation of several static schemes using simulation shows that both operations under this scheme significantly reduces aggregate costs but lacks performance in situation where models with different costs associated with each link Non-static schemes could further be classified into adaptive and dynamic natured schemes. Naor and Levy in [3], proposed an adaptive threshold based scheme where MH updates location information depending on an adaptive timer threshold value. This value varies according to signal load on the BS. Under random mobility pattern along with linear model, numerical results have proven that both adaptive and dynamic scheme outperforms most static timer based update scheme [8].

3.1. Dynamic update schemes

Dynamic schemes can be classified into five major categories: time based, pointer based, replication based, caching based and per user based dynamic update schemes as shown in Figure 5.

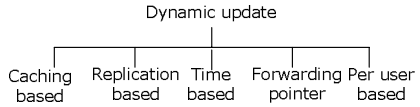

Figure 5: Classification of dynamic update schemes.

In a simple time based dynamic scheme, location update information is dependant on a dynamic timer value. Using this scheme, the total cost gets high as the CMR value remains small, since more cells are involved to locate a mobile node thus raising the paging cost.

Pointer based dynamic update schemes could be classified into simple forwarding based and level forwarding based schemes [9]. A simple pointer based scheme works by setting up a forwarding pointer between HLR and new VLR instead of old VLR. A pointer threshold value is used to avoid lengthy delay. One this threshold value has been reached, the user needs to update its location at HLR again. A two-level forwarding pointer based algorithm introduces the concept of virtual management network of mobility agents [10]. These mobility agents are a set of VLR traversed by any particular MH.

The multi-level forwarding based scheme works on the basis of flooding. The overall performance of this scheme depends on the individual resources of any nodes in a hierarchy [11]. There are few major constraints of pointer forwarding scheme as radio frequency (RF) have direct influence on the routing itself so the value of RF needs to be constant to achieve maximum performance. Wastage of system resources and handshake process between nodes and protocols can be major drawbacks of such a model.

A general replication scheme defines replication level along with replication placement of data in a distributed environment. We can classify replication based update schemes in two categories such as: replicated user profile and working set. In replicated user profile scheme, user profiles are replicated at selected local databases. It can result in higher overall signalling cost but survives single point of failure. These schemes are expensive to implement, requires excessive computational power and network bandwidth. Replication schemes such as the one proposed in [12], depends on the observation of set of sources used by any specific MHs. Numerical results have shown that, with low CMR value these schemes perform same as non-replicated schemes.

A simple caching based scheme such as two location tracking algorithm (TLA) incorporates use of local memory in a mobile node [13]. TLA works with great efficiency when a mobile node travels between two RAs repeatedly. In eager caching every time a MH travels to new location, cached information regarding that user is immediately updated. They require local knowledge and introduce fault tolerance. In per user based caching scheme [14], location information is cached in nearby signal transferring point (STP) in a LA. The overall cost of such scheme is higher than IS-41 with cache misses. Lazy update algorithm also known as path-based algorithm works based on the compression algorithm by Ziv and Lampel using user movement history. The user movement is also maintained in the network as user's profile [15].

In per user based LM schemes can be classified into time based, state based, distance based and movement based update schemes. Using a variation of per user based dynamic location update scheme, the LM system stores per MH's most likely path records [16]. Using profile based schemes (PBS) a database is able to gain exact location information about a user. PBS scheme can reduce overall update cost while increasing paging cost or delays while paging.

In per user time based scheme such as the one proposed in [17], the location update time interval is determined based on probability distribution of inter-arrival call time. Less computational power requirements is a great advantage of such schemes along with scalability. Unconstrained paging delay is a major drawback of such algorithms.

In a state based update scheme, update is dependent on the MH's state at any given time that includes number of cell, current location, time since last update, distance between two last visited cells etc [18]. The result of such algorithm proved to be suboptimal using greedy techniques for overall location update cost under no-delay constraints.

In a distance based dynamic update algorithm a MH uses different distance based information to perform update operation [2]. And there also exists few variations of these schemes. Numerical results have shown that, the distance-based scheme is better than time-based and movement-based schemes in terms of the expected update rate for which required search numbers are greater in time and movement based than that of distance-based scheme but require significant computational power at MH [2].

In a movement threshold based update scheme, a predefined threshold value is set. Thus setting a suitable threshold value is a crucial component for gaining maximum performance from such scheme[19]. It uses counter in MH to count cell boundaries. Using selective movement based scheme, a MH uses counter to calculate cell crossing values that resets depending on threshold value. Where as in a probabilistic movement based scheme such as mobility pattern based schemes (MPBS), artificial intelligence is used to perform successive location update. MPBS can reduce update cost significantly compared to IS-41 and GSM MAP schemes. It has been statistically proven that, when CMR is low, paging delays are 70% less in MPBS than that of PBS. Paging delay remains as one of the major concern in MPBS along with update numbers [16] [17] and [19].

4. Search operation

Searching/paging is the process of locating a subscribed MH. Most paging schemes can be classified in to iteration based and method based search schemes. The iteration based search schemes can be again classified into parallel and sequential sub categories based on the nature of search iteration. Parallel paging results in minimum delay in locating a MH. In a sequential paging if a MH can be found while paging first time, no further paging is required to locate MH and might save a lot of signal but introduces paging delay [10].

Under method based categorization, paging schemes can be classified as static in a sense that, while locating a MH a cell has priori knowledge of the LA to be broadcasted. A major drawback of static paging is that, worst case is performed in most cases as all subsequent nodes are paged at the same time. Non-static such as adaptive paging scheme, uses hierarchical locations that changes dynamically with traffic patterns as well as estimates the location probability of MH. Such schemes show better performance when user movement pattern is repetitive within few cells. One major drawback of such scheme is the huge amount of redundant traffic for a system-wide paging [20].

4.1. Dynamic search schemes

Existing dynamic search schemes can be classified as: operational delay based, iteration based, per user based, IP based and LA based as shown in Figure 6.

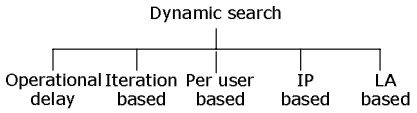

Figure 6: Classification of dynamic search schemes.

Operational delay based schemes can be classified as: with or without delay constraint. Using blanket polling under scheme with delay constraint, when a call arrives, all subsequent cells within LA of MH are polled simultaneously. One major drawback of such scheme is higher paging cost when the LA covers a larger area with many cells underneath [2].

In a shortest-distance-first scheme, initial paging is done depending on the last updated cell information and moving onward in a shortest-distance-first order. Here distance represents number of calculated cells from last updated location. Paging delay can be introduced in such model by grouping cells at different distances for each polling cycle [2].

Schemes without incorporating delay constraints can again be classified as: sequential paging and shortest distance first based schemes. Using sequential paging scheme, current location of MH is predicted based on its location probability distribution and signals are sent only to selective locations. A version of shortest distance scheme without incorporated delay constraint has been discussed in [2]. Numerical result shows that, uniform location distribution also generates highest paging cost and delay.

Per user behaviour based search schemes can be classified further based on their working principals into: movement pattern, integrated scheme and time and state information based schemes. They use user behaviour parameters as primary source of information collection as well as operational strategy generation.

A movement pattern based prediction scheme such as the one described in [21], uses user mobility pattern as the basis of formulating prediction areas to be paged when a call arrives. The main advantage of such algorithm is that, even with the worst case scenario the paged area under this scheme is limited to dynamically predicted locations only, not world-wide. It saves a lot of signalling cost compared to LA based schemes.

An integrated dynamic paging scheme such as the one described in [22], uses user velocity and reduces paging cost by minimizing paging area. Here users are grouped into different classes based on their velocities while updating. It integrates information such as last location information, velocity class index and last registration time from user's profile.

A time and state based algorithm uses information based on user state and time. One such scheme proposed in [23], uses user specific activities at a location along with time zone, duration, transition matrix etc. The scheme proved to out perform most other similar schemes in terms of overall cost. One major drawback of this scheme would be overdependence on user profile.

Using IP based paging techniques each MH reports its location ID as it crosses paging area. Thus to locate the same MH, the scheme searches the reported paging area. These IP based algorithms can be again classified into three major sub categories such as static, adaptive and dynamic depending on the nature of paging procedures. Static IP based schemes such as paging extensions for mobile IP or P-MIP [24] introduces architectural and protocol issues. They are considered static in a sense that the covered paging area is predefined. Thus it is infeasible to determine optimal paging area using static schemes.

Adaptive IP based paging scheme displays dynamic behaviour but in an adaptive manner. For example, algorithm proposed in [20], takes into account user movement history over certain period of time to calculate most probable LA as well as future probable LA to generate an adaptive paging solution each time a call is initiated. Most variations of such model have proved to demonstrate better performance when MH is in almost-uniform motion.

Dynamic IP based paging schemes have been proved to be advantageous than static natured ones as they tend to make adaptation of paging area simple as well as free from consistent registration traffic in the boundary cells. Numerical results have proven to reduce overall LM cost using such scheme. The update cost is less than static algorithm while paging cost remains similar in most cases [25].

LA based dynamic search schemes can be classified into dynamic LA paging and base station controller (BSC) based paging schemes. In dynamic LA based search algorithm, LA operates under a single VLR but different BSC. Using this scheme the VLR needs to keep track of MH's last visited BSC as well as probable location based on intelligent algorithms [26]. In BSC based paging scheme, paging control point is located at BSC and it also records MH's last location update as well as call setup. They scale well and over all performance is similar result to most dynamic algorithms [26].

5. Conclusion

LM schemes have always been a field of major research interest since the introduction of wireless communication technologies. This paper focuses on an alternate approach to classify existing LM schemes by

surveying major LM schemes along with their classification as well as evaluation characteristics. Various LM schemes use location information of underneath MHs by exploiting various MHs' behaviour, environmental and artificial intelligence based parameters to increase the overall efficiency of mobility management. Thus various LM schemes exist exploiting one or more of these parameters in order to improve performance of overall mobility management. Although most of the scheme seems to demonstrate good performance but developing an optimal LM scheme remains a promising research topic.

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