CENTRAL ISSUES AND CLASSIFICATIONS OF LOCATION MANAGEMENT TECHNIQUES IN WIRELESS AND MOBILE COMPUTING SYSTEMS

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Abstract: The rapid growth in mobile and wireless computing technology continuous to present new challenges. Mobile users access information, independent of their location, through wireless and wired networks. In 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 his current location and report new locations to a home base station. Several techniques have been proposed to optimally manage the location of mobile hosts. In this paper, we present an overview of some principal issues, concepts and definitions used, and techniques proposed and developed for location management in mobile computing systems. The performance of these techniques is dependent on several parameters, such as the Call-to-Mobility Ratio (CMR). It also depends on update and routing costs, calls, and moves. We discuss different approaches introduced and assess their effectiveness. This will be followed by a survey of existing classifications of location management solutions. Finally, we introduce an alternative way of classifying these techniques in light of the central issues identified and in order to facilitate the development and design of a framework for these systems.
Keywords: Wireless and Mobile Computing, Location Management Techniques, CMR, Classification of LMTs.

1. INTRODUCTION

In mobile and wireless computing environments, mobile hosts may relocate from one cell location to another. In order to keep track of mobile hosts, the system must record and know the information about mobile hosts' current location. In recent years, several location management algorithms have been proposed to reduce the update and lookup costs accruing as a result of maintaining host information. An update occurs when a mobile host sends a message to update its stored location. A lookup occurs when it is required to locate a user each time a call is placed to that user or when a message is sent to her. The location updates and lookups are evaluated in terms of the number of messages sent, the size of messages, the distance the message needs to travel, the bandwidth consumed, the processing overhead and the delay incurred in answering locations queries. The main criterion used for efficient update is low signaling cost incurred by relocation of hosts between cells. The cost should be kept small enough not to affect network performance. This mobile communication network technology is expected to further develop to smaller cells for greater bandwidth sharing and reuse. The signaling load for location updates will be higher due to more frequent relocation for small cells [Hacacute and Liu, 1998]. A good location management scheme should attempt to optimize all of these parameters. Tracking mobile hosts and establishing efficient routing are basic functions of a mobile computing system. The system needs to be updated and provided information about the location of mobile hosts regularly. Typically, the location area structure has several cells in it, and a mobile computing environment structure consists of several location areas, which may overlap with each other. Depending on the algorithm employed, an update will occur when the mobile host moves from one cell to another or from one location area to another location area.

A general mobile system consists of mobile hosts (MHs) that interact with a static network through fixed hosts, known as mobile base stations (MBSs). MBSs are augmented with a wireless interface, and they provide a gateway for communication between the wireless network and the static network. A mobile host can communicate with a mobile base station within a limited region around it. This region is referred to as a mobile base station's cell. Cells can have different sizes, and the average size of a cell is typically around 1 to 2 miles in diameter. A mobile host communicates with one mobile base station at any given time. An MBS is responsible for forwarding data between the mobile host and the static network. Due to mobility, a mobile host may cross the boundary between two cells while being active. Thus, the task of forwarding data between the static network and the mobile host must be transferred to the new cell's mobile base station [Krisha et al, 1996]. This process, known as *handoff*, is transparent to the mobile user. Handoff takes place when a mobile host moves from one cell to another

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during a communication session. The information transmitted to the original mobile base station is easily forwarded to the new mobile base station through their common link. Note that handoffs and location management serve different purposes. The former is not required unless a communication session is in progress while a mobile host moves from one cell to another, whereas the latter is always required [Doley et al, 1996].

2. CALL-TO-MOBILITY RATIO

In a mobile computing environment, there are two important factors to consider: calls and moves. During a given time period, the number of calls and the number of moves determine how many data packets a mobile host is sent and how many movements the host has made, respectively. Classes of users are characterized by their call-to-mobility ratio (CMR) [Jain and Lin, 1995]. CMR is the average number of calls to a user per unit time, divided by the average number of times the user changes registration areas per unit time. We also define a local CMR (LCMR), which is the average number of calls to a user from a given originating signal transfer point per unit time. The LCMR can be used to relate the hit ratio to users' calling and mobility patterns directly. To do so, we need to make some assumptions about the distributions of the user's calls and moves. Let the call arrivals from an MBS to a user be a Poisson process with arrival rate λ, and the time that the user resides in a registration area be $1/\mu$. Then, LCMR can be expressed as: LCMR = λ / μ.

Since we are dealing with non-negative random variables, it is convenient to associate with a probability density function, f(s), its Laplace transform, $f^*(s)$. Let the residual time of a user at an RA be a random variable with a general density function f_m. Then, its Laplace transform is given by $f_m^*(s) = \int_{t=0}^{\infty} f_m(t) e^{-st} dt$. Let t be the time interval between two consecutive calls from the MBS to the user, and t_1 be the time interval between the first call and the time when the user moves to a new RA. From the random observer property of the arrival call stream [Feller, 1968], if call arrivals are Poisson distributed and $F(t)$ is an exponential distribution, the hit ratio of a user calling can be given by $p = \int_{t=0}^{\infty} \lambda e^{-\lambda t} \int_{t_1=t}^{\infty} f(t_1) dt_1 dt$, where $f(t_1)$ is exponentially distributed with parameter μ. That is, $f(t_1) = \mu e^{-\mu t_1}$, and $F(x) = 1 - e^{-\mu x}, x \geq 0$. From these relationships, we can express the hit ratio as follows [Jain and Lin, 1995]: $p = \int_{t=0}^{\infty} \lambda e^{-\lambda t} \int_{t_1=t}^{\infty} \mu e^{-\mu t_1} dt_1 dt = \lambda/(\lambda+\mu)$. Note that for different values of LCMR, there will be different values of hit ratio.

Several works have used the CMR to compare different algorithms and to show that it is one of the factors that could heavily affect the performance of these systems. For instance, the number of calls and moves generated by a mobile host in a unit time can be modeled as a Poisson distributed random variables. Then, the time interval between successive moves or calls can be obtained from the product of CMR and the Poisson distributed variables [Cho, 1998]. In his simulation study, each mobile host component repeatedly fires the call or move event with the time interval computed, and runs a corresponding routine. The simulation results obtained in the study showed that the number of location updates was dependent on two simulation parameters: the CMR and the symmetric rate, which is defined as the ratio between the time a mobile host stays at its home MBS and the time it spends in other MBSs. One study, [Ho and Akyildiz, 1997], argued that in general, the relative cost increases with the CMR. When the CMR is low, the mobility rate is high and the cost for the location registration dominates. When the CMR is high, the mobility rate is low and the cost saving from location registration diminishes. Therefore, the cost reduction is most significant when the CMR is low and the cost for accessing the home base station is high. Interestingly, FBFind algorithm [Kim and Smari, 2003a] showed different results. In this work, LCMR was varied from 1 to 10 and the cost of the algorithm was measured. They found that the algorithm saved about 40% more in costs when the LCMR was 10 than when it was 1, i.e., the algorithm saved more in costs with higher LCMR. In another work on distance-based updating cost analysis [Kim and Smari 2003b], they modified the FBFind algorithm's system model and measured the cost of the algorithm. They found that they could save more than 50% of the costs when the LCMR is 10 than when it is 1.

3. LOCATION UPDATE & LOOKUP SCHEMES

Mobile hosts within a cell communicate with other hosts through a MBS which is installed within the cell, as illustrated in Figure 1. This MBS is connected to other MBS through an underlying wire line network. In order for the network to efficiently route incoming messages to a mobile host, each mobile host is required to report its location to the network. This reporting process is called location update. The purpose of location update is to reduce the cost for tracking down the mobile host. An effective location update policy should reduce the average cost as much as possible compared to the no-update policy. There are a number of ways to determine these location update points. The most commonly used scheme is to group the cells into location areas. A mobile host performs location update whenever it enters a new location area [Akyildiz and Ho, 1995].

Typically, location update is done in the following way. First, each MBS broadcasts the identity of its location area periodically. Second, the mobile hosts always listen to the network broadcast information and store the current location area identity sent. If the received location area identity number is different with its previously stored number, the mobile hosts trigger location update procedure.

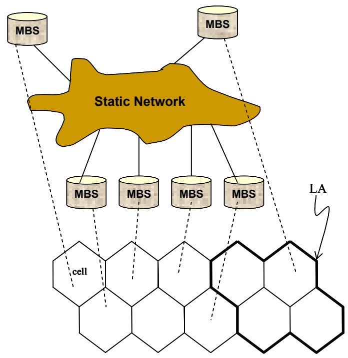

Figure 1 A General Mobile Computing System

In the case of a lookup scheme: when a call is placed to a mobile host or a message is sent to it, the system must be able to locate the host by tracking its movements. To make host tracking easy, the mobile network is partitioned into Location Areas, which are chunks of cells, as was mentioned before [Weng and Huang, 2000]. Now, to perform a lookup scheme, two steps of processing are taken. First, determine the LA where the mobile host is currently located at, and second, page the cells of this particular LA to determine the exact cell within where the MH is residing. There are several schemes introduced to reduce lookup time. Replication [Shivakumar and Widom 1997] and caching [Minh and Van As 2001] schemes are two well known techniques used for this purpose. Replication is different from caching in that it always keeps all copies up-to-date and there is no invalidation problem. But the associated costs of replication will increase rapidly, especially for frequently moving mobile hosts.

In addition to mobile host, mobility agents are very important entities for location and routing. A mobility agent provides the wireless interface between mobile hosts and the rest of the network. It maintains a set of mobility bindings-an association of the host's home identifier with a current locator for the hosts locally or remotely under its control. The agent works a router, and if necessary, forwards packets to a host's current location using the binding information it has. If a host is initially registered with this agent, the agent is called the home agent, otherwise, it is known as a foreign agent. When the host moves to another agent, the current agent becomes known as the previous agent [Cho, 1998].

Source messages intended for a mobile host can be routed in one of two ways: informed routing or triangle routing [Yates et al, 1996]. In informed routing, the source knows the direct route to the mobile host, and is informed of all location changes by the mobile host. In triangle routing, the source directs messages to a home agent that forwards messages to the mobile host.

Routing impacts update procedure performance directly. We can say that the efficiency of a location update depends on how to distribute the location information through the entire network. Usually, the efficiency of location update is measured by the total cost of routing a packet to its destination mobile host. The total cost to route a packet to its destination mobile host is contributed by two parts, update cost and routing cost. Update cost consists of both registration cost and patron service update cost, while routing cost consists of search cost and hop cost between the node in which the mobile host's location binding is found and the destination mobile host [Hacacute and Huang, 2000].

4. GENERAL CLASSIFICATION OF LOCATION UPDATE SCHEMES

Classifying location management schemes can be considered from several perspectives. One way is to look at these schemes under the two main components of any management technique, namely, updates and lookups. Most of the literature has focused on the former. Due to space constraints, we will concentrate on it too in this work. Update schemes can be of three main types: dynamic [Akyildiz and Ho, 1995; Austin and Stuber, 1996; Bhattacharaya and Sajal, 2002; Chen, 2000; Cho, 1998; Doley et al, 1996; Hacacute and Huang, 2000; Ho and Akyildiz, 1997; Kim and Smari, 2003; Krishnamurthi et at, 1998; Lee et al, 2001; Lin, 1997; Liu and Maguire, 1996; Maass, 1998; Pissinou et al, 1999; Rocha et al, 1999; Scourias and Kunz, 1999; Suh et al, 2000; Wang and Huey, 1999]; static [Krisha et al, 1996]; and adaptive [Bharghavan,1997; Yates et al, 1996]. Figure 2 shows this type of classification.

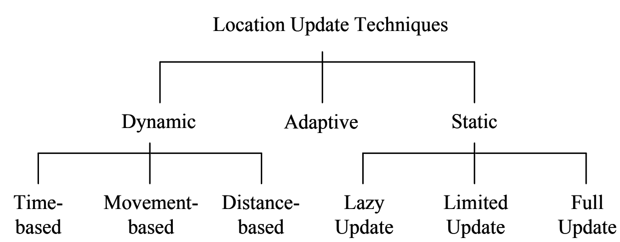

Figure 2 Traditional LUA Classification

A static algorithm may fall under one of three different types of updating methods: lazy update (LU), limited update (LMU), and full update (FU), depending on the update cost metric [Krisha et al, 1996]. Here, the updating occurs by querying from mobile base stations (either home MBS or visitor MBSs). The lazy update (LU) is the simplest update scheme, where an update occurs only at home MBS and the last visited MBS. In this case, the cost of update is zero because no update messages are sent to other visited MBSs. On the other hand, in the full update (FU) case, the update messages are sent to all visited MBSs through the last visited MBS. Hence, the cost of this update depends on the number of visited MBSs. Lastly, in the limited update (LMU) case, the update messages are sent to a specified number of visited MBSs.

Dynamic location update methods [Bhattacharaya and Sajal, 2002] can be classified into three categories too: time-based, movement-based and distance-based. Under strategies using the three categories, location updates are performed based on the time elapsed, the number of movements performed, and the distance traveled since the last location update, respectively.

An adaptive location management algorithm is sought when seamless location update is required across different mobile networks (i.e., between intranets). If a mobile host moves from one mobile network to another, the algorithm provides the necessary mechanisms to maintain service across the networks quickly and without losing connectivity. For example, mobility from indoor to outdoor mobile computing networks may result in a bandwidth decrease by two orders of magnitude. In order to provide a graceful degradation of the operating environment, mechanisms for system and application levels adaptation are necessary [Yates et al, 1996].

Table 1 summarizes algorithms that are referenced in this paper and indicates the respective category for each algorithm. The first column shows the reference cited in the article. The second column lists the name of the location update algorithm (LUA). The third column shows the type of policies used: static (S), dynamic (D), or adaptive (A) and their respective subcategories (e.g., time, movement or distance for dynamic, lazy, limited or full for static). The fourth column denotes the method used to model or solve the problem. (Markov) indicates that authors use a Markovian model to develop their solutions. Similarly, (Prob) is for a probabilistic mathematical approach, (Math) is for other mathematical techniques, such as Gaussian, Laplace transform, ratios, etc., (Pseudo) is for a pseudocode based algorithm. Last, (Simul) indicates that simulation was employed for the solution. The last column indicates whether the corresponding algorithm uses hierarchical (H) or nonhierarchical method (N), which will be discussed later, and the targeted application type (V for video and D for data) for the mobile system.

It is worth noting also that several studies have been carried out to compare many of the policies mentioned above [Hacacute and Liu 1998; Krisha et al, 1996; Siddiqi and Kunz 1999].

Table 1 The LUAs Categorization

Author year	*Name of (LUA)*	*Policy*	*Method*	*Type /App*
Akyil95	Dynamic mobile terminal LUA	D-t	Markov	N/V
Austin96	Direction biased handoff algorithm	D-m	Math.	N/V
Bharg97	PRAYER	A	Simul.	N/D
Bhatta02	LeZi LUA	D-m	Markov	H/V
Chen00	TLA, FRA	D-m	Markov	N/V
Chen98	FRA	A	Markov	H/V
Cho98	Route optimized LUA	D-t	Math.	N/D
Dolev96	Modified tree method	D-t	Pseudo	H/D
Hacac00	LU routing schemes	D-m	Review	H/D
Ho97	Dynamic Hierarchical LUA	D-m	Prob.	H/V
Janni97	HiPER LUA	S-l	Simul.	H/D
Kim03 a	FBFind algorithm	D-d	Prob.	H/D
Kim03 b	DBLM algorithm	D-d	Prob.	H/D
Krishn98	Optimal LUA	D-d	Prob.	N/V
Lee01	LUA for frequently visited locations	D-m	Prob.	H/V
Lin97	Two Location Algorithm	D-m	Math.	N/V
Liu96	Prediction Algorithms	D-m	Markov	H/D
Maass98	Location aware mobile algorithms	D-m	Pseudo	H/D
Madh95	Dynamic programming method	D-d	Markov	N/V
Pissin99	Location and query management algo.	D-m	Pseudo	N/D
Rocha99	Mobile unit tracking algorithm	D-m	Pseudo	N/V
Scouri99	Activity based LUA	D-m	Simul.	N/V
Suh00	Hierarchical LUA	D-m	Prob.	H/D
Wang99	Distributed LUA	D-m	Markov	N/D
Yates96	Mobile assisted adaptive LUA	A	Prob.	N/D

5. A NEW CLASSIFICATION METHOD

We propose a new taxonomy for location management schemes based on the modeling technique employed. At this taxonomy's top level, we consider *hierarchical* [Bhattacharaya and Sajal, 2002; Chen, 98; Doley et al, 1996; Hacacute and Huang, 2000; Ho and Akyildiz, 1997; Jannink et al, 1997; Kim and Smari, 2003a and b; Krisha et al, 1996; Lee et al, 2001; Liu and Maguire, 1996; Maass, 1998; Suh et al, 2000] versus *non-hierarchical* modeling techniques [Akyildiz and Ho, 1995;Austin and Stuber, 1996; Bhargavan, 1997; Chen, 2000; Cho, 1998; Ho and Akyildiz, 1997; Krishnamurthi et at, 1998; Lin, 1997; Pissinou et al, 1999; Rocha et al, 1999; Scourias and Kunz, 1999; Siddiqi and Kunz, 1999; Yates et al, 1996]. The motivation for considering the hierarchy of models in classifying location management approaches of mobile systems is due to the fact that these systems, by design, are either hierarchical or nonhierarchical. As such, their models must be of corresponding nature. Hence, using this classification should prove useful in understanding, analyzing and designing these systems. Figure 3 shows the overall proposed classification.

A basic hierarchical model of a mobile system consists of multiple layers. Each layer stores databases that correspond to information about the lower layer to it. At the lowest layer, which is referred to as the MBS layer, the database information stored consists of information about all mobile hosts that visit the cell (or location area) serviced by that MBS. The second lowest layer stores database information about the MBS layer. At the highest level, i.e., the hierarchy's root, the database includes information about all the children of that root. Typical information may include database ID, user ID, user profiles and pointers. In practice, this conceptual root may be "distributed" over several lower level "roots", each of which can service its own lower levels. This way one database (at the actual root) need not store all users' information nor service all root level queries and updates [Jannink et al, 1997]. When using a hierarchical technique, which employs a tree like modeling of the mobile system, there are two main subcategories to consider: threshold-based (using time, movement, and distance criteria) and non threshold-based (partitioning, grouping, and caching). These will be discussed further shortly.

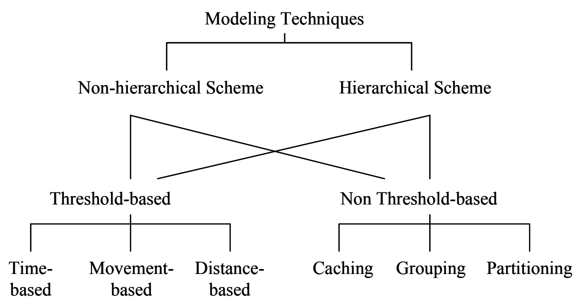

Figure 3 A New Classification of LM Algorithms

In a non-hierarchical technique, which Elnahas and Adly [Elnahas and Adly, 2000] referred to as a two-tier scheme, the current location of a mobile host is stored at two possible locations in the network. If the mobile host is at its home MBS, then its current location is maintained in that MBS. If, on the other hand, the mobile host is visiting another cell (or LA), then, its current location is maintained in its home MBS as well as in the MBS that services the cell it is visiting. The current location is updated at each move. Nonhierarchical schemes may also be of two subcategories: threshold- and non threshold-based. These will also be further discussed shortly.

5.1 Threshold-based Schemes

In a threshold-based scheme, a pre-specified value is used to trigger events of interest. This threshold value may relate to time, distance, or movement associated with the mobile host. For example, an update or lookup may occur if a prescribed time has elapsed since the last update or lookup. Threshold based schemes may be used to design update or lookup policies. In either case, there are three taxonomy subcategories that can be considered: time-, movement-, or distance-based.

In a time-based threshold scheme, the mobile host sends periodic updates (or lookups) to the system (a MBS). The period or time threshold T between updates can be programmed into the mobile hosts using timers. However, the cost due to redundant updates made by stationary mobile hosts has to be tolerated. Obviously, these stationary mobile hosts do not need to send updates which represent no new data. Akyildiz and Ho [Akyildiz and Ho, 1995] address this problem by proposing the use of time points to check the mobile host location: if no movement is detected, then the MH need not send any update; otherwise, it will be allowed to. The method records the time spent by an MH in each location and uses these times to establish the MH movement time patterns. Then, it uses these patterns to determine the time for the next update (i.e., the MH did move).

In a movement-based threshold approach, the mobile host sends update messages to the system (a MBS) when it crosses a pre-specified number of cells. That means, the mobile host needs to count the number of cell boundary crossings and update when the count reaches certain threshold M. For efficiency purposes, cell sizes may differ between, for example, urban and rural areas. It is expected then that the number of crossings will change in these two cases. Applying a threshold policy means more updates will be made in the former case. Hence, one of the drawbacks of this scheme is increased signaling traffic due to different sizes of the cells. Scourias and Kunz [Scourias and Kunz, 1999] use the mobile host's mobility patterns to reduce this signaling traffic. They develop a model that stores information about the mobile hosts' daily movement patterns to minimize the traffic costs.

In a distance-based threshold solution, the mobile host is required to track the Euclidean distance from the location of the previous update and initiates a new update if the distance exceeds a specified threshold D. The distance could be specified in terms of the distance units used or the number of cells between the two positions. Madhow et al [Madhow et al, 1995] discuss finding the optimal value of D by using the expectation functions of the sum of update costs until the next update. They compare an iterative algorithm and a difference equation to find the optimal D and show that the proposed iterative algorithm works better.

5.2 Non-Threshold-based Schemes

In a non-threshold-based technique, no pre-specified value is used to trigger events of interest or to reduce the costs. Instead, these approaches use grouping methods, caching methods and so on. A well-known method under this category is location area partitioning. In this method, the service area under the static network is partitioned into location areas (LA) formed out of neighboring cells. The LAs could be overlapping. A mobile host must update whenever it crosses an LA boundary. Its location uncertainty is reduced by expanding the search space to the set of cells under the current LA rather than having per cell searches. All cells under an LA are paged simultaneously upon a call arrival, resulting in an assured success within a single step (i.e., an MH in that LA will connect). The MBSs must broadcast the LA-id (along with the cell-id) to help the MHs perform the update.

Weng and Huang [Weng and Huang, 2000] introduce a modified grouping method to achieve maximum cost savings in the network. They consider location areas with different sizes and calculate costs associated with each. The claim is that this method could yield a significant improvement over the conventional cell structure. However, there is a drawback: if a system has LAs of larger size, the technique increases the routing costs.

Bharghavan [Bharghavan,1997] discusses a data caching method. This method reduces access time but causes higher wireless traffic by reducing cache size. It also introduces a related problem: data consistency, since multiple copies of shared data are maintained. Thus, most approaches to caching 'hoard' data aggressively, and allow the mobile user to manipulate the cached copy at the portable when disconnected. The modified data is reintegrated with the server copy upon reconnection and update conflicts are typically reconciled by human intervention in the worst case.

5.3 The Taxonomy

Figure 4 shows the new classification of location management techniques. We can organize the known techniques of location management into this 144-cell taxonomy. For instances, the A algorithm represents a dynamic update technique under hierarchical model that deals with voice transmission application, using distance based threshold approach. Likewise, the B algorithm indicates a static lookup technique with non hierarchical partitioning model and voice transmission application, with non threshold approach. Hence, using this taxonomy, we can easily identify any LM problem at a glance.

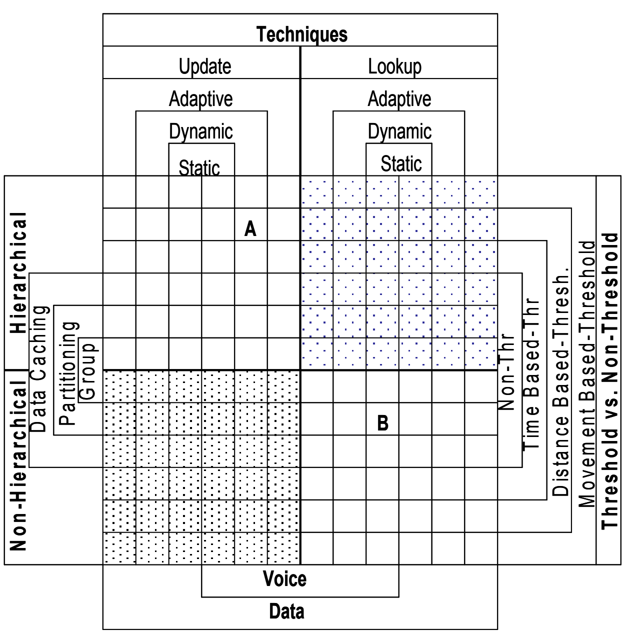

Figure 4 The New Classification of Location Management Techniques

6. CONCLUSIONS AND FUTURE WORK

In the past few years, location management issues and solutions have received a good deal of attention, both in literature and industry. Efficient location management techniques are an important aspect to consider in the design of future mobile and wireless environments, especially since the number of mobile hosts is poised to increase at a high rate. In this study, we defined the location management problem and its terminology, reviewed some of the main accomplishments achieved by researchers in the field, and established the fundamental issues that impact this problem. We also attempted to compare the solutions qualitatively according to their effectiveness for different types of updating techniques. That analysis led us to propose a new taxonomy for location management techniques in mobile and wireless environments based on several important factors. For future work, we plan to extend our analysis to other possible solutions of the location management problem and help devise more efficient and robust ones.

In closing, it is worth speculating on the long-term impact of location management issues on mobile and wireless environments and their design. The future for wireless and mobile computing is promising indeed, especially since technological advances continue to support more sophisticated applications for these environments.

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