Performance evaluation of a hybrid location management scheme for mobile systems

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Hierarchical location management schemes have been proposed to cope with the large number of users in future personal communication systems. We have previously proposed a Hybrid scheme that combines the hierarchical architecture and the two-tier architecture into one scheme. The Hybrid scheme benefits from the scalability offered by the Hierarchical scheme while reducing the number of databases updated and queried. In this paper we quantify the costs and benefits of the Hybrid scheme and one of its variations. Unlike our previous work where we considered the user's calling and mobility behavior in terms of the aggregated Regional Call-to-Mobility Ratio (RCMR), in this paper the performance evaluation is done in terms of the Call-to-Mobility Ratio (CMR) of the user while modeling real life scenarios using an event-driven simulator. It is shown that the Hybrid scheme can result in improvements over the Hierarchical scheme for high values of CMR reaching 20% for the communication cost and 60% for the database cost.

اقترحت الأنظمة الهرمية لإدارة بيانات المواقع للأنظمة المتحركة للتعامل مع العدد الكبير من مستخدمي أنظمة الاتصالات الشخصية المستقبلية. و لقد قمنا في بحث سابق بعرض نظام جديد يجمع بين العمارة الهرمية و العمارة السطحية. النظام المختلط ينتفع من التوسعية المقدمة من العمارة الهرمية و أيضا يقلل من عدد قواعد البيانات التي يتم تحديثها أو استعلامها. هذا البحث يقوم بتقييم التكلفة و التحسين الناتج من النظام المختلط و أحد مشتقاته. بخلاف البحث السابق و الذى أرسى التقييم بناءا على نسبة الاتصال إلى الحركة المحلية RCMR فإن هذا البحث يقيم النظام لمدى من نسبة الاتصال إلى الحركة و لمستخدمين يتبعون نماذج اتصال و حركة مختلفة تمثل مجريات الأحداث اليومية باستخدام نظام محاكاة مستحدث للحدث. و تبين أنه عند ارتفاع نسبة الاتصال إلى الحركة فإن النظام المختلط يؤدى إلى تحسين فى الأداء بنسبة تتراوح بين ٢٠% إلى ٦٠% عن النظام الهرمي.

Keywords: Software systems, Mobile computing, Location management, Mobile databases

1. Introduction

In location management schemes, databases are used to store information about the location of moving users. A location scheme can be described by two main operations: a *Move* operation and a *Lookup* operation. The *Move* operation updates the database when a user moves from one location to another, and the *Lookup* operation locates the mobile user – based on the information stored at the database – each time a call is placed to that user.

In current wireless systems, such as GSM and IS-41 [1], each user has a *home* database, Home Location Register (HLR), which maintains his current location and is updated at each move. Further, a Visitor Location Register (VLR) is maintained at each zone. It stores a copy of user's profile not at home and currently located at that zone. When a user at cell i calls user x, the VLR at zone i is queried first, and if not found, then x's HLR is interrogated. This architecture is termed as the *two-tier architecture* and several of its variations have been proposed [2-5]. The HLR/VLR scheme serves well certain mobility and calling patterns but result in remote updates and queries for others, which increases consumed bandwidth and incurs high latency. Further, the scheme imposes a high overhead on the HLR nodes.

With the increase in user population, the need for a scalable architecture that could reduce the signaling traffic, especially observing the locality of users, became a must. Therefore, the *hierarchical architecture* has been proposed [6] and became the base for third generation mobile systems. The hierarchical location schemes maintain a hierarchy of locations databases, usually in the form of a tree, where a location database at a leaf node serves a single zone and contains entries for all users located in that zone. Each database in the higher levels of the hierarchy, stores *pointers* (user ID + database ID) to the next lower level database that stores the user's profile. When a user moves from location i to j, the databases along the path from j to the Least Common Ancestor of nodes i and j, denoted LCA(i,j), are updated to register x and those along the path from LCA(i,j) to i are updated to deregister x. Looking up a user starts at a leaf node and proceeds up querying higher level in the hierarchy until an entry for the user is found, then it propagates down the hierarchy following pointers until the leaf where the user is located [6-13].

Hierarchical schemes enhance scalability by distributing the load on various databases in the hierarchy rather than overloading the HLR. Further, they reduce the communication overhead when most calls and moves are localised, independent of the home location of users. However, this is on the expenses of increasing the cost of updates and lookups since the number of location databases updated and queried are larger than the two-tier scheme. Various techniques such as forwarding pointers [9], replication [10,11] and caching [12,13] have been proposed to reduce the signaling impact of mobile systems. For a survey of location management techniques under both architectures please refer to [14,15].

In a previous paper [16] we have proposed a Hybrid scheme that combines both techniques in order to offer better performance for larger number of classes of users within one scheme. The main idea of the Hybrid scheme is to apply the Hierarchical scheme up to level m in the hierarchy. So, a user x moving from one location to another results in updating the path in the hierarchy up to level m only. Further, a forwarding pointer is added at the node on the home path of user x at level m, denoted $HLR_{x,m}$, containing the current location of x. When a user tries to locate x, it searches the higher level of the hierarchy up to level m, if x is not found then the query is directed to $HLR_{x,m}$. We developed a simplified first-cut analytical model and quantified the costs and benefits of the Hybrid scheme in terms of the user's Regional Call-to-Mobility Ratio (RCMR). The RCMR for a user with respect to nodes s and t is defined as the average number of calls from the subtree rooted at s to the user while it is in the subtree rooted at t. However, it is more realistic to evaluate in terms of the user's Call-to-Mobility Ratio (CMR), which is the total ratio of number of calls to the number of moves.

In this paper, we have developed an event-driven simulator that allowed us to evaluate the performance of the Hybrid scheme and one of its variations, in terms of the CMR while modeling different mobility and calling behavior representing real life scenarios. A number of experiments have been conducted for a wide range of call to mobility ratios and the results showed that the Hybrid scheme can result in improvements over the Hierarchical scheme for high values of CMR reaching 20% for the communication cost and 60% for the database cost. The Variant scheme was shown to improve the move cost of the Hybrid scheme at the expense of increasing the lookup cost.

The paper is organized as follows. The Hierarchical and Hybrid location schemes are presented in Section 2. Section 3 describes our models for the call and mobility behavior of user and briefly describes our cost model. Experiments and results are presented in Section 4 and finally, in Section 5, we conclude the paper.

2. The location strategy

2.1. The hierarchical location scheme

The Hierarchical scheme can be described in terms of its two main operations: *Hierarchical Move* and *Hierarchical Lookup* (see fig. 1). Consider a user x moving from location i to a new location k. The *Hierarchical Move* proceeds as follows:

begin
User x registers at database k;
Add x at databases on the path from k to LCA(i,k);

Remove x's entries from databases on the path from LCA(i,k) to i;
User x deregisters from database i;
Acknowledgement message is propagated up the tree from i back to k;
end

When a user at location j calls user x located at k, the *Hierarchical Lookup* operation works as follows. The database at node j is queried for an entry of x. If not found, then the query propagates up the tree until an entry for x is found, which will occur at LCA(k,j). A message then propagates downwards from LCA(k,j) following the pointers associated with x until the leaf database k is reached. Database k returns an acknowledgment message containing the information required to set up the call. This strategy is the same as described in [6,8].

2.2. The Hybrid location scheme

We describe the Hybrid scheme by describing its two main operations: *Hybrid Move* and *Hybrid Lookup*. We introduce a parameter m, which denotes the level at which the Hierarchical scheme will be applied to as well as the level at which the forwarding pointer will be placed (see fig. 1). Consider a user x who is registered at node HLR_x to be its home node, We denote $HLR_{x,m}$ to be the ancestor of HLR_x at level m. This node will act as an HLR proxy for all users x whose HLR_x is in the subtree rooted at $HLR_{x,m}$. Assume user x is currently located at i. We denote $VLR_{i,m}$ to be the ancestor of i at level m. This node will host a chain of downwards pointers to x as long as x is moving in the subtree rooted at $VLR_{i,m}$. That is we can view that the HLR and VLR are assigned at level m rather than at leaves.

Consider user x moving from location i to k, the *Hybrid Move* proceeds as follows:

begin
User x deregisters from database i;
Remove x from databases on the path from i to $VLR_{i,m}$;
User x registers at database k;
Add x at databases on the path from k to $VLR_{k,m}$;
Add forwarding pointer to $HLR_{x,m}$ pointing to node k;
$HLR_{x,m}$ sends an acknowledgement back to $VLR_{k,m}$;
end

When a user at node j calls user x who is located at node k, the *Hybrid Lookup* proceeds as follows:

begin
Query databases on the path from j to $VLR_{j,m}$;
if an entry for x is found **then**
Follow the chain of downwards pointers until k;
Node k returns acknowledgement message back to j containing the information required to setup the call;
else
Query database at $HLR_{x,m}$ and get location of x;
Access node k to get info required to setup the call;
Return acknowledgment message back to j;
fi;
end

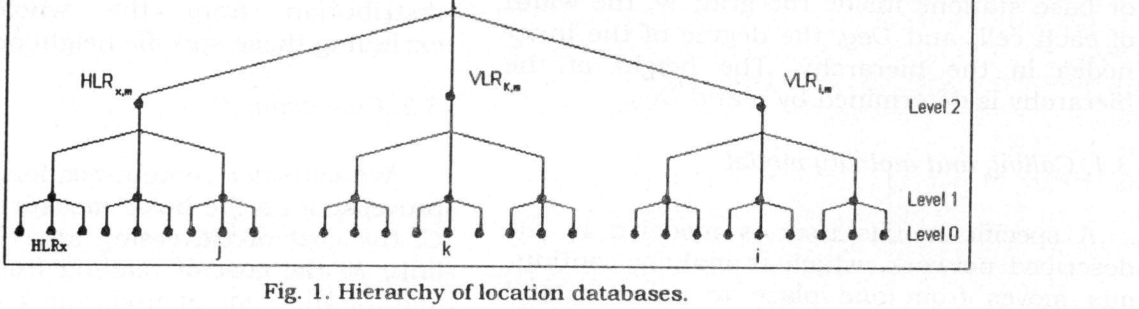

Fig. 1. Hierarchy of location databases.

A variation of the Hybrid scheme, referred to as the *Variant scheme*, is to place the forwarding pointer at $HLR_{x,m}$ to be pointing to $VLR_{k,m}$, instead of k. This would result in reduction in the cost of updates since $HLR_{x,m}$ need not be updated at each move. It will need to be updated only if user x moves outside of the subtree rooted at $VLR_{k,m}$. Therefore, the update cost will reduce for users performing localised moves. However this would be on the expenses of the increase in the lookup cost since querying $HLR_{x,m}$ returns $VLR_{k,m}$, then a chain a downwards pointers needs to be followed until k to locate x.

3. The system model

The hierarchy of the location databases is modeled as a tree whose nodes are covering a two-dimensional area. This area is considered to be a square grid divided into equal square cells. The leaf nodes of the tree represent the base stations, where each node covers one square cell. The location of the inner nodes of the hierarchy inside the grid is at the center of its direct descendants (see fig. 2).

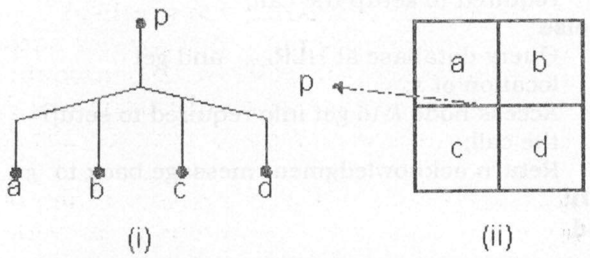

Fig. 2. (i) A hierarchy of 2 levels and 4 leaf nodes. (ii) The distribution of nodes along the 2-D grid.

The network is represented by a number of parameters including: n, the number of cells or base stations inside the grid; W, the width of each cell; and Deg, the degree of the inner nodes in the hierarchy. The height of the hierarchy is determined by n and Deg.

3.1. Calling and mobility model

A specific mobile user is modeled in the described network, which is making continuous moves from one place to another, and receiving calls from different locations. The user has a home location, *Home*, and an initial location, *InitLoc*, where he starts his journey.

The inter-move and inter-call times follow an exponential distribution with means t_c and t_m respectively, where CMR = t_m/t_c . Choosing the location of the next caller or the next user's move was modeled to follow one of the following patterns.

1- *Random locations:* In this pattern, a location is chosen randomly from the whole grid using a uniform distribution.

2- *Localized locations:* This pattern represents a user moving within, or receiving all his calls from, a certain neighborhood. This can be for example the user's home or work, and their surroundings. A neighborhood is modeled as a square defined by its center and its local diameter, *LocalD*. A location is chosen randomly from that neighborhood using a uniform distribution.

3- *Specific Neighborhoods:* This pattern represents a user continuously receiving calls from, or moving across, a set of specific neighborhoods. This corresponds to a real-life situation in which the user moves to, or is called by, a set of other users at specific locations e.g. home, work or regular customers. For calls, a location is chosen randomly from one of the specified frequent neighborhoods. For moves, the user is modeled to move within a certain neighborhood with mean t_m, and between the specified frequent neighborhoods with a mean time t_f , where $t_f > t_m$. Again, a neighborhood is defined by its center and its local diameter.

4- *Irregular Patterns:* This pattern accounts for cases where the location of the caller, or the next user's destination, is always away from specific neighborhoods, e.g. calls incoming away from home or current neighborhood. The location is thus selected using uniform distribution from the whole grid area excluding those specific neighborhoods.

3.2. Cost estimation

We consider communication and database processing as the basic measures of cost. Let, C: the cost of traversing any communication link, R: the cost of reading from a database, and U: the cost of updating a database. We assume that the underlying Common Channel Signaling network is not necessarily a tree; therefore shortcuts between interior nodes are possible. The direct communication between two nodes is estimated to be α times the communication cost if no shortcuts are available, where $0<\alpha\leq 1$ Let the costs of the Move operation be denoted by M, M' and M'' for the Hierarchical scheme, Hybrid scheme and its variation respectively. The costs of the Lookup operation are correspondingly denoted by L, L' and L''

Consider a move operation where a user x moves from location i to location k, LCA(i,k) is at q level above i and k and LCA($HLR_{x,m}$,k) is at level w. Consider a lookup operation where the caller is at location j, the callee is located at k, LCA(j,k) is at r level above j and k and LCA($HLR_{x,m},j$) is at level w'.

For the Hierarchical scheme, the cost of the move operation is,

$$M = [(2q + 1)R + (2q + 1)U]+ [4qC].$$

The cost of the lookup operation is,

$$L = [(2r + 1)R]+ [2rC] +[2rC\alpha].$$

For the Hybrid scheme, the cost of the move operation is,

$$M' = \begin{cases} M + [2((w - q) + (w - m))C\alpha + U] & q \leq m \\ M + [4(w - m)C\alpha + U] - [(2(q - m) - 1)R + \\ (2(q - m) - 1)U + 4(q - m)C] & q \succ m. \end{cases}$$

The cost of the lookup operation is,

$$L' = \begin{cases} L & r \leq m \\ [(r + 1)R + rC + rC\alpha] + [2rC\alpha + R] & r = m = w' \\ [(m + 1)R + mC] + [2(w'-m)C\alpha + R] + \\ [(2w - m)C\alpha + R] + [2rC\alpha] & r \succ m \end{cases}$$

For the Variant scheme the cost of the move operation is,

$$M'' = \begin{cases} M & q \leq m \\ M' & q \succ m. \end{cases}$$

The cost of the lookup operation is,

$$L'' = \begin{cases} L & r \leq m \\ [(m + 1)R + mC] + [2(w'-m)C\alpha + R] + \\ [2(w - m)C\alpha + R] + [mR + mC] + [2rC\alpha] & r \succ m. \end{cases}$$

4. Experiments and results

The developed event-driven simulator was used to conduct a number of experiments in order to examine the impact of using the Hybrid scheme and the Variant scheme on the total cost of the system as compared to the cost of the basic Hierarchical scheme The experiments represented different cases and scenarios for the user's call and mobility patterns. Let the total cost of all moves and calls for each of the three schemes be TC, TC' and TC''. In each case we examined the values of TC'/TC and TC''/TC considering the communication costs and database costs separately, in order not to mix quantities of different units. The CMR value was varied from 0.01 to 512, representing at the lower end a user mainly moving while rarely receiving calls and at the higher end representing a user mainly receiving calls while rarely moving. The value of the parameter m, was varied from 2 to 5 All experiments were run for a total of 3000 move and call events, unless otherwise specified

Table 1 presents the main parameters used for the simulator in the different experiments These settings represent a hierarchy of 8 levels, and covering a square area of about 2620 km^2.

In what follows, we will present a set of experiments that allow examining a wide range of call and mobility scenarios.

Experiment 1

This is an experiment representing a user moving in his home neighborhood (*InitLoc=Home*), and receiving calls from locations far away from home.

As observed in figs. 3 and 4, the Hybrid scheme outperforms the Hierarchical scheme for CMR>1 and for all values of m. The caller being away from the user, the Hybrid lookups require no queries to be performed above level m, while the Hierarchical scheme does. The improvements reach 23% and 60% for the communication and database costs respec tively. For CMR<1, a degradation of 10%

Table 1
Simulation parameters

Parameter	Description	Default value
n	Number of base stations	16384
W	Width of each cell	0.4 km
Deg	Degree of the hierarchy	4
Home	User's home location	(12.8km,12.8km)
InitLoc	User's initial location	Varies
t_m	Mean inter-move time	60 min
t_c	Mean inter-call time	60x0.01-60x512 min
LocalD	Local neighborhoods' diameter	2 km
t_f	Mean time spent in frequent neighborhoods	300 min
R	Cost of one database read	(0 or 1)
U	Cost of one database update	(0 or 1)
C	Cost of one communication link	(0 or 1)
M	Hybrid scheme parameter	2 - 5
α	Network connectivity measure	0.5

20% in the communication cost and of 5% - 10% in the database cost is observed for $m>3$ due to the overhead of direct communication with the $HLR_{x,m}$. For $m\leq3$, improvements reaching 22% and 20% are achieved for the communication and database costs, respectively because the savings, due to limiting the updates to level m, exceed the overhead of updating the $HLR_{x,m}$.

Figs. 5 and 6 show that for low values of m the Variant scheme managed to improve the costs for CMR<1 by achieving gains reaching 28% for the communication cost and 20% for the database cost. This is due to the reduced rate of updating the $HLR_{x,m}$ since moves are localized. For CMR>1, the improvements are only 10% - 15% for the communication cost and up to 45% for the database cost. The degradation over the Hybrid scheme is due to the increase in the lookup cost since the $HLR_{x,m}$ does not return the exact user location.

Experiment 2

This experiment describes a user moving in his home neighborhood (*InitLoc=Home*), and he is receiving calls from his home neighborhood as well.

The results shown in figs. 7 and 8 indicate that for CMR>2 and $m<5$, the Hybrid scheme outperforms the Hierarchical scheme with improvements reaching 10% - 24% for the communication cost and 20% - 42% for the database cost. For $m=5$, the Hybrid scheme approaches the Hierarchical scheme since no savings are made in the lookup path and they behave almost similarly. For CMR<2, a degradation reaching 20% for the communication cost and 10% for the database cost is observed for $m>3$ due to the extra cost of updating the $HLR_{x,m}$. For $m\leq3$, improvements reaching 29% and 22% are achieved for the communication and database costs respectively because of limiting the updates up to level m only.

Figs. 9 and 10 show that for CMR<2, the Variant scheme achieved gains reaching 31% for the communication cost and 22% for the database cost since the $HLR_{x,m}$ is updated less frequently because of the localized moves. For CMR>2, the improvements of the Variant scheme are in the range of 5% - 20% for the communication cost and up to 25% for the database cost. This relative degradation compared to the Hybrid scheme is because the exact user location is not returned directly by the $HLR_{x,m}$. For $m\geq3$, the Variant scheme behaves like the Hierarchical scheme for all values of CMR since the moves and lookups are localized at home, and thus no savings are achieved.

Experiment 3

This experiment describes a user moving in a neighborhood that is far away from his home (*InitLoc*=(10km,10km)) and receiving calls from his current neighborhood.

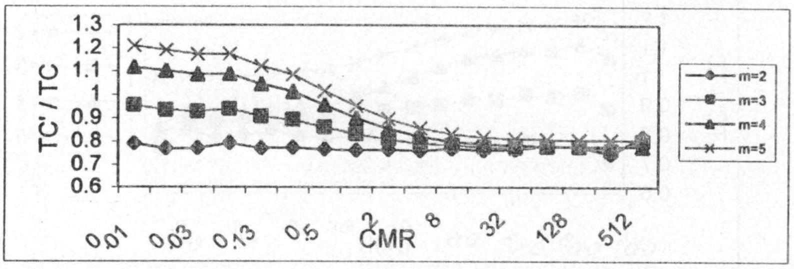

Fig. 3. Experiment 1: communication costs, C=1, R=U=0.

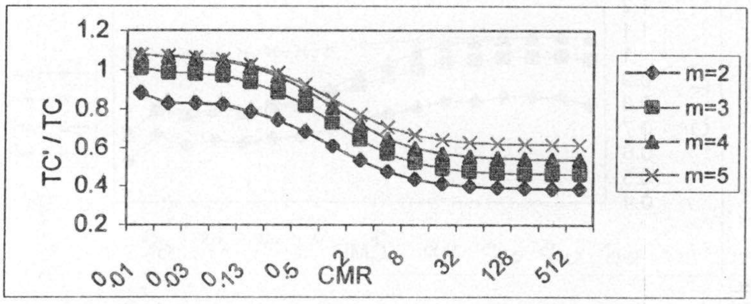

Fig. 4. Experiment 1: database costs, C=0, R=U=1.

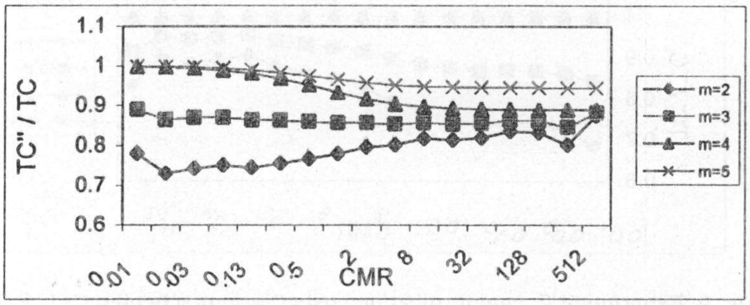

Fig. 5. Experiment 1: communication costs (Variant scheme), C=1, R=U=0.

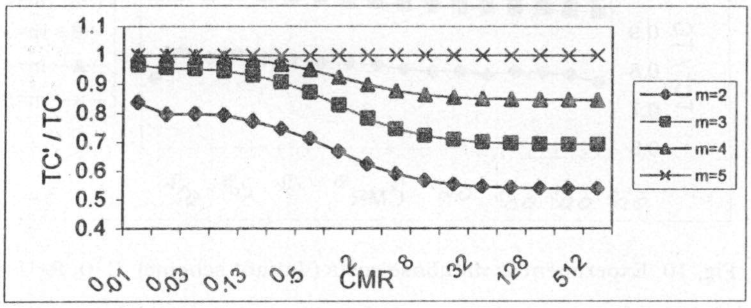

Fig. 6. Experiment 1: database costs (Variant scheme), C=0, R=U=1.

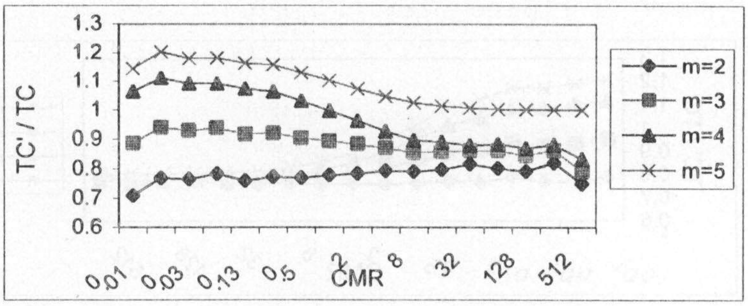

Fig. 7. Experiment 2: communication costs, C=1, R=U=0.

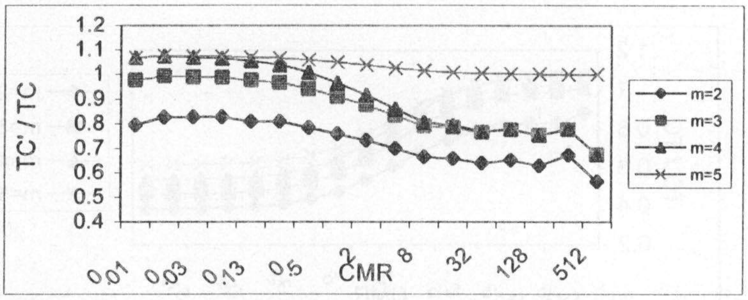

Fig. 8. Experiment 2: database costs, C=0, R=U=1.

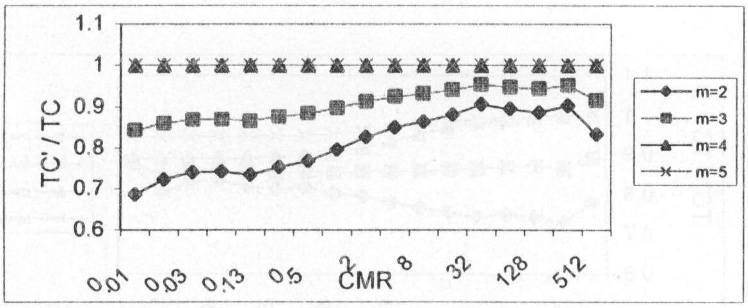

Fig. 9. Experiment 2: communication costs (Variant scheme), C=1, R=U=0.

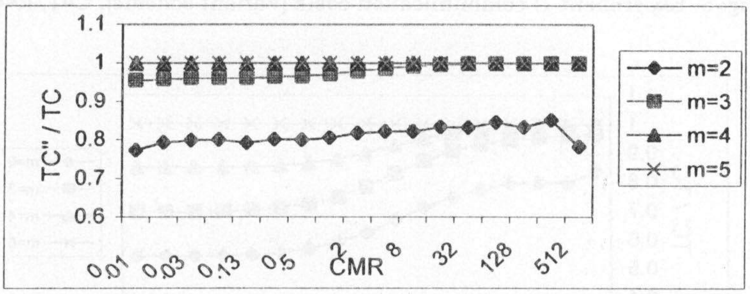

Fig. 10. Experiment 2: database costs (Variant scheme), C=0, R=U=1.

Figs. 11 and 12 show that the Hybrid scheme outperforms the Hierarchical scheme only in the database cost for $m<4$ and for all values of CMR. The improvements range from 10% - 40%. For CMR>4, a degradation of 15% - 20% is observed in the communication cost of the Hybrid scheme for $m<4$ due to the overhead of querying the remote $HLR_{x,m}$, while it approaches the Hierarchical scheme for $m \geq 4$. For CMR<4, there is a degradation of 20% - 42% for the communication cost and 8% for the database cost. This is due to the overhead of continuously updating the $HLR_{x,m}$.

The Variant scheme, as shown in figs. 13 and 14, limited the degradation for CMR<2 to 10% in the communication cost. It achieved gains reaching 22% in the database cost for $m<4$. For CMR>2, the degradation in the communication cost reached 10% - 30%, while the improvements in the database cost were only 10% - 20%. The Variant scheme behaved exactly as the Hierarchical scheme for $m \geq 4$ since both the update and lookup operations were below level m.

Experiment 4

This experiment models a user moving in a neighborhood that is far away from home (*InitLoc*=(10km,10km)) e.g. customers' locations, and receiving calls from another far neighborhood, e.g the headquarters.

It is observed in figs. 15 and 16 that the Hybrid scheme outperforms the Hierarchical scheme for CMR>2. The caller being away from the user, leads to Hybrid lookups requiring no queries to be performed above level m and directing the query to $HLR_{x,m}$. The improvements reach 8% - 18% for the communication cost and 43% - 64% for the database cost. For CMR<2, a degradation of 10% - 46% is observed in the communication cost, while improvements ranging from 5% - 40% are achieved in the database cost. The degradation is a result of the continuous updates made to the $HLR_{x,m}$.

Further experiments have shown that for CMR<2, the degradation of the Variant scheme over the Hierarchical scheme did not exceed 10% in the communication cost, while it achieved improvements ranging from 5% - 40% in the database cost. The improvement over the Hybrid scheme is because of the localized moves which do not result in updates to the $HLR_{x,m}$. For CMR>2, the Variant scheme approached the hierarchical scheme in the communication cost, while the improvements in the database cost reached 53%. The $HLR_{x,m}$, pointing to the $VLR_{x,m}$ instead of the exact user location, is the cause of this relative degradation compared to the Hybrid scheme.

Experiment 5

This experiment models a user moving in a neighborhood that is far away from home (*InitLoc*=(10km,10km)), and receiving calls from his home neighborhood.

As shown in figs. 17 and 18, the Hybrid scheme outperforms the Hierarchical scheme for CMR>1. The improvements reach 20% for the communication cost and 40% - 60% for the database cost. For CMR<1, there is a degradation of 10% - 47% in the communication cost and around 9% in the

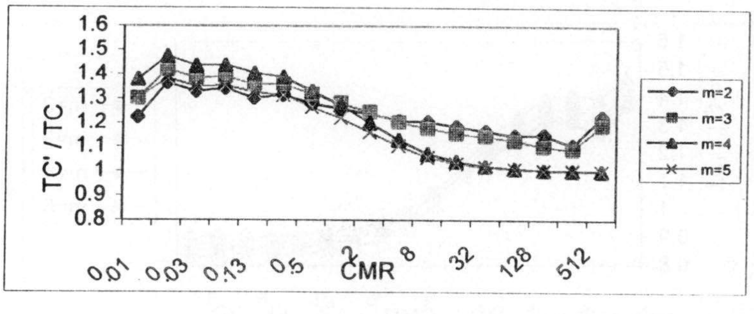

Fig. 11. Experiment 3: communication costs, C=1, R=U=0.

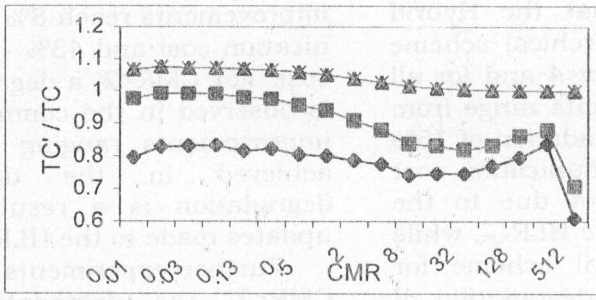

Fig. 12. Experiment 3: database costs, C=0, R=U=1.

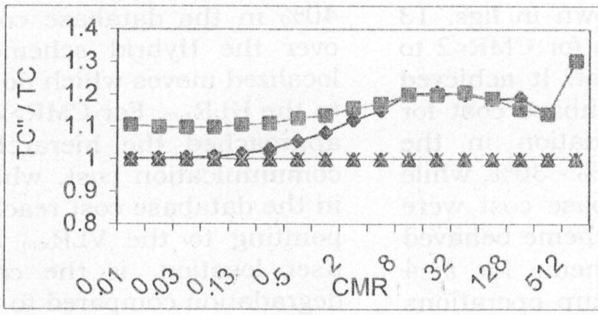

Fig. 13. Experiment 3: communication costs (Variant scheme), C=1, R=U=0.

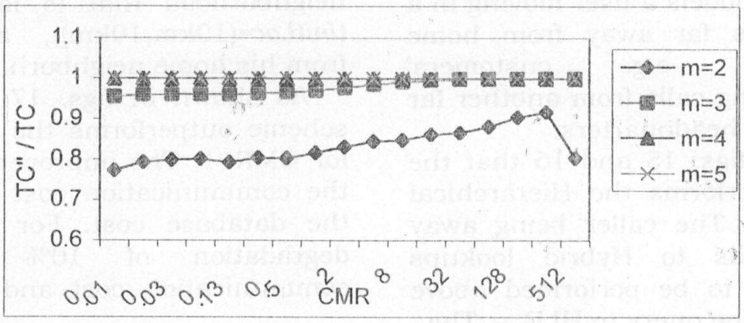

Fig 14. Experiment 3: database cost (Variant scheme). C=0, R=U=1.

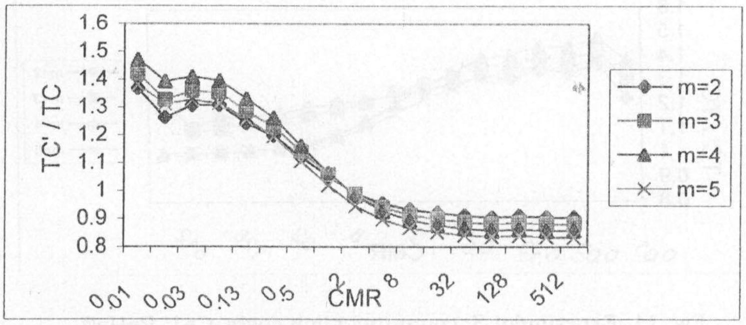

Fig. 15. Experiment 4: communication costs, C=1, R=U=0.

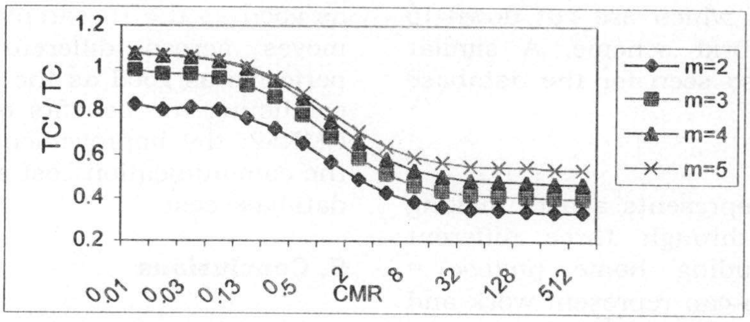

Fig. 16. Experiment 4: database costs, C=0, R=U=1.

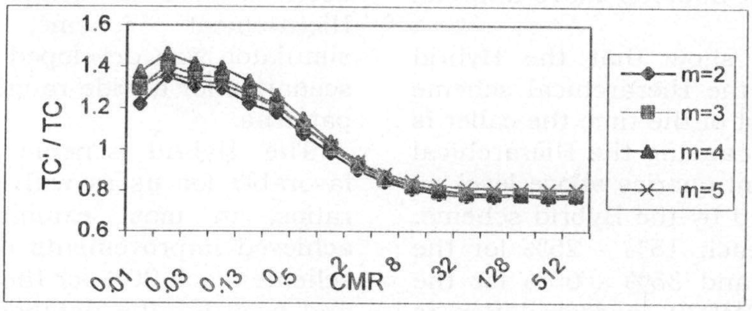

Fig. 17. Experiment 5: communication costs, C=1, R=U=0.

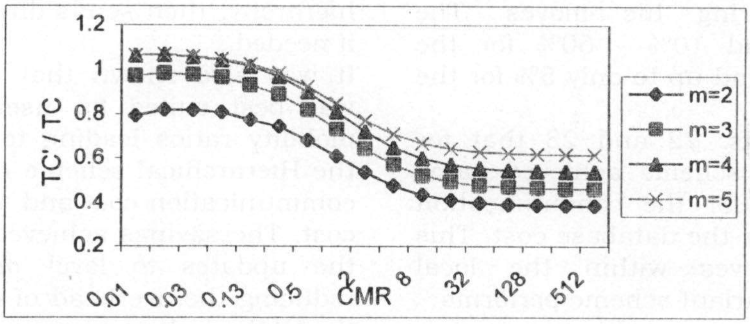

Fig. 18. Experiment 5: database costs, C=0, R=U=1.

database cost. This is a result of the continuous updates to the $HLR_{x,m}$. An improvement reaching 20%, however, is achieved in the database cost for low values of *m*.

It was shown in further experiments that for CMR<1, the Variant scheme resulted in a maximum degradation in the communication cost of 10% and improved the database cost by 25%. The reduced rate of updates to the $HLR_{x,m}$ due to the localized moves are the reason behind this relative improvement over the Hybrid scheme. For CMR>1, the improvements of the Variant scheme were only 5% - 18% for the communication cost and 18% - 44% for the database cost. This is because the $HLR_{x,m}$ points only to $VLR_{x,m}$ and not to the exact user location.

The effect of varying the size of local neighborhoods, *LocalD*, has been studied and it was shown that the larger the value of *LocalD*, the lower the communication cost of the Hybrid move operations. Fig. 19 shows the effect of varying *LocalD* from 0.6km – 3km for CMR=0.03. It is observed that the degradation is reduced from 350% down to about 20%. This is because moving within a large neighborhood leads to long trajectories for the

Hierarchical scheme, which are cut down to level *m* by the Hybrid scheme. A similar improvement was also seen for the database cost.

Experiment 6

This experiment represents a user making continuous moves through three different neighborhoods, including home (*InitLoc* = *Home*). The other two can represent work and a regular customer. The user is receiving calls from his home neighborhood. This experiment was run for a total of 300,000 move and call events.

Figs. 20 and 21 show that the Hybrid scheme outperforms the Hierarchical scheme for CMR>2, since most of the time the caller is away from the user, causing the Hierarchical scheme has to perform queries above level *m*, which are not required by the Hybrid scheme. The improvements reach 15% - 25% for the communication cost and 35% - 60% for the database cost. For CMR<2, a degradation is observed due to the continuous updates of the $HLR_{x,m}$, which is usually remote w.r.t. the user's location, during his moves. The degradation is around 10% - 60% for the communication cost and up to only 5% for the database cost.

It is shown in figs. 22 and 23 that for CMR<2, the Variant scheme achieved gains reaching 7% - 22% for the communication cost and 5% - 30% for the database cost. This is because for moves within the local neighborhoods, the Variant scheme performs as good as the Hierarchical scheme, while for moves across different neighborhoods, it performs as good as the Hybrid scheme, thus combining the benefits of both schemes. For CMR>2, the improvements are 7% - 20% for the communication cost and 5% - 43% for the database cost.

5. Conclusions

In this paper, the performance of the Hybrid scheme and one of its variations has been studied in comparison to the basic Hierarchical scheme. An event-driven simulator was developed to simulate real-life scenarios for a wide range of call and mobility patterns.

The Hybrid scheme was shown to be favorable for users with high call-to-mobility ratios, in most examined scenarios. The achieved improvements over the Hierarchical scheme reach 20% for the communication cost and 60% for the database cost. The savings are mainly because the Hybrid scheme limits updates and queries to level *m* of the hierarchy, then sends direct queries to $HLR_{x,m}$ if needed.

It was also shown that the Variant scheme was best suited for users with low call-to-mobility ratios leading to improvements over the Hierarchical scheme reaching 25% for the communication cost and 40% for the database cost. The savings achieved are due to limiting the updates to level *m* only, as well as reducing the overhead of communicating with the $HLR_{x,m}$, when moves are localized.

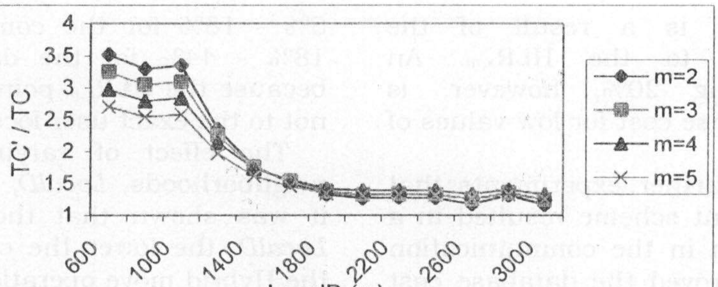

Fig. 19. Experiment 5: effect of the size of local neighborhoods on move communication costs, C=1, R=U=0, CMR=0.03.

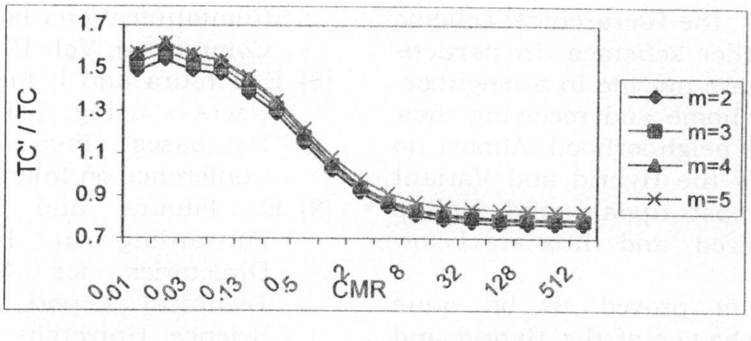

Fig. 20. Experiment 6: communication costs, C=1, R=U=0.

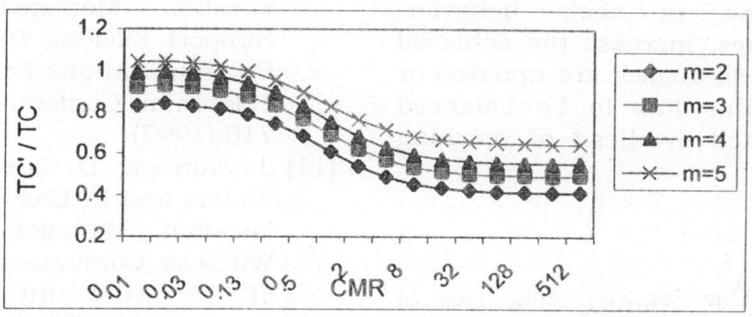

Fig. 21. Experiment 6: database costs, C=0, R=U=1.

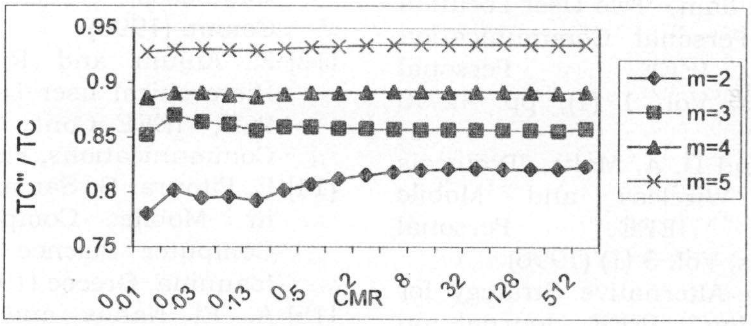

Fig. 22. Experiment 6: communication costs (Variant scheme), C=1, R=U=0.

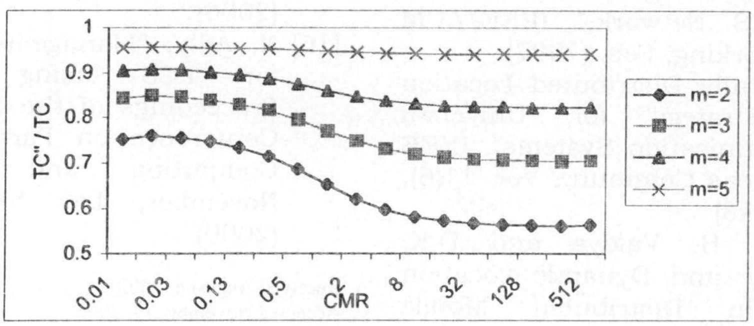

Fig. 23. Experiment 6: database costs (Variant scheme), C=0, R=U=1.

In some scenarios, the Hierarchical scheme outperformed the other schemes. In particular, when the users are moving in a neighborhood far from their home and receiving their calls from that same neighborhood. Almost no savings are made by the Hybrid and Variant schemes because most update and lookup operations are localized, and thus are below level *m*.

The parameter *m* proved to be quite significant to the behavior of the Hybrid and Variant schemes. Choosing high values of *m* can lead those schemes to approach the Hierarchical scheme in their behavior. Choosing lower values, increase the achieved savings since fewer databases are updated or queried. However, this has to be balanced against the associated overhead of reaching the $HLR_{x,m}$.

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