이동망에서 정적 Cache & Carry을 이용한 위치관리

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요 약

이동통신망에서 사용자들이 이동할 때, 이동 클라이언트들이 어떠한 방법으로 위치하는가가 중요한 문제이다. 하나의 이동 클라이언트의 위치를 관리하기 위한 주 된 이동성 관리는 호의 등록과 호의 위치 추적이다. 기존의 연구는 두 개의 운영 관리 중에 하나의 경우 만 이동성 경비를 최소화시키는데 연구되었지 두 개의 운영을 최소화시키지 못 하였다. 본 논문에서는 두 개의 운영 관리를 최소화시키는 위치관리기법을 제안한다. 제안된 기법은 수학적 분석과 시뮬레이션 분석을 하며, 분석 결과를 통해서 제안된 기법이 기존기법보다 우수하다는 것을 보인다.

Location Management Using Static Cache & Carry in Mobile Networks

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ABSTRACT

Even when users are moving, a major problem in such a mobile networks is how to locate mobile clients. Two major operations are involved in managing a mobile client's location : the location registration operation and the call tracking operation. The past methods can only minimize the cost of one of these two operations, but not both. The contribution of this paper is to propose strategy that minimize the costs of both operations simultaneously. Our performance analysis proves that the proposed strategies are superior to the past methods.

키워드 : 이동통신망(mobile networks), 호의 등록(location registration operation), 호의 위치 추적(call tracking operation)

1. Introduction

A great difference between wireless communication environment and traditional wired communication environment us that it allows users to migrate anywhere and to retrieve all kinds of data they want anytime in mobile computing environment. (Figure 1) shows the architecture of a wireless communication system. To effectively monitor the movement of each mobile client, a large geographical region is partitioned into small registration areas (RA). Each RA has a mobile switch center (MSC, also called a base station (BS)) which serves as the local processing center of the RA. The profiles of mobile clients inside a RA are kept, in the MSC's visitor location register (VLR). On top of several MSC/VLRs is a local signaling transfer point (LSTP) and on top of several LSTPs again is a remote signaling transfer point (RSTP). In this way, the whole system forms a hierarchy of station. The LSTP and the RSTP are routers for handling message transfer between stations. For one RSTP there is a home location register (HLR). Each mobile client must register in a HLR. When a MSC (say MSC_a) needs to communicate with another MSC (say MSC_b). MSC_a first sends a message to the LSTP on top of it. If MSC_b is under the same LSTP as MSC_a, then the message is forwarded to MSC_b without going through the RSTP. Otherwise, the message has to be through the RSTP and then down to a proper LSTP ad then to MSC_b. Communication cost depends on how high the message has to go up the hierarchy, as it indicates the distance and routers it has to go through.

In spite of many advantages available in wireless communication. It is not without difficulties to realize such systems. The first problem is how to locate a mobile user in a wireless environment. The Basic HLR/VLR strategy is most often referred in resolving this problem. IS-41 used in the United States and GMS [6] used in Europe are examples of this strategy.

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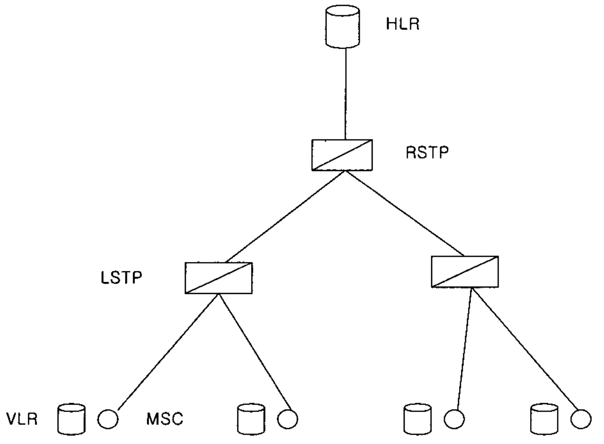


(Figure 1) Architecture of a wireless communication system.

Many papers in the literature have demonstrated that the Basic HLR/VLR strategy does not perform well. This is mainly because whenever a mobile client moves. The VLR of a RA (registration area) which detected the arrival of the client always reports to the HLR about the client's new location. For convenience in presentation in the rest of the paper we will simply regard VLR as a general term which represents the local hardware/software system managing mobile client information within a RA. While a call is placed, the callee is also located by going to the HLR's database to find the callee's new location. As the HLR could be far away from a VLR, communication to the HLR is costly. Several other location management strategies have been proposed to improve the performance of the Basic strategy. Among them, the Forwarding strategy [4, 5, 12], the Local Anchor (LA) strategy [8], and the Caching strategy [11] are representatives of the old VLR (that the mobile client has just left) to the new VLR (that the mobile client just came into). Update of the client's location to the HLR's database is not always needed to minimize communications to the HLR. To locate a client (callee) however, some extra time is required to follow the forwarding link(s) to locate the client. When the number of the forwarding links (or simply the "length" of the forwarding links) is high, the locating cost becomes significant.

Our strategy, termed the Static Cache & Carry (SC&C) strategy, tries to further improve the performance of these past methods by past methods by minimizing both the movement cost and the locating cost at the same time. The key idea is for each mobile client (1) we define the VLRs that have been linked to by the same LA as the overseen VLRs of this LA, (2) a link from the overseen VLR to its LA is cached in the VLR, and (3) we allow multiple such LAs (that a mobile client has traveled through) to be linked together by using forwarding links. In order to computer the performance improvement over the past methods can be achieved.

The remainder of this paper is organized as follows. In Section 2, we present the Basic HLR/VLR standard. In Section 3, we present the proposed SC&C strategy. Then the cost model of each strategy is derived in Section 4. The evaluation results are given in section 5. Finally, we summarize the paper and describe our future work in Section 6.

2. The Basic HLR/VLR Strategy

According to the Basic HLR/VLR strategy, the HLR always knows exactly the ID of the serving VLR of a mobile terminal. We outline the major steps of the IS-41 location registration scheme as follows (see (Figure 2)(a)) [6] :

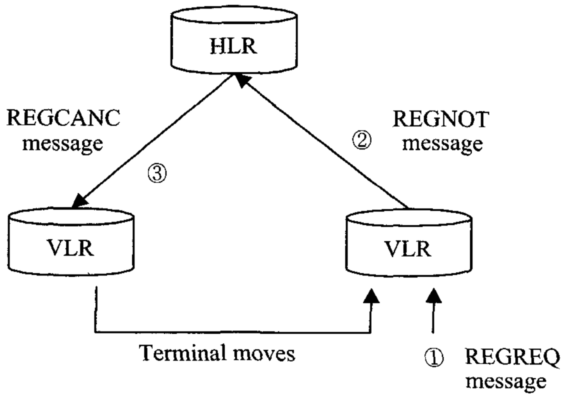
1) The mobile terminal sends a registration request (REGREQ) message to the new VLR.
2) The new VLR checks whether the terminal is already registered. If not, it sends a registration notification (REGNOT) message to the HLR
3) The HLR sends a registration cancellation (REGCANC) message to the old VLR.

The old VLR deletes the information of the terminal and the IS-41 call tracking scheme is outlined as follows (see (Figure 2)(b)) :

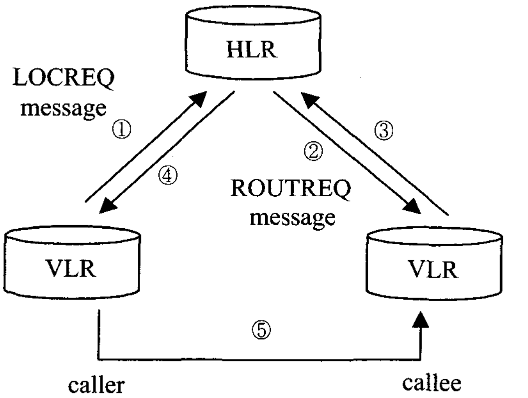
1) The VLR of caller is queried for the information of callee. If the callee is registered to the VLR, the SEARCH process is over and the call is established. If not, the VLR sends a location Request (LOCREQ) message to the HLR.
2) The HLR finds out to which VLR the callee is registered, and sends a routing request (ROUTREQ) message to the VLR serving the callee. The VLR finds out the location information of the callee.
3) The serving MSC assigns a temporary local directory numbers (TLDN) and returns the digits to the VLR which sends it to the HLR.
4) The HLR sends the TLDN to the MSC of the caller.
5) The MSC of the caller establishes a call by using the TLDN to the MSC of the callee.

Among the above 5 steps, the SEARCH process is composed of step1 and step 2.

Like many other works such as [5, 13], we assume local calls could be treated in the VLR only, and do not consider supplement services.



(a) Location registration



(b) Call tracking

(Figure 2) Basic HLR/VLR strategy management scheme

3. Static C&C Strategy

The past methods for improving the Basic HLR/VLR mechanism were all designed to reduce either the movement cost or the locating cost. None of then is able to reduce both costs simultaneously.

3.1 The Supporting Data Structure

We observed that the persons we often contact in real life are mostly those we are familiar with. Hence, if the records about these persons' visiting a certain VLRs can be saved in these VLRs. Then it may be helpful in reducing the cost of locating these persons. The proposed SC&C strategy is designed based on this simple concept. That is, when a call is made, instead of asking the callee's HLR the system will find the callee's VLR and from there the LA and then the callee. To accomplish this, the concept of the past LA strategy is adopted in this work. But the difference between our work and the past LA strategy is that in our SC&C strategy the callee's profile is not deleted from the RA's database after the callee has left the VLR, while the LA strategy dose. This information is kept for future use when locating the callee is needed.

Depending on whether the caller's VLR statically or determine where to search for the callee. In both of these methods, the callee's profile needs to be kept in his/her visited VLRs. To serve for this purpose, a data structure named the Mobile Client Landmark (MCL) table is defined to save some information of visited mobile users for each VLR. As shown in (Figure 3), this table maintains for each visited mobile client the client's ID (MC_{id}), a Type and a Pointer. The MC_{id} has the identifier of the client. Each client is assumed to have a different MC_{id}.

MC_{id}	Type	Pointer

(Figure 3) The schema of the MCL table in VLRs

The second attribute Type is to keep the type of a VLR. There are four types for each VLR. They are used together with the third attribute a pointer, to locate a callee. The four types are the Latest VLR, the Latest LA, the visited VLR3 and the Visited LA. We describe the Type and the Pointer values as well as their meanings in the following. For convenience in illustration, we will sometimes refer to the region of a VLR (or LA) simply as a VLR (LA) when there is no confusion.

1) Latest VLR : A Type value of "Latest VLR" means that this mobile client (e.g.MC_{id}) is right at this VLR (more precisely, the RA managed by this VLR). The Pointer value is NULL in this case, representing that it is the end of a link.
2) Latest LA : The value "Latest LA" indicates that this MC_{id} is currently at a LA (also a VLR) to which the Pointer is pointing.
3) Visited VLR : The value "Visited VLR" means that MC_{id} had visited this VLR and is not here at this moment. The Pointer filed of this mobile client's record

in the MCL table records the LA to which this VLR belongs.

4) Visited LA : The value "Visited LA" means that this MC_{id} had visited this VLR and has left, and this VLR is also a LA. Its Pointer filed records the next LA that the MC_{id} had moved to.

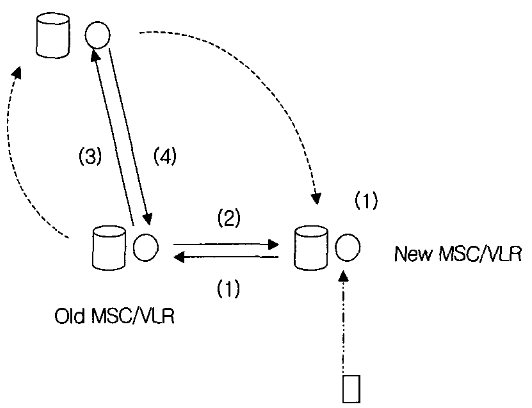
Every VLR maintains a MCL table records the information discussed above for each mobile client who has visited this VLR. Whether a VLR is the LA of a mobile client can be examined by using the value of Type in the MCL table. The schema of the MCL table is quite simple and easy to implement. The size of each record in this table can be as small as eight byte wide (assuming that the size of a MC_{id} is four bytes. The size of Type value is two bits and that of a Pointer value is also four bytes (4 bytes + 2 bits + 4 bytes ≈ 8 bytes)). Hence, even if a VLR is managing for instance 100,000 mobile clients (which is a large number for one VLR), the size of the MCL table is only 800Kbtes (even less than 1 Mbytes). It is easily manageable by any current DBMS. However the size of a MCL table grows when more and more clients visited this VLR (as a record is kept for each visited mobile user). This problem can be easily resolved by removing obsolete records from the table when necessary. Deleting obsolete data from the MCL table does not cause any problem except that locating the callee will leave to be from the call's HLR. Resulting in higher locating cost. This is because to locate a client in our strategies (to be presented shortly), the MCL table will be searched first. If from the table the system cannot locate the client, then the system simply asks the HLR of the callee about the current location of the callee (i.e.,back to the Basic HLR/VLR scheme). However, as the size of the MCL table is very small, the record of a mobile client who visited the VLR long time ago could still be kept in the table to minimize the chance of a hit-miss.

3.2 Location Registration Operation

We formally present the algorithms in the following subsections. First, we present the movement operation of the Static C&C strategy. Basically, take of movement operation are (1) to save a new record in visiting VLR (if this is the first time the mobile client visits this VLR), and (2) to update location of the mobile client recorded in the old VLR.

(Figure 4) gives the takes when a mobile user moves to a new RA. The solid lines in this figure as well as in all the other figures in this section represent messages transmitting between the RAs and the broken lines are to represent the location to which the Pointer's value refers. Also, for convenience we provide for each algorithm a figure to illustrate how the algorithm works. The step number in the algorithm coincides with a number in a parenthesis in the figure. For instance, step 1 in the following coincides with (1) on top of a circle beside the string "new MSC/VLR" in (Figure 4).

1) The new VLR learns that the mobile client is inside its territory and informs the old VLR that mobile client is in its RA. The MCL table of the new VLR is inserted a new record describing the coming mobile client (i.e., the client's MC_{id}, a Type value of "Latest VLR", and a NULL in the Pointer filed). If the mobile client visited this new VLR in the past (i.e., the new VLR has its record), then the system only updates the Type and the Pointer values.
2) The old VLR replies an acknowledgement to the new VLR.
3) The old VLR informs the LA that the mobile client has moved to the new VLR. Also the old VLR update its own MCL table by replacing the mobile client's Type value with "Visited VLR" and the Pointer value with the LA's ; location.
4) The LA replies a message to the old VLR, and updates its own MCL table. The Type value of the mobile client is not changed. The Pointer value is modified to the new VLR's location.
5) End of the movement operation.

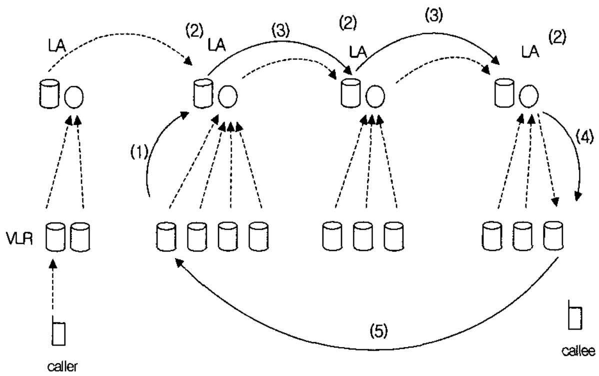


(Figure 4) The new VLR informs the LA of the mobile client's new Location

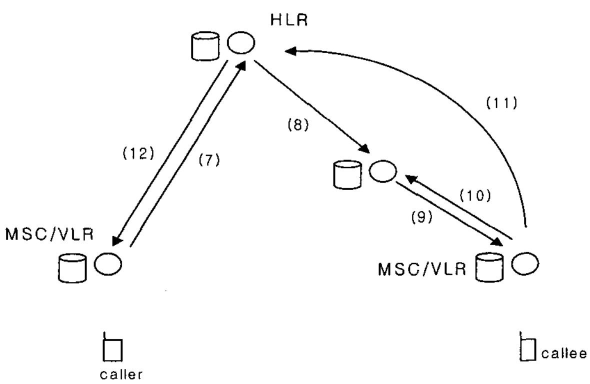
3.3 Call Tracking Operation

Next, we describe the locating operation of the SC&C strategy. (Figure 5) and (Figure 6) are two cases that could occur while locating the callee. (Figure 5) shows how to locate the callee if the system can find the callee though the chain of LAs that the callee have visited in the past. (Figure 6) shows the other case that the system cannot locate the callee from the LAs that the callee have visited and hence has to locate the callee through HLR. Still, the number in a parenthesis in these two figures coincides with the step in the following strategy. The details of the operation is as follows.

1) When a VLR receives a request of locating a callee, it first checks whether its MCL table has the callee's record. If yes, then sends the locating requite to the LA stated in this record. Otherwise, jump to Step 7.
2) /* The caller is currently at a location where the callee visited before. */
   if the record of the MCL table of the LA stated in Step 1 says that this LA is a "Visited LA", then goto Step 3. If it says "Latest LA", goto Step 4.
3) The Locating request is forwarded to this visited LA (following the pointer given in the record of Step 2). While the request is forwarded to the next LA, the callee's record is again searched from this LA's MCL table. Goto Step 2.
4) The latest LA (who is overseeing the callee) finds the callee's record from the MCL table. If the value of the Pointer field is NULL, then the callee is right in one of this LA's governing Ras. Hence, a message is forwarded to the caller's VLR to make the connection. Goto step 13. If the value of the Pointer field is not NULL, then it must be a VLR who is currently overseeing the callee. Hence, the locating request is sent to the latest VLR to which the Pointer field refers.
5) The latest VLR sends a message to the caller's VLR to make a connection.
6) Goto Step 13
7) /* The caller is at a location where the callee has not visited before. Updates of the callee's new location in the LA, VLR, and HLR are associated with this locating operation */
8) The HLR forwards the request to the callee's LA. (We have mentioned that what the HIR has recorded must be the latest LA, i.e., the LA who is overseeing the callee)
9) The callee's latest LA forwards the request to the latest VLR (where the callee currently locates). Also, the callee's record in this VLR's MCL table is updated by replacing its Type with "Latest LA" and Pointer with NULL.
10) The callee's VLR acknowledges the receipt of the message to the LA and the LA will then update the callee's record in its MCL table by replacing type with "Visited LA" and Pointer with a pointer to the callee's current residing VLR (i.e., the latest LA).
11) the callee's VLR sends a message to the GLR. The HLR updates the callee's new location to the new latest LA (i.e., the callee's current VLR).
12) The HLR forwards the message about the current location (VLR) of the callee to the caller's VLR and the connection between the caller's VLR and the callee's VLR is built.
13) End of the locating operation.



(Figure 5) Scenario 1 : Locating the callee through linked LAs



(Figure 6) Scenario 2 : Locating the callee through HLR

4. Cost Model

In this Section, we present the cost models that used to evaluate the performance of the proposed strategy. We first list the parameters used in the models. Then, we derive the cost functions for the locating strategies to be compared.

4.1 Parameters

The parameters used in our cost models are listed in (Figure 7). The costs of the Basic HLR/VLR strategy, was discussed in the literature [4, 8, 12]. But the environments and the details that were referenced in their derivations are different in many ways. In order to make a fair and reasonable comparison, we make some general assumptions and based on which we derive their cost functions in a uniform way. As the local database processing cost is insignificant comparing to the long communication time, we only consider communication cost in this derivation. Communication cost is dependent on the "distance" between two parties, and is classified into three levels : two parties are under different RSTPs, two parties are under the same RSTP but different LSTPs, and two parties under the same LSTP. Their costs are respectively h_1, h_2 and h_3, we also need to use probability to model the location distribution of two communicating parties. There are only two cases :

- Two adjacent VLRs : This case is to model the situation that the mobile client leaves one VLR and enters a neighbor VLR. We use P_L and P_R (given in (Figure 7)) to represent respectively the probabilities of these two VLRs being within the same LSTP and within different LSTPs but the same RSTP. The latter occurs when the two VLRs happen to be on different sides of the border of a RSTP region.
- Arbitrarily distributed communication parties : This case includes three sub-cases : two arbitrary VLRs, a LA and a VLR, and two Las. They are to model respectively communication between the caller's VLR and the callee's VLR, a LA and its belonging.

VLR, and two linked Las. For simplicity, in all three sub-cases we assume that the two communicating parties (such as two linked LAs) are arbitrarily distributed. That is, the chances of (1) the two communicating parties are within the same LSTP, (2) within different LSTPs but the same RSTP, (3) within different RSTPs are equal.

System Parameters

Symbol	*Meaning*
h_1	The cost of sending a message from VLR to another VLR under a different RSTP ;
h_2	The cost of sending a message from VLR to another VLR under a different LSTP but the same RSTP ;
h_3	The cost of sending a message from VLR to another VLR under the same LSTP ;
P_L	The probability of a mobile clients moving into a new RA which is under the same LSTP as the last RA that the client just left ;
P_R	The probability of a mobile clients moving into a new RA which is under the same RSTP as the last RA that the client just left ;
CMR	The call-to-mobility ratio ;

Strategy Related Parameters

Symbol	*Meaning*
C_Y^X	The cost of performing X in strategy Y, Where $X \in \{M, L, total\}$ and $Y \in \{Basic, SC\&C\}$ The meaning of each term in the two sets is as follows : R : the registration operation T : the call tracking operation Total : all operations Basic : the Basic HLR/VLR strategy SC&C : the Static C&C strategy
$C_{SC\&C-link}$	The communication cost between two VLRs through a forwarding link
$k_{SC\&C}$	The length of a forwarding link using the C&C strategy
P_i	The probability that a caller's request is issued from LA_i and its overseeing VLRs

(Figure 7) The symbols of the parameters and their meanings

4.2 Derivation of Cost Functions

The tasks of location management include managing registration operations and managing call tracking operations. Hence, the location management cost is computed according to these two operations. As the ratio of the number of calls (locating a callee) to mobility and defined as

$$totalcost = \frac{1}{CMR} \cdot Registrationcost + Calltrackingcost$$

We will use this definition in calculating the total cost of each strategy. For each operation, the time (cost) is counted from the instant that the VLR of the mobile client submits a request is finished. The cost of an operation that is not directly related to the movement/locating operation is not counted in our cost functions. For instance, in the Basic HLR/VLR scheme the movement operation is counted from the time the client's new arriving VLR sending a request to the HLR till the time this VLE receives a message from the HLR to indicate that the location of the client has been update in the HLR. This is the cost of a movement operation in the Basic HLR/VLR scheme. Other operations such as sending a message from the HLR to the former VLR (the one that the client has just left) to remove the obsolete record from its table are not counted in our cost models. This is mainly because these operations are not as urgent and can be executed at a later time. Note that ignoring such a cost in our model is for reason of understanding the effect of other key steps in an operation. All such operations in different strategies are treated in the same way.

4.2.1 Cost Functions of the Basic HLR/VLR Strategy

Basic HLR/VLR strategy is a standard scheme and is often used to be compared with other strategy. Hence, we first present the cost functions of the Basic HLR/VLR strategy. Based on the definition of total cost, the total cost of the Basic HLR/VLR strategy can be represented as follows.

$$C^{total}_{Basic} = (\frac{1}{CMR}) \cdot C^{R}_{Basic} + C^{T}_{Basic}$$

For clearness reason, we list the steps of the Basic HLR/VLR strategy in the following for a reference. Its idea has been discussed in Section 2.The registration cost of the Basic HLR/VLR strategy is therefore.

$$C^{R}_{Basic} = 2 \cdot h_1.$$

In this algorithm, the call tracking cost of the strategy becomes

$$C^{T}_{Basic} = 4 \cdot h_1.$$

4.2.2 Cost Functions of the Static C&C Strategy

Depending on the way data are processed, we introduce the cost functions of the Static C&C strategy. Similar to the other strategies, the total cost can be represented as

$$C^{tatal}_{SC\&C} = (\frac{1}{CMR}) \cdot C^{R}_{SC\&C} + C^{T}_{SC\&C}$$

From the previous discussion, we understand that the difference of the registration operation between the Static C&C strategy and the Static LA strategy [4, 12] is that in the C&C strategy the MCL record of a client is saved in the VLRs that the client has visited, whereas it's not in the LA strategy. This difference, however, does not affect the cost of the registration operation. Therefore, the registration cost of those two strategies should be the same. That is,

$$C^{R}_{SC\&C} = P_L \cdot (2 \cdot h_3) + P_R \cdot (2 \cdot h_2) + (1 - P_L - P_R) \cdot (2 \cdot h_1)$$

For the call tracking operation, two cases are involved :

1) Locate the callee through HLR (i.e., the caller is at a VLR that the callee has never visited).
2) Locate the callee through a VLR where the callee visited before (i.e., the caller is at a VLR that the callee visited before).

The cost of the first case is the same as C^{L}_{SLA}. The probability of the occurrence of Case 1 is $1 - \sum_{i=0}^{KC\&C} p_i$, because the HLR is needed to locate a callee only when the callee is not in any of the VLRs that the client has visited. For Case 2, it includes the following four tasks : (a) the caller's VLR informs its overseeing LA (say, LA_0) where the callee's record in the MCL table is found, (b) LA_0 follows the forwarding links of length passing the locating request to the latest LA, (c) the latest LA informs the latest VLR of the callee. And (d) the latest VLR of the callee sends a message to the caller's VLR to make a connection. In the Forwarding Strategy, two linked VLRs are always adjacent. Hence, the probability P_R and P_L can be applied in that strategy to obtain the expected cost. In the LA strategy, there is always just one LA to manage the location of the callee. So, a forwarding message between Las will never occur. This issue, however, has to be dealt in our SC&C strategy, because many LAs may be linked to facilitate location a callee. But computing the cost becomes quite complicated by the above four cases. To simplify the derivation we simply apply our simplification assumption again to this cost. That is, we assume the cost between any two parties mentioned in the above (a), (b), (c), and (d) is $\frac{1}{3}(h_1 + h_2 + h_3)$, except that in (b) the cost is multiplied by i as it involves i such links. This is an average cost of h_1, h_2, and h_3, and is denoted as $C_{SC\&C-link}$ as given in (Figure 7). Obviously, this simplification in computation represents a worse situation of our algorithm because the costs of (a) and (c) should be less than $C_{SC\&C-link}$. That is, the cost of Case 2 above is

$$C^{T}_{SC\&C} = (1-\sum_{i=0}^{KC\&C} p_i)\cdot C^{T}_{SLA} + \sum_{i=0}^{KC\&C}(p_i\cdot(C_{SC\&C-link} + i\cdot C_{SC\&C-link} + C_{SC\&C-link} + C_{SC\&C-link})).$$

5. Performance Analysis

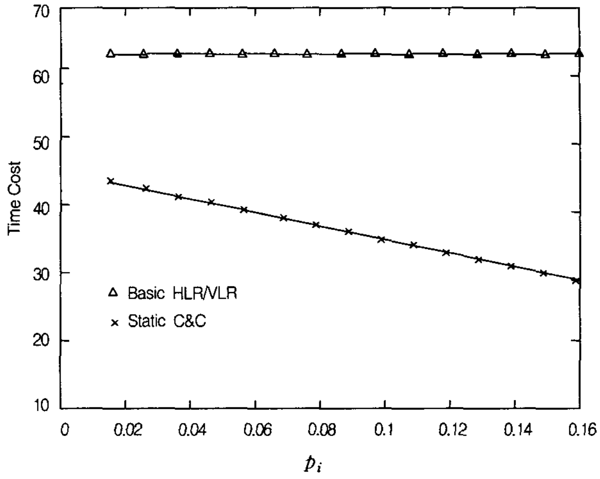
From the above discussion, we see two important factors that affect the performance of the SC&C strategy : $k_{C\&C}$ and p_i. Both of these parameters help to indicate how many calls could be from a VLR that the callee has visited in the past. For such callers, the locating cost could be cheap. But the tradeoff is that a long LA link will increase the cost for traversing through the Las. Hence, we first study the effect of these two factors to the SC&C strategies. Also, we vary the ratio h_1/h_3, which represents varying region size of a RSTP versus a LSTP. This is a general factor which affects all strategies. The optimal length of the LA links is also explored at the end of this section. The default values of the parameters used in our evaluation are given (Figure 8).

Parameter	Default Value
h_1	8
h_2	4
h_3	1
p_L	0.7
p_R	0.2
CMR	0.5
$k_{SC\&C}$	6
p_i	0.05

(Figure 8) Default values of parameters

4.1 The Effect of p_i

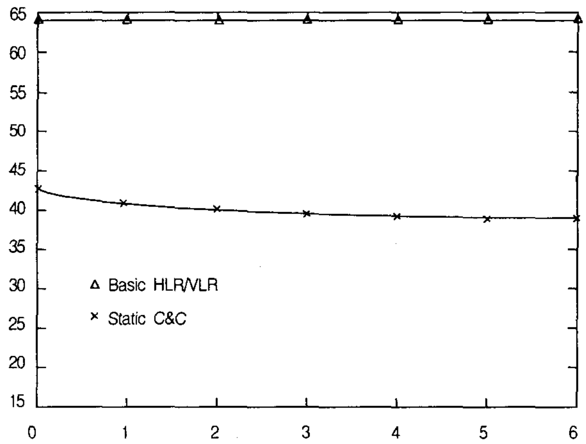
p_i is the probability that a caller places a call from a VLR that happens to be under one of the linked Las of the callee. When this occurs, the locating cost is cheap. We vary p_i from 0.01 to 0.16. As the default $k_{C\&C}$ is 6, the total probability of a call from the VLR under a linked Las (i.e., $\sum_{i=1}^{KC\&C} p_i$) is actually 0.06~0.96. The result given in (Figure 10) shows. However, for the C&C strategies a dramatic decrease of the cost when p_i increases. Although in general p_i may not be large for every kind of mobile clients, it could definitely be so for a certain type of users. For instance, most of the commuters always drive along the same route between their offices and houses. Many office workers and students, etc., also appear at several fixed location regularly. Our performance result shows that the C&C strategy is especially good for managing mobile clients of this kind. The curves of the other strategies are flat because they are independent of the varying parameter p_i.



(Figure 9) The effect of p_i to the strategies

4.2 The Effect of $k_{SC\&C}$

In our proposed strategy, multiple LAs may be liked together due to the movement of a mobile client. The length of this link is represented by $k_{SC\&C}$. (Figure 10) shows the result by varying $k_{SC\&C}$. A large $k_{SC\&C}$ means that many VLRs that are under the linked Las can locate a callee through the providing links of Las, which helps to reduce the locating cost. Hence, the higher the $k_{SC\&C}$, the lower the cost of the SC&C strategies. However, the curves of the



(Figure 10) The effect of $k_{C\&C}$ to the Static C&C strategies

SC&C strategy will become high after a certain $k_{SC\&C}$ point. This is because the locating cost will increase with the lengthy linked LAs. The longer the linked LAs, the longer it takes to locate a callee. According to our derivation earlier, the length of the link should be less than $[4 * h_l/c_l - 3]$ in order to have benefit. The improvement of the C&C strategy over the Basic strategies is very significant.

The reason is the links in the C&C strategy are built on LAs. While a mobile client moves, he/she may move out of the boundary of a VLR easily and get into another VLR. But in the C&C strategy, the client doe not move out of the boundary of a LA so easily because the region of a LA could be much larger than that of a VLR.

6. Conclusions

In this paper we proposed a new location management strategy, called the SC&C strategy. Different from the past strategies, the SC&C strategy can reduce both the movement cost and the locating cost at the same time. The SC&C strategy avoids updating the client's location to the HLR when the client moves to a new VLR. The client's new VLR always updates the client's location to the LA. We also derived the cost models of the proposed strategies and several other related works. Our analysis results reveal that in most case the SC&C strategy performs better than the Basic HLR/VLR strategies. This is mainly because it can reduce the movement cost and the locating cost simultaneously, while the other strategies only reduces one of them. Our strategies are also easy to implement based on current mobile computing technology.

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