

# Storage-based Location Tracking in Mobile Networks

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**Abstract**—with the increasing number of mobile terminals, it is a challenge how to reduce the cost and provide fast and efficient call delivery to the mobile terminals. In the existing mobile networks, the call connection between the two terminals is based on the registration of their identity in the databases known as home location register and visitor location register. Conventional registration strategies will incur a high volume of signaling traffic. These strategies can work well up to a certain level of call to mobility ratio. In this paper, we propose a storage-based location tracking scheme based on the storage of the location of a mobile terminal at the repository database, which efficiently reduces the location updates and searching cost in the mobile networks.

**Keywords**—Repository; Visitor location register; Home location Register; Call to mobility ratio; mobile networks.

## I. INTRODUCTION

Mobile communication is one of the emerging fields in the area of communication. In the mobile networks, the location of a mobile terminal changes frequently so it is difficult to trace a mobile terminal's location. There are three main strategies proposed for location tracking in the hprevious work; these are local anchoring strategy (LAS) [1] [5] [12], IS-41[5], and group registration (GR) [1] technique for location tracking in mobile networks.

In the previous studies, several strategies such as local anchoring strategy (LAS), forwarding strategy (FS) [7] [11] [12][16] and replication strategy (RS) [17] were proposed to reduce the burden on the HLR. Since, a user may change his mobility patterns frequently, any single strategy can not cope with such time-varying mobility patterns efficiently. In this paper, an efficient strategy based on storage of information about the location of mobile terminal known as storage-based (SB) location tracking strategy is proposed which works well with a good level of call to mobility ratio (CMR). To reduce cost, we applied a repository database which will result in low cost and also have low complexity of database handling.

The remainder of this paper is organized as follows: In Section 2, we explain the SB strategy. This section also includes the details of location registration and updating procedure in SB strategy. In Section 3, we describe the analytical model. In Section 4, numerical results are described. Finally, conclusion is given in Section 5.

## II. PROPOSED STRATEGY

### A. Basic approach for SB location tracking

The proposed SB location tracking approach is based on the Group Registration Technique [1], which is modified to reduce the cost of mobile communication. In this strategy it is proposed to attach a database for storage which has a good capacity and the information from it can be easily accessed and provided for further processing. Each location area (LA) maintains a registration waiting list (RWL) to keep the newly arrived MTs identities (IDs). However, before the location of the newly moved in MTs is updated at the HLR, a mechanism should be placed so that any incoming call for these MTs can be successfully delivered to their current LA. For this purpose, either forwarding or local anchoring can be used to set up a forwarding pointer from the old LA to the new LA or local anchoring if the LA as the MT changes its LA. The main factor which reduces the cost

of mobile tracking is the repository database which stores the information about the mobile terminal and updates this information in the neighboring visitor location register (VLR). Two methods were introduced [1] to report the location change to the HLR: 1) Static local anchoring (SL): an MT's local anchor is changed to its new VLR upon the arrival of its next incoming call. 2) Dynamic local anchoring (DL): in addition to method 1, the MT's new VLR becomes its local anchor if such a change results in a lower cost.

### B. Location Update Procedure in SB Strategy

When a MT changes its LA, the following procedure is performed (Figure 1) [1]

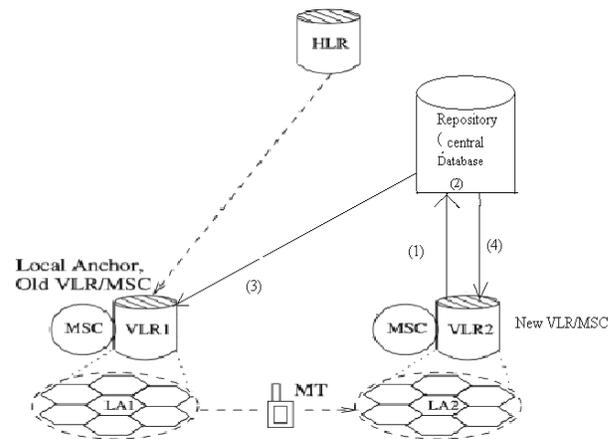


Figure 1. Location Update Procedure in SB Strategy old VLR is the Local Anchor

1. The new MSC detects that the MT enters an LA in its area and sends a message to inform to repository (central database) that MT has entered in it.
2. The repository updates the location of MT in its memory from old MSC to new MSC.
3. Repository sends a message to the old mobile terminal about the current location so that it can find it easily.
4. Repository sends an acknowledgement to the new MT that it has updated the location of MT in the database. The Old MSC checks if it's associated VLR is the local anchor of the MT. If yes (Figure 1), the local anchor is updated to point to the MT's current VLR, and the location update procedure is complete, otherwise (Figure 2) [1], go to the next step.
5. The old VLR removes the MT's ID from its old LA's RWL. A location update message is sent to the MT's local anchor, which then updates itself to point to the MT's new VLR.
6. The local anchor sends back an acknowledgment message to the MT's old MSC. The location update procedure is complete.

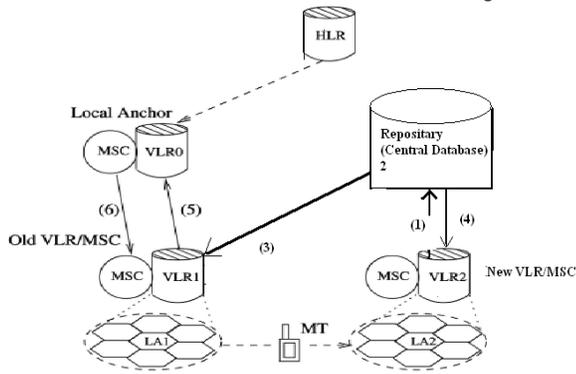


Figure 2 Location Update Procedure in SB Strategy old VLR is not the Local Anchor

### C. Call Delivery Procedure

Local anchor changes occur only during the call delivery procedure. The call delivery procedure proceeds as follows:

1. When a call for an MT is originated (the caller can be a wire line or mobile phone), a location request message is sent to the MT's HLR.
2. The HLR obtains the ID of the called MT's local anchor and sends a route request message to the local anchor.
3. If the local anchor is the current VLR of the MT (Figure.3), go to the next step; otherwise (Figure. 4), the route request message is forwarded to the current VLR/MSV.
4. The called MSC searches for the called MT. If the MT is found, a temporary local directory number (TLDN) is allocated to the MT.
5. If the RWL of the called MT's current LA is not empty, all MT IDs in the RWL are sent to the HLR in the route response message along with the TLDN.
6. The current VLR registers the mobile terminal's location information to the repository which stores it in the database.
7. Meanwhile, except for the called MT, for each other MT in the RWL, the current VLR sends a deregistration message to its local anchor, which removes the MT's forwarding pointer entry. The RWL is then emptied. The current VLR becomes the local anchor of all MTs in the RWL.
8. After receiving the route response message from the VLR, the HLR forwards the TLDN to the calling MSC. If the route response message contains any to be- updated MT's ID, the HLR changes these MTs' local anchors to the current VLR.
9. After receiving the TLDN, the calling MSC can set up a connection to the called MSC

## III. ANALYTICAL MODEL

### A Location Update Cost of the Proposed Strategy

Assume that the MTs arrive at an LA according to a

Poisson process; the incoming calls to an MT follow a Poisson Process, and an MT's residence time in an LA follows an exponential distribution [1]. To evaluate the cost of proposed strategy following cost notation is used

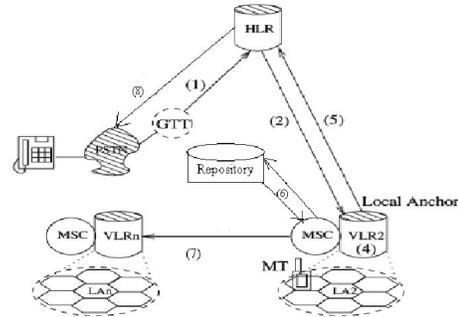


Figure 3 Call Delivery Procedure Current VLR is the Local Anchor [1]

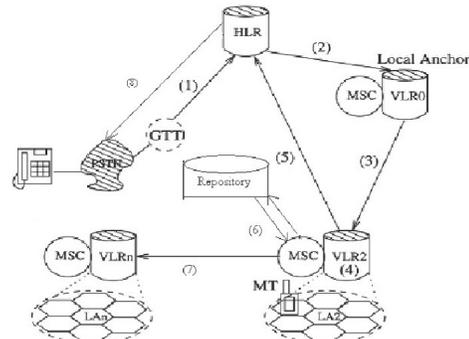


Figure 4 Call Delivery Procedure Current VLR is not the Local Anchor [1]

$C_v$  Cost for a query or an update of the VLR.

$C_h$  Cost for a query or an update of the HLR.

$C_{vv}$  Cost for transmitting a signaling message between two VLRs.

$C_{hv}$  Cost for transmitting a signaling message between a VLR and the HLR.

As seen from call update procedure, in the proposed strategy, as an MT changes its LA, a location update is performed. However, the location update procedure may be different [1].

There exist two cases that incur different location update costs:

Case 1. The old VLR of the moved-out MT is its local anchor (Figure. 1).

Case 2. The old VLR of the moved-out MT is not its local anchor (Figure. 2).

Location updates cost in Case 1. During the time period that a MT stays in an LA, if there is at least one incoming call arriving for any MT in the LA, then the MT's current VLR becomes its local anchor and its location is updated at the HLR during the call delivery procedure for the first incoming call to this LA. In this case, when the MT moves to another LA, the cost incurred by the LA change,  $U_1$  is (Figure. 1)

$$U_1 = 2(C_v) \tag{1}$$

Where the cost for the old VLR deleting the user profile and creating a forwarding pointer is  $C_v$ , and the

Location updates cost in Case 2. If there is no incoming call to any MT in an LA during a MT's residence period in the LA, steps 5 and 6 in the location update procedure needs to be executed when the MT moves to another LA. In this case, the cost incurred by the LA boundary crossing,  $U_2$  is (Figure. 2)

$$U_2 = 4(C_v) \quad (2)$$

where in addition to the costs in, the old VLR removing the MT's ID from its old LA's RWL incurs  $C_v$ , the old local anchor updating the forwarding pointer incurs  $C_v$ . Given MT, let  $p_1$  be the probability that there is no incoming call to any MT in  $m_0$  LA during  $m_0$ 's residence period in the LA (i.e., Case 2). Then, the expected location updates cost incurred by an LA change in the proposed Strategy [1]

$$\begin{aligned} C_u &= (1 - p_1)U_1 + p_1U_2 \\ &= 2(1 + p_1)C_v \end{aligned} \quad (3)$$

In the following, we calculate the expected location update cost per call arrival for MT  $m_0$ . Let  $f(y_0)$  be the density function of  $m_0$ 's LA residence time with mean  $1/\lambda_0$  and  $g(x_0)$  be the density function of  $m_0$ 's inter call interval with mean  $1/\mu_0$  [1], i.e.,

$$f(y_0) = \lambda_0 e^{-\lambda_0 y_0}, \quad g(x_0) = \mu_0 e^{-\mu_0 x_0}$$

The probability that  $n$  LA boundary crossings occur between two call arrivals is

$$\alpha(n) = \begin{cases} \frac{1 - f^*(\mu_0)}{\rho} & n=0 \\ \frac{1 - f^*(\mu_0)}{\rho} f^*(\mu_0)^{n-1} & n>0 \end{cases} \quad (4)$$

where  $\rho = \frac{\mu_0}{\lambda_0}$  is the call-to-mobility ratio (CMR) of MT  $m_0$  and  $f^*(s)$  is the Laplace-Stieltjes transform of  $f(y_0)$ .

Then, the expected location update cost per call arrival is

$$C_{u,s} = C_u \sum_{n=1}^{\infty} n \alpha(n) \quad (5)$$

## B. Call Delivery Cost of the Proposed Strategy

There are two types of calls for which the call delivery cost may be different:

The first incoming call to an MT after the MT moved into a LA. The rest of the incoming calls to the MT during the period that the MT stays in the LA.

We will compare the proposed strategy to the IS-41, local anchoring strategy and Group Registration Strategy. Since the cost for message exchanges between the caller and the callee's HLR is the same for these four strategies, this cost is not included in the cost estimation in this paper. Note that the call delivery cost can be calculated in the same way for both handoff calls and non handoff calls, while the cost triggered by the handoff process can be omitted, since this cost would be the same for all the four strategies when the same handoff mechanism is adopted. When the first incoming call at an LA is for another MT in the LA since MT  $m_0$  moved into the LA, the HLR is pointing to the current VLR of  $m_0$  an incoming call arrives for  $m_0$ . In this case, the call delivery procedure shown in Figure.3 is performed to deliver an incoming call to  $m_0$ . The call delivery cost,  $V_1$ , is

$$V_1 = 2C_{hv} + C_v + \theta C_h + RL * C_v \quad (6)$$

where the cost for the HLR sending the location request message to the called MT's current VLR is  $C_{hv}$ , the cost for the current VLR retrieving the location of the MT's current LA is  $C_v$ , the cost for the current VLR sending the TLDN and the MT IDs in the RWL, if any, to the HLR is  $C_h$ , and the cost for the HLR to update the MTs' service profiles is  $C_h$ . The last term represents the cost of step 6 for local anchor deregistration  $\theta$  is the probability that there is at least one MT ID in the RWL and  $RL$  is the average number of MTs in the RWL [1].

When an MT receives the first incoming call to an LA after the MT moved into the LA, the MT's HLR is still pointing to the MT's local anchor, and the call delivery procedure shown in Figure. 4 is followed. The call delivery cost,  $V_2$  is

$$V_2 = 2C_{hv} + 2C_v + C_h + Y C_v \quad (7)$$

where the cost for the HLR sending the location request message to the called MT's local anchor is  $C_{hv}$ , the cost for the local anchor retrieving and removing the forwarding pointer is  $C_v$ , the cost for the current VLR retrieving the location of the MT's current LA is  $C_v$ , the cost for the current VLR sending the TLDN and then to-be-registered MTs' IDs to the HLR is  $C_h$ , and the cost for the HLR to update the MTs' service profiles is  $C_h$ . In addition, the cost incurred by step 6 of the call delivery procedure is  $C_v$  for each MT in the RWL (except for the called MT whose local anchor is deregistered in step 3 of the call delivery procedure).  $Y$  denotes the average number of MTs in the RWL (excluding the called MT) [1].

Let  $p_2$  be the probability that  $m_0$  receives the first incoming call to  $m_0$ 's LA since  $m_0$  moved into the LA. The average cost of the first incoming call since an MT moved into its current LA,  $V$  is

$$\begin{aligned} V &= (1 - p_1)V_1 + p_2V_2 \\ &= 2C_{hv} + [p_2(1 - \theta) + RL]C_v + C_v \end{aligned}$$

After the first incoming call, any subsequent incoming call to  $m_0$  while it remains in its current LA invokes cost  $V_1$ . Thus, the expected cost per call arrival is [1]

$$C_{c,s} = \begin{cases} V \\ \frac{1}{\rho}(V + [\rho - 1]V_1), \end{cases} \quad \begin{matrix} \rho \leq 1 \\ \rho > 1 \end{matrix} \quad (9)$$

Note that, only when  $\rho > 1$ , there are likely more than one incoming calls to the MT during its residence at an LA.

Therefore, the total cost per call arrival for the proposed strategy, denoted by  $C_{T,s}$  is

$$C_{T,s} = C_{u,s} + C_{c,s} \quad (10)$$

#### C. Tracking Cost of the IS-41 Strategy

The location update cost incurred by each LA change in the conventional IS-41 strategy is  $4C_{hv} + 2C_v + C_h$ . Thus, the expected location update cost per call arrival in the conventional strategy is

$$C_{u,c} = (4C_{hv} + 2C_v + C_h) \sum_{n=1}^{\infty} n\alpha(n) \quad (11)$$

The call delivery cost per call arrival of the conventional strategy is

$$C_{c,c} = 2C_{hv} + C_v \quad (12)$$

Note that, as mentioned earlier, the cost of message exchanges between the caller and the callee's HLR is not included in the preceding equation.

Therefore, the total cost per call arrival for the conventional strategy, denoted by  $C_{T,c}$  is

$$C_{T,c} = 2C_{u,c} + C_{c,c} \quad (13)$$

#### D. Tracking Cost of the Local Anchoring Strategy

The local anchor of an MT in the LAS strategy could be the current VLR of the MT or a different VLR. In the former case, the location update cost per LA change is  $U_1$ , while in the latter case the location update cost per LA change is  $U_2 - C_v$ . (No RWL operation is needed here.) The average location update cost incurred by each LA change in the LAS strategy is

$$C_l = (1 - Pr\{E_0\})U_1 + Pr\{E_0\}(U_2 - C_v) \\ = \left( \frac{2\mu_0}{\lambda_0 + \mu_0} \right) (C_{vv} + C_v) + \frac{\lambda_0}{\lambda_0 + \mu_0} (4C_{vv} + 3C_{vv})$$

where  $Pr\{E_0\}$  is the probability that an MT receives no call while residing in an LA [1].

Then, the expected location update cost per call arrival in the LAS strategy is

$$C_{u,l} = C_l \sum_{n=1}^{\infty} n\alpha(n) \quad (15)$$

The delivery cost of the first incoming call in the LAS strategy is

$$C_{l,1} = 2C_{hv} + C_{vv} + 2C_v + C_h + (C_{vv} + C_v) \\ = 2C_{hv} + 2C_{vv} + 3C_v + C_h, \quad (16)$$

where  $C_{vv} + C_v$  represents the cost of local anchor deregistration.

The delivery cost of any subsequent incoming call to an MT after its first incoming call is  $2C_{hv} + C_v$ . Thus, the expected cost per call arrival in the LAS strategy is

$$C_{c,l} = \begin{cases} C_{l,1}, & \rho \leq 1 \\ \frac{1}{[\rho]} [C_{l,1} + [\rho - 1](2C_{hv} + C_v)], & \rho > 1 \end{cases} \quad (17)$$

Therefore, the total cost per call arrival for the LAS strategy, denoted by

$$C_{T,l} = C_{u,l} + C_{c,l} \quad (18)$$

#### E. Call Delivery Cost in the Group Registration Strategy

Call delivery cost in GR strategy is very much similar to the SB strategy the main difference lies in the updating and delivering cost with the interaction of two VLRs. Here is the cost of GR strategy is given [1].

$$U_1 = 2(C_{vv} + C_v) \quad (19)$$

$$U_2 = 4(C_{vv} + C_v) \quad (20)$$

$$C_u = (1 - p)U_1 + pU_2 \\ = 2(1 + p)C_v \quad (21)$$

$$C_{u,g} = C_u \sum_{n=1}^{\infty} n\alpha(n) \quad (22)$$

All the symbols used in this strategy is same as used in the SB strategy and the total cost calculated below as.

$$V_1 = 2C_{hv} + C_v + \theta C_h + R_L(C_{vv} + C_v), \\ V_2 = 2C_{hv} + C_{vv} + 2C_v + C_h + \gamma(C_{vv} + C_v)$$

$$= 2Chv + [p_2(1-\theta) + RL](C_{vv} + C_v) + C_v + [p_2 + (1-p_2)\theta]Ch \quad (23)$$

Total Cost in GR strategy is

$$C_{T,g} = C_{u,g} + C_{c,g} \quad (24)$$

#### IV. NUMERICAL RESULTS AND DISCUSSIONS

In this section, performance comparison studied. First, several critical parameters of the proposed strategy, namely,  $p_1$ ,  $p_2$ ,  $\theta$ , and  $\beta(k)$  are taken [1] and their impact on the proposed strategy is discussed, after that the proposed strategy is compared with the IS-41, LAS, GR strategies under different scenarios. The proposed strategy and the simulations in this section are applicable to any user movement patterns such as random walk, moving back and forth across adjacent LAs, etc. In Figures 5, 6, 7, 8, and 9, it is assumed that  $\lambda_{n,i}$  ( $i=1,2,\dots,8$ ) are uniformly distributed over (0.1,3) and the incoming call arrival rates  $\phi_i$  ( $i=1,2,3,\dots,M$ ) at all MTs in the LA are uniformly distributed over (0.2, 3), which implies that the  $\mu_{n,i}$  ( $i=1,2,3,\dots,8$ ) are also uniformly distributed over (0.2, 3)

##### A. Parameter Evaluations

Figure. 5 shows the graph of probabilities  $p_1$  and  $p_2$  versus  $\lambda_0$  where  $N_i = 20$  ( $i= 1, 2 \dots 8$ ) are used for demonstration purposes. From Figure. 5, we can see that  $p_1$  and  $p_2$  are very small. As  $N_i$  ( $i=1, 2, \dots, 8$ ) increases,  $p_1$  and  $p_2$  decrease further  $p_1$  increases as  $\lambda_0$  increases. This is true since as the mean LA residence time,  $(1/\lambda_0)$ , of MT decreases, the probability that there is no incoming call to an LA during the MT's stay at the LA increases. It is also noted that the impact of  $\mu_0$  on  $p_1$  is negligible. On the other hand,  $p_1$  decreases as  $\mu_0$  decreases and the impact of  $\lambda_0$  on  $p_2$  is negligible. That is, as the mean of an MT's intercall interval,  $1/\mu_0$  increases the probability that the MT receives the first incoming call to its current LA decreases. In real mobile networks,  $N_i$  ( $i=1,2,\dots,8$ ) may be much larger than 20, therefore,  $p_1$  and  $p_2$  would become much smaller. Thus, the location updates process shown in Figure. 1 and the call delivery process shown in Figure. 3 are invoked by the proposed strategy most of the time, resulting in less cost than those processes shown in Figure. 2 and Figure 4 Figure. 6 studies the impact of the MT arrival rate at a LA on the probability  $\theta$  [1] that the RWL is not empty when an incoming call arrives to the LA, under different numbers  $M$  of MTs registered at an LA. From Figure 6, it can be seen that  $\theta$  decreases as  $\eta$  decreases or  $M$  increases. This is true because a smaller MT arrival rate to an LA increases the probability that the RWL is empty upon the arrival of a call. On the other hand, more MTs in an LA will make the LA receive calls more often and the RWL will be emptied more frequently, thus the probability that the RWL is not empty becomes smaller, resulting in a smaller cost for the proposed strategy. Figure.7 studies the probability  $\beta(k)$  that there are  $k$  MTs in the RWL, which determines the cost of piggybacking the RWL in the route request acknowledgment message as well as the memory

requirement for maintaining the RWL in the VLR. Three sets of  $(M,\eta)$  i.e., (200,100), (200, 50), and (400, 50), are considered. It is observed from Figure. 7 that the first set of  $(M,\eta)$  results in the greatest  $\beta(k)$  ( $k= 1, 2 \dots$ ). As the MT arrival rate at the LA decreases or the number of MTs  $M$  in the LA increases,  $\beta(k)$  ( $k=1,2,3,\dots$ ) decreases. It can be seen that  $\beta(k)$  approaches zero when  $k \geq 4$  for all given parameter sets.

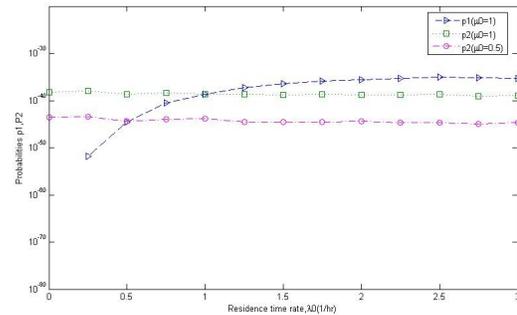


Figure 5 Probabilities  $p_1$ ,  $p_2$  versus residence time rate

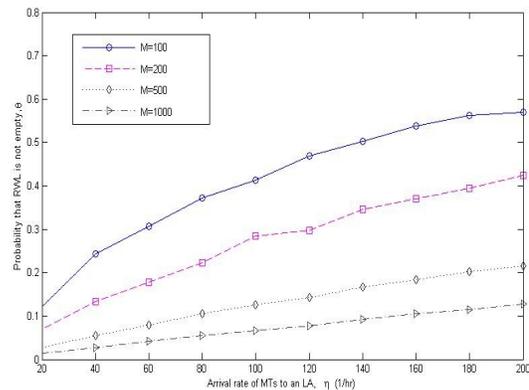


Figure 6 Probability of the RWL not empty versus arrival rate of a MT to a LA

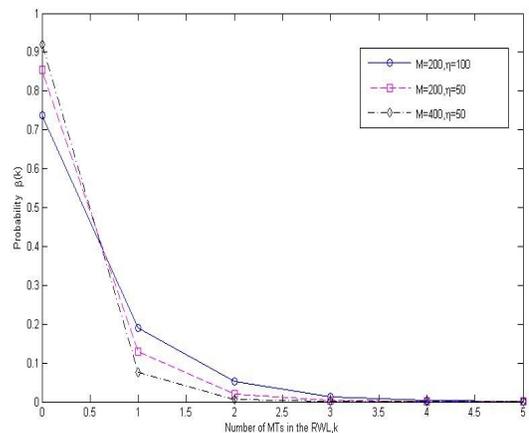


Figure 7. Probability of the  $k$  MTs in the RWL,  $\beta(k)$  versus number of MTs in the RWL

The International Mobile Subscriber Identity (IMSI) is usually used to identify an MT in location management and its length is no more than 15 digits. If one digit is 1 byte long, then  $N$  MT IDs in the RWL require a space of  $15 \times N$  bytes. For  $N=4$ , the required space is 60 bytes. As indicated in Figure. 7, usually a much smaller space is needed for the RWL.

Figure. 8 compares the total cost per call arrival of the proposed strategy with those of the conventional IS-41 strategy, GR strategy and the LAS strategy under different  $\lambda_0$  values, where  $(M,\eta)$  is set to  $(200,100)$ . In Figures. 8 and 4.5, the following cost values are used:  $C_v=1$ ,  $Ch=1.5$ ,  $C_{vv}=1$ , and  $Chv=2$ . It is assumed that a query or an update at the HLR incurs a larger cost than that at the VLR, and the message exchanges between the HLR and a VLR incur a larger cost than those between two VLRs.

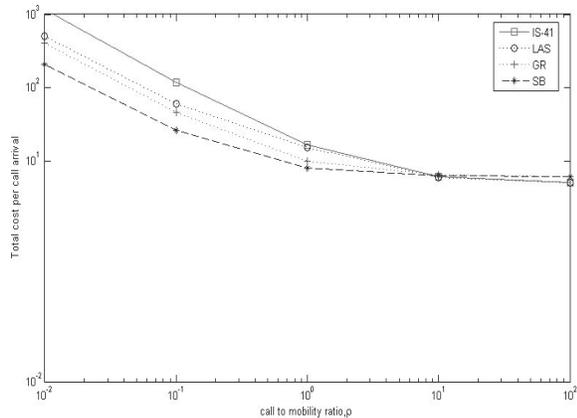


Figure 8 (a) Total cost per call arrival versus CMR for different strategies with  $\lambda_0 = 0.5$  per hour

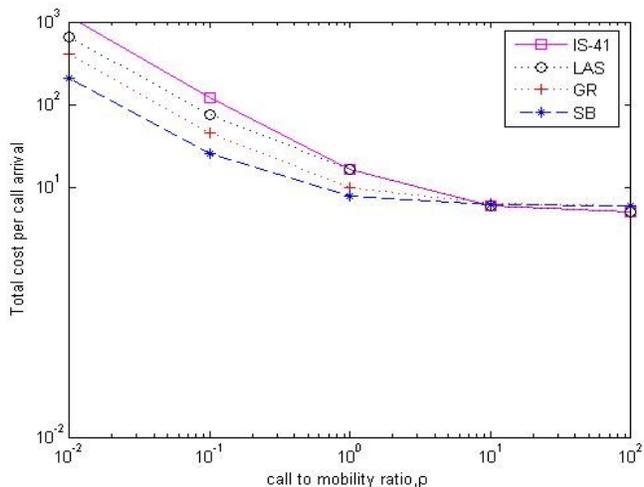


Figure 8 (b) Total cost per call arrival versus CMR for different strategies with  $\lambda_0 = 5.0$  per hour

This reflects the generic view that the resources at the HLR are usually more expensive to consume than those at the VLR and the distance between the HLR and VLR is larger than that between two VLRs. From Figure 9, it is observed that the proposed SB strategy incurs a smaller total cost per call arrival than three other conventional strategy and the LAS strategy when an MT's CMR  $\rho < 10$ , while for  $\rho > 10$ , the proposed strategy incurs a slightly Equivalent cost to the other three strategies. Moreover, the impact  $\lambda_0$  on the total cost per call arrival of the proposed strategy is negligible.

The preceding observations can be explained as follows Compared to the IS-41 strategy, the SB strategy has a smaller location update cost by reporting its location changes to the local anchor. Compared to the LAS strategy, the SB strategy incurs both smaller location update and call delivery costs. The SB strategy also has low cost than the GR strategy in both the cases.

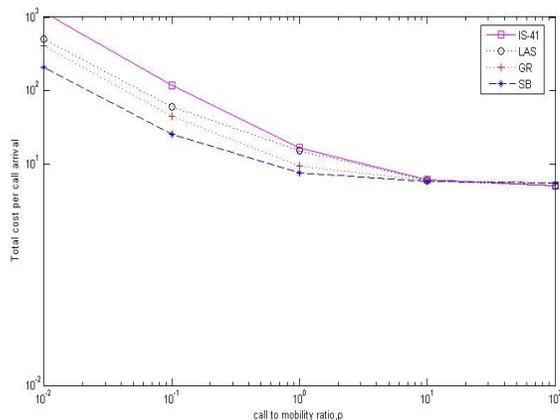


Figure 9 (a) Total cost per call arrival versus CMR for different strategies with  $M=200$  and  $\eta=50$

In Figure. 9, we compare the proposed strategy to the IS-41 strategy, LAS strategy and the GR strategy under two different sets of  $(M,\eta)$ :  $(200, 50)$  and  $(400, 50)$  We observe that, as  $M$  increases, the proposed strategy outperforms the IS-41,GR and

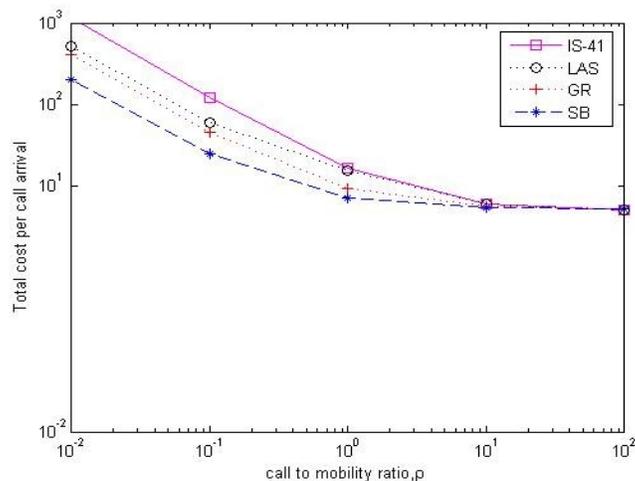


Figure 9(b) Total cost per call arrival versus CMR for different strategies with  $M=400$  and  $\eta=50$

LAS strategies over a wider range of  $\rho$ . When comparing Figure. 8a to Figure. 9a, we observe that as  $\eta$  decreases, the proposed strategy results in a smaller cost for high  $\rho$  values. These observations are readily understood in that a larger number of MTs in the LA or a smaller MT arrival rate to the LA results in a smaller RWL (i.e., RL), thus reducing the call delivery cost of the proposed strategy (which especially benefits high  $\rho$  values). Furthermore, a larger  $M$  results in smaller  $P_1$  and  $P_2$ , reducing both the expected location update cost and calls delivery cost in the SB strategy.

## V. CONCLUSIONS

A SB location tracking strategy has been proposed in this paper which is based on the modified version of group registration technique. It uses one repository as a central database which stores the information about the mobile terminal and also the updated location of it. An analytical model of the strategy is described and numerical result is presented for the performance evaluation. The proposed strategy is compared to IS-41, the LAS and the GR strategies and it is observed that the proposed strategy can achieve a cost reduction over a

wide range of CMRs. Moreover, the proposed strategy is based on the concept of central database and storage of information about MT deployed in existing mobile systems and does not require the system to collect the mobility and calling statistics for individual mobile terminals. The proposed strategy work well for low CMR.

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