A New Location Caching with Fixed Local Anchor for Reducing Overall Location Management Cost in Wireless Mobile Networks

Md. Mohsin Ali mohsin_kuet_cse@yahoo.com
Department of Computer Science and Engineering (CSE)
Khulna University of Engineering & Technology (KUET)
Khulna, 9203, Bangladesh

G. M. Mashrur-E-Elahi ranju2k4cse_kuet@yahoo.com
Department of Computer Science and Engineering (CSE)
Khulna University of Engineering & Technology (KUET)
Khulna, 9203, Bangladesh

Md. Asadul Islam asad_kuet@yahoo.com
Department of Computer Science and Engineering (CSE)
Khulna University of Engineering & Technology (KUET)
Khulna, 9203, Bangladesh

Abstract

The proposed approach in this paper selects a fixed Visitor Location Register (VLR) as a Fixed Local Anchor (FLA) for each group of Registration Areas (RAs). During call delivery process, the calling VLR/FLA caches are updated with the called Mobile Terminal's (MT's) location information and the called VLR and FLA caches are updated with the calling MT's location information. Furthermore, the FLA and the old VLR caches are updated with MT's new location information during inter-RA handoff as a part of informing this to the FLA of that region. But for another case, it updates the new FLA, old FLA, and old VLR caches with new location information together with directly informing this to the Home Location Register (HLR). This location caching policy in local anchor strategy maximizes the probability of finding MTs' location information in caches. As a result, it minimizes the total number of HLR access for finding MT's location information prior to deliver a call. So, it significantly reduces the total location management cost in terms of location registration cost and call delivery cost. The analytical and experimental results also demonstrate that the proposed method outperforms all other previous methods regardless of the MT's calling and mobility pattern.

Keywords: location management, location registration, call delivery, cache, fixed local anchor.

1. INTRODUCTION

Wireless mobile networks and personal communication networks provide services to its subscribers that travel within the network coverage area. In order to correctly deliver incoming calls to MTs within this area, the up-to-date location information of each MT needs to be identified. Therefore, a location management strategy is necessary to effectively keep track of the MTs before initiating the call setup procedure. The basic operations of this strategy are location registration, call delivery, and paging or searching. The first one is the process of informing the network about the MT's current location information; the second one is the connection establishment between the caller and called MTs, and the third one is the operation of determining the location of the MT. It is also observed that there are some trade-offs among the location registration, paging, and call arrival rate. If the MT registers its location during RA crossing, the network can precisely maintain its location and prevents the need for paging. However, in the case of lower call arrival rate, the network resources are wasted for processing frequent update information and the MT wastes its power by transmitting the update signal. On the other hand, a large coverage area has to be searched during call arrival process if the MT performs infrequent location registration - which eventually wastes the radio bandwidth [1]. Therefore, the central problem of location management is to develop algorithms and architectures with a view to minimizing the overall cost for location registration, call delivery, and paging.

Two standard architectures currently exist in wireless mobile networks are IS-41 [2] and GSM [3]. Both these architectures are based on a two-level database hierarchy. Two types of database called HLR and VLR are used to store the MTs' location information. Figure 1 shows the basic architecture of the wireless mobile networks under this two-level database hierarchy. The whole network coverage area is divided into cells having same size and shape. Each cell has a Base Transceiver Station (BTS) to communicate with the network through wireless link. The cells are grouped together to form larger areas called Registration Areas (RAs). All the BTS belonging to a given RA are wired to a Mobile Switching Center (MSC) which plays the role of the interface between the wireless and the wired portions of the network. In Figure 1, it is assumed that each VLR co-locates with the MSC and a group of RAs are interfaced with the Local Signaling Transfer Point (LSTP) following HLR. There may exist one or more HLRs in the network depending on its configuration. An HLR is the centralized database that contains the records of all users' profiles together with MTs' location information for the entire network. On the other hand, each VLR stores replications of the user profiles of the subscribers currently residing in its corresponding RA. Whenever an MT enters into a new RA, it needs to report its new location information to the MSC. The MSC updates its associated VLR and transmits this new information to the HLR. The HLR acknowledges the MSC about this successful registration and also sends back a location deregistration message to the MT's old VLR in the corresponding RA. In order to deliver a call to a target MT, the HLR is queried to determine the serving MSC of that target MT. The HLR then sends a message to this MSC with a view to determining the serving BTS of the target MT by searching all cells within the corresponding RA [5].

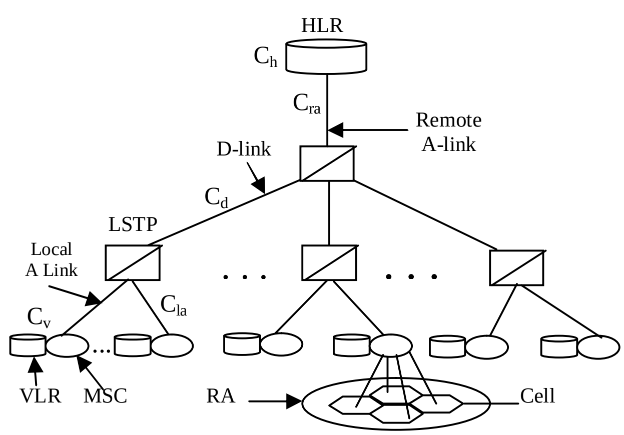


FIGURE 1: Signaling System No. 7 architecture.

As the number of MTs within the network is exploding day by day, location management under the IS-41 has suffered various critical problems like increasing signaling traffic in the network and the HLR bottleneck. As a result, a number of efforts have been reported to overcome these problems [4], [5], [6], [7], [8], and [9]. However, all of these approaches have some specific working criteria. As for example, the location caching strategy [4] or replication strategy [8] effectively works for larger call-to-mobility ratio (CMR), while the local anchor strategy [5], [6] or forwarding-pointer strategy works better for small CMR values. A profile-based location caching with fixed local anchor strategy is proposed in [9], but suffers signaling overheads throughout the network during the MT's inter-LSTP movement.

Symbol	Description
( )	Corresponding message number
[ ]	Cost for the particular signaling exchange
{ }	Cost for accessing the particular database
→	Exchange of the particular signaling message
←	Acknowledgement of the corresponding signaling message

TABLE 1: Description of Symbols Shown in Figure 2–Figure 10.

In this paper, a new location caching strategy is proposed by effectively using the MTs' calling and mobility pattern and combined with the local anchor strategy [5], [6]. Simply, it effectively exploits the concepts of both the location caching strategy [4] and the local anchor strategy [5], [6]. It also relieves the network from signaling overheads during inter-LSTP movement unlike the profile-based location caching with fixed local anchor strategy [9]. In the general location caching strategy [4], the called MT's location information is updated only in the call originating VLR cache at call originating time. This updating strategy can also be applied to the local anchor strategy [5], [6]. But, there is a scope of updating the called MT's VLR and FLA caches with the calling MT's location information for the same call too. On the other hand, location deregistration messages are sent to the old VLR and FLA when an MT performs an inter-RA or inter-LSTP movement. The old VLR and FLA caches can also be updated with MT's new location information together with the deregistration message. Moreover, there is another scope of updating new FLA cache with MT's new location information during inter-LSTP movement. This enhanced cache updating policy prepares the cache with up-to-date information frequently as it updates more than one cache for each call delivery and even updates them during location registration. So, the probability of searching the HLR decreases for call delivery and there is also no location update to the HLR for inter-RA handoff. As a result, the total location management cost in terms of location registration cost and call delivery cost decreases.

The rest of the paper is organized as follows. Section 2 provides an overview of the related recent research work. Proposed approach is described in Section 3. Section 4 gives the analytical modeling. Numerical results and comparison among different methods based on some experimental results are described in Section 5. Section 6 provides a concluding remark of this paper.

2. EXISTING LOCATION MANAGEMENT STRATEGIES

An extensive work has been done on location management to reduce the overall location management cost in terms of location registration cost and call delivery cost [2], [4], [5], [6], [7], [8], and [9]. Some of them are basic scheme which are generally used to manage the location irrespective of all the wireless networks. Some others are based on reusing the user location information obtained during the previous call to the user. This effectively reduces the call delivery cost. While some others are based on managing the local handoff locally instead of informing the centralized HLR. This reduces the location registration cost. There are also some methods which use the MT's calling statistics from the HLR and replicate its location information to these calling VLR cache. These also manage the local handoff locally instead of accessing the heavily congested HLR. This reduces both the location registration and call delivery cost. The existing location management strategies are shown in Figure 2– Figure 8 and the symbols used in these figures are described in Table 1. The location management procedures of these strategies are described in the following subsections.

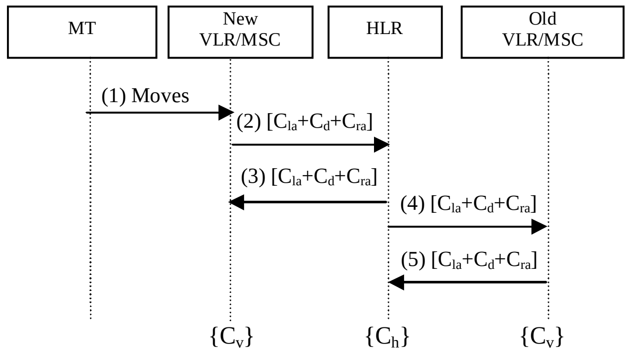


FIGURE 2: Location Registration under Both the IS-41 and LC Strategies.

2.1. IS-41 Strategy

The basic IS-41 standard is proposed in [2] where each MT informs its location information to the HLR during all type of handoff procedures. The call delivery procedure is performed by searching the MT's location information in the HLR prior to setup a call.

The location registration procedure of this strategy is described as follows (see Figure 2).

(1) An MT handoffs into a new RA and informs its new location to the new MSC through the nearby BTS.
(2) The MSC updates its associated VLR about this MT and sends a location registration to the HLR.
(3) The HLR updates the MT's record and sends back a registration acknowledgement message to the new VLR.
(4) It also sends a registration cancellation message to the old VLR.
(5) The old VLR removes the record of the MT and sends back a cancellation acknowledgement message to the HLR.

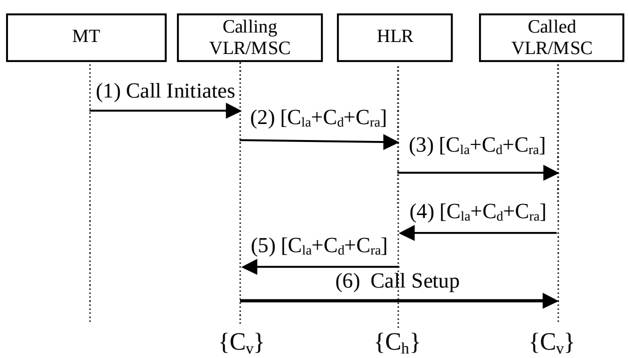


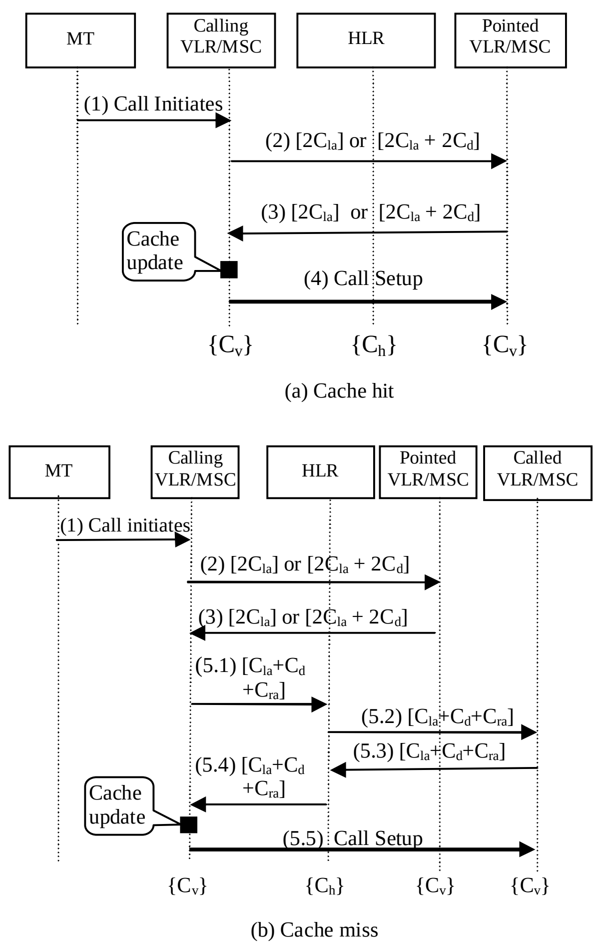
FIGURE 3: Call Delivery under the IS-41 Strategy.

On the other hand, the call delivery procedure under this strategy is described as follows (see Figure 3).

(1) The calling MT initiates a call and sends a message to its serving MSC through a nearby BTS.
(2) The calling MSC sends a message to the HLR with a request of the called MT's location information.
(3) The HLR determines the called MT's current serving MSC and sends a location request message to that MSC.
(4) The MSC allocates a Temporary Local Directory Number (TLDN) [9] to the MT and sends back a reply to the HLR together with the TLDN.
(5) The HLR sends this information back to the calling MSC
(6) The MSC sends a request message of call setup to the called MSC through the network shown in Figure 1.

2.2. Location Caching (LC) Strategy

A per-user location caching strategy is proposed in [4] where the called MT's location information is stored in the calling MT's VLR cache prior to call setup during each call delivery process. So to deliver a call, the called MT's location information is first searched at VLR cache instead of directly going to the HLR. This reduces the frequency of HLR access for delivering calls and eventually reduces the location management cost.



(a) Cache hit

(b) Cache miss

FIGURE 4: Call Delivery under the LC Strategy.

The location registration procedure of this strategy is the same as that of the IS-41 and described in Section 2.1 (see Figure 2). The call delivery procedure under this strategy is described as follows (see Figure 4).

(1) The MT sends a call initiation message to the calling MSC through the nearby BTS.
(2) The called MT's location information is searched in the calling VLR cache and it is assumed that there will be such an entry there. Then it sends a route request message to the pointed VLR/MSC.
(3) The pointed VLR verifies whether this information is exact or obsolete. If exact, then sends back an acknowledgement message stating cache hit with a TLDN to the calling MSC. Otherwise, sends a negative acknowledgement message stating cache miss to the calling MSC and go to step 5.
(4) The calling VLR updates its cache with the called MT's location information. Following this, the MSC sends a call setup message to the called MSC through the network shown in Figure 1 (Call delivery procedure is complete. Do not proceed to the next step).
(5) If the location information found in the pointed VLR is obsolete (cache miss), then follow the steps.

    (5.1) The calling MSC sends a location request message to the HLR.
    (5.2) The HLR determines the current serving MSC of the called MT and sends a location request message to the called MSC.
    (5.3) The called MSC allocates a TLDN to the MT and sends it back to the HLR.
    (5.4) The HLR forwards this message back to the calling MSC.
    (5.5) The calling VLR updates its cache with the called MT's location information and the calling MSC sends a call setup message to the called MSC (Call delivery is complete. Do not proceed to the next step).

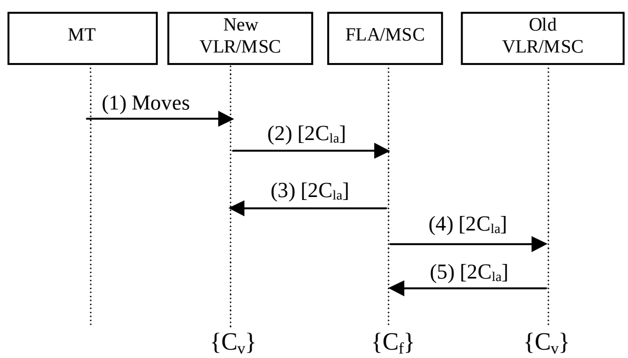


FIGURE 5: Intra-LSTP Movement Location Registration under Both the FLA and PCFLA Strategies.

2.3. Fixed Local Anchor (FLA) Strategy

The Fixed Local Anchor strategy is proposed in [5], [6] where local handoffs are managed locally without overwhelming the centralized HLR. An LSTP group is defined with some of the RAs and a fixed VLR plays the role of the Fixed Local Anchor (FLA) within this group. This FLA handles all the intra-LSTP handoff within this group and HLR tracks the location information of these FLAs.

The location registration procedure is divided into two categories: intra-LSTP movement and inter-LSTP movement. The intra-LSTP movement registration of this strategy is given in Figure 5 and inter-LSTP of that is given in Figure 6. These are described as follows.

(1) An MT handoffs into a new RA and informs its new location to the new MSC through the nearby BTS.
(2) The new MSC forwards a location registration message to its associated FLA within its region.
(3) The FLA verifies the MT's profile. If there is an MT's record, then update it with the new location information and sends back an acknowledgement message together with a copy of the MT's profile to the new MSC. Otherwise go to step 6.
(4) The FLA sends a deregistration message to the old MSC.

(5) The old MSC clears the record for that MT from the VLR and replies a confirmation message to the FLA (Location registration by intra-LSTP movement is complete. Do not proceed to the next step).
(6) If the FLA does not have the MT's record, the followings are performed.

(6.1) The serving MSC of the MT's new FLA sends a location registration message to the HLR.
(6.2) The HLR updates the MT's record in terms of MT's new FLA and sends back a copy of the MT's profile to that new FLA.
(6.3) The FLA updates the MT's record in terms of new VLR and acknowledges the new VLR with a copy of the MT's profile.
(6.4) The HLR sends a deregistration message to the MT's old FLA.
(6.5) The old FLA removes the MT's record from it and sends a deregistration acknowledgement message back to the HLR.
(6.6) The old FLA sends a deregistration message to the MT's old VLR.
(6.7) The old VLR removes the MT's record and sends a deregistration acknowledgement message back to the old FLA (Location registration by inter-LSTP movement is complete).

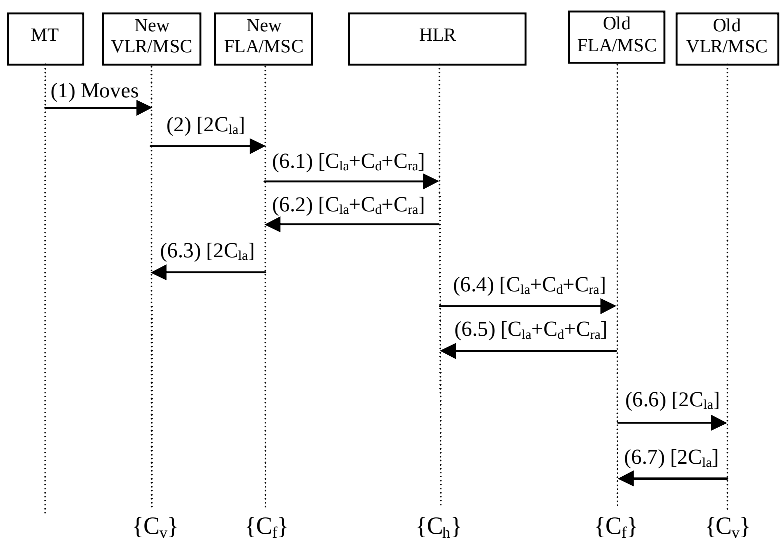


FIGURE 6: Inter-LSTP Movement Location Registration under the FLA Strategy.

On the other hand, the call delivery procedure under this strategy is described as follows (see Figure 8(b)).

(1) The MT sends a call initiation message to the calling MSC through the nearby BTS.

(6.1) The calling MSC sends a location request message to the HLR.
(6.2) The HLR sends a message requesting the called MT's location information to the called FLA.
(6.3) The called FLA forwards this message to the called VLR/MSC.
(6.4) The called VLR/MSC sends a location route back to the HLR together with a TLDN to the MT.
(6.5) The HLR forwards this message back to the calling MSC.
(6.6) The calling MSC sends a call setup request message to the called MSC through the network shown in Figure 1 (Call delivery is complete).

2.4. Profile-based Location Caching with Fixed Local Anchor (PCFLA) Strategy

A Profile-based Location Caching with Fixed Local Anchor strategy is proposed in [9] where user profiles are effectively utilized to determine at which sites throughout the networks user's location information should be cached. In this approach, these site lists are prepared based on the long-term call related statistics maintained by the HLR from the callee's user profile. These lists are used to store the callees' location information to some of the most frequently calling VLR caches of the corresponding callees. On the other hand, an FLA is used to manage the intra-LSTP handoff locally like FLA strategy described in Section 2.3. The intra-LSTP movement location registration under this strategy is the same as that of the FLA strategy and step 1 to 5 of Section 2.3 describes that (see Figure 5).

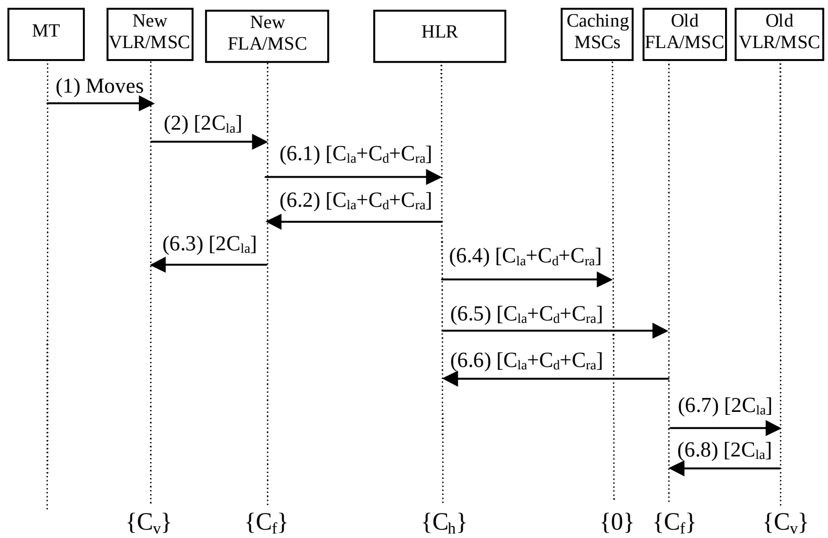


FIGURE 7: Inter-LSTP Movement Location Registration under the PCFLA Strategy.

The inter-LSTP movement location registration following the intra-LSTP location registration (step 1 to 5 of Section 2.3) is described as follows (see Figure 7).

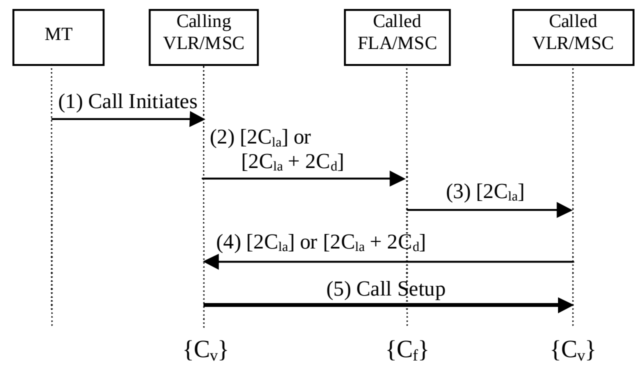
(6) If the FLA does not have the MT's record, the followings are performed.

(6.1) The serving MSC of the MT's new FLA sends a location registration message to the HLR.
(6.2) The HLR updates the MT's record in terms of MT's new FLA and sends back a copy of the MT's profile to that new FLA.
(6.3) The FLA updates the MT's record in terms of new VLR and acknowledges the new VLR with a copy of the MT's profile.
(6.4) The HLR sends location cache update messages to MSCs selected by the long-term calling statistics maintained by the HLR which have location caches for that MT.
(6.5) The HLR sends a deregistration message to the MT's old FLA.
(6.6) The old FLA removes the MT's record from it and sends a deregistration acknowledgement message back to the HLR.
(6.7) The old FLA sends a deregistration message to the MT's old VLR.
(6.8) The old VLR removes the MT's record and sends a deregistration acknowledgement message back to the old FLA (Location registration by inter-LSTP movement is complete).

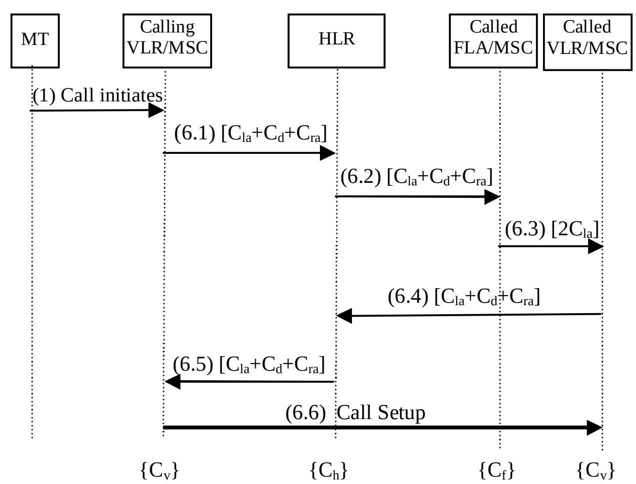
On the other hand, the call delivery procedure under this strategy is described as follows (see Figures 8(a) and 8(b)).

(1) The MT sends a call initiation message to the calling MSC through the nearby BTS.

(2) The calling MSC verifies if it has the called MT's location information in the VLR cache. If yes, then it sends a called MT's location request message to the called FLA. Otherwise go to step 6.
(3) The called FLA forwards this message to the called MSC.
(4) The called MSC sends an acknowledgement message to the calling MSC together with a TLDN to the MT.
(5) The calling MSC sends a call setup request message to the called MSC through the network shown in Figure 1 (Call delivery is complete. Do not proceed to the next step).
(6) If the calling MSC does not contain location cache for the called FLA, then it follows the call delivery steps 6.1 through 6.6 of the FLA strategy described in Section 2.3.



(a) When the calling MSC has location cache for the called FLA

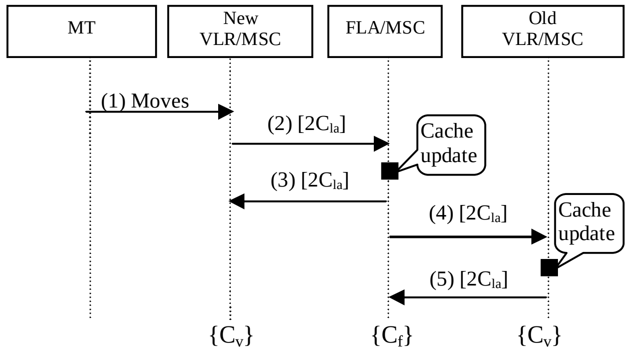


(b) When the calling MSC does not have location cache for the called FLA

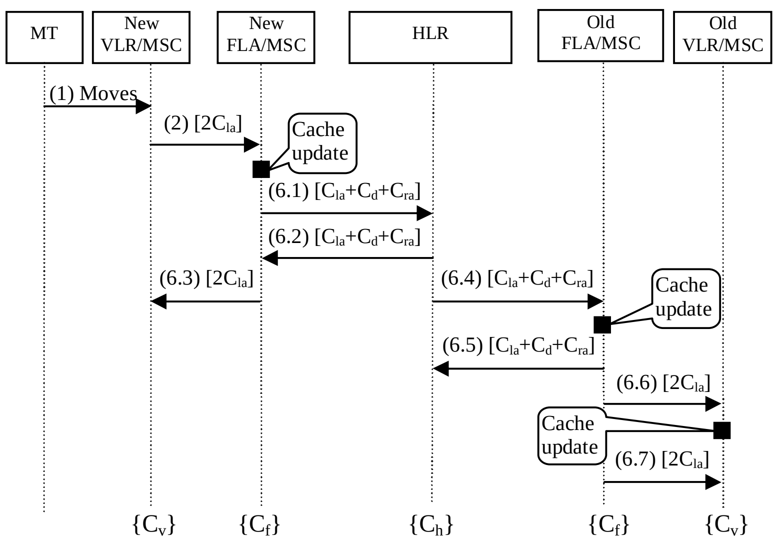
FIGURE 8: Call Delivery under the PCFLA (a and b) and FLA (b) Strategies.

3. PROPOSED NEW LOCATION CACHING WITH FIXED LOCAL ANCHOR (NLCFLA) STRATEGY

In the following, a simple but effective location management strategy is proposed for the next-generation wireless mobile networks. In this strategy, FLA strategy is used for location registration and users' calling and mobility patterns are used to update the MTs' location information in the caches of the calling MTs' VLR, called MTs' VLR, calling MTs' FLA, called MTs' FLA, old FLA, and old VLR. However, this strategy effectively exploits the advantages of both the LC and FLA strategies and does not make the centralized HLR congested with enormous signaling messages during inter-LSTP handoff like PCFLA. In the LC strategy, the calling MT's VLR cache is updated with the called MT's location information just prior to setup each call between the calling and called MTs. But in the NLCFLA strategy, caches of the calling MT's VLR are updated with the called MT's location information, and caches of the pointed/called MT's FLA and VLR are updated with the calling MT's location information during each call setup procedure. No separate signaling messages are needed to update these caches. These are updated during the regular signaling message exchange. Moreover, it also updates the caches of the new FLA,



(a) Intra-LSTP movement



(b) Inter-LSTP movement

FIGURE 9: Location Registration under the NLCFLA Strategy.

old FLA, and old VLR during intra-LSTP or inter-LSTP handoffs. This also does not need to separate signaling message. When an MT handoffs to a new VLR/MSC, it sends its location information to its designated FLA. This designated FLA cache is updated with the MT's new location information together with the same regular registration message. On the other hand, registration cancellation messages are sent to the old FLA and VLR at the time of normal registration procedure. The caches of these old FLA and VLR also updated with the MT's new location information together with the regular registration cancellation message. But in the PCFLA, the MT's new location information is sent to the frequently calling VLR sites using separate explicit signaling messages throughout the networks. During each call delivery process, the calling MT's VLR cache is first searched for the called MT's location information. If that location information is found, it initiates the call setup procedure directly to that called MT without accessing the HLR for location query. This pointed VLR cache information may be obsolete. In that case, it directly communicates to the HLR for querying location information. But, the probability of having obsolete information in these caches is much lower as many caches are updated for each call delivery as well as handoff rather than only one location update in LC strategy. So, the overall location management cost under this strategy outperforms all other previous strategy. The location management procedure under this strategy is shown in Figure 9 and Figure 10 and the symbols used in these figures are described in Table 1.

The location registration under this strategy is divided into two categories: intra-LSTP movement and inter-LSTP movement. These strategies are described as follows (see Figure 9).

(1) An MT handoffs into a new RA and informs its new location to the new MSC through the nearby BTS.
(2) The new MSC forwards a location registration message to its associated FLA within its region.
(3) The FLA updates its cache with MT's new location information. Following this, the FLA verifies the MT's profile. If there is an MT's record, then update it with the new location information and sends back an acknowledgement message together with a copy of the MT's profile to the new MSC. Otherwise go to step 6.
(4) The FLA sends a deregistration message to the old MSC.
(5) The old VLR updates its cache with MT's new location information. Following this, the old MSC clears the record for that MT from the VLR and replies a confirmation message to the FLA (Location registration by intra-LSTP movement is complete. Do not proceed to the next step).
(6) If the FLA does not have the MT's record, the followings are performed.

    (6.1) The serving MSC of the MT's new FLA sends a location registration message to the HLR.
    (6.2) The HLR updates the MT's record in terms of MT's new FLA and sends back a copy of the MT's profile to that new FLA.
    (6.3) The FLA updates the MT's record in terms of new VLR and acknowledges the new VLR with a copy of the MT's profile.
    (6.4) The HLR sends a deregistration message to the MT's old FLA.
    (6.5) The old FLA updates its cache with MT's new location information. Following this, the old FLA removes the MT's record from it and sends a deregistration acknowledgement message back to the HLR.
    (6.6) The old FLA sends a deregistration message to the MT's old VLR.
    (6.7) The old VLR updates its cache with MT's new location information. Following this, the old VLR removes the MT's record and sends a deregistration acknowledgement message back to the old FLA (Location registration by inter-LSTP movement is complete).

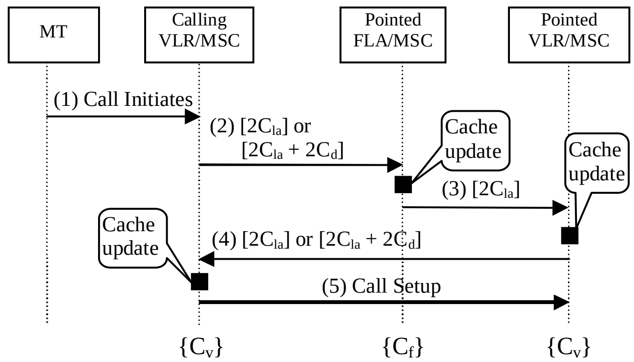
On the other hand, the call delivery procedure under this strategy is described as follows (see Figures 10(a) and 10(b)).

(1) The MT sends a call initiation message to the calling MSC through the nearby BTS.
(2) The called MT's location information is searched in the calling VLR cache and it is assumed that there will be such an entry there. Then it sends a route request message to the pointed FLA/MSC.
(3) The pointed FLA cache is updated with the calling MT's location information. Following this, the pointed FLA searches the entry for the called MT's location information and forwards this message to the pointed VLR/MSC.
(4) The pointed VLR cache is updated with the calling MT's location information. Following this, the pointed VLR/MSC verifies whether the location information for the called MT is exact or obsolete. If exact (cache hit), then it sends an acknowledgement message to the calling

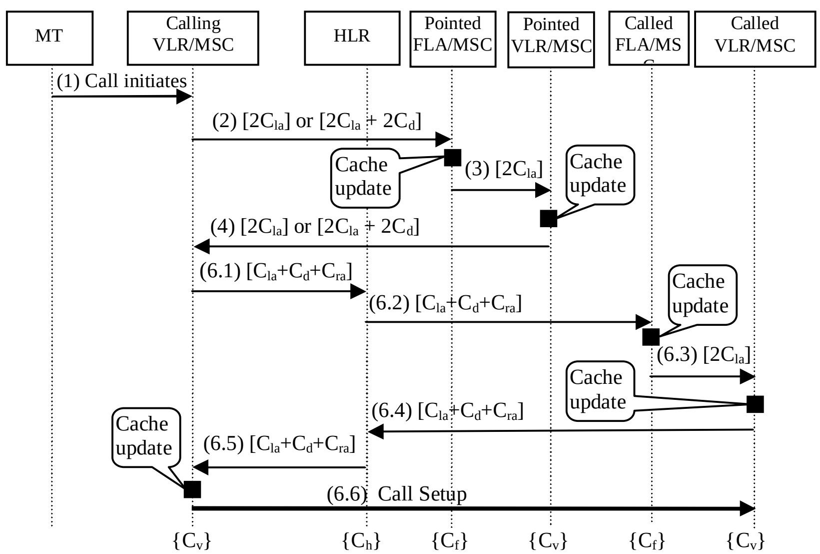
MSC together with a TLDN to the MT. Otherwise, it sends a negative acknowledgement message (cache miss) to the calling MSC and go to step 6.

(5) The calling VLR cache is updated with the called MT's location information. Following this, the calling MSC sends a call setup request message to the called MSC through the network shown in Figure 1 (Call delivery is complete. Do not proceed to the next step).

(6) If the pointed VLR/MSC contain obsolete location information (cache miss), then it follows the steps below.



(a) Cache hit



(b) Cache miss

FIGURE 10: Call Delivery under the NLCFLA Strategy.

(6.1) The calling MSC sends a location request message to the HLR.

(6.2) The HLR sends a message requesting the called MT's location information to the called FLA.

(6.3) The called FLA cache is updated with the calling MT's location information and the called FLA forwards the location request message to the called VLR/MSC.

(6.4) The called VLR cache is updated with the calling MT's location information. Following this, the called VLR/MSC sends a location route back to the HLR together with a TLDN to the MT.

(6.5) The HLR forwards this message back to the calling MSC.

(6.6) The calling VLR cache is updated with the called MT's location information. Following this, the calling MSC sends a call setup request message to the called MSC through the network shown in Figure 1 (Call delivery is complete).

4. ANALYTICAL MODELING

A fluid flow mobility model [10] is considered in order to evaluate the performance of the proposed and the related approaches. It is assumed that MTs are moving at an average speed of v in uniformly distributed direction over $[0, 2\pi]$ with a view to crossing the LSTP region composed of N equal rectangular-shaped and sized RAs [9]. The parameters used for the MTs' movement rates analysis are defined as follows.

- γ: the MT's movement rate out of an RA
- μ: the MT's movement rate out of an LSTP region
- λ: the MT's movement rate to an adjacent RA within a given LSTP region

According to [11], these parameters are calculated as follows.

$$\gamma = \frac{4\upsilon}{\pi\sqrt{S}} \tag{1}$$

$$\mu = \frac{4\upsilon}{\pi\sqrt{NS}} \tag{2}$$

$$\lambda = \gamma - \mu = \left(1 - \frac{1}{\sqrt{N}}\right)\gamma \tag{3}$$

Where v is the average moving speed of an MT, S is the size of the RA, and N is the number of RAs within a LSTP region.

A continuous-time Markov Chain state transition diagram is used in Figure 11 to show an MT's RA movement representing the fluid flow mobility model. Each state $i\,(i \geq 0)$ defines the RA number of a given LSTP region where an MT can stay and state 0 means the MT stays outside of this region. The state transition $a_{i,i+1}\,(i \geq 1)$ represents an MT's movement rate to an adjacent RA within a given LSTP region, and $a_{0,1}$ represents an MT's movement rate to an RA of that region from another one. On the other hand, $b_{i,0}\,(i \geq 1)$ represents an MT's inter-LSTP region movement rate and it is assumed that there are maximum K number of such movements.

Therefore, from Figure 11, it is obtained that $a_{i,i+1}\,(i \geq 1) = \lambda$ and $a_{0,1} = b_{i,0} = \mu$, respectively.

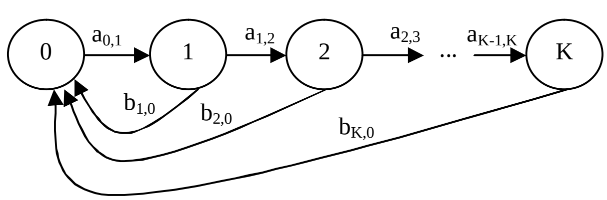


FIGURE 11: State Transition Diagram of an MT's RA Movement.

On the other hand, if π_i is the equilibrium probability of state i, the following equations can be obtained from a continuous-time Markov Chain given in Figure 11.

$$\mu\pi_0 = \mu\sum_{i=1}^{K}\pi_i \tag{4}$$

$$\mu\pi_{i-1} = (\lambda + \mu)\pi_i, \qquad i = 1 \tag{5}$$
$$\lambda\pi_{i-1} = (\lambda + \mu)\pi_i, \qquad 2 \le i \le K-1 \tag{6}$$
$$\lambda\pi_{i-1} = \mu\pi_i, \qquad i = K \tag{7}$$

Additionally, the sum of the probabilities of all states is 1. So,

$$\pi_0 + \pi_1 + \pi_2 + \cdots + \pi_K = \sum_{i=0}^{K} \pi_i = 1 \tag{8}$$

By substituting (8) into (4), it can be obtained the equilibrium probability of state 0, π_0. So,

$$\pi_0 = \frac{1}{2} \tag{9}$$

Finally, from (5), (6), (7) and (9), π_i is obtained as follows.

$$\pi_i = \begin{cases} \frac{1}{2} & if\ i = 0 \\ \frac{1}{2}\left(\frac{\mu}{\lambda+\mu}\right)\left(\frac{\lambda}{\lambda+\mu}\right)^{i-1} & if\ 1 \le i \le K-1 \\ \frac{1}{2}\left(\frac{\lambda}{\lambda+\mu}\right)^{i-1} & if\ i = K \end{cases} \tag{10}$$

Parameter	Description
c_{la}	Cost of sending a signaling message through the local A-link
c_d	Cost of sending a signaling message through the D-link
c_{ra}	Cost of sending a signaling message through the remote A-link
c_v	Cost of a query or an update of the VLR
c_f	Cost of a query or an update of the FLA
c_h	Cost of a query or an update of the HLR

TABLE 2: Description of Cost Parameters Shown in Figure 1.

4.1. Analysis of Location Management Costs

In order to analyze the location registration cost, call delivery cost, and total location management cost of the IS-41, LC, FLA, PCFLA, and NLCFLA strategies, different parameters shown in Table 2 and 3 are considered. The following notations are also used to represent the cost of each strategy [9].

- U_X : the average location registration cost of the X strategy for an MT staying in an LSTP region
- S_X : the average call delivery cost of the X strategy for an MT staying in an LSTP region

- T_X : the average total location management cost of the X strategy for an MT staying in an LSTP region
- U_X^Y : the average location registration cost of the X strategy generated by movement type Y for an MT staying in an LSTP region

Parameter	Description
P_l	Probability of locating caller and callee within the same LSTP region
P_n	Probability of playing a new VLR as the role of an FLA
P_o	Probability of playing an old VLR as the role of an FLA
P_f	Probability of locating callee in the FLA area
P_c	Probability of calling MSC having location cache for the called FLA
q	The MT's call-to-mobility ratio (CMR)
τ	The MT's cache hit ratio under the LC and NLCFLA strategies
α	The MT's call arrival rate through MSC
m	Number of location servers (HLRs) in the system

TABLE 3: Parameters Used for the Cost Analysis.

Furthermore, the average number of unique RAs that an MT visits within a given LSTP for K movements can be calculated from Figure 11 and represented by the following equation.

$$\Phi(K) = \pi_1 + 2\pi_2 + 3\pi_3 + \cdots + K\pi_K = \sum_{i=1}^{K} i\pi_i \tag{11}$$

The location management cost functions of the IS-41, LC, FLA, PCFLA, and NLCFLA strategies can be derived from Figure 2 – 10.

1) *IS-41 Strategy*

The average location registration cost of the IS-41 strategy is derived as follows.

$$\begin{aligned} U_{IS-41} &= \pi_0 U_{IS-41}^{inter} + (\Phi(K)-1)U_{IS-41}^{intra} \\ &= \pi_0 \times \{4(C_{la}+C_d+C_{ra})+(2C_\upsilon+C_h)\} + (\Phi(K)-1)\times\{4(C_{la}+C_d+C_{ra})+(2C_\upsilon+C_h)\} \\ &= \{\pi_0 + (\Phi(K)-1)\}\{4(C_{la}+C_d+C_{ra})+(2C_\upsilon+C_h)\} \end{aligned} \tag{12}$$

The average call delivery cost of the IS-41 is defined as follows (see Figure 3).

$$S_{IS-41} = 4(C_{la}+C_d+C_{ra})+(2C_\upsilon+C_h) \tag{13}$$

So, the average total cost of the IS-41 strategy is expressed as follows.

$$T_{IS-41} = U_{IS-41} + qS_{IS-41} \tag{14}$$

2) LC Strategy

The average location registration cost of the LC strategy is defined as follows.

$$U_{LC} = U_{IS-41}$$

$$= \{\pi_0 + (\Phi(K)-1)\}\{4(C_{la} + C_d + C_{ra}) + (2C_\upsilon + C_h)\} \tag{15}$$

The average call delivery cost of the LC strategy is expressed as follows.

$$S_{LC} = \tau C_{LC}^{hit} + (1-\tau)C_{LC}^{miss} \tag{16}$$

Where C_{LC}^{hit} and C_{LC}^{miss} represents the call delivery cost of the LC strategy when location information pointed by cache for the called MT is correct and obsolete, respectively (see Figures 4(a) and 4(b)). τ and these two parameters are calculated by the following equations.

$$\begin{aligned}\tau &= \frac{\tau\times\alpha+(1-\tau)\times\alpha}{\tau\times\alpha+(1-\tau)\times\alpha+\lambda} \\ &= \frac{\alpha}{\alpha+\lambda}\end{aligned} \tag{17}$$

Since the caches in LC strategy are updated only at call arrival time.

According to [12],

$$q = \frac{\alpha}{\lambda} \tag{18}$$

So, (17) is expressed as follows.

$$\tau = \frac{q}{1+q} \tag{19}$$

Again,

$$C_{LC}^{hit} = P_l(4C_{la} + 2C_\upsilon) + (1-P_l)(4C_{la} + 4C_d + 2C_\upsilon) \tag{20}$$

$$\begin{aligned}C_{LC}^{miss} &= C_{LC}^{hit} + S_{IS-41} \\ &= \{P_l(4C_{la} + 2C_\upsilon) + (1-P_l)(4C_{la} + 4C_d + 2C_\upsilon)\} + \{4(C_{la} + C_d + C_{ra}) + (2C_\upsilon + C_h)\}\end{aligned} \tag{21}$$

So, the average total cost of the LC strategy is expressed as follows.

$$T_{LC} = U_{LC} + qS_{LC} \tag{22}$$

3) FLA Strategy

The average location registration cost of the FLA strategy is defined as follows.

$$U_{FLA} = \pi_0 U_{FLA}^{inter} + (\Phi(K)-1)U_{FLA}^{intra} \tag{23}$$

Three possible cases occur in intra-LSTP movement: (a) new VLR is the FLA and old VLR is not the FLA, (b) old VLR is the FLA and new VLR is not the FLA, and (c) neither new VLR nor old VLR is the FLA. On the other hand, four possible cases occur in inter-LSTP movement: (a) new VLR is the FLA and old VLR is not the FLA, (b) old VLR is the FLA and new VLR is not the FLA, (c) both new and old VLR are the FLA, and (d) neither new VLR nor old VLR is the FLA. According to these possible cases, U_{FLA}^{intra} and U_{FLA}^{inter} are calculated as follows.

$$U_{FLA}^{intra} = P_n(1-P_0)F_1 + P_0(1-P_n)F_2 + (1-P_n)(1-P_0)F_4 \tag{24}$$

$$U_{FLA}^{inter} = P_n(1-P_0)F_5 + P_0(1-P_n)F_6 + P_nP_0F_7 + (1-P_n)(1-P_0)F_8 \tag{25}$$

Where F_1, F_2, F_4, F_5, F_6, F_7, and F_8 are expressed as follows (see Figure 5 and Figure 6).

$$F_1 = F_2 = 2\times 2C_{la} + C_v + C_f \tag{26}$$

$$F_4 = 4\times 2C_{la} + 2\times C_v + C_f \tag{27}$$

$$F_5 = F_6 = 4(C_{la} + C_d + C_{ra}) + 4C_{la} + C_v + 2C_f + C_h \quad (28)$$

$$F_7 = 4(C_{la} + C_d + C_{ra}) + 2C_f + C_h \quad (29)$$

$$F_8 = 4(C_{la} + C_d + C_{ra}) + 8C_{la} + 2C_v + 2C_f + C_h \quad (30)$$

The average call delivery cost under this strategy depends on whether the called MT located in the same FLA area or in different FLA area. Thus this cost is expressed as follows.

$$S_{FLA} = P_f D_1 + (1 - P_f) D_2 \quad (31)$$

Where D_1 and D_2 are expressed as follows (see Figure 8(b)).

$$D_1 = 4(C_{la} + C_d + C_{ra}) + (C_v + C_f + C_h) \quad (32)$$

$$D_2 = 4(C_{la} + C_d + C_{ra}) + (2C_v + C_f + C_h) + 2C_{la} \quad (33)$$

So, the average total cost under this strategy is expressed as follows.

$$T_{FLA} = U_{FLA} + qS_{FLA} \quad (34)$$

4) PCFLA Strategy

The average location registration cost under the PCFLA strategy is defined as follows.

$$U_{PCFLA} = \pi_0 U_{PCFLA}^{inter} + (\Phi(K) - 1) U_{PCFLA}^{intra} \quad (35)$$

The three possible cases that occur in intra-LSTP movement and four possible cases that occur in inter-LSTP movement are the same as that of the FLA strategy. According to these possible cases, U_{PCFLA}^{intra} and U_{PCFLA}^{inter} are calculated as follows.

$$U_{PCFLA}^{intra} = P_n(1 - P_0)C_1 + P_0(1 - P_n)C_2 + (1 - P_n)(1 - P_0)C_4 \quad (36)$$

$$U_{PCFLA}^{inter} = P_n(1 - P_0)C_5 + P_0(1 - P_n)C_6 + P_n P_0 C_7 + (1 - P_n)(1 - P_0)C_8 \quad (37)$$

Where C_1, C_2, C_4, C_5, C_6, C_7, and C_8 are expressed as follows (see Figure 5 and Figure 7).

$$C_1 = C_2 = 2 \times 2C_{la} + C_v + C_f \quad (38)$$

$$C_4 = 4 \times 2C_{la} + 2 \times C_v + C_f \quad (39)$$

$$C_5 = C_6 = 4(C_{la} + C_d + C_{ra}) + 4C_{la} + C_v + 2C_f + C_h + m(C_{la} + C_d + C_{ra}) \quad (40)$$

$$C_7 = 4(C_{la} + C_d + C_{ra}) + 2C_f + C_h + m(C_{la} + C_d + C_{ra}) \quad (41)$$

$$C_8 = 4(C_{la} + C_d + C_{ra}) + 8C_{la} + 2C_v + 2C_f + C_h + m(C_{la} + C_d + C_{ra}) \quad (42)$$

On the other hand, the average call delivery cost under this strategy is calculated as follows

$$S_{PCFLA} = P_c C_{PCFLA}^{cache} + (1 - P_c) C_{PCFLA}^{nocache} \quad (43)$$

Where C_{PCFLA}^{cache} and $C_{PCFLA}^{nocache}$ are the call delivery costs under the PCFLA strategy when the calling MT's MSC contain location cache for the called FLA and when the calling MT's MSC does not have location cache for the called FLA, respectively.

There are four possible cases occur for delivering a call under this strategy: (a) the calling and called MTs are located within the same LSTP region and the called MT is resided in the FLA area, (b) the calling and called MTs are located within the same LSTP region and the called MT is resided in the other VLR area, (c) the calling and called MTs are located in the different LSTP regions and the called MT is resided in the FLA area, and (d) the calling and called MTs are located in the different LSTP regions and the called MT is resided in the other VLR area. According to these possible cases, C_{PCFLA}^{cache} and $C_{PCFLA}^{nocache}$ is calculated as follows (see Figures 8(a) and 8(b)).

$$C_{PCFLA}^{cache} = P_l\{P_f N_1 + (1-P_f)N_2\} + (1-P_l)\{P_f N_3 + (1-P_f)N_4\} \quad (44)$$

$$C_{PCFLA}^{nocache} = S_{FLA} = P_f D_1 + (1-P_f)D_2 \quad (45)$$

Where N_1, N_2, N_3, and N_4 are defined as follows (see Figures 8(a) and 8(b)).

$$N_1 = 2\times 2C_{la} + C_v + C_f \quad (46)$$

$$N_2 = 3\times 2C_{la} + 2\times C_v + C_f \quad (47)$$

$$N_3 = 2\times(2C_{la} + 2C_d) + C_v + C_f \quad (48)$$

$$N_4 = 2\times(2C_{la} + 2C_d) + 2\times C_v + C_f + 2C_{la} \quad (49)$$

As a result, the average total cost of this strategy is expressed as follows.

$$T_{PCFLA} = U_{PCFLA} + qS_{PCFLA} \quad (50)$$

<table>
<tr><th colspan="2">Criteria</th><th>Condition</th><th>No. of cache update(s)</th><th colspan="2">Average No. of cache update(s)</th></tr>
<tr><td colspan="2" rowspan="2">Cache hit</td><td>Pointed VLR is found in the FLA area</td><td>2</td><td colspan="2" rowspan="2">2.5</td></tr>
<tr><td>Pointed VLR is not found in the FLA area</td><td>3</td></tr>
<tr><td colspan="2" rowspan="4">Cache miss</td><td>Pointed VLR is found in the FLA area and the called VLR is found in the FLA area</td><td>3</td><td colspan="2" rowspan="4">4</td></tr>
<tr><td>Pointed VLR is found in the FLA area and the called VLR is not found in the FLA area</td><td>4</td></tr>
<tr><td>Pointed VLR is not found in the FLA area and the called VLR is found in the FLA area</td><td>4</td></tr>
<tr><td>Pointed VLR is not found in the FLA area and the called VLR is not found in the FLA area</td><td>5</td></tr>
<tr><td rowspan="7">Location registration</td><td rowspan="3">Intra-LSTP movement</td><td>New VLR is the FLA and old VLR is not the FLA</td><td>1</td><td rowspan="3">1.33</td><td rowspan="7">1.67</td></tr>
<tr><td>New VLR is not the FLA and old VLR is the FLA</td><td>1</td></tr>
<tr><td>New VLR is not the FLA and old VLR is not the FLA</td><td>2</td></tr>
<tr><td rowspan="4">Inter-LSTP movement</td><td>New VLR is the FLA and old VLR is not the FLA</td><td>2</td><td rowspan="4">2</td></tr>
<tr><td>New VLR is not the FLA and old VLR is the FLA</td><td>2</td></tr>
<tr><td>New VLR is not the FLA and old VLR is not the FLA</td><td>3</td></tr>
<tr><td>New VLR is the FLA and old VLR is the FLA</td><td>1</td></tr>
</table>

TABLE 4: Average No. of Cache Updates per Call.

5) NLCFLA Strategy

The average location registration cost under the NLCFLA strategy is defined as follows (see Figure 9).

$$U_{NLCFLA} = U_{FLA} = \pi_0 U_{FLA}^{inter} + (\Phi(K)-1)U_{FLA}^{intra} \quad (51)$$

Where U_{FLA}^{inter} and U_{FLA}^{intra} are the same as that of the FLA strategy and calculated in Section 4.1(3).

On the other hand, the average call delivery cost under the NLCFLA strategy is expressed as follows (see Figure 10).

$$S_{NLCFLA} = \tau C_{PCFLA}^{cache} + (1-\tau)(C_{PCFLA}^{cache} + C_{PCFLA}^{nocache}) \tag{52}$$

Where C_{PCFLA}^{cache} and $C_{PCFLA}^{nocache}$ are the same as that of the PCFLA strategy and these are calculated in Section 4.1*(4)*. Moreover, τ for the NLCFLA strategy is calculated as follows (see Table 4).

$$\tau = \frac{\tau \times 2.5\alpha + (1-\tau)\times 4\alpha + 1.67\lambda}{\tau \times 2.5\alpha + (1-\tau)\times 4\alpha + 1.67\lambda + \lambda} \tag{53}$$

By solving this, the following result for τ is obtained as a function of α and λ .

$$\tau = \frac{5.5\alpha + 2.67\lambda - \sqrt{6.25\alpha^2 + 19.35\alpha\lambda + 7.13\lambda^2}}{3\alpha} \tag{54}$$

By solving (53) after applying (18) to it, the following result for τ is obtained as a function of q.

$$\tau = \frac{5.5q + 2.67 - \sqrt{6.25q^2 + 19.35q + 7.13}}{3q} \tag{55}$$

As a result, the average total cost of this strategy is expressed as follows.

$$T_{NLCFLA} = U_{NLCFLA} + qS_{NLCFLA} \tag{56}$$

Set	C_{la}	C_d	C_{ra}
1	1	1	1
2	1	3	3
3	1	3	6
4	1	5	10

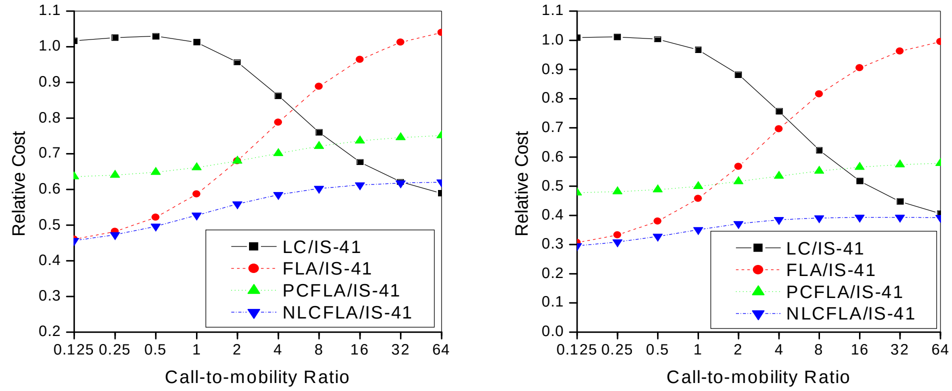
TABLE 5: Signaling Costs Parameter Set.

Set	C_v	C_f	C_h
5	1	1	1
6	1	2	3
7	1	2	3
8	1	3	5

TABLE 6: Database Access Costs Parameter Set.

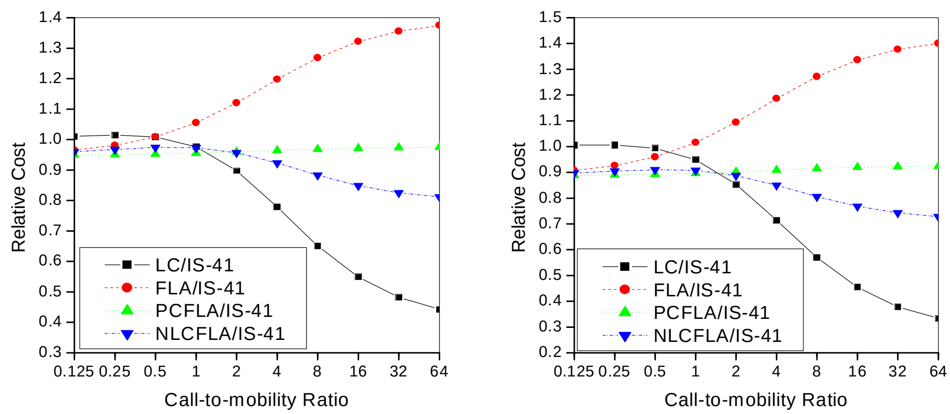
5. NUMERICAL RESULTS AND COMPARISONS

We have implemented the proposed and all other approaches containing equations (14), (22), (34), (50), and (56) using C programming language and execute them on a Windows XP Operating System installed computer having configuration of Pentium 4 processor with 3.00 GHz speed and 512 MB of RAM. We assume N = 55, v = 5.6 km/h, S = 20 km^2, P_l = 0.043, K = 55, and m = 5 [9] for generating various numerical results of these approaches. In addition to these fixed parameters, we compare the performance of the LC, FLA, PCFLA, and NLCFLA strategies with that of the IS-41 under various conditions given in Table 5 and 6. These are compared in terms of



(a) set 2 (b) set 4

FIGURE 12: Relative Signaling Cost.



(a) set 7 (b) set 8

FIGURE 13: Relative Database Access Cost.

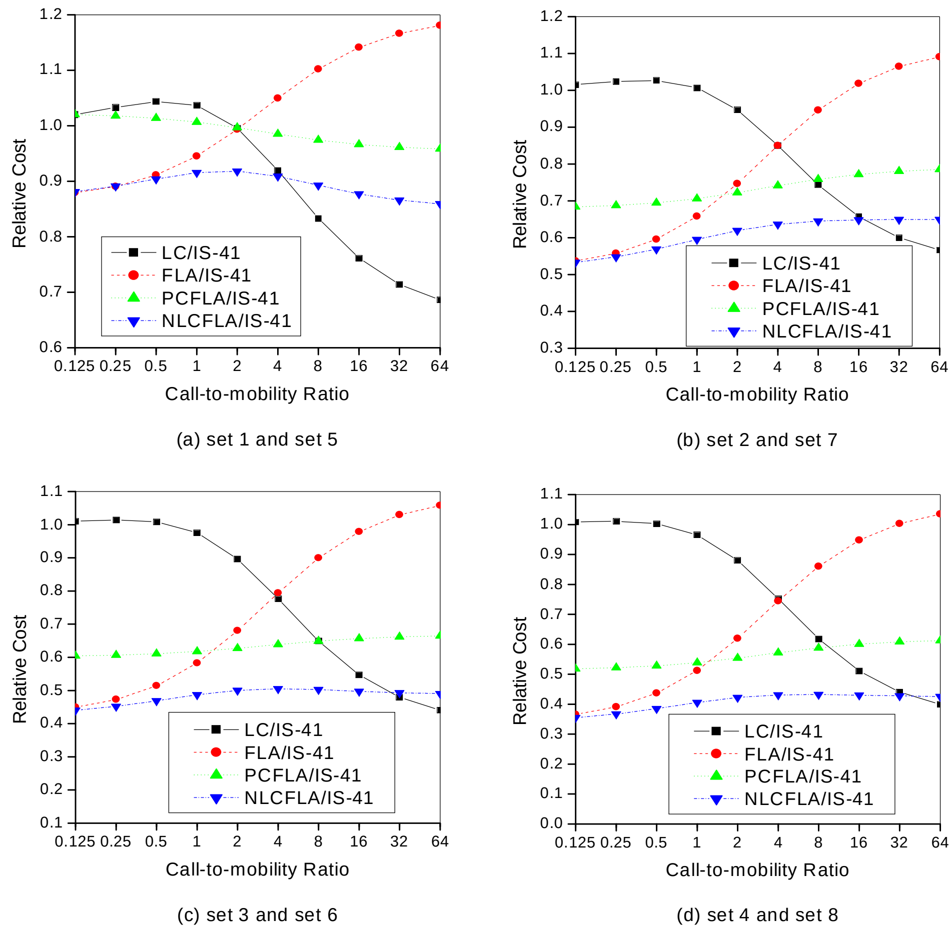
$$Relative\ cost = \frac{T_X}{T_{IS-41}} \tag{57}$$

relative cost where its value 1 means that the costs under both strategies are exactly the same. The relative cost of the X strategy can be defined as the ratio of the average total cost of the X strategy to that of the IS-41 strategy using the following equation.

5.1 Signaling Costs, Database Access Costs, and Total Costs

Figures 12, 13, and 14 show the relative signaling costs, relative database access costs, and relative total costs of the LC, FLA, PCFLA, and NLCFLA strategies with respect to CMR for different parameter sets given in Table 5 and 6, respectively. In Figure 12, signaling cost dominates the database access cost by setting the cost parameters C_v, C_f and C_h to 0, whereas in Figure 13, database access cost dominates the signaling cost by setting the cost parameters C_{la}, C_d, and C_{ra} to 0. On the other hand, all the cost parameters have the same domination effect in Figure 14.

We see from the graphs that the cost of the LC strategy gets lower as CMR increases, while the cost of the FLA strategy gets lower as CMR decreases. These trends are expected and easily



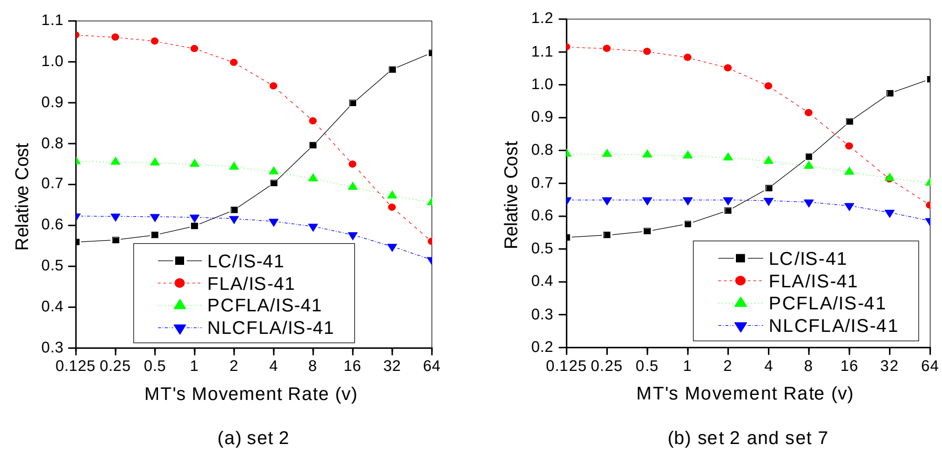
(a) set 1 and set 5

(b) set 2 and set 7

(c) set 3 and set 6

(d) set 4 and set 8

FIGURE 14: Relative Total Cost.



(a) set 2

(b) set 2 and set 7

FIGURE 15: Relative Signaling Cost (a) and Total Cost (b).

explainable from the working principle of these two strategies. As CMR increases, the call delivery becomes dominated, and thus the cost of the LC strategy gets lower. Alternatively, as CMR decreases, the location registration becomes dominated, and thus the cost of the FLA strategy gets lower. Moreover, it is observed from the graphs that the costs of both the PCFLA and NLCFLA strategies are not much sensitive to the change of CMR and the cost of the latter strategy is always lower than that of the former one. These trends are also expected and easily explainable from the working procedure of these two strategies. These two are the combination of the FLA strategy and a modified form of the LC strategy. The FLA strategy works better for lower CMR as location registration dominates for this condition. On the other hand, the modified form of the LC strategy works better for increased CMR as call delivery dominates for this condition. As a result, the combination of these two makes the PCFLA and NLCFLA strategies less sensitive to the CMR. But, the cost of the latter strategy is always less than that of the former strategy. The reason behind this trend is that the PCFLA strategy sends separate excessive location caching message to the MSCs during inter-LSTP movement registration, whereas the NLCFLA strategy performs location caching during the exchange of regular messages. It also does not send separate location caching message and these are performed in call delivery time as well as location registration time. So the cost of this strategy always gets lower.

The relative signaling and total costs of the LC, FLA, PCFLA, and NLCFLA strategies with respect to MT's mobility rate (v) are shown in Figure 15. This graph is generated by assuming α = 50 and replacing λ of (17) and (54) by v. It is observed from this graph that the cost of the LC strategy increases as v increases and the FLA strategy shows increased cost as v decreases. Moreover, the PCFLA and NLCFLA strategies are less sensitive to the change of v and the latter strategy always outperforms the former one irrespective of the values of v. These are expected and easily explainable with the same dominating principle as described in the previous paragraph.

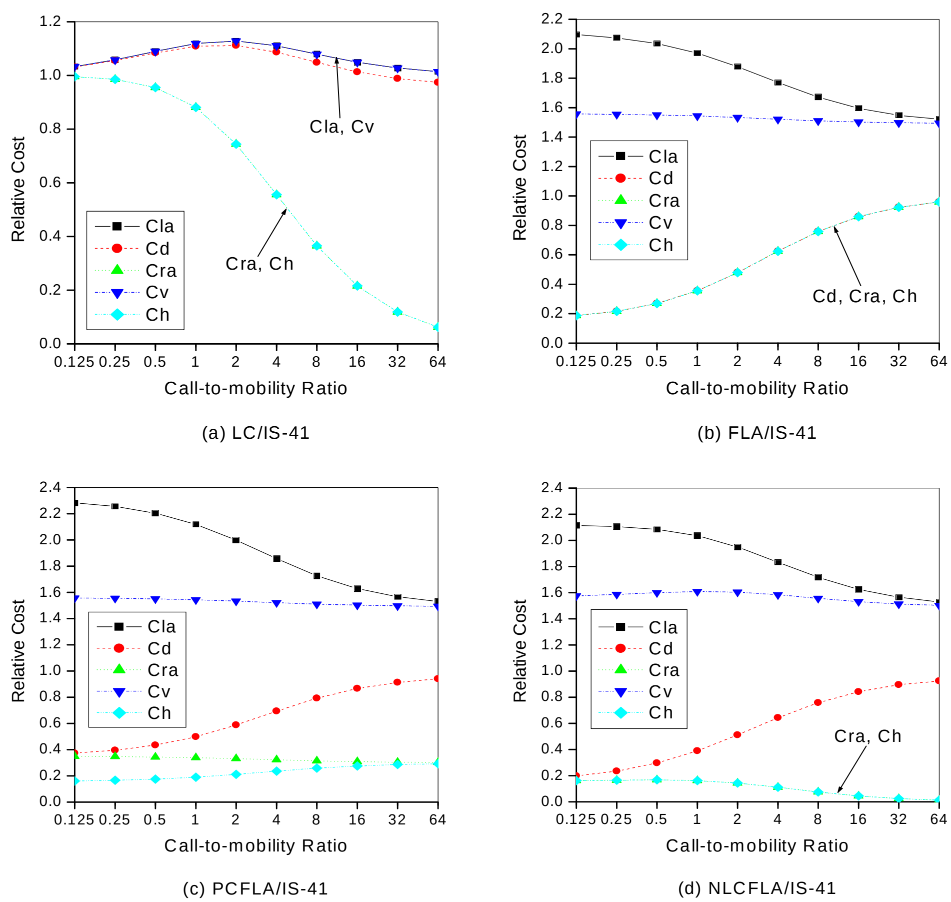


FIGURE 16: Impact of C_{la}, C_d, C_{ra}, C_v, and C_h.

5.2 Impact of C_{la}, C_d, C_{ra}, C_v, and C_h.

Figure 16 shows how the individual cost terms C_{la}, C_d, C_{ra}, C_v, *and* C_h affect on the overall relative costs of the LC, FLA, PCFLA, and NLCFLA strategies with respect to CMR for set 2 and 7 data given in Table 5 and 6. The values of C_v and C_f are assumed to be equal for the analysis as C_f is one of the form of C_v. As CMR increases, the cost of the LC strategy gets lower, whereas the cost of the FLA strategy gets higher for dominant cost terms C_{ra} and C_h. But, the cost of both the PCFLA and NLCFLA strategies remain almost same with a little decrease for the latter strategy with the increase of CMR for these dominant cost terms. These are easily explainable from the working principle of these strategies. The LC strategy shows this behavior since it needs small access to the HLR for increased CMR due to its availability of MTs' location information in the caches. On the other hand, FLA needs more access to the HLR for increased CMR since there are no caches maintained here. Alternatively, the PCFLA and NLCFLA strategies use both caches and FLA for optimizing call delivery and location registration. But, the NLCFLA strategy outperforms the PCFLA as it does not need to send separate location caching message during inter-LSTP movement. Moreover, it is observed from the graphs that the cost of the FLA, PCFLA, and NLCFLA strategies for the dominant cost terms C_{la} and C_v are higher than that of the IS-41 strategy. This is due to the fact that these strategies except IS-41 distribute the functionality of the HLR to the VLRs.

6. CONCLUSION

Location management in wireless mobile networks is one of the most important and challenging issues in the current world. To manage the location effectively and efficiently, a simple but efficient location management strategy called NLCFLA is proposed in this paper. This strategy uses FLA strategy which optimizes the location registration cost with a view to managing the local location registration locally instead of informing to the HLR. It also updates the MT's location information in VLR caches during the exchange of regular messages to the network at call origination time, call delivery time and also at location registration time. It does not use separate messages for location caching like previous strategy. This updating strategy eventually optimizes the call delivery cost. As a result, it minimizes the total location management cost in terms of location registration cost and call delivery cost regardless of the CMR. The various cost functions under the same analytical modeling for the proposed and related strategies are derived. It also investigates the effects of individual cost parameters for each strategy. The numerical results obtained from these cost functions show that the proposed NLCFLA strategy outperforms all the related previous strategies irrespective of the MT's calling and mobility pattern.

Currently, it is being observed that how this caching strategy can be combined with other location management strategies to get better result.

7. REFERENCES

[1] W. Wong and V. Leung. "*Location management for next generation personal communication networks*". IEEE Network, 14(5):18–24, September 2000.
[2] EIA/TIA. "*Cellular radio-telecommunications intersystem operations*". Tech. Rep. IS-41 Revision B, EIA/TIA, December 1991.
[3] M. Mouly and M. B. Pautet. "*The GSM system for mobile communications*". Telecom Publishing, 49 rue Louise Bruneau, Palaiseau, France, January 1992.
[4] R. Jain, Y.B. Lin, and S. Mohan. "*A caching strategy to reduce network impacts of PCS*". IEEE Journal on Selected Areas in Communications, 12(8):1434–1444, October 1994.
[5] J. Ho and I. Akyildiz. "*Local anchor scheme for reducing signaling costs in personal communications networks*". IEEE/ACM Transactions on Networking, 4(5):709–725, October 1996.
[6] E. Bae, M. Chung, and D. Sung. "*Performance analysis of fixed local anchor scheme for supporting UPT services*". Computer Communications, 23(18):1763–1776, December 2000.
[7] R. Jain and Y. B. Lin. "*An auxiliary user location strategy employing forwarding pointers to reduce network impacts of PCS*". ACM-Baltzer Journal on Wireless Networks, 1(2):197–210, July 1995.

[8] N. Shivakumar and J. Widom. "*User profile replication for faster location lookup in mobile environments*". In Proceedings of the 1st Annual International Conference on Mobile Computing and Networking, pp. 161–169, 1995.
[9] K. Kong. "*Performance analysis of profile-based location caching with fixed local anchor for next-generation wireless networks*". IEICE transactions on communications, E91-B(11):3595–3607, November 2008.
[10] F. Baumann and I. Niemegeers. "*An evaluation of location management procedures*". In Proceedings of the Third Annual International Conference on Universal Personal Communications, USA, pp. 359–364, September 1994.
[11] K. Kong, M. Song, K. Park, and C. Hwang. "*A comparative analysis on the signaling load of Mobile IPv6 and Hierarchical Mobile IPv6: Analytical approach*". IEICE Transactions on Information and Systems, E89-D(1):139–149, Japan, January 2006.
[12] E. Pitoura and G. Samaras. "Data *Management for Mobile Computing*". Kluwer Academic Publishers, vol. 10, 1998.