A New Hashing and Caching Approach for Minimizing Overall Location Management Cost in Next-Generation Wireless Networks

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***Abstract*—This paper proposes a new hashing and caching strategy (NHC) in order to reduce the overall location management cost in wireless mobile networks. It uses caches whose up-to-date information is responsible for dropping this cost and these caches are updated not only at call arrival time from the calling Mobile Terminals (MTs) but also at call receiving time to those MTs, and even at location registration time. To achieve load balancing among replicated Home Location Registers (HLRs), hashing technique is used and this load is also affected by the up-to-date cache information. The analytical modeling and numerical results show that our proposed method more frequently prepares the caches with up-to-date information with the increase of average call arrival rate, average call receiving rate, and even with MT's increased mobility rate. This increases the probability of finding called MT's location as well as hit ratio in the caches. As a result, the overall location management cost including load on a particular location server (HLR) are minimized considerably than all other previous approaches.**

***Keywords*—Location management, location registration, call delivery, cache, hashing function.**

I. INTRODUCTION

Location management in wireless mobile networks is concerned with the issues of tracking and finding MTs in order to roaming in the network coverage area. In order to maintain the MTs' locations, two types of standards are currently used in all wireless communication systems such as basic IS-41 [1] and GSM [2]. Both these architectures are based on a two-level database hierarchy. This hierarchy includes two types of databases called HLR and Visitor Location Register (VLR) which are used to store the MTs' location information. Fig. 1 shows the architecture of the wireless mobile networks under this two-level hierarchy. The whole network coverage area is divided into same sized and shaped cells. Each cell has a Base Transceiver Station (BTS) through which MTs of the cell communicate through a wireless link. The cells are grouped together to form larger areas called Registration Areas (RAs). All the BTSs belonging to a given RA are wire-connected to a Mobile Switching Center (MSC) and the MTs are wireless-connected to these BTS. In Fig. 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 the 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 MTs' profiles together with location information for the entire network. Similarly, each VLR stores replications of the user profiles of the subscribers currently residing in its corresponding RA.

Two basic operations in location management are location registration and call delivery. The former one is the process of informing the network about the MT's current location information; whereas the latter one is the process of determining the serving VLR and the cell location of the called MT prior to connection establishment between the caller and called MTs. An MT needs to report its new location information to the MSC whenever it enters into a new RA. The MSC updates its associated VLR and transmits the message together with this new information to the HLR. The HLR acknowledges the MSC about this successful registration and also sends a location deregistration message to the MT's old VLR in the corresponding RA prior to receive an acknowledgement. In order to deliver a call to a called MT, the HLR is searched to determine the serving MSC of that called MT. Following this, the HLR sends a message to this MSC with an aim to determine the serving BTS of the called MT by searching all cells within the corresponding RA [3].

As the number of MTs within the network and their service requirements are exploding rapidly day-by-day, location management under the basic IS-41 can not sufficiently support these MTs. For instance, increased users and their requirements make the network overwhelm by exchanging enormous signaling message as well as make the location server congested. In order to overcome these problems, several approaches are proposed in terms of designing signaling exchange algorithms and network architectures. As a part of this, it has been shown that the average location registration and call delivery costs can be reduced by location caching technique [7] and hashing and caching technique [10].

In this paper, a new location caching strategy is proposed by effectively using the MTs' calling and mobility pattern. In the location caching strategy [7] and hashing and caching strategy [10], the called MT's location information is updated only in the call originating VLR cache at call arrival time from that MT. But, there is another scope of updating the called MT's cache with calling MT's location information for the same call too. On the other hand, location deregistration

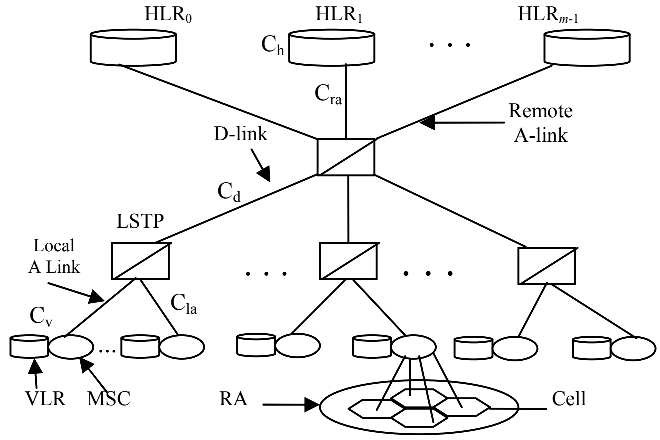
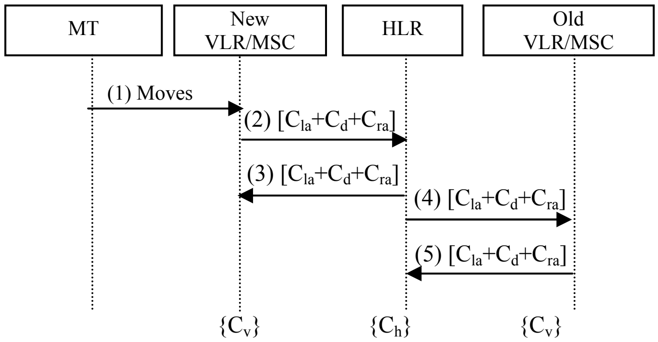


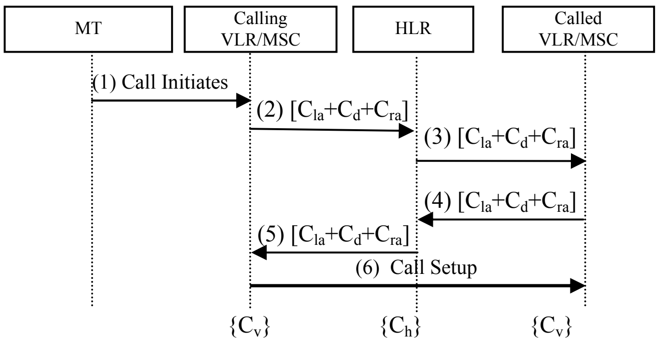
Figure 1. Signaling System No. 7 architecture with *m* HLRs.

TABLE I. DESCRIPTION OF SYMBOLS SHOWN IN FIG. 2–FIG. 5

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



(a) Location registration



(b) Call delivery

Figure 2. Location management under IS-41 strategy.

messages are sent to the old VLR when an MT performs an inter-RA or inter-LSTP movement. This old VLR cache can also be updated with MT's new location information together with the deregistration message. This innovative cache updating strategy prepares the cache with up-to-date information frequently as it updates more than one cache for each call delivery and even updates these during location registration. So, the probability of accessing the HLR decreases for call delivery. As a result, the total location management cost in terms of location registration cost and call delivery cost decreases. Moreover, the hashing strategy dynamically selects one of the *m* location servers (HLRs) containing replicated information. This eventually relieves the location server (HLR) from bottleneck.

The rest of the paper is organized as follows. Section II provides an overview of the existing related research work. Our proposed approach is described in section III. Section IV provides the analytical modeling of the related and proposed approaches. Numerical results and comparison among different approaches based on some experimental results are described in section V. We provide a concluding remark in section VI.

II. EXISTING RELATED WORK

A considerable amount of work has been done on location management to improve the overall performance of the wireless mobile networks [1], [4], [5], [6], [7], [8], [9], [10]. These location management strategies are divided into two categories. The first one is based on the centralized database (HLR/VLR) architecture and the second one is based on the distributed database architecture. Both these strategies use the same components of the networks, but vary on the basis of their distribution principles.

In the centralized architecture, MT's location information databases are maintained centrally in one location server (HLR). For instance, a basic IS-41 approach is proposed in [1] where only one HLR is used as a central server for storing MT's location information. It needs to access the HLR for finding the called MT's location information prior to deliver each MT's call. The architecture of this approach is the same as that of Fig. 1 except only one HLR. The location management procedure under this strategy is shown in Fig. 2 where the symbols used in this figure are described in Table I. For location registration in this approach, calling MT sends a location update message to the new MSC through the nearby BTS when it moves to the new RA [12]. The MSC updates its associated VLR about this MT and sends a location registration message to the HLR. The HLR sends back a registration acknowledgement message to the new VLR and sends a registration cancellation message to the old VLR. The old VLR removes the record of the MT and returns a cancellation acknowledgement message back to the HLR. In this way it completes location registration process. On the other hand, for call delivery under this approach, the calling MT sends a call initiation message to its serving MSC through a nearby BTS. The calling MSC sends a location request message to the HLR. The HLR determines the current serving MSC of the called MT and sends a location request message to that MSC. The MSC allocates a Temporary Local Directory Number (TLDN) [12] to the MT and sends back a reply to the HLR together with the TLDN. The HLR forwards this information back to the calling MSC and this MSC requests a call setup to the called MSC through the network shown in Fig. 1. This is the way by which call delivery process is completed. But, to reduce the searching cost of the MTs, their location information can be stored at callers VLR caches from where majority of the calls are originated [5]. A location caching strategy using centralized HLR database is proposed in [7]. In this approach, called MTs' location information are stored in the calling MTs' VLR caches during call delivery process. So, to deliver a call, called MT's location information is searched in the calling VLR caches first instead of directly searching the centralized HLR. Thus, probability of accessing HLR gets lower and as a result location management cost is minimized.

On the other hand, recently, the distributed database (location server) architecture based on hierarchical organization is used for locating MTs rather than using centralized database architecture [8]. A number of replicated centralized databases (HLRs) can be maintained to reduce the load on these databases. To achieve the load balancing among the replicated HLRs, a protocol is proposed in [9]. Location updates and queries are multicasted to subsets of location servers. These subsets vary with time and depends on the location of the MT's querying of VLR/MSC and load on the server. At least one common database can exist at each pair of subsets. In [10], a hashing and caching approach (HC) based on distributed database (HLR) architecture for location management is proposed. It considers only call arrival rate to store the called MT's location information in calling MT's VLR cache to reduce the average location management cost. Moreover, only one location server (HLR) is selected among the *m* replicated servers using the hashing function which simplifies the load balancing protocol and reduces the database operations. Fig. 1 shows the network architecture with *m* location servers (HLRs) both for the HC and NHC strategies. It uses caches in VLRs to store MTs location information and hashing function for load balancing among replicated HLRs. The location management procedure under this HC strategy is nearly the same as that of the NHC strategy except the cache updating policy. This is described in section III-*A* and III-*B*. This is also shown in Figs. 3, 4, and 5 where the symbols used in these figures are described in Table I and location updating is performed only at "Δ" pointed signaling places in these figures.

III. PROPOSED APPROACH

In our proposed approach (NHC), a set of identical and replicated location servers (HLRs) are used which is shown in Fig. 1. To select one of these servers dynamically for the called MT's location identification, a hashing function is used. Each MT, location server, and VLR has specific Mobile Terminal Identifier (*MTID*), Server Identifier (*SERVERID*), and VLR Identifier (*VLRID*), respectively to implement this approach. Assume there are *m* location servers (*0* to *m-1*) in the system. We use the following hashing function to find the specific location server among these *m* servers containing called MT's location information identified as *MTID*.

$$\begin{aligned} SERVERID &= f(MTID, VLRID, m) \\ &= (MTID + VLRID) \bmod m \end{aligned} \tag{1}$$

The MTs' location information is also stored at each VLR cache to reduce the average location management cost and location server's load. The cached information of each MT is updated not only at call arrival time from the calling MT like HC, but also at call receiving time to that MT, and even at location registration time of that MT. Each call or signaling message at MSC is checked to identify whether it is arrival call, receiving call, or location update. In the case of call arrival, it searches the cache for the called MT's location information, but forwarding this to the called MT depends on whether this information is found in the cache or not. Finding this information in cache also depends on whether it is exact information or obsolete. It maintains some predefined sequence of steps to handle these cases. For instance, call setup is established without accessing the HLR for cache hit and this establishment also depends on whether the caller and callee MTs are located within the same LSTP region or separate LSTP region. Alternatively, it always needs to access the HLR through hashing function for information unavailability in cache and cache miss cases. However, it updates the calling MT's VLR cache with called MT's VLR/MSC location information just before call setup. In the case of call receiving, pointed or called MT's VLR cache is updated with calling MT's VLR/MSC location information. On the other hand, when an MT performs a handoff to another RA, it informs its new location information to one of the *m* HLRs selected uniformly by hashing function of (1). This new information is also multicasted to the remaining (*m* – *1*) HLRs. As a part of sending deregistration message back to the old VLR/MSC, this HLR also sends the MT's new location information together with this message to that VLR for updating its cache. The location management procedure of this strategy under the cases of call arrival, call receiving, and MT's movement is shown in Figs. 3, 4, and 5 using state diagrams. The symbols used in these figures are described in Table I and location updating is performed unlike HC at both "Δ" and "❋" pointed signaling places in these diagrams. The sequence of steps for location registration and call delivery

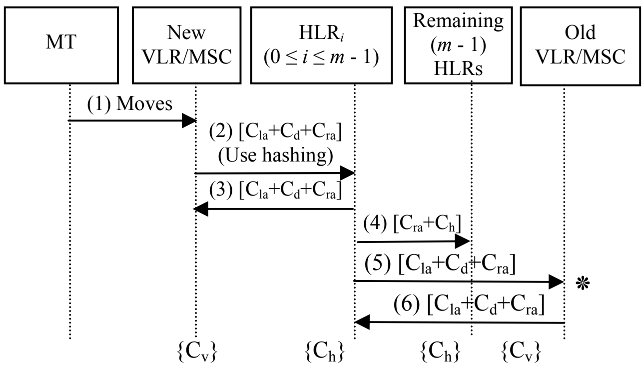
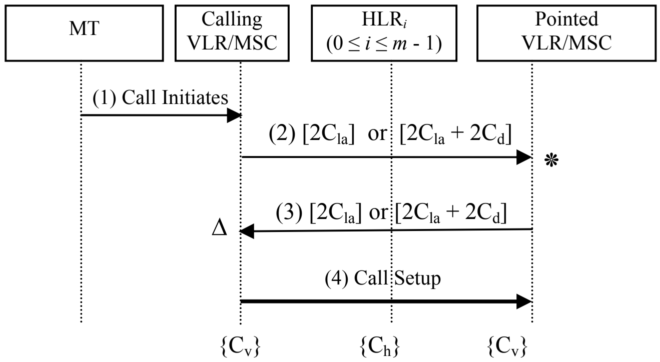
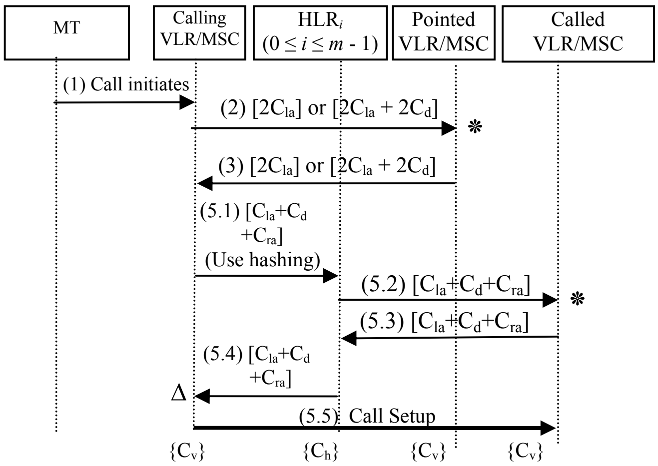


Figure 3. Location registration under the HC and NHC strategies.



(a) Cache hit



(b) Cache miss

Figure 4. Call delivery under the HC and NHC strategies when the called MT's location information is present in the VLR cache.

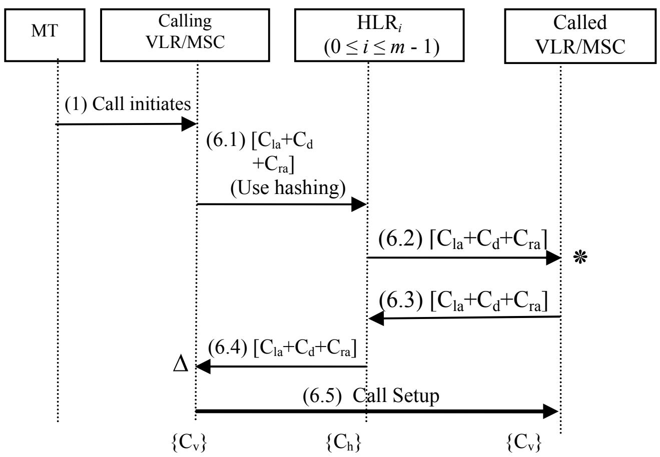


Figure 5. Call delivery under the HC and NHC strategies when the called MT's location information is absent in the VLR cache.

"Δ": update calling VLR cache with called MT's VLR/MSC location information (for both HC and NHC strategies).

"❋": update pointed or called VLR/MSC cache with calling MT's VLR/MSC location information (for NHC strategy only).

process is described as follows.

A. Location Registration

The location registration procedure under the NHC (and for some cases HC) strategy is described as follows (see Fig. 3).

(1) The MT performs a handoff into a new RA and sends the location update signaling message to the new MSC through the nearby BTS.

(2) The new MSC updates its corresponding VLR with the corresponding MT's location information and sends a location registration message to the HLR$_i$ ($0 \le i \le m$ - 1) selected by hashing function of (1).

(3) The HLR$_i$ sends back a registration acknowledgement message to the new VLR.

(4) The HLR$_i$ multicasts this same location registration message to the remaining (m - 1) HLRs.

(5) The HLR$_i$ sends a registration cancellation message to the old VLR and updates its cache with the calling MT's VLR/MSC location information upon receiving this message (this update is performed only in NHC).

(6) The old VLR removes the record of the MT and returns a cancellation acknowledgement message to the HLR$_i$.

B. Call Delivery

The call delivery procedure under the NHC (and for some cases HC) strategy is described as follows (see Figs. 4 and 5).

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

(2) The calling MT's MSC verifies whether it has called MT's location information in its VLR cache or not. If yes, then this MSC sends a location request message to the pointed MSC and the pointed VLR update its cache with the calling MT's location information (this update is performed only in NHC). Here, the signaling cost may vary depending on whether the caller and callee are within the same LSTP region or not. Otherwise, go to step 6.

(3) The pointed VLR/MSC determines whether its pointed location information is exact or obsolete. If exact, then pointed MSC allocates a TLDN to the MT and sends it back to the calling MSC stating that it is a cache hit and update the calling VLR cache with the called MT's location information (this update is performed both in HC and NHC). Here, the signaling cost also may vary depending on whether the caller and callee are within the same LSTP region or not. Otherwise, go to step 5.

(4) The calling MSC sends a call setup request message to the called MSC through the network shown in Fig. 1 (call delivery is complete. Do not proceed to the next step).

(5) If the calling VLR cache has the obsolete location information of the called MT (cache miss), it executes the following steps.

(5.1) The calling MSC sends a location request message to the HLR_i ($0 \le i \le m - 1$) selected by hashing function of (1).

(5.2) The HLR_i determines the current serving MSC of the called MT and sends a location request message to the called MSC, and the called VLR update its cache with the calling MT's location information (this update is performed only in NHC).

(5.3) The called MSC allocates a TLDN to the MT and sends it back to the HLR_i.

(5.4) The HLR_i forwards this information back to the calling MSC and update the calling VLR cache with the called MT's location information (this update is performed both in HC and NHC).

(5.5) The calling MSC sends a request message of call setup to the called MSC through the network shown in Fig. 1 (call delivery is complete. Do not proceed to the next step).

(6) If the calling VLR cache does not have the called MT's location information, then it follows the steps below.

(6.1) The calling MSC sends a location request message to the HLR_i ($0 \le i \le m - 1$) selected by hashing function of (1).

(6.2) The HLR_i determines the current serving MSC of the called MT and sends a location request message to the called MSC, and the called VLR update its cache with the calling MT's location information (this update is performed only in NHC).

(6.3) The called MSC allocates a TLDN to the MT and sends it back to the HLR_i.

(6.4) The HLR_i forwards this information back to the calling MSC and update the calling VLR cache with the called MT's location information (this update is performed both in HC and NHC).

(6.5) The calling MSC sends a request message of call setup to the called MSC through the network shown in Fig. 1 (call delivery is complete).

IV. Analytical Modeling

We consider a fluid flow mobility model [11] 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, 2π] with a view to crossing the LSTP region composed of N equal rectangular-shaped and sized RAs [12]. The parameters used for the MT's 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 [13], these parameters are calculated as follows.

$$\gamma = \frac{4\upsilon}{\pi\sqrt{S}} \quad (2)$$

$$\mu = \frac{4\upsilon}{\pi\sqrt{NS}} \quad (3)$$

$$\lambda = \gamma - \mu = \left(1 - \frac{1}{\sqrt{N}}\right)\gamma \quad (4)$$

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 Fig. 6 to show an MT's RA movement representing the fluid flow mobility model. Each state $i\,(i \ge 0)$ 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 $a_{i,i+1}\,(i \ge 1)$ 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, $b_{i,0}\,(i \ge 1)$ represents an MT's inter-LSTP region movement rate and it is assumed that there are maximum K number of such movements.

Therefore, from Fig. 6, we get $a_{i,i+1}\,(i \ge 1) = \lambda$ and $a_{0,1} = b_{i,0} = \mu$, respectively.

On the other hand, if π_i is the equilibrium probability of state i, we can obtain the following equations from a continuous-time Markov Chain given in Fig. 6.

$$\mu\pi_0 = \mu\sum_{i=1}^{K}\pi_i \quad (5)$$

$$\mu\pi_{i-1} = (\lambda + \mu)\pi_i, \quad i = 1 \quad (6)$$

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

$$\lambda\pi_{i-1} = \mu\pi_i, \quad i = K \quad (8)$$

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

$$\pi_0 + \pi_1 + \pi_2 + \cdots + \pi_K = \sum_{i=0}^{K}\pi_i = 1 \quad (9)$$

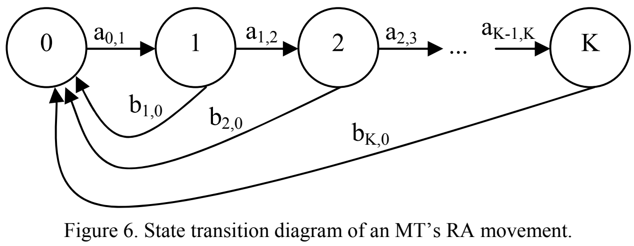


Figure 6. State transition diagram of an MT's RA movement.

By substituting (9) into (5), we can obtain the equilibrium probability of state 0, π_0. So,

$$\pi_0 = \frac{1}{2} \tag{10}$$

Finally, from (6), (7), (8) and (10), π_i is obtained as follows.

$$\pi_i = \begin{cases} \frac{1}{2} & \text{if } i = 0 \\ \frac{1}{2}\left(\frac{\mu}{\lambda+\mu}\right)\left(\frac{\lambda}{\lambda+\mu}\right)^{i-1} & \text{if } 1 \le i \le K-1 \\ \frac{1}{2}\left(\frac{\lambda}{\lambda+\mu}\right)^{i-1} & \text{if } i = K \end{cases} \tag{11}$$

A. Analysis of Location Management Costs

In order to analyze the location registration cost, call delivery cost, total location management cost, and location server's (HLR) load of the IS-41, HC, and NHC strategies, we consider different parameters shown in Table II and III. The following notations are also used to represent the cost of each strategy [12].

- 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
- X_Z^c : the average throughput of the location *server*$_i$ (HLR$_i$), $0 \le i \le m$ of the Z strategy

Furthermore, the average number of unique RAs that an MT visits within a given LSTP for K movements can be calculated from Fig. 6 and represented by the following equation.

$$\Phi(K) = \pi_1 + 2\pi_2 + 3\pi_3 + \cdots + K\pi_K = \sum_{i=1}^{K} i\pi_i \tag{12}$$

The location management cost functions of the IS-41, the HC strategy, and the NHC strategy can be derived from Figs. 2 – 5.

1) *IS-41 Strategy*

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

$$\begin{aligned} &U_{IS-41} \\ &= \pi_0 U_{IS-41}^{inter} + (\Phi(K)-1)U_{IS-41}^{intra} \\ &= \pi_0 \times \{4(C_{la}+C_d+C_{ra})+(2C_\upsilon+C_h)\} \\ &\quad +(\Phi(K)-1)\times\{4(C_{la}+C_d+C_{ra})+(2C_\upsilon+C_h)\} \\ &= \{\pi_0+(\Phi(K)-1)\}\{4(C_{la}+C_d+C_{ra})+(2C_\upsilon+C_h)\} \end{aligned} \tag{13}$$

The average call delivery cost of the IS-41 is expressed as follows.

$$S_{IS-41} = 4(C_{la}+C_d+C_{ra})+(2C_\upsilon+C_h) \tag{14}$$

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

$$T_{IS-41} = U_{IS-41} + qS_{IS-41} \tag{15}$$

In the IS-41 strategy only one location server is used instead of *m*. So, the average throughput of the location server, *server*$_i$, $i = 0, 1, 2, \ldots, m$, under this strategy is calculated as follows [10].

$$X_{IS-41}^c = \alpha \tag{16}$$

TABLE II. DESCRIPTION OF COST PARAMETERS SHOWN IN FIG. 1

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_h	Cost of a query or an update of the HLR

TABLE III. PARAMETERS USED FOR THE COST ANALYSIS

Parameter	Description
P_l	Probability of locating caller and callee within the same LSTP region
P	Probability of having callee's location information in the caller VLR cache
q	The MT's call-to-mobility ratio (CMR)
$q_{\max}$	The MT's maximum call-to-mobility ratio (CMR)
τ	The MT's cache hit ratio under the HC and NHC strategies
α	The MT's call arrival rate through MSC
$\alpha_{\max}$	The MT's maximum call arrival rate through MSC
$\lambda_{\max}$	The MT's maximum movement rate to an adjacent RA within a given LSTP region
m	Number of location servers (HLRs) in the system

2) HC Strategy

The average location registration cost of the HC strategy is calculated as follows.

$$\begin{aligned} U_{HC} &= U_{IS-41} + (m-1)(C_{ra} + C_h) \\ &= \{\pi_0 + (\Phi(K)-1)\}\{4(C_{la} + C_d + C_{ra}) + (2C_\upsilon + C_h)\} \\ &\quad + (m-1)(C_{ra} + C_h) \end{aligned} \quad (17)$$

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

$$S_{HC} = P\{\tau C_{HC}^{hit} + (1-\tau) C_{HC}^{miss}\} + (1-P) S_{IS-41} \quad (18)$$

Where C_{HC}^{hit} and C_{HC}^{miss} represents the call delivery cost of the HC strategy when location information pointed by cache for called MT is correct and obsolete, respectively and can be calculated [see Figs. 4(a) and 4(b)] with.

$$P = \frac{\alpha}{\alpha_{\max}} \quad (19)$$

$$\begin{aligned} \tau &= \frac{P\{\tau\alpha + (1-\tau)\alpha\} + (1-P)\alpha}{P\{\tau\alpha + (1-\tau)\alpha\} + (1-P)\alpha + \lambda} \\ &= \frac{\alpha}{\alpha + \lambda} \end{aligned} \quad (20)$$

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

According to [6],

$$q = \frac{\alpha}{\lambda} \quad (21)$$

So, (20) is expressed as follows.

$$\tau = \frac{q}{1+q} \quad (22)$$

Again,

$$C_{HC}^{hit} = P_l(4C_{la} + 2C_\upsilon) + (1-P_l)(4C_{la} + 4C_d + 2C_\upsilon) \quad (23)$$

$$\begin{aligned} C_{HC}^{miss} &= C_{HC}^{hit} + S_{IS-41} \\ &= \{P_l(4C_{la} + 2C_\upsilon) + (1-P_l)(4C_{la} + 4C_d + 2C_\upsilon)\} \\ &\quad + \{4(C_{la} + C_d + C_{ra}) + (2C_\upsilon + C_h)\} \end{aligned} \quad (24)$$

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

$$T_{HC} = U_{HC} + qS_{HC} \quad (25)$$

The average throughput of the location server, *server*$_i$, i = 1, 2, …, *m,* under the HC strategy is expressed as follows [10].

$$X_{HC}^{c} = \frac{\alpha(1-P)}{m} \quad (26)$$

Where P is the same as (19).

3) NHC Strategy

The average location registration cost of the NHC strategy is exactly the same as that of the HC. So, it becomes as follows.

$$\begin{aligned} U_{NHC} &= U_{HC} \\ &= \{\pi_0 + (\Phi(K)-1)\}\{4(C_{la} + C_d + C_{ra}) + (2C_\upsilon + C_h)\} \\ &\quad + (m-1)(C_{ra} + C_h) \end{aligned} \quad (27)$$

The average call delivery cost of the NHC strategy is the same as that of the HC, but there is a variation in P and τ, and is expressed as follows.

$$\begin{aligned} S_{NHC} &= S_{HC} \\ &= P\{\tau C_{HC}^{hit} + (1-\tau) C_{HC}^{miss}\} + (1-P) S_{IS-41} \end{aligned} \quad (28)$$

Where P is represented as follows.

$$P = \frac{2\alpha}{\alpha_{\max}} - \frac{\alpha^2}{\alpha_{\max}{}^2} + (1 - \frac{2\alpha}{\alpha_{\max}} + \frac{\alpha^2}{\alpha_{\max}{}^2}) \frac{\lambda}{\lambda_{\max}} \quad (29)$$

We get the following solution of P from (21) and (29).

$$P = \frac{2q}{q_{\max}} - \frac{q^2}{q_{\max}{}^2} + (1 - \frac{2q}{q_{\max}} + \frac{q^2}{q_{\max}{}^2}) \frac{\lambda}{\lambda_{\max}} \quad (30)$$

And τ is expressed as follows.

$$\tau = \frac{P\{\tau 2\alpha + (1-\tau)3\alpha\} + (1-P)2\alpha + \lambda}{P\{\tau 2\alpha + (1-\tau)3\alpha\} + (1-P)2\alpha + \lambda + \lambda} \quad (31)$$

Since the caches in the NHC strategy are updated at call arrival time, call receiving time, and even location registration time (two times for each cache hit, three times for each cache miss, two times for each case of location information not finding in cache, and one time for each location registration).

By solving this equation we get the following result.

$$\tau = \frac{2P\alpha + 2\alpha + 2\lambda - \sqrt{4\alpha^2 + 4P\alpha\lambda + 8\alpha\lambda + 4\lambda^2}}{2P\alpha} \quad (32)$$

From (21) and (31), we get the following solution of τ.

$$\tau = \frac{2Pq + 2q + 2 - \sqrt{4q^2 + 4Pq + 8q + 4}}{2Pq} \quad (33)$$

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

TABLE IV. SIGNALING COSTS PARAMETER SET

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

TABLE V. DATABASE ACCESS COSTS PARAMETER SET

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

$$T_{NHC} = U_{NHC} + qS_{NHC} \tag{34}$$

The average throughput of the location server, $server_i$, i = 1, 2, …, m, under the NHC strategy is expressed as follows [10].

$$X^c_{NHC} = \frac{\alpha(1-P)}{m} \tag{35}$$

Where P is expressed by (29).

V. NUMERICAL RESULTS AND COMPARISONS

We compare the performance of the NHC strategy and HC strategy with that of the IS-41 under various conditions given in Table IV and V in terms of 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.

$$Relative\ cost = \frac{T_X}{T_{IS-41}} \tag{36}$$

Also the relative server load of any location server (HLR) of the Z strategy can be defined as the ratio of the average throughput of the Z strategy to that of the IS-41 strategy using the following equation.

$$Relative\ server\ load = \frac{X^c_Z}{X^c_{IS-41}} \tag{37}$$

We assume N = 55, v = 5.6 km/h, S = 20 km^2, P_l = 0.043, K = 55, m = 5 [12], α_{max} = 80, and λ_{max} = 80 for generating various numerical results.

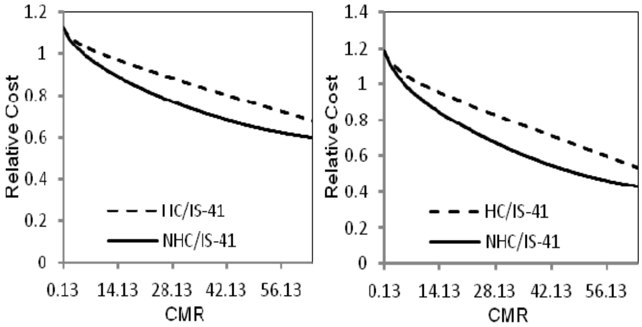
A. Signaling Costs, Database Access Costs, and Total Costs

Figs. 7, 8, and 9 show the relative signaling costs, relative database access costs, and relative total costs for the HC and the NHC strategies with different parameter sets given in Table VI and V, respectively. In Fig. 7, signaling cost dominates the database access cost by setting the cost parameters C_v and C_h to 0, whereas in Fig. 8, 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 Fig. 9. We see from the graphs that the relative costs for both strategies are higher than 1 at the beginning for small values of CMR and show downward trends as CMR increases. It is also observed that the relative cost of the NHC strategy is always lower than that of the HC strategy. These trends are expected and easily explainable from the working procedure of the IS-41, HC, and NHC strategies. As CMR increases, call arrival from MTs becomes dominated over location registration, and thus the cost of the HC and NHC strategies gets lower since the caches are more updated with increased values of call arrival. As a result, the probability of getting the called MT's location information in calling MT's VLR caches increases and need relatively small HLR accesses for call forwarding. On the other hand, as CMR decreases, location registration becomes dominated over call forwarding, and shows exactly the opposite effect as that of the increased CMR. Thus, the probability of getting the called MT's location information in calling MT's VLR caches decreases and sometimes these cache information become obsolete due to MT's high mobility rate. These obsolete information create more cache miss rate for very small values of CMR and the relative costs of both strategies become higher than 1 as there are some cost penalties including cost of IS-41 for cache misses. However, the costs of the NHC strategy are always smaller than that of the HC strategy, because caches for NHC are updated not only at call arrival time from MTs but also at call receiving time to these MTs and even at location registration time. It is also observed from different graphs that increasing the cost parameters value also increases the relative cost.

The relative signaling and total costs of the NHC and HC strategies with respect to MT's mobility rate (v) are shown in Fig. 10. These are generated by assuming $\alpha = 50$ and by replacing λ of (20), (29), and (32) with v. From these figures it is also observed that the NHC strategy outperforms the HC strategy. This is true; because the mobility rate has a positive impact on cache update for the NHC but not for the HC strategy.

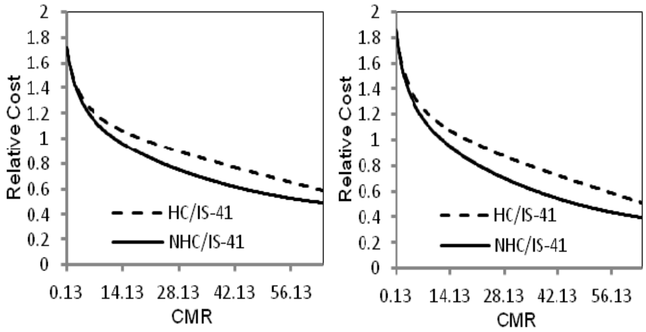
B. Impact of C_{la}, C_d, C_{ra}, C_v, and C_h.

Fig. 11 shows how the individual cost terms C_{la}, C_d, C_{ra}, C_v, *and* C_h may affect on the overall relative costs of the HC and NHC strategies with the changes of CMR. As CMR increases, the relative cost of the NHC strategy gets much lower than that of the HC strategy for C_{ra} and C_h, but remains almost fixed for C_{la}, C_d, *and* C_v on both strategies. The reason behind this tendency can also be explained by cache update policy of these strategies. The more the cache hit, the less the probability of accessing the HLR through costs C_{ra} and C_h, but C_{la}, C_d, and C_v will be included in the total cost irrespective of



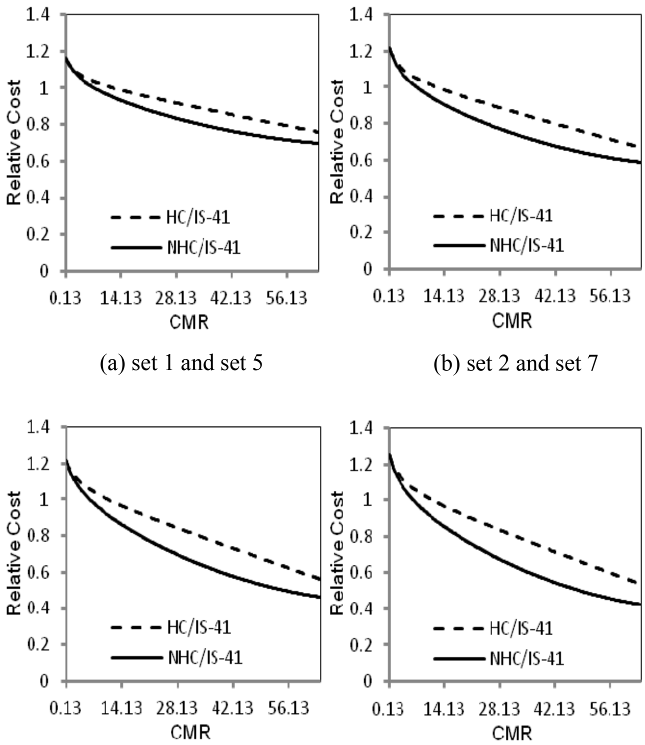
(a) set 2 (b) set 4

Figure 7. Relative signaling cost.



(a) set 7 (b) set 8

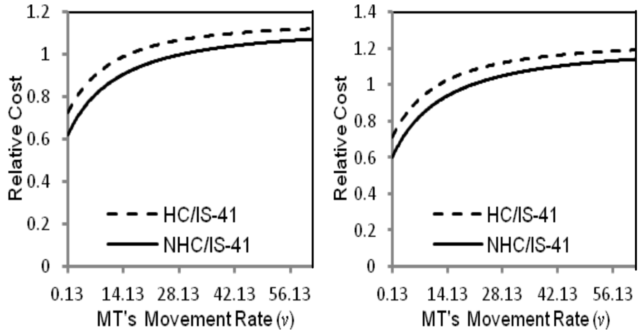
Figure 8. Relative database access cost.



(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 9. Relative total cost.



(a) set 2 (b) set 2 and set 7

Figure 10. Relative signaling cost (a) and total cost (b).

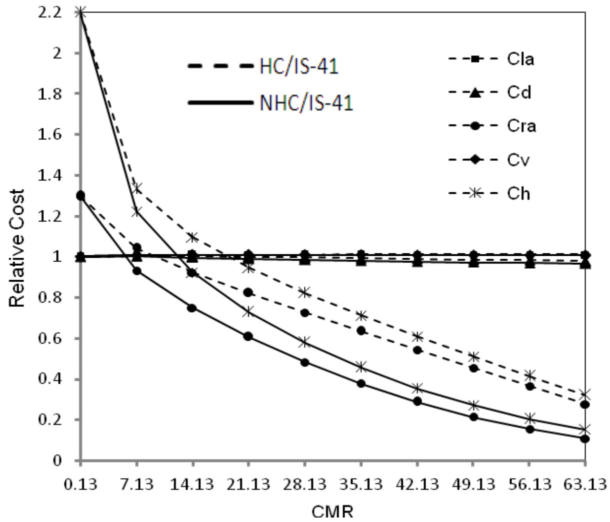


Figure 11. Impact of C_{la}, C_d, C_{ra}, C_v, and C_h.

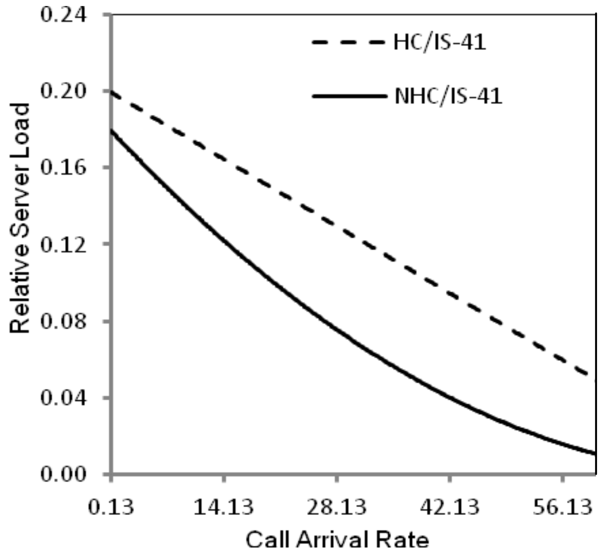


Figure 12. Relative server load.

the values of the cache hit ratio.

C. Relative Server Load

Fig. 12 shows the relative server (HLR) load of the HC and NHC strategies with respect to call arrival rate. It is observed that the relative server load of both strategies decreases from 0.2 to negligible values with the increase of call arrival rate. This is reasonable as location registration dominates for small values of call arrival and we consider five HLRs for the HC and NHC instead of only one in the IS-41. For this reason both strategies show about 20% server loads of the IS-41 for small values of call arrival rate. As the call arrival rate increases, these loads decreases, since the probability of getting the location information in caches increases with the increase of call arrival rate without going to the HLR. However, the NHC strategy always outperforms the HC as caches are updated at call arrival time, call receiving time, and even location registration time for the NHC instead of only call arrival time for the HC.

VI. Conclusion

In this paper we propose a new hashing and caching approach to improve the overall performance of the wireless mobile networks in terms of location management cost and location server's load. Caches in VLR are used for storing MT's location information and it is shown that the cache hit ratio increases as the call arrival rate, call receiving rate, and even MT's mobility rate are considered for updating caches information. A hashing function is also used for load balancing among replicated location servers and this load also depends on the cache hit ratio. The analytical modeling and numerical results illustrate that the probability of finding MT's location in caches also increases with the improvement of hit ratio. As a result, the overall location management cost and location server's load are reduced significantly for this proposed approach compared to all other related approaches.

We are currently working with more appropriate hashing function for selecting one of the location servers with low congestion and minimized load.

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