Tracking Mobile Users Using User Locality in Mobile Computing Systems

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Abstract

Managing location information of mobile terminals is an important issue in mobile computing systems. The IS-41and the GSM schemes are done inefficiently in the following situations: 1) mobile terminals frequently move to neighboring registration area, 2) frequently communicate with mobile terminals that reside at neighboring registration area. In this paper, we propose a new location management scheme that solves these problems. We compare the performance of the our scheme with that of the IS-41 scheme in respect of communication cost, database cost, and total cost. Simulation results show that the proposed scheme performs better than the IS-41 scheme.

1 Introduction

Personal Communications Service(PCS) provides seamless and uninterrupted communication to mobile users. PCS users carrying Mobile Terminals(MT's) can communicate with a remote terminal(mobile or static) regardless of its current location and mobility pattern. However, unlike static networks, such ad the Internet, where routing information is embedded in the address of each node on the network, the current location of an MT cannot be obtained from its identification number. A location management scheme, therefore, is necessary to effectively keep track of the MT's and to locate a called MT when a call is initiated.

Two standards currently exist for Personal Communication Service Network (PCN) location management: IS-41 and GSM[1, 2, 3]. Both of these standards are based on two-level database hierarchy. *Home Location Register* (HLR) and *Visitor Location Register* (VLR) are used to store location information of the MT's. Operations on these databases are two types: *location update* and *location query*.

In order to locate effectively a MT when a call arrives, each MT is required to update its location information whenever it enters a new *Location Area*(LA). We call this procedure *location update*.

In order to query a MT for call delivery, the HLR is queried to determine the serving VLR of the called MT. We call this procedure *location query*. The HLR then sends a location request message to VLR which in turn will determine the serving base station of the MT by paging all cells within its associated LA[3, 4, 5].

These standards require the exchange of signaling message between the HLR and the new and old VLR's whenever the MT crosses a LA boundary[3, 4, 5, 6]. These schemes update HLR whenever user moves neighboring LA and query HLR whenever user calls the user in the neighboring LA. These schemes may result in signaling traffic overload *Signaling System No. 7* (SS7) network, location update delay, and location query delay[7, 8, 9].

In this paper, we propose a new location management scheme with the goal of reducing location update and query cost. In our approach, the coverage area of the *Local Signal Transfer Point*(LSTP) in which a MT's *Second HLR*(SHLR) is located, is termed the *Home Area*(HA). In this approach, we use one level of updating/querying for MT's in their HA, and a two level updating/querying approach only for MT's visiting other areas.

The rest of this paper is organized as follows: In Section 2, we describe the reference PCN architecture. In Section 3, we describe the system model. In Section 4, we describe the proposed scheme for location management. A comparative analysis of the proposed scheme with the IS-41 scheme is included in Section 5. Conclusions are presented in Section 6.

2 PCN Architecture

The Personal Communications Service(PCS) coverage area is divided into *cells*. All MT's within a cell communicate with a *base station* through wireless links. The base station is, in turn, connected to the wired network through a *Mobile Switching Center*(MSC). The wired network carries user information and signaling messages among the MSC's and the location databases. In current PCS systems, the *Public Switched Telephone Network*(PSTN) is used as the backbone wired network.

Both the IS-41 and GSM standards employ a two-level database architecture consisting of the HLR and the VLR's. The HLR is a centralized database containing the user profile of its assigned subscribers. These user profiles record information such as the type of services subscribed, the Quality of Service(QoS) requirements, the billing information, and the current locations of the MT's. The VLR's are distributed throughout the PCS network, and each one stores the information of the MT's currently residing in its associated area. Depending on the network configuration, the user profile of an MT may be replicated at its current serving VLR. There are two possible implementations of the database structure. In the first implementation, the VLR serves a number of MSC's and the major function of the VLR is to offload the query and signaling load at the HLR. In the second implementation, each VLR serves a single MSC and the VLR acts as an auxiliary processor to the MSC. The second implementation is more widely used in today's PCS networks.

We assumes throughout this paper that the VLR is colocated with the MSC. The PCN architecture given in Figure 1 assumes that the HLR and the VLR's communicate through a *Regional Signal Transfer Point*(RSTP) and the LSTP's. A message between the HLR and a VLR may go through several intermediate switches inside the connection network before reaching its destination. The cost for transfer a signaling message between the HLR and different VLRs may vary.

According to Figure 1, there are three types of connection among the network elements. The *remote A link* connects the HLR to the RSTP, the *D links* connect the RSTP to the LSTPs and the *local A links* connect the LSTPs to their associated Mobile Switching Center(MSC)s and VLRs[1, 2, 3, 4]. Procedures for location update and query are proposed in the IS-41 standard.

We outline the major steps of the IS-41 location update scheme as follows:

1. The MT sends an update message to the new VLR.
2. The new VLR sends an update message to the HLR.
3. The HLR sends an update ACK message to the new VLR.
4. The HLR sends an update cancellation message to the old VLR.
5. The old VLR sends a cancellation ACK message to the HLR.

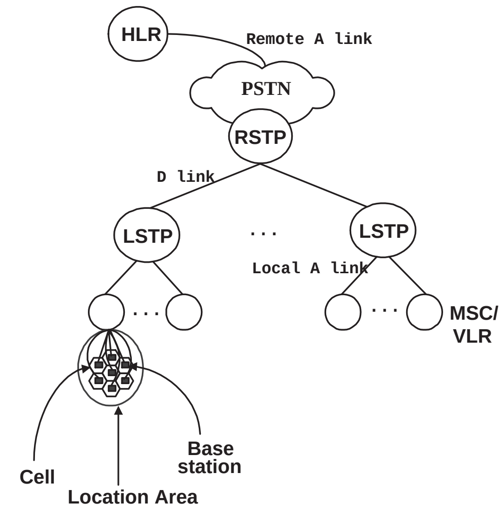

Figure 1. Reference architecture

The IS-41 location query scheme is outlined as follows:

1. The VLR of the calling MT sends a location information request message to the HLR.
2. The HLR sends a location information request message to the VLR of the called MT.
3. The VLR determines the cell location of the called MT and sends a location information to the HLR.
4. The HLR sends a location information to the VLR of the calling MT.

3 System Model

When the MT moves to neighboring LA, the location update scheme that proposed in the IS-41 standard increases location update cost. Also, when the mobile terminal calls the MT in the neighboring LA, the location query scheme that proposed in the IS-41 standard increases location query cost.

In order to solve these problems, we propose the same system model as Figure 2. The proposed system model is based on that of the IS-41 standard with the addition of a new level of databases called Second HLR(SHLR) and Proxy VLR(PVLR). The placements and the operations of the HLR, the VLR's, and the MSC's remain mostly unchanged, while additional processing is handled by the SHLR's and the PVLR's. Figure 2 shows the proposed system model which contains the HLR, the SHLR's, the PVLR's, and the VLR's. The area covered by a SHLR is called the Home Area(HA).

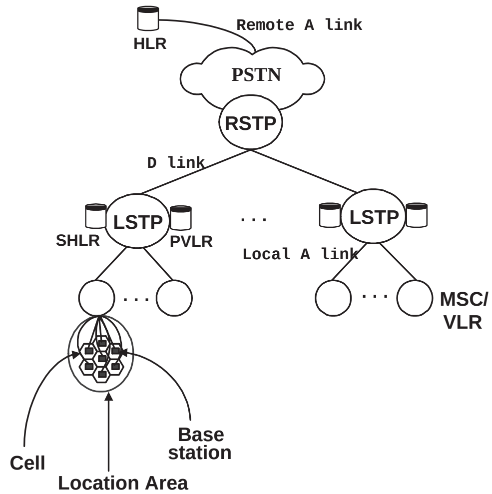

Figure 2. System model

throughout this paper, we assume a SHLR consists of the database and the computer for providing the required location management functions. The responsibilities of the SHLR's are as follows:

1. store location pointers which indicate the current locations of home MT's.
2. forward location update and call initiation requests from it associated MT's to the appropriate network elements as indicated by the location pointer.

Also, we assume a PVLR consists of the database and the computer for providing the required location management functions. The responsibilities of the PVLR's are as follows:

1. store location pointers which indicate the current locations of remote MT's.
2. forward location update and call initiation requests from it associated MT's to the appropriate network elements as indicated by the location pointer.

4 Location Management

Since MT's communicate with neighboring users frequently, call patterns between callers and callees have call locality. Also, since probability that MT's move to neighboring LA's is higher, user mobility patterns between old location and new LA have mobility locality.

Considering call locality and mobility locality, location management scheme can reduce location update and query cost. In this approach, we use one level of updating for MT's in their HA, and a two-level updating approach only for MT's visiting other areas, referred to as remote MT's.

For home MT's, the location is updated directly by the SHLR(Second HLR) of the MT. For each remote MT, a PVLR(Proxy VLR) is assigned in the current area of the MT to update its location.

We first describe location update procedure of the proposed scheme in Section 4.1 and then present its location query procedure in Section 4.1.

4.1 Location update procedure

When a MT enters HA, location update procedure updates the SHLR and when a MT newly enters visiting other area, location update procedure updates the PVLR, the HLR, and old the HLR and PVLR. When a MT enters LA in visiting area, update procedure updates the PVLR.

The proposed location update scheme is as follows:

1. The MT sends an update request message to the new VLR.
2. If (the MT is home MT)
   (a) The new VLR sends an update request message to the SHLR.
   (b) The SHLR sends an update ACK. message to the new VLR.
3. Else if(the ID of the MT exists in the PVLR) The PVLR sends an update ACK. message to the new VLR.
4. Else
   (a) The PVLR sends an update request message to the HLR.
   (b) The HLR sends an update ACK. message to the PVLR.
   (c) The PVLR sends an update ACK. message to the new VLR.
   (d) The HLR sends an update cancellation message to the old SHLR.
   (e) The old SHLR sends an update cancellation ACK. message to the HLR.
5. Location update is complete.

In this paper, cancellation of the pointers at the old LA is assumed to the timer-based.

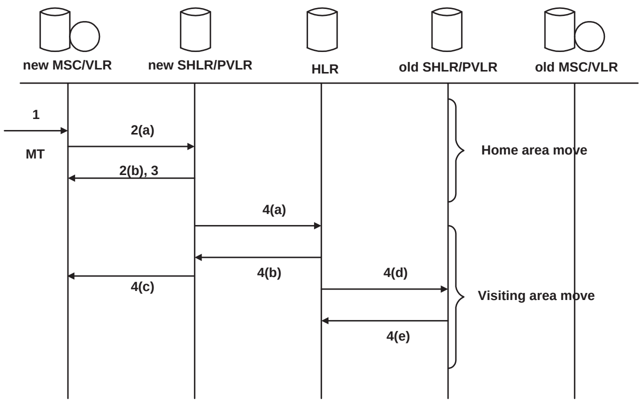

Figure 3. Location update procedure

4.2 Location query procedure

For the home MT, network queries its SHLR. For the remote MT, network queries its PVLR. If ID and location information of the called MT do not exist in the SHLR and the PVLR, network queries the HLR. The proposed location query scheme is as follows:

1. The new VLR of the calling MT sends a location query message to the SHLR.
2. If (the ID of the called MT exists in the SHLR(PVLR))
   (a) The SHLR (PVLR) sends a location query request message to the VLR serving the called MT.
   (b) The VLR determines the cell location of the called MT and sends a location information to the HLR (PHLR).
   (c) The SHLR (PVLR) sends a location information to the new VLR.
3. Else
   (a) The PVLR sends a location information request message to the HLR.
   (b) The HLR sends a location query request message to the SHLR serving the called MT.
   (c) The SHLR sends a location query request message to the VLR serving the called MT.
   (d) The VLR serving the called MT determines the cell location of the called MT and sends a location information to the SHLR.
   (e) The SHLR serving the called MT sends a location information message to the HLR.
   (f) The HLR sends a location information message to the PVLR of the calling MT.
   (g) The PVLR of the calling MT sends a location information message to the VLR of the calling MT.
4. Location query is complete.

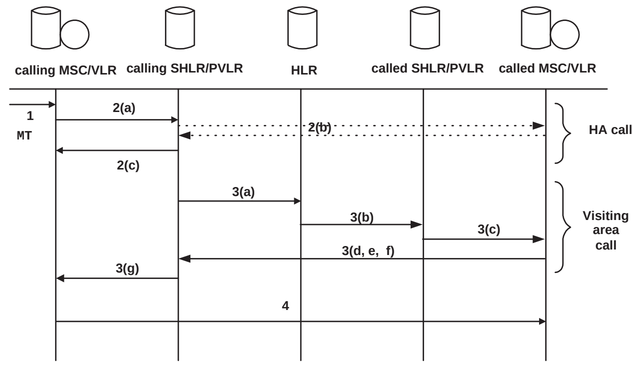

Figure 4. Location query procedure

The above location querying procedure assumes that the calling and called mobile terminals are residing in different LA's. If they are located in the same location area, no HLR query is necessary as the information of the called mobile terminal is available locally.

5 Performance Analysis

In this section, using the location update and query cost, we analytically compare the IS-41 scheme with the proposed scheme in section 4. We use a cost formulation for the computation of update and query costs. This formulation allows for the comparison of the signaling cost and the database accesses of two schemes. In this paper, when calculate costs, we use the same parameters as database access cost, network cost, p, and q. Database cost consists of the HLR, the MSC/VLR, the PVLR, and the SHLR access cost. Network cost consists of the costs for sending a message through the local A link, the D link, and the remote A link.

We define the cost parameters to be as follows:

5.1 Proposed scheme

In this section, we analyze the cost of the updating and querying procedures proposed in this paper. Location updating cost consists of the number of database access and network cost. Database access cost consists of the new MSC/VLR, the HLR, the PVLR, and the SHLR updating cost. Network cost consists of the message cost through the local A link, the D link, and the remote A link. The location updating cost per move incurred by the proposed scheme is given by (1).

Table 1. List of parameters

Parameters	Meaning
D_h	The cost for accessing the HLR/PVLR.
D_v	The cost for accessing the VLR.
D_s	The cost for accessing the SHLR.
N_d	Thee cost for sending a message through the D link.
N_{la}	The cost for sending a message through the local A link.
N_{ra}	The cost for sending a message through the remote A link.
p	Probability that MT moves the same LSTP.
q	Probability that calling and called MT reside at the same LSTP.

$$U = D_v + D_h + 2L_c + (1-p)(D_s + D_h + 2(2R_c + H_c)) \quad (1)$$

Location querying cost consists of the number of database access and network cost. Database access cost consists of the new MSC/VLR, the HLR, the PVLR, and the SHLR querying cost. Network cost consists of the costs for sending a message through the local A link, the D link, and the remote A link. The location querying cost per move incurred by the proposed scheme is given by (2).

$$Q = D_v + D_h + 2L_c + (1-q)(D_s + D_h + 2(L_c + R_c + H_c)) \quad (2)$$

5.2 IS-41 scheme

In this section, we analyze the cost of the IS-41 location management scheme for the co-located MSC/VLR configuration. The location update cost per move incurred by the IS-41 scheme is given by (3).

$$U_{is} = D_v + D_h + D_v + 4(L_c + R_c + H_c) \quad (3)$$

The MT location query cost incurred by the IS-41 standard consists of cost of querying the HLR, cost of querying the MSC/VLR, and the cost of the associated signaling. The location querying cost per call incurred by the IS-41 standard is given by (4).

$$Q_{is} = D_v + D_h + 2(L_c + R_c + H_c) \quad (4)$$

Table 2. Cost parameters

Class	$D_s(N_{ra})$	$D_h(N_d)$	$D_v(N_{la})$
1	1	1	1
2	4	2	1
3	6	2	1
4	6	3	1
5	9	3	1

5.3 Performance result

The total cost of a location management scheme depends on the location updating cost and the location querying cost of that scheme. In order to be able to estimate the total cost, the rate of call arrivals at a mobile,λ_c and the rate at which the mobile moves between registration areas, λ_m, are needed. Total cost, T^n, is computed as shown in (5), where U and Q represent the location updating cost per move and location querying cost per call, respectively.

$$\begin{aligned} U &= \lambda_m U \\ Q &= \lambda_c Q \\ T &= U + Q \end{aligned} \quad (5)$$

The total cost of the IS-41 scheme,T_{is}, is computed as shown in (6), where U_{is} and Q_{is} represent the location updating cost per move and location querying cost per call, respectively.

$$\begin{aligned} U_{is} &= \lambda_m U_{is} \\ Q_{is} &= \lambda_c Q_{is} \\ T_{is} &= U_{is} + Q_{is} \end{aligned} \quad (6)$$

Since the main objective of the proposed scheme is to improve the performance over the IS-41 scheme, we define the cost of a scheme to be the ratio of the total cost in the scheme to that of total cost in the IS-41 scheme. The cost of a scheme is given by (6).

$$T^n = \frac{\lambda_m U + \lambda_c Q}{\lambda_m U_{is} + \lambda_c Q_{is}} \leq 1 \quad (7)$$

We use the CMR (Call-to-Mobility Ratio) to study the performance of these schemes. Using this definition of CMR, the cost T^n, is given by (7).

$$T^n = \frac{U + \rho Q}{U_{is} + \rho Q_{is}} \leq 1 \quad (8)$$

where, $\rho = \lambda_m / \lambda_c$.

Database access cost of the schemes is calculated by setting the values of the network cost to 0 in (1) to (8). We use five sets of values for the cost parameters D_s, D_h and D_v as given in Table2. The value of D_v is normalized to 1 since it is the lowest among the three cost parameters. Parameters sets 4 to 5 capture the cases when it is significantly more expensive accessing the D_s than accessing the D_v. Parameters sets 1 to 3 capture the cases when the costs for accessing the D_s is relatively low.Plots in Figure 3 show the variation of the normalized database access cost with CMR for different values of p and q.

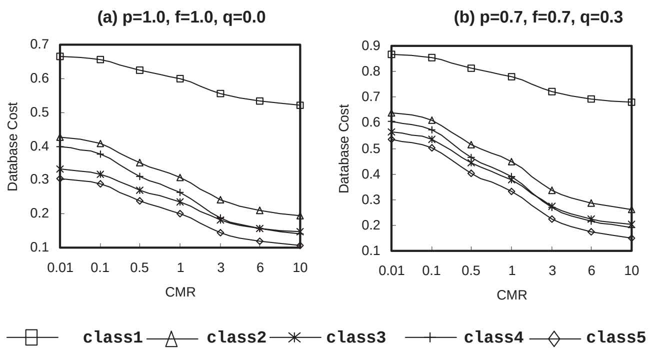

Figure 5. Database cost

Network cost of the schemes is calculated by setting the values of the database access to 0 in (1) to (8). We use five sets of values for the cost parameters N_{la}, N_d and N_{ra} as given in Table2. The value of N_{la} is normalized to 1 since it is the lowest among the three cost parameters. Parameters sets 4 to 5 capture the cases when it is significantly more expensive sending a message through the N_{ra} than sending a message through the N_{la}. Parameters sets 1 to 3 capture the cases when the costs for sending a message through the N_{ra} is relatively low. Plots in Figure 4 show the variation of the network cost with CMR for different values of p and q.

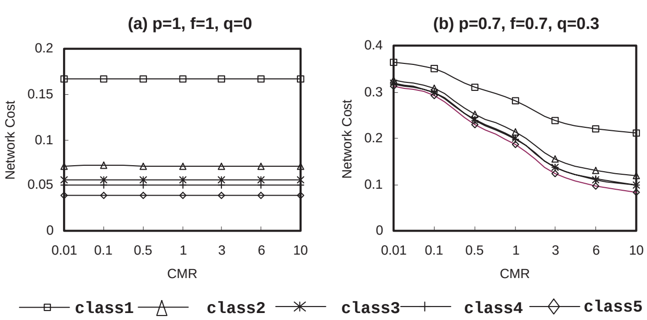

Figure 6. Network cost

6 Conclusions

Managing location information of MT's is an important issue in mobile computing systems. In this paper, we proposed a new location management scheme considering call locality and movement locality. Our scheme had the following features:1) for mobile terminals in neighboring LA's, location update required a one-hop message exchange, 2) for the MT in neighboring LA's, location query required a one-hop message exchange.

We compared the performance of the our scheme with that of the IS-41 scheme in respect of the network cost, the database cost, and the total cost. Simulation results show that the proposed scheme performs better than the IS-41 scheme

References

[1] EIA/TIA, "Cellualr Radio Telecommunication Intersystem Operations," TIA/EIA PN-2991, November 1995.

[2] M.Mouly and M.B.Pautet, "The GSM System for Mobile Communications," 49 rueLouise Bruneau, Palaiseau, France, 1992.

[3] K.S.Meier-Hellstem and E.Alonso, "The use of SS7 and GSM to support high density personal communication services," presented at the IEEE ICC, 1992

[4] J.Z.Wang, "A Fully Distributed Location Registration Strategy for Universal Personal Communication Systems," *IEEE Journal on Selected Areas in Communications*, Vol.11, August 1993.

[5] S.Mohan and R.Jain, "Two User Location Stratergies for Personal Communication Services," *IEEE Personal Communications*, First Quarter 1994.

[6] R.Jain, Y.B.Lin, "An Auxiliary User Location Strategy Employing Forwarding Pointers to Reduce Network Impact of PCS," *ACM-Baltzer Journal of Wireless Network*, July 1995.

[7] Yi-Bing Kin, "Reducing location update cost in a PCS network," IEEE/ACM Trans. Networking, vol.5, no. 1, Feb. 1997.

[8] Joseph S. M. Ho and Jim Xu, "History-based location tracking for personal communications networks," in Proc. 48th IEEE Veh. Technol. Conf., 1998.

[9] Dong Geun Jeong and Whs Sook Jeon, "Probabilistic location update for advanced cellular mobile networks," IEEE Communications Letters, vol.2, no. 1, Jan. 1998.