Paper

Improvement of the Performance of Database Access Operations in Cellular Networks

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Abstract—Reducing the traffic volume of location updating is a critical issue for tracking mobile users in a cellular network. Besides, when user *x* wants to communicate with user *y*, the location of user *y* must be extracted from databases. Therefore, one or more databases must be accessed for updating, recording, deleting, and searching. Thus, the most important criterion of a location tracking algorithm is to provide a small database access time. In this paper, we propose a new location tracking scheme, called Virtual Overlap Region with Forwarding Pointer (VF), and compare the number of database accesses required for updating, deleting, and searching operations for the proposed scheme and other approaches proposed for cellular networks. Our VF scheme like Overlap Region scheme reduces the updating information when a user frequently moves in boundaries of LAs. Unlike Overlap Region, the VF can reduce number of database accesses for searching users' information.

Keywords—Cellular networks, deleting cost, GSM, searching cost, tracking mobile users, UMTS, updating cost.

1. Introduction

In mobile communications (e.g., GSM, UMTS, 3G, ...), the location of users is not fixed and may change in time. Therefore, to make a communication between user *x* and user *y*, the system must first find the location of user *y*. Therefore, the location of users must be tracked from time to time [1]. In mobile communications, a small geographical area (called cell) is served by a Base Station (BS). Several cells are grouped into a Location Area (LA) and several LAs make a mobile communications network. The Mobile Terminals (MTs) in a cell directly communicate with the BS of the cell. Several BSs are connected to a Base Station Controller (BSC) and several BSCs are connected to a Mobile Switching Center (MSC) [2], [3].

In a typical telephone system, we have one database that stores all users' information permanently. Therefore, the location of each user can be found easily by searching the database. However, in cellular networks the location of users is not fixed. When a user enters a new location, the information of this user must be updated. With the increase of the number of mobile users in cellular networks, the database access time becomes a bottleneck because more database access operations (for updating, deleting, searching, and recording new information) are necessitated in time [4]. Thus, choosing a good algorithm for tracking users in cellular networks depends on the number of needed database accesses.

The objective of this paper is to propose a new method for tracking mobile users and compare the number of database accesses for the proposed method with other available methods. The proposed scheme uses the concept of virtual overlap region and forwarding pointer, but with a different policy for updating the information when a user frequently moves in boundaries of LAs in one overlap region. Indeed, the number of database accesses for searching users' locations and updating their information can be reduced efficiently. To the best of our knowledge, this is the first time mobile tracking schemes have been compared based on their database access operations (updating, searching, deleting, etc.), except our recent work in [5].

Our contributions in this paper are proposal of the Virtual Overlap Region with Forwarding Pointer (VF) location tracking scheme, and comparison of location tracking schemes based on database access operations.

The remainder of this paper is organized as follows. Location management schemes are explained in Section 2. The proposed VF method is described in Section 3. In Section 4, we compare location management methods. Finally, a brief conclusion is presented in Section 5.

2. The Schemes Proposed for Tracking Mobile Users

Many strategies have been proposed to reduce the overhead of database accesses in mobile communications networks [6]–[13]. In this section, we will briefly describe and compare some location management approaches such as two-tier architecture [7], Forwarding Pointer [6], Virtual Layer [8], Virtual Layer with Forwarding Pointer [9], and Overlap Region [10].

2.1. Two-Tier Architecture

Two-tier architecture [7] uses a two-level database system: HLR that maintains all permanent information of each user and a pointer to another database; and Visitor Location Register (VLR) that stores temporary location information

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of users. The VLR database is maintained at each LA. Therefore,

- When mobile user x enters the mobile communications network (i.e., user turns the mobile on), a new record is created in both HLR and VLR in order to store the information of user x. Thus, one HLR and one VLR accesses are required.
- When mobile user x moves from LA_i to LA_j, the information of the user x in VLR_i is deleted and a new record is created in VLR_j. In addition, a message is sent to HLR by VLR_j in order to update the user x pointer from VLR_i to VLR_j. Therefore, one HLR access and two VLR accesses are necessary.
- When mobile user x decides to call mobile user y:
  - if both user x and user y are in the same LA_i, the location of user y is found from VLR_i. Thus, one VLR access is needed;
  - if both user x and user y are not in the same LA_i, first, the location of user y is searched in VLR_i. Since the information cannot be found in VLR_i, the relevant VLR_j can be found from HLR. Finally, the location of user y is found from VLR_j. Therefore, one HLR access and two VLR accesses are required to find the location of user y.

  Since the access of the HLR database takes more time than the access of a VLR database due to the large size of the HLR database, the two-tier architecture can reduce the search cost when both user x and user y are in the same LA. However, when user x and user y are not in the same LA, the HLR, the new VLR, and old VLR all must be accessed for appropriate functions. This, in turn, increases the number of database accesses.
- Finally, when user x turns his/her mobile off or exits from the mobile communications network, the information of user x in HLR and VLR should be deleted. To delete the information of user x, one HLR and one VLR accesses are necessitated.

2.2. Forwarding Pointer

When a user frequently moves in a boundary between LAs, more HLR accesses are required for updating in the two-tier architecture and HLR may likely become a bottleneck. The Forwarding Pointers scheme [6] has been proposed to efficiently reduce the volume of HLR accesses required for updating. In this approach, the main idea is to set up a forwarding pointer from an old database to a new database when a user leaves the old LA toward a new LA. Therefore,

- When mobile user x enters a mobile communications network (i.e., user x turns his/her mobile on), a new record is created in both HLR and VLR in order to store the information of user x. Thus, one HLR and one VLR accesses are needed.
- When mobile user x moves from LA_i to LA_j, a new record is created in VLR_j and a pointer is set to VLR_j from VLR_i. Therefore, two VLR accesses are only needed.
- When mobile user x calls mobile user y:
  - If both user x and user y are in the same LA_i, the location of user y is either directly found from VLR_i, or is following the pointers chain. Thus, l VLR accesses are necessitated where l is the length of the pointers chain. We have $l = 1$ if the information is retrieved directly from VLR_i.
  - If both user x and user y are not in the same LA_i, the location of user y is first searched in VLR_i and the relevant pointers chain. Since the information cannot be found, the relevant VLR_j can be found from HLR. Finally, the location of user y is either directly found from VLR_j or by following the pointers chain. Therefore, one HLR access and $2 \times l$ VLR accesses are needed to find the location of user y.
- Finally, when user x turns his/her mobile off or exits from the mobile communications network, the information of user x in HLR and VLR must be deleted. One HLR and l VLR accesses are needed to delete the information of user x.

Since no update is required in the HLR database, the update cost goes down. When the length of the pointer chain is less than five, according to analytical estimation in [6], this scheme can reduce the total cost by 20% to 60%. Although, this scheme can reduce the total cost, the frequent updates problem still exists when a user moves back and forward in the boundary of an LA.

2.3. Virtual Layer Scheme

The virtual layer scheme [8] has been proposed to construct a new location database architecture (see Fig. 1). The bold lines in Fig. 1 represent the original layer and the dotted lines represent the virtual layer. For every virtual layer, one VLR is needed (i.e., subVLR).
In this scheme, one SubMSC is necessitated for each virtual layer. The SubMSCs are connected to the covered MSC. For example in Fig. 1, consider MT_x moves from position A to B, B to C and then comes back to position A. Initially in position A, HLR and VLR1 have created an entry for MT_x. When MT_x moves to position B, the SubMSC4 creates a new entry for MT_x and VLR1 must be updated. Then, when MT_x moves from position B to C and C to A, no update is needed because the virtual layer has not changed.

The goal of this scheme is to reduce both location updating rate and location updating cost, especially when the MTs

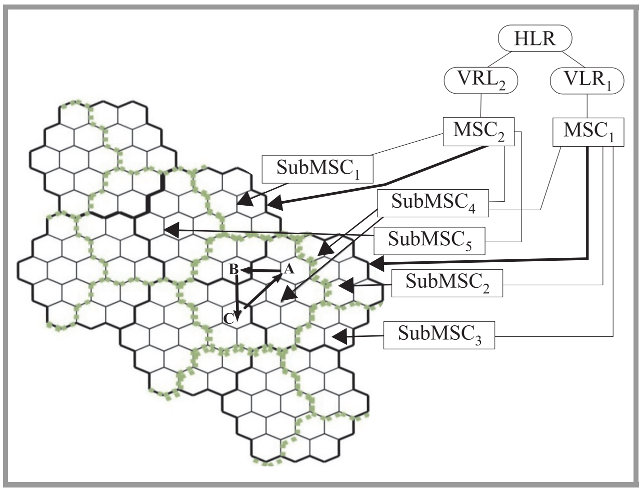

Fig. 1. The demonstration of the virtual layer.

reside near the boundaries of LA and frequently cross through the boundary to another LA.

- When mobile user x enters the mobile communications network (i.e., user x turns the mobile on), a new record is created in both HLR and VLR in order to store the information of user x . Thus, one HLR and one VLR accesses are necessitated.
- When VLR is active: mobile user x moves from one LA_i to LA_j:
  - If the information of user x already exists in $subVLR_k$, VLR_i must be deactivated and $subVLR_k$ must be activated. Therefore, one VLR and one subVLR accesses are necessary.
  - If the information of user x does not exist in $subVLR_k$, a new record is created in $subVLR_k$ and the information in previous subVLR must be deleted. Besides, VLR_i must be deactivated and $subVLR_k$ must be activated. Therefore, one VLR and two subVLR accesses should be done.
- When subVLR is active: mobile user x moves from virtual layer i to virtual layer j:
  - If the information exists in VLR_k, the information in VLR_k is updated. VLR_k must be activated and $subVLR_i$ must be deactivated. Therefore, one VLR and one subVLR accesses are required.
  - If the information does not exist in VLR_k, a new record is created in VLR_k and the previous record must be deleted. Hence, a message is sent to HLR by VLR_k in order to update the user x VLR pointer (from previous VLR to VLR_k). Besides, VLR_k must be activated and $subVLR_i$ must be deactivated. Thus, one HLR access, one subVLR, and two VLR accesses are required.
- When mobile user x calls mobile user y:
  - If both user x and user y are in the same LA_i, the location of user y is found from VLR_i. Thus, one VLR access is needed.
  - If both user x and user y are not in the same LA_i, the location of user y is first searched in VLR_i. Since the information cannot be found from VLR_i, the relevant VLR_j can be found from HLR. Finally, the location of user y is found from VLR_j. Therefore, one HLR access and 2 VLR accesses are necessitated to find the location of user y.
- Finally, when user x turns his/her mobile off, or exits from the mobile communications network, the information of user x in HLR and VLR should be deleted. For this purpose, one HLR and one VLR accesses are necessary.

2.4. Virtual Layer with Forwarding Pointers

Chang and Lin have proposed an improved scheme [9] that uses forwarding pointers in virtual layer to reduce the update cost. The possible state of a user in this scheme is:

- When mobile user x enters the mobile communications network (i.e., user x turns the mobile on), a new record is created in both HLR and VLR in order to store the information of user x. Thus, one HLR and one VLR accesses are necessitated.
- When VLR is active: mobile user x moves from one LA_i to LA_j:
  - If the information of user x already exists in $subVLR_k$, VLR_i must be deactivated and $subVLR_k$ must be activated. Therefore, one VLR and one subVLR accesses should be performed.
  - If the information of user x cannot be found in $subVLR_k$, a new record is created in $subVLR_k$ and the information in previous subVLR must be deleted. Besides, VLR_i must be deactivated and $subVLR_k$ must be activated. Therefore, one VLR and two subVLR accesses are required.
- When subVLR is active: mobile user x moves from virtual layer i to virtual layer j:
  - If the information exists in VLR_k, the information in VLR_k is updated. VLR_k must be activated and $subVLR_i$ must be deactivated. Therefore, one VLR and one subVLR accesses are needed.
  - If the information does not exist in VLR_k, a new record is created in VLR_k and a message is sent by VLR_k to previous VLR to set a pointer to VLR_k. Furthermore, VLR_k must be activated

and $subVLR_i$ must be deactivated. Thus, one subVLR and two VLR accesses are required.

- When mobile user x calls mobile user y:
  - If both user x and user y are in the same LA_i, the location of user y is directly found from VLR_i or by following the pointers chain. Thus, l VLR accesses are needed.
  - If both user x and user y are not in the same LA_i, first the location of user y is searched in VLR_i and relevant pointers chain. Since the information cannot be found, the relevant VLR_j can be found from HLR. Finally, the location of user y is directly found from VLR_j or by following the pointers chain. Therefore, one HLR access and $2 \times l$ VLR accesses are required to find the location of user y.
- Finally, when user x turns his/her mobile off, or exits from the mobile communications network, the information of user x in HLR and VLR should be deleted. To do this, one HLR and l VLR accesses are required.

2.5. Overlap Region

The Virtual Layer scheme [8] requires the reconstruction of the mobile communications network architecture. The architecture requires extra equipments. To overcome the reconstruction of the mobile communications network, the Virtual Overlap scheme [10] with time stamp has been proposed. Figure 2 depicts the structure of the Virtual Overlap [10]. Each Overlap Region (OR) has seven LAs. The bold line in Fig. 2 represents the Overlapping Region for LA_5, and therefore, we have $OR_5 = \{LA_1, LA_2, LA_4, LA_5, LA_6, LA_9, LA_{10}\}$. In Fig. 2, the OR for LA_6 is $OR_6 = \{LA_2, LA_3, LA_5, LA_6, LA_7, LA_{10}, LA_{11}\}$. Each LA has an associated MSC and VLR.

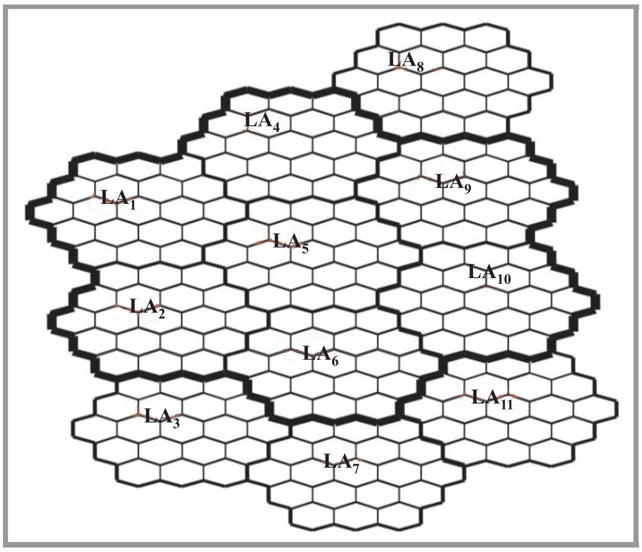

Fig. 2. The structure of virtual overlap in mobile communications network.

In the Virtual Overlap scheme [10], each VLR has two fields: TS which indicates the time that a mobile user enters the associated LA, and OR which indicates the Overlap Region in which the mobile user has registered last time. Therefore,

- When mobile user x enters the mobile communications network (i.e., user x turns his/her mobile on), a new record is created in both HLR and VLR in order to store the information of user x. Thus, one HLR and one VLR accesses are necessary.
- When mobile user x moves from LA_i to LA_j:
  - If LA_i and LA_j are in the same virtual overlap region, a new record is created in VLR_j and the TS field of VLR_j records the current time. Therefore, one VLR access is necessitated.
  - If LA_i and LA_j are not in the same virtual overlap region, a new record is created in VLR_j and the TS field of VLR_j records the current time. Thus, a message is sent to HLR in order to update the user x data. Furthermore, the information of user x in previous OR (with seven VLRs) must be deleted. Therefore, one HLR and eight VLR accesses are required.
- When mobile user x calls mobile user y:
  - If both user x and user y are in the same LA_i, the location of user y is found from seven VLRs in the relevant OR. Thus, seven VLR accesses are needed.
  - If both user x and user y are not in the same LA_i, first the location of user y is searched in VLR_i. Since the information cannot be found from VLR_i, a message is sent to HLR by VLR_i and then the relevant VLR_j can be found in HLR. Finally, the associated overlap region is found from the OR field of VLR_j, and then the location of user x is searched in seven VLRs in the relevant OR. Therefore, one HLR access and eight VLR accesses are required to find the location of user y.
- Finally, when user x turns his/her mobile off or leaves the mobile communications network, the information of user x in HLR and seven VLRs on the OR that user has resided before should be deleted. To delete the information of user x, one HLR and seven VLR accesses are necessary.

3. The Virtual Overlap Region with Forwarding Pointer Scheme

In this section, we shall propose a new approach for location updating based on the concepts of the virtual overlapping region and forwarding pointers. The goal of our VF is to reduce the number of database accesses for updating and searching the information.

3.1. The Architecture of VF

Now, we detail the VF scheme. The VLR database that maintains current user location information keeps two fields as the LA ID and pointer PO. The LA ID field indicates the identification number of a LA and the PO field is a pointer to another VLR. Note that each LA has a unique identifier number. If the LA ID is –1, the PO field is used to find the LA ID in another VLR.

3.2. The Procedure of Location Registration

When a new mobile user (i.e., mobile user x) resides in a location area LA_i, the associated database VLR_i will create a new entry for mobile user x and will record the LA identification number. Then, the system gives the LA ID to the mobile user x and sends a message to the HLR to record the current location of mobile user x. When mobile user x moves, the procedure of the location registration is as follows:

- When mobile user x detects a new LA_j, the mobile user x sends the LA ID that assigned previously in LA_i to the associated service switch through its BS.
- Determine if the new LA_j and previous LA_i belong to the same overlap region.
- If yes, the VLR_i will update its LA ID to LA_j ID.
- If no, the VLR_j will create a new entry for mobile user x and sends a message to VLR_i in order to set a pointer to VLR_j and change the LA ID field to –1. Then, a new location number is sent by VLR_j to mobile user x.

3.3. The Procedure of Call Delivery

When mobile user x wants to call mobile user y in LA_i, the following steps are required for the call delivery as:

- The system first searches mobile user y in VLR_i.
- Determine whether mobile user y can be found in VLR_i.
- If yes, the mobile user y's LA is retrieved from the LA ID field:
  - According to the location information of VLR, the service switch MSC_j can be found.
  - The service switch MSC_j determines the cell location of the mobile user y and assigns a Temporary Location Directory Number (TLDN) to mobile user y. Then, the TLDN is returned from the MSC_j to the MSC_i. By this way, MSC_i knows where to send the information relevant to mobile user x.
- If no, a message is sent to HLR:
  - From the HLR, the associated VLR can be found.
  - According to the location information of VLR, the service switch MSC_j can be found.
  - The service switch MSC_j determines the cell location of the mobile user y and assigns a TLDN. Then, the TLDN is returned from the current VLR to the HLR.
  - Upon receiving the TLDN, if the current VLR is different from the last VLR registered, the HLR updates the relevant pointer to point to the current VLR, and deletes the chain of forwarding pointers.
  - The HLR sends the TLDN to the original switch (i.e., MSC_i) and the connection between the caller user and the called user is set up using the TLDN.

According to the above details, the numbers of database accesses in VF are as follows:

- When mobile user x enters a mobile communications network (i.e., user x turns his/her mobile on), a new record is created in both HLR and VLR in order to store the information of user x. Thus, one HLR and one VLR accesses are necessary.
- When mobile user x moves from LA_i to LA_j:
  - If LA_i and LA_j are in the same virtual overlap region, the LA ID field in VLR_i is updated. Therefore, one VLR access is necessitated.
  - If LA_i and LA_j are not in the same virtual overlap region, a new record is created in VLR_j and a pointer is set up from VLR_i to VLR_j. therefore, two VLR database accesses are needed.
- When mobile user x calls mobile user y:
  - If both user x and user y are in the same LA_j, the location of user y is found from LA ID in the relevant VLR. Thus, one VLR access is needed.
  - If both user x and user y are not in the same LA_j, first the location of user y is searched in VLR_j. Since the information cannot be found from VLR_j, a message is sent to HLR by VLR_j and then the relevant VLR_i can be found in HLR. Finally, the location of user x is obtained from LA ID in the relevant VLR. Therefore, one HLR access and 2 VLR accesses are required to find the location of user y.
- Finally, when user x turns his/her mobile off or leaves the mobile communications network, the information of user x in HLR and l VLRs must be deleted. To delete the information of user x, one HLR and l VLR accesses are necessary.

Table 1
Comparison of database accesses

Scheme		Two-tier architecture [7]		Forwarding Pointer [6]		Virtual Layer [8]		Virtual Layer with Forwarding Pointers [9]		Overlap Region [10]		VF	
Operation		HLR	VLR	HLR	VLR	HLR	VLR	HLR	VLR	HLR	VLR	HLR	VLR
User is turned on		1	1	1	1	1	1	1	1	1	1	1	1
User is turned off		1	1	1	l	1	1	1	l	1	7	1	l
Searching a user	minimum access	0	1	0	1	0	1	0	1	0	7	0	1
	maximum access	1	2	1	$2\times l$	1	2	1	$2\times l$	1	8	1	$2\times l$
User moves from one LA to another LA	minimum access	1	2	0	2	0	0	0	0	0	1	0	1
	maximum access	1	2	0	2	1	3	0	3	1	8	0	2

Table 2
Ranking of schemes when $l < 7$

Scheme	Two-tier architecture [7]	Forwarding Pointer [6]	Virtual Layer [8]	Virtual Layer with Forwarding Pointers [9]	Overlap Region [10]	VF
User is turned on	1	1	1	1	1	1
User is turned off	1	2	1	2	3	2
Searching a user	1	2	1	2	3	2
User moves from one LA to another LA	5	1	3	2	4	1

4. Performance Evaluation

In this section, we shall compare VF scheme with the schemes stated in Section 2. First, the number of database accesses under different schemes will be illustrated for each possible action of a user. Then, we shall discuss the number of databases by an example.

4.1. Performance Evaluation of Database Accesses

In mobile communications, tracking mobile users could be the most important issue. Therefore, a good scheme must provide a small database when a user moves from one LA to another LA. Table 1 shows the comparison of different schemes in terms of the number of database accesses for possible status of a user. In this table, VF, Virtual Layer and Virtual Layer with Forwarding Pointers have small database accesses, but Virtual Layer and Virtual Layer with Forwarding Pointers need reconstruction of the mobile communications network. Furthermore, when the length of the chain in Forwarding Pointer and Virtual Layer with Forwarding Pointer schemes goes up, the number of database accesses increases. Since the access of HLR database takes more time, Overlap Region and VF reduces an update cost when an user goes back and forth in boundary of LAs (just need one VLR access) which is comparable with the two-tier architecture (that needs one HLR and two VLRs accesses). While searching the user location, the VF, two-tier architecture and Virtual Layer always provide small number of database accesses, and Overlap Region has more database accesses than other schemes.

Based on the number of database accesses, Table 2 ranks the proposed schemes when the Forwarding Pointer chain length is $l < 7$. When a user mobile is turned on, a new record is created in HLR and VLR databases. Therefore, the number of database accesses for all schemes are the same. When a user mobile is turned off, all information must be deleted. In this case, the overlap region scheme is the worst. For searching user information, again, the overlap region scheme has more database accesses. For a movement from one LA to another, which is more important in cellular networks, VF and Forwarding Pointer schemes are the best candidates and the two-tier scheme is the worst.

On the other hand, Table 3 depicts the ranking of schemes when the Forwarding Pointer chain length is $l \geq 7$. In this

Table 3
Ranking of schemes when $l \geq 7$

Scheme	Two-tier architecture [7]	Forwarding Pointer [6]	Virtual Layer [8]	Virtual Layer with Forwarding Pointers [9]	Overlap Region [10]	VF
User is turned on	1	1	1	1	1	1
User is turned off	1	3	1	3	2	3
Searching a user	1	3	1	3	2	3
User moves from one LA to another LA	5	1	3	2	4	1

situation, the number of database accesses for deleting and searching the information in VF, Forwarding Pointer and Virtual Layer with Forwarding Pointer goes up.

4.2. Impact of Users' Mobility

Figure 3 shows an example in which user x moves from position A to position F through positions B, C, D, E, and F.

- Initially, user x enters LA_5 or is turned on in LA_5. The following procedures are performed:
  - VLR_5 creates a new entry for user x.
  - VLR_5 sends a registration message to HLR to create an entry and to set a pointer to VLR_5.
- When user x moves from A to B:
  - **Two-tier architecture**. VLR_9 creates a new record for user x and sends a message to HLR to update information. Then, the information in VLR_5 is deleted.

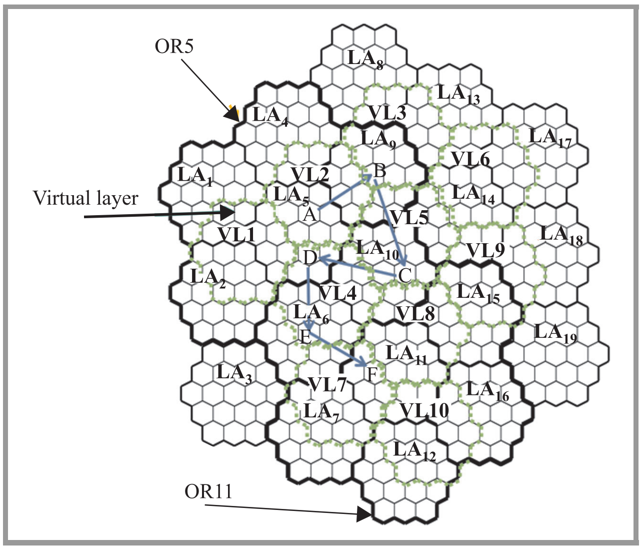

Fig. 3. An example of user movement in mobile communications network.

  - **Forwarding Pointer**. VLR_9 creates a new record for user x and sends a message to VLR_5 to set a pointer to VLR_9.
  - **Virtual Layer**. When user x enters LA_9, a new record is created in $subVLR_2$ and VLR_5 is deactivated. Then, user x enters the virtual layer 3 from virtual layer 2. Therefore, a new record is created in VLR_9 and the information in VLR_5 is deleted. Hence, a message is sent to HLR by VLR_9 to update relevant information.
  - **Virtual Layer with Forwarding Pointer**. When user x enters LA_9, a new record is created in $subVLR_2$ and VLR_5 is deactivated. Then, user x enters the virtual layer 3 from virtual layer 2. Therefore, a new record is created in VLR_9 and the information in VLR_5 is deleted. Hence, a message is sent to VLR_5 to set a pointer to VLR_9.
  - **Overlap Region with Time Stamp**. When a user enters LA_9, because LA_9 is in OR_5 a new record is created in VLR_9 and the TS field of VLR_9 stores the time that user has entered LA_9. Moreover, the OR field of VLR_9 stores the user x overlap region number (OR_5).
  - **VF**. When a user enters LA_9, the LA ID field in VLR_5 is updated from 5 to 9 since LA_9 is in OR_5.
- Movement from position B to position C:
  - **Two-tier architecture**. VLR_{10} creates a new record for user x and sends a message to HLR to update information. Then, the information in VLR_9 is deleted.
  - **Forwarding Pointer**. VLR_{10} creates a new record for user x and sends a message to VLR_9 to set a pointer to VLR_{10}.
  - **Virtual Layer and Virtual Layer with Forwarding Pointer**. When user x enters LA_{10}, a new record is created in $subVLR_5$ and VLR_9 is deactivated. Furthermore, the information of user x is deleted from $subVLR_2$.

- **Overlap Region with Time Stamp**. When a user enters LA_{10}, because LA_{10} is in OR_5 a new record is created in VLR_{10} and the TS field of VRL_{10} records the time that user has entered LA_{10}. In addition, the OR field of VLR_{10} stores the user x overlap region number (OR_5).
- **VF**. When a user enters LA_{10}, the LA ID field in VLR_5 is updated from 9 to 10 because LA_{10} is in OR_5.

- When user x moves from position C to position D:
  - **Two-tier architecture**. VLR_5 creates a new record for user x and sends a message to HLR to update information. Then, the information in VLR_{10} is deleted.
  - **Forwarding Pointer**. VLR_5 updates user x information, because the information already exists in VLR_5. Then, a message is sent to VLR_{10} to set a pointer to VLR_5.
  - **Virtual Layer**. When user x crosses the boundary of virtual layers in the direction of C to D, VLR_{10} creates a new record and sends a message to HLR to update information. Then, the information in VLR_9 is deleted. When a user reenters LA_5 again, a new record is created in $subVLR_4$ and VLR_{10} is deactivated. Furthermore, the information of user x is deleted from $subVLR_5$.
  - **Virtual Layer with Forwarding Pointer**. When user x crosses the boundary of virtual layers in the direction of C to D, VLR_{10} creates a new record and sends a message to VLR_9 to set a pointer to VLR_{10}. Then, when a user enters LA_5, a new record is created in subVLR4 and VLR_{10} is deactivated. Furthermore, the information of user x is deleted from $subVLR_5$.
  - **Overlap Region with Time Stamp**. When a user enters LA_5, because LA_5 is in OR_5 and the information already exists in VLR_5, the TS field of VLR_5 is only updated.
  - **VF**. When a user enters LA_5, because LA_5 is in OR_5 the LA ID field in VLR_5 is updated from 10 to 5.

- When user x moves from position D to position E:
  - **Two-tier architecture**. VLR_5 creates a new record for user x and sends a message to HLR to update information. Then, the information in VLR_{10} is deleted.
  - **Forwarding Pointer**. VLR_6 creates a new record for user x and sends a message to VLR_5 to set a pointer to VLR_6.
  - **Virtual Layer and Virtual Layer with Forwarding Pointer**. Since the movement is in the same virtual layer, no update is required.
  - **Overlap Region with Time Stamp**. When a user enters LA_6, because LA_6 is in OR_5 a new record is created in VLR_6 and the TS field of VLR_6 stores the time that user has entered LA_6. Furthermore, the OR field of VLR_6 stores the user x overlap region number (OR_5).
  - **VF**. When a user enters LA_6, because LA_6 is in OR_5 the LA ID field in VLR_5 is updated from 5 to 6.

- Finally, user x moves from position E to position F:
  - **Two-tier architecture**. VLR_{11} creates a new record for user x and sends a message to HLR to update information. Then, the information in VLR_6 is deleted.
  - **Forwarding Pointer**. VLR_{11} creates a new record for user x and sends a message to VLR_6 to set a pointer to VLR_{11}.
  - **Virtual Layer**. When user x crosses the boundary of virtual layers in the direction of E to F, VLR_6 creates a new record and sends a message to HLR to update information. Then, the information in VLR_{10} is deleted. Then, when user enters LA_{11}, a new record is created in $subVLR_7$ and the information of user x is deleted from $subVLR_4$.
  - **Virtual Layer with Forwarding Pointer**. When user x crosses the boundary of virtual layers in the direction of E to F, VLR_6 creates a new record and sends a message to VLR_{10} to set a pointer to VLR_6.Then, when a user enters LA_{11}, a new record is created in $subVLR_7$ and VLR_6 is deactivated and $subVLR_7$ is activated.
  - **Overlap Region with Time Stamp**. When a user enters LA_{11}, because LA_{11} is not in OR_5, a new record is created in VLR_{11} and the TS field is set to the current time. In addition, the OR field of VLR_{11} is set to OR_{11}. Then, a message is sent to HLR by VLR_{11} to update the information. After all, the information of user x is deleted from all VLRs in OR_5.
  - **VF**. When a user enters LA_{11}, because LA_{11} is not in OR_5 a new record is created in VLR_{11} and a pointer is set up from VLR_5 to VLR_{11}. In addition the LA ID field in VLR_5 is updated to –1 and user x takes new LA ID from VLR_{11} (i.e., 11).

Let's suppose that user y in LA_{14} wants to call user x. First, VLR_{14} is queried, but the relevant information cannot be found. Hence, a message is sent to HLR by VLR_{14}.

- **Two-tier architecture**. From the HLR database, the associated VLR (i.e., VLR_{11}) is found and the information is retrieved from VLR_{11}.

Table 4
Comparison of database accesses under the example showed in Fig. 3

Scheme	Two-tier architecture [7]		Forwarding Pointer [6]		Virtual Layer [8]		Virtual Layer with Forwarding Pointers [9]		Overlap Region [10]		VF	
Path	HLR	VLR	HLR	VLR	HLR	VLR	HLR	VLR	HLR	VLR	HLR	VLR
A (Initial)	1	1	1	1	1	1	1	1	1	1	1	1
A → B	1	2	0	2	1	3	0	3	0	1	0	1
B → C	1	2	0	2	0	3	0	3	0	1	0	1
C → D	1	2	0	2	1	5	0	5	0	1	0	1
D → E	1	2	0	2	0	0	0	0	0	1	0	1
E → F	1	2	0	2	1	5	0	5	1	8	0	2
User y call user x	1	2	1	5	1	2	1	5	1	8	1	2
Total database access	7	13	2	16	5	19	2	22	3	21	2	9
Normalized cost $C_{U,T}/C_{U,V}$	$7\alpha+13$		$2\alpha+16$		$5\alpha+19$		$2\alpha+22$		$3\alpha+21$		$2\alpha+9$	

– **Forwarding Pointer**. From the HLR database, the associated VLR (i.e., VLR_5) is found and the information is retrieved from VLR_5 by following the chains (i.e., VLR_6, VLR_{11}).

– **Virtual Layer**. From the HLR database, the associated VLR (i.e., VLR_{11}) is found and the information is retrieved from VLR_{11}.

– **Virtual Layer with Forwarding Pointer**. From the HLR database, the associated VLR (i.e., VLR_5) is found and the information is retrieved from VLR_5 by following the chains (i.e., VLR_6, VLR_{11}).

– **Overlap Region with Time Stamp**. From the HLR database, the associated VLR (i.e., VLR_{11}) is found. Then, the information is searched in OR_{11} that consists of VLR_6, VLR_7, VLR_{10}, VLR_{11}, VLR_{12}, VLR_{15}, and VLR_{16}.

– **VF**. From the HLR database, the associated VLR (i.e., VLR5) is found and the information is retrieved from VLR5 by following the chains (i.e., VLR_{11}).

Table 4 shows the number of database accesses among different schemes for this example. We assume that all database accesses have the same cost.
Let the database access cost for HLR ($C_{U,H}$) be equal to

$$C_{U,H} = \alpha \times C_{U,V}\,, \tag{1}$$

where $C_{U,V}$ is the VLR access cost and $\alpha \geq 1$. Then, the total database access cost ($C_{U,T}$) according to VLR access cost can be obtained from Eq. (2).

$$C_{U,T} = C_{U,H} + C_{U,V}\,. \tag{2}$$

From Eq. (2), the normalized access cost value of $C_{U,T}/C_{U,V}$ can be obtained (see the last row in Table 4).

As a result for the example in Fig. 3, the VF has the smallest database accesses in total (11 accesses: 9 VLR and 2 HLR accesses). Therefore, this scheme is better than others. Virtual Layer and Virtual Layer with Forwarding Pointer need reconstruction of the mobile communications network. Overlap Region scheme reduces database access for updating, however, it needs more database accesses for searching the location of users.

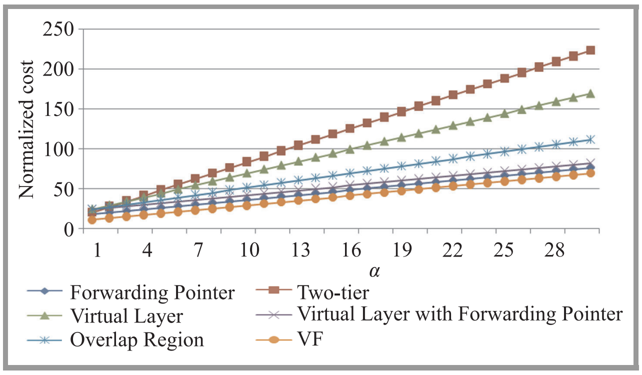

Fig. 4. Normalized cost for example of Fig. 3 for different values of α.

According to Fig. 4, with the increase of α, the two-tier architecture scheme has larger cost than the other schemes. Note that the HLR database must be accessed for every action in mobile communications network including searching, updating, deleting, and creating new record. Since in VF, Forwarding Pointer and Virtual Layer with Forwarding Pointer, access to HLR is avoided by using the forwarding pointer chain from one VLR to another VLR, the cost of these schemes is lower than others.

5. Conclusion

In this paper, we have studied five location management schemes and the number of database accesses for inserting, updating, deleting, and searching operations. When a user frequently makes a call to other users, Overlap Region needs more database accesses than others. In Forwarding Pointer, when a user frequently moves within boundaries of LAs, the number of database accesses becomes high. Virtual Layer and Virtual Layer with Forwarding Pointer need the reconstruction of mobile communications network. With the increases of the mobile users in the mobile communications network, the size of the HLR database goes up and the two-tier architecture cannot be a good scheme at all. This is because the HLR database must be accessed for every action including inserting, updating, deleting, and searching operations.

In addition, we have proposed a new scheme (VF) and compared it with other schemes. According to our comparisons, VF has a small number of database accesses when a user frequently moves within the boundary of LAs. For searching the user location, VF still has smaller database accesses than others. Therefore, VF could be the best candidate either when a user frequently moves within boundaries of LAs or frequently makes a call to other users.

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