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A Modified Multi-HLR Architecture for Implicit De-registration Strategies

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ABSTRACT
This study proposes a modification in the de-registration policy of Multi-HLR architecture. This architecture has made an attempt to overcome the drawbacks of Single centralized HLR architecture by introducing multiple HLRs in PCS networks in performing location managements of mobile units using explicit de-registration policy. This paper presents a modification in the de-registration policy of Multi-HLR architecture by applying the concept of implicit de-registration strategies and gives a performance analysis of this modified architecture to show how these implicit de-registration policies outperform the explicit de-registration strategy.

Keywords
Location Management, Location Updation, Explicit de-registration, Implicit de-registration

1. INTRODUCTION
Personal Communication Service (PCS) networks provide wireless communication services that enable Mobile Units (MUs) to transfer any form of information between any location at any time. Location management, i.e., how to track the MUs that move from place to place is a key issue in PCS networks [1], [2], [3], [5], [6], [10].

Due to rapid growth registered by mobile users in recent past, it has become the need of hour to reduce the system overheads involved with the location management [4], [6], [13], [14],[17]. Methods for reducing the overheads are critically important for the design and implementation of PCS networks.

The PCS network [5], [6] is based on two-tier system of Home Location Register (HLR) and the Visitor Location Register (VLR). The HLR contains the permanent data (e.g., directory number, profile information, current location, and validation period) of the MUs whose primary subscription is within the area. For each MU, it contains a pointer to the VLR to assist routing incoming calls.

A VLR is associated with a Mobile Switching Center (MSC) in the networks. It contains temporary record for all MUs currently active within the service area of the MSC. The VLR retrieves information for handling calls to or from a visiting MU. The PCS network is composed of many Registration Areas (RAs) for facilitating the location tracking of a moving MU. Each RA may include tens or hundreds of cells, which is a basic unit of area served by a base station (BS). Each RA is serviced by a VLR. An HLR is associated with hundreds of VLRs. The service area served by an HLR is referred to as Service Area (SA). In a PCS network, there are several HLRs forming different SAs. For each MU, the HLR that contains the permanent data information is referred to as the master or resident HLR of the MU. The SA that is associated with the master HLR is called the master SA for the MU. When an MU moves to another new SA, the new SA that the MU resides is called the current SA. The associated HLR is called the current HLR for the MU. All the popular existing PCS networks such as GSM, IS-41 employ the HLR/VLR architecture.

In the existing location management schemes, only the master HLR is used for an MU even though it may move to another SA associated with another HLR. When an MU moves far away from its master HLR, the communication costs for accessing the master HLR for both location registration and call delivery will increase dramatically. This problem leads us to consider why we cannot use the current HLR of an MU for the location management to improve the system performance.

There are two basic operations in location management: *location registration* and *call delivery*. Location registration is the process through which system tracks the locations of MUs that move in the networks. The MU reports its up-to-date location information dynamically to the VLR that it visits currently by performing *registration*. The system not only registers the new location of MU in new VLRs area but also *deregisters* it from the old VLR, which MU was visiting previously. This is termed as *Explicit De-registration* [11], [13].

When an incoming call arrives, the system searches for the called MU (the "callee") by sending a location request message to the HLR of the callee. The HLR determines the VLR of callee and sends a location message the associated MSC. Then the MSC sends the polling signals to all the cells in the RA to determine the cell location of the callee. This searching process is referred to as call delivery.

In the existing location management schemes, only the master HLR is used for an MU even though it may move to another SA associated with another HLR. When an MU moves far away from its master HLR, the communication costs for accessing the master HLR for both location registration and call delivery will increase dramatically. This problem leads to the consideration of current HLR of an MU for the location management to improve the system performance. A number of attempts [8], [9], [16] by researchers have been made to develop different analytical models to address the issue of signaling overheads so that efficiency of location management can be improved.

In this paper one such analytical model is being introduced and analyzed that uses multiple HLR with implicit de-registration.

The remaining part of this paper is organized as follows: section 2 gives an introduction to Multi-HLR architecture [8], [9], [12] and the use of the explicit de-registration. The modified Multi-HLR architecture implementing implicit de-registration is explained in section 3. Results and analysis of this modified architecture are discussed in section 4, which is followed, by conclusion and references in section 5 and 6 respectively.

2. MULTI-HLR ARCHITECTURE

The Multi-HLR Architecture as shown in figure 2 employs several HLRs instead of one HLR concept used in conventional architecture (figure 1). Each HLR serves many VLRs and each of these VLRs serves many location areas (LAs). All these LAs, which fall under VLR, make a Registration Area (RA) for it. Many VLRs make a Service Area (SA) for one HLR. In present standards like GSM, IS-41, there are many SAs each with one HLR but each HLR takes care of its registered MU as its master HLR even in the SA of some other HLR. As this MU goes away from SA of its master HLR, MU's location tracking incurs a heavy penalty on the network due to high transmission cost of location updation and searching. This concept has been modified so that in the process of location updation and searching of an MU, the HLR of current SA can also be involved. Thus, each MU at any time may roam in the SA of one the two types of HLRs- a master HLR that contains permanent information about MU or a serving HLR in whose area the MU is currently roaming. The serving HLR, in contrast to existing GSM or IS-41, can also participate actively in location registration and location search of MU by taking only required information from previous HLR that may be either a master or a serving HLR.

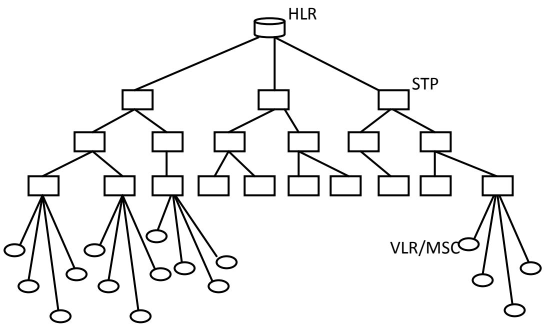

Fig. 1: Conventional HLR/VLR architecture

When a MU is called, the VLR of the calling unit verifies if the called MU is local. If it is, then the called MU is located. Otherwise, the VLR forwards the call request to its HLR which verifies whether the called MU's is roaming in its covering area but under different VLR or in the covering area of another HLR. Then this HLR forwards the call request to the appropriate network.

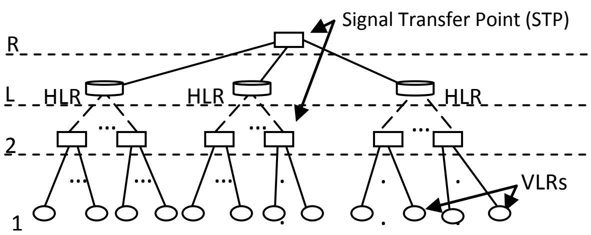

Fig. 2: Multi HLR architecture

Location update procedure: This architecture distinguishes between several types of MU moves: intra-VLR move, intra-HLR move and inter-HLR move. The location update scenarios associated with these moves are as follows -

Intra-VLR move: This move occurs when the MU moves between two LAs that belong to the same VLR. The MU's location profile is then updated only at the VLR level.

Intra-HLR move: The movement of MU between two VLRs which are in the serving area of the same HLR. The steps of intra-HLR movement can be understood from the following fig. 3:

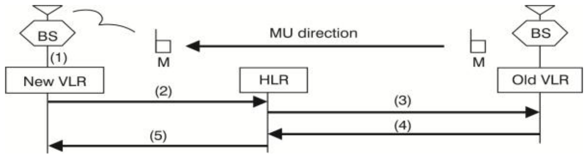

Fig. 3: Location update procedure of an intra-HLR move

Inter-HLR move: The movement of MU between Las of two VLRs which are not in the serving area of the same HLR, i.e. each is served by a different HLR. There are total three possibilities:

(a) The MU moves from the SA of resident HLR and enters the SA of another HLR. This new HLR becomes the MU's serving HLR.

(b) The return of MU to SA of resident HLR from a SA of another HLR.

(c) The movement of MU is between two HLRs and no HLR is MU's resident HLR.

The main steps of this scenario are described as following:

Step 1: The MU enters a new LA and registers with the VLR of this LA.

Step 2: If the case (a) prevails, then:

i). The VLR of the new LA sends a location update request to its HLR. This HLR becomes the serving HLR for the MU (serving HLR 1 in Figure 5).

ii). The serving HLR sends a location update request to the MU's resident HLR.

iii). The resident HLR sends a registration cancellation request to the old VLR.

iv). The old VLR sends the registration cancellation acknowledgment to the resident HLR.

v). Upon receiving this acknowledgment, the resident HLR updates the profile of the MU and sends a location update acknowledgment to the serving HLR.

vi). The serving HLR, in its turn, sends a registration acknowledgment to the current VLR of the MU. Then this VLR starts to serve the MU.

Step 3: If the case (b) prevails, then:

i). The MU's new VLR sends a location update request to its HLR, which is the MU's resident HLR.

ii). The resident HLR forwards this request to the MU's old serving HLR.

iii). The old serving HLR sends a registration cancellation request to the MU's old VLR.

iv). The old VLR acknowledges the registration cancellation request.

v). The old serving HLR forwards the acknowledgment to the MU's resident HLR then it deletes the MU profile. The resident HLR updates the MU profile.

vi). The resident HLR, in its turn, sends a location update acknowledgment to the VLR of the new LA, which starts, in its turn, serving the MU.

Step 4: If the case (c) prevails, then:

i). The VLR of the new LA sends a location update request to its HLR. This HLR becomes the MU's new serving HLR.

ii). The new serving HLR sends a location update request to resident HLR. The resident HLR updates the MU profile to indicate its new serving HLR.

iii). The MU's resident HLR, in its turn, sends a registration cancellation request to the MU's old serving HLR.

iv). The old serving HLR forwards the cancellation request to the MU's old VLR.

v). The old VLR sends a cancellation acknowledgment to the old serving HLR.

vi). Upon receiving this acknowledgement, the old serving HLR forwards the acknowledgement to the MU's resident HLR and deletes the MU profiles.

vii). The resident HLR acknowledges the location update to the new serving HLR which updates the MU profile to indicate the VLR of its new LA.

viii). The new serving HLR sends a location update acknowledgment to the new VLR. Upon receiving this acknowledgment, the new VLR starts serving the MU.

The analytical model of this architecture can be understood from a hierarchical tree of HLRs, VLRs and Signal Transfer Points (STPs) as shown in figure 2. STP is a switch on the SS7 network [15] responsible for routing of signaling messages from an MSC based on their destination addresses. The layer R contains the root node and the layer 1 contains the leaf nodes. In the current HLR/VLRs scheme, the network database, HLR, is situated on the only node of layer R and the VLRs are installed on the leaf nodes. Here, the HLRs are installed on the nodes of layer L (1<L<R), while the VLRs remain installed on the leaf nodes. The following terms are used in making performance analysis of location updating by using explicit and implicit de-registration:

$m_{x,y}$ - Layer of the closest common node to LA x and LA y.

p - Probability that the MU move is intra-VLR.

α - Probability that the MU move is inter-HLR.

β - Probability that the MU's resident HLR is involved in the inter-HLR move, i.e., the MU leaves or returns to its resident HLR covering area.

n - New LA of the MU.

a - Old LA of the MU.

P(**$m_{x,y}$**=i) is defined as the probability that the closest common node to LA x and LA y is in layer i. This probability can be calculated by the following equation.

$$P(m_{a,n}=i) = p(1-p)^{i-1} \text{ for } i = 1,2\ldots\ldots\ldots R-1 \qquad (1)$$
$$(1-p)^{i-1} \text{ for } i = R$$

The costs of various operations used in this analysis are denoted as follows:-

T (i, j) - Cost of transmitting a message over a link between two adjacent layers i and j.

C_m(i) - Cost of accessing or updating a database in layer i.

$M_{Explict}$ - Estimated cost of a location update in the multi HLR model using explicit de-registration scheme.

$M_{Polling}$ - Estimated cost of a location update in the multi HLR model using polling de-registration scheme.

$M_{Time-out}$ -Estimated cost of a location update in the multi HLR model using Time-out de-registration scheme.

M_{Group_dereg} - Estimated cost of a location update in the multi HLR model using Group de-registration scheme.

The estimated cost of a location update in the Multi HLR architecture with explicit de-registration strategy is given by equation 2. The first part illustrates the cost of the location update procedure of an intra-VLR move and intra-HLR move. The second part of this equation illustrates the scenario after an inter-HLR move. T(1,L) = T(1, 2) + T(2, 3)+…+ T(L-1, L) is equal to the cost of traversing links between a node of layer 1 (i.e., VLR) and the node of layer L (i.e., where an HLR is located in the multi HLR scheme). This cost is multiplied by 4 because, when a signaling message is sent from a VLR to the HLR, the latter sends a similar message to the old VLR.

$$M_{Explicit} = P(m_{a,n}=1) \times C_m(1) + \sum_{i=2}^{L} P(m_{a,n}=i) \times \{2C_m(1) + C_m(L) + 4T(1,L)\} + \propto \left\{ 2C_m(1) + C_m(L) + 4T(1,L) + \sum_{i=L+1}^{R} P(m_{a,n}=i) \times \begin{bmatrix} \beta \times \left(\sum_{j=L}^{i-1} 4T(j,j+1) + C_m(L)\right) + \\ (1-\beta) \times \left(\sum_{j=L}^{i-1} 8T(j,j+1) + 2C_m(L)\right) \end{bmatrix} \right\}$$

where $\propto = \sum_{i=1}^{L} P(m_{a,n}=i)$ **(2)**

This cost is multiplied by 4 because, when a signaling message is sent from a VLR to the HLR, the HLR sends a de-registration message to the old VLR. By adding the cost of the acknowledgment from the old VLR to the HLR and then from the HLR to the current VLR, we can justify the 4T(1,L). Similar analysis applies on transmitting costs in second part of the equation. The term which gets multiplied by β again contains 4T(j,j+1) which is the transmission cost of signaling message traversing to and fro between two HLRs(one resident and one non-resident) via STP. This transmission cost becomes 8*T (j,j+1) when MU makes inter-HLR movement between two (old and new serving) HLRs and these HLRs also interact with master or resident HLR via STP.

3. MODIFIED MULTI-HLR ARCHITECTURE WITH IMPLICIT DE-REGISTRATION STRATEGIES

Before modifying analytical model discussed in previous section, we need to understand the concept of implicit de-registration policies [11], [18]. In *implicit de-registration* schemes, to-and-fro signaling messages between HLR and the old VLR are avoided which results in saving the message transmission cost. So, implicit de-registration scheme(s) are more efficient than the explicit de-registration scheme. If an MU leaves the Registration Area (RA) of a VLR, it should remove its invalid entry from the database. To remove the invalid entries from the old VLR, methods of ascertaining the departure of MU from RA of old VLR to a RA of new VLR are required. For this purpose, various de-registration schemes [7], [12] were suggested by researchers. The schemes considered for modifying registration policy of the Multi-HLR architecture are - polling, timeout and group de-registration schemes. By making application of these policies, the reverse signal from old VLR, which is to be transmitted as an acknowledgement of explicit de-registration of MU from old VLR, is eliminated. This reduction in transmission cost makes a signification contribution in improving the overall cost of location update. The following details explain the contribution made by each of these three policies in reducing the location updation cost due to this modification.

In polling de-registration scheme, the BSC belonging to current VLR periodically polls MU to ensure its presence in its RA by sending alert messages through BTS. The acknowledgement sent by MU in repose, confirms its presence in RA of current VLR. Failing to receive acknowledgement, the VLR assumes that it has moved out of its RA.

Application of polling de-registration scheme concept to analytical model presented in previous section makes following changes in estimated cost calculation of location update:

$$M_{polling} = \left[P(m_{a,n}=1) \times C_m(1) + 2T(0,1)\right] + \sum_{i=2}^{L} P(m_{a,n}=i) \times \{2C_m(1) + C_m(L) + 2T(1,L) + 2T(0,1)\} + \propto \left\{ 2C_m(1) + C_m(L) + 2T(1,L) + 2T(0,1) + \sum_{i=L+1}^{R} P(m_{a,n}=i) \times \begin{bmatrix} \beta \times \left(\sum_{j=L}^{i-1} 2T(j,j+1) + C_m(L)\right) + \\ (1-\beta) \times \left(\sum_{j=L}^{i-1} 4T(j,j+1) + 2C_m(L)\right) \end{bmatrix} \right\} \qquad \textbf{(3)}$$

In the first part of the equation 3, the cost of location update is due to intra-VLR move. Here, in comparison to equation 2, additional term T(0,1) having cost 1 is added as transmission cost of polling between VLR and MU. This term has also contributed in terms related to inter-VLR and inter-HLR moves respectively. Further since we follow implicit de-registration over here so in remaining terms, the transmission cost is taken as 2T(1,L) as opposed to 4T(1,L) taken in equation 2 since no reverse signaling takes place from old VLR's side. As MU is polled while in RA, the old VLR is updated about its absence i.e. MU is deregistered. So, database updation of old and new VLR contributes to the term $2C_m(1)$ in above equation.

If we apply, time-out de-registration policy, MU informs periodically to its RA's VLR about its presence. Due to this the term 2T(0,1) will become only T(0,1) as one-way transmission from MU's side. Rest of concepts related to database updation cost remains similar to equation 3. So, Time-out de-registration scheme can be formulated as:

$$M_{Time-out} = \left[P(m_{a,n} = 1) \times C_m(1) + T(0,1)\right] + \sum_{i=2}^{L} P(m_{a,n} = i) \times \{2C_m(1) + C_m(L) + 2T(1,L) + T(0,1)\} + \propto \Bigg\{ 2C_m(1) + C_m(L) + 2T(1,L) + T(0,1) + \sum_{i=L+1}^{R} P(m_{a,n} = i) \times \begin{bmatrix} \beta \times \left(\sum_{j=L}^{i-1} 2T(j,j+1) + C_m(L)\right) \\ +(1-\beta) \times \left(\sum_{j=L}^{i-1} 4T(j,j+1) + 2C_m(L)\right) \end{bmatrix} \Bigg\} \quad \textbf{(4)}$$

It is clear from equation 4 that the estimated cost of location update in time-out strategy is less than polling strategy.

The third implicit de-registration scheme considered for multi HLR model is Group de-registration. As per this scheme, when an MU leaves one RA and enters into another RA belonging to the different VLR, new VLR sends registration request to the HLR for the MU. On receiving the request, HLR puts the MU's id into a list called old mobile list (OML) of old VLR. This list contains information about all those MUs which have left the RA of a particular VLR. The HLR maintains one such list for each of its associated VLR. Therefore, it must be having one OML for new VLR also. When HLR sends registration confirmation request as an acknowledgement to new VLR, it also sends the new VLR's OML information and empties its OML. By this way, each VLR is updated about all of its departed MUs through the information contained in its corresponding OML at HLR. Based on this information, the receiving VLR removes service profiles of these departed MUs. It is worth to mention that this updation information about old departed MUs from HLR to VLR comes only when a new MU enters in RA of the VLR and the VLR contacts HLR for new MU's location registration. So this de-registration strategy rely on mobility of MU rather that time.
By applying, the above group de-registration concept, the estimated location update cost can be evaluated as:

$$M_{Group\_dereg} = \left[P(m_{a,n} = 1) \times C_m(1)\right] + \sum_{i=2}^{L} P(m_{a,n} = i) \times \{2C_m(1) + 3C_m(L) + 2T(1,L)\} + \propto \Bigg\{ 2C_m(1) + 2C_m(L) + 2T(1,L) + \sum_{i=L+1}^{R} P(m_{a,n} = i) \times \begin{bmatrix} \beta \times \left(\sum_{j=L}^{i-1} 2T(j,j+1) + 2C_m(L)\right) + \\ (1-\beta) \times \left(\sum_{j=L}^{i-1} 4T(j,j+1) + 3C_m(L)\right) \end{bmatrix} \Bigg\} \quad \textbf{(5)}$$

In equation 5, the first part of location update is in intra-VLR move. The next move depicts inter-VLR move. Here the cost $C_m(L)$ is multiplied by 3 because upon receiving registration request from new VLR, the HLR first puts the information related to old VLR into its corresponding OML. It then registers MU with new VLR and along with registration confirmation acknowledgment, sends the fetched information from OML of new VLR. When the MU's move is inter-HLR, having involvement of its master HLR as old or new VLR, the HLR of new VLR is updated/ accessed twice- first time for registration updating of MU with new VLR and second time, to fetch the information contained in the OML of new VLR to send it to new VLR along with acknowledgement. The old HLR is also consulted by new HLR to inform and update it about the departure of its MU from its SA. This old HLR is again updated twice- first time, to put departed MU's information into OML of old VLR and then for deleting service profile related information of moved MU. In inter-HLR move without involving its master HLR as old or new HLR, requires total five database updations. The new HLR is updated twice as in previous case. It then contacts master HLR to update it for MU's new location. The old HLR is also updated twice as happened in previous inter-HLR movement case.

4. RESULTS

We present the numerical results of the comparison between implicit de-registration policies (polling, time-out and group registration) and explicit de-registration policies of modified Multi-HLR architecture. Various values of R, L and probability p are considered for evaluation. The results in figure 4 and figure 5 show the estimated location update cost in explicit as well three implicit de-registration strategies for different values of R and L. It becomes clear from these figures that time-out implicit strategy gives the best result.

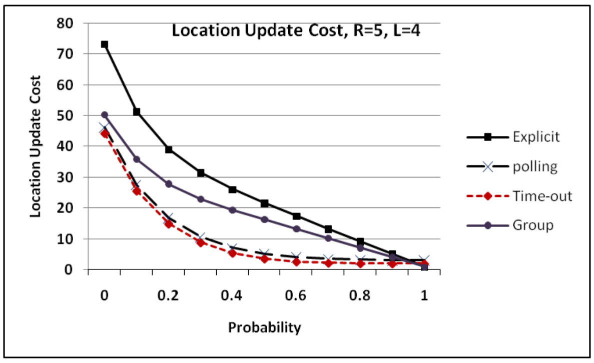

Fig. 4

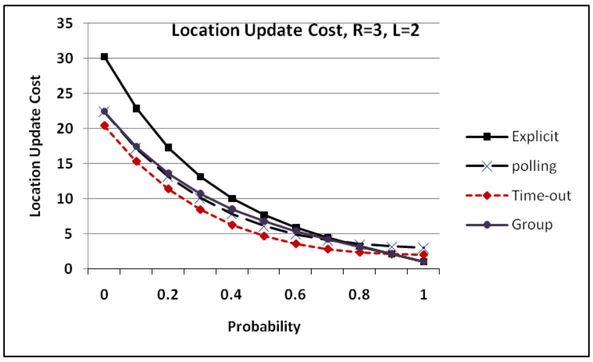

Fig. 5

The location update costs in figure 4 are smaller than of figure 5. This happens due to less number of layers i.e. less transmission cost due to less number of intermediate STPs in HLR-HLR and HLR-VLR interactions. Since probability along x-axis is the probability of intra-VLR move so at p=1, group de-registration outperforms the other two implicit techniques as the MU polling and Time-out signaling prove costlier.

The relative analysis for R=5, L=4 is also carried out and is shown in figure 6. It clearly indicates the consistent performance of group de-registration strategy against explicit de-registration. Although, still time-out de-registration proves to be better than other two schemes, especially in cases where moves are not local.

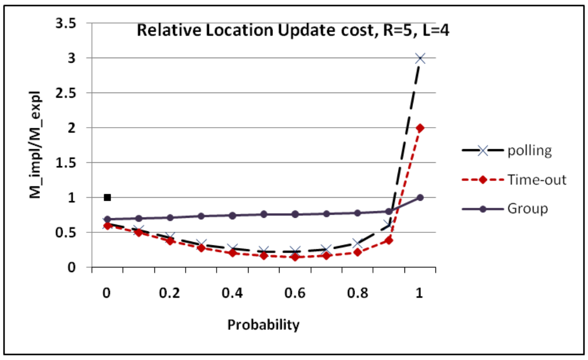

Fig. 6

5. CONCLUSION

Analysis made in this paper shows that the location updation cost calculated using implicit deregistration proves to be better in all cases than explicit de-registration. Although group de-registration is not performing at par with polling and time-out de-registration strategies but the ever increasing excessive MU mobility promises a better performance of this scheme in comparison to other implicit and explicit de-registrations as it depends on mobility rather than time. Finally, we conclude that this modified multi-HLR model is potentially beneficial for large classes of users and can contribute to substantial reduction in location management costs of the cellular networks. .

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