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# PERFORMANCE ANALYSIS OF IMPLICIT DE-REGISTRATION STRATEGIES FOR SINGLE AND MULTI-HLR ARCHITECTURE

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***ABSTRACT***

*Location Management is a key issue in PCS networks. De-registration is one of major steps in location management which contributes significantly in mobile location update cost. Attempts have been made by researchers to reduce the location management cost by introducing the concept of implicit de-registrations and by modifying the single-HLR (HLR-VLR centralized) architecture to multi-HLR. This paper attempts to modify the Multi-HLR architecture's explicit de-registration strategy by using two types of implicit de-registration strategies, namely-polling and time-out and shows the impact of this modification on location update cost of mobile users. To evaluate the overall reduction in location update cost due to this modification, it considers signle-HLR architecture with same implicit de-registration strategies as a reference and makes a comparative analysis.*

***KEYWORDS:*** *Location Management, Single- HLR, Multi-HLR, Explicit De-registration, Implicit De-registration.*

## I. INTRODUCTION

The requirement of continuous location trapping of MU has made it desirable to have the efficient location management schemes [1], [2], [3], [4], [5], [6], [8], [12], [13], [14], [15], [16], [20], [21] so that the overheads involved in location updations in VLR and HLR databases can be minimized. One such attempt is the modification of registration (location update) strategy. This 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* [7], [12], [14], [15]. The explicit de-registration incurs a signalling over head penalty as every time when MU gets registered with new VLR, its attachment to previous VLR is required to be cancelled. In order to avoid this, the *Implicit de-registration* concept is used where MU is not required to be de-registered explicitly from its previous VLR upon its movement to a new VLR's area. Various schemes for implicit de-registration [7], [9], [10], [11] have appeared in mobile research area that attempt to reduce location updation cost. In an attempt to reduce HLR and VLR database updation cost of registration process, two of the implicit de-registration strategies called polling de-registration scheme and time-out de-registration scheme are considered in this paper. This paper proposes a modified multi HLR architecture [17], [18], [20] by making application of polling and time-out implicit de-re-registration schemes. By applying same two implicit de-registration schemes to single-HLR mobile network like GSM, IS-41, this paper presents a performance comparison of single and multi HLR architectures having implicit de-registration and makes an analysis of the performance outcomes.

The remaining part of this paper is organized as follows: section 2 discusses single-HLR architecture and the concept of two implicit de-registration strategies, namely Polling and Time-out. Section 3 presents an overview of multi-HLR architecture. This is followed by section 4 that presents analytical models for multi and single HLR architectures. The comparative performance analysis of these two models with polling and time-out implicit de-registration strategies is presented in section 5 and section 6 presents the results and conclusions of this study.

## II. SINGLE-HLR ARCHITECTURE & IMPLICIT DE-REGISTRATION TECHNIQUES

This is the current model used in GSM, IS-41 like standards [12], [13], [22], [23], [24]. The two-tier system of Home Location Register (HLR) and the Visitor Location Register (VLR) databases is used for the location management. 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. To facilitate the tracking of a moving MU, a PCS network is partitioned into many Registration Areas (RAs). 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 tens or 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 as shown in Fig. 1. For convenience, we call the HLR that contains the permanent data information of an MU the *master* HLR for the MU. The SA that is associated with the master HLR is called the *master* SA for the MU.

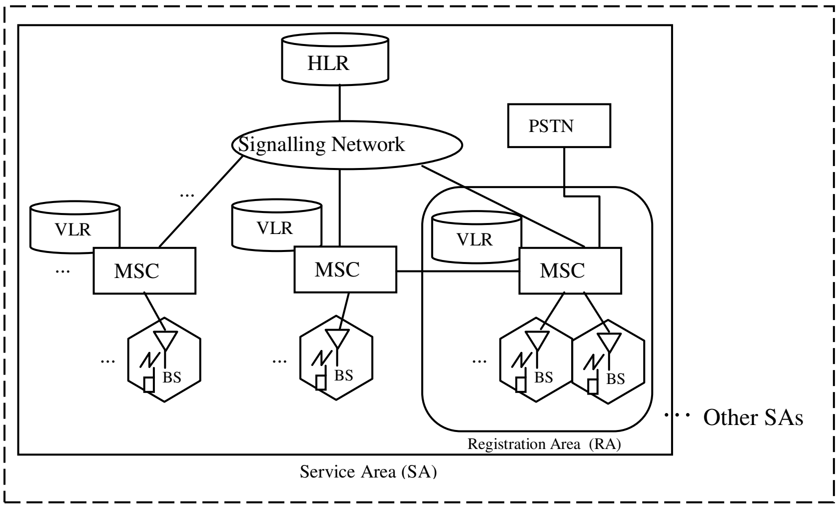


**Figure 1:** HLR-VLR Architecture

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.

The location update process of MU can be understood from fig. 2.Whenever a MU moves to a new RA of different VLR, it sends (1) a location update message to the nearby base station.

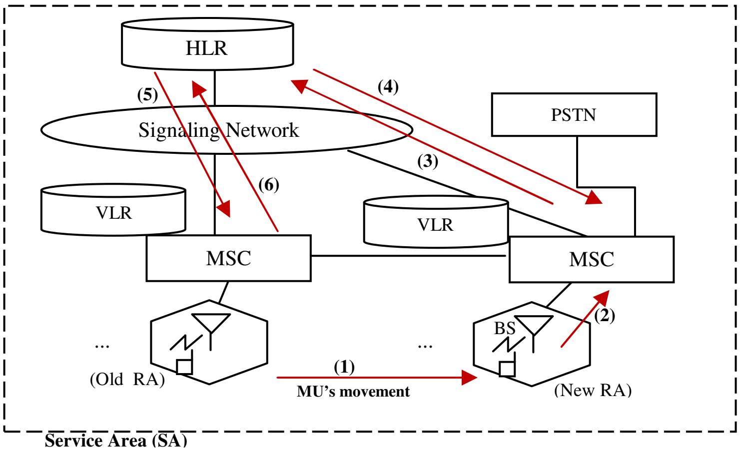


**Figure 2:** Location Update Process

(2) The base station forwards this message to the new serving MSC. (3) The new MSC updates its associated VLR, indicating that the mobile terminal is now residing in its services area and sends a location registration message to the HLR. (4) The HLR sends a registration acknowledgment message to the new MSC/VLR together with a copy of the subscriber's user profile. (5) The HLR sends a registration cancellation message to the old MSC/VLR. (6) The old MSC removes the record for the mobile terminal at its associated VLR and sends a cancellation acknowledgment message to the HLR. Step (5) and (6) of fig. 2 indicate explicit de-registration. In order to avoid this signaling overhead, the concept of implicit de-registration strategies like polling and time-out [9], [14] can be applied.

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. The acknowledgement sent by MU in repose, confirms its presence in RA of current VLR. Failing to receive confirmation acknowledgement, the VLR concludes that the polled MU has moved out of its RA. In case of time-out implicit de-registration, MU informs periodically to its VLR about its presence. If no information from MU's side is received by VLR, it concludes about MU's departure from its RA.

Due to periodical polling and time-out signaling, the old VLR concludes MU's departure from its RA easily. Therefore, no explicit exchange of signal (step 5 and 6) is required.

## III. MULTI-HLR 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 and poses a heavy signaling load on network. This problem leads us to consider use the current (serving) HLR of an MU for the location management to improve the system performance. The Multi-HLR Architecture [5], [17], [18], [20] as shown in fig. 3 employs several HLRs instead of one master HLR used in location management of conventional mobile architecture.

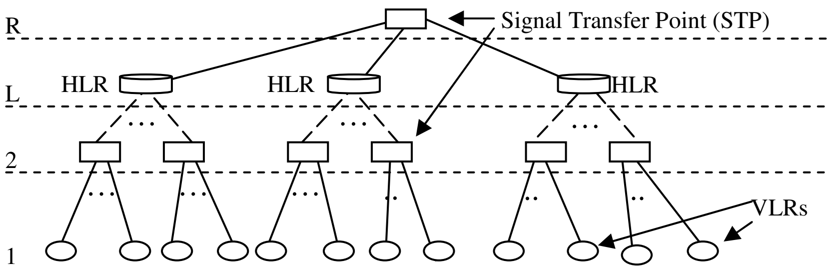


**Figure 3:** Multi HLR architecture

As per this model, 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. STP is a switch on the SS7 network [19] responsible for routing of signaling messages from an MSC based on their destination addresses.

**Location update procedure:** The location update scenarios associated with MU's moves are as follows -

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

**Intra-HLR move:** This move occurs when the MU moves between two RAs served by two different VLRs but within the covering area of the same HLR. Its main steps, shown in Figure 4, are as under:

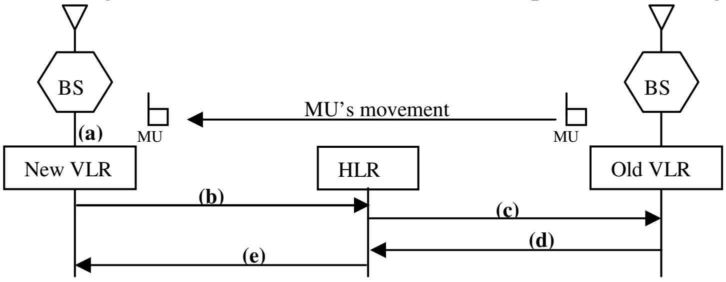


**Figure 4:** Location update procedure of an intra-HLR move

a) The MU moves to a new RA served by a different VLR and registers with this VLR.
b) The VLR of the new RA sends a location update request to its HLR.
c) The HLR, in its turn, sends a location cancellation request to the VLR of the old RA.
d) The old VLR sends a location cancellation acknowledgment to the HLR.
e) Upon receiving this acknowledgment, the HLR acknowledges the location update to the new VLR, which instructs the new RA to start serving the MU.

**Inter-HLR move:** This move occurs when the MU between two RAs are served by two VLRs that belong to two different HLRs. In this context, three cases are studied:

a) The MU leaves the covering area of its resident HLR and enters the covering area of another HLR. This new HLR becomes the MU's serving HLR.

b) The MU returns to its resident HLR, i.e. the MU returns to the covering area of its resident HLR from the covering area of another HLR.

c) The MU moves between two distinct HLRs that are different than its resident HLR.

The main steps of this scenario are described as following:

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

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

i). The VLR of the new RA sends a location update request to its HLR. This HLR becomes the serving HLR for the MU (serving HLR 1 in Figure 4).
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 RA, which starts, in its turn, serving the MU.

**Step 4:** If the case (c) prevails, then:
i). The VLR of the new RA 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 RA.
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.

# IV. ANALYTICAL MODELS FOR MULTI AND SINGLE HLR ARCHITECTURES

The analytical models for single and multi HLR [17], [18] architectures can be understood from a hierarchical tree of HLRs, VLRs and Signal Transfer Points (STPs) as shown in figure 3. The layer R contains the root node and the layer 1 contains the leaf nodes. In the single HLR architecture, the network database, HLR, is the only node of layer R and the VLRs are installed on the leaf nodes while in case of multi HLR architecture, 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 polling and time-out implicit de-registration strategies in single as well as multi HLR architectures.

$\mathbf{m}_{x,y}$ - Layer of the closest common node to RA x and RA y. **p** - Probability that the MU move is intra-VLR. $\alpha$ - Probability that the MU move is inter-HLR. $\beta$ - 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 RA of the MU. **a** - Old RA of the MU. P($\mathbf{m}_{x,y}$=i) is defined as the probability that the closest common node to RA x and RA y is in layer i.

This probability can be calculated by the following equation.

$$P(m_{a,n}=i) = \begin{cases} p(1-p)^{i-1} & \text{for } i = 1,2\ldots\ldots\ldots..R-1 \\ (1-p)^{i-1} & \text{for } i = R \end{cases} \quad (1)$$

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.

$\mathbf{C_m}$(i): Cost of accessing or updating a database in layer i.

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

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

$\mathbf{M_{Polling\_SHLR}}$ : Estimated cost of a location update in the single HLR model using polling de-registration scheme.

$\mathbf{M_{Time\text{-}out\_SHLR}}$ : Estimated cost of a location update in the single HLR model using Time-out de-registration scheme.

## 4.1 Multi HLR analytical model

Let's consider multi HLR analytical model first. The estimated cost of a location update in the Multi HLR architecture with polling 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 2 instead of 4 because, when a signaling message is sent from a VLR to the HLR, no reverse signaling takes place between HLR and the old VLR as opposed to explicit de-registration.

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

Here, an 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 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 eq. 2. Therefore, Time-out de-registration scheme can be formulated as:

$$M_{TIME\text{-}OUT\_MHLR} = \left[P(M_{A,N}=1)\times C_M(1) + T(0,1)\right] + \sum_{I=2}^{L} P(M_{A,N}=I)\times\{2C_M(1)+C_M(L)+2T(1,L)+T(0,1)\} + \propto \left\{ 2C_M(1)+C_M(L)+2T(1,L)+T(0,1) + \sum_{I=L+1}^{R} P(M_{A,N}=I)\times \left[ \begin{array}{c} B\times\left(\sum_{J=L}^{I-1} 2T(J,J+1)+C_M(L)\right) \\ +(1-B)\times\left(\sum_{J=L}^{I-1} 4T(J,J+1)+2C_M(L)\right) \end{array} \right] \right\} \quad (3)$$

It is clear from eq. 3 that the estimated cost of location update in time-out strategy is less than polling strategy.

### 4.2 Single HLR analytical model

In current GSM and IS-41 standards, though we have multiple HLRs governing their associated SAs, we use single HLR name because in every case of inter-HLR location update and location search, always the master HLR is consulted or updated by new VLR, that may even belong to foreign SA. The local HLR of serving SA does not play any role in location updation and location searching. Taking the references of fig. 3 of multi HLR, it is considered that no HLR to HLR interaction takes place (and hence we consider only one HLR at layer R), therefore there is no layer of intermediate HLRs as defined layer L and in every location update, only master HLR plays a role. Therefore, in single HLR analytical model, the estimated cost of location update in Polling de-registration can be formulated as:

$$M_{polling\_SHLR} = \left[P(m_{a,n}=1)\times C_m(1) + 2T(0,1)\right] + \sum_{i=2}^{R} P(m_{a,n}=i) \times \{2C_m(1)+C_m(R)+2T(1,R)+2T(0,1)\} \quad (4)$$

The first part of Eq. (3) is the cost of location update in intra-VLR move. The second part illustrates the scenario after an inter-VLR move. T (1, R) =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 R (i.e., where an HLR is located). This cost is multiplied by 2 because old VLR is not required to send an acknowledgement in response to the HLR and finally to new VLR. The periodical message transmission cost can be calculated as: T (0, 1) =1. The cost of polling the MU at VLR end will be 2*T (0, 1) =2 as link is being traversed twice.

In the same way in timeout de-registration strategy message transmission cost will be T(0,1)=1 only and the estimated cost can be given as equation 5.

$$M_{Time-out\_SHLR} = [P(m_{a,n} = 1) \times C_m(1) + T(0,1)] + \sum_{i=2}^{R} P(m_{a,n} = i) \times \{2C_m(1) + C_m(R) + 2T(1,R) + T(0,1)\} \quad (5)$$

## PERFORMANCE ANALYSIS

The performance analysis of polling de-registration for Multi HLR and Single HLR is made by taking different values of probability and the corresponding location update cost for different values of R and L. It can be seen in fig. 5 that when R=5 for both architectures and L=2, 3, 4, the polling techniques applied in multi HLR perform better than single HLR.

When p=1, the updation cost becomes same; this is due the fact that the move is in intra-VLR and therefore location update is confined to current VLR only in both single as well as multi HLR models. Therefore, the second term becomes zero in eq. 2, and 4 and update cost is found same in both models. When L=2 or low, the STP nodes contribute more in transmission cost due to increased number of intermediate layers between layer L and layer R (fig.3). Therefore, the location update cost becomes slightly higher relative to the larger values of L in multi HLR architecture, however, still it is lower than single HLR polling de-registration model.

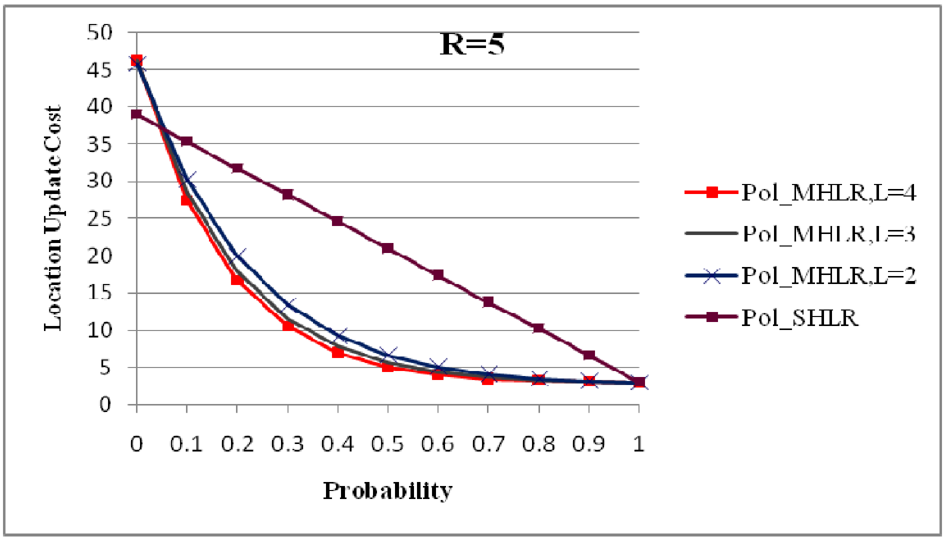


Figure 5

Similar analysis has been carried out for different values of L and probability p for time-out de-registration scheme applied in both architectures in fig. 6. Here also, the time-out implicit de-registration strategy when applied to multi-HLR proves to be better than its application in single HLR architecture. Again, this scheme in both models converges to the same value when p=1. This is because at p=1, the move of MU becomes local i.e. confined to RA of the same VLR, therefore there is no role left to be played by master as well as serving HLR so update cost becomes same in single as well as multi HLR models.

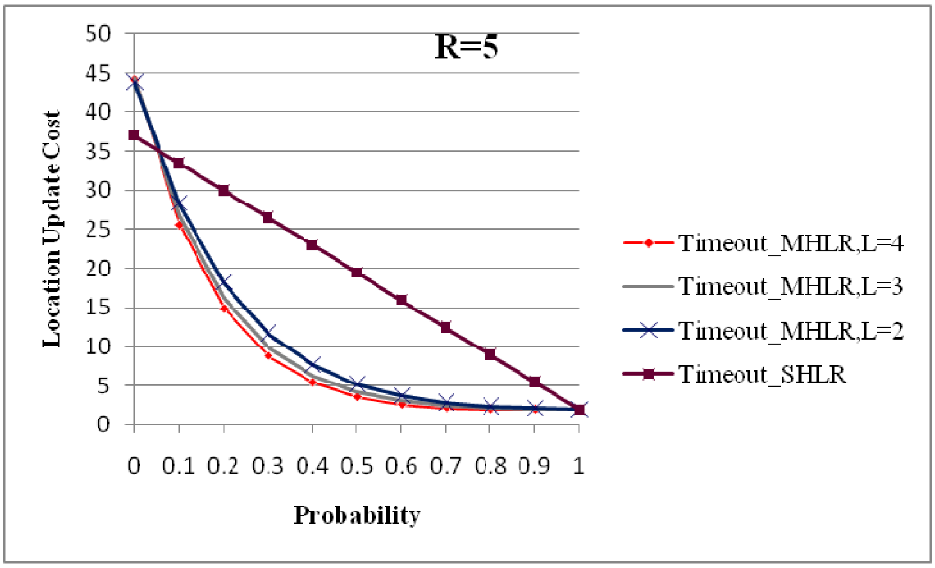


Figure 6

In order to get an overall picture of efficiency of time-out de-registration over polling de-registration in single as well as multi HLR architectures, the value of R and L are taken as 3 and a graph is drawn as fig. 7.

This is the case when master and serving HLRs belong to same layer without having any STP at higher layer. Different values of p are taken along x-axis while y-axis shows the values of $M_{polling\_MHLR}$/ $M_{polling\_SHLR}$ and $M_{Tme-out\_MHLR}$/ $M_{Time-out\_SHLR}$ . This ratio is depicted by a general term M_MHLR/M_SHLR along y-axis.

This can be seen from fig. 7 that the time-out de-registration strategy out performs the polling de-registration strategy.

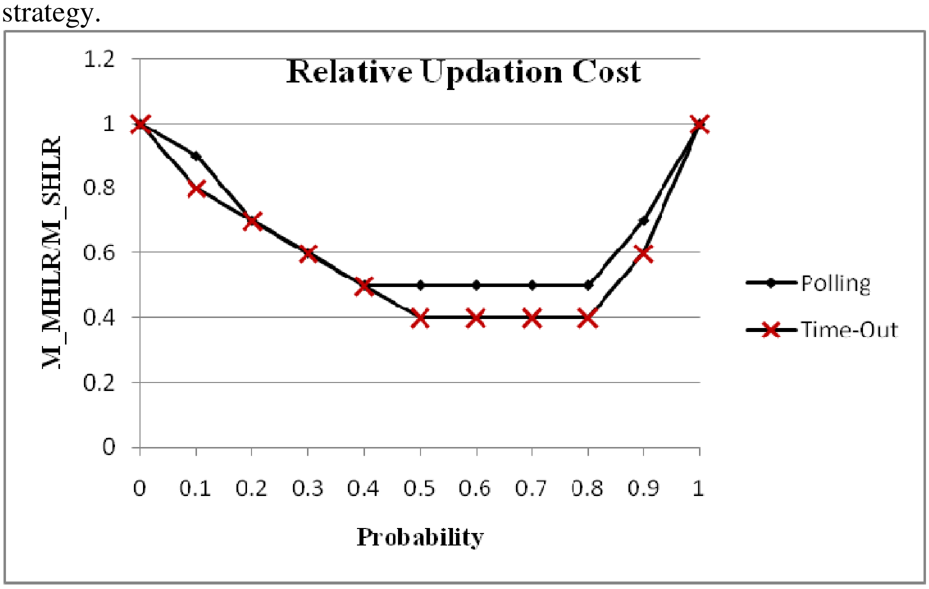


Figure 7. When **R=3, L=3**

We can also conclude that both architectures give similar results for moderate values of p in each de-registration scheme. Since the values of M_MHLR/ M_SHLR corresponding to different probabilities in both strategies remain <=1, therefore, it is concluded that polling and timeout de-registration strategies give better result in multi HLR model as compared to single HLR model. On the basis of comparative analysis made in fig. 5, 6 and 7, it can be stated that the best combination is time-out implicit strategy with multi HLR architecture as it reduces location update cost of mobiles and gives the best result.

## V. CONCLUSION

Analysis made in this paper shows that the location updation cost in case of multi HLR architecture calculated using implicit deregistration proves to be better in both polling as well as time-out cases than single HLR architecture. In context to multi HLR architecture, the time-out strategy performs better than polling strategy. Finally, we conclude that the multi-HLR model with one of the implicit de-registration strategies 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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