Location Tracking in IP-based Mobile Networks

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Abstract

This paper presents a mobility tracking mechanism for IP-based networks. The Motivation behind proposed mechanism is that most of the mobile hosts tend to move locally within a limited geographical area. We have observed that a recently proposed mobility management scheme, called Dynamic hierarchical Mobile IP (DHMIP) performs better than MIP in terms of saving in signaling cost. But, it is not suitable for low call-to-mobility ratio (CMR). Our proposal provides significant improvement over DHMIP for low CMR values, typically less than 1. We use random-walk mobility model and analyze the results using continuous-time Markov chain. The result has been compared with MIP and DHMIP.

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Key Words: Location tracking, Random-walk model, Distributed Architecture, Markov chain.

1. Introduction

The Mobile IP (MIP) [1] is considered as the starting point towards the emergence of wireless Internet era. It is an extension of its wireline counterpart, the IP, with two additional mobility agents namely the home agent (HA) and the foreign agent (FA). The HA is located at the home network of the mobile hosts (MHs) and assigns a permanent IP address to them which remains unchanged during the move. Similarly, each visited or foreign network has a FA which assigns a temporary IP address called as care-of-address (CoA) to the MHs. This CoA is valid only as long as the MH resides in the coverage area of the FA. When the MH changes its point-of-attachment (PoA), it attains a new CoA from the visited FA. The HA is informed about the new CoA after every change in PoA of the MH. The HA and the FA maintain the global and the local location databases of the MHs, respectively and establish the requested communications based on the most recent location information in the two databases. All the data packets are routed via the HA to the visited FA and then, finally, to the intended MH.

The multimedia traffic is expected to be around 90% of the entire communications traffic by the year 2015. It is, also, forecast that the cell sizes will radically dwindle to accommodate the increasing mobile Internet population and to enhance the channel speed, in future [2]. This will significantly reduce the subnet residence time of the users resulting in frequent handovers from one subnet to the other. This incredible scenario puts forth a great challenge for the mobility management in future IP-based mobile networks.

The MIP is an elegant solution for slow mobile users which rarely change their PoA. But, for the hosts with high mobility and roaming far distant from the HA, MIP contributes to huge signaling cost and longer handover delay. To this end, some micro-mobility protocols like hierarchical Mobile IP (HMIP), Cellular IP and HAWAII attempt to manage the mobility of the users locally so that the signaling cost can be reduced. These protocols work in conjunction with MIP. They rely on the fact that the entire network is divided into several regions or domains, each of them consisting of a group of FAs or base stations. Each region/domain has a centralized gateway or a domain router through which underlying FAs or base stations connect the MHs to access the Internet. For the details of these micro-mobility protocols and their comparisons, the interested may refer to [3-8].

In this paper, we present a new micro-mobility protocol wherein the mobile hosts use the neighboring subnet numbers to form the overlapping location areas and the paging areas. The proposed scheme is completely distributed and dynamic in the sense that any subnet agent can have the gateway and the paging functionalities. The scheme uses the subnets of the arbitrary shape for the analysis purposes. Analytical analysis has been carried out to compare the signaling cost with Mobile IP.

The Rest of the paper is organized as follows: section 2 presents an overview of the current related works; section 3 describes the mobility-tracking mechanism; section 4 gives the continuous-time Markov chain model and its analysis; section 5 presents the performance result and comparison with MIP and DHMIP, and, finally, section 6 concludes the paper.

2. Related work

During the last decade, the mobility management in IP-based mobile networks has been a challenging area for the researchers. IDMP [9] provides two level hierarchy for the MHs. A mobility agent (MA) handles the mobility within a domain, and a subnet agent (SA) holds this responsibility at a subnet level. The basic principle is similar to HMIP. In [10], authors incorporate the concept of regional registration and propose a novel distributed and dynamic regional location management for mobile IP. The regional network boundaries are dynamically adjusted according to the up-to-date mobility and traffic load for each terminal. The scheme is fully distributed wherein each FA can act as an FA or GFA (Gateway Foreign Agent) depending on the user mobility. When an MN enters a regional network, the first FA of the subnet acts as the GFA of this regional network. The responsibilities of the GFA are similar as in HMIP. Other FAs, except than GFA, in the regional network act as the general foreign agents for the MH. The number of FAs underlying a GFA is optimized for each MH to minimize the total signaling traffic. In DHMIP [11], the new FA sends a location pointer to the previous FA till a certain movement threshold is reached. Once the threshold is reached, the MH requests for a registration with the HA. The threshold is computed based on packet arrival rate, subnet crossing rate etc.

3. Proposed micro-mobility protocol

3.1 System description

This section introduces a distributed and mobility-tracking mechanism for IP-based mobile networks. In [10], we have used a regular hexagon network architecture for our analysis, but in real situations, the subnets have irregular shapes, and, therefore, the number of neighboring subnets may vary from one subnet to another [11, 12]. In this paper, we use an arbitrary configuration of the network, as shown in fig. 1, wherein the number of neighboring subnets may be varying. We assume that each subnet in the network is associated with a mobility agent, called subnet agent (SA) and is directly connected to the Internet.

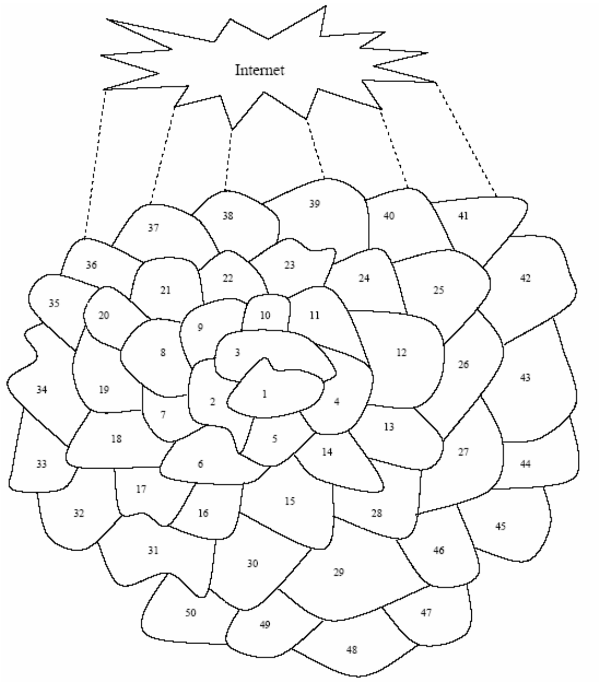

Fig. 1 Network Architecture

A subnet is identified by an IP address that includes a network prefix and a subnet number (SN). We consider that each SA knows the SNs of its neighboring SAs that it periodically transmits in its subnet, via access points, in the form of the beacon signal [18-19]. For example, the SA1, in the fig. 1, transmits the SNs {1, 2, 3, 4, 5} and, similarly, the SA11 transmits the SNs {3, 4, 10, 11, 12, 23, 24} in its beacon signal.

The network uses two-level hierarchy for mobility tracking, a gateway mobility agent (GMA) at the higher level and a reporting mobility agent (RMA) at the lower level in the hierarchy. The scheme utilizes two kinds of registrations for tracking the MH in the network. One, the macro-registration, a request made by the MH to register its location, via its GMA, with the HA using MIP, and the second is the micro-registration which is used to register the MH locally, via its RMA, with the GMA only. Each SA can act as either a GMA, or a RMA, or simply as a SA. A SA that last requested for the macro-registration acts as a GMA for the MH. GMA is responsible for handling the mobility of the MH in a group of subnets which form a location area. In this area, the MH can freely roam from one subnet to the other without any further macro-registration. Thus, the movement of the MH within a location area is completely transparent to the HA. The number of the subnets in the location area is computed using the algorithm in section 3.2. When the MH moves out of its location area, its visiting SA becomes the new GMA with a different location area size, and a macro-registration takes place. The GMA is responsible for handling all the incoming/outgoing control and data messages to/from an MH from/to the HA within its location area.

Each location area consists of several dynamically configured paging areas having varying sizes. By incorporating the concept of paging, a significant amount of power saving and enhancement in the battery life for a dormant MH can be achieved. Within a location area, a SA that last reported the location of an active or a dormant MH to the GMA acts as a RMA. For a dormant MH, the paging area is considered to be consisting of the RMA and its neighboring SAs. Thus, the paging area size depends only upon the number of neighboring SAs to the RMA. The RMA reports the location of the MH, both in dormant as well as active mode, to the GMA as it traverses within the location area. For a dormant MH, the GMA knows about its coarse location only, meaning that the location of the MH within a paging area is transparent to the GMA. The RMA, also, acts as the paging initiator for the dormant MHs residing in its paging area when the data packets arrive. It is noteworthy that just after the macro-registration, the GMA itself acts as the RMA until the MH leaves the paging area consisting of the GMA and its neighboring SAs.

For an active MH, it is necessary that the MH updates its precise location to the GMA after every change in its PoA. Therefore, each visiting SA within a location area acts as a RMA when the session is in progress. When the session terminates and the MH enters into the dormant mode, the visiting SA of the MH becomes its RMA and a new paging area consisting of the RMA and its neighboring SAs is constituted. The proposed scheme uses overlapping location areas and paging areas that completely mitigates the ping-pong effect near their respective boundaries.

3.2 Registration

We use fig. 2 to illustrate our proposed micro-mobility protocol. Each SA is identified by its subnet number, as shown in the circles. Also, each SA, together with its neighboring SAs, constitutes a paging area and periodically transmits the list of SAs in its paging area so that the MH currently visiting a subnet is, also, aware of the SNs of neighboring SAs while on move. Each MH uses three registers namely $R_1, R_2\ and\ R_3$ to decide for initiating a macro- or a micro-registration. The MH uses these registers to store the list of SAs obtained from the agent advertisements from the GMA, RMA and the visiting SA, respectively. The SAs in the register R_1 remain unaltered throughout the movement in a location area while as the SAs in the registers $R_2\ and\ R_3$ keep on varying with the movement of the MH inside the location area. Note that the SAs in the register R_2 together constitute the paging area for a MH. The content of the register R_2 gets altered after every change in the paging area of the MH while as the content of the R_3 changes with every change of the SA. Since, we consider a dynamic scheme wherein location areas and paging areas overlap, some of the SAs in previous and new contents of the registers $R_2\ and\ R_3$ are common.

Just after a macro-registration, the SAs in three registers $R_1, R_2\ and\ R_3$ are identical because the GMA, RMA and the visiting SA are the same. The steps in the algorithm for the macro-registration and micro-registration are listed below:

1. The MH registers with the HA.
2. The MH listens the visiting SA identifier (its own SN and the SNs of its neighboring SAs) from its agent advertisement and stores in register R_3.
3. The visiting SA becomes GMA and RMA of the MH.
4. The MH stores the SNs, in agent advertisement, in registers $R_1, R_2\ and\ R_3$. At this time, the SAs in $R_1, R_2\ and\ R_3$ are same.
5. The content of R_3 changes at every new subnet.
6. The content of R_2 changes at every new paging area.
7. The content of R_1 changes at every new location area.
8. Each time the MH crosses the SA boundary, it receives a new SA identifier computes $R_2 \cap R_3$ and $R_1 \cap R_3$.
9. If the number of SAs in $R_2 \cap R_3 \le 2$, and $R_1 \cap R_3 \ne \{\}$, the paging area changes (micro-registration). $R_2 \xleftarrow{SNs} R_3$.
10. If $R_1 \cap R_3 = \{\}$, where {} denotes a null set i.e. no SA is available in $R_1 \cap R_3$, then GO TO step 1 (macro-registration). $R_1 \xleftarrow{SNs} R_3$.

We clarify it, further, with an example wherein a MH moves from SA27 to SA35 via SA31, using the path shown in the fig. 2. Let the MH macro-registers at SA27. At this moment, the contents of the registers $R_1, R_2\ and\ R_3$ will be same, as listed below:

$R_1 = \{27,28,13,26,43,44,45,46\}$

$R_2 = \{27,28,13,26,43,44,45,46\}$

$R_3 = \{27,28,13,26,43,44,45,46\}$

When the MH moves from SA27 to SA43, the contents of the register change to:

$R_3 = \{43,44,27,26,42\}$

The MH computes:

$R_1 \cap R_3 = \{26,27,43,44\}$; $\# SAs = 4 \neq \{\}$; Macro-registration not required.

$R_2 \cap R_3 = \{26,27,43,44\}$; $\# SAs = 4 > 2$; Micro-registration not required.

On moving from SA43 to SA42,

$R_3 = \{42,43,26,25,41\}$

$R_1 \cap R_3 = \{26,43\}$; $\# SAs = 2 \neq \{\}$

$R_2 \cap R_3 = \{26,43\}$; $\# SAs = 2$; Micro-registration required.

At this stage, the content of the register changes to:

$R_2 \xleftarrow{SNs} R_3$

$R_2 = \{42,43,26,25,41\}$

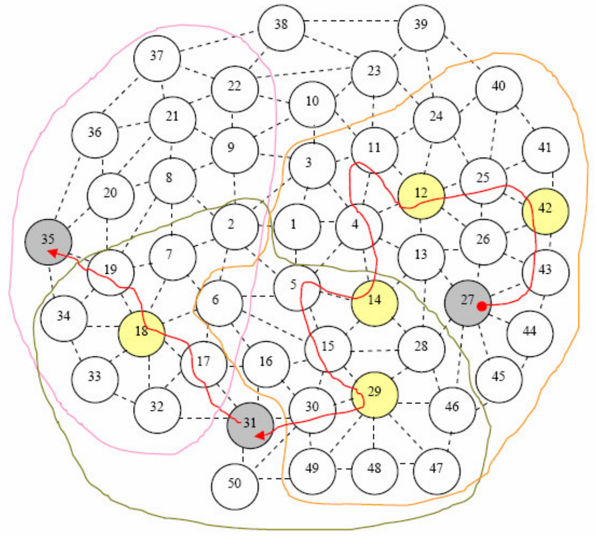

Fig.2 Formation of location areas and paging areas

Similarly, the MH, while moving on the path shown in fig.2, micro-registers at SA12, SA14 and SA29, and the contents of the R_2 changes at these SAs, to the current SA identifier.

When it moves from SA30 to SA 31:

$R_3 = \{31,32,17,16,30,50\}$

$R_1 \cap R_3 = \{\}$; $\# SAs = 0$.

Therefore, the MH requests for a macro-registration and the SA31 becomes new GMA and RMA of the MH and the contents of R_1 and R_2 get modified.

$R_1 \xleftarrow{SNs} R_3$; $R_1 = \{31,32,17,16,30,50\}$

$R_2 \xleftarrow{SNs} R_3$; $R_2 = \{31,32,17,16,30,50\}$

Similarly, the MH micro-registers at SA18 and macro-registers at SA35.

Using this scheme, if the MH micro-registers at SA4, SA14 or SA15, it can move to SA5 without any registrations. But, if the MH micro-registers at SA12 and moves directly from SA4 to any of SA1, SA3 or SA5, it requires a macro-registration.

3.3 Packet delivery

All the packets intended for an MH are routed via the HA. The HA forwards these packets to the last registered GMA. After receiving the data, the GMA searches its location database for the last registered RMA of the MH. The GMA, then, forwards the data packets to the RMA of the MH. The RMA buffers the data packets and sends a paging request message to its neighboring SAs i.e. in its paging area. The MH receives the paging request message via access points and enters into active mode. If the MH is residing with the RMA, the data is directly delivered to the MH via the RMA. If the MH stays with any of its neighboring SAs, it sends a paging acknowledgement message to its RMA. The MH, simultaneously, requests its visiting SA for a micro-registration. The visiting SA becomes the new RMA (nRMA) for the MH and completes the micro-registration formalities with the GMA. The previous RMA (pRMA) forwards the buffered data packets to the MH via the nRMA. Thereafter, the MH receives the data packets from the GMA directly via the nRMA. The data packets can be buffered at the GMA as well, but buffering the data packets at pRMA avoids the packet loss during the micro-registration after each subnet crossing for an active MH.

4. Analytical model and analysis

We make following assumptions:

- The packet arrival rate for a MH follows a Poisson distribution with mean λ_a.
- The subnet residence time (the time between the MH entering and leaving a subnet) follows a general distribution with mean $1/\lambda_m$, where λ_m is the subnet crossing rate.
- After residing in a subnet for a random period of time, a MH moves out to any one of the neighboring subnets. Also, most of the users have only localized movement.

It has been found that about 69% of the users move locally within their nearby vicinity [18]. Under these conditions, the mobility model we use is the 2-D random-walk model. Using this model, a GMA can be considered having been surrounded by three layers of the SAs, as shown in fig. 3 for the case when a MH macro-registers at SA25.

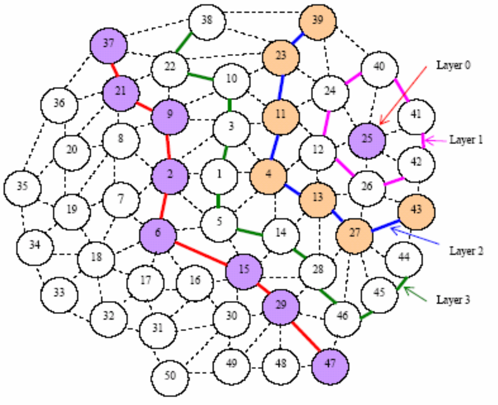

Fig. 3 Layered location area

Therefore, a location area consists of the four layers of the SAs, the GMA being at the 0th layer of the LA. The MH registers the HA when its distance from the 0th layer exceeds a threshold d_{LA} (equal to three), for all the users. We have seen that, for a dormant MH, each paging area includes the RMA and its neighboring SAs, and the MH registers locally with the GMA when it leaves the paging area. Therefore, a paging area can be considered as consisting of two layers of the SAs, the RMA being at 0th layer and the group of neighboring SAs at the 1st layer of the paging area. A dormant MH requests for a micro-registration when its distance from the 0th layer of the PA exceeds a threshold d_{PA} (equal to one).

Since, each SA in the network can act as a GMA; the number of location areas is the same as the number of the SAs in the network. However, SAs only in layers $l_0, l_1, and\, l_2$ can act as RMAs. Therefore, if $n_0^k, n_1^k\ and\ n_2^k$ represent the number of SAs in layers $l_0^k, l_1^k\ and\ l_2^k$ respectively, then the number of paging areas in k^{th} location area is given by:

$$N_{PA,\,k} = \sum_{i=0}^{2} n_i^k \qquad (1)$$

If $\phi_l^{(i,k)}$ denotes the number of neighboring SAs of l^{th} SA at the i^{th} layer in k^{th} LA, then the paging area size, when this SA acts as a RMA, will be $\phi_l^{(i,k)} + 1$, where $l \in n_i^k$.

If the MH is residing with a SA of the i^{th} layer in k^{th} LA, then the transition probabilities $p_{i,j}^{(k)}$ that the MH will move to a SA in the j^{th} layer of the same LA are given by:

$$p_{i,j}^{(k)} = \begin{cases} 1 & i=0, j=1 \\ \dfrac{1}{\eta_i^{(k)}} \displaystyle\sum_{l=1}^{\eta_i^{(k)}} \dfrac{\eta_{i,j}^{(l)}}{\phi_l^{(i,k)}} & 1 \le i \le 3, j=(i-1), i, (i+1) \\ 0 & otherwise \end{cases} \qquad (2)$$

where,

$\eta_i^{(k)} \rightarrow$ Number of SAs in i^{th} layer of the k^{th} LA;

$\eta_{i,j}^{(l,k)} \rightarrow$ Number of SAs at j^{th} layer which are adjacent to l^{th} SA at i^{th} layer in k^{th} LA;

$\phi_l^{(i,k)} \rightarrow$ Number of neighboring SAs of l^{th} SA at i^{th} layer in k^{th} LA;

The transition rates $q_{i,j}^{(k)}$ of a MH from i^{th} layer to j^{th} layer, in k^{th} LA, can be written as

$$q_{i,j}^{(k)} = \lambda_m p_{i,j}^{(k)} \qquad (3)$$

The analytical analysis of the proposed scheme can be carried out using continuous-time Markov chain for the macro-registration and the micro-registration.

4.1 Macro-registration

Since, each location area in the network may have different number of SAs and each SA in a location area may have different number of neighboring SAs, the transition rates for different location areas will differ from one another. In [10], we analyze the results using discrete-time Markov-chain model. But, since the transition from one state to other depends upon the mobility rate of the user, therefore, here, we employ a continuous-time Markov chain analysis for the macro-registration process in k^{th} LA of the network. Each LA is divided in four layers. The state '0' represents the SA at the layer l_0 i.e. the GMA, and the states 1, 2 and 3 represent a SA from the groups of SAs in layers l_1, l_2 and l_3, respectively. It is evident that after leaving layer l_3 SAs (distance threshold=3), the MH enters into the SA of layer l_0 i.e. the next visiting SA becomes the GMA of the MH and a macro-registration for the MH is required.

The state transition rate matrix $Q_{i,j}^{(k)}$ of the state transition diagram for k^{th} LA is given by

$$Q_{i,j}^{k} = \left[q_{i,j}^{(k)}\right] = \begin{bmatrix} q_{0,0}^{(k)} & q_{0,1}^{(k)} & 0 & 0 \\ q_{1,0}^{(k)} & q_{1,1}^{(k)} & q_{1,2}^{(k)} & 0 \\ 0 & q_{2,1}^{(k)} & q_{2,2}^{(k)} & q_{2,3}^{(k)} \\ q_{3,0}^{(k)} & 0 & q_{3,2}^{(k)} & q_{3,3}^{(k)} \end{bmatrix}$$

where, $q_{0,0}^{(k)} = -q_{0,1}^{(k)}$

$$q_{1,1}^{(k)} = -(q_{1,0}^{(k)} + q_{1,2}^{(k)})$$

$$q_{2,2}^{(k)} = -(q_{2,1}^{(k)} + q_{2,3}^{(k)})$$

and $q_{3,3}^{(k)} = -(q_{3,0}^{(k)} + q_{3,2}^{(k)})$

Here, $q_{3,0}^{(k)} = q_{3,4}^{(k)} + q_{2\_3,\,3}^{(k)} + \lambda_a$, where $q_{2\_3,\,3}^{(k)}$ represents the average transition rate that a dormant MH will leave its paging area from a SA of 2nd or 3rd layer of the paging area to a SA in 3rd layer, in k^{th} LA.

The steady-state or stationary probability vector, $\pi_i^{(k)}$, of a state i in k^{th} Markov chain, can be obtained by solving the balance equations given by

$$\pi_i^{(k)} . Q_{i,j}^{(k)} = 0 \qquad (4)$$

satisfying the condition that $\sum_{i=0}^{3} \pi_i^{(k)} = 1$ (5)

4.2 Micro-registration

As mentioned in section 3, the micro-registration occurs when a dormant MH leaves the paging area, or when an active MH crosses the subnet boundary while the session is in progress. Thus, the micro-registration process can be modeled using Markov chain with two states only [10]. Here, the state 0 represents the SA in layer l_0 of a paging area that acts as a RMA, and the state 1 represents a SA from the group of SAs in layer l_1 i.e. neighboring SAs in the paging area. For an active MH, each visited SA acts as the RMA because the MH needs to update its precise location with the GMA after every subnet crossing.

The state transition rate matrix for l^{th} paging area of k^{th} location area is given as under:

$$Q_{i,j}^{(l,k)} = \begin{bmatrix} -q_{0,1}^{(l,k)} & q_{0,1}^{(l,k)} \\ q_{1,0}^{(l,k)} + q_{1,2}^{(l,k)} + \lambda_a & -(q_{1,0}^{(l,k)} + q_{1,2}^{(l,k)} + \lambda_a) \end{bmatrix}$$

The steady state probabilities $\pi_i^{(l,k)}$ of the state i in the l^{th} Markov chain of the k^{th} location area can be found using following balance equations:

$$\pi_i^{(l,k)} Q_{i,j}^{l,k} = 0 \qquad i = 0,1; \;\; l \in N_{PA,k} \qquad (6)$$

with the requirement that $\sum_{i=0}^{1} \pi_i^{(l,k)} = 1$. (7)

5. Performance Evaluation

Let us assume that the cost for performing a macro-registration is C_{macro} , and C_{micro}^{k} represents the cost of a micro registration in k^{th} location area. Also, if $C_{data\,delivery}^{k}$ is the cost for data delivery in the k^{th} location area, then the total average signaling cost per call arrival, C_T , can be written as below:

$$C_T = 1/N_{LA} \sum_{k=1}^{N_{LA}} \frac{1}{\rho} [\pi_3^{(k)} \; (p_{3,4}^{(k)} + p_{2\_3}^{(k)}) C_{macr}$$

$$+ 1/N_{PA,k} \sum_{l=1}^{N_{PAk}} \pi_1^{(l,k)} \; p_{1,2}^{l,k} \, C_{micro}^{k} + C_{datadelivery}^{k}] \qquad (8)$$

where, $\rho = \frac{\lambda_a}{\lambda_m}$ is the call-to-mobility ratio (CMR). We have used the data available from [12] for performance evaluation of the proposed scheme. In our analysis, $C_{data\,delivery}^{k}$ includes the paging cost for the paging area as well. Cost of paging a subnet has been taken as 15 and the average distance between GMA and RMA is 1.5.

In the above equation, the first term, in the parentheses, represents the macro-registration cost for k^{th} location area, the second term represents the average micro-registration cost within a location area, and the third term represents the average data delivery cost in a location area.

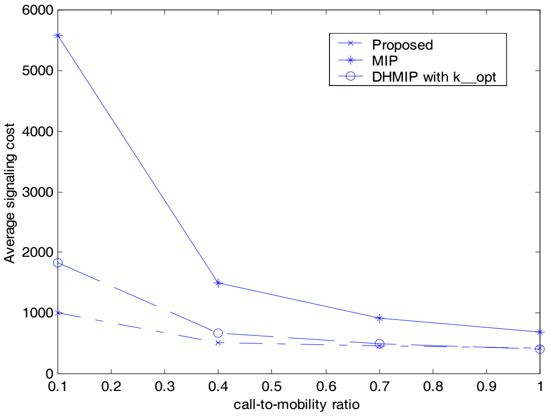

Fig. 4 Signaling cost vs. CMR

We observe that, for $\rho < 1$, our proposed scheme performs better than MIP and DHMIP.

6. Conclusion

In this paper, we have presented a new distributed and dynamic mobility management scheme which tends to reduce the traffic burden on the network. The scheme, also, eliminates the ping-pong effect near the location update and paging update boundaries. An analytical modeling has been carried out and performance, in terms of signaling cost, has been evaluated. It has been shown that the proposed scheme out performs the MIP and DHMIP for $\rho < 1$.

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