An Efficient Mobility Management Scheme Based on Location Anchoring and Pointer Forwarding

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Abstract— **Personal Communication Systems (PCSs) must have an efficient way to locate mobile users. The location management fulfills this task through location registration and paging. To reduce the signaling traffic, many schemes such as local anchoring, pointer forwarding and two-level pointer forwarding schemes have been proposed in the past. In this paper, we present a novel location management scheme which intends to mitigate the signaling traffic as well as reduces the connection setup delay in the PCS networks. In this strategy, one VLR is selected as the Mobility Agents (MA) for that user at a time, which forms another level of management to make some registration signaling traffic localized. The analytical results show that this strategy can significantly reduce the network signaling traffic for users without increasing much of the call setup delay. Also in our new scheme, the signaling burden is evenly distributed and the selection of MA is dynamic for every user.**

I. INTRODUCTION

In Personal Communication Systems (PCSs), the mobile users can change their locations from time to time in the network coverage area. Two standards currently exist for PCS location management: IS-41 ([1]) and GSM MAP ([2]). For the third generation systems, although some new functional entities are introduced for new technologies, the basic scheme for location management has not changed significantly. The registration areas (RAs) in the third generation systems are becoming smaller and smaller. Small RA size can facilitate systems to trace users more exactly and quickly; however it may result in heavy location management signaling traffic to the network. Currently, both the IS-41 and GSM MAP adopt a two-tier database system consisting of *Home Location Register* (HLR) and *Visitor Location Register* (VLR). Based on these strategies, a series of update (registration) operations will be initiated by the user terminal every time the user crosses the boundary of a registration area. If many mobile users are far away from their HLRs, heavy signaling traffic over the network can occur. This problem becomes more serious with the increase of the mobile user number and the reduction of RA size. In the local anchoring scheme ([3]), a VLR close to the user is selected as the local anchor for the user. The local anchor can act as the HLR for the mobile user whenever the user enters a new RA. The local anchoring scheme avoids the frequent updates to HLR at the expense of increasing the local signaling traffic. The drawback of this scheme is that when the user keeps moving constantly without receiving any call, the updates to the local anchor may become costly, a similar bottleneck as the HLR is. Jain and Lin proposed another scheme called *per-user pointer forwarding scheme* ([4]). In this scheme, when a mobile user moves from one RA to another, a pointer is set up from the previous VLR to the current one, then the user can be traced along a pointer chain during the call delivery procedure. However, the penalty of this scheme is the longe time delay for tracing the user. To improve the performance of the above two schemes, we recently proposed the two-level pointer forwarding strategy in [11]. In our scheme, we use two kinds of pointers. Some VLRs are selected as the *Mobility Agents* (MAs), which are responsible for location management in a larger area comparing with the RAs and can be geographically distributed. Two kinds of pointers are set up among MAs and VLRs. The user location can be determined by following the two kinds of pointer chains to the user's current VLR. The chain threshold in the two-level pointer forwarding strategy can be much longer than that in [4]; however it can have shorter call setup delay. In this paper, we propose a new location management scheme called *pointer forwarding based local anchoring scheme (POFLA)*, which combines pointer forwarding with local anchoring to take advantages of both schemes with simple implementation. It is similar to the two-level pointer forwarding scheme in the sense that some VLRs are selected as MAs and there are two kinds of pointers in both schemes. However, the major difference is that there is only one MA in the pointer chain for POFLA at any given time while there may be multiple MAs for two-level pointer scheme concurrently. In this paper, we carry out the performance evaluation of the above four schemes under various conditions using a new analytical approach. We show that the POFLA performs better than the per-user forwarding and the local anchor schemes. Although the two-level pointer forwarding scheme may show similar achievement as our new strategy does, the POFLA is simpler to implement in practical systems.

The paper is organized as follows. The details of the new scheme is introduced in section II; in section III, we derive the cost functions of the POFLA scheme; section IV compares the

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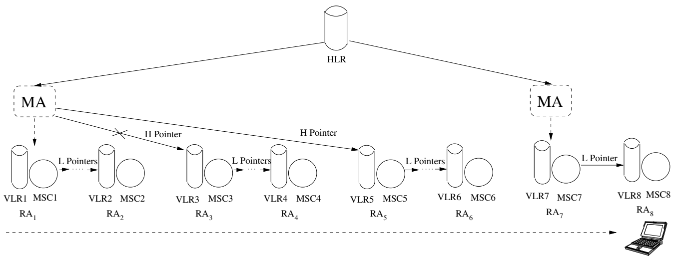

Fig. 1. POFLA strategy procedures

performances of different strategies under various conditions and the conclusions are given in section V.

II. POFLA Scheme

In the POFLA Scheme, the basic location update and call delivery procedures are modified to achieve better performance. In this scheme, every time a user enters a new RA served by a different VLR, the mobile terminal registers to the new VLR and informs the new VLR about the old VLR and MA. The MA may be the same VLR the user is currently visiting. The VLR at the new RA determines what to do based on the mobile location update information. The new VLR has three options: it can request the old VLR to set up a pointer to itself, which is called *Low Level Pointer* (or L Pointer) in our scheme; it can update the MA and request to set up a pointer from the MA to itself, this is called *High Level Pointer* (or H Pointer); and it can also decide to update the user's new location to the HLR directly and itself becomes the new MA. Fig. 1 shows the location update and call delivery procedures in the POFLA scheme with the H pointer chain length setting three. Assume a mobile user moves from RA_1 to RA_8 (these RAs are not necessary to be adjacent) and VLR_1 is the user's current MA. At the beginning, the user is in RA_1 and VLR_1 is the user's current serving VLR. The VLR_1 is selected as the user's current MA because either the user just receives an incoming call in RA_1 or the VLR_1 just updates the user's new location to the HLR. When the user leaves RA_1, but before enters RA_3, the mobile terminal informs the new VLR and a pointer chain consisting of L pointers is set up just as in the per-user forwarding scheme ([4]). When the user enters RA_3, the chain threshold for L pointers is reached. In this situation, the VLR_3 will update the user's new location to the current MA, i.e. VLR_1. At the mean time, the L pointer chain is reset. The same procedure is used in VLR_5 and the previous H pointer is reset. If the user keeps moving, in RA_7, the threshold for L pointer chain is reached again. This time, the limit of the H pointer length is reached too. Instead of exchanging information with the previous MA and setting up a new H pointer, the VLR_7 will update the user's location to the HLR directly and VLR_7 is selected as the new MA for that the user. The reason of updating the HLR instead of the MA is that the cost of setting up and traversing the pointer chain between MA and current serving VLR may be costly when the user is far away from the MA and the connection setup delay for an incoming call may be intolerable. If an incoming call arrives before the mobile user changes his or her MA, the current serving VLR is selected as the user's current MA because the HLR has the knowledge of the user's current location after the connection setup and is not necessary to go through the pointer chain again to locate the user for the future service deliveries.

The call delivery procedure in the POFLA scheme are straightforward. When the subsequent calls are initiated from some other switches to the user, the user's HLR is queried first as in the basic procedure and a pointer to the user's potentially outdated MA is obtained. The pointer chain is followed to find the user's current location.

III. Signaling Cost Functions

The mobile users in a PCS can be characterized by their *call-to-mobility ratios* (CMRs). In this paper, if calls are *received* by the user at an average rate λ and the time the user resides in a given RA has average value $1/\mu$, then, the CMR, denoted as ρ, is given by

$$\rho = \lambda/\mu. \tag{1}$$

Because a mobile terminal needs to update its location only when the mobile terminal does not engage communications with the fixed communication infrastructure (i.e., the network), hence we only need to compare the signaling traffic in the time interval between call services ([5], [6]). Assume a mobile user crosses a number of RAs during inter-service time, if the basic user location update scheme (IS-41) is used, the user's HLR will be updated every time the user moves to a new RA. In the POFLA scheme, the HLR is updated only every $K_1 \cdot K_2$ moves (K_1 and K_2 are the L pointer chain threshold and H pointer length limit, respectively), and pointers are set up for all other moves. We define C and C' to be the total costs of updating the location information (location update) and tracking the user (call delivery) during the inter-service time for the basic IS-41 and the POFLA strategies respectively. For convenience, we list all notations used in our analysis as follows:

- m: the average cost of location update to the HLR.
- F: the total cost of call delivery in the IS-41 scheme.
- M': the total location update cost in the POFLA scheme during the inter-service time.
- F': the total call delivery cost in the POFLA scheme.
- $\alpha(i)$: the probability that there are i RA crossings during the inter-service time.
- P: the processing cost of setting up a pointer.
- G: the signaling cost of setting up an L pointer.
- β: the cost coefficient for H pointer ($\beta \geq 1$).

Then, we can express the total costs during the inter-service time for the two location management scheme as follows:

$$C = m/\rho + F, \tag{2}$$
$$C' = M' + F'. \tag{3}$$

Since pointers are set up in the POFLA scheme, we need to define the pointer setup and traversing costs for further analysis. Every time a pointer is set up, the signaling messages will be transmitted back and forth. For pointer traversing, the signaling message is transmitted only in one direction. So we define the costs of pointer setup and traversing for the L pointer as S_1 and T_1, respectively:

$$S_1 = G+P, \quad (4)$$
$$T_1 = \frac{1}{2}G+P. \quad (5)$$

The costs of H pointers are not fixed value because the length of the H pointers changes with the user's mobility. In this paper, we express the costs for H pointers as follows:

$$S_{2,j} = \begin{cases} 0 & \text{if } j=0 \\ j\beta G+P & \text{Otherwise} \end{cases} \quad (6)$$
$$T_{2,j} = \begin{cases} 0 & \text{if } j=0 \\ \frac{1}{2}j\beta G+P & \text{Otherwise} \end{cases} \quad (7)$$

where the subscript j means the setup cost or the traversing cost for the jth H pointer.

Now, we can derive the formula for M' and F' as follows: suppose that a user crosses i RA boundaries during the inter-service time. The HLR is updated $\lfloor \frac{i}{K_1K_2} \rfloor$ times. If we call the summation of the costs for H pointer setup from the $0th$ to the $(K_2-1)th$ H pointer, $\sum_{j=0}^{K_2-1} S_{2,j}$, the MA update cost, then there are $\lfloor \frac{i}{K_1K_2} \rfloor$ times such MA update costs that would incur during the inter-service time with i RA crossings. In addition, there are $\lfloor \frac{i-\lfloor \frac{i}{K_1K_2}\rfloor K_1K_2}{K_1} \rfloor$ H pointer setups and $i-\lfloor \frac{i}{K_1} \rfloor$ L pointer setups occurred in the remaining RA crossings. Thus, we can obtain

$$M' = \sum_{i=0}^{\infty}\{\lfloor \frac{i}{K_1K_2}\rfloor m + (i-\lfloor \frac{i}{K_1}\rfloor)S_1 + \lfloor \frac{i}{K_1K_2}\rfloor (\sum_{j=0}^{K_2-1} S_{2,j}) + \sum_{j=0}^{\lfloor \frac{i-\lfloor \frac{i}{K_1K_2}\rfloor K_1K_2}{K_1}\rfloor} S_{2,j}\}\alpha(i). \quad (8)$$

The function of F' can be derived straightforward. In order to reach the user's current location, the signaling message is sent to the MA and then travels through one H pointer (if any) and $i-\lfloor \frac{i}{K_1}\rfloor K_1$ L pointers before reaching the current location. So, we have

$$F' = F + \sum_{i=0}^{\infty}\{T_{2,\zeta} + (i-\lfloor \frac{i}{K_1}\rfloor K_1)T_1\}\alpha(i), \quad (9)$$

where $\zeta = \lfloor \frac{i-\lfloor \frac{i}{K_1K_2}\rfloor K_1K_2}{K_1} \rfloor$. Equation (8) can be expressed as

$$M' = \underbrace{S_1\sum_{i=0}^{\infty} i\alpha(i)}_{M_1} - \underbrace{S_1\sum_{i=0}^{\infty}\lfloor \frac{i}{K_1}\rfloor\alpha(i)}_{M_2} + \underbrace{\frac{\beta G}{2}\sum_{i=0}^{\infty}\lfloor \frac{i-\lfloor \frac{i}{K_1K_2}\rfloor K_1K_2}{K_1}\rfloor^2 \alpha(i)}_{M_3} + \underbrace{\frac{(K_2-1)K_2\beta G + 2(K_2-1)P+2m}{2}\sum_{i=0}^{\infty}\lfloor \frac{i}{K_1K_2}\rfloor\alpha(i)}_{M_4} + \underbrace{\frac{\beta G+2P}{2}\sum_{i=0}^{\infty}\lfloor \frac{i-\lfloor \frac{i}{K_1K_2}\rfloor K_1K_2}{K_1}\rfloor\alpha(i)}_{M_5}. \quad (10)$$

M_1 can be simplified from the definition of $\alpha(i)$,

$$M_1 = \frac{S_1}{\rho} = \frac{G+P}{\rho}.$$

In order to evaluate $\alpha(i)$, we assume that the inter-service time is exponentially distributed with average $1/\lambda$ and the residence time of the mobile at a registration area is a random variable with a general probability density function $f_m(t)$ and Laplace transform $f_m^*(s) = \int_{t=0}^{\infty} f_m(t)e^{-st}dt$, and with average RA residence time $1/\mu$. For simplicity, we denote $g = f_m^*(s)$. Based on the above assumptions, we obtain the probability $\alpha(i)$ (see [7] for the detailed derivation),

$$\alpha(i) = \frac{(1-g)^2 g^{i-1}}{\rho}. \quad (11)$$

Applying variable substitution $i = jK_1 + k$, then we obtain

$$\alpha(jK_1+k) = \frac{(1-g)^2}{\rho g}(g^{K_1})^j g^k = yz^jx^k,$$

thus, we have

$$M_2 = yS_1\sum_{j=0}^{\infty}\sum_{k=0}^{K_1-1} jz^jx^k = \frac{(1-g)(G+P)g^{K_1-1}}{\rho(1-g^{K_1})}.$$

Similarly, we can obtain following results:

$$M_3 = \frac{\beta G(1-g)}{2\rho g(1-g^{K_1K_2})(1-g^{K_1})^2} \cdot\{g^{K_1}+g^{2K_1}-K_2^2g^{K_1K_2}+(2K_2^2-2K_2-1) \cdot g^{K_1(K_2+1)} - (K_2-1)^2g^{K_1(K_2+2)}\},$$
$$M_4 = \frac{(K_2-1)K_2\beta G+2(K_2-1)P+2m}{2}\cdot\frac{(1-g)g^{K_1K_2-1}}{\rho(1-g^{K_1K_2})},$$
$$M_5 = \frac{(\beta G+2P)(1-g)}{2\rho g(1-g^{K_1K_2})(1-g^{K_1})} \cdot[(K_2-1)g^{K_1(K_2+1)} - K_2g^{K_1K_2} + g^{K_1}].$$

Finally, we obtain the expression $M' = M_1 - M_2 + M_3 + M_4 + M_5$.

We can compute F' in a similar fashion. Notice that if we use the substitution $i = jK_1K_2 + k$, when $k = 0, 1, \cdots, K_1 -$

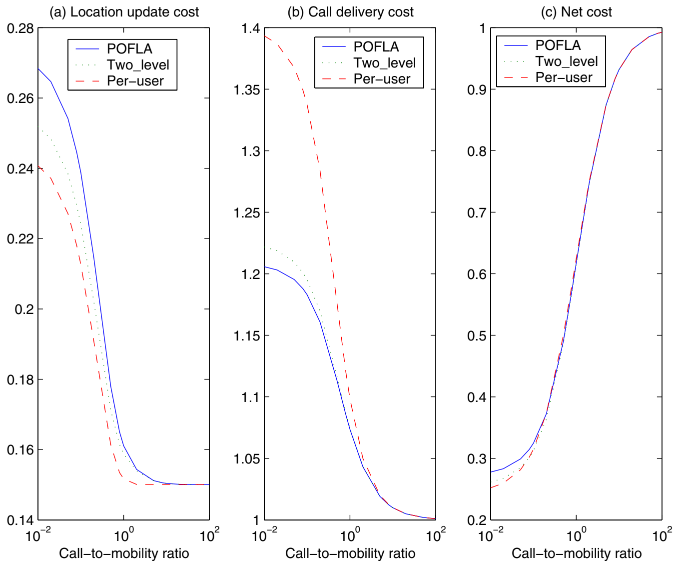

Fig. 2. The relative costs for the three schemes with $P = 0.05$, $G = 0.1$ and $\beta = 1.5$

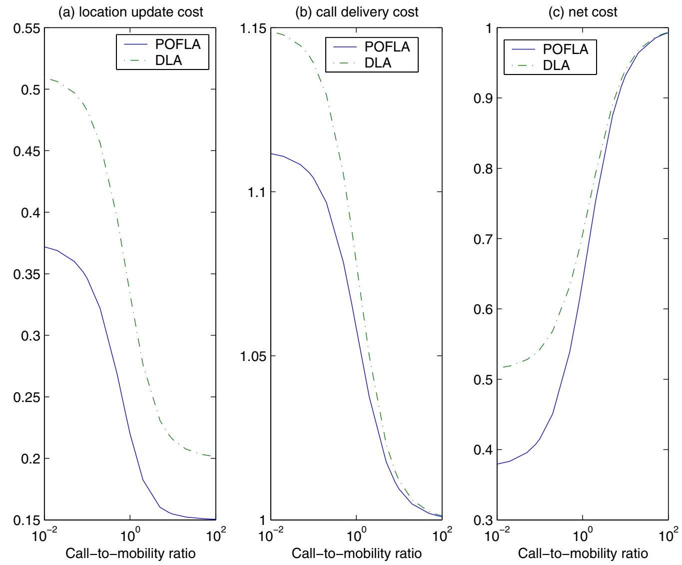

Fig. 3. The relative costs for the POFLA and DLA

1, $T_{2,\zeta} = 0$. So we can obtain F' as follows:

$$\begin{aligned} F' &= F + \frac{G+2P}{2\rho}[1 - \frac{K_1(1-g)g^{K_1-1}}{1-g^{K_1}}] \\ &+ \frac{P(1-g)(g^{K_1-1} - g^{K_1K_2-1})}{\rho(1-g^{K_1K_2})} \\ &+ \frac{\beta G(1-g)[(K_2-1)g^{K_1(K_2+1)} - K_2 g^{K_1K_2} + g^{K_1}]}{2\rho g(1-g^{K_1K_2})(1-g^{K_1})}. \end{aligned} \quad (12)$$

IV. PERFORMANCE ANALYSIS

For demonstration purposes, we assume that the RA residence time is Gamma distributed with mean $1/\mu$. Thus, we have,

$$g = f_m^*(\lambda) = \left(\frac{\gamma\mu}{\lambda+\gamma\mu}\right)^\gamma = \left(\frac{\gamma}{\rho+\gamma}\right)^\gamma. \quad (13)$$

A. Exponential RA Residence Time

We first consider the situation when the RA residence time is exponentially distributed. By setting $\gamma = 1$, (13) becomes $g = \frac{1}{1+\rho}$.

In our analysis, we do not address issues regarding the contents of messages and other information transfer which may occur during a call connection setup. Notice that, in the simplified IS-41 or GSM MAP procedures, the location update and call delivery involve the same number of messages between HLR and VLR databases, so we choose $m = F$. Without loss of generality, we normalize $m = F = 1$. G is the signaling transmission cost and P is the processing cost, they should be much less than m or F.

In Fig.2, we plots the relative location update, call delivery and net costs of three schemes as functions of CMR. Here for the POFLA scheme and the two-level pointer forwarding scheme, we assume $K_1 = K_2 = 3$; for the per-user forwarding scheme, the threshold is nine ($K_1 \times K_2$). As we can see in Fig. 2(a), the POFLA scheme generates higher values than the per-user forwarding scheme. It is obvious because in the latter scheme, only the L pointers are set up while in the POFLA scheme, a new VLR may set up an H pointer to the MA, which costs more than an L pointer. For the two-level pointer forwarding scheme, the level_2 pointer is the L pointer and the level_1 pointer is usually shorter than the H pointer ([11]). So the location update cost for the two-level pointer forwarding scheme is in the middle of them. Although, with the same length of the pointer threshold, the per-user forwarding scheme can generate less location update cost, it will have the largest call delivery cost among the three strategies (see Fig. 2(b)). For some users with small CMR, the call delivery cost for the per-user forwarding scheme is much higher than those for the other two schemes. In practical systems, it could be embodied as the delay the users have to wait before any connections setup. In the POFLA scheme, normally fewer pointers need be traversed than the two-level pointer forwarding scheme; so the POFLA scheme has the least call delivery cost. In Fig. 2(b), the performance of the POFLA scheme dose not degrade much comparing to the two-level pointer scheme; however the POFLA is easier to implement in practical systems. Although the three schemes perform differently in location update and call delivery, the total net cost for the three schemes are similar for high CMRs (Fig. 2(c)).

In [3], the authors has suggested two variants of the local anchoring scheme—the static and dynamic. The dynamic local anchoring scheme is more difficult to implement; however the results in [3] show that it can guarantee that the net cost is less than the basic IS-41 or GSM MAP strategy, and the static scheme might generate higher cost than the basic scheme does under some conditions. The performance comparisons of the dynamic local anchoring scheme with the POFLA scheme are shown in Fig.3. In order to make the comparison fair, the

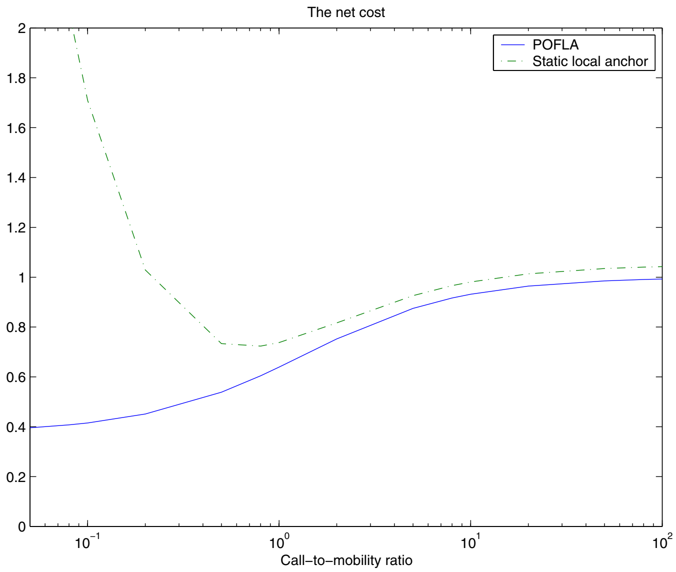

Fig. 4. The relative net costs for the POFLA and SLA

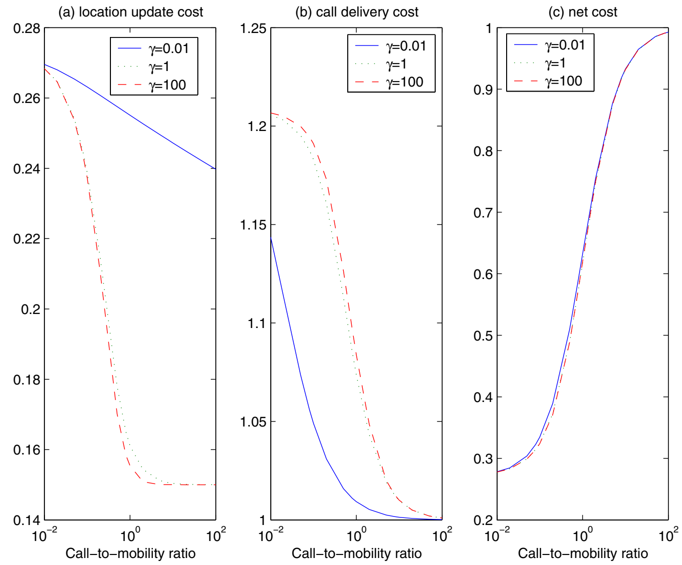

Fig. 5. The effect of variance of residence time (γ) with $P = 0.05$, $G = 0.1$ and $\beta = 1.5$

effective pointer chain length ($K_1 \times K_2$) in the POFLA scheme is the same as the dynamic local anchoring scheme. In Fig.3, we assume $P = 0.05$, $G = 0.1$, $\beta = 1.5$ and $m = F = 1$. Based on these assumption, we obtain the effective pointer chain length is four, so we set $K_1 = K_2 = 2$. It can be seen that in both the local update, call delivery and the total net cost, the POFLA scheme has better performance than the dynamic local anchoring scheme does. In Fig. 4, we also compare the total net cost of the POFLA scheme with that of the static local anchoring scheme. In this figure, we assume $K_1 = K_2 = 3$. We can see that when the CMR is low, the static local anchoring scheme involves higher traffic load.

B. Sensitivity to the Variance of the RA Residence Time

We assume that the RA residence time has a Gamma distribution. For a Gamma distribution, the variance is $V = \frac{\mu^2}{\gamma}$, i.e. a large γ implies a small variance.

Fig.5 shows the effect of γ on M'/M, F'/F and C'/C, respectively. In these figures, we know that large variance means the RA numbers the user crossed between two consecutive call arrivals vary greatly. The result makes the M'/M ratio increase and F'/F decrease; However the net effect on C_F/C_B is not significant.

V. Conclusions

In this paper, we proposed a new location management scheme—pointer forwarding based local anchoring (POFLA) scheme. In this scheme, one mobility agent and two kinds of pointers are introduced. The location update to the HLR can be mitigated by setting up pointer from the mobility agent or the previous VLR to the current VLR . The scheme can reduce the long distance signaling traffic at the expense of certain increase in the local signaling traffic. The advantage of the POFLA is that it can keep the call delivery cost low and reduce the total system cost at the same time. In this paper, we also undertake the performance comparison of the new scheme with the per-user forwarding scheme, the local anchoring scheme and the two-level pointer forwarding scheme using analytical approach.

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