Location Management Employing Two-Level Forwarding Pointers in PCS Networks

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Abstract— **In this paper, we present a new location tracking scheme which intends to mitigate the signaling traffic for location management in the PCS systems. For a PCS network to effectively deliver services to its mobile users, it must have an efficient way to locate the mobile users. The location management fulfills this task through location registration and paging. To reduce the signaling traffic, many schemes such as Local Anchor (LA) scheme, per-user caching scheme and pointer forwarding scheme have been proposed. In our two-level forwarding strategy, we choose a set of VLRs traversed by users as the Mobility Agents (MA), which form another level of location management to make many registrations localized. Pointers can then be setup between VLRs as the traditional pointer forwarding scheme as well as between MAs. The numerical results show that this strategy can significantly reduce the network signaling traffic for users with low CMR without increasing much of the call setup delay.**

I. INTRODUCTION

The Personal Communications System (PCS) can provide wireless communication services to users on the move. It is important for PCS networks to have an efficient way to locate where the mobile users are [7]. In order to improve the system performance, many research works have been carried out to overcome heavy signaling traffic problem [6]. The local anchor (LA) scheme, proposed by Ho and Akyildiz[3], reduces the signaling traffic by using a local anchor. The drawback of this scheme is that when a user keeps moving constantly without receiving any call, the updates to LA may become costly, a similar bottleneck as the HLR is. Jain and Lin proposed another scheme called per-user pointer forwarding scheme[4]. The traffic to the HLR is decreased by using the pointer chain, the penalty, however, is the time delay for tracking a mobile user when a call to the user arrives. To avoid long setup delay, a threshold of the length of the pointer chain is used. The user needs to perform registration to the HLR after the chain threshold is reached. In order to overcome the drawbacks of the above two schemes, we propose a two-level pointer forwarding strategy. Two kinds of pointers are used in this scheme. In our scheme, some VLRs are selected as the Mobility Agents (MA), which will be responsible for location management in a larger area comparing to the RAs and can be geographically distributed. The pointers between MAs are level_1 pointers and those between VLRs in the same charging domain of MAs are level_2 pointers. Calls to a given user will query the HLR first and follow the level_1 pointer chain to the current MA, then find the user's current VLR by tracking the level_2 pointer chain. The user does not need to update the HLR until the level_1 pointer chain threshold is reached. The chain threshold in two-level pointer forwarding strategy can be much longer than that in simple pointer forwarding scheme, but can have shorter call setup delay due to the level_1 pointer chain. The two-level pointer forwarding scheme can avoid the possible costly updates to HLR and the bottleneck of local anchor. More importantly,the thresholds for the pointer chains are two parameters which can provide more flexibility in the design comparing to the one-parameter traditional pointer forwarding strategy.

This paper is organized as follows. In section 2, we describe the basic PCS network architecture. Section 3 introduces the basic IS-41 location management and the new two-level point forwarding strategy in detail. We analyze the performance of the new scheme and compare it with the basic IS-41 scheme analytically in section 4. We also compare the performance of the new scheme with those of per-user and local anchor schemes in section 5. Section 6 provides the conclusions.

II. PCS NETWORK ARCHITECTURE

In the PCS networks, the service area covered by a PCS network is divided into cells. Each cell is primarily served by one base station, although a base station may serve one or more cells. An RA consists of an aggregation of a number of cells, forming a contiguous geographical region. The signaling network used to set up calls is distinct from the network used to actually transport the information contents of the calls. Specially, we assume a Common Channel Signaling (CCS) network is used to set up calls which uses the Signaling System No.7 (SS7) protocols. All the base stations in an RA are connected via a wire-line network to an end-office switch or Service Switching Point (SSP). Each SSP serves an RA. All the SSPs of different RAs are in turn connected to Local Signaling Transfer Points (LSTP), which are connected to a Regional STP (RSTP). The RSTPs are also connected to a Service Control Point (SCP). Each SCP is equipped with a HLR database. For simplicity, we assume each VLR is associated with one Mobile Switching Center (MSC), which connects the BSs and backbone communication infrastructure. Therefore, we assume that an MSC, an SSP and an VLR database are associated together to serve an RA. The configuration may vary in practice, however, the assumption is reasonable for performance analysis. Since we do not deal with the content of the messages, we assume that the message sizes are equal for all transactions. We will com-

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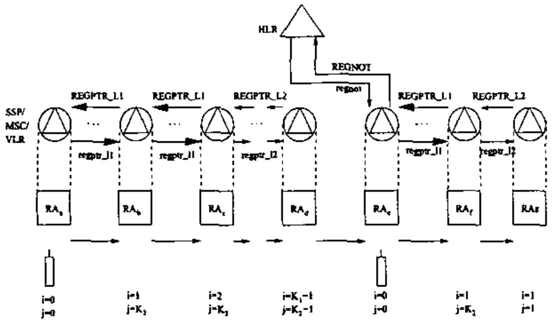

Fig. 1. The *TwoLevelFwdMOVE()* procedure

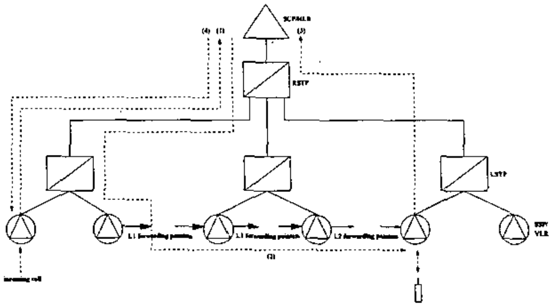

Fig. 2. The *TwoLevelFwdFIND()* procedure

pare the cost of the basic strategy with the two-level forwarding scheme in terms of signaling traffic.

III. TWO-LEVEL POINTER FORWARDING STRATEGY

To facilitate the presentation, the following two operations are defined

1. *MOVE*: the PCS user moves from one RA to another, and
2. *FIND*:determinati on of the RA where the PCS user is currently located.

A. Basic user location management scheme in IS-41

We call the *MOVE* and *FIND* used in current PCS standards such as IS-41 or GSM MAP the *BasicMOVE* and *BasicFIND*. In the *BasicMOVE* procedures, when a mobile terminal detects that it is in a new registration area, it will send a registration message to the new VLR. The new VLR forwards the registration to the user's HLR. The HLR sends confirmation message back and sends a cancellation message to the old VLR, then the registration procedures end. In the *BasicFIND* procedure, when a switch detects a call is originated in its charge area, the switch queries the callee's HLR. The HLR will query the callee's current VLR. When the HLR receives the feedback from the VLR and forwards it back to the calling party, the procedures complete.

B. Two-level pointer forwarding scheme

The two-level pointer forwarding procedures modify the basic procedures as follows. When a mobile terminal moves from one RA to another, it informs the switch (and the VLR) at the new RA about the old RA. It also informs the new RA about the previous MA it was registered. The switch at the new RA determines whether to invoke the *BasicMOVE* or the *TwoLevelFwdMOVE* procedures.

In *TwoLevelFwdMOVE*, the new VLR exchanges messages with the old VLR or the old MA to set up a forwarding pointer from the old VLR to the new VLR. If a pointer is set up from the previous MA, the new VLR is selected as the current MA. The *TwoLevelFwdMOVE* procedures do not involve the user's HLR. Fig.1 shows a *Two-Level Forward MOVE* procedures with level_1 pointers chain threshold limited to 3. Assume a user moves from RAa to RAg (these RAs are not necessary to be adjacent) and RAa is the user's MA. When the user leaves RAa but before enters RAb, the user informs the new VLRs and the level_2 pointers are built from the old VLR to the new VLR. When the user enters RAb, the chain threshold for level_2 pointer is reached, so RAb is selected as the user's new MA and a level_1 pointer is set up from the old MA to the new MA. At the same time, level_2 pointer chain is reset. The similar procedures are used at RAc. A level_1 pointer is set up from RAb to RAc, and the VLR in RAc is the new user's MA. As the user keeps moving, in RAe, the threshold of level_2 pointer chain is reached again, while this time the threshold of the level_1 pointer chain is reached too. Instead of exchanging information with the previous MA, the *BasicMOVE* procedure is invoked. The messages REGPTR_L1 and REGPTR_L2 are messages from the new VLR to the old VLR specifying that a level_1 or level_2 forwarding pointer is to be set up; messages regptr_l1 and regptr_l2 are the confirmations from the old VLR (or MA). In this figure, the VLRs in RAa, RAb, RAe and RAf are selected as the user's MAs.

The *TwolevelFwdFIND* procedure is invoked for the subsequent calls to the user from some other switches. The user's HLR is queried first as in the basic strategy, and a pointer to the user's potentially outdated MA is obtained. The pointer chain is followed to find out the user's current location (see Fig.2). As we can see, in the two-level forwarding scheme, the chain length can be longer than that in the basic pointer forwarding scheme without increasing the *Find* penalty significantly. The previous study [4] shows that more saving can be obtained with longer chain. However, the pointer chain length is limited by the delay requirement. By appropriately tuning the two thresholds in our schemes, we can mitigate the signaling cost without too much increase in the call setup delay.

IV. PERFORMANCE ANALYSIS

We characterize the classes of users according to their call-to-mobility ratio (CMR). If calls are *received* by the user at a mean rate λ and the time the user resides in a given RA has a mean $1/\mu$, then the CMR, denoted as p, is given by

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

We define C_B and C_F to be the total costs of maintaining the location information (location updating) and locating the user (location tracking) between two consecutive calls for the basic strategy and the two-level forwarding strategy, respectively. The following notations will be used in our analysis:

$m =$ the cost of a single invocation of *BasicMOVE*.
$M =$ the total cost of all the *BasicMOVEs* between two consecutive calls.
$F =$ the cost of a single *BasicFIND*.
$M' =$ the expected cost of all *TwoLevelFwdMOVEs* between two consecutive calls.
$F' =$ the average cost of the *TwoLevelFwdFIND*.
$S_1 =$ the cost of setting up a forwarding pointer (level_1 pointer) between MAs during a *Two-LevelFwdMOVE*.
$S_2 =$ the cost of setting up a forwarding pointer (level_2 pointer) between VLRs during a *Two-LevelFwdMOVE*.
$T_1 =$ the cost of traversing a forwarding pointer (level_1 pointer) between MAs during a *Two-LevelFwdFIND*.
$T_2 =$ the cost of traversing a forwarding pointer (level_2 pointer) between VLRs during a *Two-LevelFwdFIND*.
$K_1 =$ the threshold of level_1 pointer chain.
$K_2 =$ the threshold of level_2 pointer chain.

Then, we have

$$C_B = M + F = m/p + F. \tag{2}$$
$$C_F = M' + F'. \tag{3}$$

Now, we need to derive formulas for M' and F'. We further make the following assumptions.

1. The call arrivals to a user form a Poisson process with arrival rate λ.
2. The residence time of a user at a registration area is a random variable with a general density function $f_m(t)$ and a Laplace transform $f_m^*(s)$.

The expected residence time of a user at an RA is $1/\mu$. We denote $g = f_m^*(\lambda)$ for convenience. With these assumptions, it can be shown that:

$$\begin{aligned} M' &= \frac{S_2}{p} + \frac{(1-g)g^{K_2-1}(S_1-S_2)}{p(1-g^{K_2})} \\ &\quad + \frac{(1-g)g^{K_1K_2-1}(m-S_1)}{p(1-g^{K_1K_2})}. \end{aligned} \tag{4}$$

$$\begin{aligned} F' &= F + \frac{[1-K_1K_2g^{K_1K_2-1}+(K_1K_2-1)g^{K_1K_2}]T_2}{p(1-g^{K_1K_2})} \\ &\quad + \frac{g^{K_2}-K_1g^{K_1K_2}+(K_1-1)g^{(K_1+1)K_2}}{(1-g^{K_1K_2})(1-g^{K_2})} \\ &\quad \cdot \frac{(T_1-K_2T_2)(1-g)}{pg}. \end{aligned} \tag{5}$$

For demonstration purpose, we assume that the RA residence time of aus er is Gamma distributed with mean $1/\mu$. The Laplace transform of a Gamma distribution is

$$g = f_m^*(\lambda) = (\frac{\gamma\mu}{\lambda+\gamma\mu})^\gamma = (\frac{\gamma}{p+\gamma})^\gamma. \tag{6}$$

In particular, when $\gamma = 1$,we have an exponential distribution for the RA residence time.

Now,we consider the situation when the RA residence time is exponentially distributed. By setting $\gamma = 1$ in (6), and from (4), (5) and (3) we obtain

$$\begin{aligned} C_F &= F + \frac{T_2+S_2}{p} + \frac{S_1-S_2}{(1+p)^{K_2}-1} \\ &\quad + \frac{m-S_1-T_2K_1K_2}{(1+p)^{K_1K_2}-1} \\ &\quad + \frac{(1+p)^{K_1K_2}-K_1(1+p)^{K_2}+K_1-1}{(1+p)^{K_2}-1} \\ &\quad \cdot \frac{T_1-K_2T_2}{(1+p)^{K_1K_2}-1}. \end{aligned} \tag{7}$$

We notice that updating the HLR and performing a *BasicFIND* involve the same number of messages between HLR and VLR databases, so we set $m = F = 1$. We also assume that the cost of setting up a forwarding pointer is about twice the cost of traversing it, since twice as many messages are involved, i.e., we set $S_1 = 2T_1$ and $S_2 = 2T_2$. We consider $S_2 = \delta$ with $\delta < 1$. Since the level_1 pointer is more expensive than level_2 pointer in terms of setup cost, we can assume $S_1 = KS_2$ with $K \geq 1$. It is reasonable to assume that $S_1 < 1$ too. From (2), (4), (5) and (7), we obtain

$$C_B = 1 + \frac{1}{p}, \tag{8}$$

$$\frac{M'}{M} = \delta + \frac{(K-1)\delta p}{(1+p)^{K_2}-1} + \frac{(1-K\delta)p}{(1+p)^{K_1K_2}-1}, \tag{9}$$

$$\begin{aligned} \frac{F'}{F} &= 1 + \frac{\delta}{2p} - \frac{K_1K_2\delta}{2[(1+p)^{K_1K_2}-1]} \\ &\quad + \frac{(1+p)^{K_1K_2}-K_1(1+p)^{K_2}+K_1-1}{(1+p)^{K_2}-1} \\ &\quad \cdot \frac{\delta(K-K_2)}{2[(1+p)^{K_1K_2}-1]}, \end{aligned} \tag{10}$$

$$\begin{aligned} \frac{C_F}{C_B} &= \left\{ 1 + \frac{3\delta}{2p} + \frac{(K-1)\delta}{(1+p)^{K_2}-1} + \frac{1-(K+\frac{1}{2}K_1K_2)\delta}{(1+p)^{K_1K_2}-1} \right. \\ &\quad + \frac{(1+p)^{K_1K_2}-K_1(1+p)^{K_2}+K_1-1}{(1+p)^{K_2}-1} \\ &\quad \left. \cdot \frac{\delta(K-K_2)}{2[(1+p)^{K_1K_2}-1]} \right\} \frac{p}{1+p}. \end{aligned} \tag{11}$$

In Fig.3 and Fig.4, we plot the costs as functions of CMR for various values of K_1, K_2 and δ.

Fig.3(a) shows that under certain conditions ($\delta = 0.3, K = 1.5$), two-level forwarding can result in $60\% - 70\%$ reductions in location update cost comparing to the basic strategy.

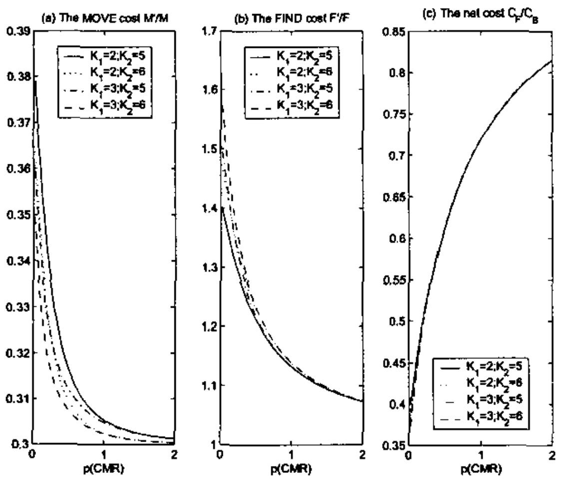

Fig. 3. Relative *MOVE* and *FIND* costs of forwarding with $\delta = 0.3, K = 1.5$

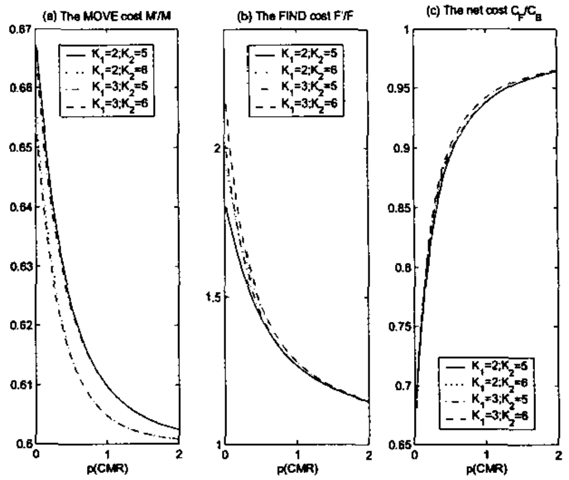

Fig. 4. Relative *MOVE* and *FIND* costs of forwarding with $\delta = 0.6, K = 1.5$

However, the Fig.3(b) indicates that the *FIND cost* of the two-level forwarding scheme is higher than basic strategy. The reason is that the call for the user needs to traverse the pointer chain to find the user's current location. However, as we observe in Fig.3(c), the two-level forwarding strategy can result in *20%−60% reduction in the total cost. The improvement of total* cost is more pronounced when p is small, this is because most *MOVEs* do not result in HLR updates but pointer creations. Examining the Fig.3(a) again, we can observe more saving in the *MOVEs* with longer pointer chain because more updates to HLR can be substituted with pointer creations. However, long pointer chain increases the *FIND* penalty at the same time. An advantage of two-level forwarding strategy is that it can have long pointer chain without increasing the delay penalty significantly, because the pointer chain can be shortened by the level_1 pointers between MAs. Under the assumed conditions, the maximum pointer chain length can increase from 10 to 18 with less 20% *FIND* penalty increase. We have also carried out the cost analysis for varying value K and obtained similar results shown in Fig.3 (we omit all figures due to the space limitation). We observe that even when the cost of setting up a level_1 pointer exceeds the cost of updating HLR, there is only a slight increase of the total cost. The *MOVE* and *FIND* costs both increase because the cost of setting up and traversing level_1 pointers chain increases. Since level_1 pointer is built up only when level_2 pointer chain threshold is reached and the number of level_2 pointers is dominant, the two-level forwarding strategy is not sensitive to the variation of K. The Fig.4(a)-(c) indicate that the level_2 pointer operation cost δ has more effect on the system performance. In Fig.4(a)-(c), δ is increased from 0.3 to 0.6. The *MOVE, FIND* and the net cost all increase. Finally, we can observe that for small δ,increasing pointer chain length reduces the cost of two-level forwarding scheme (because the pointer operations are cheaper). As we can see from the previous sections, the per-user forwarding scheme[4] is a special case of the the two-level forwarding scheme. When we set $K_1 = 1$ or $K_2 = 1$, the two-level forwarding strategy reduces to the per-user forwarding scheme.

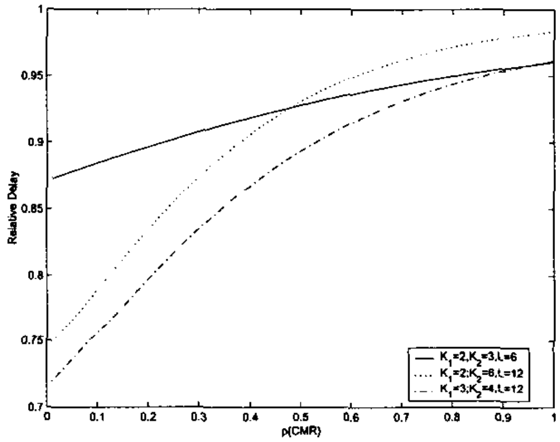

Fig. 5. Relative Delay with $\delta = 0.3, K = 1.5$

V. PERFORMANCE COMPARISONS

One of the advantages of the two-level pointer forwarding strategy is that it can have a long pointer chain without much increase of the *FIND* delay. The longer the pointer chain is, the fewer updates to the HLR.

In order to see this more clearly, we plot the relative finding delay for these two schemes in Fig.5. The L is the pointer chain length threshold of per-user forwarding scheme. The relative delay here is defined as the ratio of the finding delay for two-level pointer forwarding scheme (the proposed scheme) to that for per-user pointer forwarding scheme. In Fig.5, we assume that the signaling message will travel back and forth along the same route from HLR to the user's current VLR and that the traversing delay for level_1 pointer is 1.5 times of that for level_2 pointer. As we can see from Fig.5, when the CMR is less than 1, the delay in two-level pointer forwarding scheme is significantly less than that in per-user forwarding strategy. The effect is more obvious when the pointer length is longer. Since the thresholds for pointer chain are two parameters in our scheme, it is more flexible for the system operator to select different strategies for different users. We observe from the curves, for pointer chain length 12, the delay for $K_1 = 3, K_2 = 4$ is less than that for $K_1 = 2, K_2 = 6$. The reason is that the system traverses more level_1 pointers and less level_2 pointers in the first case. However, there are more local signaling message exchanges in the first case because the level_2 pointer chain threshold is shorter. This is the tradeoff the operator can make for different classes of users with different QoS requirements.

In the local anchor scheme, a VLR near the user is selected as the local anchor, and the user will update his/her location to the local anchor upon every move. The local anchor will not change until a call arrives to the user. The advantage is that the local anchor is usually closer to the user than HLR is, so the total cost will be saved. However, if the user keeps moving away from his/her LA, the cost of updating the location to the LA will become higher and higher, the total cost will become higher too. For the comparison purpose, we will use the same notation in [3] described as follows:

h_1 : The cost for sending a signaling message from one MSC to another MSC through the HLR.
h_2 : The cost for sending a signaling message from one MSC to another MSC through the LSTP.
h_3 : The cost for sending a signaling message from one MSC to another MSC through the RSTP.

Because the cost in local anchor scheme for location update and call delivery heavily depends on the user location, we need to consider various location scenarios. Three location types are defined in [3]: *HOME*, *LOCAL* and *REMOTE*. The authors also gave nine possible combinations of the location types when an additional movement, the $(n+1)th$ movement, is performed after the nth movement (see [3] for details). In this comparison, for simplicity, we choose two scenarios: (1) three movement combination types–the user moves around the LA, and the probability for each type is $\frac{1}{3}$;(2) four movement combination types–the user moves away from the LA, the probability for one type is 0.1 and the probability for each of the rest three types is 0.3. Based on these two scenarios, we compare the costs for the proposed scheme and the local anchor scheme. Table I shows the relative cost of the LA and two-level pointer forwarding schemes. It can be expected that the values for scenario (1) will be smaller than those for scenario (2). As we can see from table I, h_2 is normalized to 1 because it is the smallest one. The two-level pointer forwarding strategy could be adopted if its values are smaller than scenario (2). For the parameter sets 1, 2 and 4, the two-level pointer forwarding scheme performs better than the LA scheme. The smaller the local signaling cost relative to the long distance signaling cost, the better the result. For the parameter set 3, the cost for sending a signaling message through RSTP is not more expensive than h_2. In this case, it is more efficient to set a long pointer from LA to the user than to set a chain consisting of shorter pointers, which is why the scenario (2) is smaller.

TABLE I
RELATIVE COST FOR LA AND TWO-LEVEL POINTER FORWARDING STRATEGIES

Set	h_1	h_2	h_3	Sce. (1)	Sce. (2)T	wo_level
1	10	1	9	0.0667	0.615	0.3668
2	10	1	5	0.0667	0.355	0.3153
3	10	1	2	0.0667	0.16	0.2767
4	3	1	3	0.2222	0.75	0.6233

VI. CONCLUSIONS

In this paper, we propose a new location management scheme called the two-level forwarding strategy, which intends to reduce the cost of location management by localizing or distributing the signaling traffic and to overcome the HLR bottleneck problem. The traditional pointer forwarding scheme reduces the total cost with the expense of longer call setup time than IS-41. The two-level forward strategy,ho wever, can shorten the pointer chain automatically when the chain is long, then reduces the call setup penalty while improves the system performance at the same time. For the 3G wireless communication systems, a new *gateway location register* is introduced between the VLR/SGSN and the HLR, so the proposed scheme can be easily tailored for the 3G wireless systems in which gateway location register is used.

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