Flat Location Management Scheme for PCNs

Gopal Dommety
Dept. of Computer Science
Ohio State University
Columbus, OH 43210
dommety@cis.ohio-state.edu

Malathi Veeraraghavan
Bell Laboratories
101 Crawfords Corner Road
Holmdel, NJ 07733
mv@bell-labs.com

Mukesh Singhal
Dept. of Computer Science
Ohio State University
Columbus, OH 43210
singhal@cis.ohio-state.edu

Abstract

This paper presents a "flat" mobile location management scheme for Personal Communication Networks (PCNs) with the goal of reducing both mobile tracking and location costs. Mobile tracking costs are reduced by the use of one-level tracking for mobiles in their "home area", and a two-level tracking approach for mobiles visiting other areas. Mobile location costs are reduced by using an improved mobile location strategy, which requires a one-hop message exchange for mobiles in their home area, and a two-hop message exchange for mobiles visiting other areas. Analytical models are set up to analyze the performance of the flat scheme, and compare it with that of the other approaches. The measures of comparison used are the computation cost (database accesses), the communication cost (signaling messages), the average total cost, and the mobile location cost (call setup delay). For all these measures, the proposed flat scheme performs better than the location management scheme defined in the IS-41 standard. Results also show that for medium and high values of call-to-mobility ratio (> 0.07, i.e., less than 14 moves per call), the flat scheme performs better than other approaches proposed in the literature.

Keywords: Personal Communication Networks (PCNs), Mobility Management, Location Registers, Mobile Tracking, Mobile Location, Call-to-Mobility Ratio (CMR).

1. Introduction

Mobility management algorithms enable networks to support mobile users allowing them to move, while simultaneously offering them incoming calls, data packets and other services. In connection-oriented networks, *mobility management* consists of handoff management and location management. *Handoff management* consists of rerouting connections, on which the mobile user was communicating while moving, while maintaining the quality of service of the connections. Location management consists of tracking mobiles and locating them prior to establishing an incoming call. There are two aspects to the problem of location management, mobile tracking and mobile location. *Mobile tracking* is the procedure by which the network elements update information about the location of the mobile. *Mobile location* is the procedure by which the network finds the exact location of the mobile. The information acquired during the tracking phase is used in the locating phase.

In this paper, we propose a solution for the location management problem in Personal Communication Networks (PCNs). PCNs provide communication services to mobile users who move freely within the coverage area of the network. Location management procedures are defined as part of the North American IS-41 cellular standard [1], and the European GSM standard for mobile communications [2]. Several other schemes have also been proposed to track and locate users within these networks [3-8]. Previous studies [9][10] have shown that with predicted levels of usage, there will be significant loads on the signaling network and on network databases. References [3-5] illustrate how their location management schemes reduce the load on the signaling network. In this paper, we propose a *flat location management scheme* with the goal of not only reducing the signaling load (communication cost) but also the number of database accesses (computation cost), and mobile location delay (and hence call setup delay).

The rest of the paper is organized as follows. In Section 2, we briefly review the prior work on location management in PCNs. In Section 3, we describe the proposed flat scheme for location management. A comparative analysis of the flat scheme with existing schemes is included in Section 4. Conclusions are presented in Section 5.

2. Review of existing location management schemes

Location management schemes track mobiles with the help of a hierarchy of location registers. The number of levels in the hierarchy are different in different schemes. The IS-41 standards scheme [1] for location management is based on a hierarchical arrangement of MSCs (Mobile Switching Centers), VLRs (Visitor Location Registers) and HLRs (Home Location Registers). A minimum of two levels of hierarchy and a maximum of three levels of hierarchy are possible in an IS-41 based network. To reduce signaling costs relative to the IS-41 scheme, the forwarding scheme [3], the anchor scheme [4] and the hierarchical schemes [5-7] propose increasing the number of levels of hierarchy. The first two schemes reduce “long-distance” signaling costs incurred by mobile tracking, while the hierarchical approach reduces “long-distance” signaling costs for both mobile tracking and mobile locating. However, the computation costs of adding extra levels of location registers is not considered.

We observe that instead of increasing the number of levels of hierarchy for all mobiles, a single level of hierarchy could be used for home mobiles to lower both computation and communication costs. In small networks, where the communication costs are not high, the computation cost becomes the dominant factor. In such cases, the need to create VLRs at MSCs, consuming additional computational resources, becomes unnecessary. Even if the network is large, it can be divided into "areas", with mobiles in their home areas directly tracked by their HLRs and mobiles outside their home areas being assigned a proxy HLR while in the remote area. This creates a two-level hierarchy only on an as-needed basis. We thus propose the *flat* scheme to allow for networks to be implemented with a single-level tracking for home mobiles and a "two-level" tracking for "remote" mobiles.

In this paper, we analytically compare the proposed flat scheme with the IS-41 scheme, the anchor scheme, and the forwarding scheme. The hierarchical scheme [5] has been excluded from this comparison, but is considered in detail in a related paper [11]. In the rest of this section, we review details of the IS-41 scheme, the forwarding scheme, and the anchor scheme needed in the subsequent performance analysis.

2.1 Standards approach

Fig. 1 shows the cellular network architecture and the mobile tracking scheme defined in the cellular standards. The network elements consist of BS (base stations), MSCs (Mobile Switching Centers), VLRs (Visitor Location Registers) and HLRs (Home Location Registers). Base stations provide wireless access to mobiles. MSCs are the switching centers through which connections to and from mobiles are made. HLRs and VLRs track the location of mobiles and answer queries for mobile locations. The cellular standards allow for two variations of the network architecture: *col-located VLR/MSCs* and *separated VLRs and MSCs* as shown in Fig. 1.

Mobile tracking begins with mobiles generating registrations to the network. For the purposes of this paper, we assume that *zone-change registrations* are generated by each mobile. Zone-change registrations allow the network to track a mobile user on a larger scale than on a per base station move basis. A z*one* is defined to include all the base stations under an MSC (Mobile Switching Center). Each base station emits a periodic broadcast beacon carrying the zone identifier of the base station. This allows a listening mobile to identify when it moves into a new zone. An effect of this form of tracking is that a *page* needs to be generated by the MSC to determine the exact base station at which a mobile is located during call setup. The zone size, which determines the level of granularity at which mobiles are tracked, should be chosen to limit the number

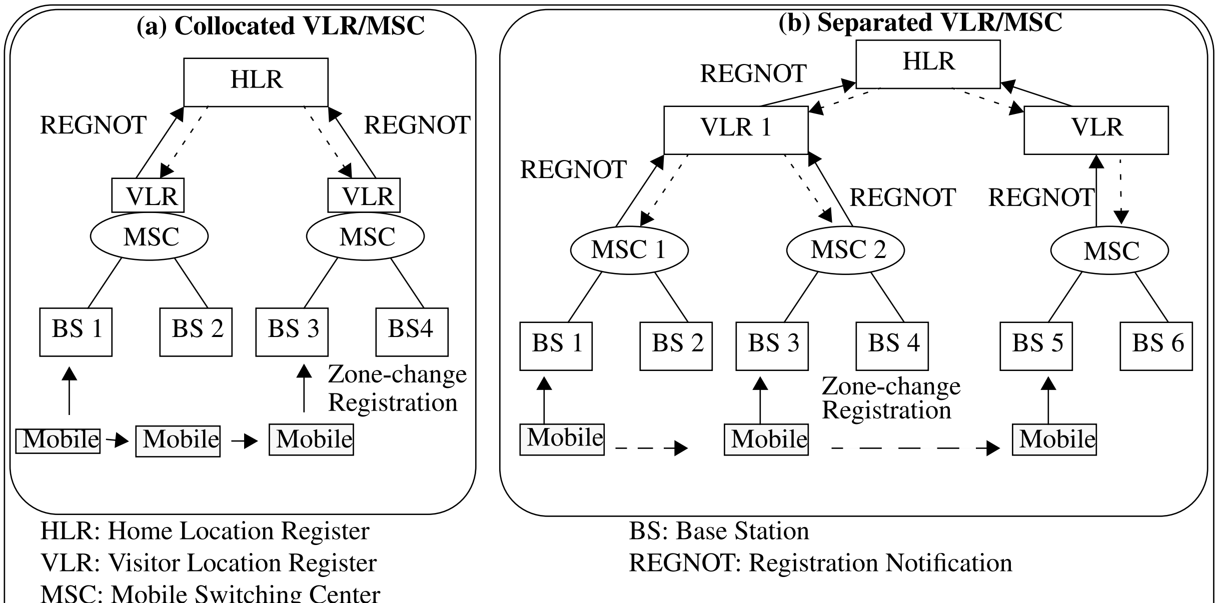

Fig. 1 Mobile location tracking

of registrations received by the network without increasing the paging load significantly. In Fig. 1, when a user moves from base station 1 to base station 2, it does not generate a registration, since both base stations are in the same zone. A zone-change registration is sent by the mobile only when the user moves from base station 2 to base station 3. These registrations are conveyed from the base station to the MSC (Mobile Switching Center) using IS-634 messages [12].

The network response to receiving a registration from a mobile is dependent on the network configuration. As shown in Fig. 1, MSCs may be collocated with VLRs (Visitor Location Registers) or they may be separate. In the network configuration where MSC/VLR are collocated, the MSC on receipt of the IS-634 message sends a REGNOT (Registration Notification) message to the HLR of the mobile, which in turn sends a REGCANC (Registration Cancellation) message to the old MSC/VLR. In the network configuration where MSCs and VLRs are separate entities, the MSC generates a REGNOT message to the VLR, which in turn, generates a REGCANC message to the old MSC, if the old MSC is connected to the current VLR. Otherwise, it generates a REGNOT message to the HLR of the mobile. On receiving the REGNOT message, the HLR then initiates a registration cancellation procedure with the old VLR.

Given the two IS-41-based forms of mobile tracking shown in Fig. 1, the corresponding *mobile location* procedures are shown in Fig. 2. To deliver an incoming call to a mobile M, the calling party's switch (originating switch) sends a LOCREQ (Location Request) message to the HLR of mobile M as shown in Fig. 2. Since cellular telephony networks use geographical addressing, the HLR of a mobile is determined from the identity of the mobile. The HLR sends a ROUTEREQ

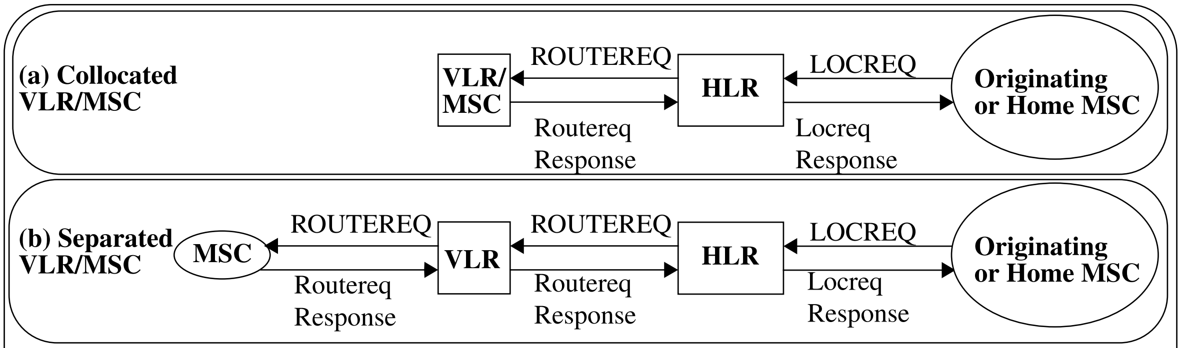

Fig. 2 Locating a mobile for incoming call delivery

(Route request) to the VLR/MSC from which it received the last registration message for mobile M. In case (a), where the VLR is collocated with the MSC, the VLR/MSC allocates a TLDN (Temporary Location Directory Number) for this mobile and returns this value in the response back to the HLR. The HLR sends this parameter in its response to the originating MSC. This allows the originating MSC to initiate connection setup to the MSC of the called mobile. Routing of the connection through the network is done using the TLDN which indicates the far end MSC (of the called mobile). When the call setup message reaches the MSC of the called mobile, the latter issues a page to locate the exact base station at which the mobile is located for call completion. In case (b), two ROUTEREQ messages are required as shown in Fig. 2. While the hierarchical arrangement of separated VLRs and MSCs reduces the signaling traffic generated by mobile tracking, it is clear from Fig. 2b that the penalty paid is increased mobile location delay.

2.2 Forwarding and anchor schemes

In the *forwarding scheme* [3], a chain of forwarding pointers is maintained, as shown in Fig. 3a, to limit the registration (tracking) signaling load. As a user moves between base stations con-

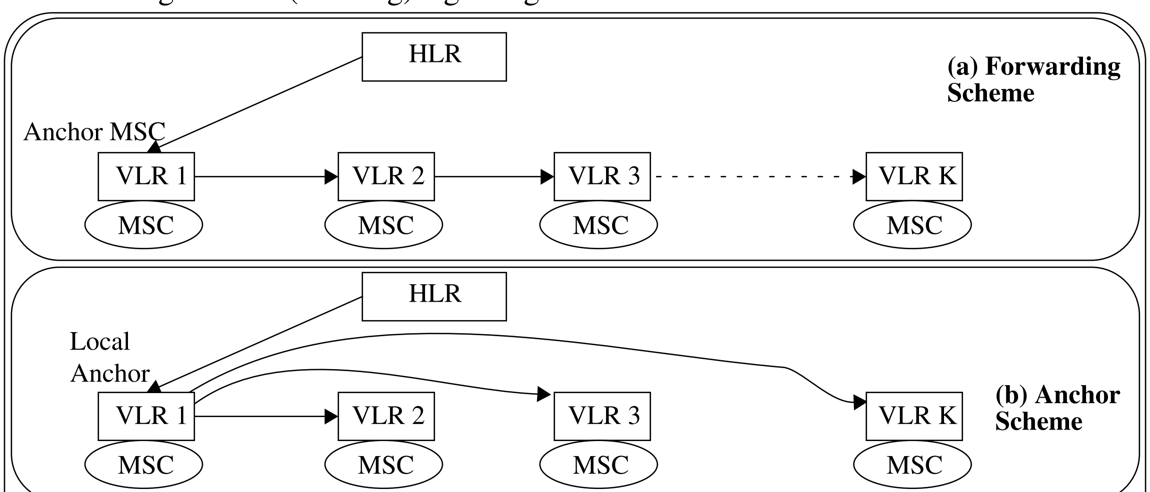

Fig. 3 Two schemes to improve mobile tracking costs

nected to different VLR/MSC nodes, registration messages are sent by the mobile to the network. The new VLR/MSC simply communicates with the old VLR/MSC which adds a pointer to the forwarding chain. Thus, registration signaling traffic is localized. However, during call setup, a chain of pointers need to be traced to locate a mobile, potentially leading to long setup delays. This scheme is proposed for networks with low CMRs (Call-to-Mobility Ratios).

An improvement to this scheme is proposed in [4] where a *local anchor VLR* is created. As users move, the pointer at the local anchor is updated as shown in Fig. 3b. This localizes registration signaling and, at the same time, achieves lower mobile location delays than the forwarding scheme. We note that at low CMRs, the anchor scheme is similar to the IS-41 scheme with separated VLR/MSCs by comparing Fig. 2b and Fig. 3b. In effect, by creating a local anchor, the mobile location requires a three-hop message exchange (HLR -> Anchor VLR/MSC -> Current VLR/MSC). Similarly, in the IS-41 model with separated VLRs and MSCs, the mobile location requires a three-hop message exchange (HLR -> VLR -> MSC). One difference between these two schemes is that the assignment of VLRs to MSCs is static in IS-41, leading to automatic updates of the VLR as a user moves, while in [4], the local anchor is changed either on each call arrival (*static local anchoring*), or in a dynamic manner only if the expected cost is lower (*dynamic local anchoring*). At high CMRs, since the local anchor will be frequently updated to be the current VLR/MSC, the anchor scheme resembles the IS-41 scheme with collocated VLRs/MSCs more closely than the scheme with separated VLRs and MSCs.

The tracking costs of the forwarding scheme are smaller than the tracking costs of the anchor scheme because only two messages are exchanged during a move in the forwarding scheme, while four messages are required in the anchor scheme (to update the local anchor and to cancel records of the mobile in the old VLR). However, the search costs are smaller in the anchor scheme compared to the forwarding scheme. Furthermore in the anchor scheme, if the cancellation of the information at the old VLR is done by a timer-based mechanism, the tracking cost is same as in the forwarding scheme.

3. Proposed flat scheme

In this section, we propose a “flat” scheme for location management in PCNs with the goal of reducing both communication and computation costs. In this approach, we use one level of tracking for mobiles in their “home area”, and a two-level tracking approach only for mobiles visiting other areas, referred to as “remote” mobiles. For home mobiles, the location is tracked directly by the HLR of the mobile. For each remote mobile, a Proxy HLR is assigned in the current "area" of the mobile to track its location. The HLRs of remote mobiles track the Proxy HLR assigned to each such mobile. The "home area" of a mobile could include the entire network of its service provider, if the service provider's network is reasonably contained. For service providers with large networks, local signaling networks are defined, each corresponding to an "area". The home area of a mobile corresponds to the coverage area of the local signaling network in which its home switch is located. Local signaling networks are interconnected by a wide area network for such large service providers.

We first describe the *mobile location procedure* of the flat scheme in Section 3.1 and then present its *mobile tracking* procedure in Section 3.2.

3.1 Mobile location

Fig. 4 shows the mobile location procedure in the presence of such a flat tracking scheme. If

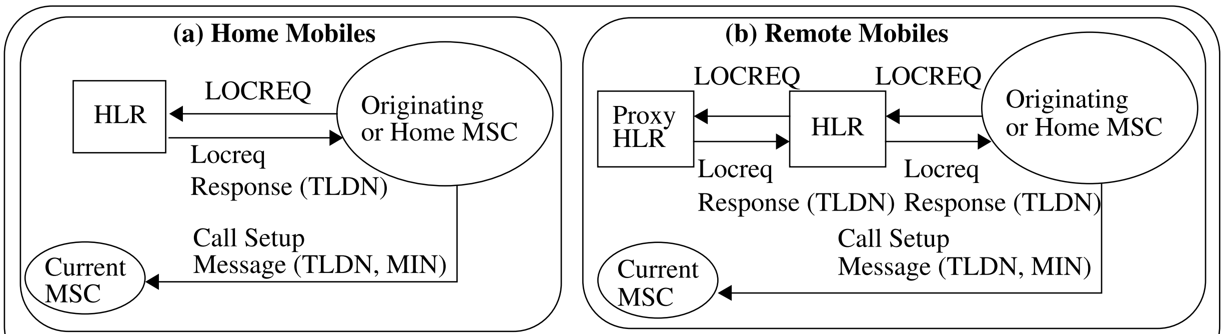

Fig. 4 Mobile location procedures in a flat tracking scheme

the mobile is located in its home network, mobile location only requires a one-hop message exchange. Given that the HLR knows the current MSC of its home mobiles, we note that the HLR can return a TLDN (Temporary Location Directory Number) identifying the current MSC of the mobile without sending a message to the MSC as in the IS-41 scheme (Section 2.1). This solution of HLRs assigning TLDNs is adopted for the location of home mobiles as shown in Fig. 4a. For remote mobiles, a two-hop location request procedure is carried out as shown in Fig. 4b. The originating MSC sends a location query to the HLR of the called mobile. Since the HLR knows the address of the Proxy HLR tracking the called remote mobile, it generates a new location query to the Proxy HLR. The Proxy HLR selects a TLDN based on its knowledge of the current MSC of the called mobile, which is returned in two hops as shown in Fig. 4b. Call setup then proceeds from the originating MSC to the current MSC using the returned TLDN as in the case of home mobiles. Thus, if most mobiles are home mobiles, *mobile location delay is reduced* by only requiring a one-hop location request.

Next, we consider the issue of TLDN to MIN (Mobile Identification Number) mappings, i.e., the mapping of the temporary address (TLDN) to the actual address (MIN) of the mobile. *Two* solutions are possible for this TLDN to MIN mapping problem. The *first* solution is for the HLR/ Proxy HLR to assign a default TLDN (Temporary Directory Local Number) using the identifier of the current MSC at which the mobile is located (given that it knows the MSC locations of its mobiles). For example, if the MSC is identified by 908-872-xxxx, then a default TLDN 908-872-0000 is used for all mobiles. Call setup proceeds using the TLDN from the originating MSC to the MSC of the called mobile since routing of connections to the appropriate switches are based on the first six digits (908-872). Since the TLDN only indicates that the called party is a mobile without an exact association to a specific mobile, the MIN (Mobile Identification Number) of the mobile should be passed as an additional parameter in the call setup message as shown in Fig. 4. Thus, the mobile's actual address (MIN) is *tunnelled* in call setup messages which carry the temporary address (TLDN) of the mobile as the called party address. This can be achieved using a "mobility-related service control" parameter to carry the MIN, much like a CUG (Closed User Group) indicator used for virtual private networking [13].

A drawback of the above solution is that the format of the call setup message needs to be redefined to allow for the tunnelling of MINs. Our *second* solution avoids this drawback by having the current MSC of a mobile assign a TLDN during mobile registration. This assigned TLDN is sent in the REGNOT message to the HLR. In this approach, since the MSC has assigned the TLDN, it can keep a mapping of MINs to assigned TLDNs, which can then be used to determine the specific MIN corresponding to a TLDN during call setup. Thus, MINs do not need to be tunnelled in call setup messages. This in turn implies that no changes are needed to the existing signaling standards. However, this approach was considered in GSM standards as reported in [14]. The reason this scheme was not accepted in the GSM standards is that it is likely that an MSC may run out of TLDNs given that only four digits are typically reserved for endpoints at an MSC, which, in addition to mobiles may also have fixed endpoints. A solution to the problem is arrived at by the observation that the last four digits of the TLDN are BCD (Binary Coded Decimal) numbers and a nibble is used to represent each of the BCD digits. This allows for 64K numbers of which only 10,000 correspond to valid TLDNs. We refer to the rest of the representations as Invalid TLDNs (ITLDNs). To handle the issue of MSCs running out of numbers, the MSC can assign an ITLDN, rather than a valid TLDN, during mobile registration. By maintaining a map of MINs to assigned

ITLDNs, on call arrival to a particular ITLDN, the MIN of the mobile is readily determined.

3.2 Mobile tracking

The basic mobile tracking procedure of the flat scheme is fairly simple. As stated earlier, mobiles in their home areas are tracked directly by their HLRs. Remote mobiles are assigned Proxy HLRs. When such a mobile moves from one area to the next, a new Proxy HLR is assigned to track the mobile in its new area. The assignment of Proxy HLRs for remote mobiles localizes the registration traffic. In other words, only mobiles moving out of the current network area will incur long distance registration signaling. This hybrid scheme will incur a lower communication cost than an "all-out flat" scheme, where all mobiles, irrespective of whether they are home mobiles or remote mobiles, register directly with their HLRs. Thus, the choice of choosing a two-level hierarchy for remote mobiles will reduce mobile tracking cost.

To further reduce mobile tracking costs without increasing mobile location delay, we propose an add-on concept to the basic tracking scheme by creating a logical base station controller-HLR interface to send registration messages directly from the BSC (Base Station Controller) to HLR bypassing the MSC. This proposal results from the observation that the current reference point definitions, with different protocols defined for the base station-MSC interface (IS-634) and for the MSC-HLR interface (IS-41), has certain inefficiencies. Fig. 5 shows the protocol stacks for

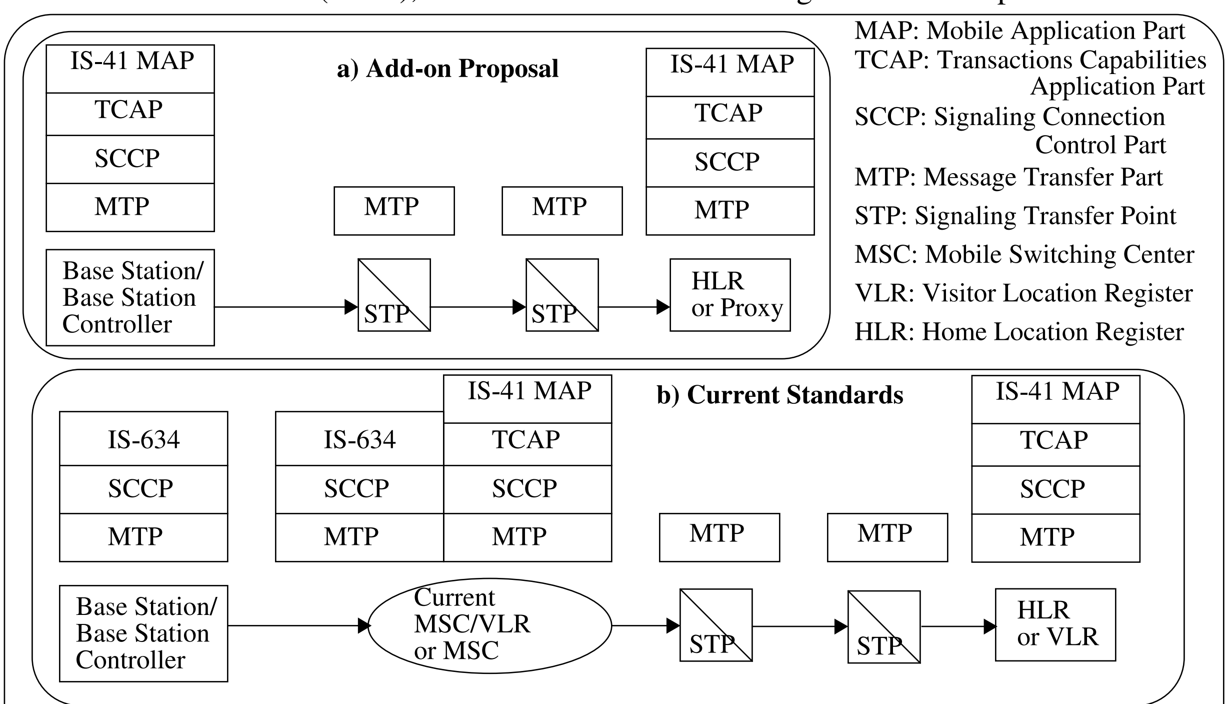

Fig. 5 Comparison of mobile tracking approaches

this proposed scheme in comparison with the one used in the current standards. In our proposed scheme, an IS-41 MAP REGNOT message is created by the base station/base station controller. This message is routed through datagram routers, STPs (Signaling Transfer Points), where only the MTP (Message Transfer Part) layer is terminated. Termination of the IS-41 MAP layer is only done at the HLR. On the other hand, in the current standards approach, an MSC needs to receive and parse IS-634 messages, and then create IS-41 MAP messages to the HLR. This will clearly add to both the computation and communication costs of mobile tracking. In the proposed scheme, base stations still retain the notion of "zones" and only receive zone-change registrations as shown in Fig. 1. Thus, the same number of registrations are received by the network irrespective of whether the base station is sending the REGNOT directly to the HLRs or the MSC sends the REGNOT.

In order for a base station to send the REGNOT to the appropriate location register, the base station first needs to determine whether the registering mobile is a home or remote mobile. Since cellular networks use hierarchical network-based addressing, the base station can determine this from the MIN of the mobile. Next, for home mobiles, it needs to know the identities of the HLRs of mobiles. Given the use of hierarchical addressing, each range of MINs can be associated with an HLR address. For remote mobiles, if there is only one Proxy HLR per network area, then the base stations simply send all registrations for remote mobiles to the Proxy HLR. However, if there are multiple Proxy HLRs, then a base station to which a mobile moves needs to know which Proxy HLR to send the registration for a given MIN. One approach to solve this problem is to have each remote mobile know the identity of the Proxy HLR tracking it. This identifier can be sent by the network in response to the first registration. Subsequently, as the remote mobile moves, it includes the identifier of its Proxy HLR in its registration allowing the base station to send the REGNOT to the appropriate Proxy HLR.

A major implication of the proposal shown in Fig. 5a is that Base Station Controllers (BSCs) will now require IS-41 software. This will clearly increase the cost of base station controllers. Furthermore, if the registration messages do not pass through the MSC, the second solution described in Section 3.1 requiring the MSCs to assign ITLDNs to the mobiles during the registration procedure cannot be used. Therefore, only the first solution of having HLR/Proxy HLRs assign default TLDNs can be used, which implies that the call setup message format needs to be changed. Due to these implications, for analysis purposes, we consider the flat scheme without this add-on proposal of sending registration messages directly to the HLR/Proxy HLR[1].

4. Performance analysis

In this section, we analytically compare four schemes for their mobile tracking and locating costs. The four schemes are the IS-41 scheme with collocated MSC/VLRs (Section 2.1), the forwarding scheme (Section 2.2), the anchor scheme (Section 2.2), and the flat scheme proposed in Section 3. We use a generalized cost formulation for the computation of tracking and locating costs. This generalized formulation allows for the comparison of *signaling loads* (communication costs), *database accesses* (computation cost), and *call setup delays* (mobile location delays) of the different schemes.

For analysis purposes, we use a simplified PCN architecture as shown in Fig. 6. This reference

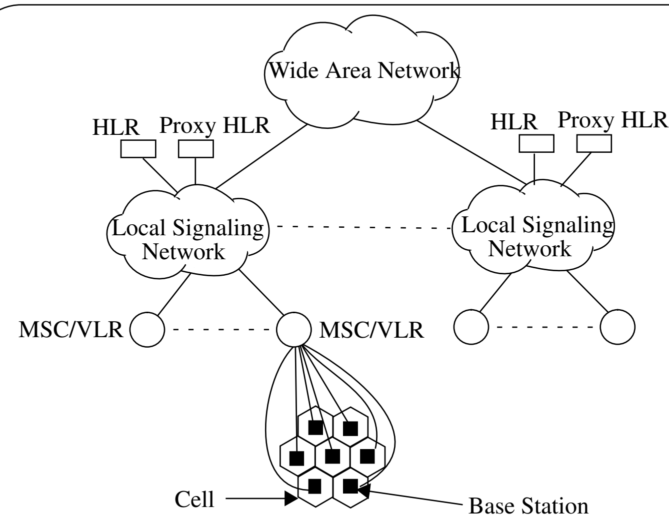

Fig. 6 Reference signaling architecture

architecture is used for all the schemes being analyzed. The entire coverage area is divided into cells, and cells are grouped into zones or registration areas. Cell sites belonging to a zone are connected to an *MSC/VLR* (Mobile Switching Center/Visitor Location Register). MSC/VLRs within an "area" are interconnected by a *Local Signaling Network (LSN)*. Messages are sent between LSNs via the *Wide Area Network*. Messages sent over the wide area network are assumed to be "long distance signaling messages", and hence incur a larger cost than messages sent within an LSN. HLRs within an area are connected to MSC/VLRs in that area via the Local Signaling Network of that area. The coverage area of the Local Signaling Network in which a mobile's HLR is located, is termed the "home area" as mentioned in Section 3. When away from the home area, the mobile is termed a "remote mobile". The HLRs and MSC/VLRs shown in Fig. 6 are used in

1. In spite of the implications, we recorded the add-on scheme in this paper for future consideration in designing of new PCN configurations.

the IS-41 scheme, the anchor scheme, and the forwarding scheme. For the flat scheme, we introduce a new set of location registers called *Proxy HLRs* also connected to the LSNs as shown in Fig. 6. In the flat scheme, VLR functionality is not needed in the MSC. The notation used in the analysis is listed in Table 1.

Table 1: Notation

Symbol	Meaning
L	Cost to transport a signaling message in a Local Signaling Network
R	Cost to transport a signaling message in a Wide Area Network
f	Fraction of the mobiles that are remote (i.e., not in their home network area)
Q_h	Cost to query/update a HLR/Proxy HLR
Q_s	Cost incurred at an MSC
Q_{sv}	Cost incurred at an MSC/VLR
k	Maximum number of MSC/VLRs in the forwarding chain allowed in the forwarding scheme
t	Fraction of calls that originate within the current Local Signaling Network of the called mobile
q	Fraction of moves of the mobile that result in movement out of the current Local Signaling Network

4.1 Tracking/locating costs in the flat scheme

For analysis purposes, as stated in Section 3.2 we assume that the flat scheme is implemented without the add-on proposal shown in Fig. 5a. In other words, mobile tracking is as shown in Fig. 5b with MSCs generating REGNOTs and the mobile location procedure is as shown in Fig. 4. The mobile tracking procedure used in the flat scheme is illustrated in Fig. 7. Mobile tracking cost

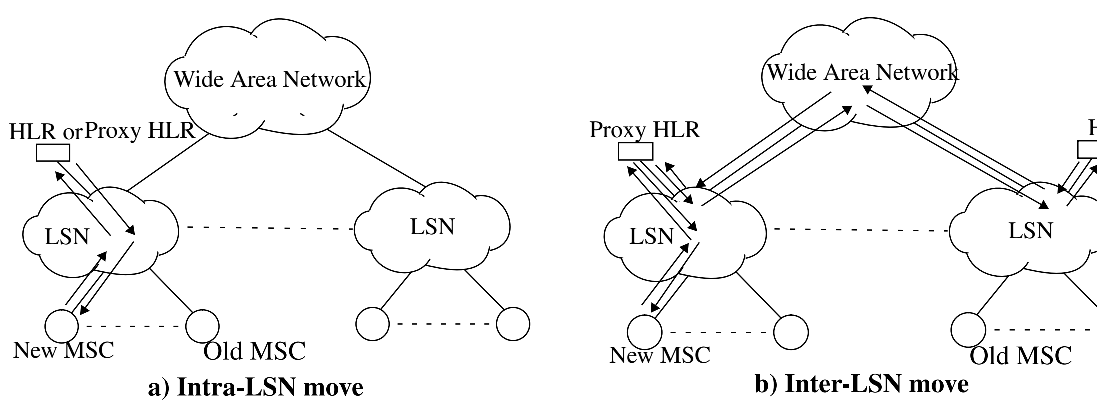

Fig. 7 Mobile tracking procedures in the flat scheme

consists of *(i)* cost incurred at the new MSC ( ), *(ii)* cost incurred at the HLR (for home mobiles) or the Proxy HLR (for remote mobiles)(Q_h), and *(iii)* cost of signaling between the HLR/Proxy HLR and the new MSC ($2L$). When the mobile moves across from one network area (area served by a Local Signaling Network) to another, it incurs an additional cost of $(2(L+R+L)+Q_h)$, which is the cost of an HLR access (Q_h), and the associated signaling between HLR and the Proxy HLR. Cancellation of the pointers at the old locations are assumed to the timer-based[1]. This assumption has also been applied to the anchor scheme and the forwarding scheme. The average tracking cost per move incurred by the flat scheme (M_{fl}) is given by (EQ 1), where q denotes the probability of movement from one network area to another.

$$M_{fl} = Q_s + Q_h + 2L + q(2(L+R+L)+Q_h) \qquad \text{(EQ 1)}$$

The mobile location procedure used in the flat scheme is shown in Fig. 4. The location cost for home mobiles only consists of the cost incurred at the HLR for handling a location query (Q_h). For remote mobiles, an additional cost of querying the Proxy HLR (Q_h) and the cost of the associated signaling is incurred. The average locating (Find) cost per call incurred by the flat scheme (F_{fl}) is given by (EQ 2). The cost of signaling between the originating MSC and the HLR is not included in the equation, since this cost is incurred by the location procedures of all the schemes being analyzed.

$$F_{fl} = Q_h + \overbrace{f \times (2 \times (R + 2 \times L) + Q_h)} \qquad \text{(EQ 2)}$$

4.2 Tracking/locating costs in the IS-41 scheme

In this section, we analyze the cost of the IS-41 location management scheme for the collocated MSC/VLR configuration (see Fig. 1a). The mobile tracking cost consists of *(i)* cost of updating the new MSC/VLR (Q_{sv}), *(ii)* cost of cancelling the old MSC/VLR (Q_{sv}), *(iii)* cost of updating the HLR (Q_h) and *(iv)* cost of signaling between the MSC/VLRs and the HLR. The average tracking cost per move incurred by the IS-41 scheme (M_{is}) is given by (EQ 3). For a remote mobile, the signaling between the MSC/VLRs and the HLR occurs over the Wide Area Network for both intra-LSN and inter-LSN moves. On the other hand, for a home mobile, the signaling between the new MSC/VLR and the HLR occurs over the Wide Area Network only during an inter-LSN move. The scenario in which a remote mobile moves back to its home area is

1. In IS-41 standards, all the location requests are sent to the HLR independent of the location of the called mobile. Therefore, timer-based cancellations of information at the old locations are justified, since the outdated information at old locations are never consulted.

ignored in this analysis.

$$M_{is} = Q_{sv} + Q_h + Q_{sv} + f(4(2L+R)) + (1-f)((1-q)(4L) + q(2L + 2(2L+R))) \quad \text{(EQ 3)}$$

The mobile location cost incurred by the IS-41 scheme consists of cost of querying the HLR (Q_h), cost of querying the VLR/MSC (Q_{sv}), and the cost of the associated signaling. The average locating cost per call incurred by the IS-41 scheme (F_{is}) is given by (EQ 4).

$$F_{is} = Q_h + Q_{sv} + \overbrace{2(L + f \times (R+L))} \quad \text{(EQ 4)}$$

4.3 Tracking/locating costs in the forwarding scheme

In this section, we analyze the cost of tracking and locating procedures used in the forwarding scheme [3]. Tracking in the forwarding scheme is done by setting a pointer to the new MSC/VLR at the old MSC/VLR. If the maximum length of the forwarding chain has k nodes, forwarding pointers are set for $k-1$ moves and on the k^{th} move, an IS-41 registration procedure is performed. So, the tracking cost consists of *(i)* cost of setting up forwarding pointers for the first $k-1$ moves, and *(ii)* cost of an IS-41 tracking in the k^{th} move. We assume that the cancellation of the pointers at the $k-2$ intermediate MSC/VLRs is done by a timer-based mechanism as explained in Section 4.1. The average tracking cost per move incurred by the forwarding scheme (M_{fp}) is given by (EQ 5).

$$M_{fp} = \left\{(k-1) \times 2 \times (Q_{sv} + \overbrace{L + q \times (R+L)}) + M_{is}\right\}/k \quad \text{(EQ 5)}$$

In the forwarding scheme, on location query, the HLR returns information about the anchor MSC to the originating MSC. The originating MSC then sends a location query to the anchor MSC (shown in Fig. 3a), which is sent along the forwarding chain until the current MSC of the mobile is reached. The current MSC assigns a TLDN, which is returned to the originating MSC.

The location cost in the forwarding scheme consists of *(i)* cost of querying the HLR (Q_h), *(ii)* cost of signaling between the originating MSC and the anchor MSC ($L + (1-t)(R+L)$, where t denotes the fraction of calls that originate within the current Local Signaling Network of the called mobile), *(iii)* cost of querying the anchor VLR/MSC (Q_{sv}), and *(iv)* cost of traversing the forwarding pointers. The average number of forwarding pointers traversed is $\frac{k-1}{2}$. The average locating cost per call incurred by the forwarding scheme (F_{fp}) is given by (EQ 6).

$$F_{fp} = Q_h + \overbrace{2(L + (1-t)(R+L))} + Q_{sv} + \left(\frac{k-1}{2}\right)\left(\overbrace{2(L + q(R+L))} + Q_{sv}\right) \qquad \text{(EQ 6)}$$

4.4 Tracking/locating costs in the anchor scheme

In this section, we analyze the cost of locating/tracking for the static case of the anchor scheme [4]. Tracking cost consists of the cost of updating the anchor (Q_{sv}), the cost of updating the new MSC/VLR of the mobile (Q_{sv}), and the cost of signaling between the local anchor and the new MSC/VLR of the mobile. The cancellation at the old MSC/VLR is assumed to be timer- based as explained in Section 4.1. The average tracking cost per move incurred by the anchor scheme (M_{la}) is given by (EQ 7). The scenario in which a mobile moves back to its local anchor area is ignored in this analysis.

$$M_{la} = 2Q_{sv} + \overbrace{2(L + q(R+L))} \qquad \text{(EQ 7)}$$

The location cost in the anchor scheme consists of *(i)* cost of querying the HLR (Q_h), *(ii)* cost of signaling between the HLR and the anchor MSC/VLR, and *(iii)* cost of querying the MSC/VLR (Q_{sv}). If the mobile has moved since the last call arrival (i.e., the mobile is not at the anchor MSC/VLR), the location cost also consists of the cost of signaling between the local anchor and the current MSC/VLR, and the cost of querying the current MSC/VLR. The equilibrium probability that a mobile is in its local anchor area is P_0 and is computed to be $\frac{\rho}{1+\rho}$ in [4], where ρ is the CMR (Call-to-Mobility Ratio). The average mobile locating cost per call incurred by the anchor scheme is given by (EQ 8).

$$F_{la} = Q_h + 2(f \times (R+L) + L) + Q_{sv} + (1-P_0)(2(L + q(R+L)) + Q_{sv}) \qquad \text{(EQ 8)}$$

4.5 Average total costs

The total cost of a location management scheme depends on the tracking cost and the locating cost of that scheme. In order to be able to estimate the average total cost, the rate of call arrivals at a mobile, λ_c, and the rate at which the mobile moves between registration areas, λ_m, are needed. The average tracking cost per unit time, average locating cost per unit time, and the average total cost per unit time, are given in (EQ 9), where M and F represent the average tracking cost per move and average locating cost per call, respectively.

$$\hat{M} = \lambda_m M \qquad \hat{F} = \lambda_c F \qquad T = \hat{M} + \hat{F} \qquad \text{(EQ 9)}$$

Since the main objective of the forwarding scheme, anchor scheme, and the flat scheme is to improve the performance over the IS-41 standards approach, we define the normalized cost of a scheme to be the ratio of the average total cost in the scheme to that of the average total cost in the IS-41 scheme. The normalized cost of a scheme, T^n, is given below.

$$T^n = \frac{\lambda_m M + \lambda_c F}{\lambda_m M_{is} + \lambda_c F_{is}} \qquad \text{(EQ 10)}$$

Since we do not have exact numbers for λ_c and λ_m, we use the CMR (Call-to-Mobility Ratio), denoted as ρ (defined as the number of call arrivals per move) [3], to study the performance of these schemes. Using this definition of CMR, the normalized cost, T^n, is given by

$$T^n = \frac{M + \rho F}{M_{is} + \rho F_{is}} \qquad \text{(EQ 11)}$$

where $\rho = \lambda_c / \lambda_m$.

4.6 Numerical results

In this section, we present the quantitative results of our comparison. The measures of comparison include computation costs (number of database accesses), communication costs (signaling load), the average total cost, and the call setup delay. The numerical comparison uses the formulas derived in Sections 4.1 to 4.5.

Input Data: Values of input parameters assumed for this numerical computation are shown in Table 2 (see Table 1 for definitions of these parameters). For the sake of this quantitative comparison, we assume that the values of Q_{sv}, Q_s, and Q_h are equal unless otherwise specified and the value is referred to as Q. The value of q is estimated to be 0.13, considering each LATA

Table 2: Input parameters

Parameter	Value
k	4
q	0.13
t	1
f	0.3
Q	3
L	1
R	2

(Local Access and Transport Area) to be a local signaling network area [3]. We observe that the exact numerical results are dependent on the exact values chosen for these parameters. We also note that the cost incurred at a network entity could be potentially different in different schemes. Sensitivity of the comparative results to the input parameters is also analyzed.

4.6.1 Computation costs

Computation cost consists of the cost of querying/updating databases, namely MSC/VLRs, HLRs, and Proxy HLRs. The computation costs of the schemes are calculated by setting the values of L and R to 0 in equations 1 to 8. In other words, the signaling costs are set to 0. Plots in Fig. 8 show the variation of the normalized computation cost with CMR for different values of f

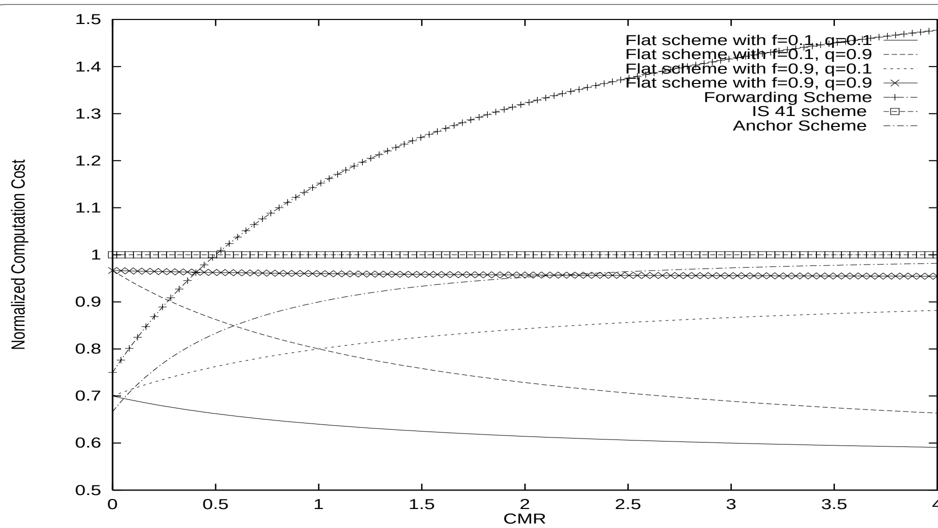

Fig. 8 Comparison of computation costs

(fraction of remote mobiles) and q (fraction of inter-LSN moves). Plots with varying values of f and q are shown only for the flat scheme, since the computation resource requirements of the other schemes are independent of the values of f and q (refer (EQ 3) to (EQ 8)). The plots show that at high CMRs, the flat scheme has the least computation cost for all values of f and q, but at low CMRs, the computation cost depends on the values of f and q. The plots also show that the computation cost of the flat scheme increases with an increase in the values of f and/or q.

Next, we consider the sensitivity of these results to a variation in the values of f and q. With an increase in the value of f, the computation cost of the location procedure in the flat scheme increases, since the number of mobiles that require location queries to Proxy HLRs increases. From (EQ 1), we observe that the computation cost of the tracking procedure is independent of f. Since the computation cost of only the location procedure increases with increase in f, the computation cost of the flat scheme increases with increase in f at high CMRs. With an increase in the value of q, the computation cost of the tracking procedure increases, since the tracking procedure of the flat scheme updates the HLR on every inter-LSN move. From (EQ 2), we observe that the computation cost of the locating procedure is independent of q. Since the computation cost of only the tracking procedure increases with increase in q, the computation cost of the flat scheme increases with increase in q at low CMRs. It is interesting to note that the computation cost of the flat scheme is less than or equal to that of the IS-41 scheme (limiting to the IS-41 scheme, when the values of f and q are equal to 1). In general for low-tier PCS applications, where the CMR is high, the flat scheme incurs a lower computation cost.

4.6.2 Communication costs

Communication cost consists of the cost of signaling over the LSN and the Wide Area Network. The communication costs of the schemes are computed by considering only the cost of signaling (i.e., ignoring the cost incurred by database accesses). In other words, the value of Q is set to 0 in evaluating equations 1 to 8. Plots in Fig. 9 show the variation of the normalized communi-

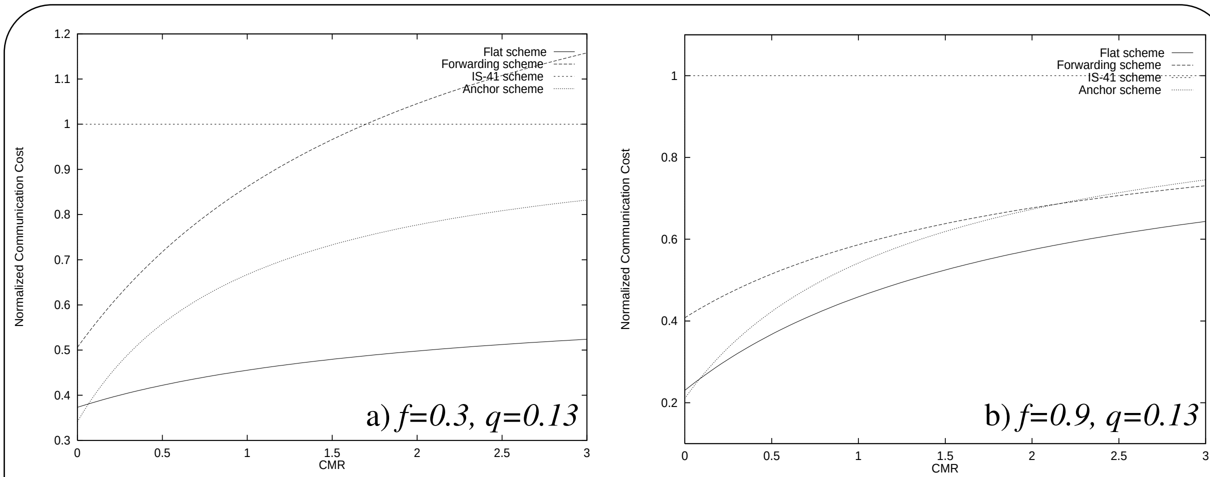

Fig. 9 Comparison of the communication costs

cation cost with CMR. These plots show that at high CMRs, the flat scheme has the least communication cost for all values of f and q, but at low CMRs, the communication cost depends on the values of f and q.

In general, as the number of levels of hierarchy decreases, the location management scheme is expected to incur a higher communication cost. On the contrary, Fig. 9 shows that, for a wide range of CMRs the flat scheme has a lower communication cost than the other schemes. This trend in the decrease of communication cost in the flat scheme is due to: *i) the improved mobile* *location procedure*, where signaling messages to the MSC/VLR for the assignment of the TLDN (Temporary Location Directory Number) are avoided, and *ii) the use of Proxy HLRs for remote mobiles*, which eliminates long-distance signaling messages for moves within the Local Signalling Network area. For a move across LSNs, long-distance signaling cost across the Wide Area Network is incurred in all the schemes.

Next, we consider the sensitivity of these results to a variation in the values of f and q. Table 3 shows the terms in the location and tracking signaling (communication) cost formulations that

Table 3: Dependence on f and q

Cost	Flat Scheme	Anchor Scheme	Forwarding Scheme	IS-41 Scheme
Tracking	$2q(R+2L)$	$2q(R+L)$	$\frac{2(q(1-f)+2f)(R+L)}{k}$	$2(q(1-f)+2f)(R+L)$
Location	$2f(R+2L)$	$2(f+q(1-P_0))(R+L)$	$q(k-1)(R+L)$	$2f(R+L)$

are dependent on the values of f and q. From Table 3 we observe that, for the flat scheme, the signaling cost of the tracking procedure increases with an increase in q, and the signaling cost during locating procedure increases with an increase in f. At low CMRs, the signaling cost of the tracking procedure dominates, while at high CMRs, the signaling cost during the locating procedure dominates. Therefore, at low CMRs, the total signaling cost in the flat scheme is affected significantly by the variation in q and not by the variation in f. We observe that the rate of increase in signaling cost with an increase in q is greater of the flat scheme than in any other scheme. Therefore at low CMRs, with increase in the value of q, the communication cost in the flat scheme increases relative to that of the other schemes.

4.6.3 Average total cost

The average total cost of a scheme is computed using, the equations derived in sections 4.1 to 4.5, and the input values from Table 2. Plots of the average total cost show the combined effect of the computation and communication costs. Therefore, these plots will vary with variations in the ratio of the cost of computation to communication (Q/L, Q being the cost incurred at a database, and L being the cost of signaling over an LSN). For high values (low values) of Q/L, these plots will show a similar trend as the plots of computation costs (communication costs). For example, if the computation cost (communication cost) of scheme is lower than that of another for values greater than a certain CMR, as the value of Q/L increases (decreases) the crossover point of the total cost plots will approach the value of that CMR. We demonstrated in Sections 4.6.1 and 4.6.2 that, in most of the cases, the trends in the communication and computation costs are similar. Therefore, in general, the Q/L ratio which determines, whether the computation cost should be emphasized or the communication cost, will effect all the curves in a similar manner. This is demonstrated in Fig. 10, which plots the normalized average total cost against CMR. An exception is

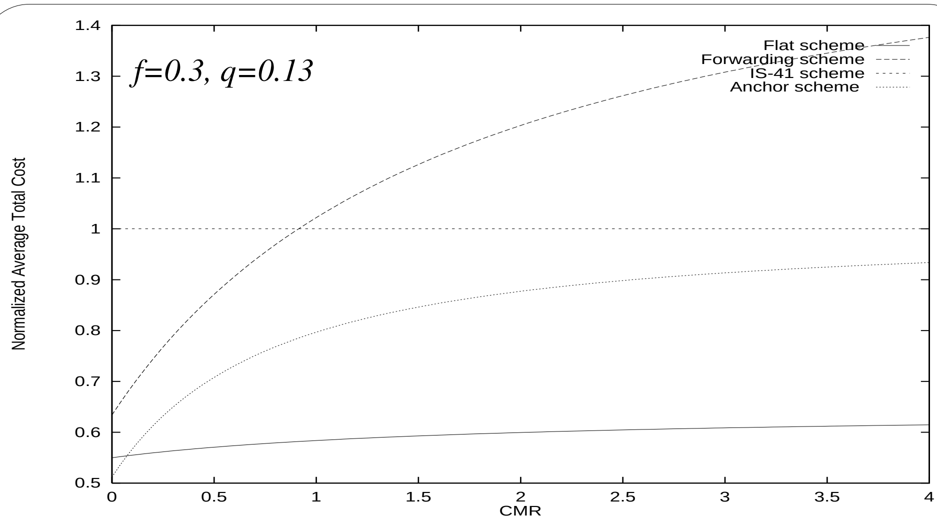

Fig. 10 Comparison of the average total cost

seen while comparing the IS-41 and the forwarding schemes for values of $f = 0.9$, and $q = 0.13$. In Section 4.6.2, the plot (see Fig. 9b) shows that the forwarding scheme incurs a lower communication cost than the IS-41 scheme at all CMRs but in Section 4.6.1 the plot shows that the forwarding scheme has a crossover CMR above which it incurs a high computation cost. So while comparing the total costs of the forwarding and the IS-41 schemes, the Q/L ratio matters. On the other hand, both computation and communication costs of the flat scheme show similar trends in that both costs are lower relative to the other schemes at high CMRs but could be higher at low CMRs. Hence the total cost behavior of the flat scheme relative to other schemes varies only marginally with different Q/L ratios. From the plots showing the variation of the normalized average total cost with CMR (see Fig. 10), we observe that, for very low values of CMR (<0.07, i.e., greater than 14 moves per call) the anchor scheme incurs the least cost, and for higher values of CMR (> 0.07) the flat approach incurs the least cost.

4.6.4 Call setup delay

Incoming calls to mobiles require a mobile location procedure prior to actual connection setup. If we assume that the connection setup procedure is the same in all the schemes, by comparing the mobile location delay, we compare the call setup delays in the schemes. Normalized location delay of a scheme is computed as the ratio of location cost in that scheme to the location cost in the IS-41 scheme. Fig. 16 shows the variation of mobile location cost, hence call setup delay, with

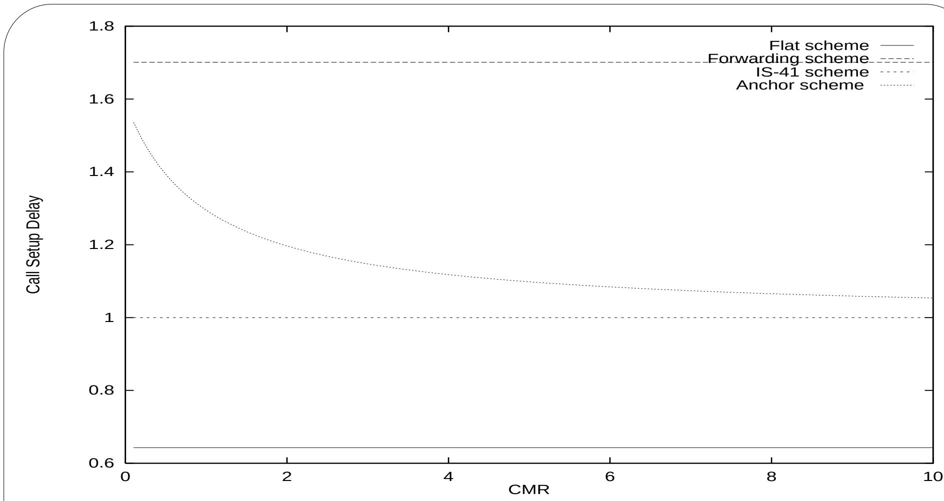

Fig. 16 Comparison of call setup delay

CMR. Plots show that the flat scheme has lower mobile location cost than any of the other schemes. This is because for home mobiles, the flat scheme only requires one database access, while for all the other schemes at least two database accesses are required. Mobile location delay varies with CMR only for the anchor scheme, since at high CMRs the mobile is typically located at the local anchor, while at low CMRs, a pointer will most likely exist from the local anchor to the current MSC/VLR.

Variation of q and f affects the mobile location cost. With an increase in the value of q (i.e., increase in inter-LSN moves), the cost of the mobile location procedure increases in the anchor scheme and the forwarding scheme. With an increase in the value of f, the cost of the locating procedure increases in the flat scheme, the anchor scheme and the IS-41 scheme. For high values of f, the mobile location delay of the flat scheme is similar to that of the IS-41 scheme.

5. Conclusions

This paper presented a "flat" mobile location management scheme for Personal Communication Networks (PCNs). The objective of this scheme is to reduce both mobile tracking and location costs. Mobile tracking costs are reduced by *(i)* the use of one level of tracking for mobiles in their "home area", and a two-level tracking approach only for mobiles visiting other areas, and *(ii)* creating a logical base station controller-HLR interface to send registration message directly from the BSC to the HLR, bypassing the MSC. Mobile location costs are reduced by using an improved mobile location strategy, which requires a one-hop message exchange for “home” mobiles, and a two-hop message only for “remote” mobiles.

We analytically modeled the costs incurred during the tracking and locating procedures of the different schemes, and compared their performance. The measures of comparison used were the computation cost (database accesses), the communication cost (signaling messages), the average total cost, and the mobile location cost (call setup delay). Analysis results showed that the proposed flat scheme reduces the number of database accesses, number of signaling messages, and the call setup delay when compared to the location management strategy proposed in the IS-41 standard. Results also show that for medium and high values of CMR (> 0.07, i.e., less than 14 moves per call), the flat scheme performs better than the forwarding scheme and the anchor scheme. In most cases, the performance of the flat scheme relative to other schemes varied only marginally with different Q/L (Q being the cost incurred at a database, and L being the cost of signaling over an LSN) ratios.

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