Int. Computer Symposium, Dec. 15-17, 2004, Taipei, Taiwan.

Another Two-level Pointer Strategy for Location Management in PCS Networks

Po-Jen Chuang and Shien-Da Chang
Department of Electrical Engineering
Tamkang University
Tamsui, Taipei County, Taiwan 25137 R.O.C.
Email: pjchuang@ee.tku.edu.tw, sdchang@dgt.gov.tw

Abstract

We propose an auxiliary scheme called another two-level pointer strategy, with a new procedure for updating and locating users who move from place to place while using Personal Communication Service (PCS) networks. The new scheme reduces the cost of registration using the pointer to replace updating a user's location information to the Home Location Register (HLR) when the user moves to a new registration area (RA). Moreover, to reduce the cost of HLR update, we utilize a local pointer to replace updating the user's current location information to the HLR upon every Kth pointer forwarding.

1. Introduction

In the IS-41 scheme [1,2], a user performs registration at the HLR and deregisters at the previous Visitor Location Register (VLR) every time when he changes registration areas. In call delivery of the IS-41 scheme, calls to a given user will first query the user's HLR to determine the VLR in which the user is registered. When the user turns on his mobile and registers at a VLR, the VLR is called the local VLR of the user in this paper. Another two-level pointer, like the other pointer forwarding strategies, is suitable for users whose call to mobility ratios (CMRs) are low. When CMR < 0.5, the performance of the new scheme can significantly decrease the location tracking cost. As we know, the purpose of updating a user's location information in registration is only for successful call delivery. To reduce the registration cost without losing the user's location information, the new scheme uses the pointer to replace updating the user's location information to the HLR when he moves to a new registration area (RA). We also replace updating the user's current location information to the HLR by a local pointer upon every Kth pointer forwarding. In practice, a mobile user's moving pattern usually exhibits spatial locality [3]. This phenomenon makes the traversal cost of a local pointer only slightly higher than that of a forwarding pointer.

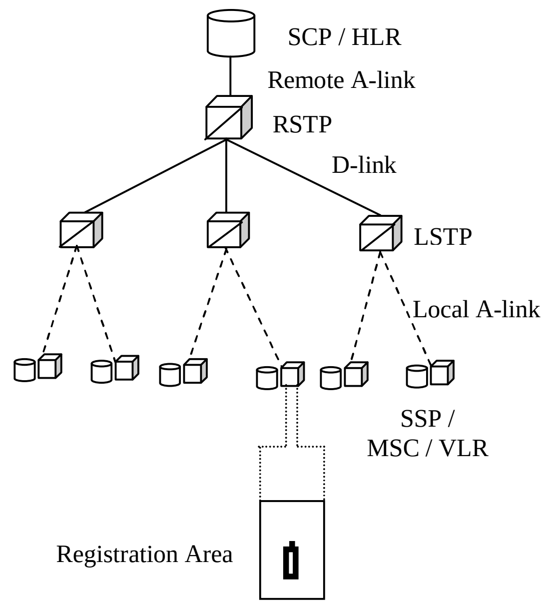


Figure 1. A PCS network architecture.

A PCS network architecture [4-7] is given in Figure 1. This model assumes that the HLR resides in the Service Control Point (SCP), which is connected to a Regional Signal Transfer Point (RSTP). Through a connection network, RSTP connects to all Local STPs (LSTPs) in the region, which performs message routing translation and screening functions in the Signaling System 7 network. The individual STP illustrated in Figure 1 actually represents the mated-pair configuration. Every LSTP comprises a Local Access Transport Area (LATA) geographical area, which connects to multiple Service Switching Points (SSPs). The Mobile Switching Center (MSC) and a VLR are collocated with an SSP. An RA consists of one or more radio port coverage areas or cells [8]. We assume that each RA is served by a single MSC/VLR. The MSC of an RA is responsible for maintaining and accessing the VLR and for switching between radio ports. The VLR associated with an RA is responsible for maintaining a subset of the user information contained in the HLR [9]. The VLR is collocated with the MSC, and the combination of MSC/VLR is to evolve to be SS7 compatible.

The outline of this paper is as follows. Section 2 gives the proposed strategy. Section 3 presents the analytic model. Performance comparisons between the proposed strategy and other strategies are given in Section 4. Section 5 concludes the paper.

2. The Proposed Strategy

We modify the IS-41 scheme [1,2] and pointer forwarding strategies [4,7] to obtain another two-level pointer strategy as follows. When a user moves from one RA to another, it informs the switch (and VLR) at the new RA it arrives at. The switch at the new RA determines whether to employ the basic MOVE (when the user turns on the mobile) or the MOVE in our two-level pointer scheme. We use the following pseudo-code to describe the AnotherptrMOVE() and AnotherptrFIND() procedures in our scheme (also illustrated in Figures 2 and 3).

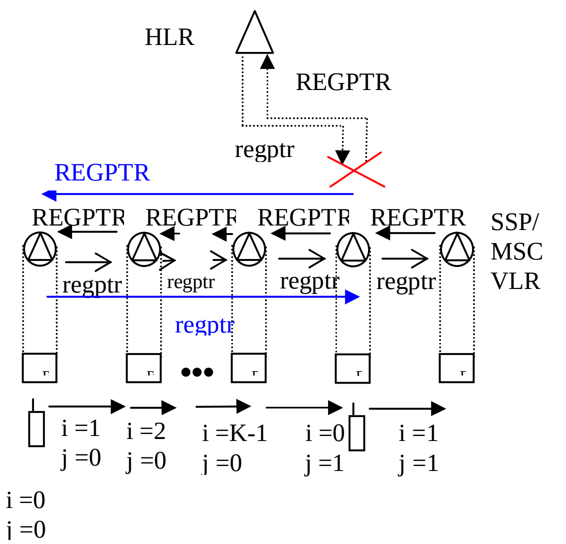


Figure 2. The AnotherptrMOVE() procedure.

AnotherptrMOVE ( ) {
/* The forwarding pointer i is initially set to be 0 and the local pointer j is 0 */
if (i < K-1 and j ≤ 1) {
The user registers at the new RA / VLR, passing ids of the former RA/VLR and local RA$_0$/VLR$_0$;
The new VLR deregisters the user at the old VLR;
The old VLR sends ACK and the user's service profile to the new VLR;
i : = i + 1 ;
}
else if (i ≥ K-1 and j ≤ 1) {
The user registers at the new RA/VLR, passing ids of the former RA/VLR and local RA$_0$/VLR$_0$;
The new VLR deregisters the user at the old VLR and sends REGPTR to local RA$_0$/VLR$_0$;
The old VLR sends ACK and the user's service profile to the new VLR ;
i : = 0 ; j : = 1;
}
}

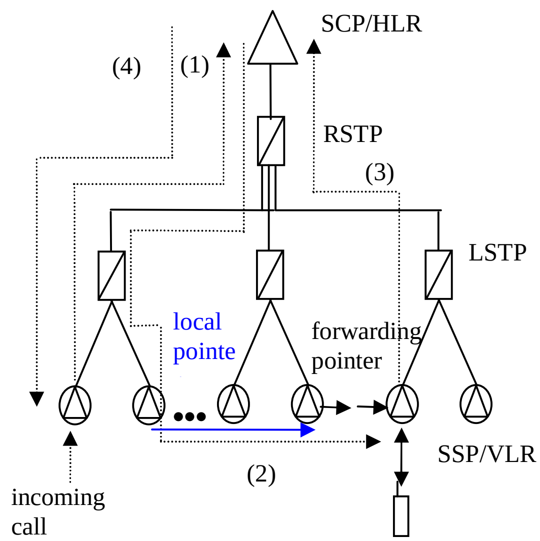


Figure 3. The AnotherptrFIND ( ) procedure.

AnotherptrFIND ( ) {
A call to a user is detected at the local switch ;
if the called user is in the same RA then return ;
The switch queries the called user's HLR ;
HLR responds to the caller's switch with local RA$_0$/VLR$_0$;
The caller's switch queries local RA$_0$/VLR$_0$;
While (the queried VLR is not the called user's current VLR)
The VLR queries the next VLR in the pointer chain (local pointer or forwarding pointer) ;
/ * The called user's VLR has been found */
i : =0 ; j : =0 ;
The called user's current VLR sends user location to HLR ;
HLR sends the user's location to the caller's switch ;
}

3. The Analytic Model

In this section, we develop an analytic model (the same as in [5,7]) to study the performance of our two-level pointer scheme based on different parameters for different classes of users. We characterize users by their call-to mobility ratios (CMRs). The CMR of a user is defined as the expected number of calls to a user during the period when the user visits an RA. (Note that the CMR is defined here in terms of calls received by a particular user, not calls originating from the user.) If the user's call arrival rate is a mean rate λ, and the time the user resides in a given RA has a mean 1/μ, then the CMR, denoted as p, is given by

$$CMR = p = \frac{l}{m} \tag{1}$$

We define C_B and C_F to be the total cost for maintaining users' information (location updating) and locating the user (location tracking) between two consecutive calls for the IS-41 basic scheme and for our pointer scheme. The following notations will be used in our analysis：

M′ = expected cost of all AnotherptrMOVEs between two consecutive calls.
F′ = average cost of the AnotherptrFIND.
M = total cost of all the BasicMOVEs between two consecutive calls.
m = cost of a single invocation of the BasicMOVE.
F = cost of a single BasicFIND.
S_1 = cost of setting up a forwarding pointer between VLRs during an AnotherptrMOVE.
S_2 = cost of setting up a local pointer between VLRs and local VLR during an AnotherptrMOVE.
T_1 = cost of traversing a forwarding pointer between VLRs during an AnotherptrFIND.
T_2 = cost of traversing a local pointer between VLRs and local VLR during an AnotherptrFIND.
K = the threshold number of RAs (that a user moves across) to set up a local pointer between two consecutive calls; also the threshold number of forwarding pointers in a chain.

Then, we have

$$C_B = M + F = m / p + F \tag{2}$$

Before deriving formulas for our another two-level pointer scheme, we 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 an RA is a random variable with a general density function $f_m(t)$ and the Laplace transform.

Suppose that a user crosses i RA boundaries between two consecutive calls. Then, there are $i - \left\lfloor \frac{i}{K} \right\rfloor$ forwarding pointer creations (every K moves require K-1 forwarding pointer creations and 1 local pointer creation). The local pointer is always created for the last $\left\lfloor \frac{i}{K} \right\rfloor$ moves. Thus,

$$M' = \sum_{i=0}^{\infty} \left[\left(i - \left\lfloor \frac{i}{K} \right\rfloor \right) S_1 + \left\lfloor \frac{i}{K} \right\rfloor S_2 \right] a(i) \tag{3}$$

Cost F′ is derived as follows. After the last BasicMOVE operation (if any), the user traverses $\left\lfloor \frac{i}{K} \right\rfloor - \left\lfloor \frac{(i-K)}{K} \right\rfloor$ local pointers and $i - K\left\lfloor \frac{i}{K} \right\rfloor$ forwarding pointers. Thus, we obtain

$$F' = F + \sum_{i=0}^{\infty} \left\{ \left(i - K\left\lfloor \frac{i}{K} \right\rfloor \right) T_1 + \left(\left\lfloor \frac{i}{K} \right\rfloor - \left\lfloor \frac{i-K}{K} \right\rfloor \right) T_2 \right\} a(i) \tag{4}$$

Let $a(i)$ be the probability that there are K RA crossings between two call arrivals. Probability $a(i)$ is expressed as in [5,7]

$$a(i) = \frac{m}{l} \left[1 - fm^*(l) \right]^2 \left[fm^*(l) \right]^{i-1} = \frac{(1-g)^2 g^{i-1}}{p} \tag{5}$$

$$f_m^{\,*}(s) = \int_{t=0}^{\infty} f_m(t) e^{-st}\, dt \tag{6}$$

From (5), (6) and the two assumptions, we can rewrite (3) and (4) as

$$M' = \frac{S_1}{p} + \frac{(1-g) g^{K-1} (S_2 - S_1)}{p(1-g^K)} \tag{7}$$

$$F' = F + \frac{T_1}{p} + \frac{(T_2 - KT_1)(1-g) g^{K-1}}{p(1-g^K)} - \frac{T_2}{p}(1-g)\left[\frac{g^{K-1}}{(1-g^K)} - \frac{1}{g} \right] \tag{8}$$

We assume that the RA residence time of a user is Gamma distributed with mean 1 / μ. The Laplace transform of a Gamma distribution is $fm^*(s) = \left(\frac{gm}{l + gm} \right)^g$. Thus we have,

$$g = fm^*(l) = \left(\frac{gm}{l + gm} \right)^g = \left(\frac{g}{p+g} \right)^g.$$

In particular, when γ = 1, we have an exponential distribution for the RA residence time. We first consider the situation when the RA residence time is exponentially distributed. By setting γ = 1, we have

$$g = \frac{1}{1+p}$$

Thus, (7) and (8) can be rewritten as

$$\mathrm{M}' = \frac{\mathrm{S}_1}{\mathrm{p}} + \frac{S_2 - S_1}{(1+p)^K - 1} \qquad (9)$$

$$\mathrm{F}' = F + T_2 + \frac{T_1}{p} - \frac{KT_1}{(1+p)^K - 1} \qquad (10)$$

From (9) and (10) we obtain

$$C_F = M' + F'$$

$$= F + T_2 + \frac{(S_1 + T_1)}{p} + \left(\frac{(S_2 - S_1) - KT_1}{(1+p)^K - 1} \right) \qquad (11)$$

4. Performance Comparison

In the IS-41 scheme, updating the HLR and performing a BasicFIND involve the same number of messages between HLR and VLR databases, so we set m = F. Without loss of generality, we can normalize m = 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. That is, we set $S_1 = 2T_1$ and $S_2 = 2T_2$. We consider $S_1 = \delta$ with $\delta < 1$. Since the local pointer is more expensive than the forwarding pointer in terms of the setup cost, we can assume $S_2 = NS_1$ with $N > 1$. It is reasonable to assume that $S_2 < 1$, too. From (2), (9), (10) and (11), we obtain

$$C_B = 1 + \frac{1}{p} \qquad (12)$$

$$\frac{\mathrm{M}'}{M} = d + \frac{(N-1)d \quad p}{(1+p)^K - 1} \qquad (13)$$

$$\frac{\mathrm{F}'}{F} = 1 + \frac{Nd}{2} + \frac{d}{2p} - \frac{Kd}{2[\ (1+p)^K - 1\ ]} \qquad (14)$$

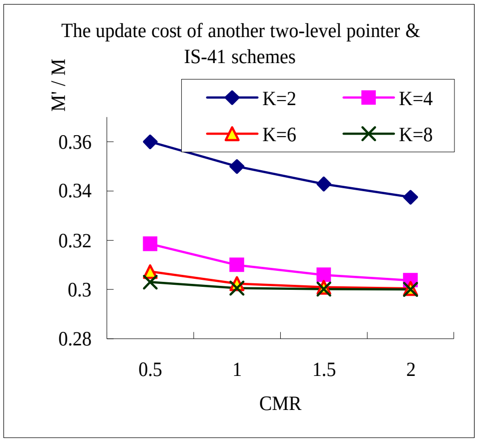
$$\frac{C_F}{C_B} = \frac{p}{1+p} \{\ 1 + \frac{Nd}{2} + \frac{3d}{2p} + \frac{[2(N-1) - K]d}{2[\ (1+p)^K - 1\ ]}\ \} \qquad (15)$$

In Figures 4, 5 and 6, we plot the costs as function of CMR for various values of K, N and δ. Figure 4(a) shows that when δ = 0.3 and N = 1.5, another two-level pointer can result in 60 – 70 percent reductions in location update cost compared to the IS-41 basic scheme. Figure 4(b) indicates that the FIND cost of another two-level pointer scheme is higher than that of the basic scheme. The reason is that the call to the user needs to traverse the pointer chain to find the user’s current location. However, our another two-level pointer scheme can result in a 5 – 35 percent reduction in the total cost as shown in Figure 4(c). We observe that both the relative MOVE and FIND costs are decreasing functions of p (CMR). When p is small, the user crosses RAs more frequently. The pointers need to be set up and a long chain of pointers have to be traversed, leading to the high set up cost. Without HLR updating for all MOVEs, pointer creations can result in cost reduction. Especially when p decreases with a longer pointer chain, setting up pointers can save more registration at the HLR. However, a long pointer chain increases the FIND penalty in general. But another two-level pointer can solve this problem by using local pointers to decrease the length of the pointer chain and also the delay time for setting up the call.

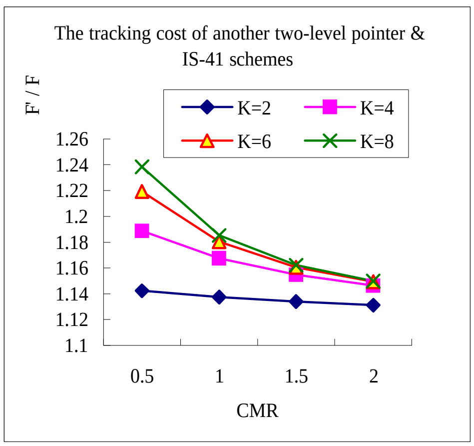
Figures 5(a), 5(b) and 5(c) show the plots when N increases from 1.5 to 3. Even in this case, the cost of setting up a local pointer is slightly less than the cost of updating the HLR. The performance of another two-level pointer under CMR = 1 also excels that of the IS-41 scheme. Figures 6(a), 6(b) and 6(c) show cost comparisons between our scheme and the per-user forwarding strategy [5] under CMR ≤ 0.5. Figure 6(a) indicates that another two-level pointer saves more cost than the per-user forwarding in the MOVE procedure. In the FIND procedure in Figure 6(b), another two-level pointer is shown to yield more tracking cost. The total cost of another two-level pointer strategy is slightly higher than that of the per-user forwarding strategy, as shown in Figure 6(c). Based on the above result, it is observed that the proposed another two-level pointer strategy is suitable for users who change PCS registration areas frequently but receive calls less frequently.

5. Conclusions

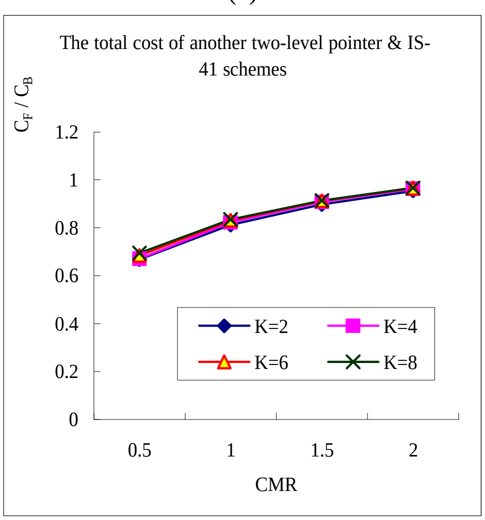
In this paper, we propose a new location management scheme, called another two-level pointer strategy. To update information, we use the local pointer to replace registration at the HLR, thus reducing the signaling traffic and database load of the HLR. A local pointer can maintain a user’s location information at the HLR useful. In location tracking, the locating cost of local pointers may be a little more than that of the forwarding pointers, but it is worthwhile as the length of the pointer chain can be shortened and the delay time for setting up the call can be reduced. Moreover, the user’s location information at the HLR can be updated and reused after “found”. Our studies indicate that our another two-level pointer scheme is suitable for users who change PCS registration areas frequently but receive calls less frequently (the total cost of our another two-level pointer strategy is especially lower under CMR < 0.3). The overall result of performance comparison demonstrates that our new scheme outperforms the IS-41 scheme.



(a)

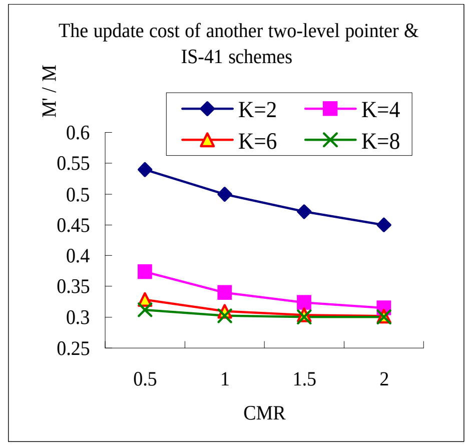


(b)

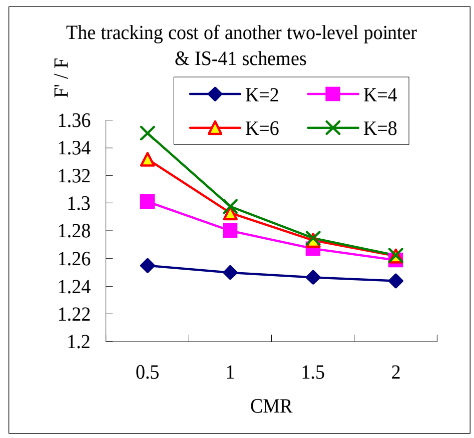


(c)

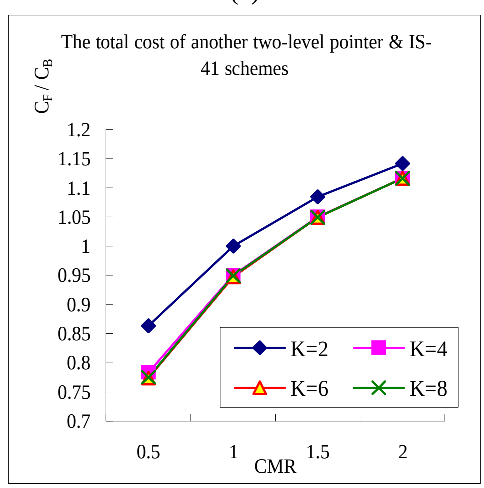
Figure 4. Relative cost of another two-level pointer and IS-41 schemes with $\delta = 0.3$ and N = 1.5 (a) the MOVE cost M' / M (b) the FIND cost F' / F (c) the total cost C_F / C_B.



(a)

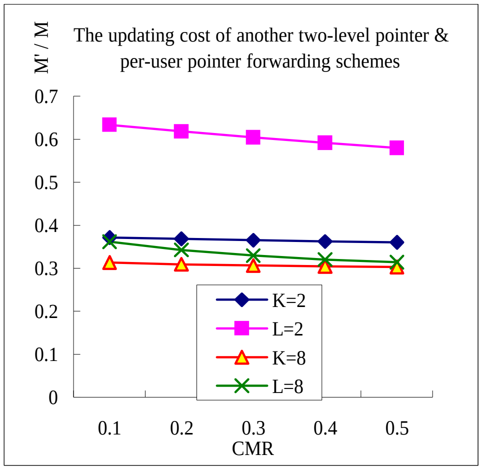


(b)

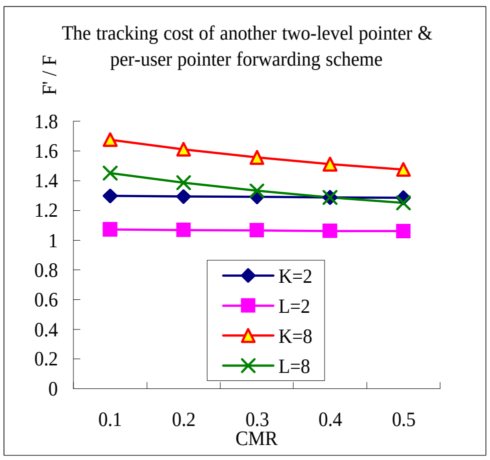


(c)

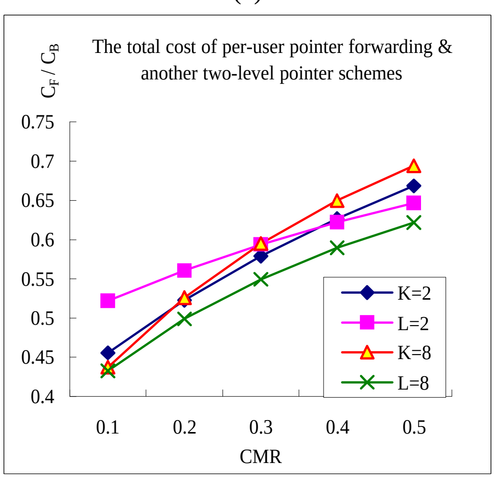
Figure 5. Relative cost of another two-level pointer and IS-41 schemes with $\delta = 0.3$ and N = 3 (a) the MOVE cost M' / M (b) the FIND cost F' / F (c) the total cost C_F / C_B.



(a)



(b)



(c)

Figure 6. Relative cost of another two-level pointer and per-user pointer forwarding schemes with $\delta = 0.3$ and $N = 3$ (a) the MOVE cost M' / M (b) the FIND cost F' / F (c) the total cost C_F / C_B.

References

[1] EIA/TIA, "Cellular Radio Telecommunications Inter-system Operations," *Technical Report IS-41 (Revision B)*, EIA/TIA, 1991.

[2] D. R. Wilson, "Signaling System No. 7, IS-41 and Cellular Telephony Networking," *Proc. IEEE*, Vol. 80, No. 4, pp. 652-664, Apr. 1992.

[3] Z. Mao and C. Douligeris, "An Integrated Strategy for Location Tracking in Mobile Networks," *IEEE Networks Commun. Conf.*, pp.777-781, 2000.

[4] R. Jain, Y.-B. Lin, Charles Lo, and S. Mohan, "A Forwarding Strategy to Reduce Network Impacts of PCS," *Applied Research*, Bellcore, Morristown, NJ07960, 1995.

[5] R. Jain, and Y.-B. Lin, "An Auxiliary User Location Strategy Employing Forwarding Pointers to Reduce Network Impacts of PCS," *ACM-JCM Wireless Networks*, pp.197-210, 1995.

[6] R. Jain, Y.-B. Lin, C. Lo and S. Mohan, "A Forwarding Strategy to Reduce Network Impacts of PCS," *IEEE J. Select. Areas Commun.*, Vol.15, Oct. 1995.

[7] W. Ma, and Y. Fang, "Two-level Pointer Forwarding Strategy for Location Management in PCS Networks," *IEEE Trans. Mobile Computing*, Vol.1, pp.32-45, 2001.

[8] K.-L. Sue and C.-C. Tseng, "One-step Pointer Forwarding Strategy for Location Tracking in Distributed HLR Environment," *IEEE J. Select. Areas Commun.*, Vol.15, pp.1455-1466, 1997.

[9] S. Mohan and R. Jain, "Two User Location Strategies for Personal Communications Services," *IEEE Pers. Commun.*, pp.42-50, First Quarter 1994.