Determination of the Registration Point for Location Update by Dynamic Programming in PCS

Chae Y. Lee and Seon G. Chang
Department of Industrial Engineering, KAIST
373-1, Kusung-Dong, Taejon, Korea, 305-701
cylee@heuristic.kaist.ac.kr

Abstract – Location management is important to effectively keep track of mobile terminals with reduced signal flows and database queries. Even though dynamic location management strategies are known to show good performance, we in this paper consider the static location management strategy which is easy to implement. A system with single home location register and pointer forwarding is assumed. A mobile terminal is assumed to have memory to store the IDs of visitor location registers (VLRs) each of which has the forwarding pointer to identify its current location. To obtain the registration point which minimizes the database access and signaling cost from the current time to the time of power-off probabilistic dynamic programming formulation is presented. A Selective Pointer Forwarding scheme is proposed which is based on one-step dynamic programming. The proposed location update scheme determines the least cost temporary VLR which point forwards the latest location of the mobile. The computational results show that the proposed scheme outperforms IS-41, pure Pointer Forwarding, and One-step Pointer Forwarding at the expense of small storage and a few computations at the mobile terminals.

Index Terms – Location Management, IS-41, Pointer Forwarding, Dynamic Programming

I. INTRODUCTION

The personal communication service (PCS) is a system that aims to allow for communication anywhere in the world. In a PCS system, the location of a called mobile terminal (MT) must be determined before the connection can be established. Location tracking operation in a PCS network is expensive because many signal flows and database queries are needed to achieve the task. Therefore, a location management scheme is necessary to effectively keep track of the MTs and to locate a called MT when a call is initiated.

Many location management strategies use two classes of databases of user location information: the home location register (HLR), and the visitor location register (VLR). Under two commonly used standards of IS-41 and GSM, the HLR is required to store the location of an MT. When the MT moves to another registration area (RA), a temporary record for the MT is created in the VLR of the visited system, and its new location is reported to the HLR. This process is referred to as the *registration* operation [1]. The *registration* operation may be followed by a deregistration operation to remove the obsolete record in the VLR of the RA from which the MT moves out. The deregistration operation may not be performed immediately after a *registration* operation. In *timeout deregistration*, the obsolete entries are cancelled periodically. In *implicit deregistration*, no deregistration operation is performed [1]. To simplify our analysis, *implicit deregistration* is assumed in this study. When the PCS system attempts to deliver a call to an MT, another procedure called *call delivery* is executed based on the record stored in the HLR.

In addition to the strategy in IS-41 and GSM, several methods have been proposed to improve the efficiency of location management strategy [3], [4]. They can be classified into two categories: Dynamic and static location management strategies. Three methods are prevalent as the dynamic location management; *time-based*, *movement-based*, and *distance-based* methods. Under these three schemes, *registrations* are respectively generated based on time elapsed, the number of cell boundary crossings and the distance traveled since the last *registration*. In [2], Bar-Noy et al. examine the performance of the three methods. It is demonstrated that distance-based schemes produce the best results. The implementation methods of the distance-based scheme are proposed in [5] and [6]. In addition to the three methods, many other methods have been proposed in [7]-[10] to adapt the movement behavior of MTs and the geographical information.

It is generally demonstrated that the dynamic location management schemes produce better results than the static methods. However, the dynamic location management schemes cannot be easily implemented in the near future because of the complexity of the procedures. Therefore, we consider the static location management schemes in this paper.

The static schemes include Pointer Forwarding (PF), hierarchical HLR, and distributed HLR schemes, in addition to the strategy in IS-41. PF strategy has been proposed to avoid the expensive HLR access each time an MT moves to a new RA. The PF schemes proposed in [11] and [12] are based on the observation that it is possible to avoid the registrations at the HLR by simply setting up a forwarding pointer from the previous VLR. A call to a user will first query the user's HLR to determine the first VLR where the user was registered and then follow a chain of forwarding pointers to the user's current VLR.

Hierarchical and distributed HLR schemes proposed in [13]-[15] and [16] respectively, can prevent HLR from becoming bottleneck in the signaling network. Hierarchical structure consists of a number of databases each of which is connected to others only through its root. Due to the localized nature of calling and mobility patterns, this scheme effectively reduces the location management cost. However, the hierarchical HLR may require many database accesses during the procedure of *call delivery* and *registration*. The distributed HLR requires multiple HLR updates to maintain all distributed HLRs containing the valid location information. To provide a new location management strategy which overcomes such a limitation, the pointer forwarding strategy and the concept of distributed HLRs are combined in [17]. However, the length of a forwarding pointer chain may be lengthened in the traditional pointer forwarding strategy. In [18], One-step Pointer Forwarding (OPF) with distributed HLRs was proposed to overcome this potential problem. The length of any forwarding pointer chain does not exceed one in the strategy. The idea of OPF can be easily applied to the single HLR case.

Here, by assuming single HLR for each subscriber we provide a more efficient strategy which reduces location management costs compared to the IS-41, PF, and OPF with single HLR. In the proposed scheme, an MT stores the IDs of VLRs which have information about its location. When an MT moves from one RA to another, the MT itself selectively determines how to make *registration* operation. While other schemes make *registration* operation independently of call-to-mobility ratio, proposed scheme takes the call-to-mobility ratio into account to make optimal decision. The proposed scheme decreases database access and signaling cost efficiently at the expense of a small storage and a few number of computations at MT.

II. RELATED LOCATION MANAGEMENT STRATEGIES

A. IS-41

In the IS-41 protocol, all service areas are divided into many RAs. When a user subscribes to the service, a record associated with this user is created in the system database, HLR. As a mobile roams and arrives at a new RA, a record for this MT is created in the database of the VLR. Several RAs may share a VLR. To simplify the research, we assume that every RA has its own VLR and that the mobile switching center (MSC) is near the associated VLR. Signaling flow between MSC and VLR will be ignored in this paper. “VLR” is used to represent “MSC/VLR” later. “old VLR” and “new VLR” denote the two respective VLRs of the RAs when an MT is moving from one to the other. And “current VLR” denotes the VLR currently serving the MT.

a. Registration : see Fig. 1

1) When a mobile moves from one RA to another, it is registered at the new VLR by sending a *registration-request* message.

2) This new VLR creates a temporary record for the MT, and sends a message to inform the HLR of the MT's new location.

3) HLR sends a *registration-cancel* message to the old VLR.

b. Call Delivery : see Fig. 2

When an incoming call occurs, a table lookup technique called global title translation (GTT) is required at the signal transfer point (STP) to identify the address of the HLR serving the called MT.

1) A *location-request* message is sent to query the HLR of the MT

2) The HLR determines the current VLR, and queries the VLR by sending a *route-request* signal.

3) The VLR forward the query message to the MSC. If the MT can receive the call, the MSC returns a routable address called the temporary local directory number (TLDN) to the VLR.

4) The VLR forwards the TLDN back to the originating MSC via the HLR of the MT.

5) When the originating MSC receives the TLDN, it routes the call to the MSC where the MT is located.

B. PF with Single HLR

For a mobile which frequently moves across RAs but seldom has an incoming call, traditional IS-41 *registration* operation is a waste in view of the signaling cost. PF was proposed to reduce the location update cost in a PCS network.

a. Registration

1) An MT entering to a new RA sends a *registration* message and ID of the old VLR to the new VLR.

2) The new VLR sends a message to inform the old VLR of the departure of the MT.

3) The old VLR deletes the obsolete record for the MT, and creates a forwarding pointer pointing

to the new VLR.

b. Call Delivery

When a phone call arrives, the forwarding pointers are traced to deliver the call (see Fig. 3). Also note that after a call arrives, the current VLR returns the routable address back to the HLR and the record of the HLR is updated to the current VLR as shown in Fig. 4. Since *implicit deregistration* is assumed in this paper, the pointers from RA_1 to RA_2 and from RA_2 and RA_3 remain as before even after the updating of the record of the HLR. These pointers do not affect the procedure of *call delivery* to the MT in RA_3.

C. One-step Pointer Forwarding with Single HLR

In the pure PF, the forwarding pointer chain of an MT may have long list of IDs of VLRs. It may thus cause a delay problem in *call delivery* to traverse all the VLRs in the list. OPF is proposed to overcome this potential problem. The length of any forwarding pointer chain does not exceed one in the strategy. The pointer chain consists of "Previous VLR" and current VLR. That is, HLR points to the "Previous VLR" and the "Previous VLR" keeps a pointer to the current VLR of the MT. The VLR from which the last call is connected to the MT is denoted by "Previous VLR". Then, HLR keeps the record of the "Previous VLR" as the location of the MT. An MT stores the ID of the "Previous VLR" and sends it to the VLR of the new RA when location update occurs. Then the new VLR sends a message to inform the "Previous VLR" of the arrival of the MT to its region. The "Previous VLR" then creates a forwarding pointer directly to the new VLR. Whenever a call arrives at the MT, the ID of the "Previous VLR" recorded at the MT and HLR is updated to the ID of the current VLR.

III. A SELECTIVE POINTER FORWARDING SCHEME

In this section, we first propose that an optimal location update can be solved by dynamic programming, which minimizes the *registration* and *call delivery* cost starting from the current location update to the time of power-off. However, the computational burden to solve the dynamic programming is not appropriate to implement in the real situation. Thus, a prediction algorithm by one-step dynamic programming is proposed. The proposed Selective Pointer Forwarding (SPF) scheme selectively decides the *registration* point among VLRs the MT has registered. Clearly, SPF is an advanced strategy compared to other schemes which make *registration* to the point previously determined. For example, *registration* is always made to HLR in IS-41 and to the old VLR in PF.

A. An Optimal Location Update by Dynamic Programming

For an optimal location update by dynamic programming, we introduce a temporary location register (TLR) of the MT. A TLR is a VLR which stores a forwarding pointer for a specific MT. Suppose that an MT has K TLRs. If $K = 0$, the HLR records the current VLR. Otherwise, The HLR records the first TLR. The kth TLR ($1 \le k < K$) has a pointer which points to the (k+1)th TLR. The forwarding pointer of Kth TLR points the current VLR (see Fig. 5).

When an MT moves from one RA to another, the TLR is determined which is to be informed of the mobile's new location in the proposed scheme. It selects one of the following three cases to minimize the location management costs.

Case 1: Inform the HLR of the mobile's new location.

Case 2: Inform the old VLR of the mobile's new location.

Case 3: Inform the TLR_k of the mobile's new RA as shown in Fig. 6.

In Case 3, the pointer of kth TLR is set to point the current VLR. Including Case 1 and 2, K+2 cases need to be compared and the one which minimizes the expected *registration* and *call delivery* costs for the future N *interval*s is selected. Here we assume an MT makes N location updates (see Fig. 7) until the power-off and an *interval* denotes time between two consecutive location updates. If Case 1 is selected as the minimum, then the *registration* strategy corresponds to the IS-41. If Case 2 is selected, it corresponds to the PF method. Whenever a *location update* occurs the best one among the K+2 cases is selected in the proposed scheme. To generalize the notation, let TLR_0 and TLR_{K+1} denote the HLR and the old VLR, respectively. Then the scheme is to determine the TLR to which the new VLR sends the location information of the MT.

For the optimization of the expected cost for the *N* consecutive *interval*s, we introduce the concept of probabilistic dynamic programming. Assume that $(\text{TLR}_1,...,\text{TLR}_{K_n})$ is the set of TLRs recorded at the MT at the beginning of *n*th $(1 \le n \le N)$ location update. Then the set of candidate *registration* points r_n at that time becomes $(\text{TLR}_0,...,\text{TLR}_{K_n},\text{TLR}_{K_n+1})$, where TLR_0 and TLR_{K_n+1} denote the HLR and the old VLR, respectively. Now, the input variables at the time of *n*th location update are represented by (r_n, v_n), where r_n and v_n denote the set of candidate *registration* points and the new VLR at that time, respectively. Let the decision variables k_n $(1 \le n \le N)$ be the decision of *registration* point which is one of the set r_n (see Fig. 8). Let $f_n^*(\text{r}_n, v_n)$ be the minimum expected cost from *n*th location update to the time of power-off. Note in the $f_n^*(\text{r}_n, v_n)$ that r_n is determined by the previous decision and the new VLR v_n is probabilistically distributed which depends on the move direction. Thus, probabilistic dynamic programming needs to be solved to obtain the optimal decision.

For each candidate *registration* point, the expected cost of optimal trajectory of future *registration* points is calculated given that the current *registration* is made to the candidate *registration* point. Then, the point with the minimum expected cost is selected as the current *registration* point. Now, our goal is to obtain $f_1^*(\text{r}_1, v_1)$ which minimizes the expected cost for the *N* time *interval*s. The optimal *registration* points $k_1^*, k_2^*, \cdots, k_N^*$ can be obtained by solving a set of recursive equations given in (1) and (2). In the equations, two cost functions, $C_R(k_n, v_n)$ and $C_{CD}(k_n, v_n)$ are used. $C_R(k_n, v_n)$ denotes *registration* cost from the new VLR v_n to the *registration* point k_n. And $C_{CD}(k_n, v_n)$ denotes *call delivery* cost traversing $\text{TLR}_0, \text{TLR}_1, ..., \text{TLR}_{k_n}$, and the new VLR v_n when *registration* is made to TLR k_n. Especially, $C_{CD}(\text{HLR}, v_n)$ is the *call delivery* cost of the succeeding calls, where HLR already has the information about the current location of the MT from the delivery of the first call. In addition, two random variables, NC and V_{n+1}, are included in the equations. NC is the number of call arrivals for an *interval* and is assumed to be identically and independently distributed. V_{n+1} is the VLR of the RA into which the MT is to move at the end of nth *interval,* and is dependent on v_n and the mobility pattern of the MT. It is assumed that the system is composed of M RAs.

$$f_n^*(\mathrm{r}_n, v_n) = \min_{k_n \in \mathrm{r}_n} [\, C_R(k_n, v_n) + P(NC=0) \sum_{v=1}^{M} P(V_{n+1}=v) \; f_{n+1}^*(\mathrm{r}_{n+1}, v) + \sum_{i=1}^{\infty} P(NC=i) \{ C_{CD}(k_n, v_n) + (i-1) \; C_{CD}(\mathrm{HLR}, v_n) + \sum_{v=1}^{M} P(V_{n+1}=v) \; f_{n+1}^*(\mathrm{r}_{n+1}, v) \}], \quad (1)$$

for $n = 1, \cdots, N-1$,

and

$$f_N^*(\mathrm{r}_N, v_N) = \min_{k_N \in \mathrm{r}_N} [\, C_R(k_N, v_N) + \sum_{i=1}^{\infty} P(NC=i) \{ C_{CD}(k_N, v_N) + (i-1) \; C_{CD}(\mathrm{HLR}, v_N) \}]. \quad (2)$$

The total cost at the time of nth location update is the sum of *registration* and *call delivery* cost for the *interval* and expected costs $f_{n+1}^*(\mathrm{r}_{n+1}, v)$ for the next $N-n$ consecutive *interval*s to follow. Obviously, when $NC = 0$, *call delivery* cost for the *interval* is zero. In general, $C_R(k_n, v_n)$ is the highest when *registration* is made to TLR_0 or HLR, and the lowest when *registration* is made to TLR_{K_n+1} or old VLR. When $NC = 0$, since the set of TLRs recorded at the MT at the end of the *interval* is $(\mathrm{TLR}_1, ..., \mathrm{TLR}_{k_n})$, r_{n+1} becomes $(\mathrm{TLR}_0, ..., \mathrm{TLR}_{k_n}, v)$ if V_{n+1} is v. When $NC > 0$, note that the *call delivery* costs for the first call in the *interval* and the following calls are different. This is because when a call arrival occurs, the current VLR returns a TLDN to HLR and the following calls are delivered directly from HLR to the current VLR. Moreover, if a call arrival occurs, the set of TLRs recorded at the MT is updated to (TLR_0) to keep valid information about the modified situation. Therefore, when $NC > 0$, r_{n+1} becomes (TLR_0, v) if V_{n+1} is v.

From the above formulation it is clear that the optimal strategy at a particular location depends on the probability distribution of the future trajectory of an MT. However, the probability distribution of the mobility pattern of an MT may not be well predicted. In addition, the computational burden to solve the dynamic programming grows explosively with the number of location updates. In the following subsection, we propose a selective pointer forwarding scheme that is based on the dynamic programming discussed in this subsection.

B. Selective Pointer Forwarding

At the time of initial location update we have K_1+2 candidate TLRs for location *registration* point. Among them, optimal *registration* point k_1^* is determined based on the expected cost. The cost function is given by the following equation.

$$f_1^*(\mathrm{r}_1, v_1) = \min_{k_1 \in \mathrm{r}_1} [\, C_R(k_1, v_1) + P(NC=0) \sum_{v=1}^{M} P(V_2 = v)\; f_2^*(\mathrm{r}_2, v)$$

$$+ \sum_{i=1}^{\infty} P(NC=i)\, \{\, C_{CD}(k_1, v_1) + (i-1)\; C_{CD}(\mathrm{HLR}, v_1) + \sum_{v=1}^{M} P(V_2 = v)\; f_2^*(\mathrm{r}_2, v) \,\}]. \tag{3}$$

In the above equation when $NC > 0$, since the record of HLR and the set of TLRs recorded at the MT are updated after the first *call delivery*, the succeeding *call delivery* cost and candidate *registration* point for the very next *interval* are independent of the decision of the current *interval*. Also, to approximate the above objective function let us assume that the set of candidate *registration* points r_2 is identical under any decision k_1. Then, the three items $P(NC=0) \sum_{v=1}^{M} P(V_2 = v)\; f_2^*(\mathrm{r}_2, v)$, $(i-1)\; C_{CD}(\mathrm{HLR}, v_1)$, and $P(NC>0) \sum_{v=1}^{M} P(V_2 = v)\; f_2^*(\mathrm{r}_2, v)$ are identical under any initial decision. Thus, the following approximation results. In the equation, the subscript denoting the *interval* is omitted.

$$f^*(\mathrm{r}, v) = \min_{k \in \mathrm{r}} [\, C_R(k, v) + P(NC>0) \times C_{CD}(k, v) \,]. \tag{4}$$

The *registration* and *call delivery* cost in Equation (4) consists of database access and signaling cost.

By assuming an identical VLR access cost and distance proportioned signaling cost, the costs in Equation (4) can possibly be computed by an MT with a slight modification of current system. *Registration* and *call delivery* procedures of SPF are described as follows.

a. Registration

1) When an MT moves from one RA to another, it selects one TLR among the TLRs stored in its memory based on the expected costs.
2) The MT is registered at the new VLR by sending a *registration-request* message and the ID of the selected TLR to which its new location message should be sent.
3) The VLR creates a temporary record for the MT and inform the selected TLR of the new location of the MT.

After registration, the MT updates the record of TLRs stored in the memory of the MT. Suppose that the previous record before update is (TLR_0, TLR_1, … , TLR_K). Then the record of the MT is updated as follows: When the HLR is selected in step 1), K is set to zero and the updated record becomes (TLR_0). When the old VLR is selected, the old VLR is set to TLR_{K+1} and added to the memory. As a result, the record becomes (TLR_0, TLR_1, … , TLR_K, TLR_{K+1}). In case of $1 \le k \le K$, the IDs of TLRs stored after kth TLR are removed. That is, the updated record becomes (TLR_0, TLR_1, … , TLR_k). To implement SPF, an MT should have memory to store the IDs of the current TLRs which have information about its location. The computation of the expected cost is also required by the MT.

b. Call Delivery

When a phone call arrives at the HLR, the call is delivered to the MT by tracing the forwarding pointers. Also, after a call is delivered, the current VLR returns the routable address back to the HLR and the record of the HLR is updated to the current VLR. The set of TLRs recorded at the MT is also updated to (TLR_0).

IV. PERFORMANCE ANALYSIS

This section examines the performance of SPF and compares it with IS-41, PF, and OPF. Let call-to-mobility ratio (CMR) be λ / μ, where λ is the call-arrival rate, and μ is the location update rate from current RA. We assume that call-arrivals follow poisson distribution and the residence times of an MT have exponential distribution. We also assume that the two distributions are independent of each other. In addition, estimates of network cost are made as follows to simplify the comparison.

1) The database access cost of the HLR is normalized to 1.
2) The database access cost of the VLR is α. Since HLR is a signaling bottleneck, $\alpha \leq 1$ is expected. In our study, $\alpha = 0.5$ and 1 are considered.
3) The signaling cost is $\beta \times$ distance. The assumption that signaling cost is proportional to the distance is reasonable. And β represents signaling cost of a unit distance (Euclidean distance between centers of two adjacent RAs) given that the database access cost of the HLR is normalized to 1. In our study, $\beta = 0.1$, 0.5, and 1 are considered.

A. The Mobility Model

We use two-dimensional random walk model [18]. In the two-dimensional random walk model, an MT may move in one of four possible directions with equal probability 0.25. However, in the real world, the moving pattern of the MT usually exhibits spatial locality. That is, an MT tends to roam within a bounded area. To simulate this characteristic, a two-dimensional random walk within a bounded region is used to model the moving pattern. In this paper, movement of an MT is restricted in a limited square area. If an MT is at the edge of this limited area, the probability for each direction is no longer 0.25. Fig. 9 illustrates a bounded area with 25 RAs. When a mobile is in RA_1, it is not allowed to move to the right. If it moves horizontally, it must move to the left. Therefore, the probability of moving to the left is 0.5 in RA_1. Based on the same reason, the probabilities of moving to the right and up are all 0.5 in RA_2.

B. The Analytical Model

Since the *call delivery* cost from the call originator to the HLR and radio link cost between the current VLR and the MT are the same in three schemes to compare they can be excluded in this analytical model. We thus consider the *call delivery* cost from the HLR to the current VLR and the *registration* cost from the current VLR. Let d (A - B) denote the Euclidean distance from A to B and *nc* denote the number of call-arrivals during the *interval*.

a. IS-41

During the *registration* operation, one access to HLR occurs. *Registration* and *call delivery* costs in IS-41 are respectively

$$C_R^{IS-41} = 1 + \beta \times d\,(\text{VLR}_{\text{new}} - \text{HLR}), \quad \text{and} \quad C_{CD}^{IS-41} = \beta \times d\,(\text{HLR} - \text{VLR}_{\text{new}}), \tag{5}$$

where, VLR_{new} denotes the new VLR. Therefore, the total cost between two consecutive *registrations* becomes

$$C^{IS-41} = C_R^{IS-41} + nc \times C_{CD}^{IS-41}. \tag{6}$$

b. Pointer Forwarding

Assume that the length of forwarding pointer chain is P and the chain consists of VLR_1, VLR_2, …, VLR_P after *registration* operation. VLR_P denotes the VLR of the old RA from which the MT departs. Then the *registration* cost is

$$C_R^{PF} = \alpha + \beta \times d\,(\text{VLR}_{\text{new}} - \text{VLR}_P). \tag{7}$$

The first *call delivery* cost in PF is

$$C_{FCD}^{PF} = \alpha P + \beta \times d\,(\text{HLR} - \text{VLR}_1) + \beta \times d\,(\text{VLR}_1 - \text{VLR}_2) + \ldots + \beta \times d\,(\text{VLR}_P - \text{VLR}_{\text{new}}). \tag{8}$$

After the first call arrives, the HLR updates its pointer to the current VLR. Thus the *call delivery* cost of the succeeding calls is

$$C_{SCD}^{PF} = \beta \times d\,(\text{HLR} - \text{VLR}_{\text{new}}). \tag{9}$$

Therefore, the total cost between two consecutive *registrations* becomes

$$C^{PF} = C_R^{PF}, \quad \text{if } nc = 0$$
$$= C_R^{PF} + C_{FCD}^{PF} + (nc-1) \times C_{SCD}^{PF}, \quad \text{if } nc \geq 1. \tag{10}$$

c. One-step Pointer Forwarding

The length of forwarding pointer chain is always one in the OPF. Let VLR_{pre} denote the "Previous VLR". Then the *registration* cost is

$$C_R^{OPF} = \alpha + \beta \times d\,(\text{VLR}_{\text{new}} - \text{VLR}_{\text{pre}}). \tag{11}$$

The first *call delivery* cost in OPF is

$$C_{FCD}^{OPF} = \alpha + \beta \times d\,(\text{HLR} - \text{VLR}_{\text{OPF}}) + \beta \times d\,(\text{VLR}_{\text{pre}} - \text{VLR}_{\text{new}}). \tag{12}$$

After the first call arrival, the HLR updates its pointer to the current VLR. Thus the *call delivery* cost of the succeeding calls is

$$C_{SCD}^{OPF} = \beta \times d\,(\text{HLR} - \text{VLR}_{\text{new}}). \tag{13}$$

Therefore, the total cost between two consecutive *registrations* becomes

$$C^{OPF} = C_R^{OPF}, \quad \text{if } nc = 0$$
$$= C_R^{OPF} + C_{FCD}^{OPF} + (nc-1) \times C_{SCD}^{OPF}, \quad \text{if } nc \geq 1. \tag{14}$$

d. Selective Pointer Forwarding

This section consists of two parts. The first part is to determine the TLR_{k*} satisfying Equation (4), which is informed of the latest location update. The second part is to obtain the *registration* and *call delivery* cost in the *interval* when *registration* is made to the TLR_{k*} in the proposed scheme.

First to determine the *registration* point Equation (4) is solved. To compute $P[NC > 0]$ in Equation (4), let X and Y respectively denote the first occurrence time of call-arrival and location update from the beginning of each *interval*. Then, X and Y are both exponentially distributed random variables with respective means $1/\lambda$ and $1/\mu$. Thus, we have

$$P[NC>0] = P[X<Y] = \int_0^\infty P[X < Y \mid Y = y]\mu\, e^{-\mu y} dy$$
$$= \int_0^\infty \int_0^y \lambda\, e^{-\lambda x} dx\, \mu\, e^{-\mu y} dy = \frac{\lambda}{\lambda + \mu} = \frac{\text{CMR}}{\text{CMR}+1}. \tag{15}$$

Assume that the length of forwarding pointer chain is K and the chain consists of TLR_1, TLR_2,…, TLR_K before *registration* operation. If TLR_k is informed of the new VLR, then the *registration* cost in Equation (4) becomes

$$C_R\ (k, \text{VLR}_{\text{new}}) = \alpha + \beta \times d\ (\text{VLR}_{\text{new}} - \text{TLR}_k). \tag{16}$$

The cost of first *call delivery* at the new RA is

$$\begin{aligned} C_{CD}(k, \text{VLR}_{\text{new}}) &= \alpha\ k + \beta \times d\ (\text{HLR} - \text{TLR}_1) \\ &+ \beta \times d\ (\text{TLR}_1 - \text{TLR}_2) + \ldots + \beta \times d\ (\text{TLR}_{k-1} - \text{TLR}_k) + \beta \times d\ (\text{TLR}_k - \text{VLR}_{\text{new}}). \end{aligned} \tag{17}$$

From Equations (15), (16), and (17) the expected cost of (4) is computed. Let TLR_{k*} denote the TLR determined in Equation (4).

Given that the *registration* point is determined, we calculate the cost of SPF for the *interval* to compare it with IS-41, PF, and OPF. When *registration* is made to the TLR_{k*}, the cost of *registration* and first *call delivery* is calculated in the same way as above. That is,

$$C_R^{SPF} = C_R\ (k^*, \text{VLR}_{\text{new}}) \text{ and } C_{FCD}^{SPF} = C_{CD}(k^*, \text{VLR}_{\text{new}})\ . \tag{18}$$

After the first call arrives, the HLR updates its pointer to the current VLR. Thus the *call delivery* cost of the succeeding calls is

$$C_{SCD}^{SPF} = \beta \times d\ (\text{HLR} - \text{VLR}_{\text{new}}). \tag{19}$$

Therefore, the total cost between two consecutive *registration*s becomes

$$\begin{aligned} C^{SPF} &= C_R^{SPF}, \quad \text{if } nc = 0 \\ &= C_R^{SPF} + C_{FCD}^{SPF} + (nc - 1) \times C_{SCD}^{SPF}, \quad \text{if } nc \geq 1. \end{aligned} \tag{20}$$

In the next section, we compare the SPF with IS-41, PF, and OPF strategy.

C. Simulation Results

The area is divided into 10×10 RAs in the simulation. HLR is assumed to be in RA (5,5). In the experiment ten thousand consecutive location updates are performed for each value of different CMR ranging from zero to three. At each CMR, call arrivals are generated according to the CMR. An identical series of ten thousand location updates and the same number of call arrivals are applied to IS-41, PF, OPF, and SPF. The location management cost of each scheme is dependent on the *registration* operation at each time of location update. First, the cost of suggested implementation is compared to that of the dynamic programming in Fig. 10. In the computational result, the cost of the one-step dynamic programming is slightly higher than that of the full dynamic programming. This explains that one-step dynamic programming is sufficient to reduce the expected cost unless an MT follows a certain predetermined path, for example, a straight path. The proposed SPF can be extended to more accurate solution if the mobility pattern of the MT can be precisely estimated. For example, two-step dynamic programming minimizing the expected cost of the next two intervals can be used, and three-step, and so on if the computing processor makes them feasible with low cost.

The average *registration* cost per location update and *call delivery* cost per call arrival of IS-41, PF, OPF, and SPF are compared as in Fig. 11 - 12. As was expected, the highest *registration* and lowest *call delivery* costs are obtained by the IS-41. The PF scheme shows the opposite result. The *registration* cost of the PF is equal to one since the *registration* is always made to the old VLR. Note that IS-41 and PF show constant *registration* cost under any CMR because the number of call arrivals is not considered in the two methods. Since the *registration* point in the OPF is dependent on the number of call arrivals during the previous interval, *registration* cost varies with the CMR even though OPF does not take into account the CMR. The registration cost of OPF is much higher than that of the PF under relatively low CMR. This is because when CMR is low, the OPF behaves like the IS-41 as shown in Fig. 13. A tradeoff between *registration* and *call delivery* is achieved by the proposed SPF. Also, it should be noted in Fig. 11 that the *registration* cost of the SPF is less than one when CMR is relatively low. The reason is explained as follows. Let us assume that an MT visits RA (2, 4) twice with no call arrival during the trip as in Fig. 14. At the time of the second visit, the optimal *registration* point may be determined as the VLR of the RA (2, 4) provided with extremely low CMR. In this case the signaling cost is considered to be zero. As a result, the database access and signaling cost becomes 0.5 in the case of revisit.

The total cost during an *interval* is obtained by summing the total c*all delivery* cost and the *registration* cost. We define the relative cost as the ratio of the total cost during ten thousand *interval* of each scheme to that of the proposed scheme. Fig. 15 - 19 compare the relative costs of IS-41, PF, OPF, and SPF. The proposed SPF outperforms three other schemes in any combination of VLR access cost (α) and signaling cost of a unit distance (β). The HLR access cost is normalized to one. Fig. 15-17 show that the cost increment by increasing the signaling cost is higher in IS-41 than in other schemes. In the IS-41 since an MT always updates its location to HLR, the average signaling distance is longer than other schemes. Thus, the IS-41 is sensitive to the signaling cost. Cases with higher VLR access cost are experimented in Fig. 18 and 19. Note in these cases that the pointer traversing cost becomes relatively higher. Especially in the Fig. 18, the IS-41 performs better than the PF and OPF except for the case with relatively low CMR. Thus, the proposed SPF behaves like IS-41 as CMR increases. In any case the proposed scheme consistently performs better than the other three methods. Another tendency worth noting in the figures is that the cost differences by the four strategies become smaller as the CMR increases. This is mainly due to the fact that *call delivery* costs are identical in the four schemes after the first call arrival.

Fig. 20 shows the number of TLRs kept in the SPF when (α, β) = (0.5, 0.5). In the figure, the HLR is not included in the set of TLRs. Thus, when *registration* is made to the HLR, the number of TLRs is zero. When the CMR is zero, the SPF minimizes only the *registration* cost and it behaves like the PF. During the location updates between two call arrivals, an MT may revisit the same RA several times. In this case, the number of TLRs may be decreased. Therefore, the number of TLRs is not increased to infinity even in the case of zero CMR. As the CMR increases, $P[NC>0]$ increases. That is, the expected cost of the first *call delivery* increases, while the *registration* cost remains the same as before. Thus, the SPF decreases the number of TLRs in order to decrease the expected cost of the first *call delivery*.

Finally, let us consider the computational complexity to determine the *registration* point in the SPF.

Assume that we are searching for the *registration* point from HLR to old VLR. Then one calculation of distance for *registration* cost and two additional calculations of distance for *call delivery* cost for each candidate *registration* point are required in the Equation (16)-(17). Thus when the number of TLRs recorded at an MT is K, the computational complexity to obtain the *registration* point by the SPF is $O(K)$. Moreover, except for the unrealistic case of zero CMR, the number of TLRs or K is less than four in Fig.20. Thus, including HLR and old VLR the SPF considers at most six candidate points to register even in the worst case.

V. CONCLUSION

A new effective location update scheme and its implementations in PCS are proposed. In the proposed scheme of Selective Pointer Forwarding (SPF), an MT has the IDs of TLRs each of which has the forwarding pointer to identify its current location. An MT selects one among the TLRs to register its location based on the expected database access and signaling costs for N consecutive location updates. To minimize the expected costs of *registration* and *call delivery* for the N consecutive *interval*s, the concept of probabilistic dynamic programming is introduced. We formulate the determination of the optimal *registration* point with the N-stage dynamic programming problem. Since it is unrealistic to solve and implement the N-stage dynamic programming solutions for the location update, approximated expected cost function is suggested in the SPF. In the proposed method only the *registration* and the first *call delivery* cost for the *interval* is compared to determine the *registration* point. The *registration* and *call delivery* procedures are also presented to implement the proposed SPF.

Estimates of the database access and signaling costs are made to simplify the comparison of IS-41, PF, OPF, and SPF. The respective cost functions for the four schemes are analyzed based on the distance moved and the number of calls arrived. The results show that the proposed scheme outperforms the other three methods in any combinations of database access and signaling costs. Among the four schemes, only the proposed scheme takes into account the call-to-mobility ratio to decide *registration* point. The performance of the proposed SPF is especially outstanding when the call-to-mobility ratio is relatively low.

REFERENCES

[1] Y.-B. Lin, "Reducing location update cost in a PCS network," *IEEE/ACM Trans. Network*., vol. 5, no. 1, pp. 25-33, 1997.

[2] A. Bar-Noy, I. Kessler, and M. Sidi, "Mobile users: to update or not to update?," *ACM-JCM Wireless Networks*, pp. 175-186, 1995.

[3] I. F. Akyildiz, J. S. M. Ho, and Y.-B. Lin, "Movement-based location update and selective paging for PCS networks," *IEEE/ACM Trans. Network*., vol. 4, no. 4, pp. 629-638, 1996.

[4] A. Abutaleb and V. O. K. Li, "Location update optimization in personal communication systems," *ACM-JCM Wireless Networks*, pp. 205-216, 1997.

[5] M. Verkama, "A simple implementation of distance-based location updates," *Universal Personal Communications Record*, vol. 1, pp. 163-167, 1997.

[6] Z. Naor and H. Levy, "Cell identification codes for tracking mobile users," *INFOCOM'99*, vol. 1, pp. 28-35, 1999.

[7] Chae Y. Lee and Seok J. Kim, "Modeling and analysis of the dynamic location registration and paging in microcellular systems," *IEEE Trans. Veh. Technol*., vol. 45, no. 1, pp. 82-90, 1996.

[8] H. Liu and C. Liu, "A geography based location management scheme for wireless communication systems," *VTC 2000*, vol. 2, pp. 1358-1361, 2000.

[9] G. Varsamopoulos and S. Gupta, "On dynamically adapting registration areas to user mobility

patterns in PCS networks," *Parallel Processing*, pp. 108-113, 1999.

[10] H. Hwang, M. Chang, and C. Tseng, "A direction-based location update scheme with a line-paging strategy for PCS networks," vol. 45, pp. 149-151, 2000.

[11] 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.

[12] R. Jain, Y.-B. Lin, C.N. Lo, and S. Mohan, "A caching strategy to reduce network impacts of PCS," *IEEE J. Select. Areas. Commun.*, vol. 12, pp. 1434-1445, 1994.

[13] M. Veeraraghavan and G. Dommety, "Mobile location management in ATM networks," *IEEE J. Select. Areas Commun.*, vol. 15, no. 8, pp. 1437-1454, 1997.

[14] Z. Mao and C. Douligeris, "High throughput database structures for location management in PCS networks," *INFOCOM 2000*, vol. 2, pp. 785-794, 2000.

[15] Z. Jian and W. Jing, "3-level database hierarchy for location management in PCS networks," *ICCT'98*, vol. 1, pp. 101-105, 1998.

[16] J. Z. Wang, " A fully distributed location registration strategy for universal personal communication system," *IEEE J. Select. Areas Commun.*, vol. 11, pp. 850-860, 1993.

[17] Y.-B. Lin and W.-N. Tsai, "Location tracking with distributed HLR's and pointer forwarding," *IEEE Trans. Veh. Technol.*, vol. 47, no. 1, pp. 58-64, 1998.

[18] 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, no. 8, pp. 1455-1466, 1997.

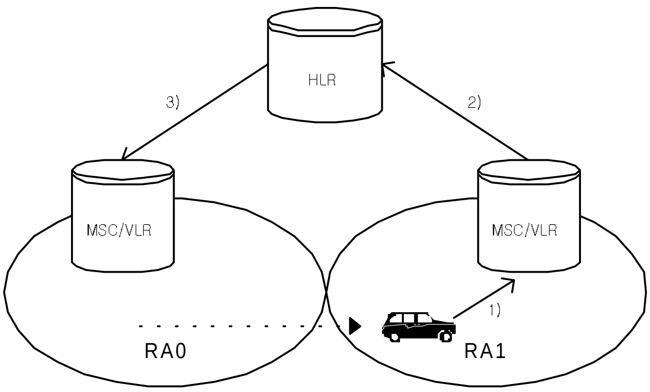

Fig. 1. ***Registration*** **in IS-41.**

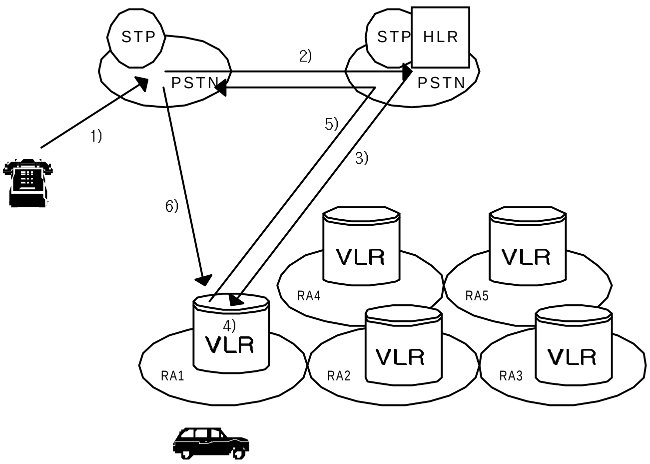

Fig. 2. ***Call delivery*** **in IS-41.**

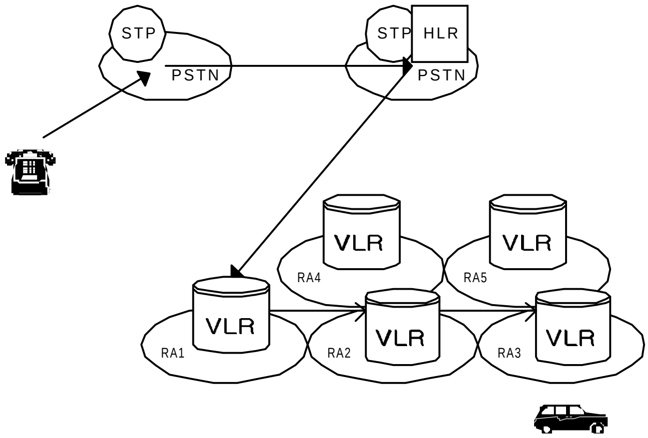

Fig. 3. Pointer Forwarding strategy.

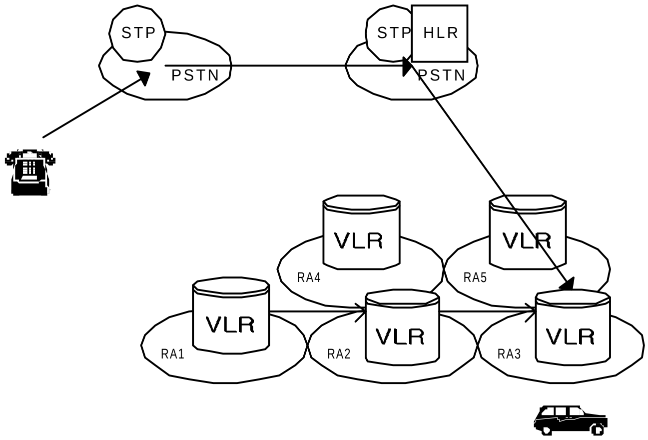

Fig. 4. Searching path after the *call delivery* in Pointer Forwarding strategy.

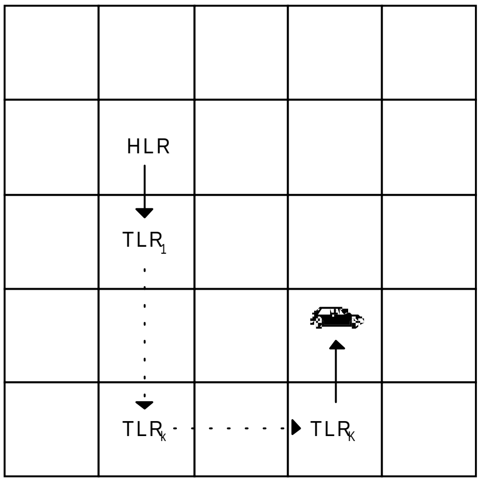

Fig. 5. TLRs in the proposed scheme.

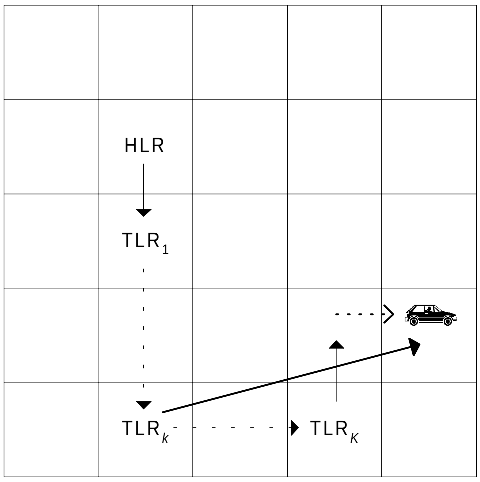

Fig. 6. ***Registration*** **in the proposed scheme.**

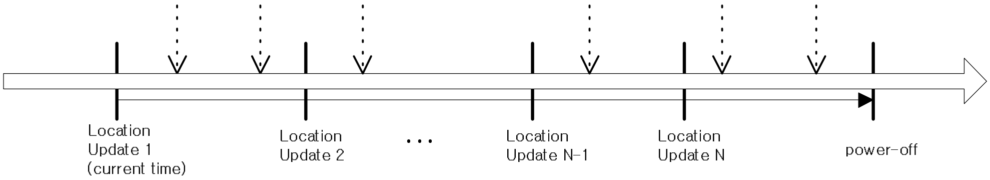

Fig. 7. Call arrivals and location updates.

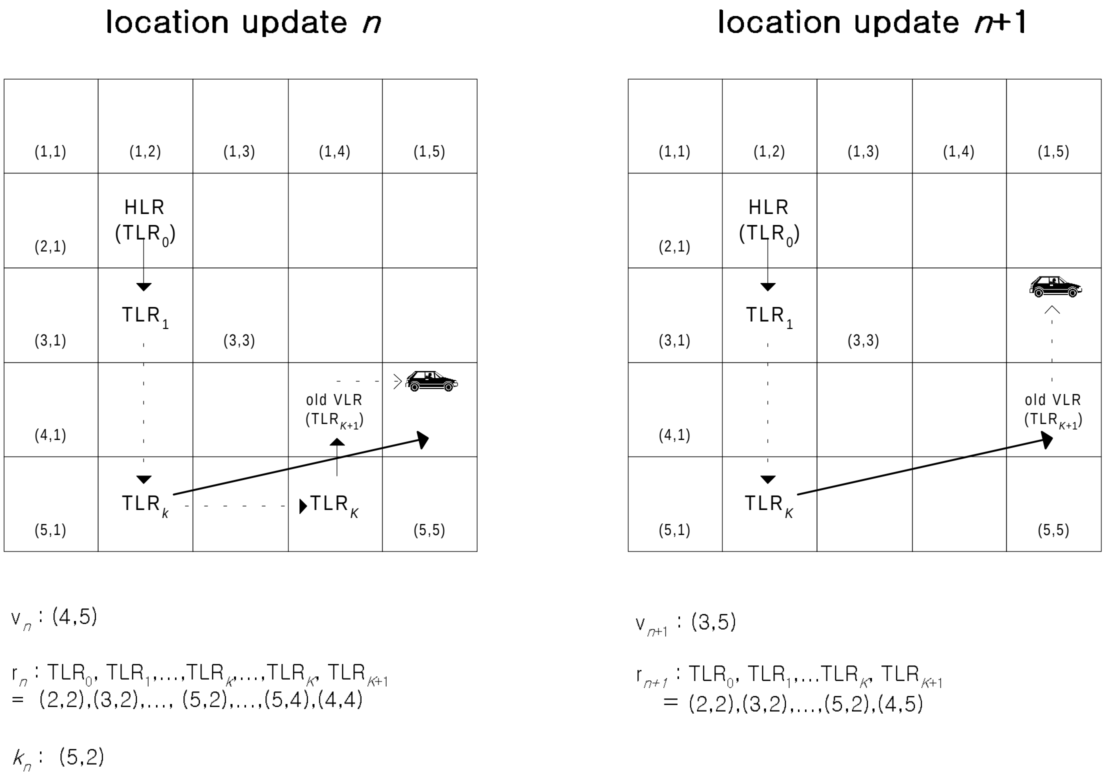

Fig. 8. Location update *n* and *n*+1.

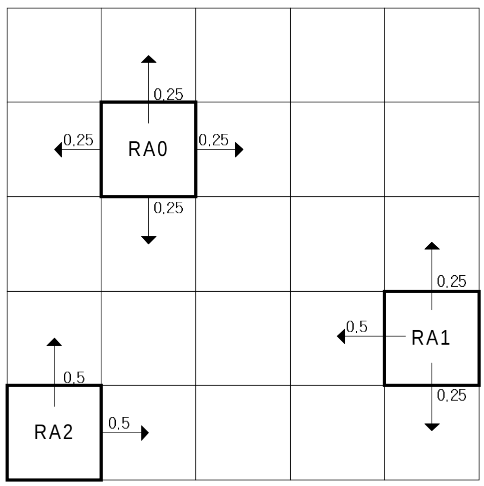

Fig. 9. Two-dimensional random walk within bounded area.

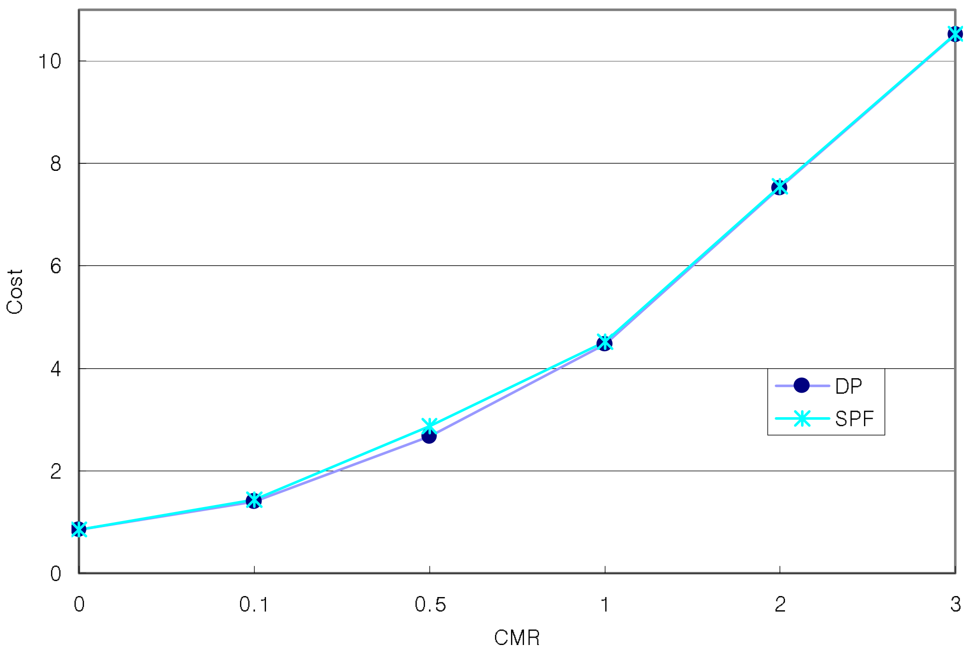

Fig. 10. The total costs of the SPF and DP when (α, β) = (0.5, 0.5).

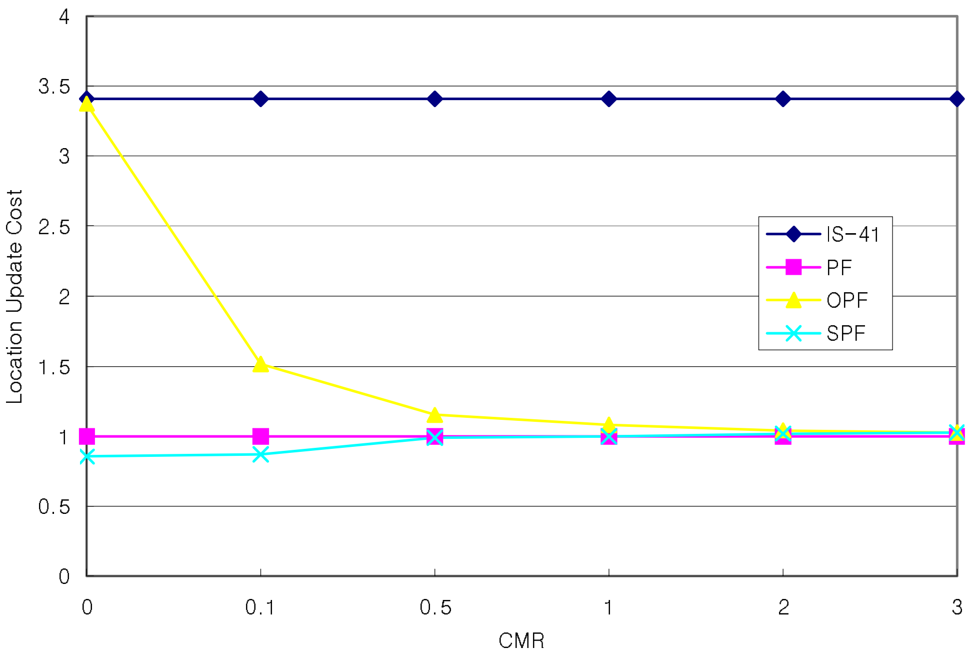

Fig. 11. ***Registration*** **cost per location update when (α, β) = (0.5, 0.5).**

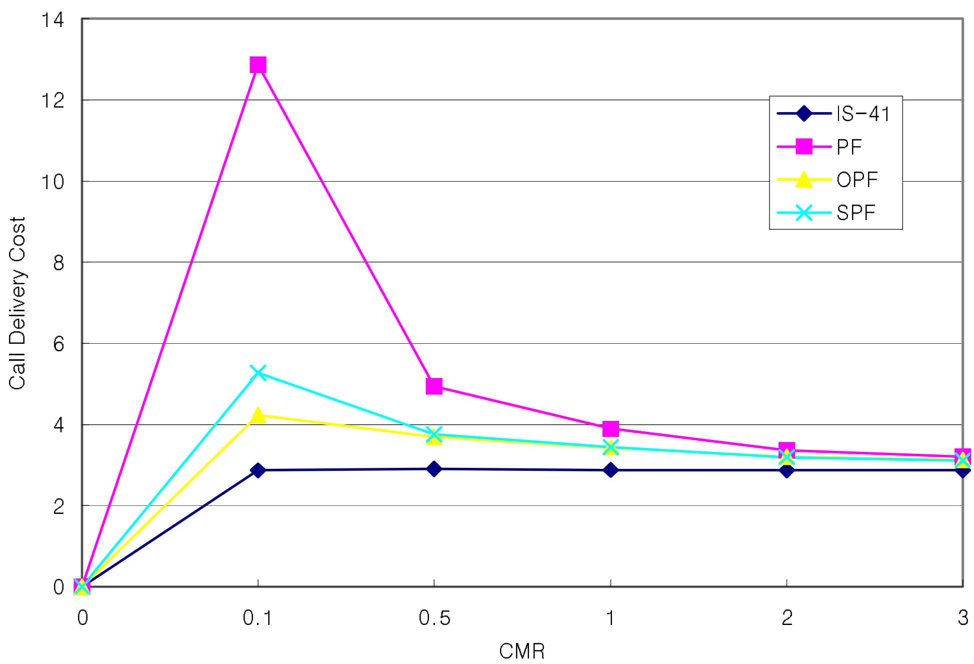

Fig. 12. C*all delivery* cost per call arrival when (α, β) = (0.5, 0.5).

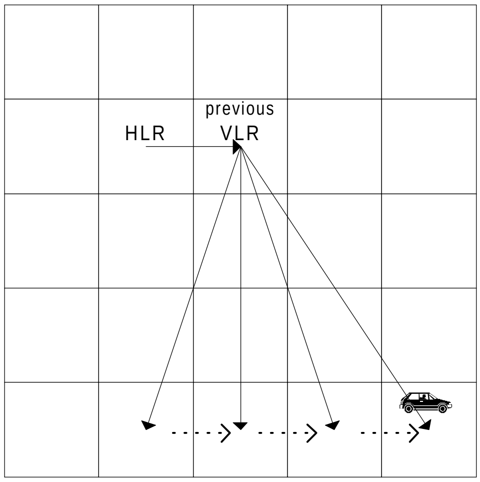

Fig. 13. ***Registration*** **in the OPF when CMR is low.**

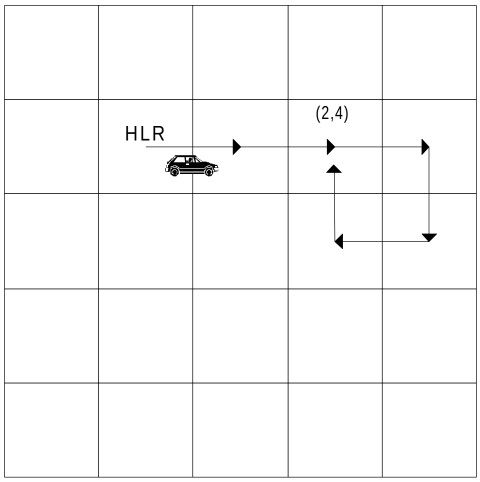

Fig. 14. Case that an MT visits a certain RA twice.

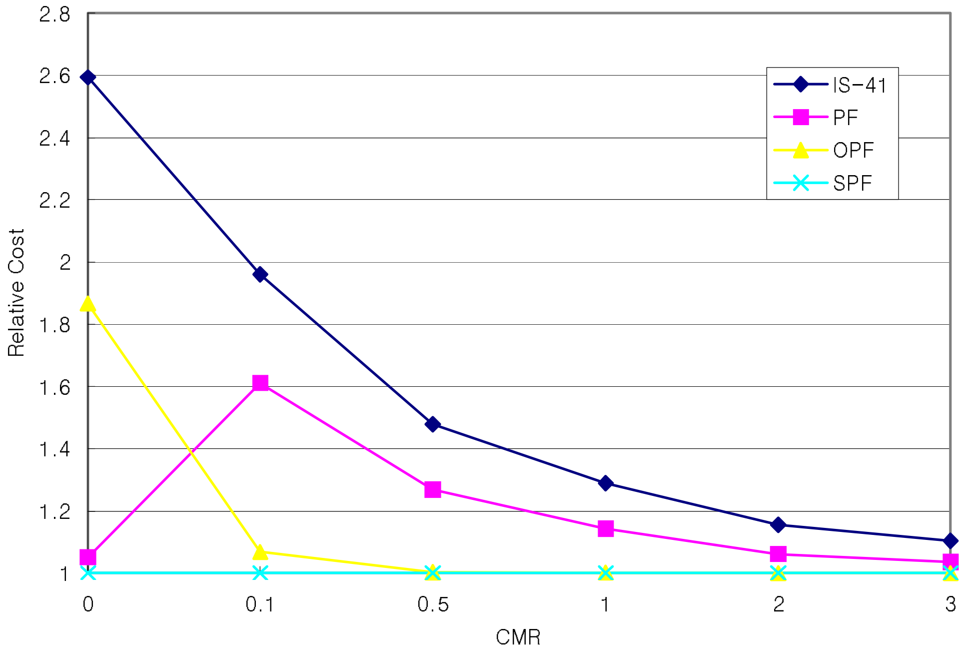

Fig. 15. Relative r*egistration* and *call delivery* cost when (α, β) = (0.5, 0.1).

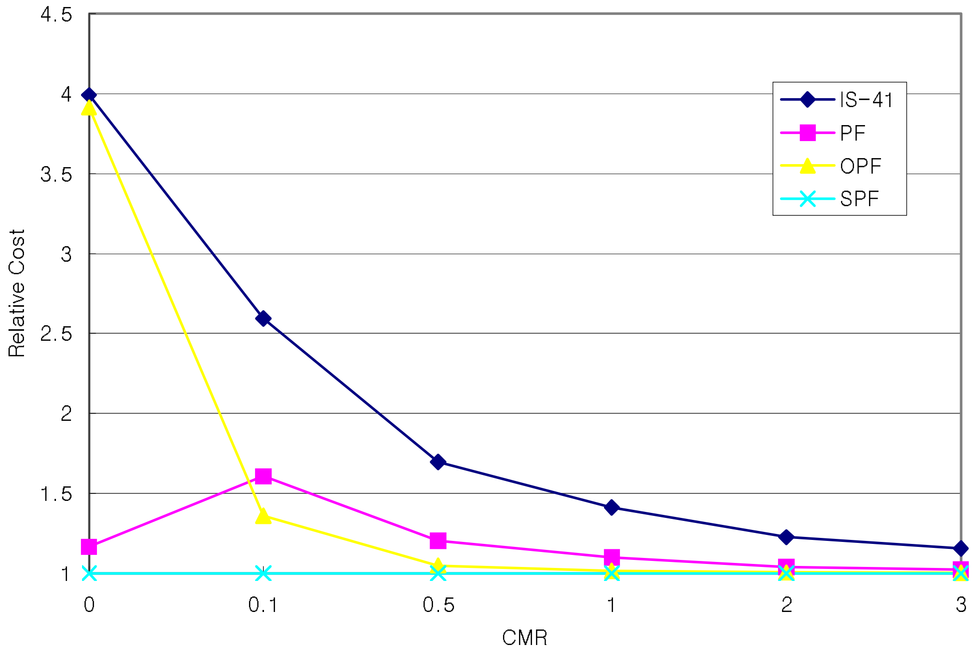

Fig. 16. Relative r*egistration* and *call delivery* cost when (α, β) = (0.5, 0.5).

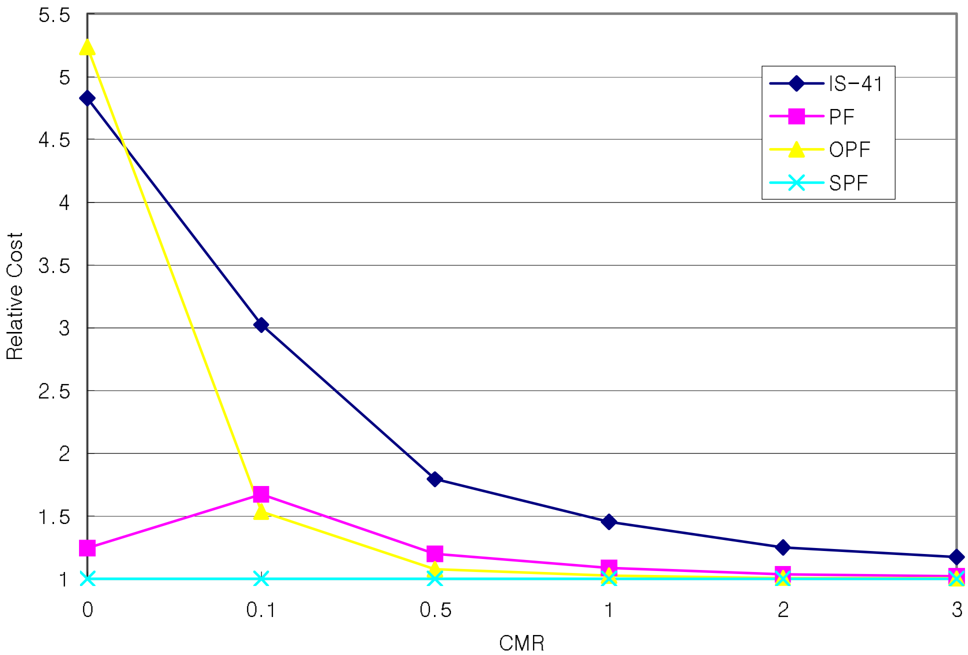

Fig. 17. Relative *registration* and *call delivery* cost when (α, β) = (0.5, 1).

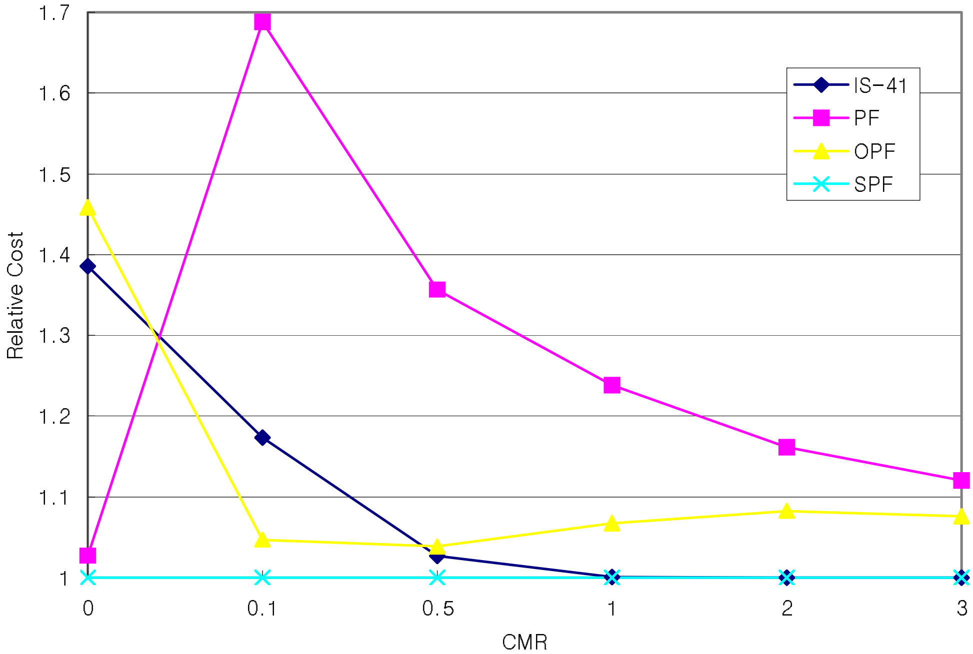

Fig. 18. Relative *registration* and *call delivery* cost when (α, β) = (1, 0.1).

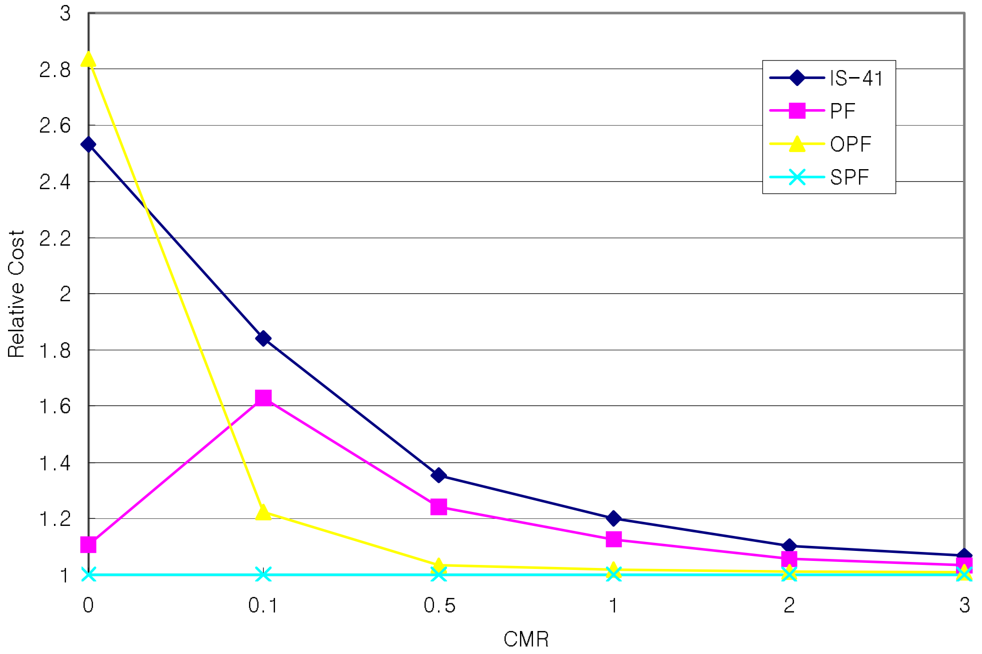

Fig. 19. Relative r*egistration* and *call delivery* cost when (α, β) = (1, 0.5).

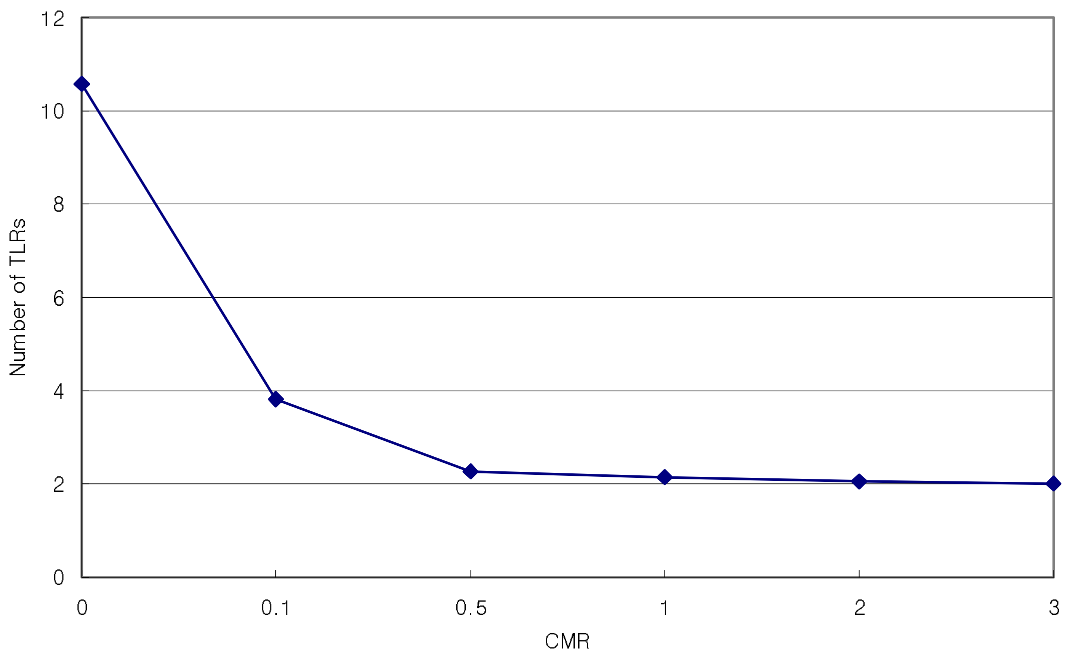

Fig. 20. Number of TLRs in the SPF.