A Probability-based Location Management Strategy for the Next Generation Communication Systems

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

The personal communication service (PCS) is a system that aims to allow for communication anywhere in the world. PCS networks support mobile terminals (MTs) that are free to travel, and the network access point of an MT changes as it moves around the network coverage area. As a result, location management is important to effectively keep track of mobile terminals with reduced signal flows and database queries. Several methods have been suggested to improve the efficiency of location management strategy. Among them, the distance-based scheme has been proved to have less mobility management cost than the others. However, the configuration of registration areas (RAs) for an MT needs to be matched with user's movement behavior, street layout, and local topology. Thus, we propose a probability-based location management strategy. In the scheme, the shape of each RA of an MT is individually and dynamically tailored to match the user's movement and the surrounding geographic conditions. Transition probability matrix is used to implement the proposed strategy. The numerical results demonstrate that the proposed scheme can significantly reduce mobility management cost compared to the distance-based strategy.

I. Introduction

The personal communication service (PCS) is a system that focuses on the communication anywhere in the world. In a PCS system, the location of a called mobile terminal (MT) needs to be determined before the connection is established. Location tracking operation in a PCS network is expensive due to many signal flows and database queries to achieve the task. Thus, 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. In addition to the strategies in IS-41 and GSM, several methods have been proposed to improve the efficiency of location management strategy. 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 the time elapsed, the number of cell boundary crossings and the distance traveled since the last registration. All three parameters can be dynamically adapted to each MT's traffic and mobility patterns, hence providing better cost-effectiveness than the static location management strategies.

In particular, in the distance-based scheme, an MT performs registration whenever it is some threshold distance away from the location where it last registered. For a system with memoryless random-walk mobility pattern, the distance-based scheme has been proved to have less mobility management cost than the others. However, the movements of most MTs have some regularity and MTs of given class (pedestrians, vehicles, etc.) may be constrained to follow certain paths. So the configuration of RAs for an MT needs to be matched with user's movement behavior, street layout, and local topology. Both the preferred size and shape of RAs depend on the individual MT and geographic conditions.

We propose a probability-based location management strategy in this paper. The shape of each RA of an MT is individually and dynamically tailored to match the user's movement and the surrounding geographic conditions. The probability that an MT moves to each adjacent cell at each time interval is assumed to be known. When location update occurs the probability is calculated and cells are included into the new RA in nonincreasing order of the probability. This paper is organized as follows. Section II refers the related studies. Section III shows the expected location update and paging cost function to propose a probability-based location management strategy. The implementation of the proposed strategy is suggested to minimize the cost function in section IV. The proposed scheme is compared to the distance-based location management strategy in section V. Section VI concludes the paper.

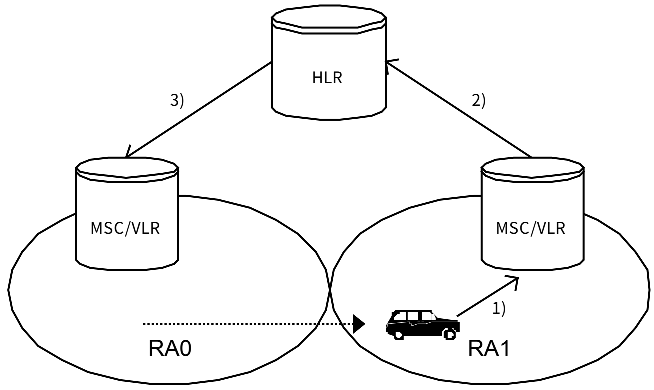

Fig. 1. *Registration* in IS-41.

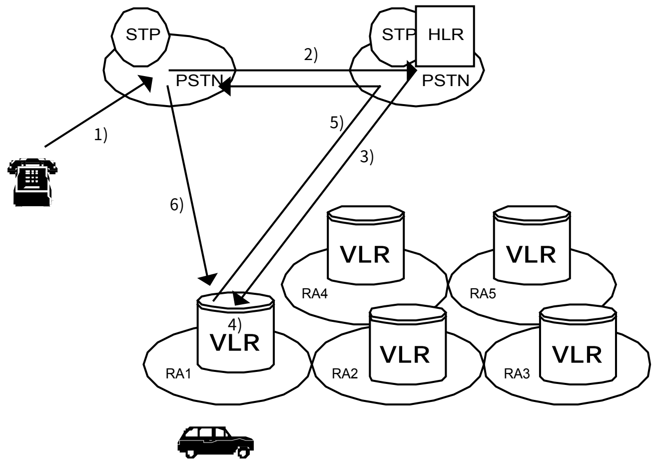

Fig. 2. *Call delivery* in IS-41.

II. Related Location Management Strategies

1. 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.

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

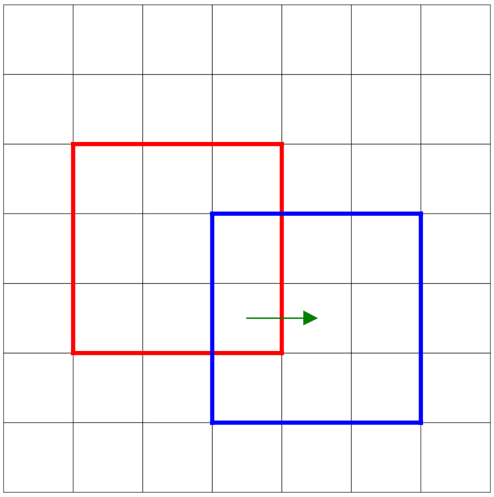

Fig. 3. Location update in the distance-based location management strategy.

1) 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.
2) A *location-request* message is sent to query the HLR of the MT
3) The HLR determines the current VLR, and queries the VLR by sending a *route-request* signal.
4) 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.
5) The VLR forwards the TLDN back to the originating MSC via the HLR of the MT.
6) When the originating MSC receives the TLDN, it routes the call to the MSC where the MT is located.

2. Distance-based Location Management Strategy

The service area is divided into predetermined RAs in the IS-41. For each MT, HLR records the RA in which the MT is located in the scheme. However, HLR records the cell for an MT as its location in the distance-based location management strategy. The MT performs registration whenever it is some threshold distance away from the location (Fig. 3). When a call arrives to the MT, paging is occurred to the cells which exist in the threshold distance.

III. New Objective Function of a Location Management Strategy

A new expected cost function is studied in this section to propose a probability-based location management strategy. First, traditional cost function used in the previous studies is examined. The followings are defined for the purpose.

C_{LU} : the average signaling and database access cost per location update

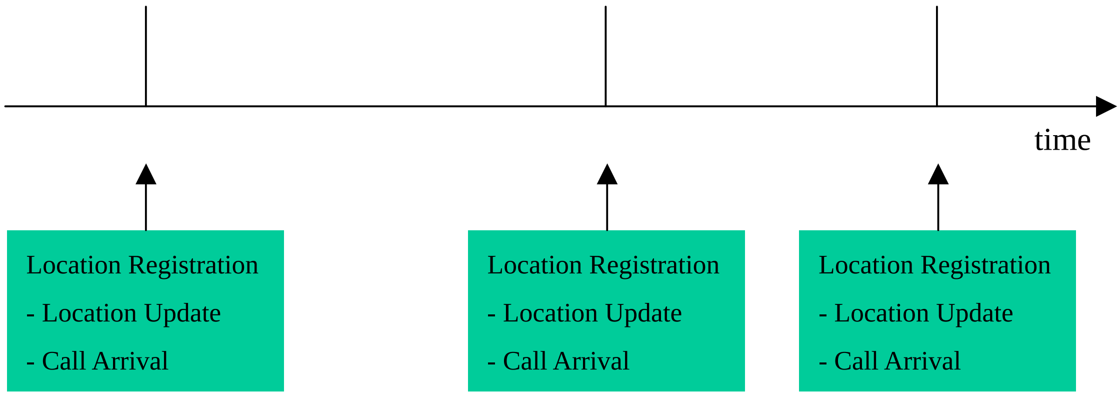

Fig. 4. Location registration process.

C_P : the average signaling cost per paging per cell

N_{LU} : the number of location updates

N_{CA} : the number of call arrivals

N_{cell} : the number of cells in one RA

Traditional cost function is defined as follows.

$$C_{LU}N_{LU} + C_P N_{cell} N_{CA} \quad (1)$$

This function has been used to compare the computational results of several strategies. The location update and paging cost during an interval can be obtained from the above cost function. However, what is important is the expected location management cost to determine an optimal location registration strategy. We define the location registration process to calculate the expected cost. In this paper, the location registration denotes the case that the location of an MT is registered to the HLR by the location update or call arrival to the MT. Then, location registrations become a renewal process since states are reset whenever a location registration is made. We call this process a location registration process (Fig. 4). The expected cost of each location management strategy is represented as the expected cost per unit time. First, the followings are defined.

$f_{LU}(t)$, $F^c_{LU}(t)$: probability and tail distribution function of location update, respectively

$f_{CA}(t)$, $F^c_{CA}(t)$: probability and tail distribution function of call arrivals, respectively

$N(t)$: the number of cells in the RA at time t

The expected cost per unit time is given as.

$$\text{E[COST]} = \int_0^\infty \frac{1}{t} F^c_{LU}(t) F^c_{CA}(t) [C_{LU} f_{LU}(t) + C_P N(t) f_{CA}(t)] dt \quad (2)$$

In the equation, $f_{LU}(t)$, $F^c_{LU}(t)$ and $N(t)$ are dependent on each location management strategy. Note that only radio and network communication resources are included in the cost. It seems reasonable that we pursue the tradeoff between the memory and computing power, and the radio and network communication resource.

IV. PROBABILITY-BASED LOCATION MANAGEMENT STRATEGY

It is assumed that the mobility pattern of an MT is represented by discrete time Markov chain. The probability that the MT exists in each cell after a certain time interval is presented in the transition probability matrix. As the interval becomes shorter, the location of the MT is more precisely predicted by the Markov chain. The transition probability matrix is recorded in both the HLR and the MT. The probability that the MT resides in each cell in the subsequent interval is calculated by multiplying the transition probability matrix by itself. In the proposed strategy, the RA of an MT during each interval is dynamically determined at the starting point of the interval. The RA in *t*th interval is determined as the set of cells to minimize the following cost function.

$$C_{LU}\, f_{LU}(t) + C_P N(t)\, f_{CA}(t) \qquad (3)$$

It is obvious that the cells must be included in the RA in nonincreasing order of the probability to minimize Function (3). Fig. 5 shows an example of transition probability matrix. If an MT makes first location registration in the cell 2 the probability that the MT exists in each cell is represented by the second raw of the matrix. In this case, the RA of the MT includes in the order of cell 2, 3, 4, and 5 to the extent that Function (3) is minimized. In the same way, new RA is determined in the second interval. Proposition 1 shows that the function (3) is a convex function to $N(t)$ given that cells are included into the RA in nonincreasing order of the probability. Therefore, no further calculation is needed when the function starts to increase by adding a new cell to the RA.

Proposition 1: Function (3) is a convex function to $N(t)$ given that cells are included into the RA in nonincreasing order of the probability.

Let $g(n)$ denote that $g(n) = C_{LU}\, f_{LU}(t) + C_P n f_{CA}(t)$. Then we prove that $g(n)$ is a convex function to n. Assume that cells are renumbered as c_1, c_2, … in the nonincreasing order of the probability that the MT resides in the cells. Let $f(c_n)$ denote the probability that the MT resides in the c_n. Then, $f(c_n) \geq f(c_{n+1})$ for all n, and when c_1, c_2, … , c_n are included in the RA $f_{LU}(t) = 1 - \sum_{i=1}^{n} f(c_i)$.

$$g(n+2) - g(n+1) = C_{LU}\, f(c_{n+2}) + C_P (n+2)\, f_{CA}(t) - C_{LU}\, f(c_{n+1}) - C_P (n+1)\, f_{CA}(t)$$

$$= C_{LU}[1 - \sum_{i=1}^{n+2} f(c_i)] + C_P (n+2)\, f_{CA}(t) - C_{LU}[1 - \sum_{i=1}^{n+1} f(c_i)] - C_P (n+1)\, f_{CA}(t)$$

$$= -C_{LU}\, f(c_{n+2}) + C_P\, f_{CA}(t) .$$

$$
\begin{array}{c|ccccc|}
 & 1 & 2 & 3 & 4 & 5 \\
1 & 0.1 & 0.2 & 0.3 & 0.4 & 0 \\
2 & 0 & 0.4 & 0.3 & 0.2 & 0.1 \\
3 & 0.2 & 0.2 & 0.2 & 0.2 & 0.2 \\
4 & 1 & 0 & 0 & 0 & 0 \\
5 & 1 & 0 & 0 & 0 & 0
\end{array}
$$

Fig. 5. An example of transition probability matrix.

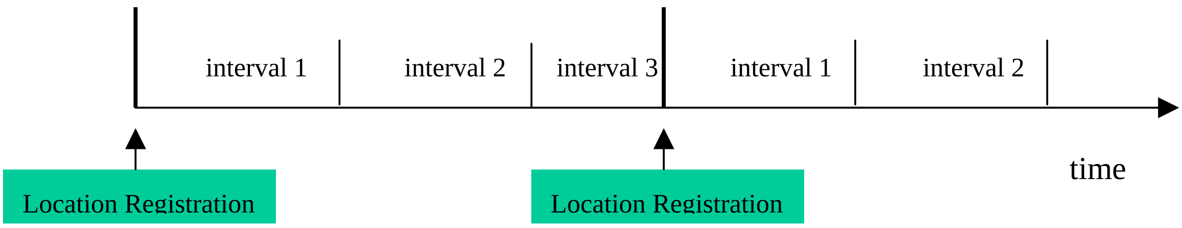

Fig. 6. Computing interval.

In the same way,

$g(n+1)-g(n) = -C_{LU}\, f(c_{n+1}) + C_P\, f_{CA}(t)$.

Therefore,

$[g(n+2)-g(n+1)]-[g(n+1)-g(n)] = [-C_{LU}\, f(c_{n+2}) + C_P\, f_{CA}(t)] - [-C_{LU}\, f(c_{n+1}) + C_P\, f_{CA}(t)]$

$= C_{LU}[\, f(c_{n+1}) - f(c_{n+2})] \geq 0 \quad \text{for all} \quad n \geq 1$.

This completes the proof ■.

Assume that a call arrival occurs in the interval 3 as shown in Fig. 6. The RA at the time has been determined at the starting point of interval 3. HLR compares the time of last registration and the current time. Then, HLR determines the RA of the MT based on the third power of the transition probability matrix and requests paging the cells in the RA.

a. Registration

When a mobile moves out of the RA determined in the interval, it sends a message to inform the HLR of the MT’s new cell.

b. Call Delivery

When an incoming call occurs, the HLR queries the cell and the time last reported about the location of the MT. Then the HLR determines the current RA of the MT by matrix multiplication and sends a *route-request* signal.

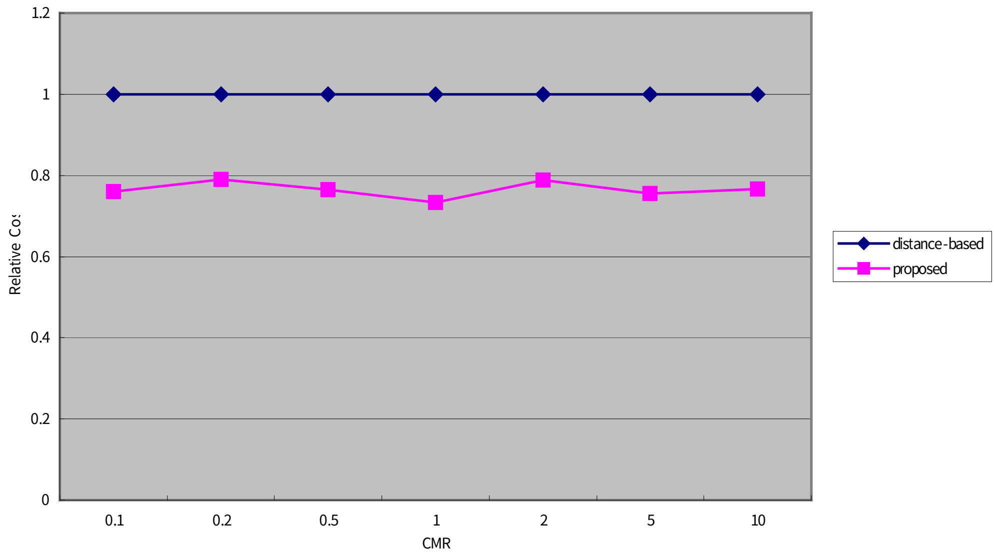

Fig. 7. Relative costs with random walk model.

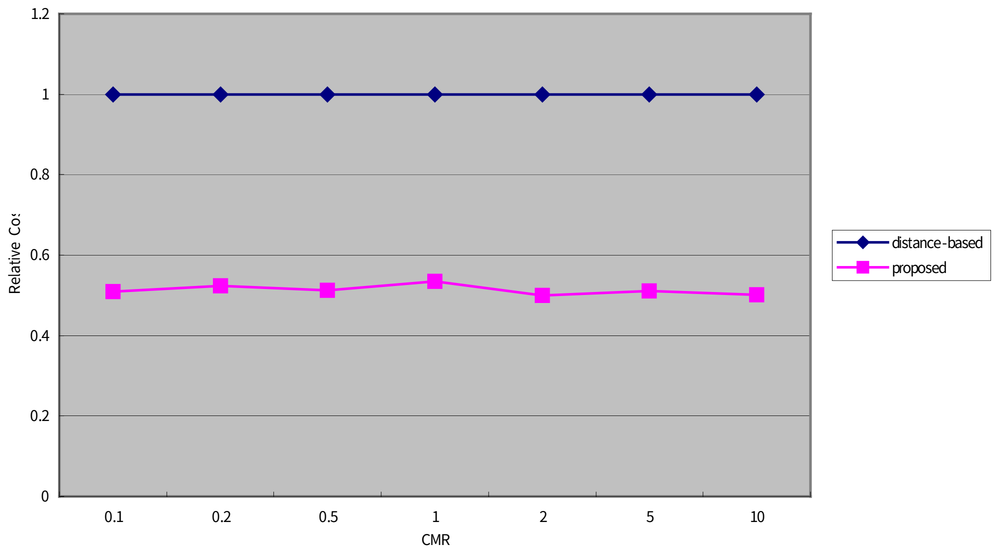

Fig. 8. Relative costs with highway model.

V. Computational Results

The proposed strategy is compared to the distance-based strategy in this section. Two mobility models are assumed. One is random walk model where an MT moves to each adjacent cell with equal probability and the other is highway model where an MT moves to only one direction. The respective results are

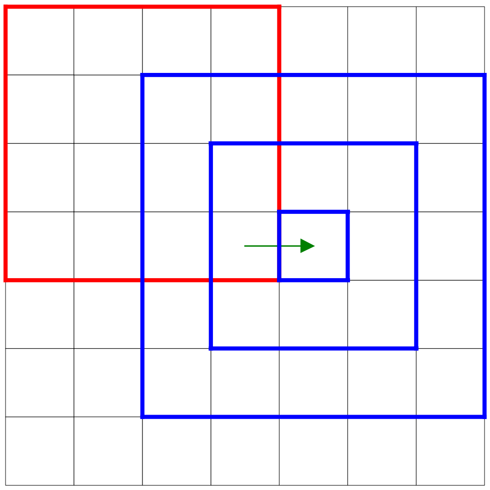

Fig. 9. Location registration area in the proposed scheme.

presented in Fig. 7 and 8. In both cases, the proposed strategy performs better than the distance-based strategy. Especially, the proposed scheme dominates the distance-based strategy in the latter case, where the characteristic of the mobility pattern of an MT is reflected better in the proposed strategy. Fig. 9 shows the shape and size of RAs in the subsequent intervals after the location registration in the proposed strategy. Random walk model is assumed in the figure. In the first interval after the location registration, the size of RA is relatively small due to the high probability that the MT exists in the cell. As time goes on, the size of RA becomes large due to the distributed probabilities.

VI. Conclusion

In this paper, we introduce an expected location update and paging cost function of a location management strategy. Probability-based location management strategy is suggested to minimize the cost function. In the scheme, the shape of each RA of an MT is individually and dynamically tailored to match the user's movement and the surrounding geographic conditions. At each interval the probability an MT resides in each cell is calculated. Transition probability matrix is used to implement the proposed strategy. Based on the probability, the RA of an MT during each interval is dynamically determined at the beginning of each interval. Cells are included into the RA in nonincreasing order of probability to the extent that the cost function is minimized. The numerical results demonstrate that the proposed scheme significantly reduces mobility management cost compared to the distance-based strategy.

References

[1] 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.

[2] 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.

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

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

[5] 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.

[6] 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.

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

[8] 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.

[9] 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.