Modeling and Analysis of Distance-Based Registration with Implicit Registration

Jang Hyun Baek and Byung Han Ryu

ABSTRACT—In this study, we consider distance-based registration (DBR) and propose a DBR with implicit registration (DBIR) in order to improve the performance of the DBR. With analytical models based on a 2-dimensional random walk in a hexagonal cell configuration, we analyzed the performance of the DBR and DBIR. Our results showed that the DBIR always outperforms the DBR.

Keywords—Mobility, distance-based registration, implicit registration.

I. Introduction

Due to limited radio resources, effective location tracking strategies are essential to improving the utility of radio channels. Several methods have been proposed with the aim of minimizing the location registration cost [1]-[4]. According to previous investigations, distance-based registration (DBR) is superior to the improved movement-based registration (IMBR) as well as the movement-based registration (MBR) [1], [2].

This study considers DBR and proposes a DBR with implicit registration (DBIR) to improve the performance of the DBR. A mobility model for mobile stations plays an important role in the performance evaluation of the registration schemes. We used analytical models based on a 2-dimensional random walk in a hexagonal cell configuration [2], [5] to analyze the performance of the DBR and the DBIR. The results from calculating the registration and paging costs showed that the DBIR always outperformed the DBR. Furthermore, we provide numerical results to demonstrate these propositions under various parameters.

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Jang Hyun Baek (phone: +82 42 860 5475, email: bjh62105@etri.re.kr) is an invited researcher in Mobile Telecommunication Research Laboratory, ETRI, Daejeon, Korea. He is also with Chonbuk National University.

Byung Han Ryu (email: rubh@etri.re.kr) is with Mobile Telecommunication Research Laboratory, ETRI, Daejeon, Korea.

II. DBR and DBIR

1. Distance-Based Registration (DBR)

Distance-based registration causes a mobile station to register when the distance between the current base station and the base station in which it last registered exceeds a distance threshold *D*. The mobile station detects a change in distance by computing a distance measure based on the difference in latitude and longitude between the current base station and the base station where the mobile station last registered and registers it if it exceeds the threshold value.

The mobile station stores the base station latitude and longitude (X_r, Y_r) of the base station whose access channel was used for the mobile station's last registration and also stores the base station latitude and longitude (X_c, Y_c) of the current base station. The mobile station computes the current base station's distance from the last registration point (*DISTANCE*) as:

$$DISTANCE = \left\lfloor \sqrt{(\Delta lat)^2 + (\Delta long)^2} \,/16 \right\rfloor,$$

where $\Delta lat = X_c - X_r$ and $\Delta long = (Y_c - Y_r) \times \cos\ (\pi/180 \times X_r/14400)$ [4]. For convenience, this study defined the *DISTANCE* between two cells as the maximum number of cells between two cells [2], [5]. In Fig. 1 for example, *DISTANCE* between two neighboring cells is 1 and *DISTANCE* between ring-0 cell and ring-2 cells is 2. Figure 1 shows the location area in the hexagonal configuration when the mobile station registers in ring-0 cell and the distance threshold *D*=3.

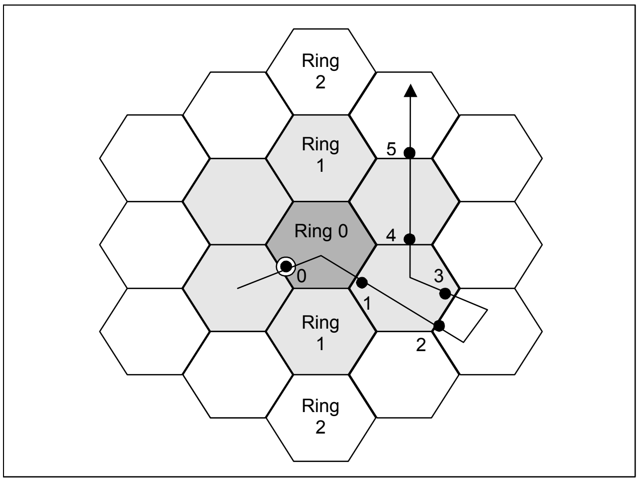

Fig. 1. Location area and rings in the hexagonal configuration (D=3).

2. Distance-Based Registration with Implicit Registration (DBIR)

According to CDMA technical requirements [4], when a mobile station successfully sends an origination message or page response message, the base station can infer the mobile station's location. This is called an implicit registration. In other words, when an outgoing call from a mobile station occurs successfully or an incoming call to a mobile station occurs successfully, the base station can infer the mobile station's cell from the origination message or a page response message without a separate registration message.

Hence, if a mobile cellular network using a DBR incorporates an implicit registration, then the network can determine the mobile station's cell whenever there is an outgoing or incoming call from or to the mobile station without a real registration process. The network sets up a new location area in which the mobile station's cell is the center cell (ring-0 cell) and reduces the number of registrations.

In this way, the performance of the DBR can be improved using an implicit registration and the performance of this combined scheme becomes better as call generation of the mobile station increases. This study proposes an enhanced scheme that combines a DBR with implicit registration (DBIR).

III. Analytical Model

We assumed that the mobile cellular network is composed of hexagonal cells of the same size as shown in Fig. 1. Furthermore, to analyze the performance, we made the following assumptions.

– When the mobile station leaves a cell, there is an equal probability that any one of six neighboring cells is selected as the destination.
– The cell residence time follows a general distribution with mean $1/\lambda_m$, and incoming and outgoing call generation to/from each mobile station follow a Poisson process with rate λ_c.

Figure 1 shows the location area of the DBR and DBIR schemes with the distance threshold D=3. A location area is composed of D rings (ring 0, 1, …, D–1). We describe analytical models to obtain the total signaling cost for registration and paging on radio channels by using a 2-dimensional random walk mobility model. Let us derive the expected registration cost per unit time.

1. Registration Cost of the DBR

To obtain the registration cost of the DBR scheme, the mobile station should be observed at each cell crossing. Each mobile station resides in a cell for a time period and then moves to one of its neighbors with equal probability, i.e., 1/6. The mobility of the mobile station is therefore a random walk in a 2-dimensional hexagonal plan and this 2-dimensional random walk can be reduced to a simple random walk (Fig. 2). In the Markov chain, a mobile station is in state i if it is currently residing in a ring-i cell. In Fig. 2 for example, $\lambda_m/3$ indicates that a mobile station moves to one cell of its 6 neighbors but is still in the same ring, since 2 cells among its 6 neighbors are in the same ring (Fig. 1).

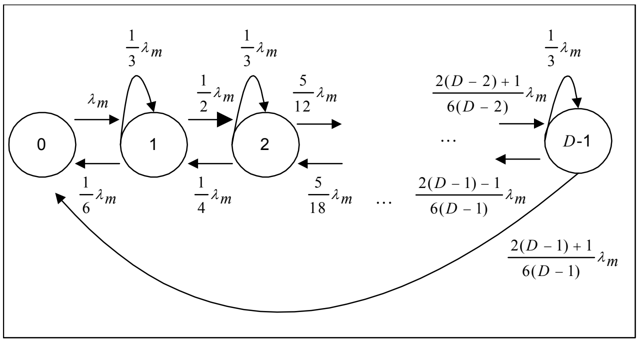

Fig. 2. State transition diagram for the DBR.

Hence, the $D \times D$ transition rate matrix Q^{dbr} for the DBR is

$$Q^{dbr} = \begin{bmatrix} -\lambda_m & \lambda_m & 0 & \cdots & 0 & 0 \\ \frac{1}{6}\lambda_m & -(\frac{1}{6}+\frac{1}{2})\lambda_m & \frac{1}{2}\lambda_m & \cdots & 0 & 0 \\ 0 & \frac{1}{4}\lambda_m & -(\frac{1}{4}+\frac{5}{12})\lambda_m & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ \lambda_c & 0 & 0 & \cdots & -\frac{2}{3}\lambda_m & \frac{2(D-2)+1}{6(D-2)}\lambda_m \\ \frac{2(D-1)+1}{6(D-1)}\lambda_m & 0 & 0 & \cdots & \frac{2(D-1)-1}{6(D-1)}\lambda_m & -\frac{2}{3}\lambda_m \end{bmatrix}.$$

Let π_i denote the stationary probability of state i, and each π

can be obtained using the following balanced equations:

$$\pi \cdot Q^{dbr} = 0, \quad \sum_i \pi_i = 1. \tag{1}$$

Letting C_U^{dbr} denote the cost of one location registration, the following equation can be derived:

$$C_U^{dbr} = UQ_{D-1,0}^{dbr}\pi_{D-1} = U\frac{2(D-1)+1}{6(D-1)}\lambda_m \pi_{D-1}, \tag{2}$$

where U is the unit registration cost required for one registration.

2. Registration Cost of the DBIR

We can also derive the registration cost for the DBIR (which is slightly different from the DBR). However, the state transition diagram changes since a call generation in the DBIR puts the mobile station in ring-0 cell (Fig. 3).

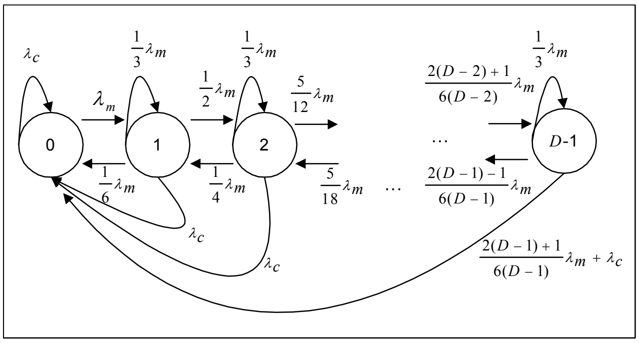

Fig. 3. State transition diagram for the DBIR.

The $D \times D$ transition rate matrix Q for the DBIR is

$$Q = \begin{bmatrix} -\lambda_m & \lambda_m & 0 & \cdots & 0 & 0 \\ \frac{1}{6}\lambda_m + \lambda_c & -\frac{2}{3}\lambda_m - \lambda_c & \frac{1}{2}\lambda_m & \cdots & 0 & 0 \\ \lambda_c & \frac{1}{4}\lambda_m & -\frac{2}{3}\lambda_m - \lambda_c & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ \lambda_c & 0 & 0 & \cdots & -\frac{2}{3}\lambda_m - \lambda_c & \frac{2(D-2)+1}{6(D-2)}\lambda_m \\ \frac{2(D-1)+1}{6(D-1)}\lambda_m + \lambda_c & 0 & 0 & \cdots & \frac{2(D-1)-1}{6(D-1)}\lambda_m & -\frac{2}{3}\lambda_m - \lambda_c \end{bmatrix}.$$

An element $Q_{D-1,0}$ in Q is the rate that a mobile station in a ring-i cell moves to a ring-0 cell, which is composed of $\frac{2(D-1)+1}{6(D-1)}\lambda_m$ and λ_c. Note that the former produces real registration but the latter produces only implicit registration and no real registration. For convenience, let $Q'_{D-1,0} = \frac{2(D-1)+1}{6(D-1)}\lambda_m$.

Letting π'_i denote the stationary probability of state i, each π'_i can be obtained using the following balanced equations:

$$\pi' \cdot Q = 0, \quad \sum_i \pi'_i = 1. \tag{3}$$

Letting C_U^{dbir} denote the cost of one location registration, the following equation can be derived:

$$C_U^{dbir} = UQ'_{D-1,0}\pi'_{D-1} = U\frac{2(D-1)+1}{6(D-1)}\lambda_m \pi'_{D-1}. \tag{4}$$

3. Paging Cost and Total Cost

Even though some efficient paging strategies have been proposed [6], most of the mobile cellular systems still use a simultaneous paging strategy [3]. Assuming all cells in a location area are paged simultaneously whenever an incoming call arrives, the paging cost is the same when both schemes are applied. Hence, the expected paging cost per unit time C_V is

$$C_V = p_t V\lambda_c[1 + \sum_{i=1}^{D-1} 6i] = p_t V\lambda_c[1 + 3D(D-1)], \tag{5}$$

where V is the unit paging cost required for one cell and p_t is the ratio of the incoming calls. Finally, the expected total cost for registration and paging per unit time will be:

$$C_T = C_U + C_V. \tag{6}$$

IV. Performance Evaluation

Proposition. For the given threshold D, the registration cost in the DBIR scheme C_U^{dbir} equals or is smaller than that of the DBR scheme C_U^{dbir}, i.e.,

$$C_U^{dbr} = U\frac{2(D-1)+1}{6(D-1)}\lambda_m \pi_{D-1} \ge U\frac{2(D-1)+1}{6(D-1)}\lambda_m \pi'_{D-1} = C_U^{dbir}.$$

Proof. To prove the above proposition, it is sufficient to show that the following is true for every D:

$$\pi_{D-1} \ge \pi'_{D-1}.$$

The left side is the probability that a mobile station is in ring D–1 in the DBR scheme and the right side is the probability that a mobile station is in ring D–1 in the DBIR scheme. Comparing the state transition diagram of the DBR scheme in Fig. 2 with the state transition diagram of the DBIR scheme in Fig. 3 reveals that the state transition diagram of Fig. 3 is obtained by adding λ_c to the rate from each state i (i =0, 1, 2, …, D–1) to state 0 of the state transition diagram of Fig. 2 and the other rates of Fig. 2 and Fig. 3 are all the same.

Note that the destination of λ_c from each state in Fig. 3 is state 0 (i.e., the farthest state from state D–1, λ_c of Fig. 3) makes it difficult to reach state D–1 compared with Fig. 2, and therefore the probability that a mobile station is in ring D–1 in the DBIR scheme (Fig. 3) π'_{D-1} is less than or equal to the probability that a mobile station is in ring D–1 in the DBR scheme (Fig. 2) π_{D-1}. □

To obtain numerical results, we assumed that U=1.0, V=0.1, p_t=0.5, and $\lambda_m = \lambda_c = 1$.

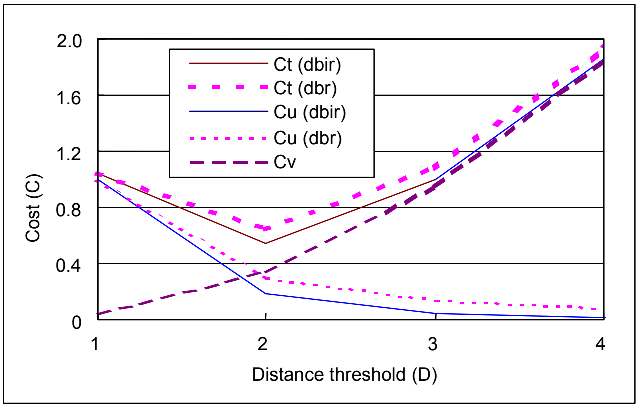

Fig. 4. Signaling cost versus distance threshold.

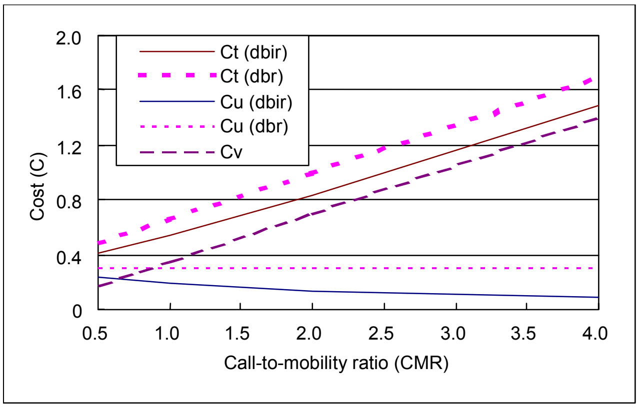

Fig. 5. Signaling cost versus CMR (D=2).

Figure 4 shows the signaling cost when the distance threshold D changes. Figure 4 also shows that the registration cost of the DBIR is less than that of the DBR in every D, and therefore the total signaling cost of the DBIR is less than that of the DBR in every D.

Figure 5 shows the signaling cost when the call-to-mobility ratio (CMR) changes assuming D=2. The figure confirms that the registration cost of the DBIR is less than that of the DBR in every CMR, and therefore the total signaling cost of the DBIR is less than that of the DBR in every CMR.

V. Conclusion

In this study, we considered distance-based registration (DBR) and proposed the DBR with implicit registration (DBIR) to improve the performance of the DBR. We used analytical models based on a 2-dimensional random walk in a hexagonal cell configuration to analyze the performance of the DBR and the DBIR. Results obtained from the study showed that the DBIR outperforms the DBR in every case. Consequently, in order to achieve the best performance, distance-based registration should be considered along with implicit registration.

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