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이동통신망에서 위치등록 방법의 성능 비교
Comparative Performance Evaluation of Location Registration Schemes in Mobile Communication Network

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Abstract. In this study, we consider the movement-based registration (MBR), location-based registration (LBR) and distance-based registration (DBR) schemes. Analytical models based on a 2-dimensional random walk in a hexagonal cell configuration are considered to analyze and compare the performances of these three schemes. We focus on the derivation of the registration costs of LBR and DBR using an analytical method and then show that DBR always outperforms both MBR and LBR. Numerical results are provided to demonstrate the validity of our models under various circumstances.

Key words: movement-based registration, location-based registration, distance-based registration, random walk mobility model.

1. Introduction

In order to accommodate the continuously increasing number of mobile subscribers and to provide them with various multimedia services and a high quality of services (QoS), it is essential to increase the efficiency of the radio channels employed, which are finite resources. Recently, as the density and mobility of the subscribers has increased, the cell size has continuously decreased and the roaming area has widened. This has significantly increased the load incurred by location registration.

In order to optimize the network performance, a number of location registration schemes have been proposed. These include the distance-based registration scheme [2, 3], movement-based registration scheme [1, 3, 5], zone-based registration scheme [5, 8] and so on.

In this study, we consider the movement-based registration (MBR), location-based registration (LBR) and distance-based registration (DBR) schemes and analytical models based on a 2-dimensional random walk in a hexagonal cell configuration are considered to analyze and compare the performance of these three schemes. The remainder of this paper is organized as follows. Section 2 describes the MBR, LBR and DBR schemes. In section 3, mobility models based on a 2-dimensional random walk in a hexagonal cell configuration are considered to calculate the signaling traffic on radio channels, and it is proved using the proposed formula that DBR always outperforms both MBR and LBR. Section 4 presents the numerical results of the performance comparisons among the three schemes. Our conclusions are given in Section 5.

2. Movement-Based Registration, Location-Based Registration and Distance-Based Registration

2.1 Movement-Based Registration (MBR)

In the MBR scheme, a mobile station (MS) performs a location registration operation when the number of cells it has entered is equal to the given movement threshold, *M* [1]. An MS has a counter for keeping the number of cells it has entered and increases the value of the counter by one whenever it enters a new cell. If the value of the counter reaches *M*, the MS registers its location and sets the value of the counter to zero.

2.2 Location-based registration (LBR)

With this scheme, each MS maintains a counter, ξ, whose value is compared to a threshold, *L*, to determine whether a location registration needs to be performed. Each MS also maintains a list of tuples (I_j, C_j) to record a part of the cells visited by the MS during a location registration interval, where I_j is the identifier of cell *j* and the identifier C_j is the value of the counter immediately after the MS entered cell *j* most recently. The cells within the list are arranged in increasing order of their C_j value. When the MS enters cell *i*, the rules used to store cell *i* in the list and update the counter are as follows:

1. If cell *i* is not in the list, counter ξ is increased by one. If $\xi = L$ a location registration is triggered and an update of the list is initiated with cell *i*; otherwise, $C_j = \xi$ and a pair of values, (I_i, C_i), is added to the list.
2. If cell *i* is already in the list, counter ξ is assigned the value of C_i and all of the cells following cell *i* currently in the list are removed from it.

2.3 Distance-based registration (DBR)

The DBR causes an MS to register whenever the distance between the current cell and the cell where it last registered exceeds the distance threshold, *D*. In this study, we assume that the distance is represented by the number of cells for the sake of convenience.

2.4 System Description

We assume that the mobile communication network is composed of hexagonal cells with the size shown in Fig.1. To analyze the performance of the network, we make the following assumptions.

1) When the MS leaves a cell, there is an equal probability for any one of the six neighboring cells to be selected as the destination.
2) The cell residence time follows a general distribution with mean $1/\lambda_m$.
3) The incoming call arrivals to each MS follow a Poisson process with rate λ_c.

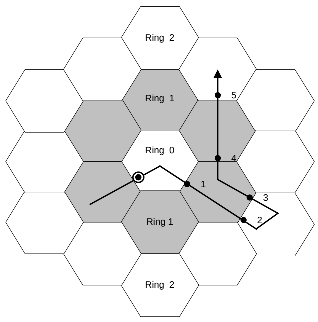

Fig. 1. Location area and rings in the hexagonal configuration (*M*=*L*=*D*=3)

A location area is composed of *M* rings (ring 0, 1, …, *M*-1) and the total number of cells in a location area is $1+\sum_{i=1}^{M-1}6i = 1+3M(M-1)$ in the MBR scheme. The same configuration can be applied in the LBR and DBR schemes with the thresholds *L* and *D*, respectively. The location areas of the MBR, LBR and DBR schemes with the thresholds *M=L=D=3* can be seen in Fig.1.

3. Analytical Model

We describe analytical models to obtain the total signaling cost on the radio channels by using a 2-dimensional random walk mobility model. The expected total cost for registration and paging per incoming call arrival is

$$C_T = C_U + C_V \qquad (1)$$

where C_U is the registration cost and C_V is the paging cost.

3.1 Paging Cost

We assume that all of the cells in the location area (or paging area) are paged one time whenever an incoming call arrives [5]. Further, we assume that the threshold of each scheme is the same, i.e., *D=L=M.* In this case, the number of cells in the paging area of each scheme is the same and so the paging cost of each scheme is also the same.

The expected paging cost per incoming call arrival C_v is

$$C_v = V[1+\sum_{i=1}^{D-1}6i] = V[1+3D(D-1)] \qquad (2)$$

where *V* is the unit paging cost required for one cell.

3.2 Registration Cost

We first derive the expected registration cost between two incoming call arrivals. The probability, $\alpha(K)$, that an MS enters *K* cells between two incoming call arrivals is as follows [5]

$$\alpha(K) = \begin{cases} 1 - \frac{1}{\theta}[1 - f_m^{*}(\lambda_c)] & K = 0 \\ \frac{1}{\theta}[1 - f_m^{*}(\lambda_c)]^2 [f_m^{*}(\lambda_c)]^{K-1} & K \geq 1 \end{cases} \qquad (3)$$

where $\theta = \lambda_c / \lambda_m$ and $f_m^{*}(s)$ is the Laplace-Stieltjes transform of the probability density of the cell residence time.

3.2.1 Movement-Based Registration

The registration cost of the MBR scheme is as follows [1]

$$C_U^{mbr} = U\sum_{i=1}^{\infty} i \sum_{j=iM}^{(i+1)M-1}\alpha(j) = U\sum_{i=M}^{\infty}\alpha(i)\lfloor i/M \rfloor \qquad (4)$$

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

3.2.2 Location-Based Registration Cost

Firstly, we define some random variables. Let *R* be a random variable denoting the number of cells that the MS has entered since the last location registration. Let *M* be a random variable denoting the number of new cells that the MS has entered since the last location registration. Let *N* be a random variable denoting the number of cells that the MS passed through during the interval between its entering and reentering a cell. For example, in the case of the MS in Fig.1, *R*=5 since the MS has entered 5 cells from the last location registration until now, and *M*=4 since 4 of these 5 cells were new cells. *N*=1 since the number of cells that the MS passed through during the interval between its entering and reentering a cell is 1.

According to the definitions of *R*, *M*, and *N*, the location registration cost between two incoming call arrivals in LBR is

$$C_U^{lbr} = U\sum_{i=1}^{\infty} i \sum_{j=il}^{\infty} \alpha(j) \sum_{k=il}^{(i+1)l-1} \Pr[M-N=k \mid R=j] \cdot \tag{5}$$

3.2.3 Distance-Based Registration Cost

Similarly, we define certain random variables. Let *R* be a random variable denoting the number of cells that the MS has entered since the last location registration; Let *F* be a random variable denoting the distance from the last cell the MS entered to the central cell after the last location registration. For example, in the case of the MS in Fig.1, *R*=5 since the MS has entered 5 cells from the last location registration until now, and *F*=2 since the distance from the last cell the MS entered to the central cell is 2.

According to the definitions of *R*, and *F*, the location registration cost between two incoming call arrivals in DBR is

$$C_U^{dbr} = U\sum_{i=1}^{\infty} i \sum_{j=id}^{\infty} \alpha(j) \sum_{k=id}^{(i+1)d-1} \Pr[F=k \mid R=j] \cdot \tag{6}$$

3.3 Performance comparison

Proposition I: For the given threshold *M*=*L*, the registration cost in the LBR scheme, C_U^{lbr}, is equals to or less than the one of the MBR scheme, C_U^{mbr}. That is,

$$U\sum_{i=1}^{\infty} i \sum_{j=iL}^{\infty} \alpha(j) \sum_{k=iL}^{(i+1)L-1} \Pr[M-N=k \mid R=j] \le U\sum_{i=1}^{\infty} i \sum_{j=iM}^{(i+1)M-1} \alpha(j)$$

Proof: For an arbitrary positive integer *j*, the coefficient, $\alpha(j)$ in the MBR scheme is $U \times \lfloor j/D \rfloor$. For convenience, let $c = \lfloor j/D \rfloor$, which is the maximum number of registrations. On the other hand, the coefficient, $\alpha(j)$ in the LBR scheme is as follows. Since $\Pr[M-N=k \mid R=j]=0$ for *n*>*m*,

$$\begin{aligned} &U\sum_{i=1}^{\infty} i \sum_{k=iL}^{(i+1)L-1} \Pr[M-N=k \mid R=j] = U\sum_{i=1}^{c} i \sum_{k=iL}^{(i+1)L-1} \Pr[M-N=k \mid R=j] \\ &= U\{\sum_{k=L}^{2L-1} \Pr[M-N=k \mid R=j] + 2\sum_{k=2L}^{3L-1} \Pr[M-N=k \mid R=j] + \cdots + c\sum_{k=cL}^{(c+1)L-1} \Pr[M-N=k \mid R=j]\} \end{aligned}$$

Let $P_0 = \sum_{i=1}^{L-1} \Pr[M-N=k \mid R=j]$ and $P_i = \sum_{k=iL}^{(i+1)L-1} \Pr[M-N=k \mid R=j]$ for *i*=1, 2, …, *c*. Recall that $\sum_{i=0}^{c} P_i = 1$. The coefficient of $\alpha(j)$ in the LBR scheme is then

$$\begin{aligned} &U \times (P_1 + 2P_2 + \cdots + cP_c) \le U \times (cP_1 + cP_2 + \cdots + cP_c) \\ &\le U \times (cP_0 + cP_1 + cP_2 + \cdots + cP_c) = U \times c \end{aligned}$$

Proposition II: For the given threshold *D*=*L*, the registration cost in DBR scheme, C_u^{dbr} is equals to or less than LBR scheme, C_u^{lbr}. That is,

$$U\sum_{i=1}^{\infty} i \sum_{j=id}^{\infty} \alpha(j) \sum_{k=id}^{(i+1)d-1} \Pr[F=k|R=j] \le U\sum_{i=1}^{\infty} i \sum_{j=il}^{\infty} \alpha(j) \sum_{k=il}^{(i+1)l-1} \Pr[M-N=k|R=j]$$

Proof: For an arbitrary positive integer *j*, the coefficient, $\alpha(j)$ in LBR scheme is $U\sum_{i=1}^{\infty} i \sum_{j=il}^{\infty} \alpha(j) \sum_{k=il}^{(i+1)l-1} \Pr[M-N=k|R=j]$; the coefficient, $\alpha(j)$ in DBR scheme is $U\sum_{i=1}^{\infty} i \sum_{j=id}^{\infty} \alpha(j) \sum_{k=id}^{(i+1)d-1} \Pr[F=k|R=j]$. Let $c = \lfloor j/d \rfloor$, which is the maximum number of registrations.

Let N_f be, from the incoming call until now, the cumulative number of new cells that the MS entered which are farther than the cell the MS visited just before, if no registration has occurred yet or, otherwise, which are farther than any of the cells the MS visited since the last registration. Let N_s be the cumulative number of new cells in the same ring that the MS entered from the incoming call until now, including the cell the MS visited just before, if no registration has occurred yet or, otherwise, including any cells the MS visited since the last registration. Let N_n be, from the incoming call until now, the cumulative number of new cells that the MS entered which are nearer than the cell the MS visited just before, if no registration has occurred yet or, otherwise, which are nearer than any of the cells the MS visited since the last registration.

Recalls that $\Pr[M-N=k|R=j] = \Pr[$ (the number of new cells that the MS entered after an incoming call) – (the number of cells that the MS passed through during the interval between its entering and reentering a cell) $=k|R=j]$. Then,

$\Pr[M-N=k|R=j] = \Pr[N_f + N_s + N_n = k|R=j]$

$\ge \Pr[N_f = k|R=j]$

$=\Pr$ [(from the incoming call until now, the cumulative number of new cells that the MS entered which are farther than the cell the MS visited just before, if no registration has occurred yet or, otherwise, which are farther than any of the cells the MS visited since the last registration) $=k\ |R=j]$

$\ge \Pr$ [(from the incoming call until now, the cumulative number of new cells that the MS entered which are farther than both the cell the MS visited just before and any of the cells the MS visited, if no registration has occurred yet or, otherwise, which are farther than any of the cells the MS visited since the last registration) $=k\ |R=j]$

$=\Pr[F=k|R=j]$.

Therefore,

$$U\sum_{i=1}^{\infty} i \sum_{j=id}^{\infty} \alpha(j) \sum_{k=id}^{(i+1)d-1} \Pr[F=k|R=j] \le U\sum_{i=1}^{\infty} i \sum_{j=il}^{\infty} \alpha(j) \sum_{k=il}^{(i+1)l-1} \Pr[M-N=k|R=j]$$

4. Numerical Results

Some numerical results are presented to compare the performance of the MBR, LBR and DBR schemes. As described previously, assume that all cells in the location area (or paging area) are paged one time whenever an incoming call arrives. It is also assumed that the threshold of each scheme is the same, i.e., *D*=*L*=*M*, in order to compare the three location registration schemes with the same paging cost. Assume that the cell residence time follows an exponential distribution with mean $1/\lambda_m$ and the incoming call arrival follows a Poison distribution with rate λ_c. To demonstrate the effects of the mobility and call arrival patterns, the call-to-mobility ratio (CMR), λ_c/λ_m is considered. The unit registration cost, *U*, is set to 10 and the unit paging cost, *V*, is set to 1, as presented in [1, 2, 5].

Fig. 2 shows the registration cost for the MBR and LBR scheme. From this figure, it is evident that the LBR scheme incurs a lower registration cost than the MBR scheme in any circumstances, as shown in proposition I.

Fig. 3 shows the registration cost for the LBR and DBR scheme. From this figure, it is evident that the DBR scheme incurs a lower registration cost than the LBR scheme in any circumstances, as shown in proposition II.

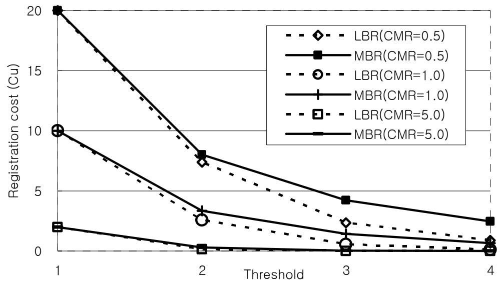

Fig. 2. Registration cost of LBR and DBR

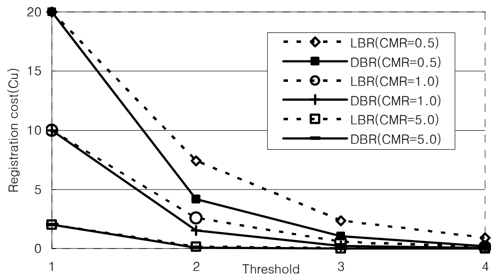

Fig. 3. Registration cost of LBR and DBR

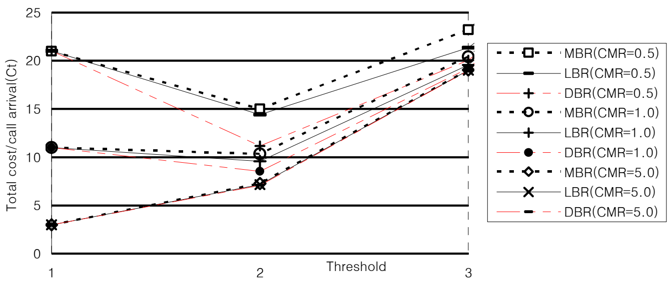

Fig. 4. Total cost of MBR, LBR and DBR

Finally, the total signaling cost of MBR, LBR and DBR schemes is shown in Fig. 4. From the figure, we conclude that MBR scheme requires the most signaling cost while DBR requires the least signaling cost among them. Fig. 4 also shows that, when the CMR is 0.5 or 1.0, all schemes have the least signaling cost at threshold=2, and when thee CMR is 5.0, all schemes have the least signaling cost at threshold=1. However, CMR=5.0 means that 5 calls are generated in average in a cell, which is a somewhat unrealistic circumstance. Therefore, we can say that the total signaling cost of each scheme reaches a minimum value at threshold=2 in most cases.

According to our numerical results, it is evident that the DBR scheme always outperforms not only the MBR but also the LBR scheme. However, it is known that DBR is not easy to implement compared to the other schemes [2]. Consequently, it is necessary to adopt the appropriate registration scheme after taking into consideration the system circumstances, easiness of implementation, expandability and so on.

5. Conclusion

We studied movement-based registration (MBR), location-based registration (LBR) and distance-based registration (DBR), and compared the performance of these three schemes. In the performance evaluation of location registration schemes, the mobility model of an MS plays an important role. In this study, analytical models based on a 2-dimensional random walk in a hexagonal cell configuration were considered to analyze and compare the performances of the MBR, LBR and DBR schemes. We calculated the registration costs of the MBR, DBR and LBR schemes using an analytical method and then showed that DBR always outperforms not only MBR but also LBR. Numerical results were provided to demonstrate the validity of our models under various circumstances. These results can be used to effectively design and evaluate registration schemes while considering the system circumstances.

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