Analysis of Movement-Based Registration
Considering Network Architecture and General Cell Residence Time

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Abstract

This study considers movement-based registration (MBR) with implicit registration, an improved version of original MBR. In order to obtain more accurate registration cost of the MBR, we consider real network architecture in which a mobile network is composed of visitor location registers (VLR), a group of cells. We show that, when the network architecture is considered, the location registration cost increases but the paging cost decreases compared to the case that the network architecture is ignored. Furthermore, we propose an imbedded Markov chain model to reflect call holding time and cell residence time of a mobile station (MS) that may follow a general distribution. Numerical results for various situations are shown to analyze the exact performance of MBR under real network architecture.

Keywords: movement-based registration, imbedded Markov chain, location registration
1 Introduction

Mobile subscribers have been increasing and more accelerated growth of smart phone subscribers. In mobile communication networks, continuous management of the mobile station (MS) location is required to connect an incoming call to the MS, since the MS is continually moving.

Location management plays an important role in mobile communication network. To connect an incoming call accurately, the network should update MS’s location. Location registration is the process that an MS registers its location area (LA) to network database whenever it enters new LA. Since an LA is composed of several base stations (BS), when an incoming call to an MS arrives, network should page the MS to know its exact BS and connect an incoming call to it, which is called paging. In general, there is a tradeoff between the paging and registration cost that result in some optimal use of radio channels.

Lots of registration methods have been proposed so far; movement-based, timer-based, distance-based and zone-based registration and so on [6, 10-11]. In this study, we consider MBR which is known to be the most practical, since it is effective and easily implemented under the framework of current systems [9]. Even though many studies on the MBR have been performed [3, 8], accurate modeling and performance analysis of the MBR under real network architecture has not been performed yet.

In this study, in order to obtain more realistic and accurate registration cost of the MBR, we consider real network architecture in which a mobile network is composed of visitor location registers (VLR), a group of cells (or base stations). In addition, we adopt an imbedded Markov chain (IMMC) model to consider MS’s call holding time and cell residence time that may follow a general distribution. Numerical results for various situations will be given to show the exact performance of MBR under real network architecture and general cell residence time.

2 Movement-Based Registration under Network Architecture

2.1 Movement-Based Registration

MBR is a simple dynamic location registration strategy. In MBR, each MS maintains a counter, whose value is compared to a movement threshold $M$ to trigger a location registration. In MBR, whenever the number of entering cells reaches the specified movement threshold $M$, the MS registers its location and its counter is reset as 0. If an incoming call to an MS arrives or an MS generates an outgoing call, the network can know the location information of the MS through the call processing messages without any registration process, which is called as implicit registration (IR) [3,6-7,9]. In this study, we only consider MBR with IR, an improved version of original MBR. From now on, MBR indicates MBR with IR in our study.
2.2 Network Architecture

A mobile communication network is composed of many mobile switching centers and each switching center has network databases called home location register (HLR) and visitor location register (VLR). In our study, we focus on VLR. From the viewpoint of VLR, a mobile communication network is composed of many VLRs and each VLR area consists of many cells.

In this study, we assume that a mobile communication network consists of square VLR area that is composed of square cells with the same size, as shown in Figure 2. The following are assumed to analyze MBR.

- When the MS leaves a cell, there is an equal probability that any one of four neighboring cells is selected as the destination.
- The cell residence time $T_m$ follows a general distribution with mean $1/\lambda_m$ and incoming and outgoing call generations to/from each MS follow a Poisson process with rate $\lambda_{ic}$ and $\lambda_{oc}$ respectively.

The LA of the MBR with the movement threshold $M=3$ can be seen in Figure 2. In general, an LA for the movement threshold $M$ is composed of $M$ rings (ring 0, 1, ..., $M-1$).

Figure 2 shows a VLR area that is composed of 12×12 square cells. Under this network architecture, an MS registers its location not only when its counter value reaches the threshold $M$ but when it moves to a new VLR. In other words, if an MS crosses the border of the VLR area, location registration is performed regardless of its current counter value.
2.3 Mobility Model

Consider the LA in Figure 2. In our study, we assume a random walk mobility model [7]. Under the random walk mobility model, it is assumed that, when the MS leaves a cell, there is an equal probability, 1/4, that any one of four neighboring cells is selected as the destination. Some studies [1, 12] used the fluid flow model to calculate the average rate with which an MS moves to other VLR. However, the rate with which an MS moves to other VLR is apparently different depending on MS’s location in the VLR area. For example, if an MS is in inner cells, there is no probability of going out to other VLR with one cell transition. In the other hand, if an MS is in edge cells, the probability of going out to other VLR is 1/2, and the probability of MS’s going out to other VLR in boundary cells is 1/4. Therefore, in order to analyze the accurate registration cost, it is necessary to consider this kind of different probabilities depending on MS’s location in the VLR area.

3 Signaling Cost of the Movement Based Registration Scheme by Imbedded Markov Chain Model

3.1 Imbedded Markov Chain Model

Let us explain an imbedded Markov chain (IMMC) model to consider i) network architecture in which a mobile network is composed of VLRs and ii) MS’s cell residence time that may follow a general distribution. For convenience sake, consider a small VLR area that is composed of 5×5 square cells, as shown in Figure. 3. Even though there are 25 cells in the VLR area, it is sufficient to
consider only 6 cells (which are marked by bold lines) since the characteristics of some cells are identical as shown in Figure 3.

As shown in Figure 3, the cell ‘33’ is the edge cell, the cell ‘11’ is the most inner cell, and the cell ‘12’ is the neighboring cell of the cell ‘11’. Note that all of cell ‘12’ has the same probabilistic characteristics.

\[
\begin{array}{cccccc}
33 & 23 & 13 & 22 & 23 & 33 \\
23 & 22 & 12 & 22 & 23 & 33 \\
13 & 12 & 11 & 12 & 13 & 33 \\
23 & 22 & 12 & 22 & 23 & 33 \\
33 & 23 & 13 & 23 & 33 & 33
\end{array}
\]

Figure 3. 5 x 5 VLR area

For example, let us consider cell ‘13’. The MS of cell ‘13’ moves i) to cell ‘12’ with probability 0.25, ii) to cell ‘23’ with probability 0.5 and iii) to other VLR with probability 0.25. In the 3rd case, the MS registers its location regardless of the counter value, which is called inter-VLR registration. In other words, it can be obtained the probability of going to other VLR and performing inter-VLR registration considering the 6 kinds of cell IDs.

Figure 4 shows a state transition diagram for the IMMC model for the MBR considering network architecture. The state in the diagram is defined as \((i,j,k)\). The former \('i,j'\) indicates cell ID in a VLR area. For example, the cell ‘11’ is the most inner cell and cell ‘12’ is the neighboring cell of the cell ‘11’. The latter \('k'\) is the counter value of the MS. Figure 4 shows a state transition diagram when \(M=2\). In this case, state \('k'\) is 0 or 1. From Figure 3, we can see that, even though there are 25 cells in the VLR area, a state transition diagram is not so complex since some of 25 cells have the same probabilistic characteristics.

Continuous-time Markov chain (CTMC) model has been proposed to analyze the performance of the MBR \([1, 3, 6]\). However, CTMC has two types of inherent problems \([14]\): First, modeling the states of an MS using a CTMC means that the cell residence time of an MS is exponentially distributed. However, in general, it cannot be assumed that the cell residence time of an MS follows an exponential distribution. Therefore, for other distributions of the cell residence time, the model yields approximate values rather than exact values. Second, even in the case of an exponential distribution for the cell residence time, the CTMC model makes the mistake of allowing a self-loop. For example, the CTMC model cannot consider incoming or outgoing calls in state \((0, 0, 0)\) in Figure 4. Nevertheless, if the CTMC model is still used, then an approximated result is obtained that does not reflect the self-loop in which an MS of state \((0, 0, 0)\) transitions back to state \((0, 0, 0)\). Therefore, in our study, we adopt an IMMC model to analyze the exact signaling cost under real network architecture. The IMMC model can reflect both the
general cell residence time and a self-loop. As such, it is expected that the proposed model will yield the exact signaling cost under real network architecture. The MBR scheme can be modeled with an IMMC, as shown in Fig. 4.

![Figure 4](image_url)

Figure 4. State transition diagram for 5 × 5 VLR area

The transition probability from all state to state ‘0’ is $1 - m = 1 - P[T_c > T_m]$ that means an MS answers a call before moving. The probability that an MS moves to another cell from any state before a call generates can be obtained as follows [9]:

$$m = P[T_c > T_m] = \int_0^\infty \int_0^\infty \lambda_c e^{-\lambda_c t_c} f_m(t_m) dt_c dt_m = f_m^*(\lambda_c)$$

Each transition probability is affected by the distribution of $T_m$, residence time of an MS in a cell. For example, if it is assumed that $T_m$ follows an exponential distribution with rate $\lambda_m$, then $P[T_c > T_m]$ is given as

$$P[T_c > T_m] = \frac{\lambda_m}{\lambda_m + \lambda_c}$$

where $\lambda_c = \lambda_o + \lambda_i$.

If it is assumed that $T_m$ follows a gamma distribution with mean $\frac{1}{\lambda_m}$ and variance $V$, then $P[T_c > T_m]$ is given as

$$P[T_c > T_m] = \left(\frac{\lambda_m \gamma}{\lambda_m \gamma + \lambda_c}\right)^\gamma$$

where $\gamma = \frac{1}{V\lambda_m}$.

Define $\pi_{i,j,k}$ as the steady-state probability of state $(i,j,k)$ for usual Markov chain $P_{i,j,k}$. Then, the steady-state probability with $\pi_{i,j,k}$ can be obtained using the following balanced equations.
\[ \pi P = \pi, \quad \sum_{i} \sum_{j} \sum_{k} \pi_{i,j,k} = 1 \]

\[
P = \begin{bmatrix}
1 - m & 0 & 1_{25}m & 0 & \cdots & 0 & 8_{25}m & 0 & 14_{25}m \\
1 - m & 0 & 0 & m & \cdots & 0 & 0 & 0 & 0 \\
1 - m & 0 & 0 & m & \cdots & 0 & 0 & 0 & 0 \\
1 - m & 0 & 0.25m & 0 & \cdots & 0 & 0 & 0 & 0 \\
\vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots \\
1 - m & 0 & 0 & 0 & \cdots & 0.25m & 0 & 0.25m & 0 \\
1 - m & 0 & 0 & 0 & \cdots & 0.25m & 0 & 0.25m & 0 \\
1 - m & 0 & 0 & 0 & \cdots & 0 & 0.5m & 0.5m & 0 \\
1 - m & 0 & 0 & 0 & \cdots & 0.5m & 0.5m & 0 & 0 \\
\end{bmatrix}
\]

\[ \text{3.2 Signaling Cost} \]

The signaling cost is composed of location registration cost and paging cost.

The location registration cost, \( C_{U}^{mbr} \), can be obtained as;

\[ C_{U}^{mbr} = U \left( \frac{1}{4} \sum_{i=1}^{n-1} \sum_{k=0}^{M-1} \pi_{i,n,k} + \frac{1}{4} \sum_{k=0}^{M-1} \pi_{n,n,k} + \sum_{i=1}^{n-1} \sum_{j=1}^{n-1} \pi_{i,j,M-1} \right) \frac{\lambda_{m}}{\lambda_{c}} \]

where \( U \) is the location registration cost for one registration, and the inter-VLR location registration cost is assumed as three times of the usual (intra-VLR) location registration cost. In the equation, \( n = \left\lceil (c + 1)/2 \right\rceil \) where \( c \) is the number of cells composing one side of a VLR area. For example, in Figure 3, \( n = \left\lceil 6/2 \right\rceil = 3 \).

Since most previous studies assumed all cells in an LA are paged simultaneously when an incoming call arrives, the number of paged cells is \( 1 + 2M(M - 1) \) for threshold \( M \). However, in our study, considering the network architecture, the number of paged cells decreases when the MS is around the boundary of the VLR.

The paging cost when considering VLR can be obtained. For example, if the threshold \( M \) is 2, the paging cost can be obtained as follows;

\[ C_{p}^{mbr} = V \times \left\{ 3\pi_{n,n} + 4 \sum_{i=1}^{n-1} \pi_{i,n} + 5 \sum_{i=1}^{n-1} \sum_{j=1}^{n-1} \pi_{i,j} \right\} m = 0 \]

\[ 4 \sum_{i=n-1}^{n} \pi_{i,n} + 4.25 \sum_{i=1}^{n-2} \pi_{i,n} + 4.5 \pi_{n-2,n-2} + 4.75 \sum_{i=1}^{n-2} \pi_{i,n-1} + 5 \sum_{i=1}^{n-2} \sum_{j=1}^{n-2} \pi_{i,j} \] \( m = 1 \)

where \( V \) is the paging cost for one cell and \( \pi_{i,j} = \sum_{k=0}^{M-1} \pi_{i,j,k} \).

Finally, the total signaling cost can be obtained as follows;

\[ C_{T} = C_{U} + C_{p} \]
4 Numerical Results

To obtain numerical results, it is assumed that the number of cells in a VLR area is $12 \times 12$ and following.

$$ U=10, \ V=1, \ \lambda_m=1, \ \lambda_c=0.5 \ (\lambda_c=\lambda_{ic}+\lambda_{oc}) $$

Figure 5 shows the total signaling cost for various thresholds. The total signaling cost is composed of the location registration cost and paging cost. In general, as the movement threshold increases, the location registration cost decreases but the paging cost increases. As a result, in our numerical example, the total signaling cost reaches a minimum at a movement threshold $M=2$.

The total signaling costs for two different situations (considering VLR or not) are also shown in Figure 5. When the VLR architecture is considered, the total signaling cost increases considerably, compared with the case that the VLR architecture is ignored. That is mainly because the number of location registration increases especially around the VLR boundary due to the network architecture.

Note that, when the VLR architecture is considered, since the paging area around the VLR boundary becomes smaller, the paging cost decreases compared to the case that the VLR architecture is ignored. However, as we can see from this study, when the VLR architecture is considered, the increase of the registration cost is more significant than the decrease of the paging cost in most cases.

![Figure 5. Signaling cost for various thresholds](image)

Figure 6 shows the total signaling cost for different distributions, when the network architecture is considered. As we can see from Figure 5 and 6, consideration of network architecture induces the increment of the total signaling cost. Even though total signaling cost increases if we consider the VLR architecture, it is necessary to consider it in order to obtain more accurate performance of the MBR. It is expected that total signaling cost will increase as the VLR area becomes smaller.
From Figure 5 and Figure 6, we can see that i) consideration of real network architecture induces slight increment of the total signaling cost and ii) the total signaling cost reaches a minimum at a specific movement threshold since there is tradeoff between registration cost and paging cost.

5 Conclusion

In this paper, MBR with implicit registration, an improved version of MBR, was considered. In order to obtain more accurate registration cost of the MBR, we considered real network architecture in which a mobile network is composed of VLRs, a group of BSs. Furthermore, we adopted an imbedded Markov chain model to reflect MS’s call holding time and cell residence time that may follow a general distribution. Numerical results for various situations were shown to obtain the exact performance of MBR under real network architecture. These results can be used effectively to design and evaluate mobility management schemes in mobile communication network.

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References


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