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Modeling and Evaluation for Distance-based Registration Scheme under Different Moving Direction Probability

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***Abstract*:** *This paper considers the distance-based registration scheme to manage the mobility of subscriber (user equipment, UE) in mobile communication networks. Assuming that the movement probabilities from one cell to another are different, a numerical model based on the Markov process approach is proposed, and the performance analysis results for various parameters are presented. Numerical results show that the larger the CMR (call-to-mobility ratio) and the smaller the OIR (out-in ratio), the better the performance of the DBR compared to the existing one. It is also observed that the threshold value of the DBR should be adjusted differently depending on the UE's moving direction and probability to other cell.*

Keywords: *mobile communication network, mobility management, distance-based registration, paging, 5G, 6G*

1. Introduction

The development of mobile communication networks and services has been a driving force for industrial innovation in both advanced and developing countries worldwide. In particular, in recent years, the 5G and 6G mobile communication systems have emerged as a key driver to develop other fourth industrial area such as self-driving car, augmented reality, smart city, smart factory and healthcare, providing eMBB (enhanced mobile broadband), URLLC (ultra-reliable and low latency communications), and mMTC (massive machine type communications) services. Figure 1 shows the relationship between 5G core services and key technologies defined by ITU-R [1,4].

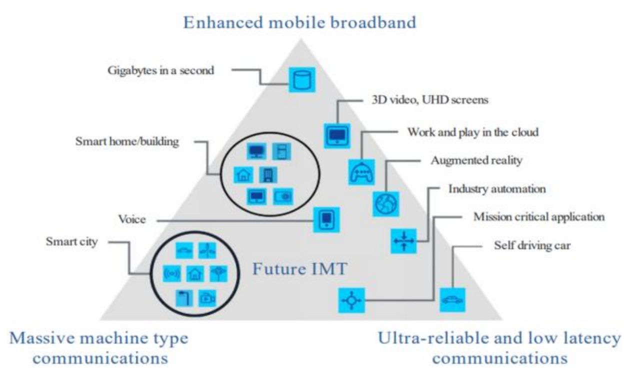


Fig. 1. 5G core services (ITU-R [4]).

The 5G main technology features are summarized as follows.

(1) eMBB: It is characterized by high-speed bandwidth and low latency, and uses technologies such as expanding and increasing the density of frequency bands, multiple antennas, and advanced signal processing.

(2) URLLC: It is designed for applications that requires ultra-low latency and high reliability communications, such as IoT and autonomous vehicles. It uses technologies such as high-speed secure communication, massive Internet traffic processing, and network slicing.

(3) mMTC: It supports communication among a massive number of devices and uses technologies such as low power consumption, support for large-scale devices, and efficient bandwidth management.

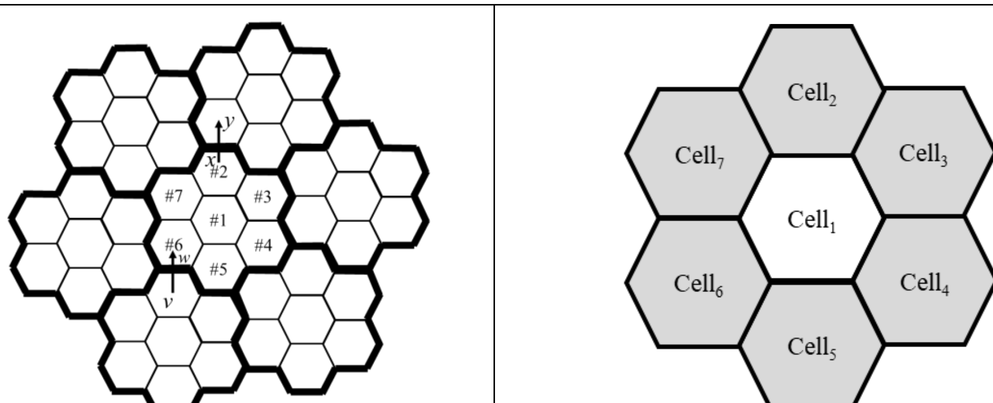
To provide mobile communication services, it is necessary to manage UE's mobility, and for this purpose, the system efficiently manages UE's mobility using location registration algorithms [2,6,7]. When a UE moves to a cell that is not included in the previously registered registration area (RA), the UE is required to perform a location registration, which is the process of registering the new location information. When a call arrives for that UE, the network uses the registered RA to request paging in the cell that is included in the same RA, and the call is successfully connected. Therefore, if the number of cells included in RA is large, the number of registrations decreases but the paging cost increases. Conversely, the number of cells included in RA is small, the paging cost decreases but registration cost increases since UE tends to cross the RA's boundary more frequently. So far, various algorithms have been proposed to efficiently handle registration and paging process [3,5,8]. Among them, in distance-based registration (DBR) method, an algorithm that requests and processes registration only when the UE moves a certain threshold (*D*, the optimal value for most parameters is known to be *D*=2) has been proven to ourperform the existing zone-based registration scheme [3,5]. However, most performance analyses of DBR have been conducted assuming that the probability of moving from any cell to another is the same.

In this paper, we analyse the performance of the DBR under the realistic environments where the probability of moving one cell to another is not equal. By presenting the Markov process modelling and numerical results for various parameters, we would like to compare them to cases where the probability of movement to other cells is the same and diagnose the performance analysis results of DBR in a real environment.

2. Modelling and Performance Evaluation

2.1. Distance-based Registration

Unlike the zone-based registration (ZBR) method, in the DBR, the UE requests a registration from the system when it move a certain threshold (*D*) away. Figure 2 illustrates an example of the registration configuration in the DBR scheme when *D*=2. As shown in Figure 2(a), if the UE stays in cell 2(#2), the UE could be seen as a new stay in cell 1(#1) after registration process when it moves from *x* to *y*. Note that, in the ZBR, the UE moves *x*→*y*, it stays in cell 6(#6) requiring registration (*v*→*w*). Therefore, in ZBR, it is on the border with new RA, so it is more likely to require registration compared to DBR. The seven cells are formed as one RA for each UE as shown in Figure 2(b) in DBR and ZBR.

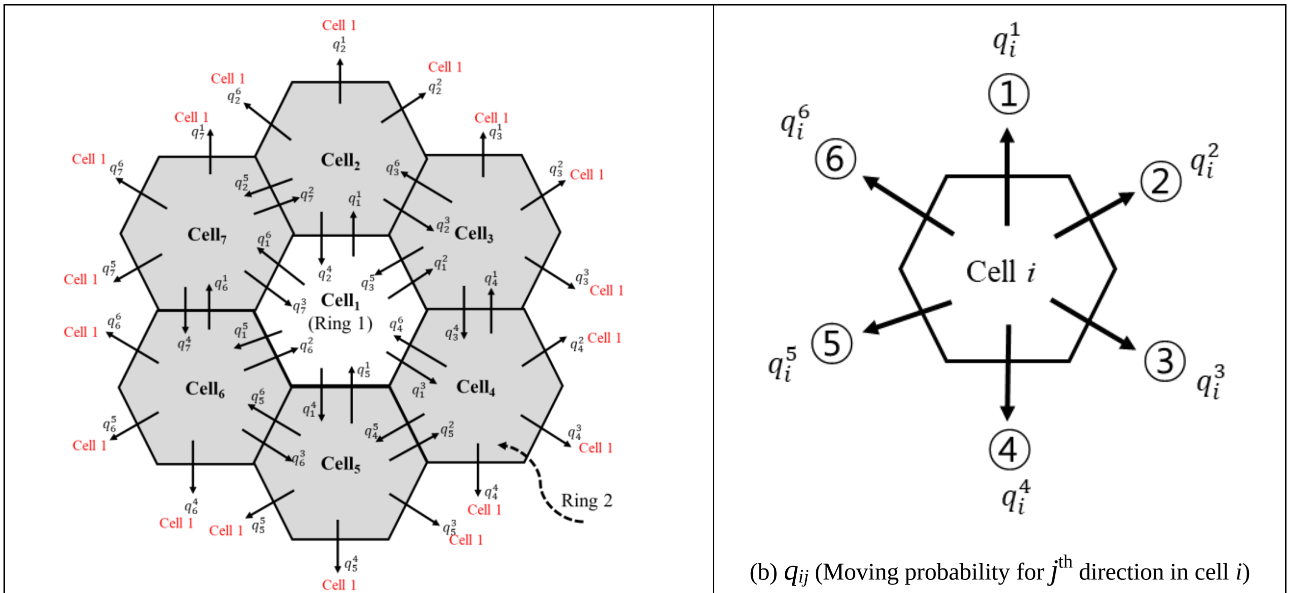


(a) UE's moving pattern (b) Registration area (RA)

Fig. 2. Registration area configuration as UE moves (*D*=2).

2.2. Markov-Process Modeling

Figure 3 shows the moving probabilities of UE for each six directions under DBR (D=2). Let q_{ij} the moving probability for j^{th} direction in cell i ($1 \le i \le 7$, $1 \le j \le 6$), then $\sum_{j=1}^{6} q_i^j = 1$ for all cell i.



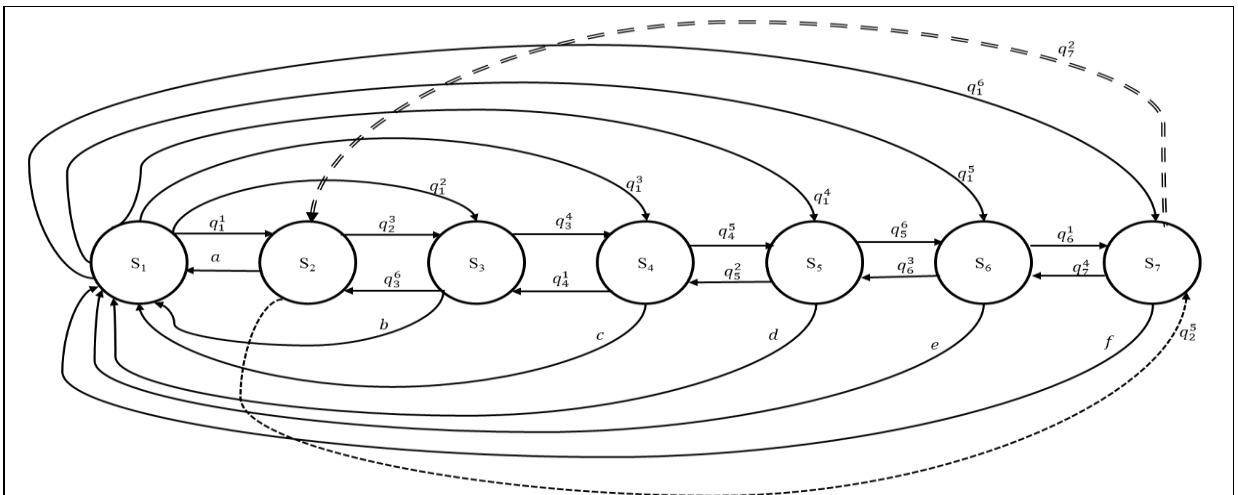
(a) The distinct probabilities of movement in each cell

(b) q_{ij} (Moving probability for j^{th} direction in cell i)

(i=1,2,3,4,5,6,7, j=1,2,3,4,5,6)

Fig. 3. The moving probability of UE from each cell.

We define that the state UE stays in cell i is S_i, and can obtain Markov-chain model as shown in Figure 4.



$a = q_2^1 + q_2^2 + q_2^4 + q_2^6$	$d = q_5^1 + q_5^3 + q_5^4 + q_5^5$
$b = q_3^1 + q_3^2 + q_3^3 + q_3^5$	$e = q_6^2 + q_6^4 + q_6^5 + q_6^6$
$c = q_4^2 + q_4^3 + q_4^4 + q_4^6$	$f = q_7^1 + q_7^3 + q_7^5 + q_7^6$

Fig. 4. State transition diagram under different moving direction probabilities in DBR.

To analyse the performance of DBR, the following notations and probabilities are defined:

$\alpha(K)$: The probability that a UE enters K cells during an interval of UE's terminating (or originating) calls [8]

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

where $\theta = \lambda_c/\lambda_m$ (CMR, call-to mobility ratio), λ_c is incoming call rate, $1/\lambda_m$ is mean of the cell residence time, and $f_m^*(\lambda_c)$ is given by the *Lapalce-Stieltjes* transform of the probability density function ($f_m(t)$) of the cell residence time.

The transition probability matrix P can be obtained from the state transition diagram as follows:

$$P = \begin{bmatrix} 0 & q_1^1 & q_1^2 & q_1^3 & q_1^4 & q_1^5 & q_1^6 \\ q_2^1+q_2^2+q_2^4+q_2^6 & 0 & q_2^3 & 0 & 0 & 0 & q_2^5 \\ q_3^1+q_3^2+q_3^3+q_3^5 & q_3^6 & 0 & q_3^4 & 0 & 0 & 0 \\ q_4^2+q_4^3+q_4^4+q_4^6 & 0 & q_4^1 & 0 & q_4^5 & 0 & 0 \\ q_5^1+q_5^3+q_5^4+q_5^5 & 0 & 0 & q_5^2 & 0 & q_5^6 & 0 \\ q_6^2+q_6^4+q_6^5+q_6^6 & 0 & 0 & 0 & q_6^3 & 0 & q_6^1 \\ q_7^1+q_7^3+q_7^5+q_7^6 & q_7^2 & 0 & 0 & 0 & q_7^4 & 0 \end{bmatrix}$$

Let π_i the probability that a UE is in a cell i, and using following balanced equations,

$$\pi = \pi P, \qquad \sum_{i=1}^{7} \pi_i = 1$$

The probability, $\beta(k, K)$ that a UE stays in cell k after K movements can be derived.

$$\beta(k,K) = \sum_{i=1}^{7} P_{i,k}^{(K)} \times \pi_i$$

where

$$P^{(K)} = \begin{cases} P, & K = 1 \\ P \times P^{(K-1)}, & K > 1. \end{cases}$$

$P_{ij}(K)$ in $P(K)$ is the probability that a UE moves from a cell i to cell j in K steps.

To calculate the registration signalling cost, we define $R(K)$ as the number of registrations when a UE enters cells K times, then we obtain it as follows.

$$\begin{aligned} R(K) &= R(K-1) + \sum_{j=2}^{7} \beta(j, K-1) \times p'_j \\ &= \left[R(K-2) + \textstyle\sum_{j=2}^{7} \beta(j, K-2) \times p'_j\right] + \textstyle\sum_{j=2}^{7} \beta(j, K-1) \times p'_j \\ &= R(1) + \textstyle\sum_{j=2}^{7} \beta(j,1) \times p'_j + \sum_{j=2}^{7} \beta(j,2) \times p'_j + \cdots + \sum_{j=2}^{7} \beta(j, K-1) \times p'_j \\ &= \textstyle\sum_{i=1}^{K-1} \sum_{j=2}^{7} \beta(j,i) \times p'_j, \quad K \geq 2 \end{aligned}$$

$$R(1) = R(0) + \sum_{j=2}^{7} \beta(j, 0) \times p'_j = 0$$

The C_R, total expected location registration cost between call arrivals, can be derived assuming R is unit cost of a registration.

$$\begin{aligned} C_R &= R \times \sum_{K=1}^{\infty} R(K)\alpha(K) \\ &= R \times \textstyle\sum_{K=2}^{\infty} \left[\sum_{i=1}^{K-1} \sum_{j=2}^{7} \beta(j,i) \times p'_j\right] \alpha(K) \\ &= R \times \textstyle\sum_{K=2}^{\infty} \left[\sum_{i=1}^{K-1} \left[\sum_{j=2}^{7} \left[\sum_{s=1}^{7} p_{s,j}^{(i)} \times \pi_s\right] \times p'_j\right]\right] \alpha(K) \end{aligned}$$

Assuming 2 step paging and V the cost for paging a cell to find UE, we can obtain the paging cost, C_v.

$$C_V = V\{\pi_1 + (1 - \pi_1) \times 7\} = V(7 - 6\pi_1)$$

Thus, the total expected cost for location registration and paging per call arrival is given by C_T.

$$C_T = C_R + C_V$$

2.3. Numerical Results

The following parameters are assumed to compare the performance according to various environments.

$R = 10$, $V = 1$, $\lambda_c = \lambda_{in} + \lambda_{out} = 0.5 + 0.5 = 1$.

For example, when a UE resides in $Cell_2$, if the ratio of out-in (OIR) is given by *out*:*in* = *g*:*h*, the probability of moving to other cells adjacent to Cell 2 is as follows.

$$\text{Out} = q_2^1 + q_2^2 + q_2^6 = 3 \times q_2^{out}$$
$$\text{In} = q_2^3 + q_2^4 + q_2^5 = 3 \times q_2^{in}$$

Therefore, *Out* : *in* = *g*:*h* = $3\times q_2^{out}:3\times q_2^{in}$ and $3\times q_2^{out} + 3\times q_2^{in} = 1$.

Using the following equations,

$$q_2^{out}\times \text{h} = q_2^{in}\times \text{g}, \quad q_2^{out} + q_2^{in} = \frac{1}{3}$$

The probability (q_2^{out}) of requesting registration while moving to another cell from cell 2 and the probability (q_2^{in}) of moving to a different cell in the same RA are derived as follows:

$$q_2^{out} = \frac{g}{3(g+h)}, \quad q_2^{in} = \frac{h}{3(g+h)}$$

Note that, in this study, the performance will be evaluated by distinguishing two probabilities: the probability of requesting registration while moving to another cell and the probability of moving to another cell within the same RA.

Figure 5 shows the performance analysis results of DBR according to different values of CMR and OIR parameters. Based on the numerical results, we can obtain the following observations:

(1) As the CMR increases, that is, as the number of arrivals during a unit time increases, the paging cost increases, leading to an increase in the total cost.

(2) When the probability of moving to each cell is the same, *i.e.*, OIR=1 (*out*:*in*=1:1), the performance of the DBR scheme is most sensitive to changes in CMR, and the total cost increases sharply depending on CMR.

(3) As the OIR value increases, that is, when the probability of requesting a new registration is higher than moving to a cell belonging to the same RA, the performance varies greatly depending on the CMR.

(4) If the CMR is less than 0.5, meaning that on average, one or fewer calls arrive when moving through two cells (note that D=2), the total cost decreases as the OIR increases. In other words, if there are few incoming calls and the cell residence time is short, resulting in frequent movements across cell boundaries, the total cost increases as the probability of moving to a different RA increases due to the increase in registration cost for the UE.

(5) On the contrary, if the CMR is greater than 0.5, that is, if the cell residence time increases and the cell boundary does not move frequently or if the call arrives frequently, the higher the probability of moving to another RA, that is, as the OIR increases, the total cost increases.

(6) Therefore, when the CMR is less than or equal to 0.5, the performance of the DBR can be improved as the OIR decreases (i.e., as the probability of new RA movements becomes smaller) compared to the case where the movement probabilities for each cell are the same.

(7) On the other hand, when the CMR is greater than 0.5 it can be observed that the total cost decreases compared to the case where the movement probabilities are the same as the OIR increases (*i.e.*, as the probability of new RA movements becomes larger).

Based on the numerical results for various CMR and OIR parameters, we observe that it is necessary to adjusts the threshold value (D) of DBR according to the movement probabilities of UEs in order to operate it more effectively. Note that by adjusting the threshold of DBR considering the direction and probability of UE's movements, it is possible to improve the performance of the DBR.

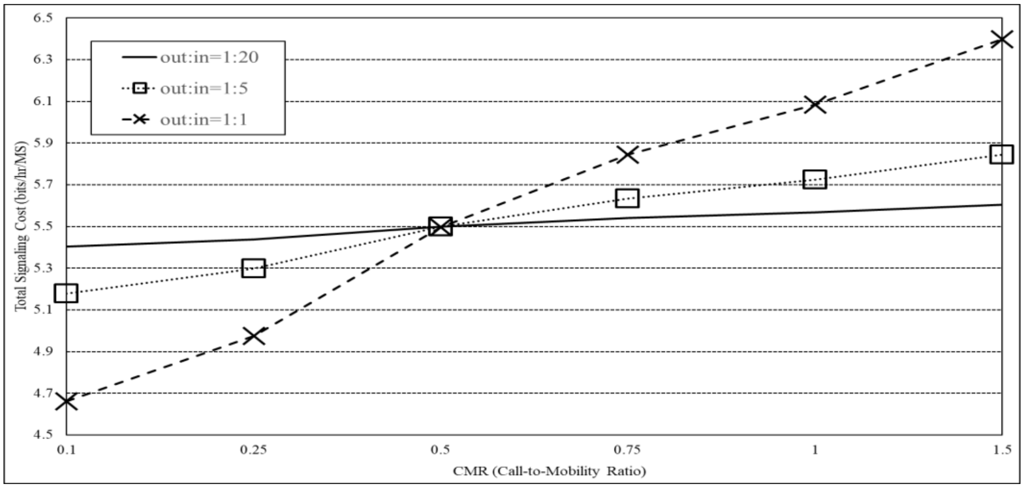


Figure 5. Total signalling cost versus CMR and OIR (*D*=2).

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