논문 2004-41TC-11-7

이동통신망에서의 향상된 시간 기반 위치 갱신 방법의 성능 분석

(Numerical Analysis of an Enhanced Time-Based Location Registration Method)

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요 약

본 논문에서는 이동 통신망에서의 향상된 시간 기반의 위치 갱신 방법을 제안하고 제안된 방법의 성능을 분석하였다. 분석에서는 포아송 분포의 호 도착시간을 가정하였고, 지수분포의 셀 체류시간을 가정하였으며 분석결과로서는 제안된 방법에서의 최적의 갱신주기를 구하였다. 부가적으로 갱신주기의 값의 변화에 따른 비용의 특성을 관찰하고자 갱신주기의 값이 0 또는 무한대로 근접할 경우에 대하여 위치관리 비용을 분석하였다. 제안된 위치갱신방법과 기존에 제안된 오리지날 시간 기반의 위치 갱신방법과의 비교를 위하여 오리지날 시간 기반의 위치갱신 방법에 대한 분석도 수행하였다. 두 방법에 대한 비교에서 제안된 방법이 주어진 환경에서 성능이 향상됨을 알 수 있었다.

Abstract

In this paper, an enhanced time-based registration method is proposed. The method reduces the registration cost when a mobile terminal stays in a cell for a long time. We also analyze the performance of the proposed method numerically. In the analysis, we assume Poisson call arrival distribution and exponential cell resident time. From the analysis we calculate the optimal time-interval. Additionally, limit cost analysis is made to investigate the behaviors in the limit conditions. To compare the performance of the proposed method with the original time-based registration method, we analyze the performance of the original time-based registration method. In the comparisons, we see that the proposed enhanced time-based registration method has better performance and is applicable to the PCS systems.

Keywords : location management, enhanced time-based update, optimal time-interval

I. Introduction

Location management and call setup process play an important role in the PCS performance[1]-[4]. The whereabouts of a user in mobile communication systems must first be known in order to correctly route an incoming call. A user's location information can be obtained from the registration initiated by the user and the paging issued by the system. However, the registration cost and the paging cost have the relation of inverse coupling in the use of network resources.

From the relation of inverse coupling, researches have been made about the performance of PCS in the three basic models; movement-based, distance-based and time-based. Recently, for the better performance, some additional parameters such as each mobile user's moving behaviors, aggregate history of mobile

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※ 본 논문은 2004년도 강원대학교 학술연구조성비로 연구하였음

접수일자: 2004년3월11일, 수정완료일: 2004년11월4일

users, moving location areas of mobile users, and so forth have been added to the models.

A new mobility management scheme that inte-grates the location area approaches with the location prediction idea was proposed[5]. A new scheme to estimate the user mobility by incorporating the aggregate history of mobile users and system parameters was proposed[6]. However, since the two schemes use the concept of moving location areas based on traffic flow theory, mobile user's moving behaviors are not properly reflected on the schemes. A new location tracking strategy called behavior-based strategy based on each mobile user's moving behavior was proposed[7], but it is not good model in that investigating each user's mobility characteristics and managing locations individually are not practical in mobile communication systems. An intra-LA location update scheme to reduce the paging cost was proposed[8]. However, the scheme is also based on each user's mobility characteristics and is not practical in mobile communication environment.

Adding some additional parameters to new schemes often causes the location management methods more complex, which makes them not applicable. Therefore, research about practical location management method applicable to PCS for better performance based on the basic models is meaningful.

A simple dynamic strategy in location update is a time-based registration method in that a mobile terminal(MT) transmits its location update messages periodically every T units of time[9]-[13]. If a call arrival occurs within T interval, the system pages the MT and the MT restarts its timer. In this paper, we call the time-based registration method original time-based registration method. However, when an MT stays in a cell for a long time, the MT still goes on updating its location every fixed T interval which results in a waste of wireless signal bandwidth. To reduce the waste of the original time-based regist-ration method, we propose an enhanced time-based registration method and analyze its performance numerically. We also compare the performance with the case of the original time-based registration method.

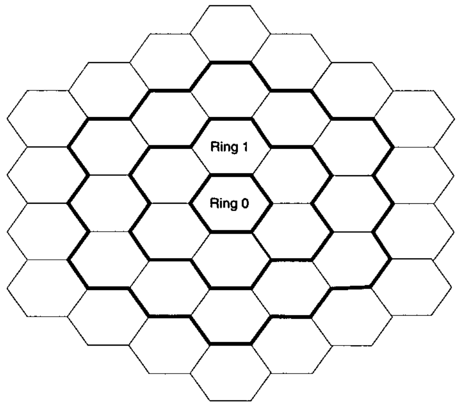

그림 1. 육각형 모양의 셀 구조
Fig. 1. Hexagonal cell structure.

II. Enhanced Time-Based Registration Method

In the enhanced time-based registration method proposed in this paper, an MT does not transmit its location update message when the timer T expires. Instead, the MT waits until it crosses the current cell boundary. At the time of the current cell crossing, the MT transmits its location update message. If a call arrival occurs before the cell crossing, the system pages the MT and the MT restarts its timer.

The paging process of the enhanced time-based registration method is the same as the original time-based registration method. Figure 1 shows the hexagonal cell structure of the mobile communication system considered in this paper. In the figure, each cell is surrounded by rings of cells. The innermost ring(ring 0) consists of only one cell and we call it center cell. Ring 0 is surrounded by ring 1 which in turn is surrounded by ring 2, and so on. When the system routes an incoming call to an MT, it first pages the center cell which is the recently registered location of the MT. If it does not succeed in finding the MT, it pages next surrounded ring. The paging goes on until it finds the MT.

Ⅲ. Model and Analysis

1. Enhanced Time-Based Registration Method

We denote some notations and assumptions. Call arrival distribution to an MT is Poisson with rate λ_c. Let a random variable t_c be the interval between two consecutive calls to the MT. Let m_i be the cell residence time at cell i and be the indepen-dent identically distributed random variable with the density function $f_{m_i}(t)$ and the mean rate λ_m.

Since the cell residence time for each cell should be identical, we have $f_{m_i}(t) = f_m(t)$. In this paper, we assume that the cell residence time has exponential distribution. Figure 2 shows the timing diagram of an MT between two consecutive calls. In the figure, M_i is the residual resident time of the MT in the current cell. Due to the memoryless characteristics of exponential distribution, the distribu-tions of M_i and m_i are identical. Therefore, we will use the notation m instead of M_i in this paper.

In the figure 2, σ represents the time interval from the recent registration time to the next call arrival. In σ, there can be some cell boundary crossings of the MT. Let $\alpha_{enh}(K)$ be the probability that the MT moves across K cells during σ. Let $\beta(j,K)$ be the probability that the MT is j rings away from the center cell given that K cell boundary crossings are performed.

For the hexagonal cell configuration in the figure 1, we assume that each MT resides in a cell for a time period then moves to one of its neighbors with the equal probability, i.e., 1/6. This assumption is meaningful when users are moving within city area because the moving area is not large and then the movement pattern can be seen to be random. Therefore, we can get $\beta(j,K)$ from a simple calculation. The value of $\beta(j,K)$ is listed in the Table 1.

Let the costs for performing a location update and for paging a cell be U and V, respectively. These costs account for the wireless and wireline bandwidth utilization and the computational overheads in order to process the location update and the paging. Let $C_{u,enh}$ be the expected location update cost in the enhanced time-based registration method per call arrival. The expected paging cost per call arrival in the enhanced time-based registration method is denoted by $C_{v,enh}$.

표 1. $\beta(j,K)$의 계산값
Table 1. Value of $\beta(j,K)$.

j \ K	1	2	3	4	5	…
0	0	0.166666	0.055555	0.069444	0.046296	…
1	1	0.333333	0.416666	0.277777	0.262345	…
2		0.5	0.333333	0.379629	0.324074	…
3			0.194444	0.203703	0.243055	…
4				0.069444	0.100308	…
5					0.023919	…
…	…	…	…	…	…	…

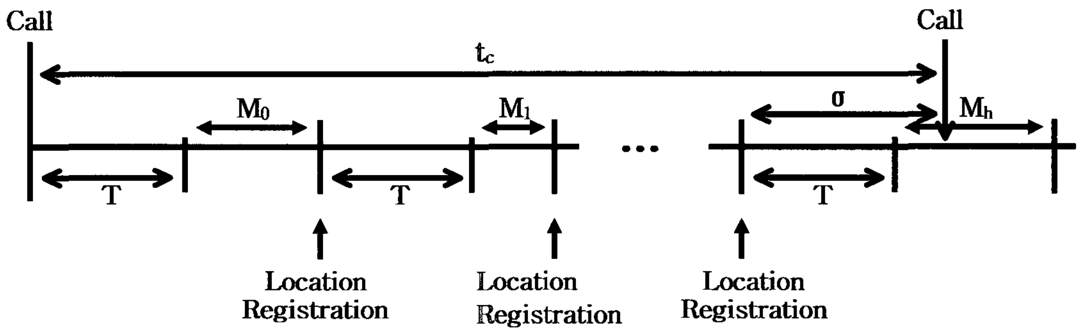

그림 2. 향상된 시간 기반의 위치 갱신 방법에서의 호와 호사이의 타이밍 다이아그램
Fig. 2. The time diagram in the enhanced time-based update mechanism.

At first, we derive the expected cost for location updates. We let q_h be the probability that there are h update messages between two successive calls. We also let g be the probability that there are no location update messages between two successive calls. Therefore, g can be expressed as

$$g = P[t_c < T+m]. \tag{1}$$

And we have

$$q_0 = g. \tag{2}$$

g is divided into two cases. The first case is that a call arrives within T. The probability of the case is

$$g_0 = P[t_c < T]. \tag{3}$$

The other case is that a call arrives after T. The probability of the case is

$$g_1 = P[T < t_c < T+m]. \tag{4}$$

Thus we have the relation

$$g = g_0 + g_1. \tag{5}$$

Since t_c and m are both memoryless, the pdfs are respectively given by

$$f_{t_c}(t) = \lambda_c e^{-\lambda_c t} \tag{6}$$

$$f_m(t) = \lambda_m e^{-\lambda_m t}. \tag{7}$$

From the above equations, we have

$$g_0 = 1 - e^{-\lambda_c T} \tag{8}$$

$$g_1 = \frac{\lambda_c/\lambda_m}{\lambda_c/\lambda_m + 1} e^{-\lambda_c T} \tag{9}$$

$$g = 1 - \frac{1}{\lambda_c/\lambda_m + 1} e^{-\lambda_c T}. \tag{10}$$

q_h has geometric distribution with parameter g. Then we have

$$q_h = g(1-g)^h. \tag{11}$$

The expected cost for location updates for the period between two consecutive calls, $C_{u,enh}$ is

$$C_{u,enh} = U\sum_{h=0}^{\infty} h q_h = U\left(\frac{1}{g} - 1\right). \tag{12}$$

Now, we derive the expected cost for paging cells. To get the probability $\alpha_{enh}(K)$, we divide it into two cases. The first case is that the MT moves across K cells when a call arrives within T. The probability of the case is denoted by $A_0(K)$. The other case is that the MT moves across K cells when a call arrives after T. The probability of the case is denoted by $A_1(K)$. Thus we have the relation

$$\alpha_{enh}(K) = A_0(K) + A_1(K). \tag{13}$$

Since the number of cell boundary crossings is Poisson distributed, we can get $A_1(K)$ and $A_0(K)$.

$$A_1(K) = \frac{g_1}{g}\frac{(\lambda_m T)^K}{K!} e^{-\lambda_m T} = \frac{g_1}{g}\frac{\left(\frac{\lambda_c T}{\lambda_c/\lambda_m}\right)^K}{K!} e^{-\frac{\lambda_c T}{\lambda_c/\lambda_m}} \tag{14}$$

$$A_0(K) = \int_0^T \frac{(\lambda_m t_1)^K}{K!} e^{-\lambda_m t_1} \cdot \frac{\lambda_c e^{-\lambda_c t_1}}{g} dt_1 = \frac{1}{g} B(K) \tag{15}$$

where

$$B(K) = \int_0^T \frac{(\lambda_m t_1)^K}{K!} e^{-\lambda_m t_1} \cdot \lambda_c e^{-\lambda_c t_1} dt_1 \tag{16}$$

Through tedious calculation, $B(K)$ can be simplified as

$$B(K) = \frac{\lambda_c/\lambda_m}{(1+\lambda_c/\lambda_m)^{K+1}} \cdot \left[1 - e^{-\left(1+\frac{1}{\lambda_c/\lambda_m}\right)\lambda_c T} \sum_{i=0}^{K} \frac{\left(\left(1+\frac{1}{\lambda_c/\lambda_m}\right)\lambda_c T\right)^i}{i!}\right] \tag{17}$$

Let $\pi_{j,enh}$ be the probability that the MT is

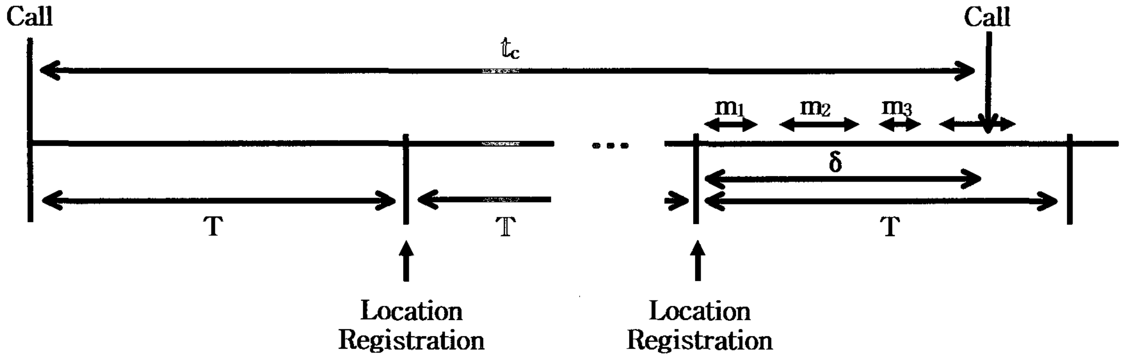

그림 3. 오리지날 시간 기반의 위치 갱신 방법에서의 호와 호사이의 타이밍 다이아그램
Fig. 3. The time diagram in the original time-based update mechanism

located in a ring j cell when a call arrival occurs. Then we have

$$\pi_{j,enh} = \sum_{K=0}^{\infty} \alpha_{enh}(K)\beta(j, K). \qquad (18)$$

Given that the MT is residing in ring j, let ω_j be the number of cells from ring 0 to ring j.

$$w_j = 1 + \sum_{i=1}^{j} 6i = 1 + 3j(j+1) \qquad (19)$$

The paging cost for the enhanced time-based location update for the period between two consecutive calls, $C_{v,enh}$ is expressed as

$$C_{v,enh} = V\sum_{j=0}^{\infty} \pi_{j,enh} w_j \,. \qquad (20)$$

The expected total cost for location updates and paging per call arrival, $C_{T,enh}$ in the enhanced time-based registration method is

$$C_{T,enh} = C_{u,enh} + C_{v,enh} \,. \qquad (21)$$

2. Original Time-Based Registration Method

Figure 3 shows the timing diagram of an MT between two consecutive calls in the original time-based registration method. The notations and assumptions are the same as in the analysis of the enhanced time-based registration method.

In the figure 3, δ represents the time interval from the recent registration time to the next call arrival. In δ, there can be some cell boundary crossings of the MT. Let $\alpha_{ori}(K)$ be the probability that the MT moves across K cells during δ. We also let $C_{u,ori}$ be the expected location update cost per call arrival. The expected paging cost per call arrival is denoted by $C_{v,ori}$.

At first, we derive the expected cost for location updates. We let p_n be the probability that there are n update messages between two successive calls. Apparently, p_n has geometric distribution with parameter $1-e^{-\lambda_c T}$. Then we have

$$p_n = e^{-n\lambda_c T}(1 - e^{-\lambda_c T}) \qquad (22)$$

The expected cost for location updates for the period between two consecutive calls, $C_{u,ori}$ is

$$C_{u,ori} = U\sum_{n=0}^{\infty} np_n = U\frac{e^{-\lambda_c T}}{1 - e^{-\lambda_c T}} \qquad (23)$$

Now, we derive the expected cost for paging cells. Since the number of cell boundary crossings is Poisson distributed, $\alpha_{ori}(K)$ can be obtained as

$$\alpha_{ori}(K) = \int_0^T \frac{(\lambda_m t_1)^K}{K!} e^{-\lambda_m t_1} \frac{\lambda_c e^{-\lambda_c t_1}}{g_0} dt_1 = \frac{B(K)}{g_0} \qquad (24)$$

Let $\pi_{j,ori}$ be the probability that the MT is located in a ring j cell when a call arrival occurs. Then we have

$$\pi_{j,ori} = \sum_{K=0}^{\infty} \alpha_{ori}(K)\beta(j, K). \quad (25)$$

The paging cost for the original time-based location update for the period between two consecutive calls, $C_{v,ori}$ is expressed as

$$C_{v,ori} = V\sum_{j=0}^{\infty} \pi_{j,ori} \cdot w_j. \quad (26)$$

The expected total cost for location updates and paging per call arrival, $C_{T,ori}$ in the original time-based registration method is

$$C_{T,ori} = C_{u,ori} + C_{v,ori} \ . \quad (27)$$

3. Limit Cost Analysis

It is meaningful to get the total cost when T goes to zero or infinite. In the original time-based registration method, the total cost goes infinite when T goes to zero because there are infinite timeouts and infinite location update messages between two consecutive calls. In the enhanced time-based registration method, the total cost approaches to $U \cdot \frac{\lambda_m}{\lambda_c} + 1 \cdot V$ when T goes to zero because an MT moves across cells $\frac{\lambda_m}{\lambda_c}$ times on the average between two consecutive calls and the MT resides in the center cell when a call arrives. Therefore we have

$$\lim_{T \to 0} C_{T,ori} \rightarrow \infty \quad (28)$$

$$\lim_{T \to 0} C_{T,enh} = U \cdot \frac{\lambda_m}{\lambda_c} + 1 \cdot V \quad (29)$$

When T goes infinite, the limit values of the total cost of the two registration methods are the same because there are no location update messages between two consecutive calls. Therefore, $C_{u,enh}$ and $C_{u,ori}$ goes to zero when T goes infinite.

From the equations for $\alpha_{enh}(K)$ and $\alpha_{ori}(K)$, we have α_{∞} as the following.

표 2. 그림 4에서의 최적 갱신주기 및 총비용
Table 2. Optimal time intervals and costs in Fig. 4.

Call-to-mobility ratio (λ_c/λ_m)	Method	Optimal time Interval $\lambda_c T$ (T/call arrival)	Minimal total Cost
0.05	Enhanced	0.087	$C_{T,enh}$=14.2
	Original	0.147	$C_{T,ori}$=14.96
0.1	Enhanced	0.076	$C_{T,enh}$=9.66
	Original	0.204	$C_{T,ori}$=10.82

$$\alpha_{\infty}(K) = \lim_{T\to\infty} \alpha_{enh}(K) = \lim_{T\to\infty} \alpha_{ori}(K) = \frac{\lambda_c/\lambda_m}{(1+\lambda_c/\lambda_m)^{K+1}} \quad (30)$$

Then we have

$$\pi_{j,\infty} = \sum_{K=0}^{\infty} \alpha_{\infty}(K)\beta(j, K). \quad (31)$$

Thus, the total cost when T goes infinite is

$$\lim_{T\to\infty} C_{T,enh} = \lim_{T\to\infty} C_{T,ori} = V\sum_{j=0}^{\infty} \pi_{j,\infty} \cdot w_j. \quad (32)$$

IV. Results and Discussion

We see that the equations for the total costs of the enhanced time-based registration method and the original time-based registration method are represen-ted with the parameters $\frac{\lambda_c}{\lambda_m}$ and $\lambda_c T$. Therefore, we get the numerical results by varying the parameters $\frac{\lambda_c}{\lambda_m}$ and $\lambda_c T$ instead of λ_c, λ_m and T respectively. $\frac{\lambda_c}{\lambda_m}$ is called call-to-mobility ratio and $\lambda_c T$ is normalized time interval about call interval. Figure 4 shows the values of the total costs, $C_{T,enh}$ and $C_{T,ori}$ as functions of T. In the

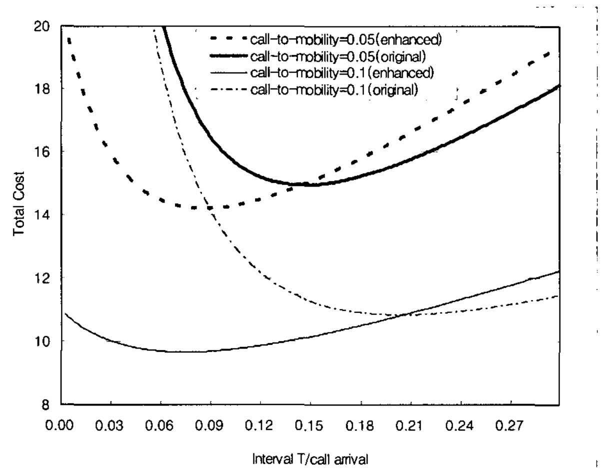

그림 4. V=1 and U=1 인 경우에 T가 변함에 따른 총비용의 변화를 나타낸 그래프
Fig. 4. Total cost versus time interval when V=1 and U=1.

figure, the values of U and V are set to one. To show the effect of call-to-mobility patterns, two call-to-mobility ratio $\frac{\lambda_c}{\lambda_m}$ = 0.05, 0.1, are considered. In the figure, it can be seen that the values of the total cost varies widely as T changes. By selecting the appropriate value of T, the total cost per call arrival could be minimal.

In the figure, we see that the minimal cost of the enhanced time-based registration method is less than that of the original time-based registration method. That is, the performance of the enhanced time-based registration method is better than that of the original time-based registration method, which means that the enhanced time-based registration method should be applied to the PCS systems in this environment. We list the optimal time intervals and their total costs in the Table 2. And the limit values of the total costs when $T \to 0$ and $T \to \infty$ are listed in the Table 3. In the figure, we also see that when call-to-mobility is small, the total cost gets high. This is because more cells should be paged to find the location of an MT which makes the paging cost high.

Fig. 5 shows the values of $C_{v,enh}$, $C_{v,ori}$, $C_{u,enh}$ and $C_{u,ori}$ as time interval varies when U=1, V=1 and call-to-mobility=0.05. As we expect, the location update cost of the enhanced time-based registration method is less than that of the original time-based registration method. About the paging cost, the situation is reversed as we also expect. Therefore, according to the values of U and V, it is determined which method makes better performance. For example, when V has large values relatively compared to U, then the cost of the enhanced time-based registration method gets higher than that of the original time-based registration method. In this environment, the enhanced time-based registration method is not applicable.

표 3. 그림 4에서의 총비용에 대한 극한값
Table 3. Limit values of the total costs in Fig. 4.

Call-to-mobility ratio (λ_c/λ_m)	Method	Total cost when $T \to 0$	Total cost when $T \to \infty$
0.05	Enhanced	$C_{T,enh}$= 21	$C_{T,enh}$= 85.08
	Original	$C_{T,ori} \to \infty$	$C_{T,ori}$= 85.08
0.1	Enhanced	$C_{T,enh}$= 11	$C_{T,enh}$= 45.07
	Original	$C_{T,ori} \to \infty$	$C_{T,ori}$= 45.07

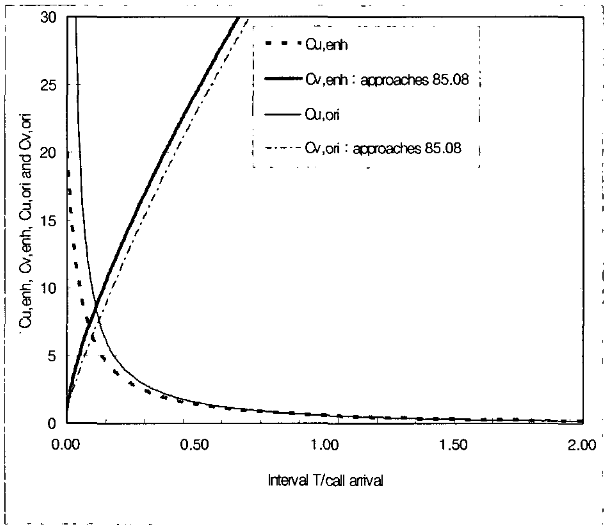

그림 5. U=1, V=1, call-to-mobility=0.05일때의 갱신주기의 변화에 따른 $C_{v,\mathrm{mod}}$, $C_{v,ori}$, $C_{u,\mathrm{mod}}$, $C_{u,ori}$ 값의 변화를 나타낸 그래프
Fig. 5 Values of $C_{v,\mathrm{mod}}$, $C_{v,ori}$, $C_{u,\mathrm{mod}}$ and $C_{u,ori}$ versus time interval when U=1, V=1 and call-to-mobility=0.05.

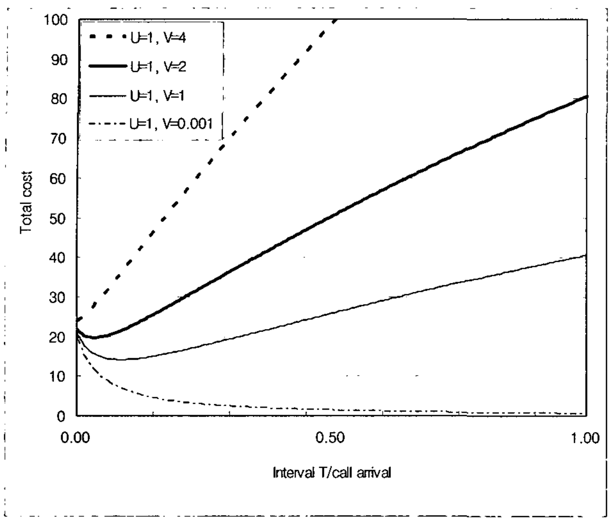

그림 6. Call-to-mobility=0.01, U=1, V=4, 2, 1, 0.001 일때의 갱신주기의 변화에 따른 제안된 방법에서의 총비용의 변화를 나타낸 그래프

Fig. 6 Total cost of the enhanced time-based registration method versus time interval when call-to-mobility=0.01, U=1 and V=4, 2, 1, 0.001.

Fig. 6 shows the total cost of the enhanced time-based registration method as time interval T varies when call-to-mobility=0.01, U=1 and V=4, 2, 1, 0.001. As we can see in the figure, the meaningful optimum values exist in the certain range of V/U. That is, if V is too large or too small compared to U, there does not exist the optimal time interval for the meaningful operation. In the figure, we also see that the optimal time interval gets smaller as the value of V gets bigger. It is because the larger paging cost causes the time interval shorten which means more location updates.

V. Conclusions

In this paper, we proposed an enhanced time-based registration method in location management and analyze the performance numerically. In the analysis, we assumed Poisson call arrival distribution and exponential cell resident time. We obtained the probability that an MT is j rings away from the center cell. And using these values, we made an exact analysis for the enhanced time-based location management cost. From the analysis we calculated the optimal time-interval.

We also analyzed the performance of the original time-based registration method. The performance of the enhanced time-based registration method is compared with the performance of the original time-based registration method. In the comparisons, we see that the proposed enhanced time-based registration method has better performance and is applicable to the PCS systems.

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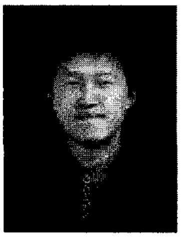
저 자 소 개



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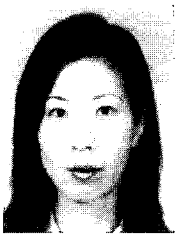

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