Numerical Analysis of Optimum Timer Value for Time-Based Location Registration Scheme

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***Abstract*—In this letter, we analyze a time-based update method in location management and calculate the optimal time-interval. We obtain the probability that an MT is j rings away from the center cell. And using these values, an exact analysis is made for the time-based location management cost. From the result, when the time-based method is applied to location update, we can get the optimal time-interval which minimizes the location management cost.**

***Index Terms*—Location management, optimal time-interval, time-based update.**

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.

Researches has been made about the performance of PCS in the three models; movement-based, distance-based, and time-based. However, exact numerical analyses have not been made for the case of time-based model. In this letter, we make an exact numerical analysis of a time-based model and determine the optimal time interval for location update.

II. TIME-BASED LOCATION UPDATE

A simple dynamic strategy in location update is a time-based method in that a mobile terminal (MT) transmits its location update messages periodically every T units of time [5]–[8]. However, if a call arrival occurs within T interval, the system pages the MT and the MT restarts its timer. The paging mechanism of the time-based method are more complex than the movement-based and distance-based updates in that it is difficult to estimate the paging area because the MT does not update its location until the time interval T expires.

Fig. 1 shows the hexagonal cell structure of the mobile communication system considered in this letter. 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.

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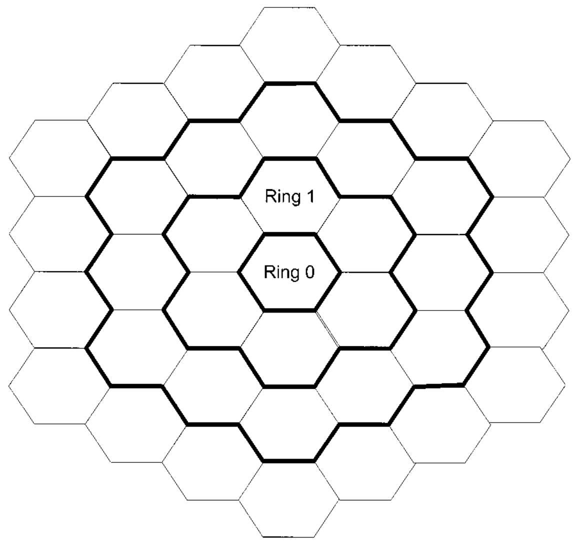

Fig. 1. Hexagonal cell structure.

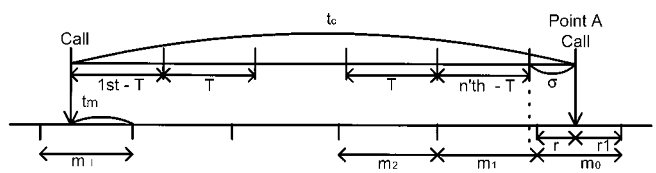

Fig. 2. The time diagram in time-based update mechanism.

III. MODEL AND ANALYSIS OF LOCATION MANAGEMENT COST FOR TIME-BASED UPDATE

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 independent identically distributed random variables with a general distribution function $F_m(t)$, a density function $f_m(t)$ and the mean value $1/\lambda_m$. Fig. 2 shows a timing diagram of an MT between two consecutive calls. The MT visits another l cells (numbered inversely in the figure) and gets a new call. The MT resides in the intermediate ith $(0 \leq i \leq l)$ cell for a period m_i.

In t_c, there are n expirations of T and the remnant σ. r_1 and r are the residual life and the age of m_0, respectively. Let $\alpha(K)$

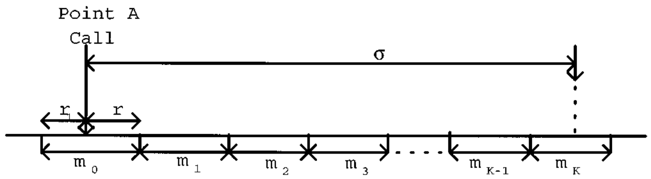

Fig. 3. The reverse time diagram.

be the probability that an MT moves across K cells during the remnant 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 Fig. 1, we assume that each MT resides in a cell for a time period then moves to one of its neighbors with equal probability, i.e., 1/6. This assumption is meaningful when users move 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 algorithm.

Let the costs for performing a location update and for paging a cell be V and U, respectively. At first, we derive the expected cost for location updates. The probability that there are n update messages between two successive calls p_n is

$$p_n = e^{-\lambda_c n T}\left(1 - e^{-\lambda_c T}\right). \quad (1)$$

The expected cost for location updates for a period between two consecutive calls, C_u is

$$C_u = U \sum_{n=0}^{\infty} n p_n. \quad (2)$$

Now, we derive the expected cost for paging cells. Let $f_\sigma(t)$, $f_r(t)$ and $f_{r_1}(t)$ be the probability density function of σ, r and r_1, respectively. Then we have

$$f_\sigma(t) = \begin{cases} \dfrac{\lambda_c e^{-\lambda_c t}}{1 - e^{-\lambda_c T}}, & 0 \le t \le T \\ 0, & \text{otherwise.} \end{cases} \quad (3)$$

From the random observer property, we can get

$$f_r(t) = f_{r_1}(t) = \lambda_m [1 - F_m(t)]. \quad (4)$$

At point A in the Fig. 2, time axis can be displayed reversely as shown in the Fig. 3.

We consider the instant, $\sigma = t_1$. Let the probability that the MT moves across K cells during $\sigma = t_1$ be $\alpha(K, t_1)$. Then we have

$$\alpha(K) = \int_0^T \alpha(K, t_1) f_\sigma(t_1)\, dt_1. \quad (5)$$

We let $b_K = r + m_1 + m_2 + \cdots + m_K = r + \sum_{i=1}^{K} m_i$. Then we can get

$$\alpha(K, t_1) = \int_0^{t_1} \left[\int_{t_1 - t}^{\infty} f_m(t_2)\, dt_2\right] b_{K-1}(t)\, dt. \quad (6)$$

From (5) and (6), we can get $\alpha(K)$.

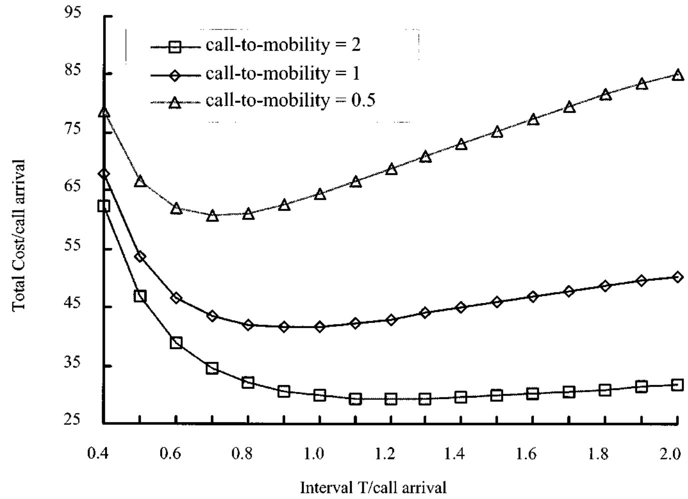

Fig. 4. Total cost versus time interval in the time-based method.

Let π_j be the probability that the MT is located in a ring j cell when a call arrival occurs. Then we have

$$\pi_j = \sum_{K=0}^{\infty} \alpha(K)\beta(j, K). \quad (7)$$

Given that the MT is residing in ring j, let ω_j be the number of cells from ring 0 to ring j. The paging cost for the time-based update, C_v is expressed by

$$C_v = V \sum_{j=0}^{\infty} \pi_j \omega_j. \quad (8)$$

The expected total cost for location updates and paging per call arrival in the time-based method is therefore

$$C_T = C_u + C_v. \quad (9)$$

From (9), we can obtain the optimal timer value T when derivative of C_T with respect to T is zero.

IV. Results and Discussion

Fig. 4 shows the values of total cost, C_T as a function of T. The values of U and V can be set to any value. However, to demonstrate the analysis of this letter, U and V are, for convenience, set to one. The distribution of cell resident time is gamma distribution with $\gamma = 2$. To show the effect of call-to-mobility patterns, three call-to-mobility ratio λ_c/λ_m, 0.5, 1.0 and 2.0, are considered. In the figure, it can be seen that the value of the total cost varies widely as T changes. By selecting the appropriate value of T, the total cost per call arrival, C_T, could be minimal.

In the figure, when T is small, C_T is large because location updates occurs frequently which increases the location update cost. When T is large, location update cost is small but paging area gets large which results in high paging cost. In the figure, we also see that when mobility is large (when call-to-mobility is small), the total cost gets high. This is because more cells should be paged to find the location of MT which makes the paging cost high.

V. Conclusion

In this letter, we made an exact analysis for a time-based location management cost. Using the result in this letter, when the time-based method is applied to location update, we can determine the optimal time-interval which minimizes the location management cost.

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