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LETTER

An Improved Timer-Based Location Management Scheme for Packet-Switched (PS) Mobile Communication Systems

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SUMMARY This letter proposes an improved timer-based location management scheme for packet-switched (PS) mobile communication systems. Compared to the conventional timer-based scheme with a single timer threshold, a new timer-based scheme with two timer thresholds is proposed to accommodate the bursty data traffic characteristics of PS service. The location update and paging costs of the proposed scheme are analyzed and compared with those of the conventional scheme. We show that the proposed scheme outperforms the conventional scheme in terms of total cost of both location update and paging with an appropriate selection of timer thresholds.

key words: *timer-based, location update, paging, location management, packet-switched (PS)*

1. Introduction

Location management consists of location update and paging, and it is one of the most essential technologies to support mobility in mobile communication systems. Mobile station (MS) updates its location in order to inform the network of its current location information and this information is retrieved if there is an incoming call. Then, the network queries the cells within the retrieved location area to find the exact cell of the MS. If the MS updates its location frequently, location update cost increases but paging cost decreases. On the other hand, if the MS seldom updates its location, location update cost decreases but paging cost increases.

Currently, a zone-based location update scheme is widely adopted in most mobile communication systems, where MS updates its location whenever it enters into a new zone consisting of a group of cells. In GSM [1] and IS-41 [2], location area (LA) and registration area (RA) are defined for zone-based location updating. LA and RA are generally of fixed size for all MSs, and thus, GSM and IS-41 do not support dynamic location updates accommodating diverse call and mobility characteristics of MSs. In order to overcome this inefficiency, several dynamic location update schemes have been proposed, which include distance-based, movement-based, and timer-based schemes. In these dynamic location update schemes, MS updates its location whenever the distance, the number of crossed cells, or the elapsed time from the last location update exceeds a certain threshold value, which can be assigned dynamically for each MS. In particular, a timer-based scheme is simple to implement and does not need to record location information during location updates, and thus, it reduces mobile transceiver use and is very desirable for power saving [3].

In [3], a timer value to minimize the cost of paging and location update was analyzed for a Poisson incoming call arrival model in a timer-based location management scheme. In [4], a new location update scheme of combining zone-based and timer-based schemes was proposed and the optimum timer value was derived for voice call service. These timer-based schemes, however, only consider circuit-switched (CS) services and are not appropriate for PS services, which have bursty data traffic characteristics. In a bursty data traffic model, data packets are generated burstily during a data session and there is a short idle period between data packets. Between data sessions, there is a long idle period. Considering the bursty data traffic characteristics of PS services, a small timer threshold may be appropriate for a short idle period between data packets in a session and a large timer threshold may be appropriate for a long idle period between data sessions. Thus, two timer thresholds T_1 and T_2 are proposed here according to data traffic activity and the performance of the proposed timer-based scheme is compared with that of the conventional timer-based scheme [3] which has only one timer threshold.

2. Performance Analysis of the Proposed Scheme with Two Timer Thresholds

Figure 1 shows the timing diagram for the proposed timer-based scheme with data traffic modeling. The data traffic modeling was adopted from [5] and is based on the ETSI packet data model with an ON/OFF source model (i.e., packet train model). If an assumed application is IP phone for either video or audio only, the traffic model is very close to a conventional CS traffic model. However, this is a special case of PS traffic and most PS traffic models such as WWW are considered to follow bursty traffic source model of [5] based on ETSI ON/OFF source model. Thus, more general PS data traffic model, as shown in Fig. 1, is assumed through this letter.

In Fig. 1, there are two idle periods, i.e., inter-session

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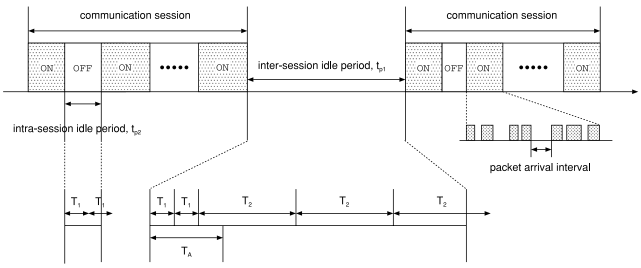


Fig. 1 Timing diagram for the proposed timer-based scheme and data traffic modeling.

idle period t_{p1} and intra-session idle period t_{p2}. It is assumed that the inter-session idle period t_{p1} has a Gamma distribution with mean $1/\lambda_{p1}$ and variance V_{p1} [5]. The Gamma distribution with mean $1/\lambda_{p1} = \eta/\lambda$ and variance $V_{p1} = \eta/\lambda^2$ has the following probability density function:

$$f_{t_{p1}}(t) = \frac{\lambda e^{-\lambda t}(\lambda t)^{n-1}}{\Gamma(\eta)}, \quad (1)$$

where $\Gamma(\eta) = \int_{z=0}^{\infty} z^{\eta-1}e^{-z}dz$ is the Gamma function, and η and λ are denoted the shape parameter and the scale parameter, respectively.

Contrary to the CS traffic model, a communication session in the PS data traffic model is characterized by ON/OFF periods, where a burst of data packets is generated during ON period and no packet is transmitted during OFF period [5]. The OFF period t_{p2} is assumed to follow a Pareto distribution with mean $1/\lambda_{p2}$ and infinite variance, which is widely used to model actual packet data traffic [5]. The Pareto distribution has the following density function:

$$f_{t_{p2}}(t) = \begin{cases} \left(\frac{\beta}{l}\right)\left(\frac{l}{t}\right)^{\beta+1} & \text{if } t \geq l \\ 0 & \text{if } t < l, \end{cases} \quad (2)$$

where β describes the heaviness of the tail of the distribution and l is the minimum value that the distribution can have. The expectation of the Pareto distribution is $E[t_{p2}] = \frac{\beta l}{\beta-1}$.

In this letter, we are concerned with downlink traffic because it is expected that the traffic pattern of next generation wireless services is highly asymmetrical and downlink traffic is over 98% of total traffic [7]. Thus, paging is needed at the beginning of each ON period. We note that no paging is needed at the packet intervals during the ON period because the idle period in the inter-packet arrival time during ON period is so small that the location of an MS is tracked at cell level implicitly by data packet transmission. If uplink traffic is also considered, the amount of location updates may be less than that of the analysis here, where only downlink traffic is considered because uplink traffic updates the location of MS implicitly. However, we note that the current approach can be justified because the main objective of this paper is to compare the performance of the proposed timer-based location management scheme with that of the conventional location management scheme and the traffic assumptions used in this paper affect the performance of the two schemes in the same way.

In the conventional timer-based scheme, only one timer threshold value T_0 is used. In the proposed scheme, MS initially updates its location periodically every T_1 units of time during idle period. Active timer T_A starts at the beginning of the idle period and is reset whenever there is a data packet exchange. We note that location update signaling transmission does not reset T_A. It is assumed that the inter-arrival time of packets during ON period is very short and there is no active timer expiration during ON period. If there is no data packet transmission during active timer T_A, the active timer expires and a new timer threshold T_2 is used for location update. If both T_1 and T_A expire at the same time, we assume that only the expiration of T_A is valid and timer T_2 is used for location update. We note that the next location update occurs $(T_2 - T_1)$ units of time later.

For notational convenience, the conventional scheme and the proposed scheme are denoted by Scheme I and Scheme II, respectively. For Scheme I, the numbers of location updates for time t in t_{p1} and t_{p2} are $N_{u_1}^I(t) = \lfloor \frac{t}{T_0} \rfloor$ and $N_{u_2}^I(t) = \lfloor \frac{t}{T_0} \rfloor$, where $\lfloor x \rfloor$ denotes the largest integer less than or equal to x. The numbers of location updates during t_{p1} and t_{p2} for Scheme I are obtained as:

$$\begin{aligned} N_{u_i}^I &= \int_0^\infty N_{u_i}^I(t) f_{t_{pi}}(t)dt \\ &= \int_0^\infty \left\lfloor \frac{t}{T_0} \right\rfloor f_{t_{pi}}(t)dt \quad (i = 1, 2). \end{aligned} \quad (3)$$

For Scheme II, the number of location updates for time t in t_{p1} is derived as:

$$N_{u_1}^{II}(t) = \begin{cases} \left\lfloor \frac{t}{T_1} \right\rfloor & \text{if } t < t^* \\ \left\lceil \frac{T_A}{T_1} \right\rceil - 1 + \left\lfloor \frac{t-t^*}{T_2} \right\rfloor & \text{if } t \geq t^*, \end{cases} \quad (4)$$

where $t^* = (\lceil \frac{T_A}{T_1} \rceil - 1)T_1$ and $\lceil x \rceil$ denotes the smallest integer larger than or equal to x. The number of location updates during t_{p1} for Scheme II is obtained as:

$$\begin{aligned} N_{u_1}^{II} &= \int_0^\infty N_{u_1}^{II}(t) f_{t_{p1}}(t)dt \\ &= \int_0^{t^*} N_{u_1}^{II}(t) f_{t_{p1}}(t)dt + \int_{t^*}^\infty N_{u_1}^{II}(t) f_{t_{p1}}(t)dt \\ &= \int_0^{t^*} \left\lfloor \frac{t}{T_1} \right\rfloor f_{t_{p1}}(t)dt + \int_{t^*}^\infty \left(\left\lceil \frac{T_A}{T_1} \right\rceil - 1 \right. \\ &\quad \left. + \left\lfloor \frac{t-t^*}{T_2} \right\rfloor \right) f_{t_{p1}}(t)dt. \end{aligned} \quad (5)$$

During t_{p2}, the number of location updates is divided into two cases (i.e., $l < t^*$ and $l \geq t^*$). For $l < t^*$, the number of location updates for time t in t_{p2} is derived as:

$$N_{u_2}^{II}(t) = \begin{cases} \left\lfloor \frac{t}{T_1} \right\rfloor & \text{if } l < t < t^* \\ \left\lceil \frac{T_A}{T_1} \right\rceil - 1 + \left\lfloor \frac{t-t^*}{T_2} \right\rfloor & \text{if } t \geq t^*. \end{cases} \quad (6)$$

The number of location updates during t_{p2} for Scheme II is obtained as:

$$\begin{aligned} N_{u_2}^{II} &= \int_l^\infty N_{u_2}^{II}(t) f_{t_{p2}}(t)dt \\ &= \int_l^{t^*} N_{u_2}^{II}(t) f_{t_{p2}}(t)dt + \int_{t^*}^\infty N_{u_2}^{II}(t) f_{t_{p2}}(t)dt \\ &= \int_l^{t^*} \left\lfloor \frac{t}{T_1} \right\rfloor f_{t_{p2}}(t)dt \\ &\quad + \int_{t^*}^\infty \left(\left\lceil \frac{T_A}{T_1} \right\rceil - 1 \left\lfloor \frac{t-t^*}{T_2} \right\rfloor \right) f_{t_{p2}}(t)dt. \end{aligned} \tag{7}$$

For $l \geq t^*$, the number of location updates for time t in t_{p2} is derived as:

$$N_{u_2}^{II}(t) = \left\lceil \frac{T_A}{T_1} \right\rceil - 1 + \left\lfloor \frac{t-t^*}{T_2} \right\rfloor. \tag{8}$$

The number of location updates during t_{p2} for Scheme II is obtained as:

$$\begin{aligned} N_{u_2}^{II} &= \int_l^\infty N_{u_2}^{II}(t) f_{t_{p2}}(t)dt \\ &= \int_l^\infty \left(\left\lceil \frac{T_A}{T_1} \right\rceil - 1 + \left\lfloor \frac{t-t^*}{T_2} \right\rfloor \right) f_{t_{p2}}(t)dt. \end{aligned} \tag{9}$$

Paging is needed at the beginning of each ON period and the number of paged cells depends on the timer threshold value used when the ON period begins. In this letter, we use a selective paging scheme [6] where the network pages the called MS starting from the cell where the MS last updated and outwards, in a shortest distance first order until the called MS is found. Although the exact number of cells to be paged depends on the time elapsed since the last location update, we simply obtain the average number of cells paged during timer threshold $T_i (i = 0, 1, 2)$ since the objective of this letter is to compare the performance of the proposed scheme with that of the conventional scheme.

In a hexagonal cell structure, the number of cells paged during timer threshold $T_i (i = 0, 1, 2)$ is derived as:

$$\begin{aligned} E[N_c] &= \sum_{k=0}^\infty N_c(k) Pr(N_{max} = k) \\ &= \sum_{k=0}^\infty (3k^2 + 3k + 1) \frac{(\lambda_m T_i)^k e^{-\lambda_m T_i}}{k!} \\ &= 1 + 6\lambda_m T_i + 3(\lambda_m T_i)^2, \end{aligned} \tag{10}$$

where N_{max} is the maximum number of rings of cells crossed by the MS during T_i and λ_m is the cell crossing rate of MS. The number of cells from the center cell to the $k-th$ ring, $N_c(k)$, is derived as [6]

$$N_c(k) = 1 + \sum_{i=1}^k 6i = 3k^2 + 3k + 1. \tag{11}$$

Then the number of cells paged at the end of inter-session and inter-session idle periods in the Scheme I is

$$N_{v_1}^I = N_{v_2}^I = 1 + 6\lambda_m T_0 + 3(\lambda_m T_0)^2. \tag{12}$$

On the contrary, the number of cells paged in Scheme II depends on the timer value used, (i.e., T_1 or T_2) and is obtained as:

$$\begin{aligned} N_{v_i}^{II} &= Pr(t_{p_i} < T_A) N_{v_i}^{II}|_{t_{p_i} < T_A} \\ &\quad + Pr(t_{p_i} \geq T_A) N_{v_i}^{II}|_{t_{p_i} \geq T_A} \quad (i = 1, 2), \end{aligned} \tag{13}$$

where

$$N_{v_i}^{II}|_{t_{p_i} < T_A} = 1 + 6\lambda_m T_1 + 3(\lambda_m T_1)^2 (i = 1, 2), \tag{14}$$

$$N_{v_i}^{II}|_{t_{p_i} \geq T_A} = 1 + 6\lambda_m T_2 + 3(\lambda_m T_2)^2 (i = 1, 2), \tag{15}$$

$$Pr(t_{p_1} < T_A) = \int_0^{T_A} \frac{\lambda e^{-\lambda t} (\lambda t)^{n-1}}{\Gamma(\eta)} dt, \tag{16}$$

$$Pr(t_{p_2} < T_A) = \int_l^{T_A} \left(\frac{\beta}{l}\right) \left(\frac{l}{t}\right)^{\beta+1} dt. \tag{17}$$

3. Numerical Examples

For numerical examples, the number of OFF periods in a communication session is assumed to follow a geometric distribution with mean $\alpha/(1-\alpha)$ $(0 \leq \alpha < 1)$ [5] based on the ETSI data traffic model. It is also assumed that the cost for performing a location update is U and the cost for paging at one cell is V. Location update cost and paging cost of Scheme $i (i = I, II)$ during a cycle of consecutive communication session and inter-session idle period are

$$C_U^i = U \left(N_{u_1}^i + \frac{\alpha}{1-\alpha} N_{u_2}^i \right), \tag{18}$$

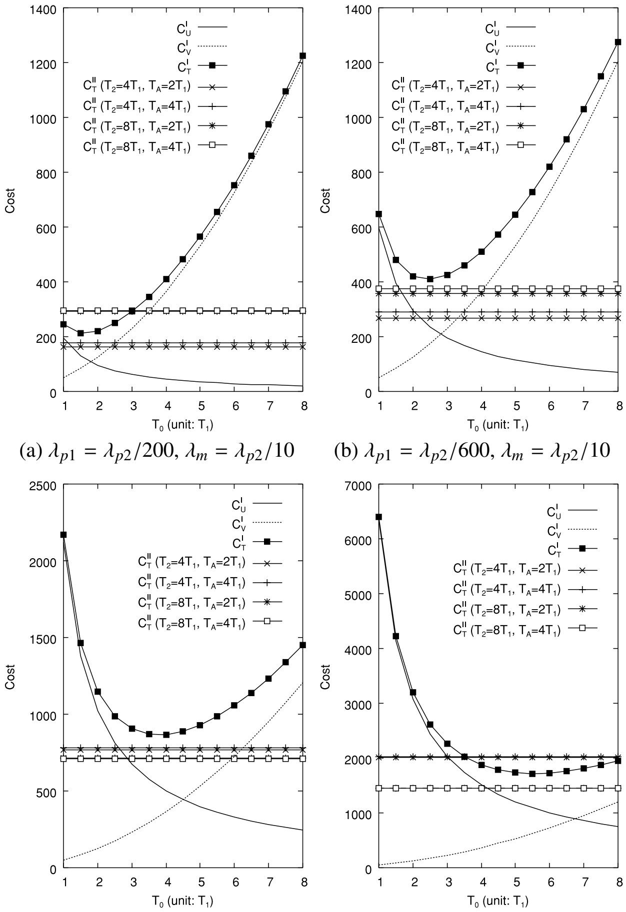
$$C_V^i = V \left(N_{v_1}^i + \frac{\alpha}{1-\alpha} N_{v_2}^i \right). \tag{19}$$

From (18) and (19), the total cost for location update and paging of Scheme $i (i = I, II)$ is

$$C_T^i = C_U^i + C_V^i. \tag{20}$$

Figure 2 shows the cost of the Schemes I and II for varying the value of T_0 with a unit of T_1 for various sets of $\lambda_{p1}, \lambda_m, T_2$, and T_A for $T_1 = 1/\lambda_m, \eta = 1, 1/\lambda_{p2} = 10.5$ (sec), $\beta = 1.2$, $l = \frac{\beta-1}{\beta\lambda_{p2}}$, $\alpha = 0.8$, $U = 10$, and $V = 1$, where some of them are referred from [5]. Since the location update cost and paging cost of Scheme II do not depend on the value of T_0, it is constant for a given set of λ_{p1}, λ_m, T_2, and T_A. Thus, the location update cost and paging cost of Scheme II are not displayed but only the total cost is displayed. The effect of inter-session idle period and mobility is analyzed by varying the values of λ_{p1} and λ_m, respectively. In Scheme I, location update cost is dominant for small values of T_0 in the total cost. On the contrary, paging cost is dominant for large values of T_0 in the total cost of Scheme I. Thus, there exists an optimal value of T_0 from the aspect of total cost of Scheme I.

For low mobility MS ($\lambda_m = \lambda_{p2}/10$, Figs. 2(a) and 2(b)), paging cost is dominant in total cost and the optimal value of T_0 is small in Scheme I. Since the paging cost is



(a) $\lambda_{p1} = \lambda_{p2}/200$, $\lambda_m = \lambda_{p2}/10$ (b) $\lambda_{p1} = \lambda_{p2}/600$, $\lambda_m = \lambda_{p2}/10$

(c) $\lambda_{p1} = \lambda_{p2}/200$, $\lambda_m = \lambda_{p2}$ (d) $\lambda_{p1} = \lambda_{p2}/600$, $\lambda_m = \lambda_{p2}$

Fig. 2 Performance of the proposed scheme.

dominant for low mobility MS, the total cost of Scheme II for $T_2 = 8T_1$ is larger than that for $T_2 = 4T_1$ due to more pagings. Although the cost of Scheme II for $T_A = 4T_1$ is higher than that for $T_A = 2T_1$ for a fixed value of T_2 due to more location updates, the difference is small and this shows that the total cost of Scheme II is insensitive to the change of T_A values. The total cost of Scheme II is always less than that of Scheme I in Fig. 2(b) and this demonstrates that for low mobility MS with large inter-session idle period, the proposed scheme generally performs better. For low mobility MS with small inter-session idle period, the performance of the proposed scheme with high values of T_2 is worse than that of the conventional for low values of T_0 due to more paging cost. For high mobility MS ($\lambda_m = \lambda_{p2}$, Figs. 2(c) and 2(d)), location update cost is dominant in total cost for Scheme I except for large values of T_0 and small inter-session idle period, and thus, the optimal value of T_0 is large in Scheme I, compared to that in Scheme II. Since the location update cost is dominant, the total cost of Scheme II for $T_2 = 4T_1$ is larger than that for $T_2 = 8T_1$ due to more location updates. The difference of the total costs of Scheme II for different values of T_A is negligible and this also shows that the total cost of Scheme II is insensitive to the change of T_A values. The total cost of Scheme II is always less than that of Scheme I in Fig. 2(c) and this shows that for high mobility MS with small inter-session idle period, the proposed scheme generally performs better. For high mobility MS with high inter-session idle period, the conventional scheme with high values of T_0 performs better than the proposed scheme with small values of T_2 due to more location update cost.

4. Conclusions and Further Studies

In this letter, an improved timer-based location management scheme for packet-switched (PS) mobile communication systems was proposed. Then, the location update and paging costs of the proposed scheme are analyzed and compared with those of the conventional scheme. From the results, it is concluded that the proposed timer-based scheme with two timer thresholds performs better than the conventional scheme in terms of total cost by accommodating the bursty traffic characteristics of PS services with an appropriate selection of timer thresholds.

As further studies, we are applying the concept of using multiple timer threshold values in timer-based location management to movement-based location management for efficient movement-based location management scheme for PS mobile communication systems. Because the extension of current studies to movement-based location management is not straightforward, the relationship between cell residence time and the number of movements should be analyzed appropriately.

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