Optimal Design of Mobile Controlled Location Update Subsystem

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Abstract

Consider connection-oriented wireless cellular networks. To establish a circuit or virtual circuit in such a network, a paging message is broadcast over a region at which the destined mobile station is presumed to reside, (identified as a paging area). For an effective paging mechanism, it is desirable to provide the location information of mobile stations to the network. In this paper, we consider a *mobile controlled location update* scheme under which each mobile station periodically reports its current location information to the network by using an inherent timer (without measuring the power of signals transmitted from base stations). Based on the latest information about a mobile station's location, a paging area is selected to page the mobile station. Note that under this scheme, a mobile station may not yet have reported its location change while sojourning out of the current paging area. In such situation, the mobile station can not receive a paging message destined to it. Frequent location updates can reduce the paging failure rate incurred by mobile stations' sojourning out of the paging area. However, larger bandwidth is needed for location update as the location update rate is increased. On the other hand, as the size of the paging area is increased, the paging failure rate is decreased, while larger bandwidth is required for paging. Thus, we first present a model for mobility, paging and location update processes, and secondly investigate the effect of network parameters on the paging failure rate and the amount of bandwidth used for paging and location update. Finally, we formulate problems to find proper values for the location update rate and paging area size under the constraints on the bandwidth usage levels for location update and paging.

1 Introduction

We consider connection-oriented wireless cellular networks, including second generation wireless cellular networks, (e.g., IS-54 (Electronic Industry Association Interim Standard 54), IS-95 and GSM (European Global System for Mobile Communications)) and wireless ATM networks [5] [7] [8]. To establish a circuit or virtual circuit in such a network, a paging message is broadcast over a region at which the destined mobile station is presumed to reside, (identified as a paging area). For an effective paging mechanism, i.e., a high success rate of paging process and a low bandwidth usage level for paging, it is desirable to provide the location information of mobile stations to the network. For this purpose, we consider a mobile controlled location update scheme under which each mobile station periodically reports its current location information to the network by using an inherent timer (without measuring the power of signals transmitted from base stations or radio ports). Based on the latest information about a mobile station's location, a paging area is selected to page the mobile station. Note that under this scheme, a mobile station may not have yet reported its location change while sojourning out of the current paging area. Then, a paging message destined to the mobile station can not reach to the mobile, and the network declares the corresponding paging process has failed to the calling party. To limit such paging failure rate (incurred by mobile station's sojourning out of the paging area) under an admissible level, we may control the location update rate and the size of paging area. Frequent location updates (equivalently, a short location update interval) reduces such paging failure rate. However, on the reverse channel from the mobile station to the network, larger bandwidth is needed for location update as the location update rate is increased. On the other hand, the paging failure rate is decreased as the size of paging area is increased. However, larger bandwidth on the forward channel is required for the delivery of paging messages from the base station to mobile stations. Thus, the location update rate and the paging area size must be selected in consideration of both paging failure rate and bandwidth usage levels for location update and paging. In this paper, we present a model for paging and location update processes and investigate the effect of network parameters (e.g., location update rate, paging area size, mobile station's speed, call-related processes) on the paging failure rate and bandwidth usage levels. Finally, we formulate problems to find proper values of the location update rate and paging area size under the constraints on the bandwidth usage levels for paging and location update. In Section 2, we describe a model for location update and call-related processes. In Section 3, we present an approximation method for calculating the paging failure rate. Section 4 is devoted to numerical examples illustrating the effect of network parameters on the paging failure rate and bandwidth usage levels. Also, optimization problems to find proper values of the location update rate and paging area size are presented.

2 Location Update and Call-related Processes

The region served by the connection-oriented wireless cellular network is geographically patitioned into location areas (LA), and a LA is also divided into cells. A base station (BS) is located in each cell, and all the BS's in a LA is controlled by a single mobile switching center (MSC) [1]. (Thus, a MSC is allocated to each LA.) A mobile station (MS) periodically reports its location information to the network. In the location update process, the location update time is computed by a timer equipped in the MS. Note that any assistance of the network or power measurement of signals transmitted from a BS is not involved in this process. A home location area (home MSC) is assigned to each MS. At the home MSC of a MS, the location area at which the latest location report of the MS takes place is registered.

For a call terminating at a MS, the paging area is selected to be the location area which is currently registered in the home MSC of the MS. Then, a paging message is broadcast over the paging area. We assume that at most a single connection is allowed to a MS at any time. Thus, the MS will not respond to the paging if it is already call-active. Note that the MS may sojourn out of the paging area while it is call-inactive. Then, the paging message can not reach the MS. For a call originating at a MS, the call request will succeed if the MS is in call-inactive state while residing at the current paging area for the MS.

3 Analysis for Paging Failure Rate

A block is the basic regional unit. It is a $d \times d$ square and represented as coordinates (x, y), where x and y are integers. A cell is modeled as a square of $n_B \times n_B$ blocks and a LA is also modeled as a square of $n_C \times n_C$ cells. Let $Z_n = (X_n, Y_n)$ denote the block a MS sojourns in $[n\tau, (n+1)\tau)$ for $n = 0, 1, \cdots$, where τ is the minimum time a MS continuously stays in a block. (We assume that a MS moves from a block to a new block at time $(n\tau)-$ instantly, if it does, for $n = 1, 2, \cdots$.) The sequences $\{X_n,\ n = 0, 1, \cdots\}$ and $\{Y_n,\ n = 0, 1, \cdots\}$ are modeled as independent random walks such that

$$\begin{aligned} X_{n+1} &= X_n + U_{n+1} \\ Y_{n+1} &= Y_n + V_{n+1}, \end{aligned} \tag{1}$$

where $\{U_n,\ n = 1, 2, \cdots\}$ and $\{V_n,\ n = 1, 2, \cdots\}$ are i.i.d. sequences such that

$$\begin{aligned} P(U_n = 1) &= \alpha^+ \\ P(U_n = -1) &= \alpha^- \\ P(U_n = 0) &= 1 - \alpha^+ - \alpha^- \\ P(V_n = 1) &= \beta^+ \\ P(V_n = -1) &= \beta^- \\ P(V_n = 0) &= 1 - \beta^+ - \beta^-. \end{aligned} \tag{2}$$

Let v^* and v denote the maximum and average speed of a MS, respectively. Then, the average speed is calculated to be

$$v = v^* \cdot [1 - (1 - \alpha^+ - \alpha^-)(1 - \beta^+ - \beta^-)]. \tag{3}$$

A MS periodically reports its location information. Let $M \cdot \tau$ be the location update time, i.e., the MS reports its location information at times $\{M \cdot k \cdot \tau : k = 0, 1, \cdots\}$. Let A_k denote the location area at which the MS resides at time $M \cdot k \cdot \tau$. Since a location area is represented as a set of blocks,

$$A_k \in \{S_{i,j} : i, j \in \mathrm{Z}\} \tag{4}$$

for $k = 0, 1, \cdots$, where

$$\begin{aligned} S_{i,j} \;=\; & \{(x, y) : x = -\lceil \frac{n_B n_C}{2} \rceil + i n_B n_C, \cdots, \\ & \lceil \frac{n_B n_C}{2} \rceil + i n_B n_C,\ y = -\lceil \frac{n_B n_C}{2} \rceil + j n_B n_C, \\ & \cdots, \lceil \frac{n_B n_C}{2} \rceil + j n_B n_C\} \} \end{aligned}$$

for n_B and n_C of odd integers. (Z is the set of integers.) Set

$$H_k = \sum_{n=Mk}^{(M+1)k-1} \tau \cdot I_{\{Z_n \notin A_k\}} \tag{5}$$

for $k = 0, 1, \cdots$. Then, H_k is the time the MS sojourns out of the location area registered at time $M \cdot k \cdot \tau$ during the kth location update inteval $[M \cdot k \cdot \tau, (M+1) \cdot k \cdot \tau)$. Note that the sequence $\{Z_n,\ n = 0, 1, \cdots\}$ is stationary. Moreover, the random variable H_k has a value in the finite set $\{0, \cdots, (M-1)\tau\}$ for all $k = 0, 1, \cdots$ and the sequence $\{H_k,\ k = 0, 1, \cdots\}$ is aperiodic. Thus, the process $\{H_k,\ k = 0, 1, \cdots\}$ is ergodic, and there exists the limit [4]

$$\lim_{l \to \infty} \frac{1}{l+1} \sum_{k=0}^{l} H_k.$$

Set

$$p_{out} = \lim_{l \to \infty} \frac{1}{M(l+1)\tau} \sum_{k=0}^{l} H_k. \tag{6}$$

Then, p_{out} is the probability that the MS is out of the most recently registered location area at steady-state.

Let λ_{MTC} and λ_{MOC} denote the request rates of calls terminating and originating at the MS, respectively. Let $\{C_i,\ i = 1, 2, \cdots\}$ denote the sequence of call request times at the MS. Assume the sequence $\{C_i,\ i = 1, 2, \cdots\}$ is a Bernoulli process with parameter λ, where

$$\lambda = (\lambda_{MTC} + \lambda_{MOC}) \cdot \tau. \tag{7}$$

Thus, a call request occurs at an integral multiple of τ. Let $\{S_i, i = 1, 2, \cdots\}$ denote the sequence of call duration times at the MS. Assume the sequence $\{S_i,\ i = 1, 2, \cdots\}$ is an i.i.d. sequence and S_i has a geometric distribution with parameter $1 - \mu$. Note that the mean call duration time

$$E(S_i) = \frac{1}{\mu} \cdot \tau. \tag{8}$$

Let N_n be the number of calls associated with the MS at time $n\tau$. Since at most a single call is allowed for a MS at any time, $N_n \in \{0, 1\}$ for $n = 0, 1, \cdots$. Assume that for all $i = 1, 2, \cdots$,

$$P(Z_{\frac{C_i}{\tau}} \notin A_{\lceil \frac{C_i}{M\tau} \rceil}) = p_{out}. \qquad (9)$$

Then, the process $\{N_n, n = 0, 1, \cdots\}$ is a Markov chain with transition matrix [2]

$$\mathbf{P} = \begin{bmatrix} 1 - \lambda(1 - p_{out}) & \lambda(1 - p_{out}) \\ \mu & 1 - \mu \end{bmatrix}. \qquad (10)$$

Thus, we have [6]

$$\begin{aligned} \lim_{n\to\infty} P(N_n = 0) &= \frac{\mu}{\lambda(1 - p_{out}) + \mu} \\ \lim_{n\to\infty} P(N_n = 1) &= \frac{\lambda(1 - p_{out})}{\lambda(1 - p_{out}) + \mu}. \end{aligned} \qquad (11)$$

Let p_{fail} denote the paging failure probability. Since a call request to a MS is blocked if the MS is already call-active or sojouns out of the registered location area,

$$p_{fail} = \lim_{i\to\infty} P(N_{\frac{C_i}{\tau}} = 1 \text{ or } Z_{\frac{C_i}{\tau}} \notin A_{\lceil \frac{C_i}{M\tau} \rceil}). \qquad (12)$$

From Equations (6) and (12), we have

$$p_{fail} = p_{out} + (1 - p_{out}) \cdot \frac{\lambda(1 - p_{out})}{\lambda(1 - p_{out}) + \mu}. \qquad (13)$$

Let p^*_{fail} denote the probability of paging failure incurred by a MS's sojourning out of the registered location area. Then,

$$p^*_{fail} = p_{fail} - \frac{\lambda}{\lambda + \mu}. \qquad (14)$$

Let δ denote the user density, i.e., the average number of users per cell. Then, the paging rate per BS, denoted by γ_{PG} is expressed as

$$\gamma_{PG} = \lambda_{MTC} \cdot \delta \cdot n_C^2. \qquad (15)$$

Let γ_{LU} denote the location update rate per BS. Since the location update time is equal to $M \cdot \tau$, we have

$$\gamma_{LU} = \frac{1}{M \cdot \tau} \cdot \delta. \qquad (16)$$

4 Numerical Examples

In this section, we demonstrate the impact of network parameters (e.g., LA size, MS's speed, location update time, call duration time, call request rate) on the paging failure rate and the bandwidth used for paging and location update. In Table 1, the parameter values used in the following examples are summarized [3]. Figures 1 and 2 show the paging failure rate with respect to the location area size and the location update time, respectively. In these figures, we observe that as the location area size is increased, the paging failure rate is decreased. On the other hand, the paging failure rate is increased as the location update time is increased. This is explained by noting that the probability that a MS sojourns out of the most recently registered location area is increased, as the location area size is decreased or as the location update time is increased.

In Figures 3 and 4, we demonstrate the effect of the location area size on the paging rate and the effect of the location update time on the location update rate, respectively. In these figures, we confirm that the paging rate is increased in proportion to the increment of location area size, while the location update rate and the location update time have a reciprocal relationship.

parameter	
block size	10×10 m^2
cell size	35×35 blocks
location area size	9×9 cells
location update time	1000 sec
average MS's speed	5 m/sec
minimum block sojourn time	1 sec
mobile terminating call rate	0.4 /hour
mobile originating call rate	0.6 /hour
mean call duration time	90 sec

Table 1: Network parameter values

The paging failure probability must be limited. On the other hand, reduced bandwidth usage levels for paging and location update are preferred. Thus, we may formulate optimization problems as follows:

Given	location update time
minimize	paging failure probability
w.r.t.	location area size
subject to	bandwidth usage level for paging $\leq \eta_{PG}$

Given	location area size
minimize	paging failure probability
w.r.t.	location update time
subject to	bandwidth usage level for location update $\leq \eta_{LU}$

where η_{PG} and η_{LU} are prescribed thresholds. From Figures 1-4, we can obtain optimal values of the location area size and the location update time for the problems given above.

5 Conclusions

In connection-oriented wireless cellular networks, we investigated a mobile controlled location update scheme under which a mobile station periodically reports its location information by using an inherent timer. For this location update scheme, an approximation method was presented to obtain the paging failure rate. Using the approximation method derived here, we presented numerical examples which illustrate the effect of the location area size and the location update rate on the paging failure rate and the bandwidth usage levels for paging and location update. From the numerical examples, we observed the following.

(1) Given location update time, the paging failure rate is decreased as the location area size is increased. However, the bandwidth usage level for paging is increased.

(2) Given location area size, the paging failure rate is

increased and the bandwidth usage level for location update is decreased as the location update time is increased. Based on these observations, we formulated optimization problems to find proper values of the location area size and the location update rate in consideration of the paging failure rate and the bandwidth usage levels for paging and location update.

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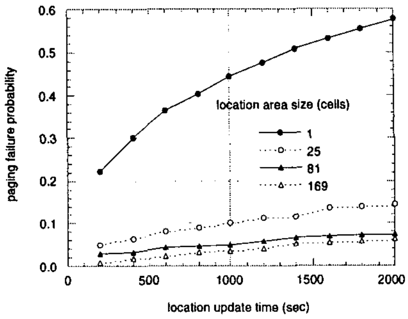

Figure 2: Paging failure probability with resepct to location area size

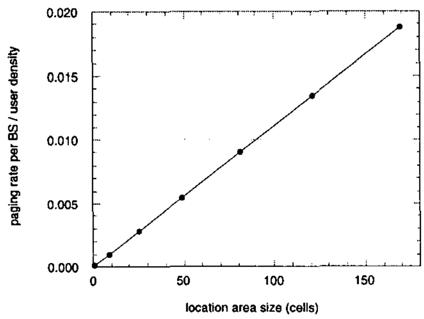

Figure 3: Paging rate / user density with respect to location area size

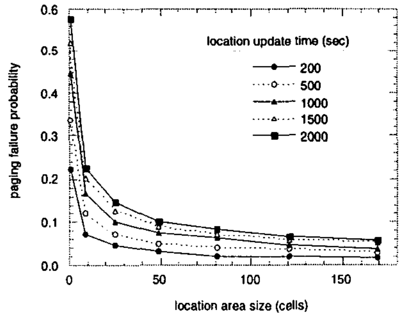

Figure 1: Paging failure probability with respect to location update time

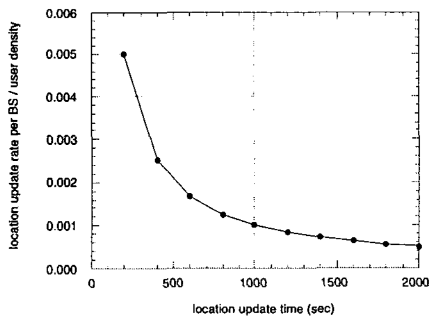

Figure 4: Location update rate / user density with respect to location update time