An Efficient Paging Strategy Based on Paging Agents of Base Stations in Cellular Mobile Networks

Bongsue Suh, Jin Seek Choi, and Song-in Choi

ABSTRACT— We propose a new paging strategy to reduce paging cost by adding paging agents at base stations. When a mobile-terminated call occurs, the base stations look up the paging agents to determine if terminal paging is actually to be made. An analytical model based on a Markov chain is used to evaluate the performance of the proposed strategy. The numerical results show that the proposed strategy significantly reduces the paging cost compared with the simultaneous paging strategy.

I. INTRODUCTION

In mobile communication systems, the exchange of information with mobile terminals should be facilitated regardless of their locations [1], [2]. To meet this requirement, the network should have well-defined functions to manage the location information and to page the target mobiles in an efficient way.

When a mobile switching center (MSC) receives a mobile-terminated call, it sends a paging request message to its base stations. All base stations of the MSC then broadcast the paging signal through a wireless paging channel. With wireless networks evolving into micro-/pico-cellular environments, however, this simultaneous paging increases the unnecessary consumption of the paging channels as the cell size of base stations becomes smaller and the number of cells under an MSC increases.

Several strategies have been proposed to reduce the paging cost. Some investigations based their paging strategies on the mobile terminal's characteristics, such as user location probability and movement-related information [3], [4]. A recent proposal for another location update strategy was based on the anchor cell for reducing the paging cost [5]. The above paging strategies, however, were based on the MSC's decision to execute the actual terminal paging.

In this Letter, we add a mobile registering function, called a paging agent, to base stations for efficient paging. As the base stations become intelligent in the next generation cellular systems, the addition of the proposed function will be feasible. Our numerical analysis involves the cost caused by managing the paging agents with consideration given to the terminal paging cost itself.

II. NEW PAGING STRATEGY

For efficient terminal paging, we propose three functions of the paging agents at base stations: mobile registration, target mobile lookup, and mobile deregistration. Compared with the simultaneous paging strategy, the difference of the proposed strategy is that each base station has a paging agent processor to manage the list of the mobiles that have visited this base station. The functions of paging agents are as follows.

1. Mobile Registration Procedure

When a mobile moves out of the coverage area of a base station and enters the new coverage of another base station, it

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sends a short message to the new base station through the access channel. The base station adds the mobile's identification number (MID) to the list of its paging agent. Note that the paging agent of the previous base station does not take any action on the mobile's departure. Deregistering of the mobile is made when the base station confirms that the corresponding mobile is no longer active under its coverage area.

2. Target Mobile Lookup Procedure

When a mobile-terminated call occurs, it is forwarded to the target mobile's MSC by the location management. The MSC sends a paging request message to all of its base stations. Each base station searches for the target MID at its paging agent. If the target MID is found, the base station sends a paging signal through the wireless paging channel. Otherwise, the base station takes no further action.

3. Mobile Deregistration Procedure

The base station deregisters a mobile from its paging agent when it confirms that the mobile is not reachable under its coverage area. This occurs in the following situations:

1) After the base station finds a target MID at its paging agent and transmits the paging signal, it does not receive a response signal from the target mobile within a given time. In this case, the base station confirms that the target mobile is not reachable and deletes the corresponding MID from its paging agent.
2) When the mobile enters the coverage area of the new MSC, the location management performs a location update at the location registers (for example, the home location register or visitor location register). In this case, the previous managing MSC sends a mobile deregistering request message to all of its base stations. The base stations that store the corresponding MID delete it from the paging agents.

The proposed strategy can be used for any paging system based on base stations, regardless of the location management strategy. Using paging agents should reduce the paging cost, since terminal paging is made over the coverage area of base stations that store the target MID. The proposed strategy, however, gives rise to an additional cost for managing the paging agents; this will be analyzed in the following section.

III. PERFORMANCE EVALUATION

In this section, by considering the various cost factors involved in using the proposed strategy, we evaluate how much the paging cost can be reduced. We assume that the coverage area of an MSC is divided into $N(R)$ hexagonal cells of the same size so that each cell has six neighboring cells (Fig. 1). We define the radius R as the distance in cells from the center to the outer border of the whole coverage area of an MSC. For simplicity, we assume that mobiles move in the coverage area of an MSC only. Then, $c_p(i)$, the paging cost of the proposed strategy to locate a mobile that is registered at i paging agents, is given by

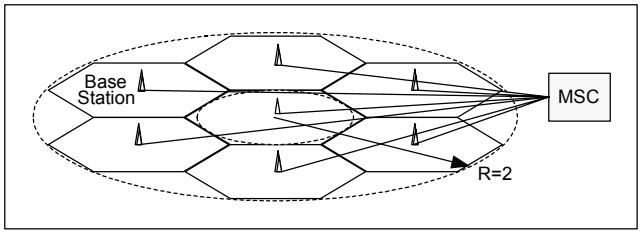

Fig. 1. Cell structure.

$$c_p(i) = C_L \times N(R) + C_T \times i + C_D \times (i-1). \quad (1)$$

In (1), $C_L \times N(R)$ is the target mobile lookup cost to determine if the actual terminal paging is to be made; $C_T \times i$ is the terminal paging cost at i base stations that have the target MID at the paging agents; and $C_D \times (i-1)$ is the mobile deregistering cost at $(i-1)$ base stations that do not receive the response signal from the mobile after the actual terminal paging. C_L, C_T and C_D are the unit costs for target mobile lookup, terminal paging, and mobile deregistering at a paging agent, respectively. Since mobile registering is made at only one base station for every inter-cell movement, we ignore the mobile registering cost.

To evaluate the paging cost of the proposed strategy, we assume that the inter-arrival time of the mobile-terminated call is exponentially distributed with parameter λ_c. We also assume that the mobile's residence time in a cell is exponentially distributed with parameter λ_m. We then define a continuous-time Markov chain, where the state i is the number of base stations that store a specific MID at paging agents.

We assume that the transition rate from state i to state i+1 is fixed to λ_m, while it may decrease as i increases in the practical situation. This assumption underestimates our paging cost. We then have the transition rate matrix **Q** from the Markov model, whose non-zero elements are as follows:

$$\begin{aligned} &q_{1,1} = -\lambda_m \\ &q_{N(R),N(R)} = -\lambda_c \\ &q_{i,1} = \lambda_c, i = 2,3,\ldots,N(R) \\ &q_{i,i} = -(\lambda_m + \lambda_c), i = 2,3,\ldots,N(R)-1 \\ &q_{i,i+1} = \lambda_m, i = 2,3,\ldots,N(R)-1. \end{aligned} \quad (2)$$

We can easily evaluate π_i, the steady-state probability from the following two equations [6]:

$$\pi \mathbf{Q} = \mathbf{0}, \tag{3}$$

$$\sum_i \pi_i = 1. \tag{4}$$

Then we have

$$[\pi_1, \pi_2, \pi_3, \ldots, \pi_{N(R)}] = \mathbf{Q}'^{-1}[1,0,0,\ldots,0], \tag{5}$$

where $\mathbf{Q}'$ is the matrix that is derived from $\mathbf{Q}$ by adding 1 to each element of its first column.

For a system having radius R, we have the average paging costs, $\overline{C}_p(R)$ for the proposed strategy and $\overline{C}_s(R)$ for the simultaneous paging strategy as follows:

$$\overline{C}_p(R) = \sum_{i=1}^{N(R)} \pi_i c_p(i) \tag{6}$$

$$\overline{C}_s(R) = C_T N(R). \tag{7}$$

We then have the average cost ratio (ACR), the ratio of the average paging costs of the proposed strategy to that of the simultaneous strategy, given by

$$ACR(R) = \frac{\overline{C}_p(R)}{\overline{C}_s(R)} = \frac{1}{N(R)} \sum_{i=1}^{N(R)} \pi_i \left[\frac{C_L}{C_T} N(R) + i + \frac{C_D}{C_T}(i-1) \right]. \tag{8}$$

We assume C_L=C_D to simplify the numerical results. Figure 2 shows the ACR versus C_L/C_T when λ_c and λ_m are fixed to 0.1. We note that the ACR increases as C_L/C_T increases. The increment is caused by the increasing cost for managing the paging agents relative to the terminal paging cost. We see that the performance of the proposed strategy is better than that of the simultaneous paging strategy when C_L is less than 0.6 C_T when R=2. In real systems, C_L is expected to be much less than C_T since the paging procedure is one of the bottlenecks in call processing.

Figure 3 shows the ACR versus the call-to-movement ratio (CMR), which is λ_c / λ_m, when C_L/C_T and C_D/C_T are fixed to 0.2. From this figure, we note that the ACR can be significantly reduced for the mobiles that have a higher call rate and lower movement rate. This can be explained from the fact that a mobile with a high call rate refreshes the paging agents more frequently, and this reduces the number of base stations making the actual terminal paging.

Our figures reveal that the paging cost of the proposed strategy decreases as R increases, while that of the simultaneous paging strategy is fixed. We can explain this from the fact that the portion of unnecessary executions of terminal paging in the proposed strategy decreases as the number of base stations of an MSC increases. This means that the proposed strategy becomes more advantageous as the wireless network evolves into micro-/pico-cellular environments.

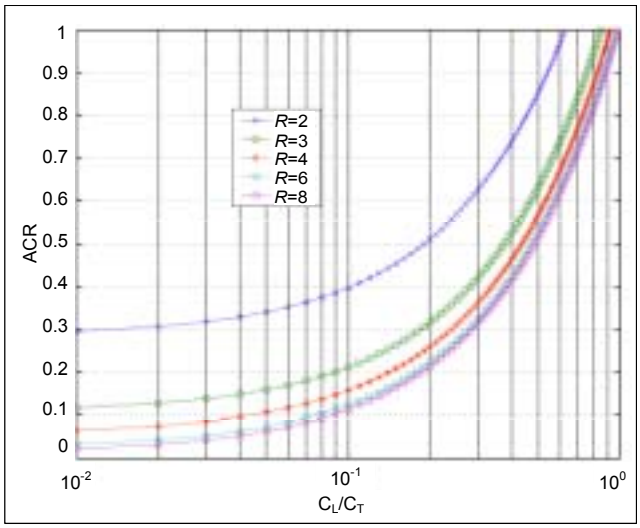

Fig. 2. ACR versus C_L/C_T ($\lambda_m = \lambda_c = 0.1$).

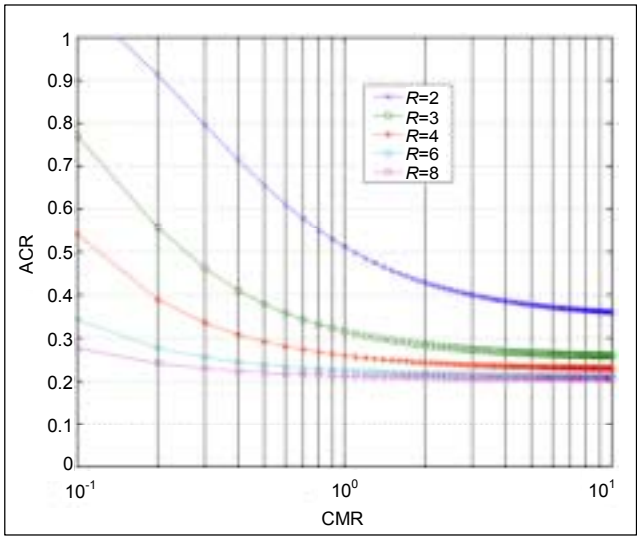

Fig. 3. ACR versus CMR ($C_L/C_T = C_D/C_T = 0.2$).

IV. CONCLUSION

This Letter proposed a new paging strategy for cellular mobile networks based on the paging agents of the base stations. According to the proposed strategy, the actual terminal paging is made at the base stations that have the target mobile's identification number at their paging agents, rather than at all the base stations of an MSC. The paging cost significantly decreases as the mobile's call-to-mobility ratio and the number of cells under an MSC increase.

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