An Efficient Two-Step Paging Strategy Using Base Station Paging Agents in Mobile Communication Networks

Jang Hyun Baek and Byung-Han Ryu

ABSTRACT— An effective paging strategy is essential for improving the utility of radio channels. This paper proposes a two-step paging strategy which involves using base station paging agents to page a single cell at each paging. An analytical model is used to evaluate the performance of the proposed strategy. The proposed strategy is compared with the traditional simultaneous paging strategy and a recent proposal using the base station paging agents. The numerical results showed that the proposed strategy proficiently reduces paging cost on radio channels compared with other paging strategies.

Keywords—Paging, paging agent, two-step paging, base station paging agent.

I. Introduction

An effective paging strategy is essential for improving the utility of radio channels. In current mobile communication networks, when a mobile-terminated call occurs, the network locates the mobile terminal by paging all cells within the location area (LA) simultaneously [1].

Many strategies have been proposed to reduce paging cost [2]-[7]. Ross [2] suggested a selective paging strategy in which the network first partitions the residing area of the called mobile terminal into several sub-areas and then polls each sub-area one after another until the mobile is found. Tung [3] proposed a sectional paging strategy to improve the performance of ring-structured selective paging, and Yang Xiao [4] proposed a parallel shuffled paging strategy to reduce the delay of the selective paging. In [5], a two-step selective paging was considered. In [6], a dynamic, anchor-cell assisted paging, a special kind of two-step selective paging, was proposed. However, their paging delays are still too long to meet the quality of service requirements.

Suh [7] recently proposed a new paging strategy based on the base station paging agents (BSPAs) that reduces the paging cost on radio channels when compared with the current simultaneous paging strategy. Applying this strategy makes it possible to page only some cells that the mobile terminal passes in the location area. However, the network may page all cells in the location area.

Inspired by the paging agents in [7], in this study we propose an efficient two-step paging strategy using BSPAs to page only one cell at each paging. When a mobile-terminated call occurs, each base station (BS) of the target location area looks up its paging agent in order to determine if the mobile's identification number (MID) is in the list of each paging agent. If the target MID is found, the BS informs the central BS paging agent of the target mobile terminal's entrance time so that the central BS paging agent determines the current BS of the target mobile; then the network pages only one cell.

An analytical model is used to evaluate the performance of the proposed strategy. Comparing the numerical results with other paging strategies, the results show that the new strategy reduces paging cost on radio channels.

II. Two-Step Paging Strategy

In this study, we introduce a two-step paging strategy using

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BSPA. In the proposed strategy, when a mobile terminal enters a new cell of the current location area, the BS informs its paging agent of the MID and the mobile terminal's entrance time (ENT). Consequently, when a mobile-terminated call occurs, the system can page only one cell to locate the target mobile followed by a two-step paging:

i) Each BSPA paging agent of the corresponding location area searches its list to determine if the target MID is included in the list. Every paging agent whose list has a target MID informs the central BSPA of the target mobile's ENT.

ii) Then, the central BSPA compares the target mobile's ENTs of the BSs in order to determine exactly where the target mobile is and then pages only one cell in the location area.

For efficient paging, the BSPA in the proposed strategy performs four functions: mobile listing, target mobile lookup, current BS determination and paging, and mobile deletion.

- Mobile listing

Whenever a mobile moves out of the coverage area of a BS and enters the new coverage of another BS of the current location area, it sends a short message containing the MID to the new BS through the access channel. The BS adds the MID and the mobile terminal's ENT to the list of its paging agent.

- Target mobile lookup

When a mobile-terminated call occurs, the MSC sends a paging request message to all of its BSs within the location area. Each BS searches the target MID at its paging agent. If the target MID is found, the BS then informs the central BSPA of the target mobile's ENT through wired lines. Otherwise, the BS ignores the message because the target mobile is not in that BS.

- Current BS determination & paging

The central BSPA compares the ENTs of the BSPAs in order to determine exactly where the target mobile is. When the target mobile's current BS is determined, the central BS then sends a target BS message to the target BS through a wired line so that only the target BS sends the paging message through a wireless paging channel.

- Mobile deletion

After informing the central BSPA of the target mobile's ENT, the BSPA deletes the target MID if the BS does not receive a target BS message from the central BS within a specified time (i.e., after the actual terminal paging).

A flow chart for our strategy, when a mobile-terminated call occurs, is shown in Fig. 1.

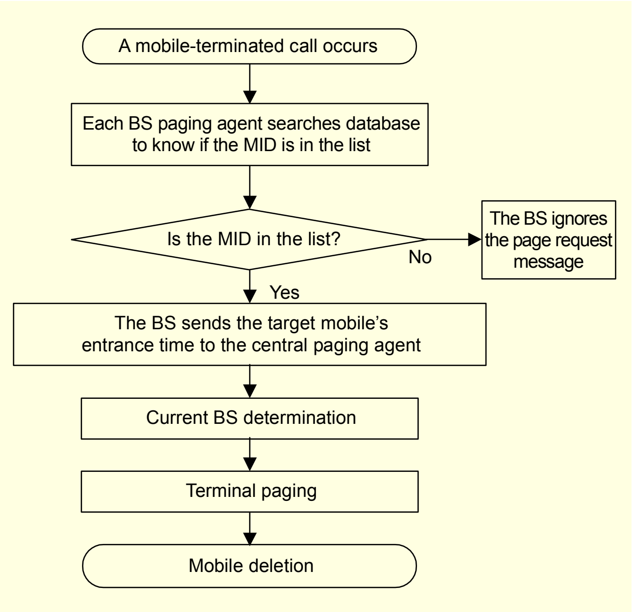


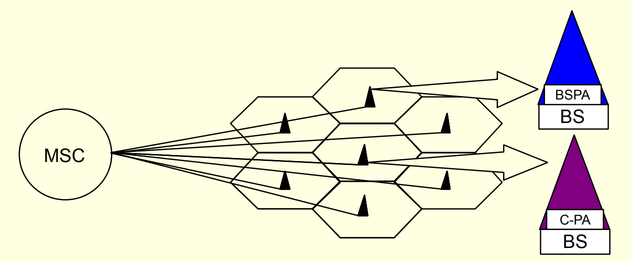
Fig. 1. Flow chart when a mobile-terminated call occurs.

As previously mentioned, Suh [7] suggested a paging strategy based on the paging agents of the BSs. For convenience, the proposed strategy by Suh will be referred to as the *BSPA strategy*. In the BSPA strategy, when a mobile enters a new cell, it sends a short message to the new BS, and the BS then adds the MID to the list of its paging agent. When a mobile-terminated call occurs, the BSPA strategy pages all cells which the mobile passes in the location area.

However, in our newly proposed strategy, when a mobile enters a new cell, the BS transmits the MID and the mobile's ENT to its paging agent. Hence, it is possible to page only one cell, and this strategy significantly reduces paging cost on limited wireless channels. The proposed strategy should reduce the paging cost, since terminal paging is made over only one cell in which the target mobile is. The proposed strategy, however, gives rise to an additional cost for managing the paging agents, which will be analyzed later in this paper.

III. Analytical Model

In this section, we evaluate how much the paging cost can be reduced in our strategy. An analytical model is introduced in order to compare the performance of the proposed strategy



C-PA: central BS paging agent

Fig. 2. Location area (R=2).

with the performance of the simultaneous paging strategy and the BSPA strategy. We assume that a mobile communication network is composed of hexagonal cells of the same size as shown in Fig. 2. We also assume that every BS has a BSPA, and the central BS of the location area has the central BSPA as shown in Fig. 2. The reference radius, *R*, is the cell distance from the center to the outer border of the whole coverage area of a location area. For example, *R* is 2 in Fig. 2.

When a mobile enters *i* cells during an interval of mobile-terminated calls, $C_2(i)$, the paging cost of the proposed two-step paging strategy can be derived as follows:

$$C_2(i)=\begin{cases} C_L\times N+C_C+C_T+C_D\times i, & i\neq 0;\\ C_L\times N+C_T, & i=0.\end{cases} \tag{1}$$

In (1), C_L is the target mobile lookup cost to determine if the target MID is in the list. *N* is the number of cells in the location area. For example, *N* is 7 in Fig. 2. C_C is the target mobile's ENT comparison cost to determine its location; C_T is the terminal paging cost at the target BS where the target mobile is located. $C_D\times i$ is the mobile deregistering cost at *i* BSs that do not receive the target BS message from the central BS after the current BS determination.

The paging cost of the BSPA strategy, $C_{PA}(i)$, can be derived [7] as follows:

$$C_{PA}(i)=C_L\times N+C_T\times(i+1)+C_D\times i. \tag{2}$$

C_L and C_T are the same as (1). Similarly to the above, $C_D\times i$ is the mobile deletion cost at *i* BSs that do not receive the response message from the mobile after the actual terminal paging.

In order to compute the paging cost, we assume that the inter-arrival time of a mobile-terminated call is exponentially distributed with parameter λ_c. We also assume that the mobile's residence time in a cell is generally distributed with mean $1/\lambda_m$. Then, the probability that a mobile enters *j* cells during an interval of mobile-terminated calls, $\alpha(j)$, is needed. We can obtain probability $\alpha(j)$ as derived in [8]. The expression of $\alpha(j)$ is

$$\alpha(j)=\begin{cases}\dfrac{1}{\theta}[1-f_m(\lambda_c)]^2[f_m(\lambda_c)]^{j-1}, & j\neq 0;\\ 1-\dfrac{1}{\theta}[1-f_m(\lambda_c)], & j=0,\end{cases}$$

where $\theta=\lambda_c/\lambda_m$ and f_m is the Laplace-Stieltjes transformation of the probability density function on the cell residence time.

Finally, the paging cost during an interval of a terminated call is derived approximately with the following equation:

$$C_2=\sum_{i=0}^{N-1}\alpha(i)C_2(i),$$

$$C_{PA}=\sum_{i=0}^{N-1}\alpha(i)C_{PA}(i).$$

Note that the above results are approximated paging costs. For a more accurate analysis, consideration should be given to mobile terminals re-entering the same cells. This study ignored mobiles re-entering the same cells for convenience, as in [7]. Assuming the call to mobility ratio (CMR) equals 1, mobiles re-entering the same cells scarcely occurs since a mobile enters one cell on average during an interval of a terminated call, and therefore there is only a slight difference between the results of this study and accurate results.

Note that the paging cost of the simultaneous paging strategy is independent of *i* and given by

$$C_{SP}=C_T\times N\,.$$

IV. Numerical Results

For numerical comparison, the target lookup cost of the BSPA strategy on wired parts, C_L, is assumed to be 1, i.e., $C_L=1$. Also, all the costs on wired parts, C_C and C_D, are assumed to be equal to C_L in order to simplify the numerical results as in [7]. Finally, reference radius *R* is assumed to be 2, i.e., *R*=2, and the CMR is assumed to be 1.

In the following figures, C_{SP}, C_{PA}, and C_2 are the paging costs of simultaneous paging, BSPA strategy, and the proposed two-step paging strategy, respectively.

Figure 3 shows the paging costs when C_T/C_L changes. In Fig. 3, C_2 and C_{PA} are smaller than C_{SP} when C_T/C_L is larger than about 1.36. This means that the proposed two-step paging and BSPA strategy show better performances than the simultaneous strategy when the terminal paging cost (C_T) is relatively large

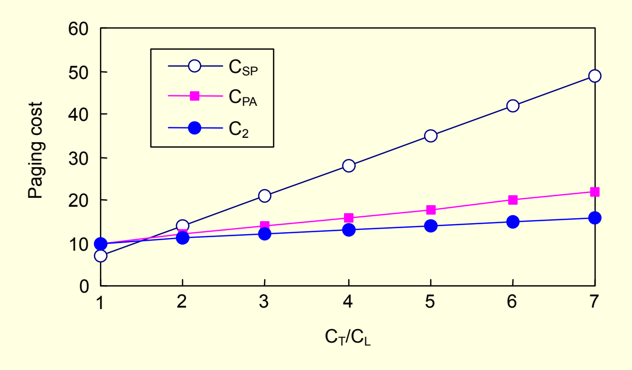


Fig. 3. Paging cost versus C_T/C_L (CMR=1)

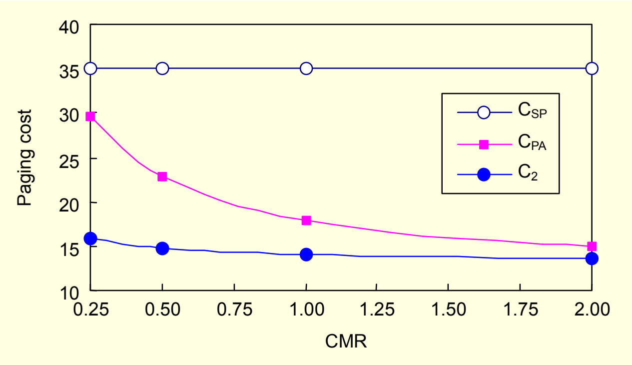


Fig. 4. Paging cost versus CMR (C_T/C_L=5)

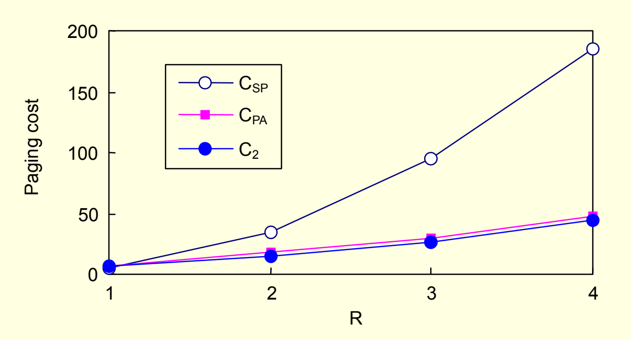


Fig. 5. Paging cost versus R (C_T/C_L=5)

for the lookup cost (C_L). Note that C_2 is less than C_{PA} in every case. This means that the proposed strategy shows an even better performance than the BSPA strategy Figure 4 shows the paging cost when the CMR, λ_c / λ_m, changes.

The CMR represents the mobility of a mobile and the frequency of mobile-terminated calls. A high CMR indicates a high call rate and low movement rate. From Fig. 4, it can be noted that the paging costs of the BSPA strategy and the proposed two-step paging strategy decrease as the CMR increases and C_2 is smaller than both C_{PA} and C_{SP} in every CMR.

Figure 5 shows the paging cost when reference radius R changes. R=1, 2, 3, or 4 indicates that the number of cells in the location area are N=1, 7, 19, or 37. From Fig. 5, it can be noted that as R increases, the paging cost of simultaneous paging (C_{SP}) increases very rapidly while the paging costs of BSPA and two-step paging (C_{PA} and C_2) increase rather slowly. Consequently, the proposed strategy is superior to BSPA as well as simultaneous paging in every R.

V. Conclusion

This paper suggested a new paging strategy in order to improve the utility of limited radio channels based on the paging agents in the BSs. In the proposed strategy, when a mobile enters a new cell of the current location area, the BS informs its paging agent of the mobile's identification number (MID) and the mobile's entrance time (ENT). Consequently, when a mobile-terminated call occurs, the system can page only one cell to locate the target mobile using the two-step paging strategy. The numerical results showed that the proposed strategy proficiently reduces the paging cost on radio channels compared with other paging strategies.

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