LETTER

Improved Paging Scheme Based on Distribution Density Information of Users in Mobile Communication Systems

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SUMMARY Intelligent paging uses the sequential paging technique with additional user information in order to reduce the paging delay cost and the paging load cost. Our proposed paging scheme uses distribution density information of users as required additional user information. This letter addresses an optimal paging sequence and introduces formulas to calculate the paging costs. These formulas are necessary to evaluate the performance of location management. The paging delay cost and the paging load cost for the proposed paging scheme and two other paging schemes are calculated and numerical analyses for these paging schemes are performed. Results show how the paging delay cost and the paging load cost vary as either the paging request arrival rates or the number of cells in an LA increases. The proposed paging scheme is more efficient in view of both the paging delay cost and the paging load cost.

key words: intelligent paging, distribution density, mobile communication systems, location management

1. Introduction

One of the most important issues for call delivery in mobile communication networks is keeping track of mobile users as they move from place to place. This is called location management and includes two basic operations of location update known as location registration and paging.

Location update and paging require a significant amount of network resources, including radio access traffic, signaling traffic for the signaling system number 7 (SS7), paging traffic, and paging delay. Studies of efficient paging have resulted in development of the simultaneous paging, the sequential paging [1], and the intelligent paging schemes [2]. In simultaneous paging, every call to a mobile station (MS) requires paging over all of the cells in a large location area (LA). In sequential paging, only a portion of an LA, known as the paging area (PA), is initially paged to find a called MS. Remaining PA’s are paged one by one until the MS is found. For intelligent paging, some kind of “intelligence” is introduced in sequential paging techniques to reduce the paging cost.

Most previous studies have focused on the location probability distribution of an MS for intelligent paging [2], [3], [6], [8]. This information may be described by the MS speed and the most-recent interaction area of MS [2], and may be used with the paging load distribution information [3]. The performance of an intelligent paging scheme depends on the accuracy of the location probability distribution of the target MS, the paging load distribution among cells, and the criteria used for selecting the paging sequence of cells. The location probability is the probability that an MS is located in a certain location in an LA after update when the MS moves on. The location probability distribution of the target MS can be obtained from the last location update cell, the speed and the moving direction of the MS, and the elapsed time of the paging request arrival since the last location update. In other words, the accuracy of the location probability distribution relies on the elapsed time of paging request arrival since the last location update and the mobility information of an MS. The last location update cell and the elapsed time can be easily obtained, but the speed and the moving direction of the MS must be estimated in a real mobile communication system. Those estimations result in additional overhead of systems. The location probability distribution of an MS is difficult to obtain accurately. Thus, the location probability distribution may not be proper in real systems.

However, distribution density information, which is how MS’s are spread in an LA, can be estimated easily using the ID’s of the last location update cells for the active MS’s in an LA without extra location updating. This information can be estimated easily using the number of the active users, who are in talk, in each cell and in an LA, because their cell ID’s will be notified to the network. The distribution density of the actual MS’s is assumed to the distribution density of the active MS’s, because the number of the actual MS’s may be proportional to the number of the active MS’s in each cell. Herein, we consider intelligent paging using distribution density information of the active MS’s in an LA instead of location probability distribution information of MS which is used in most previous studies. Distribution density information is useful to reduce the paging cost for intelligent paging.

This letter is organized as follows. System descriptions are presented in Sect. 2 and the algorithm of the proposed paging scheme is explained in Sect. 3. Sec-
tion 4 and Sect. 5 present an analysis of the paging cost and numerical results. Section 6 makes conclusions.

2. System Description

2.1 System Configuration

We assume a hexagonal or mesh cell configuration of LA’s. Each cell is surrounded by rings of cells. The innermost ring is defined as the center cell, which consists of only one cell. Let $r(i)$ $(i \geq 0)$ be the set of all cells in the $i$-th ring. Ring 0($r(0)$) is surrounded by $r(1)$, which is surrounded by $r(2)$ in turn. Then, $n(i)$, which is the number of cells in $r(i)$, is given as follows [5], [7]:

$$n(i) = \begin{cases} 6i, & \text{for hexagonal configuration} \\ 8i, & \text{for mesh configuration} \end{cases} \quad (1)$$

where $i = 1, 2, 3, \ldots$.

In real mobile communication systems, the shapes and sizes of cells may be different and the rings may have irregular shapes. We assume that the cells are homogeneous for simplicity of analysis.

2.2 Paging Cost and System Description for Considered Paging Schemes

The goal of location management is to reduce the costs associated with location update and paging. Paging is a process used to search for an MS by sending polling signals to cells in an LA. The paging load and the paging delay are associated costs. We focus on the paging cost and use distribution density information of users as required additional information for intelligent paging.

Let $C_{j}^{(i)}$ be the $j$-th cell within the $i$-th ring. And, we assume that $d_{j}^{(i)}$ is the distribution density of the active MS’s in cell $C_{j}^{(i)}$. The distribution density of the actual MS’s is assumed to be $d_{j}^{(i)}$ because the number of actual MS’s may be proportional to the number of the active MS’s in each cell. Then $d_{j}^{(i)}$ is described as:

$$d_{j}^{(i)} = \frac{\text{the number of active MS’s located in } C_{j}^{(i)}}{\text{the number of active MS’s located in LA}} \quad (2)$$

We also define the paging load cost as the average number of cells paged until the target MS is found. The paging delay cost is the average time between the request arrival time and the target MS localization time normalized by the average service time $1/\mu$. The total paging cost $C$ is defined as the weighted sum of the paging delay cost and the paging load cost:

$$C = D + W \cdot L \quad (3)$$

where $D$ is the paging delay cost, $L$ is the paging load cost, and $W$ is a weighting factor.

The paging schemes we compare with the proposed paging scheme are as follows:

1. Simultaneous paging scheme
   a. All the cells in an LA are paged for a called user simultaneously.

2. Modified sequential paging scheme
   a. The serving mobile switching center (MSC) pages the center cell.
   b. This paging is stopped if the MS is found. Otherwise, the serving MSC pages cells of the next outer ring sequentially at random.
   c. The MSC repeats paging for the cells of the next outer ring using the same method.

3. The Proposed Algorithm Based on the Distribution Density of Users

The concept of the proposed paging scheme is shown in Fig. 1. The paging algorithm based on the distribution density of users is as follows:

1. A target MS is searched in the center cell, which is located in the innermost ring ($r(0)$).
2. If the target MS is found in $r(0)$, the search is finished. If it is not found, the search is performed in a descending order of the distribution density of users $d_{j}^{(i)}$ in the cells of $r(1)$.
3. If the MS is not found in any cells of $r(1)$, the cells of the next outer ring $r(2)$ are searched. The sequence of cells searched in that ring is in a descending order of the distribution density of users $d_{j}^{(i)}$ in the cells of $r(1)$.
4. Using the same method, the target MS is continuously searched in the cells of the outer rings in sequence until the MS is found. When the target MS is found, the search is finished.

4. Paging Cost Formulation

4.1 Simultaneous Paging Scheme

Simultaneous paging is accomplished by polling all cells
simultaneously within an LA when a paging request arrives. If an MS is located in cell \( C_j^{(i)} \), the paging response time for the MS is the response time of the paging queue for \( C_j^{(i)} \).

C. Rose and R. Yates analyzed the paging delay for simultaneous paging [6]. It is assumed that the paging request arrival is a Poisson process with a rate of \( \lambda \), and the requests are queued and serviced based on FCFS at an average rate \( \mu \). Since each paging request generates simultaneous polling request to all cells, the response times at all queues are identically distributed. The normalized localization delay \( \overline{D} \) is the average time between a request arrival time and the MS localization time normalized by the average service time \( 1/\mu \). When an MS is in the queue of cell \( C_j^{(i)} \), the normalized location delay is simply the system time spent for paging the queue of \( C_j^{(i)} \). The normalized paging delay \( \overline{D} \) by the Pollaczek-Khinchin formula is expressed as [6]

\[
\overline{D}_{\text{simultaneous}}(\rho) = 1 + \rho \frac{\sigma^2}{\mu^2} + \frac{1}{2(1 - \rho)}
\]

(4)

where \( \rho = \lambda/\mu \), which is the paging load at the cell, and \( \sigma^2/\mu^2 \) is the variance of the service time normalized by \( 1/\mu^2 \). We assume exponential polling services at each location so that \( \sigma^2/\mu^2 = 1 \), and the paging delay cost is given by [6]

\[
\overline{D}(\rho) = \frac{1}{1 - \rho}.
\]

(5)

Let \( J \) be the number of total cells in an LA and \( G \) be the number of total rings, including \( r^{(0)} \) in an LA. Since the paging load cost \( \overline{L} \) is the mean number of cells searched, and \( \overline{L} \) in the simultaneous paging scheme is the number of cells included in the LA, \( \overline{L} \) is given by

\[
\overline{L} = J.
\]

(6)

4.2 Modified Sequential Paging Scheme

This paging scheme first searches the target MS in the center cell \( C_j^{(0)} \), then searches cells in the next outer ring sequentially at random until the MS is found. All the cells of a ring are paged cell by cell before the cells of the next outer ring are searched.

If an MS is located in the \( j \)-th cell of the \( i \)-th ring \( C_j^{(i)} \), the number of cells searched is \( j \) in order to find the MS in the ring \( r^{(i)} \). The probability that the MS resides in cell \( C_j^{(i)} \) is \( d_j^{(i)} \). Therefore, the mean number of cells searched in order to find an MS in an LA is described as

\[
\overline{L} = \text{the number of cells searched in } r^{(0)}, r^{(1)}, \ldots, r^{(G)}
\]

\[
= 1 \cdot d_j^{(0)} + \sum_{i=1}^{G} \sum_{j=1}^{n(i)} [n(i-1) + (j+1)] d_j^{(i)}.
\]

(7)

The paging delay cost can be obtained by applying Eq. (5) to this scheme. Since the average number of cells searched to find an MS is \( \overline{L} \), the overall arrival rate of polling requests to the system is \( \lambda \cdot \overline{L}/\mu = \rho \overline{L} \). Thus, the effective paging load per polling queue is as follows:

\[
\frac{\rho \overline{L}}{J} = \rho \alpha
\]

(8)

where \( \alpha = \overline{L}/J \) indicates the average number of paging requests for one cell.

The average normalized delay \( \overline{D} \) between a paging request arrival time and MS localization time for this paging scheme is obtained as follows from Eqs. (5), (7) and (8).

\[
\overline{D} = \overline{L} \cdot \overline{D}_{\text{simultaneous}}(\rho \alpha)
\]

\[
= \overline{L} \cdot \frac{1}{1 - \rho \alpha} = \frac{\alpha \cdot J}{1 - \rho \alpha}
\]

\[
d_j^{(0)} + \sum_{i=1}^{G} \sum_{j=1}^{n(i)} [n(i-1) + (j+1)] d_j^{(i)} = \frac{\alpha \cdot J}{1 - \rho \alpha}.
\]

(9)

4.3 Proposed Paging Scheme

The proposed paging scheme decides the paging sequence according to the distribution density of users. Cells within a ring are paged sequentially in a descending order of the distribution density. Cells are paged at random in the modified sequential paging scheme. Thus, the proposed paging scheme pags the center cell first when a paging request arrives. If the MS is found, the paging process is terminated. If the cell is not found, the cells of the next outer ring are paged sequentially in the descending order of the distribution density of users. For example, for \( n(i) \) cells of the \( i \)-th ring, the user density \( d_j^{(i)} \) of cell \( C_j^{(i)} \) is sorted in descending order, such as \( d_1^{(i)} \geq d_2^{(i)} \geq d_3^{(i)} \geq \cdots \geq d_{n(i)}^{(i)} \). Cells are then paged sequentially based on this sorted sequence. Cells of the next outer ring are paged in the same manner until the target MS is found.

The paging load \( \overline{L} \) is the mean number of cells paged in the LA. The mean number of cells paged in the LA is described as

\[
\overline{L} = 1 \cdot d_j^{(0)} + \sum_{i=1}^{G} \sum_{j=1}^{n(i)} [n(i-1) + (j+1)] d_j^{(i)}.
\]

(10)

The paging delay can be obtained from Eqs. (7)–(9). The primary difference between the proposed paging scheme and the modified sequential paging scheme is that, for the proposed scheme, the paging sequence of cells within each ring is based on the descending order of the distribution density of users. Therefore, the
average normalized delay for the proposed scheme is calculated as
\[ D = \frac{d^{(0)}\sum_{i=1}^{G} \sum_{j=1}^{n(i)} [n(i-1) + (j+1)] d^{(i)}_{ij}}{1 - \rho \alpha} \] (11)
where \( d^{(i)}_{1} \geq d^{(i)}_{2} \geq d^{(i)}_{3} \geq \cdots \geq d^{(i)}_{n(i)} \).

5. Numerical Results and Discussion

We compare the paging delay cost and the paging load cost of the proposed paging scheme with those of other conventional paging schemes. In this numerical analysis, the paging request arrival is assumed to be a Poisson process with a rate of \( \lambda \). The service rate of the paging channel is \( \mu \). We assume that the service rate is 0.01 (10 msec).

We also assume that the cell configuration of an LA is hexagonal. We consider 4 cell patterns according to the distribution density of users. The user distribution density is assumed to be a Gaussian distribution with a mean value of \( m \) and a standard deviation of \( \sigma \). The maximum number of rings is 10 and the reference distribution is assumed to be a Gaussian distribution with \( m = 0.5 \) and \( \sigma = 0.1 \). If a number generated from Gaussian distribution is less than zero, the value of zero is assigned instead. We assume that the value of \( m \) is larger than \( 3\sigma \) so that the probability of a negative value is less than 0.13% in Gaussian distribution. We consider four cell patterns as follows:

**pattern 1.** The distribution density of users is uniform for all cells in the LA.

**pattern 2.** The user distribution density of cells in the inner rings is higher compared with the outer rings. Cells of the innermost ring have a Gaussian user density distribution with \( m = 5.0 \). The distribution density for cells of the next outer ring is reduced by 50%.

**pattern 3.** The fifth cell of each ring is a hot spot cell that has a Gaussian distribution with \( m = 5.0 \).

**pattern 4.** This pattern is similar to pattern 3 except that the hot spot cell is generated at random in the ring.

5.1 Paging Costs vs. Paging Request Rate

Figures 2 and 3 show the average paging delay normalized by the average service time (1/\( \mu \)). The paging delay cost varies depending on the paging request rate \( \lambda \). Because all cells are paged simultaneously in simultaneous paging, the paging delay cost of the simultaneous paging scheme is lowest when the paging request rate is less than the service rate. Numerical results show that the proposed paging scheme is always better than the modified sequential paging scheme. Thus, the proposed paging scheme based on density information of users always has a lower paging delay. Although simultaneous paging has the best delay performance at lower paging request rate, the proposed scheme has the best performance at higher paging request rate, which is more critical in real communication systems.

The paging load depends on the paging sequence and the distribution density of users in an LA and not on paging request arrivals. Figure 4 shows that the paging load of sequential paging schemes, such as the proposed paging scheme and the modified sequential paging scheme, is lower than that of the simultaneous paging scheme. Compared with the simultaneous paging scheme, the user location of pattern 2 has the largest performance difference among the 4 patterns because the proposed paging scheme pages inner cells first. Comparing the proposed scheme with the mod-
ified sequential paging scheme, pattern 3 has a larger performance difference compared to patterns 1 and 2 because the hot spot cell, in which the probability of paging success is higher, is paged first. However, the paging load cost of the proposed paging scheme is the best, regardless of user location patterns. Thus, our scheme is advantageous in a system that has a high paging load cost.

5.2 Paging Costs vs. Number of Rings

Figure 5 shows that, except for the simultaneous paging scheme, the paging delay cost increases as the number of rings increases. The difference between the proposed paging scheme and the modified sequential paging scheme is only whether density information is considered. The result shows that the proposed paging scheme is always more efficient than the modified sequential paging scheme. As the size of an LA (the number of rings) increases, the efficiency of the proposed scheme over the modified scheme increases.

Figure 6 shows that the simultaneous paging scheme is least efficient in view of the paging load since the paging load cost increases as the number of cells in an LA increases. However, the paging load cost of the proposed paging scheme is the lowest. Thus, the paging scheme that considers the density information of users results in a lower paging cost, especially in case that the paging load is more important than the paging delay.

5.3 Total Paging Cost vs. Delay Weighting Factor

Total paging cost is defined as the sum of the paging delay cost and the weighted paging load cost of Eq. (3). Figure 7 shows that the paging costs of the proposed paging scheme and the modified sequential paging scheme are much lower than the cost of the simultaneous paging scheme when the weighting factor is larger than 1. For a system in which the paging
load is more important than the paging delay, the proposed paging scheme is more efficient with respect to the paging cost. Also, if we exclude the consideration of the simultaneous paging scheme, the proposed paging scheme is more efficient when the paging delay is more important than the paging load of system.

6. Conclusions

In this letter, we proposed an optimal paging scheme based on distribution density information which can be obtained easily instead of location probability distribution information which is used in most previous studies. We have defined the paging delay cost and the paging load cost and calculated paging costs for the proposed paging scheme. Numerical results show that the proposed paging scheme is more efficient in view of both the paging delay cost and the paging load cost when the paging request rate is greater than the paging service rate. Also, the proposed paging scheme is best in case that paging load cost is very important, regardless of the distribution density of MS’s.

References