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Location distribution of a mobile terminal and its application to paging cost reduction and minimization

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HIGHLIGHTS

- Analyze the location distribution of a mobile terminal in a paging area.
- Obtain expected costs of several selective paging methods.
- Find an important fact of progressive paging.

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ABSTRACT

Reducing the cost of dynamic mobility management in wireless communication networks has been an interesting and important issue. It is well known that by using a selective paging method, both costs for location update and terminal paging can be reduced significantly. However, an efficient selective paging method needs the information of the location distribution of a mobile terminal. Based on our previous results on random walks among rings of cell structures, we analyze the location distribution of a mobile terminal in a paging area when a phone call arrives, where the inter-call time and the cell residence time can have arbitrary probability distributions. Our analysis is conducted for both distance-based and movement-based location management schemes, and for two different call handling models, i.e., the call plus location update model and the call without location update model. Together with our earlier results on location distribution in time-based location management schemes, for several selective paging methods, including progressive paging methods, ring paging methods, and cell paging methods, we are able to obtain their expected costs of paging for distance-based, movement-based, and time-based location management schemes. We find that a progressive paging method with very small time delay can reduce the terminal paging cost dramatically, while further increasing the time delay does not result in noticeable reduction of terminal paging cost. Our work reported in this paper significantly extends our understanding of cost reduction and minimization of dynamic location management in wireless communication networks.

1. Introduction

1.1. Motivation

Reducing the cost of dynamic mobility management in wireless communication networks has been an interesting and important issue in the research community. The cost of location management includes two components, i.e., the cost of location update and the cost of terminal paging. It is well known that by using the simple paging method, there is a tradeoff between the costs of location update and terminal paging. In particular, increasing (reducing, respectively) the location update time reduces (increases, respectively) the location update cost, while increases (reduces, respectively) the terminal paging area and cost. It seems that reducing both location update cost and terminal paging cost is conflicting requirements. Fortunately, it is also well known that by using a selective paging method, which takes longer time than the simple paging method, both costs for location update and terminal paging can be reduced significantly. However, an efficient selective paging method needs the information of the location distribution of a mobile terminal. Due to lack of accurate analytical results of location distribution, there is lack of solid analytical results of the performance of selective paging methods.

The motivation of the present paper is to develop analytical results of location distribution of a mobile terminal inside a paging area (i.e., the probability that a mobile terminal is in a ring of

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a paging area) when a phone call arrives for distance-based and movement-based location management schemes. Such results are extremely useful in designing an efficient selective paging method to find a mobile terminal and analyzing its expected cost. Our results are obtained by using a very accurate ring level Markov chain as a mobility model to describe the movement of a mobile terminal [33]. Such results not only help to design and analyze selective paging methods, they are also very useful in finding more aggressive paging methods with faster paging speed and high quality of service.

1.2. Our contributions

The investigation in this paper makes the following significant contributions.

- First, based on our previous results on random walks among rings of cell structures [33], we analyze the location distribution of a mobile terminal in a paging area when a phone call arrives, where the inter-call time and the cell residence time can have arbitrary probability distributions. Our analysis is conducted for both distance-based and movement-based location management schemes, and for two different call handling models, i.e., the call plus location update model and the call without location update model.
- Second, together with our earlier results on location distribution in time-based location management schemes [35], for several selective paging methods, including progressive paging methods, ring paging methods, and cell paging methods, we are able to obtain their expected costs of paging for distance-based, movement-based, and time-based location management schemes.
- Third, we find that a progressive paging method with very small time delay can reduce the terminal paging cost dramatically, while further increasing the time delay does not result in noticeable reduction of terminal paging cost. Such an important finding has not been well documented in the existing literature.

Our work reported in this paper significantly extends our understanding of cost reduction and minimization of dynamic location management in wireless communication networks. It is worth to mention that while our earlier work [32,34,33,35] focused on the analysis of location update cost, this paper focuses on terminal paging cost reduction and minimization based on our new results on location distribution of a mobile terminal in a paging area when a phone call arrives.

The rest of the paper is organized as follows. In Section 2, we review related research. In Section 3, we provide preliminary information of our study. In Section 4, we describe mathematical background results used in this paper. In Section 5, we analyze the location distribution of a mobile terminal in a paging area. In Section 6, we present numerical data of location distribution. In Section 7, we discuss various selective paging methods. In Section 8, we demonstrate examples of paging cost reduction and minimization. In Section 9, we display numerical data to show paging cost reduction and minimization. Finally, in Section 10, we conclude the paper.

2. Related research

In this section, we review related research in analyzing dynamic mobility management and in reducing paging cost.

There are mainly three basic location update methods studied in the literature, i.e., the distance-based method, the movement-based method, and the time-based method [11]. Accordingly, there are three types of dynamic location management schemes, i.e., *distance-based location management schemes* (DBLMS), *movement-based location management schemes* (MBLMS), and *time-based location management schemes* (TBLMS). A DBLMS (an MBLMS and a TBLMS, respectively) employs the distance-based (the movement-based and the time-based, respectively) location update method. Furthermore, a DBLMS or an MBLMS or a TBLMS can use various terminal paging methods.

The design and analysis of any dynamic location management scheme depend on a mobility model of mobile terminals. Various mobility models have been proposed in the literature, including the shortest distance mobility model [3,2], the fluid flow model [7,12], the big move and the random walk models [14], the user mobility pattern scheme [16], the cell coordinates system [41], the isotropic diffusive motion model [44], one-dimensional Markov chains [4,11,15,40,49], and two-dimensional Markov chains [5,7,20,27,65].

Recently, we developed a ring level random walk model to accurately represent the movement of a mobile terminal in two-dimensional cellular structures. This Markov chain model has been used to analyze the paging area residence time and the cost of dynamic mobility management in a DBLMS [33]. It has also been used to study location distribution and reachability of a mobile terminal in a paging area, and to analyze the quality of service in a TBLMS [35]. It will continue to be employed in this paper to investigate location distribution in a DBLMS and an MBLMS, and to study paging cost reduction methods.

Dynamic mobility management is an important and fundamental research issue in wireless communication, and significant effort has been devoted by many researchers. The performance of movement-based location management schemes has been investigated in [5,11,22,36,37,32,34,38,43,61,66]. The performance of distance-based location management schemes has been studied in [2,9,11,15,27,33,40,41,63,67,68]. The performance of time-based location management schemes has been considered in [4,11,12,35,44,62]. Other studies were reported in [7,14,16,19–21,23,45,49,58], and some comparative studies were in [13,30,31,48,50]. Dynamic location management in a wireless communication network with a finite number of cells has been treated as an optimization problem which is solved by using bio-inspired methods such as simulated annealing, neural networks, and genetic algorithms [8,51,54,53,55,56]. The reader is also referred to the surveys in [6,29,52,25, (Ch. 15)], and [26, (Ch. 11)].

Terminal paging methods with low cost and time delay have been studied by several researchers [3,5,10,27,28,39,46,47,57,59,60,64]. Virtually all these studies focus on various selective paging methods. Two most important considerations for these methods are time delay and paging cost. A mobile terminal is located within certain geographical area divided into cells. At any moment, the mobile terminal resides in one of the cells. Each cell is associated with some probability that the mobile terminal is in the cell. A location distribution is a probability distribution of a mobile terminal in a geographical area. A selective paging method partitions the area into several disjoint regions, and proceeds in paging rounds when a phone call arrives. During each round, all cells in one region are polled by sending polling signals. The process is repeated until the mobile terminal is found, so that an incoming phone call can be routed to the mobile terminal. The number of paging rounds is the time delay, and the number of cells polled is the paging cost.

Minimizing both time delay and paging cost is conflicting requirements. A common strategy is to minimize paging cost with a time delay constraint. Given a location distribution over a search area and a time delay, the selective paging problem is to find a sequence of disjoint regions, such that the expected paging cost is minimized, subject to the constraint that the maximum or expected time delay does not exceed the given time limit [3,10,27,28,39,46,59,60]. The most notable result is a