A Predictive Paging Scheme for IMT-2000 Systems

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Abstract

Paging is a process to locate mobile terminals in wireless systems, which is initiated by the users calling from a fixed or mobile environment. In particular, paging issue in IMT-2000 systems is very important to maintain the wireless services to the mobile subscribers who are allowed to roam in different systems instead of stand-alone systems. In this paper, we introduce a predictive paging scheme based on the concept of boundary location register. We develop the corresponding signaling messages to describe the call delivery procedure of intersystem roaming. Since paging costs are associated with bandwidth utilization and delays influence call setup time, they are used as metrics in evaluating the performance of the proposed paging scheme.

1. Introduction

The demand to provide wireless multimedia services to an increasing population of mobile customers has placed new requirements on International Mobile Telecommunications 2000 (IMT-2000) systems. The mobile users require that reliable quality of service (QoS) constraints be maintained throughout the duration of a call as they travel not only from cell to cell, but also from one system to another system using different technologies. The IMT-2000 system is the next generation wireless system which is envisioned to provide seamless roaming communication. In the mobile environment, mobile subscribers use mobile terminals to communicate with others through the base station by radio links when they change their locations over time. It is critical for wireless systems to keep the track of mobile users for establishing call connection. In general, location tracking involves two procedures: location registration and paging. Location registration is the process in which mobile terminals inform the system about their up-to-date location information. Paging is the necessary procedure for call delivery, which is initiated by an incoming call.

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In this paper, we focus on the paging issue in IMT-2000 systems. Considering the growing number of mobile subscribers and increased service of mobile terminals in IMT-2000 systems, paging requests surge dramatically. The objective of a paging scheme is twofold: reduce the signaling cost and satisfy the delay constraint [1, 2, 11, 12]. Most of the current research work is based on cellular systems or personal communication service (PCS) networks. These paging schemes do not address the intersystem paging issue and the significant increase in signaling traffic caused by the roaming between different systems [6]. However, reducing paging costs and delays of intersystem roaming in IMT-2000 systems is very important since paging costs affect the bandwidth utilization and paging delays influence the quality of service (QoS) requirement of multimedia services. When a mobile user moves from one system to another, the paging process involves not only the system in which the mobile user subscribes services, but also the system that the user is visiting. Thus the cost and delay of intersystem paging are increased compared to paging in stand-alone systems. Here we propose a predictive paging scheme based on the concept of boundary location register (BLR) indicating the appropriate system that needs to be searched, so that the costs and delays of paging are reduced.

The rest of this paper is organized as follows. In Section 2, we present the system model in which multiple systems are included and introduce the entities for maintaining intersystem roaming. The paging procedure and signaling flow of the call delivery are described in Section 3. We analyze the costs and delays of intersystem paging in Section 4. We demonstrate the numerical results under different paging methods such as one-step and multi-step paging in Section 5. Finally, we conclude the paper in Section 6.

2. System Model

We consider a system architecture which is composed of many different systems since the mobile terminals (MTs) in IMT-2000 systems are allowed to roam among different systems instead of roaming within a stand-alone system. Each system may have its own signaling format, user identification, as well as mobility management protocol. Therefore, finding an MT in the IMT-2000 system becomes more complex because it may need to search more than one system rather than searching within a stand-alone system. We illustrate an analytical model in which there are two systems X and Y using different protocols in Figure 1. The service area of each system is divided into several location areas (LAs). Location registration is performed when a user moves from one LA to another. In Figure 1, each hexagon represents an LA and each LA consists of many cells. Note that some LAs may be on the boundary between two adjacent systems, e.g., LA_1^x, LA_2^x and LA_3^x of system X and LA_1^y, LA_2^y of system Y. We refer to these LAs as *peripheral location areas* (PLAs). It can be observed that MTs can leave a system only through these PLAs. In other words, the MTs in a system can not leave the system through the LAs which are not PLA. For example, an MT in LA_6^x of X who intends to leave system must go through any one of LA_1^x to LA_4^x if it is moving to system Y.

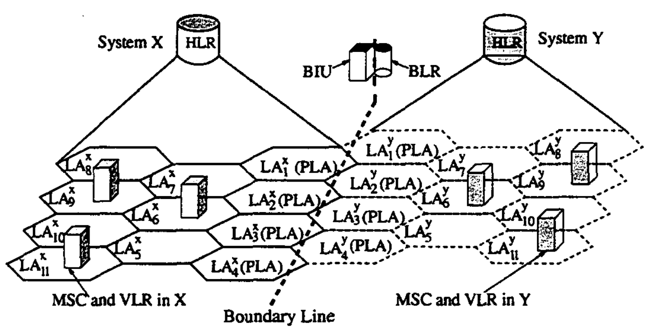

Figure 1. An analytic model of two adjacent systems with boundary location register.

When an MT subscribes its service in system X and is moving from system X to Y, it requests location registration with system Y, which is implemented through a boundary interworking unit (BIU) [13]. BIU is connected to mobile switching centers (MSCs) and visitor location registers (VLRs) in both systems and it is responsible for retrieving a user's service information and transforming message formats. Also, the BIU is assumed to handle some other issues such as the compatibility of air interfaces and the authentication of mobile users. The configuration of a BIU depends on the two adjacent systems that this BIU is coordinating. More details of BIU's functions can be found in [5, 6, 10, 15].

We designate a *boundary location register* (BLR) to be embedded in the BIU. A BLR is a cache database to maintain the roaming information of MTs moving between different systems. The roaming information is captured when the MT requests a location registration in the BIU. The BLR enables the intersystem paging to be performed within the appropriate system that an MT is currently residing in, thus reducing paging costs. Therefore, the BLR is involved in tracking the MTs that cross the boundary between two different systems. Both BIU and BLR are accessible to the two adjacent systems and are collocated to handle the intersystem roaming of MTs. On the contrary, the MSCs and VLRs are used for registration and paging of MTs crossing the boundaries between LAs within the same system and provide roaming information within a system. Another advantage of the BLR is that it alleviates the zig-zag effect caused by intersystem roaming. For example, when an MT is moving back and forth at the boundary between two adjacent systems, it only needs to update the information in the BLR rather than interacting with home location registers (HLRs) and VLRs in both systems. Besides, there is only one BLR and one BIU for a pair of neighboring systems, but there may be many VLRs and MSCs within a stand-alone system.

In addition, each BLR may store the information of MTs in several PLAs; therefore, the MTs crossing the boundary between systems can be found in the corresponding BLR. If a system has more than one neighboring system, there exists more than one BLR and each BLR is associated with one neighboring system. Since the MT performs location registration when it crosses the boundaries between the LAs, the last LA that an MT registers can be determined by querying the HLR. If the last registered LA is a PLA, then the BLR relating to the PLA is decided, and the *intersystem paging* is triggered. Otherwise, the paging process is performed in the same way as in PCS systems [3].

3. Predictive Paging Scheme and Procedure

In this section, a new paging scheme using the concept of BLR is presented to reduce the paging cost and delays for the MTs roaming among different systems.

3.1. Preditive Paging Scheme

According to the system architecture of IMT-2000, the signaling cost and paging delay of finding an MT in different systems are more than in a stand-alone system. When a call connection request arrives at system X, the last LA in which the called MT has registered is known in the HLR of

X. Given that the called MT's last registered LA within X is a PLA to Y, it is possible that the MT stays in systems X or Y when a call request arrives. The roaming information indicated in the BLR gives advance knowledge of the system to be searched. Using the concept of BLR, the system in which the MT is currently residing is determined before the implementation of the searching process. The paging scheme can be summarized as follows.

- Send a query signal to the BLR between X and Y to retrieve the MT's location information. This step is used to ascertain whether the MT has crossed the boundary.
- If the MT has already moved to Y, only the PLA in Y needs to be searched. If the MT has already moved to other PLAs or LAs in system Y, the BLR shows a pointer to the HLR in system Y. The MT's last registered LA in Y is searched.
- Otherwise, if the BLR indicates that the MT is still in system X, the last registered LA within X is searched. Within system X or Y, one or multiple polling messages are sent to the cells in the LA according to some specific paging methods with delay constraints [14].

This approach reduces the signaling costs and delays caused by intersystem paging. It is very suitable for the high traffic environment because it omits the searching procedure in two adjacent systems. If the new BLR concept is not used, the intersystem paging can still take place. The system must search X first, and if the called MT is not found, then Y will be searched. This method increases the paging cost as well as the paging delay, thus degrading the system performance.

3.2. Call Delivery Procedure

In order for the IMT-2000 system to establish the call connection for an MT whose last registered LA is a PLA, the signaling messages of call delivery involve HLRs, MSCs/VLRs, and the BLR associated with the two systems. In Figure 2, the detail procedure of delivering a call from a calling MT in system X to a called MT is described.

1. The calling MT initiates a call and its serving base station (BS) forwards the call initiation request to the corresponding MSC in system X.
2. The MSC sends a location request message to the HLR in system X.
3. The procedure of locating the called MT depends on the location information indicated in the HLR in X.
   (a) If the HLR finds the last LA with which the called MT registers to be an ordinary LA, i.e., non-PLA, it means that the called MT resides in system X, and the call delivery follows the procedure in a stand-alone system. We call this case as *intrasystem call delivery*.

   Otherwise, if the HLR finds the last LA in which the called MT registers in system X is a PLA adjoining to system Y, then we have the following.

   (b) The HLR sends a query message to the BLR associated with systems X and Y. And the following procedures are required for this *intersystem call delivery*.

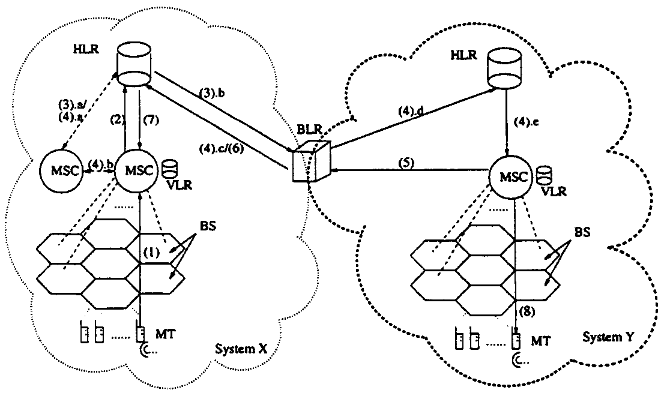

Figure 2. Call delivery procedure.

4. The BLR determines the appropriate system that needs to be searched.
   (a) If the BLR indicates that the called MT is still in X, the HLR of X sends a location request message to the MSC of the called MT.
   (b) The HLR of X performs the procedure of intrasystem call delivery. The call connection is established between the two MSCs serving the calling and called MTs.

   Otherwise, if the BLR indicates that the called MT has moved to a PLA in system Y, then we have the following.

   (c) The BIU assigns a temporary location number (TLN) to the called MT and sends this number to the HLR in X.

   Otherwise, if the BLR indicates that the called MT has moved to other LAs in system Y, we have the following.

   (d) The BLR sends a location request to the HLR in system Y.
   (e) The HLR sends a location request to the serving MSC of called MT in Y.

5. The serving MSC of called MT sends this TLN number to the BLR.
6. The BLR sends this TLN of the called MT to the HLR of calling MT in system X.
7. The HLR of the calling MT forwards the TLN to the serving MSC of the calling MT.
8. The connection between the calling and called MT is established through MSCs.

If the BLR is not used, the HLR of system X is always queried first and is followed by the intrasystem call delivery procedure as up to (3).a. If the MT has moved to system Y, this procedure informs a failure. The HLR of X must send a location request information to the HLR in Y, where the same procedure is repeated again to find the serving MSC of the called MT in system Y. Therefore, the signaling cost of the call delivery is reduced by using the concept of BLR if the called MT is close to the boundary between two systems. This benefit is considerable for MTs that go back and forth between two systems.

4. Performance Evaluation

In this section, we analyze the proposed scheme under random-walk model which is most commonly used to describe the MT's movement. The signaling cost of paging is evaluated in terms of the number of cells searched before finding the called MT. The paging delay is considered in terms of *polling cycle*, which is the elapsed time from the searching message is sent to the response is received. Within each stand-alone system such as X, the entire coverage area is assumed to be partitioned into L_x LAs of size $N(K)$, i.e., the number of cells included in the LA, where K is the outermost *ring* of the LA. Each ring is a set of cells that around the center cell of the LA. Thus the LAs are denoted as $\mathcal{A}_1, \mathcal{A}_2, \cdots, \mathcal{A}_{L_x}$ and they are mutually exclusive and collectively exhaustive.

$$\mathcal{A}_i \cap \mathcal{A}_j = \emptyset, \text{ if } \forall\, i \neq j, \text{ where } i, j = 1, 2, \cdots, L_x. \quad (1)$$

We assume that the LAs are numbered in such a way that all the PLAs are numbered first followed by the LAs which are not PLAs. We denote the number of PLAs for the adjacent system Y as $\delta_x(Y)$. All the PLAs adjoining system Y are associated with the BLR between systems X and Y since there is only one BLR for a pair of systems. Therefore, the roaming information of the MTs, which are moving from X to Y, must be indicated in the BLR no matter through which PLA they arrive at system Y. It is probable that the cell size is different from system to system. In this context, we assume that all the cells are regularized to the smaller cell, then the larger cells can be represented by multiples of the smaller cells. Then we can use the number of cells to be searched as the paging cost without considering the different cell sizes. Within each LA, all cells can be polled simultaneously. Accordingly, the paging cost in one LA depends on the number of cells in this LA, i.e., the size of the LA. For example, the cost of using one-step paging scheme in system X equals to the number of cells in LA $N(K)$.

Since the MTs change their locations from time to time, the paging cost is a function of time t and depends on the mobility pattern of MTs. Let $p_{Y|i}(t)$ be the location probability of a specific MT in system Y at time t and in $\mathcal{A}_i$ at time $t = 0$ in X. The paging cost for an MT which contacts the system last time in X, $C_p(t)$ is computed from:

$$\begin{aligned} C_p(t) \;=\; & \underbrace{\sum_{i=1}^{\delta_x(Y)}}_{\mathcal{A}_i\ \forall i \in [1, \delta_x(Y)]} p_{Y|i}(t) \cdot prob(i) \cdot C_Y \\ & + \underbrace{\sum_{i=1}^{\delta_x(Y)}}_{\mathcal{A}_i\ \forall i \in [1, \delta_x(Y)]} (1 - p_{Y|i}(t)) \cdot prob(i) \cdot C_X \\ & + \underbrace{\sum_{j=1}^{L_x}}_{\mathcal{A}_j\ \forall j \in [\delta_x(Y), L_x]} prob(j) \cdot C_X, \end{aligned} \quad (2)$$

where $prob(j)$ is the probability that an MT stays in the LAs, $\mathcal{A}_j$ in system X. C_X and C_Y are the signaling cost of paging in systems X and Y, respectively.

For simplicity, we consider the paging cost of intersystem paging at steady state, which means the average cost of searching the called MT given that the last registered LA of the called MT is a PLA. The paging cost is associated with the steady state probability $p_{Y|i}$, which can be obtained by:

$$p_{Y|i} = \sum_{k=0}^{K} p_{k,K} \cdot prob[K|k] \cdot \alpha_{K,K+1}, \quad (3)$$

where $p_{k,K}$ is the steady state probability of state k within the PLA. We define the state k ($k \geq 0$) as the distance between the current location of the MT and the center of the LA. This state is equivalent to the index of a ring in which the MT is located. Under the random-walk model, the transition probabilities $\alpha_{k,k+1}$ and $\beta_{k,k-1}$ represent the probabilities at which the distance of the MT from the center cell of the LA increases and decreases, which are given as:

$$\begin{aligned} \alpha_{k,k+1} &= \begin{cases} (1-q) & \text{if } k = 0, \\ (1-q)(\frac{1}{3} + \frac{1}{6k}) & \text{if } 1 \leq k \leq K, \end{cases} \quad (4) \\ \beta_{k,k-1} &= (1-q)(\frac{1}{3} - \frac{1}{6k}) \quad \text{if } 1 \leq k \leq K, \end{aligned}$$

where q is the probability that an MT stays in the current cell. Based on the transition probabilities in Eq.(4), $p_{k,K}$ can be expressed in terms of the steady state probability $p_{0,K}$ as:

$$p_{k,K} = \frac{1}{1+\sum_{k=1}^{K}\prod_{i=0}^{k-1}\frac{\alpha_{i,i+1}}{\beta_{i+1,i}}}\prod_{i=0}^{k-1}\frac{\alpha_{i,i+1}}{\beta_{i+1,i}} \quad \text{for } 1 \le k \le K. \tag{5}$$

where $\alpha_{i,i+1}$ and $\beta_{i+1,i}$ are obtained from Eq.(4).

Besides, $prob[K|k]$ in Eq.(3) is the steady state probability that an MT starts in state k and ends up in state K.

$$prob[K|k] = \int_0^\infty \left[e^{-\mathbf{Q}t}\right]_{k,K}\cdot \tilde{f}(t)\,dt, \tag{6}$$

where $\mathbf{Q}$ is the *transition rate matrix* in Eq.(7) and $\tilde{f}(t)$ is the pdf of residual sojourn time.

$$\mathbf{Q} = \begin{bmatrix} \frac{\alpha_{0,1}}{-\bar{t}(0)} & \frac{\alpha_{0,1}}{\bar{t}(0)} & 0 & 0 & \cdots & 0 \\ \frac{\beta_{1,0}}{\bar{t}(1)} & \frac{\alpha_{1,2}+\beta_{1,0}}{-\bar{t}(1)} & \frac{\alpha_{1,2}}{\bar{t}(1)} & 0 & \cdots & 0 \\ 0 & \frac{\beta_{2,1}}{\bar{t}(2)} & \frac{\alpha_{2,3}+\beta_{2,1}}{-\bar{t}(2)} & \frac{\alpha_{2,3}}{\bar{t}(2)} & \cdots & 0 \\ & & \ddots & & \ddots & \\ 0 & \cdots & & & & \cdots \end{bmatrix}. \tag{7}$$

To calculate $\bar{t}(k)$ which is the mean residence time in state k, we assume that the pdf of cell residence time, $f_r(t)$, is an exponential distribution [7], which has Laplace transform $F_r(s)$ with the mean value $1/\mu$.

$$F_r(s) = \frac{\mu}{s+\mu}. \tag{8}$$

As a result, the mean residence time $\bar{t}(k)$ in Eq.(7) is computed from,

$$\bar{t}(k) = -\frac{\partial[F_r(s)]^{n(k)}}{\partial s}\,|_{s=0}, \tag{9}$$

where $n(k) = 6k$ is the number of cells included in ring k.

The residence time T of an MT in the PLA is the sum of total time that an MT resides in each cell within the PLA. If the number of cells passed by an MT is assumed to be a random variable l with uniform distribution on $[1, N(K)]$, the probability mass function $h(l)$ and its Z-transform $H(z)$ can be represented as:

$$h(l) = \frac{1}{N(K)} \quad H(z) = \frac{z}{N(K)}\cdot\frac{1-z^{N(K)}}{1-z}. \tag{10}$$

Consequently, the probability density function of the residence time, $g_T(\tau)$ in the PLA has the Laplace transform, $G_T^*(s)$:

$$\begin{aligned} G_T^*(s) &= H(z)\,|_{z=F_r(s)} \qquad (11)\\ &= \frac{1}{N(K)}\cdot\frac{\mu}{s+\mu}\cdot\frac{1-\left(\frac{\mu}{s+\mu}\right)^{N(K)}}{1-\frac{\mu}{s+\mu}}, \end{aligned}$$

where $N(K)$ is computed from

$$N(K) = \sum_{k=1}^{K} 6\cdot k + 1 = 3(K+1)\cdot K + 1. \tag{12}$$

Furthermore, we determine $\tilde{f}(t)$ which is the pdf of residual sojourn time. From the property of Laplace transform, the first order moment, i.e., the mean value $\bar{\tau}$ of the residence time in the LA is:

$$\bar{\tau} = -\frac{\partial G(s)}{\partial s}\,|_{s=0} = \frac{N(K)+1}{2\mu}. \tag{13}$$

We use $\widetilde{B}^*(s)$ to denote the Laplace transform of the residual sojourn time, which is obtained as [8]:

$$\widetilde{B}^*(s) = \frac{1-G_T^*(s)}{s\bar{\tau}}, \tag{14}$$

where $\bar{\tau}$ is computed from Eq.(13). Then, $\tilde{f}(t)$ can be obtained as:

$$\tilde{f}(t) = \mathcal{L}^{-1}\left\{\widetilde{B}^*(s)\right\}. \tag{15}$$

By substituting Eqs. (7) and (15) into Eq. (6), $prob[K|k]$ can be obtained, which can be further used to calculate $p_{Y|i}$ in Eq.(3). The cost of intersystem paging, C_p, is then obtained by simplifying Eq.(2) when the call arrival rate is λ:

$$C_p = \lambda\cdot\left\{C_X\cdot(1-p_{Y|i}) + C_Y\cdot p_{Y|i}\right\}, \tag{16}$$

and the paging delay, D_p, is:

$$D_p = D_X\cdot(1-p_{Y|i}) + D_Y\cdot p_{Y|i}, \tag{17}$$

where D_X and D_Y are the paging delays in systems X and Y, respectively. And these paging delays are also determined by the specific paging schemes such as one-step and multi-step paging schemes [6, 9, 12]. On the other hand, paging cost without accessing BLR, $\widehat{C}_p$, and delay of intersystem paging, D_p, are obtained as:

$$\widehat{C}_p = \lambda\cdot\left(C_X + C_Y\cdot p_{Y|i}\right) \tag{18}$$

$$\widehat{D}_p = D_X + D_Y\cdot p_{Y|i}. \tag{19}$$

5. Numerical Results

In this section, we provide numerical results to show the effectiveness of the proposed scheme. As described before, the paging costs and delays depend on various parameters of the two adjacent wireless systems. We assume the following parameters during our study: the size of a location area $A(K)$ in terms of ring $K = 2, 3, 4, 5$ in system X, and fixed size of the LA as $K = 4$ in system Y; the call arrival rate $\lambda = 0.5, 2$; the mean of the cell residence time,

$1/\mu = 1$. Paging costs (C_X and C_Y) and delays (D_X and D_Y) are subject to specific paging schemes.

Three paging schemes, which are one-step, sequential, and uniform paging, are examined to determine paging costs and delays. Under one-step paging scheme [1, 4], the paging delay in each LA is equal to one polling cycle, which means that the system must broadcast polling message to all cells in the LA simultaneously. Correspondingly, the paging cost is equal to the number of cells in the LA. On the other hand, if the sequential paging scheme is used, the paging delays are more than one polling cycle and they depend on the number of cells included in an LA and the location probability distribution in each cell. We assume the location probability that an MT can be found is the same for all cells. Under the sequential paging scheme [12], the cells are searched one by one in decreasing order of location probabilities to minimize the paging delays. For the uniform paging scheme, we consider two cases for which the delay constraints are 2 or 5 polling cycles in each system. And these upper delay bounds are applied in calculating paging costs and delays [14].

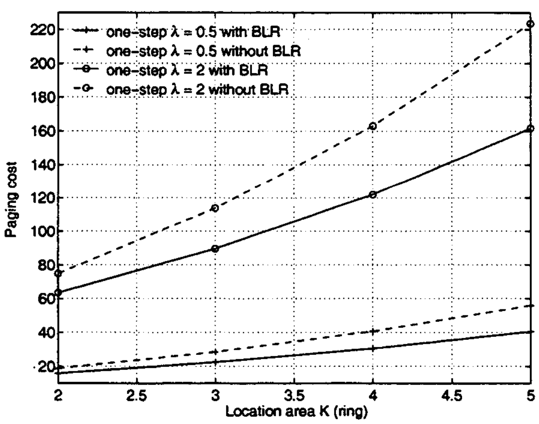

Figure 3. Paging costs using one-step paging scheme.

Figure 3-5 reveal the comparison of paging costs of using BLR and without using BLR with regard to the size of LA in home system X and call arrival rate, λ. The paging costs increase as the call arrival rate increases because the paging requests are increased. The effect of using BLR is more evident when the call arrival rate is higher and the location area becomes larger. This is very important in a mobile environment where the traffic volume is high. The costs of one-step paging are the highest among the three paging schemes, and the costs of sequential paging are the lowest. The costs of uniform paging are conditioned on the delay constraint $D = 2$, which means the delay bound of the worst case in each system is 2 polling cycles. The numerical results show that the reduction in paging cost is up to 37% when the size of the LA is large (e.g., K=5). Note that, the low paging costs are obtained at the expense of large paging delays. Thus, the tradeoff between costs and delays must be determined from specific requirements.

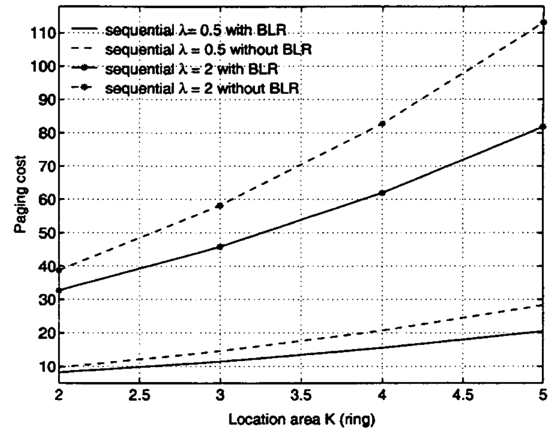

Figure 4. Paging costs using sequential paging scheme.

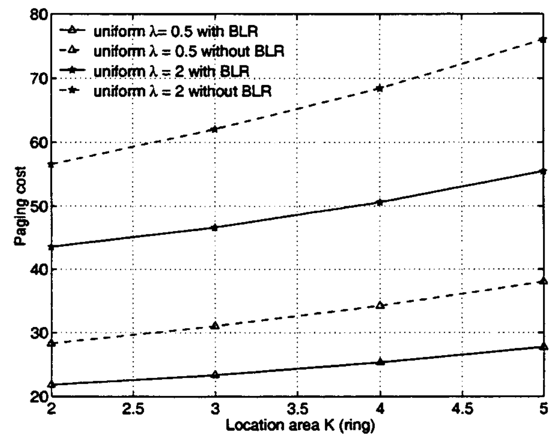

Figure 5. Paging costs under delay constraints.

We demonstrate the paging delays in Figure 6 and 7. The paging delays of using BLR are always one for one-step scheme since there is only one system that is required to be searched in one polling cycle as shown in Figure 6 (a). However, the paging delays without using BLR are greater than one because more than one system may be searched. Significant decrease in paging delays is obtained when the LA is large (e.g., $K = 5$) as shown in Figure 6 (b). The paging delays are reduced by using BLR even though the size of location area increases. If delay constraints are required, the response to paging request must be received under delay bounds. So the paging delays resulting from this scheme are larger than that of one-step scheme, but less than sequential scheme. When the BLR is used, the paging delays with lower delay bounds (e.g., D=2) are lower than that of higher delay bound (e.g., D=5) without using the BLR. These results exemplify that the proposed paging scheme is capable of reducing paging delays even though different paging schemes are used in stand-alone systems.

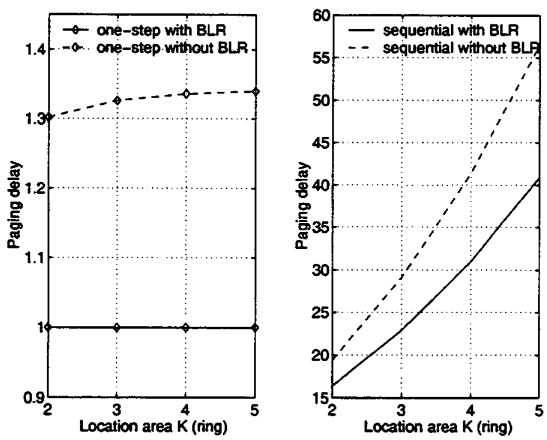

Figure 6. Paging delays of using one-step and sequential scheme.

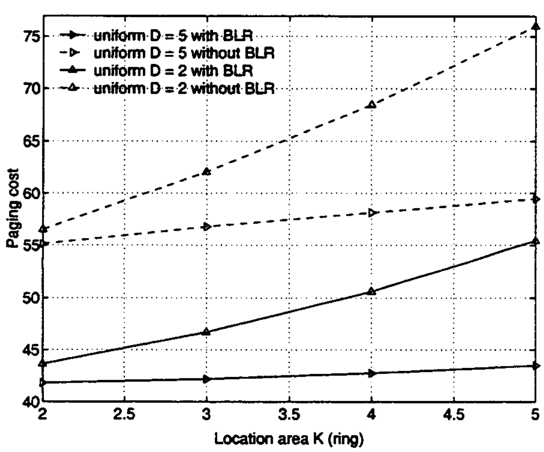

Figure 7. Paging delays under delay constraints.

6. Conclusion

In this paper, we introduced a predictive paging scheme for locating the mobile terminals (MTs) in the wireless systems. This is realized through a cache database named boundary location register (BLR) which maintains the roaming information of mobile terminals crossing two systems. It has been demonstrated that when call arrival rate is high, the paging costs and delays are reduced significantly even though the location area becomes larger. Therefore, the proposed paging scheme results in significant performance improvements for the IMT-2000 systems.

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