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Dynamic Location Management with Personalized Location Area for Future PCS Networks

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Abstract. Effective location management is critical for future personal communication service (PCS) networks, which envision smaller cells comprising a vast number of mobile terminals. In this paper we present a dynamic location management scheme with personalized location areas. The proposed technology takes into account the mobility patterns of the individual users in the system. The continuous time Markov chain is employed to model the system and analyze the location management cost. The personalized location areas are dynamically defined for each mobile terminal using a heuristic algorithm. Simulation results show that the proposed scheme offers a lower signaling cost than that achieved by some known methods.

1 Introduction

In *personal communication service* (PCS) networks, the location of each mobile terminal (MT) has to be tracked consistently to guarantee successful call delivery [1]. This process of tracking locations of mobile users at any given time is called *location management*. Location management implies two basic logical procedures, namely *location update* and *paging*; each in turn contributes to the total location management cost.

In current PCS networks, such as the Global System for Mobile Communications (GSM), the entire service area is divided into several *location areas* (LAs) and each LA is composed of one or more cells. The location update takes place when the MT moves between LAs. When an incoming call arrives for the MT, the system performs paging by sending polling messages to all the cells in the MT's last reported LA. This always-update location tracking strategy works well for a relatively small number of mobile users. For future PCS networks, such as Universal Mobile Telecommunication System (UMTS), the population of MTs will increase dramatically. Also, many new services like multimedia over telephony are provided. In order to meet the quality of service requirements, the cell size is reduced that allows for saving the power of transmission and greater frequency reuse [1]. However, smaller cells adversely cause more frequent cell crossing by MTs. The latter circumstance in turn leads to higher cost of location management.

Various LA-based schemes have been proposed to reduce the signaling cost for location management, which can be divided into two major categories: static and dynamic [1]. In the former group, the whole system is partitioned into number of LAs, which are fixed and same for all users. The partitioning is done for obtaining an optimal total management cost for all MTs [2]. In contrast, dynamic LA is based on the mobility behavior and call patterns (call arrival rate) of individual MT. Some important dynamic LA schemes are time-based LA, movement-based LA and distanced-based LA [1]. In [3], several strategies are proposed to group cells into location areas by considering movement behavior of individual MT's. The LAs are fixed for each MT but could be different for different MTs. The authors of [4] consider MT's mobility pattern to create a personalized LA for each. Once a MT leaves its current LA, a new LA will be defined based on the probabilities of crossing the boundaries of cells, or so-called transition probabilities. The new LA might have overlaps with the old one. The problem with these schemes is that they group cells only based on the transition probabilities between cells. The grouping is bounded by the LA size, which is computed as the number of cells in the area. When performing the grouping, there is no way to learn about the changes in the location management cost.

In this paper, we develop a dynamic location management scheme with a personalized location area (PLA) for each MT and evaluate its performance. We use continuous time Markov chain (CTMC) to analyze the location management cost; and then describe a heuristic algorithm to determine the personalized location area of a minimum cost.

2 Dynamic Location Management with Personalized Location Area

The essence of the proposed dynamic location management scheme lies in designing LAs for each MT individually and providing this information to them. Once the MT enters the PCS system, a personalized LA is found by minimizing the total location management cost based on the movement behavior of the MT in the system. The system then sends the IDs of all cells in the designed LA to the MT and the latter stores them in the local memory. If the MT moves into a new cell, it checks if the new cell's ID is in the list. If it is not found, then MT sends a location update message to the system and a new personalized LA is created. When there is an incoming call, the system will page all the cells in the LA to identify the cell of MT's current location and to deliver the call. Fig. 1 shows an example of the proposed location management scheme. The system has 16 cells indicated on the right hand diagram by circles. Initially the MT resides in cell 1 and the designed personalized LA for the MT includes cells 1, 2 and 5 (bounded by the solid rectangle). When the MT moves into either cell 5

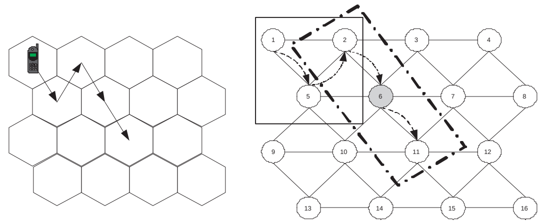

Fig. 1. Example of Dynamic Location Management Scheme; Left: MT roaming. Right: Forming location areas.

or cell 2, there is no location update performed. If a call arrives when the MT is in cell 2, the system will page all three cells to find the MT and deliver the call. The location update is performed when the MT moves for example from cell 2 to cell 6 (see, shaded circle). A new LA will be formed with cells 2, 6 and 11 (see, dashed rectangle). Note that the new LA overlays the previous one.

3 Personalized Location Area Design

We assume the network has an arbitrary topology. The PCS network can be represented as a bounded-degree, directed graph $G = (V, E)$, where V is the set of nodes representing the cells and E is a set of edges representing the interconnections between the cells. $|V|$ is denoted as the number of nodes in G. Two adjacent cells i and j relate by two directed edges (i, j) and (j, i) in the graph. The MT's movement in the network is modeled as a random walk. Under the random walk model, for each MT, there is a predefined probability p_{ij} of moving from cell i to cell j with $\sum_j p_{ij} = 1$. The residence time of the MT in cell i is assumed to be exponentially distributed with the mean $1/\lambda_{mi}$.

The behavior of the MT in a predefined LA is modeled after a continuous time Markov chain (CTMC) with absorbing states. The absorbing state denotes the state of MT of moving out of the current LA. The state space of the CTMC is $S = \{1, \ldots, k, k+1\}$ where states 1 to k are transient states that represent the cells in the LA and state $k + 1$ is the absorbing state that represents the neighboring cells of the LA (cells $k + 1$ to n). The generation matrix of the CTMC can be written as

$$\mathbf{Q} = \begin{pmatrix} \mathbf{A} & \mathbf{B} \\ \mathbf{O} & 0 \end{pmatrix} = \begin{pmatrix} -\lambda_{m1} \sum_{j \neq 1} p_{1j} & \lambda_{m1} p_{12} & \ldots & \lambda_{m1} p_{1k} & \lambda_{m1} \sum_{j=k+1}^{n} p_{1j} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \lambda_{mk} p_{k1} & \lambda_{mk} p_{k2} & \ldots & -\lambda_{mk} \sum_{j \neq k} p_{kj} & \lambda_{mk} \sum_{j=k+1}^{n} p_{kj} \\ 0 & 0 & \ldots & 0 & 0 \end{pmatrix} \quad (1)$$

where $\mathbf{A}$ is an $k \times k$ matrix with grouping the transition rates in the transient states, $\mathbf{B}$ is column vector with $\mathbf{B} = -\mathbf{A}\mathbf{e}^T$ and $\mathbf{e} = [1\ 1\ \ldots\ 1]$, $\mathbf{O}$ is a $1 \times k$ zero matrix. Without loss of generality, we assume the first cell that the MT enters in the LA is cell 1. Thus, the initial probability vector for this CMTC is $\mathbf{p}_0 = [1\ 0\ \ldots\ 0]$.

Given τ_a is the time to reach the absorbing state from $t = 0$, the probability distribution of the time until absorption can be written as

$$F_a(t) = Pr\{\tau_a \leq t\} = 1 - \mathbf{p}_0 e^{\mathbf{B}t}\mathbf{e}^T, t \geq 0 \tag{2}$$

The average residence time of the MT in the LA $\bar{t}$ which equals to the mean time to absorption $E(\tau_a)$ is then given by

$$\bar{t} = E(\tau_a) = -\mathbf{p}_0\mathbf{B}^{-1}\mathbf{e}^T \tag{3}$$

The total location management cost for MT in a specific LA K is defined as

$$C(K) = c_p\lambda_c N + c_u\Phi_u \tag{4}$$

where N is the number of cells in the LA, λ_c is the call arrival rate for the MT, Φ_u is the location update rate of the MT for the LA K which equals to $1/\bar{t}$, c_p and c_u are the per-cell paging cost and the unit location update cost, respectively. The first component of the right side of Equation 4 corresponds to the paging cost and the addend is the location update cost.

A personalized LA is formed such that the total location management cost is minimized. Because of the complexity of the optimization problem is high, an iterative greedy heuristic algorithm that yields a sub-optimal result is proposed as a rational alternative. The heuristic algorithm performs as follows.

Define:
LA: set of cells in the designed LA
TLA: set of cells in the temporary LA to be checked
$\Gamma(A)$: the set of neighboring cells of LA A
v: LU cell of the MT
C_{min}: minimum signaling cost corresponding to the designed LA
C^*: minimum signaling cost corresponding to TLA palatino

1. Initialize LA = $\{v\}$, TLA = LA and Γ(TLA), C_{min} = C(LA) = $c_p\lambda_c$ + $c_u\lambda_{mv}$
2. Include a new cell into the LA
   $C^* = \infty$
   For cell i in the Γ(LA)
     Let TLA' = TLA $\cup$ $\{i\}$
     Calculate $\bar{t}$(TLA') and C(TLA')
     If C(TLA') $<$ C^*
       C^* = C(TLA'), TLA = TLA'
     End
   End
   If C^* $<$ C_{min}
     C_{min} = C^*, LA = TLA
   End
3. If C_{min} $<$ $c_p\lambda_c$(|TLA|+1)
     Stop

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Else
  Find Γ(TLA)
  Goto Step 2
End
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Note that in step 1, $C_{min} = C(\mathrm{LA}) = c_p\lambda_c + c_u\lambda_{mv}$ is the total signaling cost of the LA only including the LU cell v. In Step 3, the algorithm will terminate if C_{min} is less than $c_p\lambda_c(|\mathrm{TLA}|+1)$ which is the paging cost of grouping when one more cell is added to the temporary LA. If the condition is met, there is no need in further check because trivially C_{min} will be less than the total cost incurred by adding any single cell.

4 Simulation

In this section we present results of simulations performed to evaluate the performance of the proposed dynamic location management scheme. We assume the incoming call follows a Poisson process with mean λ_c. The residence time of the MT in each cell is exponentially distributed with mean $1/\lambda_{mi}(i = 1, 2, \ldots, |V|)$.

In the first study, we use a network with 25 cells. The system is organized in a hexagonal grid structure for the simulation purpose, although arbitrary cell topology can be used. The transition probabilities between cells are randomly generated. We compare the proposed PLA scheme with the always-update (AU) and the distance-based location area (DBLA) schemes. The distance threshold of DBLA is set to $D = 1$. The incoming call rate (number of calls per hour) is $\lambda_c = 2$. The average mean residence time of MT in the system is taken as $1/\bar{\lambda}_m = 180$, 360, 540, 720 or 900s which corresponds to the call-to-mobility ratio (CMR) 0.1, 0.2, 0.3, 0.4 and 0.5, respectively. The per-cell paging cost c_p is 1 and the unit location update cost c_u is 10. The simulation is conducted for all the schemes using the same trace. The total number of calls generated for each simulation run is 10,000. 20 simulation runs are performed for each CMR instance. The result is obtained mean value of the 20 runs.

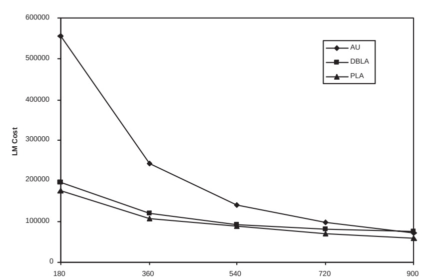

Fig. 2. Performance comparison of location management schemes

The results are shown in Fig. 2. For low CMR region (CMR = 0.1 to 0.4), DBLA performs better than AU. When the CMR becomes larger (CMR = 0.5), AU is better than DBLA. As we know, DBLA employs a larger location area than that of AU to reduce the location update rate, and consequently the location update cost. That in turn releases the paging cost. When the CMR is low, the location update rate is high and the location update cost dominates the total signaling cost. When the CMR increases, the location update rate decreases and the paging cost contributes the total signaling cost. The proposed PLA scheme defines the personalized LA by minimizing the location management cost according to the MT's movement behavior in the system and the system parameters, which makes it better candidates compared to the counterparts such as AU and DBLA.

Next, we compare the performance of the proposed scheme with the static LA (SLA) scheme [3] with the same structure and the parameters. The network has 20 cells as shown in Figure 3 of [3]. To make the CMR to 0.2 as in [3], we set the mean residence time for each cell is set to 360s and the call arrival rate is 2 calls per hour. We compare the proposed PLA scheme with the SLA scheme using the Strategy_Max_Gain partition method that gives the best result among the four strategies proposed in [3]. The location management costs for PLA and SLA obtained from simulation are 61,008 and 65,299, respectively. The results demonstrate that the proposed dynamic scheme outperforms the SLA scheme.

5 Conclusion

We have proposed the dynamic location management scheme designed for future PCS networks. In essence, a personalized location area is formed for each MT based on MT's mobility pattern in the system and with the location management cost as the objective function to be minimized. A heuristic algorithm assists in finding an optimal solution. Based on the simulation results, it can be concluded that the developed scheme significantly reduces the location management cost compared to some known schemes such as AU, DBLA and static LA, thus it can be considered as a viable candidate for future PCS networks.

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