ISSN:0975-9646
Pragyan Acharya et al, / (IJCSIT) International Journal of Computer Science and Information Technologies, Vol. 2 (4) , 2011, 1509-1512

Bloom Filter- Cost Effective Paging Mechanism

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Abstract— **In a high-capacity cellular network with limited spectral resources, it is desirable to minimize the radio bandwidth costs associated with paging while locating mobile users. Reduction of communication overhead has become a burning issue of today. It induces the intellects to innovate some means which are cost reducing by nature. Location management aims to reduce this overhead through prediction of the user location. For this paging mechanisms are adopted. In this paper a cost effective paging mechanism called Bloom Filtering is proposed which surpasses other techniques such as Simultaneous paging and Sequential paging in matter of cost reduction.**

Keywords— **Location management, Paging, Simultaneous paging, Sequential paging, Bloom filtering.**

I. Introduction

In the modern era of globalization, the world has shrunken in size. This has become accentuated by the breakthrough made in the field of information technology. The invention of cell phones is a major achievement of mankind. With the growth of population in general and with the increase in the income of the people in particular, the number of people having access to cell phone has gone up tremendously. In order to accommodate more subscribers, the size of cells must be reduced to make more efficient use of the limited frequency spectrum allocation. It necessitates the reduction of communication overhead a bare need. Location management aims to reduce this overhead through prediction of user location. The process to track the user accompanied by the efficient use of available bandwidth is called Location Management (LM) [1]. Cells are grouped into Location Areas (LA). The user has to move inside these areas on the basis of some pre-defined standards. It constitutes the very basis of LM. Frequent updates can be done to reduce the polling cost. But for this a price is to be paid in the form of rise in computational cost and increasing consumption of energy. Less location update results in storing less information about the user. This increases the paging cost. Hence a trade off has to be made between these important considerations [2] [3].

This paper aims to make a comparative study of the various paging strategies such as Simultaneous paging, Sequential paging and Bloom filtering to find out the most cost reducing one. So far as paging cost reduction is concerned it is assumed that the Bloom filtering technique is preferable to the other two. This is sought to be proved through numerical analysis and graphs. The rest of the paper is organized as follows. Section II gives a brief introduction to the various location management techniques. Section III lists the paging strategies implemented in the network for prediction of the user location. Section IV defines the paging cost and Section V makes a numerical analysis of the mentioned strategies.

II. Basic Concept

Location Management is of two types- Static LM and Dynamic LM. Static LM is based on the geographic layout of the network and dynamic LM is based on the status and state of the mobile. These two strategies have been described below.

A. Static Location Management

Location Management scheme implemented in the location areas having constant cell size and uniform for all the users is called as static LM. Presently most LM schemes are static. They are of two types: always-update and never-update.

1) Always-Update

The user updates its location every time it crosses a new cell. This strategy works wonders for users having low mobility rate and high call arrival rate. But there is more consumption of time and energy for users having high mobility rate and low call rate. However, the network will be able to track a user easily thereby reducing the paging cost.

2) Never-Update

The user never informs the networks of every inter-cell movement. It updates its location whenever there is a change in the location area. Although there is substantial decrease in the location update cost, paging cost increases because every cell inside the LA needs to be checked [4].

B. Dynamic Location Management

In order to improve the wasteful static LM schemes dynamic LM techniques have been developed which are user specific. They are intended to be customizable in such a way that each user will have his own optimal LU standard. It helps to reduce the overall number of location updates. The various types of dynamic LM schemes are as follows.

1) Time Based Location Update

The user updates its location after a certain time period. For its implementation mobile user maintains a timer. It is efficient in real life scenario.

2) Movement Based Location Update

The mobile devices update their location after a given number of boundary-crossings to other cells in the network.

3) Distance Based Location Update

The mobile device performs an update whenever it moves a certain distance from the cell where it last updated its location

4) Profile Based Location Update

The cellular system keeps the individual subscriber's mobility pattern in his/her profile. The information will be used to save the total cost [5] [6].

III. Paging

While mobile devices perform updates as per their location update scheme, the network is to be capable of precisely determining the current cell location of a user so as to enroute an incoming call. This requires the network to send a paging query to all cells where the mobile device may be located and to inform it of the incoming transmission. It is desirable to minimize the size of this paging area to reduce the cost incurred on the network with each successive paging message [5][6]. The most commonly used paging schemes are summarized below.

A. Simultaneous Paging

The Simultaneous paging scheme also known as Blanket Polling is the mechanism used in current GSM network implementations. All the cells in the user's location area are paged simultaneously to determine the location of the mobile device [5] [6].

Figure 1 illustrates two location areas LA1 and LA2. Both the LAs have seven cells each. Whenever a call is terminated to a mobile unit present in one these location areas, the network pages all the cells of the location area simultaneously.

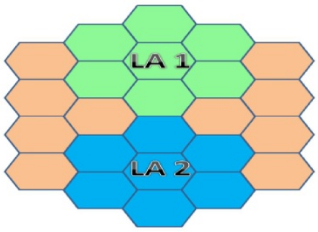

Fig 1: Location Area of seven cell each

1) Advantages: No additional information regarding user location is required. Such type of paging is beneficial for the network with large cell, less number of users and low call arrival rate.

2) Disadvantages: It generates excessive amount of paging traffic and incurs a significant cost in radio bandwidth utilization for the networks having high number of users.

B. Sequential Paging

Unlike simultaneous paging, sequential paging avoids paging every cell within a location area by segmenting it into a number of paging areas, to be polled one-by-one.

A location area is a set of N cells C = {1, 2… N} and the mobile user is guaranteed to be in one of these cells at the time a call is terminated to the mobile. We assume that the probability of a user residing in a particular cell at the time of call arrival can be estimated. Let P_i denote the probability of a user to reside in cell '*i*' at a particular time. We assume that the cells are numbered in non-increasing order of user location probabilities, i.e. i < j implies Pi > Pj. In this scheme the cells in a location area are partitioned into indexed groups called paging zones(Z) on the basis of the cell-wise user location probabilities. Let Z1, Z2, Z3…, Zw be the 'w' partitions of cell C. When a call arrives for a user, the cells in paging zone Z1 are paged simultaneously in the first round, then if the user is not found in Z1, all the cells in paging zone *Z2* are paged and so on[7].

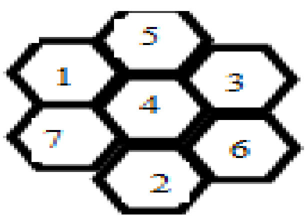

Fig 2: Location Area having 7 cells.

Figure 2 represents a location area having 7 cells. C = {1, 2, 3, 4, 5, 6, 7} and it is divided into 3 partition zones, i.e. w = 3. Cell wise user location probability Pi given as, Pi = {.2, .2, .15, .1, .05, .14, .16}. There are three paging zones Z1, Z2 and Z3.

Paging Zones: Z1 = {1, 2}
Z2 = {7, 3}
Z3 = {6, 4, 5}

Number of cells in each paging zone:
N1 = 2, N2 = 2, N3 = 3

Zone Location Probabilities:
P1 = .2 +.2 = .4
P2 = .16 + .15 = .31
P3 = .14 + .1 + .15 = .29

Cells that belong to the same paging zone need not be adjacent to one another geographically. When a call arrives, cells 1 and 2 are paged first, and if the user is not located in those two cells, then cells 7, 3 are paged. If the user is not located in those two cells then cells 6, 4 and 5 are paged.

1) Advantages: Reduces the total number of polling messages over a blanket scheme.

2) Disadvantages: It is far from optimal. This scheme necessitates knowledge of the geographical structures of the network and performs poorly for high movement rates.

C. Local Prediction of Cell Using Bloom Filtering

An n-bit Bloom Filter Identity Vector (BFID) is assigned to every Mobile Unit (MU) which is sent periodically to the local cell for location updation. Base Station receives superimposition of pulses from all the MUs in the local cell and stores it as Cell Vector. Whenever there is a call terminated to any MU, the BFID of this MU is compared in a bitwise manner with each cell vectors of the most recent LU cycle. A pulse is sent when the corresponding bit is "1". If the base station detects one or more pulses in the *i*th bit interval, it infers that at least one MU in the cell contains a "1" in the *i*th bit else it concludes that all MUs inside the cell have BFIDs that are zeros at the *i*th bit. The zero in the *i*th bit in the cell vector conveys that a MU with an ID of "1" in the *i*th bit is not in the cell.

Consider a system consisting of three cells and six MUs as depicted in figure 3. During the most recent LU cycle, the cell vectors of cell 1 to cell 3 are 10011, 11101, and 01100, respectively. Suppose a call is terminated to MU 6. We compare the BFID of MU 6 with the cell vectors. Since the third and the last bit ofMU6 are one, a paging message to the cell only if the corresponding bits of the cell vectors are also "1." It turns out that only cell 2 should receive the paging message.

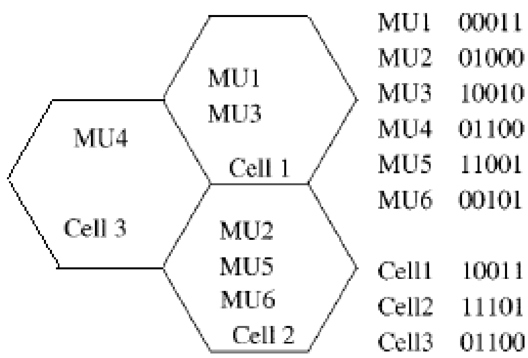

Fig. 3 Example Illustrating Bloom Filtering

Mathematically, let *li* where *i* □ [1, M], be denoted as the cell vector obtained in the most recent LU cycle in cell *i* from a system of M cells. When a call arrives for the MU with ID BFID, cell *j* is paged if

$$\text{BFID} \otimes l_j = \text{BFID} \quad (1)$$

where $\otimes$ denotes bit by bit multiplication. This operation is called Bloom filtering [8].

IV. Cost Analysis

At each LA, a user updates its location to the base station. It is assumed that the user updates immediately upon entering another location area and any subsequent call will page the user only in that area. The cost of paging will be different for different LAs depending on the number of cells and the cost of paging each cell [9].

The paging cost is defined as the product of call arrival rate λ, number of cells in the paging area (N) and a constant representing the cost per paging message.

$$\text{Paging cost} = N^* \lambda^* C_p \text{ [10]} \quad (2)$$

Where

N = No of cell in each location Area

λ = call arrival rate

C_p = Paging cost

Paging cost (C_p) is taken as unity. Cost has been calculated using the above equation.

V. Numerical Analysis

Figure 4 illustrates a geographical area having 4 location areas of different cells. A user crosses these location areas in the line of Gauss Markov Mobility Model. Simultaneous method, Sequential scheme and Bloom filtering method are used to calculate the paging cost and the best one which entails least cost is found out. . It is assumed that while a user is present in each LA, it is expected to experience a call rate of 5 calls/hr.

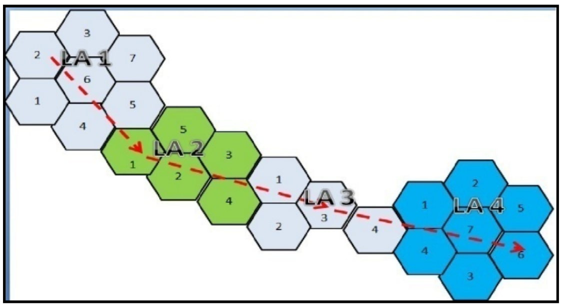

Fig. 4 Location Areas a user crosses

A. Simultaneous Paging

The above figure depicts a user crossing 4 LAs having 7, 5, 4 and 7 cells respectively. Paging cost is calculated using equation 2. Cost of paging each cell is taken as unity. Figure 5 illustrates the paging cost incurred when simultaneous paging method is used.

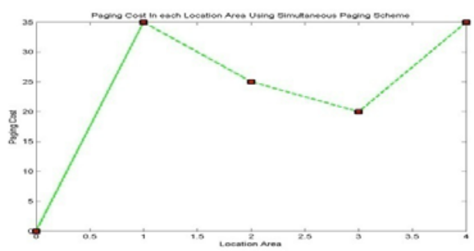

Fig. 5 Paging Cost incurred using simultaneous paging scheme

B. Sequential Paging

The high paging cost observed in the simultaneous paging method is reduced by adopting the sequential paging scheme. This is illustrated below.

1) Location Area 1:

C1 = {1, 2, 3, 4, 5, 6, 7}

Pi = {.2, .2, .15, .1, .05, .14, .16}

Number of Partition Zones (w1) = 3

Partition Zones:

Z1 = {1, 2}, Z2 = {7, 3}, Z3 = {6, 4, 5}

Number of cells in each paging zone:

N1 = 2, N2 = 2, N3 = 3

Zone Location Probabilities: P1 = .2 +.2 = .4

P2 = .16 + .15 = .31

P3 = .14 + .1 + .15 = .29

2) Location Area 2:

C2 = {1, 2, 3, 4, 5}

Pi = {.3, .3, .1, .05, .25}

Number of Partition Zones (w2) = 2

Partition Zones:

Z4 = {1, 2}, Z5 = {3, 4, 5}

Number of cells in each paging zone:

N4 = 2, N5 = 3

Zone Location Probabilities: P4 = .3 + .3 = .6

P5 = .1 + .05 + .25 = .4

3) Location Area 3:

C3 = {1, 2, 3, 4}

Pi = {.2, .3, .1, .4}

Number of Partition Zones (w3) = 2

Partition Zones:

Z6 = {1, 3}, Z7 = {2, 4}

Number of cells in each paging zone:

N6 = 2, N7 = 2

Zone Location Probabilities: P6 = .2 + .1 = .3

P7 = .3 + .4 =.7

4) Location Area 4:

C4 = {1, 2, 3, 4, 5, 6, 7}

Pi = {.2, .2, .15, .1, .05, .14, .16}

Number of Partition Zones (w4) = 2

Partition Zones:

Z8 = {1, 2, 3}, Z9 = {4, 5, 6, 7}

Number of cells in each paging zone:

N8 = 3, N9 = 4

Zone Location Probabilities: P8 = .2 + .2 + .15 = .55

P9 = .1+ .05+ .14+ 16 =.45

It is assumed that a user location is predicted in the first attempt. In LA1, LA2, LA3, LA 4 zones Z1, Z4, Z7, and Z8 are polled respectively in the first attempt. Number of cells paged in each LA is 2, 2, 2, and 3 respectively. If the user is not found in the first attempt then Z2, Z5, Z6, Z9 are polled to track the user. Figure 6 shows the cost incurred in the first attempt when sequential paging scheme is used.

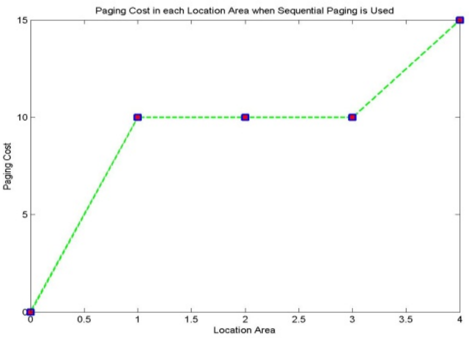

Fig. 6 Paging Cost incurred using Sequential paging scheme in the first attempt

C. Local Cell Prediction Using Bloom Filter

The User which is assigned with a BFID sends it periodically to the base station and the base station stores it as cellvector. Whenever there is a call terminated to the mobile of this user, the BFID of the MU is compared with all the cell vectors of the LA. The cell vectors are obtained from the most recent LU cycle. That cell is paged where equation 1 is satisfied. In plain words the cell where the user resides is filtered out from a group of cells. Instead of all the cells a single cell is paged which decreases the total paging cost by 1/N times where N is the total number of cells in each location area. Of the parameters N, λ and Cp, N becomes 1(duw to exact prediction of cell location), Cp is assumed to be unity. Thus Paging cost is dependent only on the call arrival rate. Greater the call arrival rate, higher is the paging cost. The cost incurred in this technique is shown in figure 7.

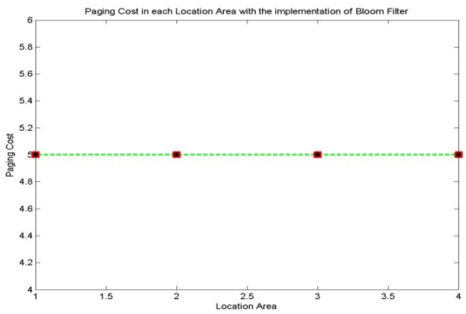

Fig. 7 Paging Cost incurred using Bloom Filter

Figure 8 gives a comparative view of the costs obtained in all the three strategies.

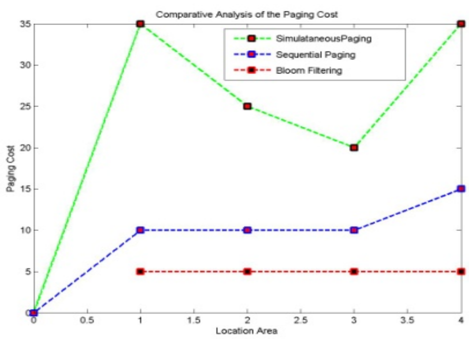

Fig. 8 Comparative Analysis of the Paging Strategies

VI. Conclusions

This Paper has made a numerical analysis of Simultaneous paging, Sequential paging and Bloom filtering mechanism and computed the paging cost incurred in all the three cases. It is found that Bloom Filtering is more effective in reducing the paging cost to a greater extent as compared to the other two. Overhead cost penalty for a Bloom filter implementation is very low. Local prediction of the cell makes efficient utilization of the bandwidth and removes the storage and processing requirements of mobile devices. This paging scheme provides an alternative paradigm on location tracking.

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