Dynamic Location Management with Variable Size Location Areas

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Abstract

This paper introduces a dynamic location management algorithm with variable size location areas(LAs), which helps in reducing location update(LU) cost and hence total location management cost. Basically there are two types of location management strategies – Static and Dynamic. In the static strategy (used in GSM), LAs consist of static and arbitrarily defined collections of cells, which do not take into account individual subscriber's mobility pattern and hence these LAs remain same for all the subscribers. Since mobility pattern of an individual subscriber may differ significantly, this approach is far from optimal. Proposed location management algorithm uses the mobility history of individual subscribers to dynamically form individualized LAs based on his previous movements from cell to cell. It defines the size of LAs based on subscriber's speed and call arrival probability. An activity-based mobility model is developed to test the proposed algorithm and the performance of this algorithm is compared with other algorithms, like fixed location strategy, grid-based location management strategy and dynamic location management algorithm. Overall, the proposed algorithm incurred significantly lower location management cost, in terms of signaling messages generated, as compared to all other algorithms.

1. Introduction

Cellular mobile phone network consists of a group of fixed base stations (BS) covering the service area and interconnected by a fixed backbone network. The coverage area of one base station is referred to as a cell.

The task necessary to manage individual communication session in a cellular network can be divided into three categories; call processing, mobility management and radio resource management. The main task of mobility management is location tracking. In the current cellular systems, networks are partitioned into LAs, where each LA may consist of one or more cells.

Two fundamental operations associated with a LA are:

- **Location Update (LU):** When a subscriber enters a new LA, his location is updated so that any incoming call to that subscriber can thus be routed to the correct LA.
- **Paging:** Network uses paging to alert the mobile subscribers (MS) of an incoming call and to get the exact location of the MS. Paging messages are broadcasted in the current LA of the MS.

Paging and LU signaling take up valuable bandwidth in the wireless network. There is an inherent tradeoff between the costs of LU and paging. This has led to extensive research activity on the important area of Location Management. Existing Location Management schemes can be broadly categorized into two types: *Static* and *Dynamic*. Moreover, there are various strategies, such as fixed LA based, grid based, and dynamically defined LA based.

In this paper, we propose a location management scheme where with each LU message from a MS, a LA is defined for the MS based on subscriber's mobility history. As long as a mobile moves within its current LA, no update message is triggered. Only when a mobile moves out of its present LA, a LU is triggered and a new LA is defined for the MS. This algorithm also considers speed and call arrival probability of the subscriber to define the LA size.

The rest of the paper is organized as follows. Section 2 presents a brief review of the earlier works done on location management strategies. Section 3 describes the proposed algorithm in detail. Simulation model and experimental results are presented in section 4, overheads comparisons are also done there in this section. Finally, section 5 concludes the paper.

2. Previous works on location management

Current cellular networks are partitioned into a number of LAs. Mobile terminal performs a LU whenever it enters a new LA. When a call arrives, the network locates the

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mobile terminal by simultaneously paging all the cells within the current LA of the mobile terminal.

The *dynamic location management* algorithm [7] attempts to utilize the mobility history of the subscriber to dynamically create LAs for individual subscribers, and to dynamically determine the most probable paging area. This algorithm performs well for those users whose mobility pattern is not very random.

In *grid-based location management* scheme [8], mobile updates its location only when it changes its grid (LA), which is nothing but a collection of cells where the cell to which mobile is registered, is at the center of the grid. This method is useful over static LA partitioning method when mobile user is moving back and forth at the boundary of two LAs. This scheme is not so useful where the user is moving in one direction (highway) only.

3. Proposed algorithm

3.1. Basic concepts

The following data structures are used in our algorithm:

- A graph to store the movement history of the subscriber.
- **S_Time:** time when the subscriber entered the LA.
- **E_Time:** time when the subscriber left the LA.
- **Cells_Crossed:** number of cells crossed within LA.
- **Prev_Speed:** Previous speed of the mobile device.
- **Cur_Speed:** Current speed of the mobile device.
- **PrevCallArrProb:** Previous call arrival probability.
- **CurCallArrProb:** Current call arrival probability.
- **LA_p:** Location area size in the p^{th} updation.
- **LA_{def}:** Default location area size.

Speed is calculated as [Cells_Crossed/(E_Time-S_Time)].
SpeedDiffRatio=(Cur_Speed-Prev_Speed)/Prev_Speed.
CallArrDiffRatio=(CurCalArrProb-PrevCallArrProb)/
PrevCallArrProb.
$LA_p=LA_{p-1}*(1+\text{SpeedDiffRatio}-\text{CallArrDiffRatio})$.

The user profile will be stored as a graph where the nodes represents visited cells and the link represents transition between cells. The value of the node indicates the traversal frequency of that node. If the user traverses a new cell but the new node can not be added to the graph, then a replacement policy can be used like *least traversed node* can be replaced by the newly visited node.

A LU is triggered whenever a subscriber enters a new cell, which is not part of the previous LA or when the mobile station is first powered on, in a cell, then a new LA is formed as described in the algorithm below.

3.2. Algorithm description

Various algorithms used to simulate the proposed location management scheme are presented in this section.

DynLocMgt()
Begin
- Call FormCellularNetwork() // Cellular Network is formed and different regions are defined in that.
- Call DefinePathsbetweenRegions() // Path is defined between all the regions
- Create a child process

  If (Child process)
  - Call GenerateCalls() // generates the calls

  End If
  Else (Parent process)
  - Call ActbasedMobilityModel() // simulates mobility model

  End Else

End DynLocMgt

FormCellularNetwork()
Begin
- A Cellular Network of 100 cells is formed and each cell is assigned an identity
- Form different regions like home, office, market, etc.

End FormCellularNetwork

DefinePathsbetweenRegions()
Begin
- Define the path between different regions

End DefinePathsbetweenRegion

GenerateCalls()
Begin
Repeat // Infinite loop
- Get current time
- Generate the probability of call arrival
- Check for call from the call arrival pattern matrix

  If(A call is to be generated)
  - Send a signal to ActbasedMobilityModel process

  End If
- Sleep for 30 minutes

End Repeat
End GenerateCalls

ActbasedMobilityModel()
Begin
- Call FormLA(CurrentCell_Id) // Form a default LA

Repeat // Infinite loop
- signal(SIGUSR1, Paging) // Paging takes place whenever a call is generated
- Get the current slot number
- Generate the probability of moving from one region to another

- Find out the next activity number based on current slot number, current region and probability
- Get next region to go using activity number assignment matrix
- Call MoveReg1toReg2(R1,R2) // move from R1 to R2
- Sleep until next slot starts

End Repeat
End ActbasedMobilityModel

Paging
Begin
- Send page message to all the cells in the current LA
- Mobile device send back the cell id of the current cell
- Paging cost is increased by the number of cells paged

End Paging

MoveReg1toReg2(R1,R2)
➢ R1: Old region
➢ R2: New region
Begin
- Find out the path from R1 to R2

Repeat
- Finds out the next cell in the path from R1 to R2

If (Cell does not belong to current LA) // LU
- Call FormLA(Cell_Id) // form a new LA
- Increase the Location Update cost by one

End If
- Get speed of the subscriber in the current cell
- Calculate sleep time and sleep for that much amount of time

Until R2 is reached
End MoveReg1toReg2

FormLA(CurrentCell_Id)
➢ CurrentCell_Id: Current Cell Identification Number
Begin
If (Current cell has not been visited previously)
- Make a default LA such that the current cell remains the center cell of the newly formed default LA

End If
Else // Current cell has been visited previously
- Call DefineLAsize() // Calculate the new LA size
- Include the current cell into the newly formed LA
- Insert the current cell into the Queue

Repeat
- Delete an element from the Queue and assign it to CELL.
- Find out the average of the number of transitions from CELL to all the neighboring cells
- Include all the neighboring cells for which the number of transitions from CELL to that cell is more than or equal to the average, into the newly formed LA and also insert it into the Queue until the size of the newly formed LA reaches the defined size or all the neighboring cells are included

Until the Queue is empty
End Else
End FormLA

DefineLAsize()
Begin
- Calculate relative change in speed
- Calculate relative change in call arrival probability
- Calculate the new LA size as described above in section 3.1

End DefineLAsize

4. Simulation details

4.1. Simulation model

4.1.1. Activity-based mobility model: An activity is equivalent to a trip purpose, which is selected based on the previous activity and the current time period. The probability of transition from one activity to another uses the activity transition matrix as shown in Fig. 2.

4.1.2. Call arrival pattern: It has been observed that among all the calls generated to a subscriber during a whole day, 20 percent calls are generated in between 00:00 to 08:00, 50 percent calls are generated in between 08:00 to 18:00 and remaining 30 percent calls are generated in between 18:00 to 24:00. Based on this, the call arrival probability is shown in Table 1.

Table 1 Call arrival probability

Time of day	Probability of incoming calls
00:00 to 08:00	0.20
08:00 to 18:00	0.50
18:00 to 24:00	0.30

4.1.3. System description: For the simulation purpose we have assumed a cellular network of 100 cells where the cells are square in shape. Some regions within the cellular network are also defined like home, office, gym, friend's home and market as shown in Fig. 1. The whole day is divided into slots as shown in Table 3. Activity-based mobility model as defined above is used to model the mobility of the subscriber. Activities are assigned number as shown in Table 2. For each activity the time period during which they can be generated is shown in Table 4

Activity transition matrix as shown in Fig. 2 defines the probability of transition from one activity to another.

Following are the assumptions we have made:
O – Office, G – Gym, H – Home, FH – Friend's home, M - Market

Total location management cost is calculated as:

Cost = C * N_{lu} + N_p

Here Cost is the total location management cost. N_{lu} is the number of LU messages generated. N_p is the number

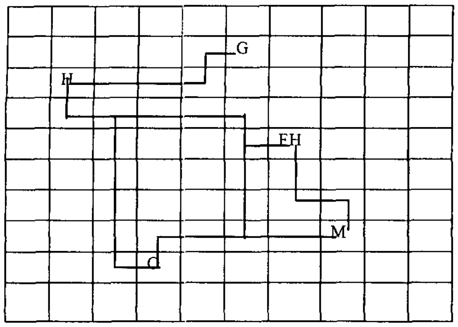

Figure 1. Cellular network

of cells paged. C is a constant representing the relative cost of update to pages and is taken as 5, roughly representative of the approximate size and number of signaling messages required by a LU as compared to a paging message.

Table 2. Activity number assignment

	H	O	G	FH	M
H		0	1	2	3
O	4			5	6
G	7				
FH	8				9
M	10	11		12	

Table 3. Slot number assignment

Time Period	Slot
06:00 – 07:00	0
07:00 – 08:00	1
08:00 – 09:00	2
09:00 – 10:00	3
10:00 – 11:00	4
11:00 – 12:00	5
12:00 – 13:00	6
16:00 – 17:00	7
17:00 – 18:00	8
18:00 – 19:00	9
19:00 – 20:00	10
20:00 – 21:00	11
21:00 – 22:00	12

4.2. Experiments performed

Simulations are done to simulate the mobile user mobility and call arrival pattern for 15 consecutive days. LU, paging and total location management cost after each day is stored into a file. Graphs are plotted to compare the LU, paging and total location management cost of the proposed algorithm with three other algorithms as shown in the following section.

Slot →

Activity number ↑		0	1	2	3	4	5	6	7	8	9	10	11	12
Home	0			.7										
	1	.7	.85									.05		
	2				.4	.3	.2			.6	.3	.1		
	3		.1	.2	.25	.2				.2	.5	.8	.1	
Office	4										.8			
	5										.05			
	6										.15			
Gym	7		.95	1										
Friend's home	8					.6	.8	.95		.3	.2	.5	.8	
	9					.05				.5	.6	.2	.2	
Market	10			.5	.4	.4		.8			.5	.6	.8	1
	11			.05										
	12				.3	.3		.2			.2	.1		

Figure 2. Activity transition matrix

Table 4. Activity timing matrix

Activity	Timing
0	08:00 – 09:00
1	06:00 – 08:00, 19:00 – 20:00
2	09:00 – 12:00, 16:00 – 20:00
3	07:00 – 11:00, 17:00 – 21:00
4	18:00 – 19:00
5	18:00 – 19:00
6	18:00 – 19:00
7	07:00 – 09:00
8	10:00 – 13:00, 17:00 – 21:00
9	10:00 – 11:00, 17:00 – 21:00
10	08:00 – 12:00, 18:00 – 22:00
11	08:00 – 09:00
12	09:00 – 12:00, 18:00 – 20:00

4.3. Experimental results

The proposed location management algorithm was compared with other location management algorithms namely fixed LA strategy, grid-based strategy and dynamic location management strategy. The overall number of LUs and cells paged were calculated, as well as the total location management cost. Simulation results show that dynamic algorithm with variable size LA outperforms fixed LA strategy, grid-based strategy and dynamic location management in terms of LUs, as shown in Figs. 3, 6 and 9. It is observed that there is hardly any difference in the number of cells paged as shown in Figs. 4, 7 and 10. So dynamic algorithm with variable size LA outperforms all other schemes in terms of total location management cost, as shown in Figs. 5, 8 and 11.

4.4. Comparison of overheads

LA_{size} is size of the LA, n is the number of cells in the cellular network and e is the number of edges in the graph.

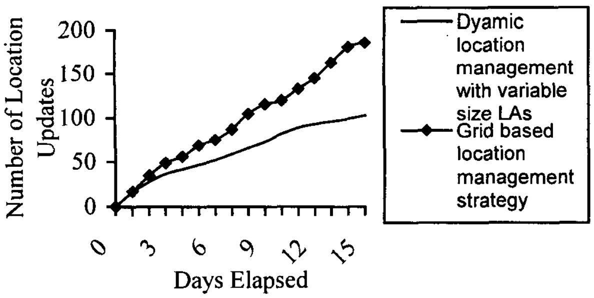

Figure 3. Comparison for number of LUs

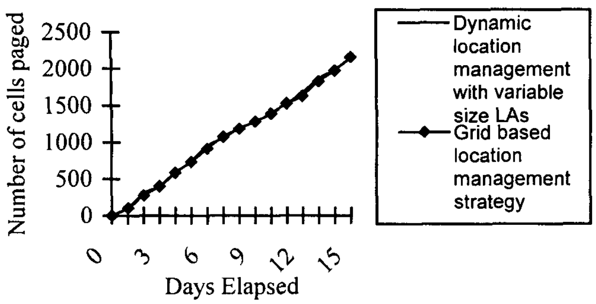

Figure 4. Comparison for number of cells paged

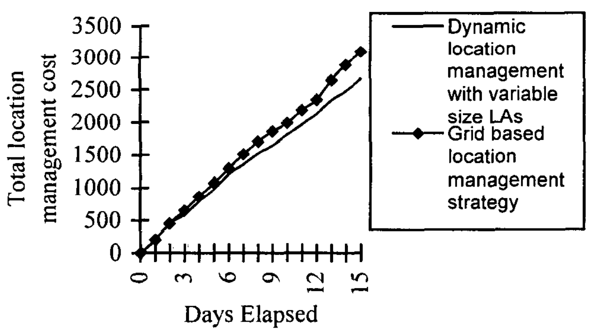

Figure 5. Comparison for total location management cost

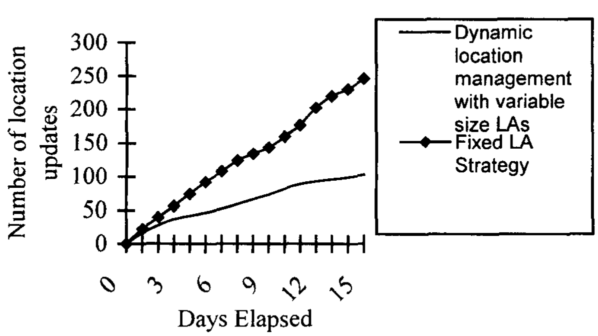

Figure 6. Comparison for number of LUs

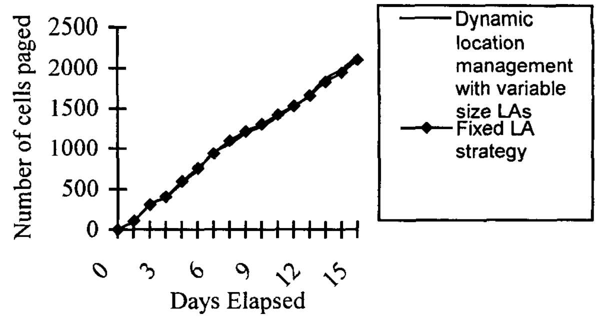

Figure 7. Comparison for number of cells paged

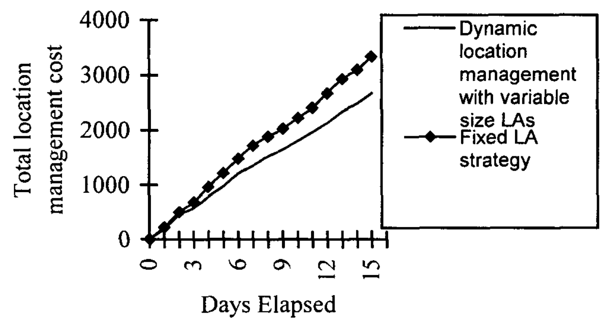

Figure 8. Comparison for total location management cost

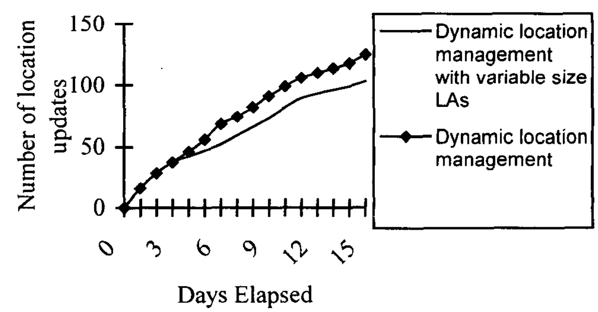

Figure 9. Comparison for number of LUs

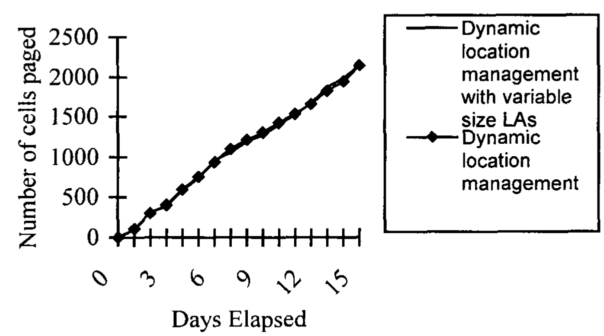

Figure 10. Comparison for number of cells paged

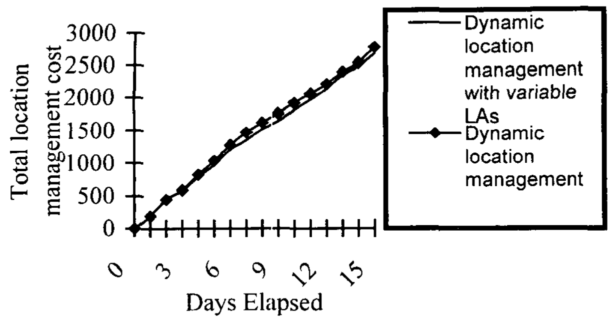

Figure 11. Comparison for total location management cost

Table 5. Time and space complexity comparison

Algorithm	Time complexity	Space complexity
Fixed LA strategy	O(1)	O(1)
Grid-based strategy	$O(LA_{size})$	$O(LA_{size})$
Dynamic location management	$O(LA_{size})$ + O(e)	$O(LA_{size})$ + O(n)
Dynamic location management with variable size LAs	$O(LA_{size})$ + O(e)	$O(LA_{size})$ + O(n)

4.5. Comparison between our algorithm and Dynamic location management algorithm

4.5.1. Similarities: Both the algorithms attempts to utilize the mobility history of the subscriber to dynamically create LAs for individual subscribers.

4.5.2. Differences: In our algorithm LA size is not fixed. It is a function of the speed and call arrival probability of the user. On the other hand, in Dynamic location management algorithm, LA size is fixed.

Dynamic location management algorithm uses information like average duration spent in each visited cell to define the most probable paging areas. In this algorithm, paging area is same as LA.

4.5.3. Additional overheads as compared to Dynamic location management algorithm:

- Additional processing power is required to calculate the speed of the subscriber.

5. Conclusion

Dynamic location management algorithm with variable size LAs generates LAs for individuals based on his profile. It also considers speed and call arrival probability of the subscriber and based on that defines the LA size for that subscriber. Since this algorithm tries to minimize location management cost for individuals, it significantly outperforms static algorithms, but it requires more processing power as compared to static algorithms.

Since wireless bandwidth is a scarce resource and is fixed, a large part of that bandwidth is wasted due to location management overhead. This algorithm reduces this overhead at the cost of some additional logic and memory in the mobile station and network. These additional logic and memory can be incorporated into the mobile station and network quite easily but wireless bandwidth cannot be increased.

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