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A Simulated Annealing Approach to Reporting Cell Planning Problem of Mobile Location Management

Falguni Mehta[1], Prashant Swadas[2]
[1] Dept. of Computer Engineering, ISTAR (offering P.G. Engineering Programs on behalf of B.V.M. Engineering College), V.V.Nagar, Anand, Gujarat, India.
Email: falguniam@yahoo.com
[2] Dept. of Computer Engineering, B.V.M. Engineering College, V.V.Nagar, Anand, Gujarat, India.
Email: prashantswadas@yahoo.com

***Abstract*— In this paper, Reporting Cell Planning Problem of Location Management in mobile computing system is addressed. In reporting cell planning, some cells in the network are designated as reporting cells and other cells are non-reporting cells. Mobile terminals update information about its current location in a database when it enters into a new reporting cell. The goal of the reporting cell planning problem is to select subset of cells in the network as reporting cells such that the total location management cost is minimized. The selection of a set of reporting cells is a combinatorial optimization problem. In this paper, a new approach based on simulated annealing meta-heuristic is presented to obtain near to optimal solution for the reporting cell planning problem.**

***Keywords*—Simulated Annealing, Reporiting Cell Planning, Location Management, Mobile Computing**

I. Introduction

Managing current location information of mobile terminal (MT) in mobile computing system is an important issue of location management (LM). Location management is concerned with tracking mobile user in communication network. Location management supports functions as paging, location updating and connection handover. The handover mechanism guarantees that whenever the MT is moving from one base station area/cell to another, radio connection is handed over to the target base station without interruption. The location update procedure, on the other hand, enables the network to keep track of the subscriber current location within the network, while paging is used to reach the handset to which a call is destined. Location update and paging mechanisms guarantee that the MT can be reached even though there is no continuous active radio link between the MT and network. Each function has a cost associated with it. The total cost of location management is the sum of location update cost and paging cost. The goal of location management is to find a strategy that balance the location update (registration) and paging (search) operation, so as to minimize the total cost of mobile terminal location tracking.

Two simple location management approaches are always-update and never update (always search). In always-update approach, MT updates its location each time it moves into a new cell and search operation needs only database lookup. The update cost is very high for this approach but searching cost is negligible. In the never-update approach, MT never performs location update operation. When a call arrives, all cells are searched to locate the user which results in very high searching cost and zero update cost. Location Area Planning and Reporting cell planning are other location management strategies.

Location area (LA) planning strategy is currently adopted by GSM network. In Location area approach, the service coverage area is partitioned into location areas. Each location area consists of several contiguous cells. The base station of each cell broadcasts the identification of the location area to which the cell belongs. Therefore, a mobile terminal knows which location area it is in. A mobile terminal will update its location whenever it moves into a cell that belongs to a new location area. On a call arrival for a particular mobile terminal, the cellular system will page all cells within the LA where mobile terminal reported at its last update. The key issue with the location area scheme is how to define location areas such that the total location management cost is minimized.

Another popular location management scheme is Reporting cell (RC) Planning [1, 2]. The Reporting Cell planning approach designates a subset of cells as reporting cells. A reporting cell periodically transmits a short message to identify its role. A mobile terminal can learn whether or not it is in a reporting cell by listening to the message. A mobile terminal will update its location when it enters a new reporting cell. When an incoming call arrives for a mobile terminal, the cellular system will page all cells within the vicinity of the reporting cell that was last reported by the mobile terminal. The key issue of the reporting cell planning scheme is how to select a set of reporting cells to minimize the total location management cost. For N cells network the solution length is N bits and each bit position in the solution can take value of non-reporting or reporting cell. For N cells network, solution space of the problem consists of total 2^N possible solutions. For very large value of N, it was shown in [3] that finding a solution having minimum location management cost, is an NP-complete problem.

In references [1, 2], heuristic methods to find near to optimal solution is described.

In this paper, a new approach based on simulated annealing is presented to obtain near to optimal solution for reporting cell planning problem. The remainder of the paper is organized as follows. Section II is a description of the location management cost functions that can be used to lead to the best solution. Section III gives an overview of simulated annealing technique. Section IV describes a simulated annealing algorithm for reporting cell planning problem. Simulation results for different test networks are presented in section V which is followed by conclusion in section VI.

II. Location Management Cost

To determine *average cost* of a location management in reporting cell planning strategy, one can associate a cost component to each *location update* performed, as well as to each *paging* of a cell. The most common cost component used is the wireless bandwidth. That is, the wireless traffic from mobile terminals to base stations (and vice-versa) during location updates and paging. For example, the following simple equation can be used to calculate the total cost of a location management strategy:

$$\text{Total Cost} = C*N_{LU} + N_P \quad (1)$$

Where N_{LU} denotes the number of location updates performed during time *T*, N_P denotes the number of paging performed during time *T* and *C* is a constant representing the cost ratio of location update and paging**.** Studies showed that the cost of location update is usually much higher than the cost of paging [4]. The value of *C = 10* is used in this study.

Wireless network consists of cells. These cells are usually represented as hexagonal cells (Figure 1), resulting in six possible neighbors for each cell. In a simple cellular system, there is one base station per cell and a large number of base stations in the system. In reporting cell approach, a subset of base stations called reporting centers is selected among all base stations. The cells associated with these base stations are referred to as reporting cells. The reporting centers periodically transmit short messages on the wireless channel to identify their roles. Thus, a MT can find out whether or not it is in a reporting cell by listening to the transmitted message.

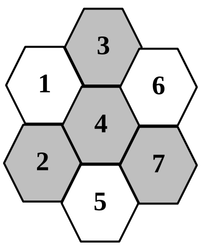

Figure 1. 7 Cells network with reporting cells

The vicinity of reporting cell *i* is the collection of all non-reporting cells that are reachable from reporting cell *i* without crossing another reporting cell. Also, cell *i* is in the vicinity of itself. Thus, each reporting cell has a number of cells as its vicinity. When a call arrives for a mobile terminal, the search is restricted within the vicinity of reporting cell to which mobile terminal last reported. An example in Figure 1 shows a network configuration in which, cells *2, 3, 4, and 7* are chosen as reporting cells (shown as shaded cell). Cell *1, 5,* and *6* are non-reporting cells. Cell *2* is directly connected to non-reporting cells *1* and 5, and there are no reporting cells between them. Thus, the vicinities of cell *2* are cells *1, 5,* and *2*. For the same reason, the vicinities of cell *3* are cells *1, 6* and *3*; the vicinities of cell *7* are cells *5, 6* and *7*; the vicinities of cell *4* are cells *1, 5, 6* and *4*.

Each non-reporting cell can also be assigned a vicinity value. However, it is clear that a non-reporting cell may belong to the vicinity of several reporting cells, which may have different vicinity values. For example, in Figure 1, cell *1* belongs to the vicinity of reporting cells *2, 3,* and *4*, with vicinity values *3, 3,* and *4* respectively. For location management cost evaluation purposes, the maximum vicinity value will be used. As such, in this case, the vicinity value of *4* is assigned to cell *1*.

In RC planning, with each cell *i* a *movement weight*, and *call arrival weight*, denoted w_{mi} and w_{ci}, respectively are associated. The movement weight represents the frequency or total number of movements into a cell, while the call arrival weight represents the frequency or total number of call arrivals within a cell. Formulas for the total number of location updates and paging (performed during a time period ***T***) are given as follows:

$$N_{LU} = \sum_{i \in S} w_{mi}$$
$$N_P = \sum_{j=0}^{N-1} w_{cj} \cdot v(j) \quad (2)$$

Where w_{mi} denotes the movement weight associated with cell *i*, w_{cj} denotes the call arrival weight associated with *cell j*, *v(j)* denotes the vicinity value of *cell j*, *N* denotes the total number of cells in the network, and *S* denotes the set of reporting cells in the network. Using equation (1) and (2), the formula to calculate the location management cost of a particular reporting cells configuration is given as follows:

$$\text{Total Cost} = C*\sum_{i \in S} w_{mi} + \sum_{j=0}^{N-1} w_{cj} \cdot v(j) \quad (3)$$

III. Simulated Annealing

Simulated Annealing is a technique proposed by Kirkpatrick, Gelatt and Vecchi (1983) for finding the global minimum of a cost function that may possess several local minima. It is an optimization procedure based on the physical process of annealing. Annealing is a process in which organized crystals are formed. During this process a physical substance is melted by raising to very high temperature, then cooled down slowly so that a long time is spent at each temperature drop which allows the molecules of substance to reach equilibrium state. If this is not done, and substance is allowed to get out of equilibrium, the resulting crystal will have many defects, or substance may form a glass, with no crystalline order and only metastable, locally optimal structure will be formed.

The goal of this annealing process is to produce a stable minimal-energy final state. In this process, physical substance usually moves from higher energy state to lower energy state. But there is some probability that a transition to higher energy state will occur. This probability is given by the function:

$$P = e^{-\Delta E/kT} \quad (4)$$

Where ΔE is the positive change in the energy level, T is the temperature, and k is Boltzmann's constant. In this annealing process, the probability that uphill moves are accepted is more in the beginning of the process. This probability decreases as the temperature decreases. This annealing process is used to define analogous process of simulated annealing.

The general procedure for the SA algorithm can be summarized as follows:

1. Evaluate initial solution and make it current solution.
2. Initialize temperature $T = T_0$ according to annealing schedule. T_0 is the initial temperature.
3. Randomly select a new neighbor solution by modifying the current solution.
4. Compare the new solution with the current solution.

   If *new solution is better than current solution* then
   Accept the new solution as current solution.
   Else
   Accept or reject the solution based on the probability $P=e^{-\Delta E/T}$.
5. Repeat step 3 and 4 until system reaches equilibrium state (In practice repeat the process n times for large value of n).
6. Decrease temperature by an amount α (cooling factor) and repeat the above steps, stop when system reaches to frozen state.

In the above procedure, ΔE represents difference between cost function of new solution and the current solution. The temperature T is managed by annealing schedule that controls the execution of the algorithm.

For successful implementation of simulated annealing, two items need to be defined carefully. The first is a method that creates a new solution and second is annealing schedule. The annealing schedule has three components. The first is the initial temperature (T_0), second is the criteria that decide when the temperature should be reduced, and third is the amount by which the temperature will be reduced each time it is changed and known as cooling factor α.

IV. Simulated Annealing Algorithm For Reporting Cell Planning Problem

The simulated annealing algorithm to solve the reporting cell planning problem is described in this section. In this algorithm energy (E) or objective function is analogous to location management cost of N-bits solution of the problem.

ALGORITHM (*Simulated Annealing for Reporting Cell Planning)*

Begin
 Make an Initial Solution, namely S.
 Calculate Initial Temperature T_0.
 Let $T=T_0$.
 Let Stopping condition $t_{Stop} = t_S$.
 Calculate cost function of solution S denoted by E(S).
 While $t_{Stop} > 0$ **do**
 Begin
  New_Solution_Accepted = FALSE.
  for i= 1 to M **do**
  Begin
   Generate new solution S_{next} by modifying S.
   Calculate cost function of solution S_{next} denoted by $E(S_{next})$.

   Let $$\Delta E = \frac{(E(S_{next}) - E(S)) \times 100}{E(S).}$$

   If $\Delta E < 0$ **then**
    Let $S = S_{next}$ and $E(S) = E(S_{next})$
    New_Solution_Accepted= TRUE.
   Else
    Generate a random number namely R between 0 and 1.0.
    If $R < e^{(-\Delta E / T)}$ **then**
     Let $S= S_{next}$ and $E(S) = E(S_{next})$.
     New_Solution_Accepted=TRUE.
    End If
   End If
  End of for
  If New_Solution_Accepted = TRUE **then**
   $t_{Stop} = t_S$.
  Else
   $t_{Stop} = t_{Stop} - 1$.
  End If
 Let T = α * T.
 End of While
End.

In above algorithm *M* is a positive integer and *α* is a cooling factor. Typical values of α lies between *0.85* and *1*. In above algorithm, as value of ΔE, only relative improvement of the new solution over current solution is considered instead of absolute difference of new and current solution's cost functions.

After describing the entire SA algorithm some key aspects presented in the algorithm need to be discussed.

A. *Make the Initial Solution, namely S.*

Making initial solution is the first step of SA algorithm. The following procedure is used to generate initial solution.

For each cell *i* of the network do the following:

If $w_{mi} < w_{ci}$ then

Make cell i a reporting cell.

Else

If $(w_{mi} / w_{ci}) < 2$ then

Make cell i a reporting cell.

Else

Make cell i a non-reporting cell

Where w_{mi} represents the frequency or total number of movements into a cell *i*, and w_{ci} represents the frequency or total number of call arrival into a cell *i*.

B. *Calculating Initial Temprature T_0.*

Initial temperature calculation is very important, because if it is too high, then it may take too long to reach the result. On the other hand, if the initial temperature is taken too small, then the algorithm does not have the freedom of making sufficient number of random moves to visit different local minima.

Here, the initial probability (P_a) of accepting an average cost solution is considered equals to *0.5*.

To calculate initial temperature T_0, first *Z* solutions are generated randomly. The average of cost functions of all *Z* randomly generated solutions, denoted by $E(S_{Avg})$ and the average costs difference of all Z solutions denoted by ΔE_{Avg} are calculated. Formula for initial temperature is given as follows.

$$T0 = \frac{-\Delta E_{Avg} \times 100}{E(S_{Avg}) \times \log(P_a)} \tag{5}$$

C. *Generating S_{next} be modifying S.*

New solution S_{next} is generated by modifying the current solution *S*. To generate S_{next}, any *n* random cells from total *N* cells of solution *S* are selected. States (reporting or non-reporting) are assumed randomly for these *n* cells. Here $n << N$ and $n = N/9$ have been used. For remaining *N minus n* number of cells, their states values are kept same as solution *S*.

D. *Stopping Criteria*

The algorithm must stop if it cannot find better solutions anymore. In this implementation, the algorithm stops if there is no change in quality of the solution over period of t_S iterations.

V. Simulation Results

In this section, simulation results of simulated annealing approach to reporting cell planning problem are presented for two different test networks with 19 and 36 cells. For this study the test networks used are same as used in earlier studies of reporting cell planning given in references [1, 2]. In order to find effectiveness of SA approach to reporting cell planning problem, the total cost of always-update and never-update strategies are also calculated for each test network. For SA scheme the algorithm was run for 50 times and the best reporting cell configuration having near to minimum LM cost for each test network are presented.

A. *19 Cells Network*

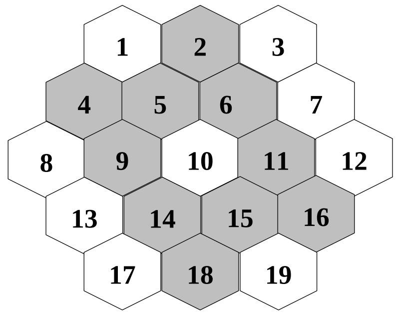

Figure 2. Best reporting cells configuration for 19 cells network obtained by SA.

TABLE 1.
Data Set for 19 Cells Network

Cell	w_{mi}	w_{ci}	Cell	w_{mi}	w_{ci}
1	96	27	10	239	55
2	27	20	11	28	6
3	134	2	12	271	2
4	7	1	13	144	27
5	46	4	14	12	16
6	43	4	15	66	29
7	64	15	16	42	71
8	32	8	17	88	22
9	40	1	18	28	59
			19	96	14

This network is shown in Figure 2, with cell attributes shown in Table 1. Note that, in each row two attributes are given: number of incoming users (w_{mi}) and number of arrived calls (w_{ci}). Average calculated value of initial temperature (T_0) for the shown best reporting cell configuration was 27.

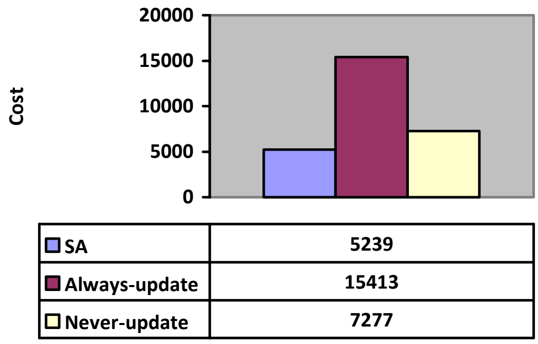

Figure 3. Comparisons of cost for 19 cells network

From Figure 3, it can be seen that the simulated annealing algorithm obtained better solutions than always-update and never-update strategies.

B. 36 Cells Network

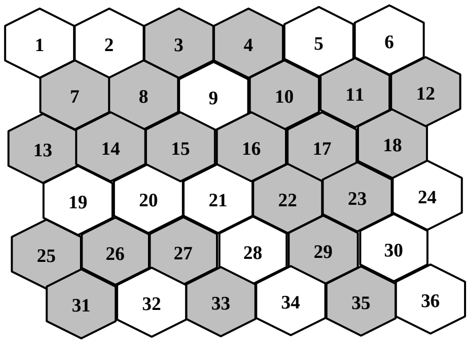

Figure 4. Best reporting cells configuration for 36 cells network obtained by SA.

This network is shown in Figure 4, with cell attributes shown in Table 2. Average calculated value of initial temperature *(T_0)* for the shown best reporting cell configuration was 30.

TABLE 2.
Data Set for 36 Cells Network

Cell	W_{mi}	W_{ci}	Cell	W_{mi}	W_{ci}	Cell	W_{mi}	W_{ci}
1	1039	714	13	507	238	25	16	328
2	1476	120	14	603	964	26	332	255
3	262	414	15	1479	789	27	1203	393
4	442	639	16	756	457	28	1342	370
5	1052	419	17	695	708	29	814	721
6	1902	332	18	356	825	30	747	769
7	444	494	19	1945	462	32	146	17
8	1103	810	20	1368	682	32	904	265
9	1829	546	21	1850	241	33	359	958
10	296	221	22	1131	700	34	1729	191
11	793	856	23	236	23	35	190	551
12	317	652	24	1622	827	36	1907	467

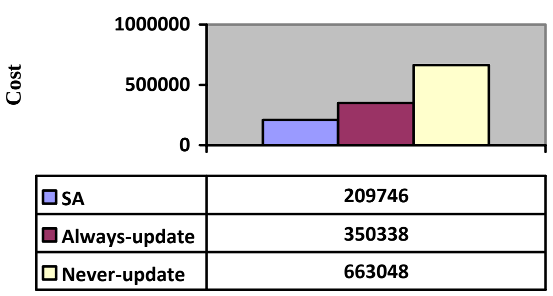

Figure 5. Comparisons of cost for 36 cells network

Results in Figure 5 for 36 cells network shows that SA algorithm obtained better solution, compared to the always-update and never-update. This result is better than those obtained by other approaches explained in ref. [2].

The following parameter values were used in simulation for both test networks: $\alpha=0.9$, $t_S = 50$, $M = 2 * N$ where N denotes total number of cells in the network.

VI. Conclusion

In this paper, a new approach based on simulated annealing technique is presented to solve the Reporting Cell Planning Problem of location management in mobile computing system. In reporting cell planning, some cells in the network are designated as reporting cells. A mobile terminal will update its location when it enters a new reporting cell. The goal of reporting cell planning problem is to select a subset of cells as reporting cells in the network such that total location management cost is minimized. Reporting cell planning problem is a difficult combinatorial optimization problem. A simulated annealing meta-heuristic is used to obtain near to optimal solution for a reporting cell planning problem. Simulation results are presented for test networks with 19 and 36 cells. Simulation results shows that simulated annealing algorithm can be effectively used to obtain near to optimal results for reporting cell planning problem. It produce better results than two classical location management strategies – always-update and never-update and also produce results competitive with results obtained by other authors.

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