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PARTITIONING OF MOBILE NETWORK INTO LOCATION AREAS USING ANT COLONY OPTIMIZATION

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Abstract. *Location determination of users in a cellular mobile network is an important issue in the area of location management. One strategy used in location management is to partition the network into location areas, in such a way that the total cost is a minimum. Total cost is the sum of handoff (update) cost and paging cost. Finding the optimal number of location areas and the corresponding configuration of the partitioned network is a difficult combinatorial optimization problem and is NP-complete. In this paper, we use an ant colony optimization method to obtain the optimal number of location areas and the corresponding configuration of the partitioned network. The work could also be useful for location of sensors in wireless sensor networks.*
Keywords: Ant colony optimization, Location management, Mobile computing, Reporting cells, Vicinity value

1. **Introduction.** In mobile communication systems, location area management deals with the location determination of users in a network. One of the strategies used in location area management is to partition the network into Location Areas (LA). Each location area has one or more number of cells. The goal of LA management is to partition the network into a given number of location areas such that the total paging cost and handoff (or update) cost is a minimum. In such partitioning approach, a balance between the handoff cost and paging cost is done with the objective of minimizing the cost of tracking the location of mobile stations.

To do efficient location determination, the network is partitioned into a given number of location areas. The objective behind the partitioning approach is to employ *never update* strategy within the location area; i.e., no location update is needed as the user moves within the same location area. In the same way, when a call arrives, only the cells in the location area are searched to find the user. Location update is performed, when a user moves out to another location area.

This location area management problem addressed in this paper, can be generally stated as: For a given a network of n cells, the objective is to partition the network into a given m location areas, without violating the underlying constraints, and with the objective of minimizing the total paging cost and handoff cost.

The mobile computing is an important area and many papers/reports are available in literature. We discuss some important results that are related to our study. The problem of assigning cells to switches is presented in [1]. In that study [1], the objective is to minimize the sum of handoff traffic cost and the cabling cost. This combinatorial optimization problem was solved by using genetic algorithm, simulated annealing and taboo search in [2]. A comparative study of the solutions obtained using taboo search and simulated annealing using only simple homing is given in [3] and shown that the taboo search performs better than the simulated annealing approach. A double homing approach is presented in [4], and a combining pricing mechanism and simulated annealing is used in [5]. An ant colony approach to obtain the solution to the objective function given in [1] is presented in [6, 7]. In [6], the attractiveness of only call volume is used and simulation result for different number of location areas are presented. In [7], ant colony optimization with local optimization using $k - opt$ technique is presented.

Another objective considered in [8, 9, 10], is to minimize the sum of handoff traffic cost and the paging cost. Simulated annealing, and a combined genetic-neural algorithm were used for the solution [8, 10]. Minimizing the location update subject to a paging bound constraint is studied in [11]. A polynomial time approximate algorithms with the objective of minimizing the sum of handoff traffic cost and paging cost are presented in [12].

Contributions of this paper: We consider the objective that minimizes the sum of paging cost and handoff (or update) cost.

$$Total\ cost \ = \ paging\ cost \ + \ handoff\ cost \tag{1}$$

In the above equation, we divide the total cost by the total number of call arrivals, and call this as *cost per call arrivals* [13, 14]. The problem considered in this paper, is to obtain the optimal number of location areas, for a given network that minimizes the above objective function. We use ant colony optimization method with different attractiveness and obtain the optimal number of location areas. We also present a comparison of the effect of these different attractiveness.

2. **Problem Formulation.**

Let us consider a network with n cells. Associated with each cell j in the network, there are two quantities *cell movement weight* (w_{mj}) and *call arrival weight* (w_{cj}). The movement weight represents the frequency or total number of movement into the cell. Call arrival weight represents the frequency or total number of call arrivals within the cell.

Let the network is partitioned into m location areas. Paging cost is the total of all paging cost of the location areas. Paging cost of a location area is obtained by multiplying the number of cells in the location area with sum of call arrival weight of all the cells in the location area. This is due to the fact that the total number of search/paging performed would be directly related to the call arrival weight of the cells in the location area. If NLA_k is the number of cells in location area k, the paging cost for this location area k (LA_k) is: $paging\ cost\ for\ LA_k \ = \ NLA_k\{\sum_{j\in k}^{n} w_{cj}\}$, for all $j = 1, ..., n$.

If two adjacent cells i and j are in two different location areas, then a cost is incurred every time a handoff between cells i and j [1]. Let $h(i, j)$ be the cost per unit time a handoff occur between cells i and j. This $h(i, j)$ depends on the movement weights of the cells i and j; i.e., (w_{mi} and w_{mj}).

In order to obtain the mathematical expression for the objective function, we define the following variables. Let M_k be the call handling capacity of location area k, and N_k be the maximum number of cells for location area k. Also, $x_{ik} = 1$, if cell i is assigned to location area k; $x_{ik} = 0$ otherwise. $z_{ijk} = x_{ik} * x_{jk}$. $y_{ij} = 1$, if both cell i and cell j are assigned to the same location area; $y_{ij} = 0$ otherwise.

We know that the total cost is the sum of paging cost and handoff cost. Let NLA_k be the number of cells in location area k. The paging cost for this partition is: $paging\ cost = \sum_{k=1}^{m} NLA_k\{\sum_{j\in k}^{n} w_{cj}\}$. The handoff cost is: $handoff\ cost = C * \sum_{i=1}^{n}\sum_{j=1}^{n}(1-y_{ij}) * h(i,j)$. Hence, we have the following objective function

$$Total\ Cost = \sum_{k=1}^{m} NLA_k\{\sum_{j\in k}^{n} w_{cj}\} + C * \sum_{i=1}^{n}\sum_{j=1}^{n}(1-y_{ij}) * h(i,j) \qquad (2)$$

The constraints are: $\sum_{k=1}^{m} x_{ik} = 1$, $y_{ij} = \sum_{k=1}^{m} z_{ijk}$, $\sum_{j=1}^{n} w_{cj}x_{jk} \le M_k$ and $\sum_{j=1}^{n} x_{jk} \le N_k$. Here, $1 \le i, j \le n$, and $1 \le k \le m$. The first constraint ensures that each cell is assigned to only one location area. The constant C represent the cost ratio of update and handoff.

We will explain the objective function further with a small example. Consider the 4×4 network with the values of movement weights (w_{mj}) and call arrival weights (w_{cj}) for all the cells [14]. Consider the partitions of this network into 4 location areas as shown in Figure 1(a). In this, cells $0, 1, 4, 5$ are in location area LA_1, cells $2, 3, 6, 7$ are in location area LA_2, cells $8, 9, 12, 13$ are in location area LA_k, and cells $10, 11, 14, 15$ are in location area LA_k. Also, the number of cells in these location areas are $NLA_1 = 4$, $NLA_2 = 4$, $NLA_3 = 4$ and $NLA_4 = 4$. The paging cost for LA_1 is $NLA_1 * (w_{c0} + w_{c1} + w_{c4} + w_{c5}) = 10732$. In the same way, the paging cost for LA_2, LA_3 and LA_4 are obtained as 5988, 4160 and 9444 respectively.

We know that if two adjacent cells i and j are in two different location areas, then a handoff cost $h(i,j)$ is incurred. The $h(i,j)$ is related to the movement weights w_{mi} of cell i. In the partition shown in Figure 1(a) consider the cell 5. This cell has 6 neighbors and the cell number of these neighbors are 1, 2, 4, 6, 9, and 10. The value of $w_{m5} = 472$. The handoff traffic from cell 5 to its neighbors are obtained by dividing the movement weight w_{m5} by the number of neighbors. So we obtain $h(5,1) = h(5,2) = h(5,4) = h(5,6) = h(5,9) = h(5,10) = 472/6 = 78.67$. In the same way all the values of $h(i,j)$ for $i, j = 1, ..., n$ are obtained. We can see that $h(i,j)$ is non-zero only when the cells i and j are adjacent cells, and they are in different location areas. Otherwise, $h(i,j)$ will be zero.

For this partition given in Figure 1(a), paging cost ($\sum_{k=1}^{m} NLA_k\{\sum_{j\in k}^{n} w_{cj}\}$ is 30324, and the handoff cost ($C * \sum_{i=1}^{n}\sum_{j=1}^{n}(1-y_{ij}) * h(i,j)$) is 48841 with $C = 10.0$. Hence, the total cost for this partition is obtained as 79165. The cost per call arrival is total cost (79165) divided by $\sum_{j=1}^{n} w_{cj}$ (7581), and is 10.4425.

This example shows the combinatorial nature of this location area optimization problem. Hence, we use an ant colony optimization method, with different attractiveness and obtain the optimal number of location areas.

3. **Ant Colony Optimization Methodology.** Ant Colony Optimization (ACO) is one of the methods used to solve difficult combinatorial optimization problems [15, 16]. In our problem, there are n cells in the given network, and this should be partitioned into a given number of location areas (m), such that the total cost is a minimum, and the constraints are satisfied. The key issues in ACO method are the movement of ants (heuristic) and the pheromone update/control. Let i be the cell number that is not assigned to any of the location areas. The probability that an individual ant j, assigns cell i to the location area k is given by

$$p_{ik}^{j} = \frac{(\tau_{ik})^{\alpha} * (\eta_{ik})^{\beta}}{\sum_{k \in m}\{(\tau_{ik})^{\alpha} * (\eta_{ik})^{\beta}\}} . \quad (3)$$

The weighting factor of pheromone (τ_{ik}) is α and the weighting factor (η_{ik}) for the heuristic is β.

The unassigned cell i is assigned to one of the m location areas using the heuristic, known as attractiveness. In our study, we use three different attractiveness by considering (i) only call volume denoted as η_{pik}, (ii) only handoff traffic denoted as η_{uik}, and (iii) both call volume and handoff traffic. These attractiveness are:

$$\eta_{pik} = \frac{1}{(s(k)+1) * \left\{\sum_{j \in LA_k} w_{cj} + w_{ci}\right\}}; \ \eta_{uik} = \sum_{j \in LA_k} B_{ij} * (h_{ij} + h_{ji}) \quad (4)$$

In the above equations, LA_k is the set of assigned cells to location area k so far, $s(k)$ is the number of cells assigned to location area k so far, and h_{ij} is handoff traffic between cell i and j. Another important issue is the selection of starting cell is done by using the *call arrival weight*. The probability of cell i being selected as the starting cell for a location area k is given by p_{ik} and is:

$$p_{ik} = \frac{w_{ci}}{\sum_{j \in LA_k} w_{cj}}, \ 0 \le i \le n . \quad (5)$$

The pheromone update (an important issue in ACO), is done once all the ants generated a partition of the network. The pheromone update information for location area k (τ_{ik}) is: $\tau_{ik}(t+1) = (1-\rho) * \tau_{ik}(t)$. This update procedure uses an evaporation rate ρ (between times t and $t+1$) in order to reduce the effect of past experience and to explore new alternates. Also, $0 < \rho < 1$. The local pheromone update for the ant j is given by: $\tau_{ik}(t+1) = \tau_{ik}(t) + \Delta\tau_{ik}^{j}$. Here, $\Delta\tau_{ik}^{j} = \frac{Q}{L_j}$, if $move(i,k) \in S_j$, and $\Delta\tau_{ik}^{j} = 0$ otherwise. S_j is the set of ant movements for the j-th ant, L_j is the evaluation value of the j-th ant, and Q is the pheromone update constant. By $move(i,k)$, we mean the movement of an ant for assigning cell i to the location area k; ($k = 1, 2, ..., m$). $\Delta\tau_{ik}^{j}$ is the amount of pheromone to be added for the moves.

Ranking Method: In the ranking pheromone update method, the pheromone update is done as: $\tau_{ik}(t+1) = \tau_{ik}(t) + \frac{(w+1-r)}{2}\Delta\tau_{ik}^{r}$. Here $\Delta\tau_{ik}^{r} = \frac{Q}{L_r}$, if $move(i,k) \in S_r$, and $\Delta\tau_{ik}^{r} = 0$, otherwise. Note that here, r is the r-th best ant, S_r is the set of ant movements for the r-th ant, L_r is the evaluation value of the r-th ant and w is the number of best ants used for ranking.

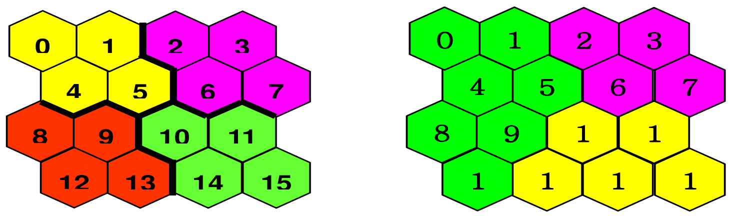
Max-Min Method: This Max-Min strategy introduces upper and lower bounds to the values of the pheromone trails. The allowed range of the pheromone trail strength is limited in the following interval: $\tau_{\min} \le \tau_{ij} \le \tau_{\max}$ for all τ_{ij}. In the next section, we present the simulation results obtained using ant colony optimization for our problem.

4. **Simulation Results and Discussions.** We consider 4×4, 6×6 and 8×8 networks, with the values of w_{mi} and w_{ci} given in [14] in our simulation. The parameters used in our ant colony optimization method are: Population=10; Pheromone control $\alpha = 0.9$; Heuristic Control $\beta = 5$; Pheromone evaporation $\rho = 0.5$; Initial pheromone $\tau_{initial} = 0.001$; Positive weight for update $Q = 1$; Maximum pheromone amount $\tau_{\max} = 9$; Minimum pheromone amount $\tau_{\min} = 0.0001$; Value for ranking update $w = 8$. For a given number of location areas, the ACO method is able to find the optimal partition of the network and the total cost. In our approach, we start with the number of location areas from 1 to n and for each of the given number of location areas we obtained the total cost.

For the 4×4 network, the value of call per call arrivals for location area 1 to 16 for different attractiveness are given in Table 1.

Table 1. Call arrival cost for various values of location area: 4×4 network

No. of location area (k)	Cost with Heuristic η_{pik}	Cost with Heuristic η_{uik}	Cost with heuristic $\eta_{pik} + \eta_{uik}$	No. of location area (k)	Cost with Heuristic η_{pik}	Cost with Heuristic η_{uik}	Cost with heuristic $\eta_{pik} + \eta_{uik}$
1	16	16	16	9	13.22961	13.22961	13.22961
2	11.03346	11.03346	11.03346	10	14.01852	14.01852	14.01852
3	*9.786352*	*9.786352*	*9.786352*	11	15.43077	15.43077	15.43077
4	10.20485	10.20485	10.20485	12	16.08482	16.08482	16.08482
5	10.6708	10.6708	10.6708	13	16.78411	16.78411	16.78411
6	11.23163	11.23163	11.23163	14	17.667485	17.667485	17.667485
7	11.69758	11.69758	11.69758	15	18.71864	18.71864	18.71864
8	12.44875	12.44875	12.44875	16	19.41841	19.41841	19.41841



(a) Example with 4 location areas

(b) Optimal configuration of partitions

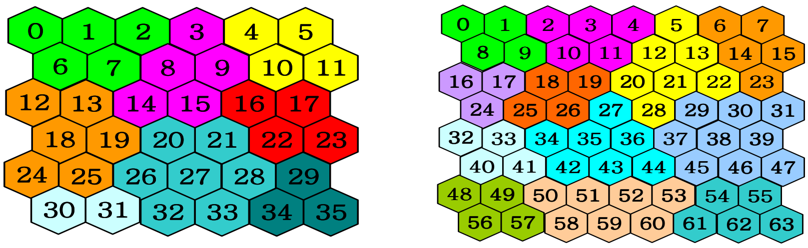
Figure 1. Partitions of 4×4 network

From this Table 1, the optimal number of location areas obtained for 4×4 network is 3, and this optimal partition is shown in Figure 1(b). From the results shown in Table 1, we see that the optimal number of location areas is 3 and the corresponding call arrival cost is 9.786352. We can see that the cost per call arrival starts decreasing as the number of location area increases up to the optimal number and then starts increasing. We can see in the Table 1, that the cost per call arrival is the same for all the three attractiveness.

A similar simulation studies are conducted for 6×6 and 8×8 networks. For these 6×6 and 8×8 networks, the cost per call arrival is different for the three attractiveness. The optimal number of partitions for 6×6 network is 8 and the cost per call arrival is 11.28603 with the attractiveness η_{pik}, the cost per call arrival is 11.23653 with the attractiveness η_{uik}, and the cost per call arrival is 11.11478 with the attractiveness $\eta_{pik} + \eta_{uik}$. As expected the attractiveness $\eta_{pik} + \eta_{uik}$ performs better than the other attractiveness. The optimal configuration of location areas for 6×6 network is shown in Figure 2(a).

For 8×8 network, the optimal number of partitions is 12 and the cost per call arrival is 14.03889 with the attractiveness η_{pik}, the cost per call arrival is 13.30168 with the attractiveness η_{uik}, and the cost per call arrival is 12.86895 with the attractiveness $\eta_{pik} + \eta_{uik}$. As expected the attractiveness $\eta_{pik} + \eta_{uik}$ performs better than the other attractiveness. We also observed that if we use only η_{pik}, then we obtain 13 as the optimal number of location areas. The optimal configuration of location areas for 8×8 network is shown in Figure 2(b).

5. **Conclusions.** We have addressed the problem of partitioning a network into location areas, with the objective of minimizing the sum of update cost and paging cost. Ant colony optimization method is used to find the optimal number of location areas, and the corresponding configuration of the partitioned network. Our simulation results show that the total cost starts decreasing as the number of location area increases up to the optimal



(a) Optimal configuration of partitions

(b) Optimal configuration of partitions

FIGURE 2. Optimal partitions for 6×6 and 8×8 networks

number and then starts increasing. We used three different attractiveness by considering (i) only call volume denoted as η_{pik}, (ii) only handoff traffic denoted as η_{uik}, and (iii) both call volume and handoff traffic. The effect of these different attractiveness on this problem is presented. The optimal partitions of 4×4, 6×6 and 8×8 networks are presented.

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