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A New Evolutionary Approach for the Optimal Location of Controllers in Wireless Networks

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Abstract. In this paper we present a new evolutionary algorithm for the optimal location of controllers in wireless networks, which is an important problem in the process of designing cellular mobile networks. Our objective functionis determined by the total distance based on finding maximum flowin bipartite graph using Ford-Fulkerson algorithm satisfies capacity constraints. The experimental results show that our proposed algorithm has achieved much better performance than known heuristic algorithms.

Keywords: Terminal Assignment (TA), Optimal Location of Controllers Problem(OLCP), Evolutionary Algorithm (EA), Wireless Networks.

1. Introduction

In the designing of a mobile phone network (cellular network) it is very important to place the base stations optimally for the cheaper and better customer service. We often involves problems of location of devices (Base station (BTS), Multiplexers, Switches, etc.)[1-2].The objective of terminal assignment problem (TA) [3] involves determining minimum cost links to form a network by connecting a given collection of terminals to a given collection of concentrators. The capacity requirement of each terminal is known and may vary from one terminal to another. The capacity of concentratorsis known. The cost of the link from each terminal to each concentrator is also known. The problem is now to identify for each terminal the concentrator to which it should be assigned, under two constraints: Each terminal must be connected to one and only one of the concentrators, and the aggregate capacity requirement of the terminals connected to any one concentrator must not exceed the capacity of that concentrator.

The assignment of BTSs to switches (controllers) problem introduced in [4].In which it is considered that both the BTSs and controllers of the network are already positioned, and its objective is to assign each BTSs to a controller, in such a way that a capacity constraint have to be fulfilled. The objective function in this case is then formed by two terms: the sum of the distances from BTSs to the switches must be minimized, and also there is another term related to *handovers*, between cells assigned to different switches which must be minimized. The optimal location of controller problem (OLCP) [5] is selecting N controllers out of M BTSs, in such a way that the objective function given by solving the corresponding TA with N concentrators and M-N terminals is minimal.

Both TA and OLCP are NP-hard optimization problems so heuristic approach is a good choice. In [1], a simulated annealing (SA) algorithm tackled the assignment of cells to controller problem. The results obtained are compared with a lower bound for the problem, and the authors show that their approach is able to obtain solutions very close to the problem's lower bound. Authors in [5] have introduced ahybrid heuristic consisting of SA and a Greedy algorithm for solving the OLCP problem. In [6-7], authors proposed a hybrid heuristic based on mixing genetic algorithm (GA), Tabu Search (TS)to solving the BTS-controller assignment problem in such a way that terminal is allocated to the closest concentrator if there is enough capacity to satisfy the requirement of the particular terminal.

In this paper, we propose a new evolution algorithm [8] based on Ford-Fulkerson algorithm find maximum flow in networks for the optimal location of controllers in a mobile communication network. Numerical results show that our proposed algorithm has achieved much better than previous studies. The rest of this paper is organized as follows. Section 2 presents the problem formulation and briefly introduces the main idea of OCLP proposed in [5].Section 3 presents our new algorithm for location of controllers in a mobile communication network based on evolutionary algorithm. Section 4 presents our simulation and analysis results, and finally, section 5 concludes this paper.

2. Problem Formulation and Related Works

Let us consider a mobile communication network formed by M nodes (BTSs), where a set of N controllers must be positioning in order to manage the network traffic. It is always fulfilled that $N<M$, and in the majority of cases $N \ll M$. We start from the premise that the existing BTSs infrastructure must be used to locate the switches, since it saves costs. Thus, the OCLP consists of selecting N nodes out of the M which form the network, in order to locate in them N controllers. To define an objective function for the OCLP, we introduce a model for the problem, based on the Terminal Assignment Problem [5].

2.1. The Terminal Assignment Problem

The TA can be defined as follows [3]:

Problem instance: Terminals: $l_1, l_2, ..., l_{M-N}$

Weights: $w_1, w_2, ..., w_{M-N}$

Concentrators: $r_1, r_2, ..., r_N$

Capacities: $p_1, p_2, ..., p_N$

Where $w_i$is weight, or capacity requirement of terminal l_i. The weights and capacity are positive integers and $w_i < \min\{p_1, p_2, ..., p_N\}, \forall i = 1,2..., M-N$ (1).The terminals and concentrator are placed on the Euclidean gird, i.e., l_i has coordinates $(l_{i1}, l_{i2})$and r_j has is located at (r_{j1}, r_{j2}).

Feasible solution:Assign each terminal to one of concentrator such that no concentrator exceeds its capacity. Let $\hat{x} = \{\hat{x}_1, \hat{x}_2, ..., \hat{x}_{M-N}\}$ Be a vector such that $\hat{x}_i = j$ means that terminal l_i has been assigned to concentrator r_j, with $\hat{x}$ is an integer such that $1 \le \hat{x} \le N$

Capacity of concentrator is not exceeded: $\sum_{i \in R_j} w_i < p_j,\ j = 1..N$ (2)

Where $R_j = \{i \mid \hat{x}_i = j\}$,i.e., R_j represents the terminals that are assigned to concentrator r_j.

Objective function: Find $\hat{x}$ which minimize: $F(\hat{x}) = \sum_{i=1}^{M-N} \text{cost}\, t_{ij} \to \min,\ j = 1,2,...N$ (3)

Where $\text{cost}\, t_{ij} = \sqrt{(l_{i1} - r_{j1})^2 + (l_{i2} - r_{j2})^2}$,i.e., the result of the distance between terminal l_i and concentrator r_j. It is important to note that in the standard definition of the TA, there is a major objective (the minimization of the distances between terminals and concentrators), and a major constraint (the capacity constraint of concentrators).

2.2. The Optimal Controller Location Problem

The complete OCLP have to solve two problems, first, the selection of the N controllers in M nodes, second for each election, an associated TA. This process can be seen in Figure 1.Authors in [5] used a Greedy algorithm to obtain this objective function that terminal is allocated to the closest concentrator if there is enough capacity to satisfy the requirement of the particular terminal. If the concentrator cannot handle the terminal, the algorithm searches for the next closest concentrator and performed the same evaluation. The terminals are assigned to concentrators following the order in $\pi(l_{M-N})$ - a random permutation of terminals. That algorithm is called by *SA-Greedy* algorithm.

In [7], the authors consider the following *Lower Bound* (LB) for the TA, as follows: $LB = \sum_{i=1}^{M-N} \min_k \left(d_{ik} \right)$ (4). The Lower Bound comes from the solution obtained by assigning each node i to the nearest controller k. Hybrid Lower Bound- Greedy algorithm is called by *LB-Greedy* algorithm.

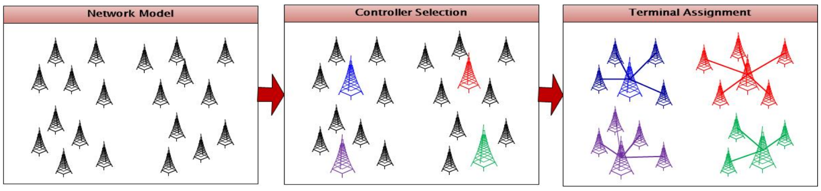


Figure 1. The Optimal Controller Location Problem.

3. Evolution Algorithm for solving the OCLP

3.1. Initialization

We consider configurations in the evolution algorithm are sets of N nodes which will be evaluated as controller for the network. The encoding of the configuration is by means of binary string of length M, say $x = \{x_1, x_2, \ldots x_M\}$ where x_i=1 in the binary string means that the corresponding node has been selected to be a controller, whereas a 0 in the binary string means that the corresponding node is not a controller, but serve as BTS.We must select N nodes to be the controllers of the network.

We use fully random initialization in order to initialize the individuals.After the mutation, the individual x will have p 1s. We present*Repairfunction*to ensure that all binary strings in individuals have exactly N 1s representing N controllers.

REPAIR FUNCTION ALGORITHM ($x = \{x_1, x_2, \ldots x_M\}$)
INPUT: The *individualx*has*p* 1s
OUTPUT: The *individualx* will have exactly N 1s
    IFp<NTHEN Adds *(N-p)* 1s in random positions
    ELSE Select *(p-N)* 1s randomly and removes them from the binary string

3.2. Evaluation function

After the mutation, each individual x has exactly N 1s representing N controllers. We construct a bipartite graph $G = (I, J, E)$ corresponding individual*x*, where $I = \{1, 2, \ldots, N\}$ is the set of controllers, $J = \{1, 2, \ldots, M-N\}$ is the set of BTS and E is the set of edge connection between the controllerr_i and the BTSl_j.We find the maximum flow (max-flow) of the bipartite graph G by adding two vertices S (Source) and D (Destination) is shown in Fig 2.

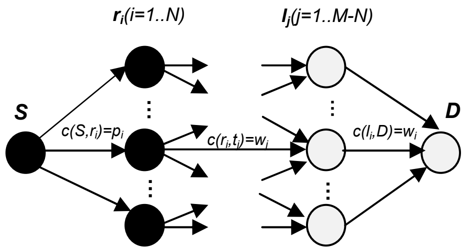


Figure 2. The bipartite graph$G = (I, J, E)$corresponding individual x

The weight of the edges on the graph is defined as follows:

The edges from vertex S to the controllersr_i is capacity of $r_i$is $c(S,r_i)=p_i$, $(i=1..N)$.

The edges from BTS l_j to vertex D is weight of l_j is$c(l_j,D)=w_j$, $(j=1..M-N)$.

The edges from the controllersr_i to the BTSs l_j is $c(r_i,l_j)=w_i$. ($(i,j) \in E$)

From the graph G, we find the max-flow satisfies capacity constraints given by the formula (4) based on Ford-Fulkerson algorithm [9]. The objective function is determined by the max-flow based on the total distance is given by: $F(x) = \sum_{i=1}^{N} \sum_{j=1}^{M-N} \sqrt{(r_{i1} - l_{j1})^2 + (r_{i2} - l_{j2})^2}$ (5)

3.3. Our evolutionary algorithm

The pseudo-code of the evolution algorithm based on Ford-Fulkerson for the optimal location of controllers in a mobile communication network, as follows:

```
EVALUTIONARY MAXFLOW ALGORITHM (EA_MAXFLOW)
BEGIN
        INITIALISE population with random candidate solutions;
        REPAIR FUNCTION (candidate);
        EVALUATEFUNCTION each candidate;
        REPEAT
                1. SELECT parents;
                2. RECOMBINE pairs of parents;
                3. MUTATION the resulting offspring;
                4. REPAIR FUNCTION (candidates);
                5. BUILD BIPARTITE GRAPH G = (I, J, E);
                6. FIND MAX_FLOW (G);
                7. EVALUATE FUNCTION new candidates;
                8. SELECT individuals for the next generation;
        UNTIL (TERMINATION CONDICTION is satisfied)
END
```

4. Experiments and results

For the experiment, we have tackled several OCLP instances of different difficulty. There are 10 OCLP instances with different values for *N* and *M*, and size networks shown in Table I.

TABLE 1. MAIN CHARACTERISTIC OF THE PROBLEMS TACKLED

Problem #	*Nodes (M)*	*Controllers (N)*	*Grid size*
1	10	2	100x100
2	15	3	100x100
3	20	4	100x100
4	40	6	200x200
5	60	8	200x200
6	80	10	400x400
7	100	15	600x600
8	120	20	800x800
9	150	25	1000x1000
10	200	50	1500x1500

In ourexperiments, we have already defined our crossover probability as 0.7, we will work with a population size of 500 and a mutation rate of $p_m = 1/m$.

Our evolutionary algorithm to tackle these problems can be specified as below in Table II.

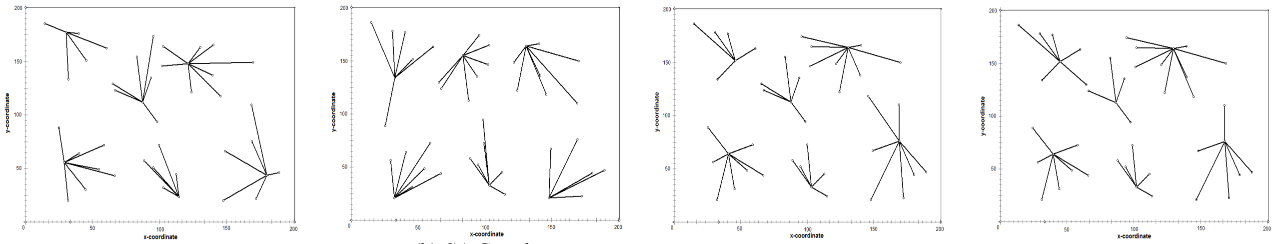
TABLE 2. EVOLUTIONARY ALGORITHM SPECIFICATIONS

Representation	Binary strings of length *m*
Recombination	One point crossover
Recombination probability	70%
Mutation	Each value inverted with independent probability p_m per position
Mutation probability p_m	1/m
Parent selection	Best out of random two
Survival selection	Generational
Population size	500
Number of offspring	500
Initialisation	Random
Termination condition	No improvement in last 100 generations

TABLE 3. RESULTS OBTAINED IN THE OCLP INSTANCES TACKLED

Prob. #	*SA*	*SA-Greedy*	*LB-Greedy*	*EA-Maxflow*
1	187.4	187.4	187.4	187.4
2	315.0	315.0	315.0	315.0
3	428.3	427.2	419.6	415.4
4	1784.7	1798.5	1658.2	1623.8
5	2135.9	2215.1	1976.3	1910.6
6	4863.2	4863.2	4627.5	4507.8
7	7955.6	8027.2	7371.9	7144.1
8	12863.7	13753.8	10863.7	9584.3
9	23638.6	26624.3	19569.2	16896.7
10	157894.2	168253.7	143665.4	141276.9

The experimental results of our algorithm propose in Table III show the objective function has achieved much better performance than other algorithms.The results show that the problems with the small grid size and small number of nodes such as problem #1, #2 and #3, all algorithms hasapproximately results.However, when the problem size is large, the results have many different such as problem #6,#7,#8,#9 and #10. In some cases, *LB-Greedy, SA-Greed* and *EA-Maxflow*algorithms choose the same set of node to be controllers, but the objective function of *EA-Maxflow*is much better, as can see in Figure 3.



(a) *Simulated Annealing* (b) *SA-Greedy* (c) *LB-Greedy* (d) *EA-Maxflow*

Figure 3. Solutions for the problem #4 given by SA, SA-Greedy, LB-Greedy and EA-Maxflow algorithms.

5. Conclusions and future work

In this paper we present a new evolutionary algorithm for the optimal location of controllers in wireless networks, which is an important problem in the process of designing cellular mobile networks.Our objective functionis determined by the total distance based on finding max-flow in bipartite graph using Ford-Fulkerson algorithmsatisfies capacity constraints. The experimental results show that our proposed algorithm has achieved much better performance than previous studies.It is also proved to be a cost-effective solution.Optimizing location of controllers in wireless networks with profit, coverage area and throughput maximization is our next research goal.

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