A Novel Particle Swarm Optimization-based Algorithm for the Optimal Centralized Wireless Access Network

Dac-Nhuong Le[1], **and Gia-Nhu Nguyen**[2]

[1] **Faculty of Information Technology, Haiphong University**
Haiphong, Vietnam

[2] **Duytan University**
Danang, Vietnam

Abstract

The wireless access networks design problem is formulated as a constrained optimization problem, where the goal is to find a network topology such that an objective function is optimized, subject to a set of constraints. The objective function may be the total cost, or some performance measure like utilization, call blocking or throughput. The constraints may be bounds on link capacities, cost elements, or some network performance measure. However, the optimization problem is too complex. In this paper, we propose a novel Particle Swarm Optimization (PSO) algorithm to finding the total cost of connecting the BSs to the MSCs, and connecting the MSCs to the LE called by the optimal centralized wireless access network. Numerical results show that performance of our proposed algorithm is much better than previous studies.

Keywords: *Wireless Access Network, Base Station, Mobile Switching Center, Particle Swarm Optimization.*

1. Introduction

The wireless access network of a cellular telephone system consists four interacting layers. These layers are the mobile station or user equipment layers, the base transceiver stations layer, the mobile switching centers layer, and lastly local exchanges of the public switched telephone network (PSTN). Each cell in the hexagonal cell grid contains one base station (BS) and mobile station (MS). A set of BS's are physically connected to and served by a mobile switching center (MSC). In turn, a set of MSC's are physically connected to and served by a local exchange (LE). Fig.1 depicts the general configuration of a cellular access network. Each BS is typically assigned a group of radio channels (*frequency carriers*) to support a number of mobile stations in its cell. BS's at adjacent cells are assigned different sets of frequencies. The antennas of a BS are designed to achieve coverage only within the particular cell. By limiting coverage of a BS to its cell area, the set of frequencies assigned to this BS can be reused at other BS's that are distant enough to keep co-channel interference within acceptable limits.

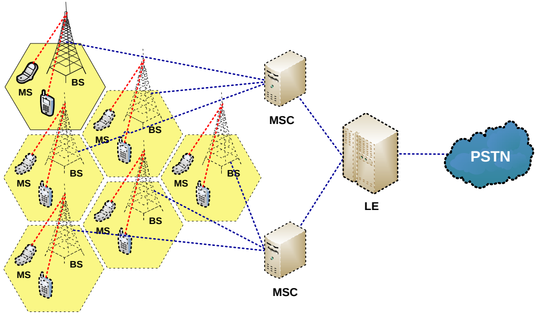

Fig.1. A cellular access network

A BS contains the radio transceivers defined for its cell, and handles the radio-link protocols with the user's wireless device (cell phone). In addition, it may house a controller that handles radio-channel setup, frequency hopping and handovers. In a large metro area, a potentially large number of BS's are deployed at pre-determined locations. The BS controllers are connected by land-wires to nearby MSC's in the area. The MSC provides all the functionality needed to handle a mobile subscriber, such as registration, authentication, location updating, handovers, and call routing to a roaming subscriber. To switch calls from/to local mobile users to/from remote users, MSCs are connected by land-cables to nearby LEs of the PSTN. The potential locations of MSCs are judiciously determined with respect to the BS locations and to the LEs in the region. Typically, the locations of the LEs are fixed, and a single LE serves an area with many BS's and multiple MSCs [1-2].

In the latest paper [3], we have proposed a novel Particle Swarm Optimization (PSO) [4] algorithm based on Ford-Fulkerson algorithm find maximum flow in networks for the optimal location of controllers in a mobile communication network. In [5], the authors have presented the topological design of the network connecting the BSs to the MSCs and the MSCs to the LEs in a typical region of the cellular system. The access network has a centralized tree topology. That is, a single LE facility controls a set of MSCs, and a single MSC controls, in turn, a set of BS's. Finally, a BS supports a group of mobile stations through wireless connections. A tree topology of the wireless access network, consisting of 1 LE, 2 MSCs, 4 BSs, and 18 MSs is shown in Fig.2.

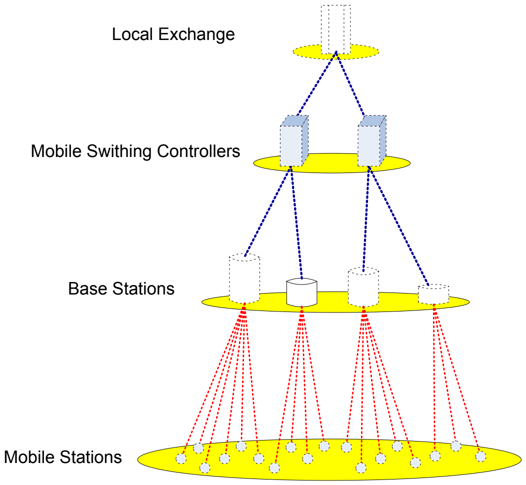

Fig.2. A Centralized access network

The topological design of access networks has been very important part of cellular network research in recent years. Recent studies are given in references [5-9]. Generally, the design problem is formulated as a constrained optimization problem, where the goal is to find a network topology such that an objective function is optimized, subject to a set of constraints. The objective function may be the total cost, or some performance measure like utilization, call blocking or throughput. The constraints may be bounds on link capacities, cost elements, or some network performance measure. However, the optimization problem is too complex, or it's computationally impractical to search for the optimal solution. So, one usually resorts to heuristic methods that enable one to determine a near-optimum network topology more easily.

The simple design of access network has one single LE. The objective function is the total cost of connecting the BSs to the MSCs, and connecting the MSCs to the LE. Authors in [6] proposed an exhaustive search algorithm to generating all the possible matrices and searches for the matrix that yields the minimum cost. In [7-9], the authors presented a heuristic algorithm to finding the best solution is the topology with the smallest cost across all the iterations.

In this paper, we propose a novel Particle Swarm Optimization (PSO) algorithm [10] to finding the total cost of connecting the BSs to the MSCs, and connecting the MSCs to the LE. Numerical results show that our proposed algorithm is much better than previous studies. The rest of this paper is organized as follows: Section 2 presents the problem formulation the simple centralized access network. Section 3 presents our new algorithm for optimization wireless access network based on PSO algorithm. Section 4 presents our simulation and analysis results, and finally, section 5 concludes the paper.

2. Problem Formulation

The simple centralized access network can be defined as follows [5]:

Let N be the number of BSs ($T_1, T_2, ..., T_N$). The locations of the N terminals are assumed known and fixed. Let M be the number of potential sites ($S_1, S_2, ..., S_M$), where up to M MSCs can be placed. In one extreme situation, none of the M sites is used, and all the N BSs are linked directly to the central LE, S_0.

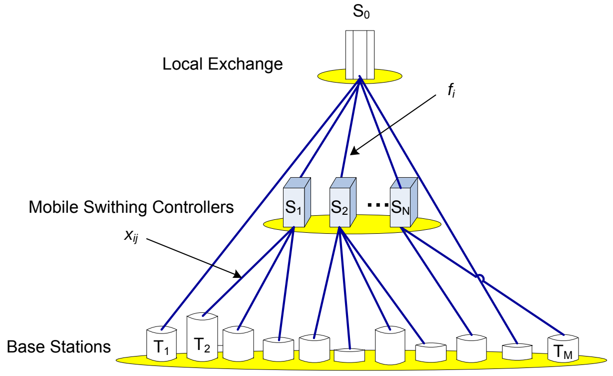

Fig.3. Simple centralized access network

In the other extreme, all the M MSC sites are used, each serving a subset of BS's. The principal constraint is that the MSC at site S_j can handle up to a maximum of P_j BSs ($j = 1..M$). This can be a hardware limitation, or a capacity constraint of the land-cable connecting the MSC to the LE. The central site is assumed to have no such constraint.

2.1 The Simple Centralized Wireless Access Network

We want to formulate the network design problem as an optimization problem. Let c_{ij} be the cost of connecting base station T_i to MSC site S_j or to the central site S_0. The cost

c_{ij} is measured in some unit (e.g., *dollar/month*), and represents the overall BS-MSC connection cost (e.g., *transmission cabling, interfacing, maintenance, leasing*). Note that a base station may be located at the site of an MSC, in which case the corresponding c_{ij} cost is zero.

These cost elements c_{ij} can be written in the form of a matrix, as follows:

$$C = \left(c_{ij}\right)_{N\times M+1} = \begin{pmatrix} c_{10} & c_{11} & \cdots & c_{1M} \\ c_{20} & c_{21} & \cdots & c_{2M} \\ \vdots & \vdots & \vdots & \vdots \\ c_{N0} & c_{N1} & \cdots & c_{NM} \end{pmatrix} \qquad \textbf{(1)}$$

If an MSC at site S_j is utilized, the MSC capital cost and its connection cost to the LE are also incurred. Let f_j be the cost of connecting an MSC at S_j to the central LE S_0, and b_j the capital cost of the MSC at S_j.

We can write these 2 costs as row vectors, as follows:

$$\begin{cases} F = \left(f_0, f_1, ..., f_M\right) \\ B = \left(b_0, b_1, ..., b_M\right) \end{cases} \qquad \textbf{(2)}$$

We assumed that the capital cost of the central LE is not counted. That is, $b_0=0$, and clearly $f_0=0$. Similarly, we can write the MSC constraints as the following row vector:

$$P = \left(p_0, p_1, ..., p_M\right) \qquad \textbf{(3)}$$

where, p_j is the maximum number of BSs that MSC at site S_j can handle $(j = 1..M)$, with $p_0=N$ (i.e., the central LE can handle all the N base stations).

A network design can be defined by the following matrix variable:

$$X = \left(x_{ij}\right)_{N\times M+1} = \begin{pmatrix} x_{10} & x_{11} & \cdots & x_{1M} \\ x_{20} & x_{21} & \cdots & x_{2M} \\ \vdots & \vdots & \vdots & \vdots \\ x_{N0} & x_{N1} & \cdots & x_{NM} \end{pmatrix} \qquad \textbf{(4)}$$

where, the element variable x_{ij} $(i = 1..N, j = 0..M)$ is defined as:

$$x_{ij} = \begin{cases} 1 \;\; if \;\; T_i \;\; is\, connected \;\; to\, S_j \\ 0 \;\; if \;\; T_i \;\; is \;\; not\, connected \;\; to\, S_j \end{cases} \qquad \textbf{(5)}$$

Note that since a BS may be connected to at most one of the M MSC sites or to the central LE site, there must be only one "1" in each row of matrix X. In addition, note that the number of 1's in column j is the number of BSs connected to the MSC at site S_j $(j = 0..M)$. Thus, an all-zero column of matrix X corresponds to an MSC site that is not used.

Displayed equations or formulas are centered and set on a separate line (with an extra line or half line space above and below). Displayed expressions should be numbered for reference. The numbers should be consecutive within each section or within the contribution, with numbers enclosed in parentheses and set on the right margin. From matrix X, we extract the following MSC-usage vector:

$$Y = \left(y_0, y_1, ..., y_M\right) \qquad \textbf{(6)}$$

where, the element variable y_j $(j = 0..M)$ is defined as:

$$y_j = \begin{cases} 1 \;\; if \;\; S_i \;\; used, \; if \sum_{i=1}^{N} x_{ij} > 0 \\ 1 \;\; if \;\; S_i \;\; not\, used, \; if \sum_{i=1}^{N} x_{ij} = 0 \end{cases} \qquad \textbf{(7)}$$

The cost of a network design (defined by matrix X and vector Y) is thus expressed as follows:

$$\begin{aligned} & Z = \sum_{i=1}^{N}\sum_{j=0}^{M}\left(c_{ij}\times x_{ij}\right) + \sum_{j=0}^{M}\left(f_j \times y_j\right) + \sum_{j=0}^{M}\left(b_j \times y_j\right) \\ & \Leftrightarrow Z = sumdiag(C \times X^T) + F \times Y^T + B \times Y^T \end{aligned} \qquad \textbf{(8)}$$

In expression (8), the superscript T means transpose of matrix or vector, and *sumdiag*(A) is a function that sums up the diagonal elements of matrix A. The first term in the cost function Z is the cost of connecting the N BSs to the M MSCs used or to the central LE, the second term is the cost of connecting the MSCs to the LE, and the third term is the hardware cost of the MSCs used.

2.2 The Optimal Centralized Wireless Access Network

The optimal centralized wireless access network (OCWAN) in network design problem can thus be stated as the following optimization problem.

Problem instance:

- A set of BSs at known locations: $T_1, T_2, ..., T_N$.
- A set of possible MSC sites: $S_1, S_2, ..., S_M$.
- BS-connection cost matrix: $C = \left(c_{ij}\right)_{N\times M+1}$
- The cost of connecting an MSC at S_j to the central LE S_0: $F = \left(f_0, f_1, ..., f_M\right)$
- The capital cost of the MSC at S_j: $B = \left(b_0, b_1, ..., b_M\right)$
- The mux capacity constraint vector: $P = \left(p_0, p_1, ..., p_M\right)$

Objective function: Find the matrix X (thus the vector Y) that minimizes the network cost Z:

$$Z = sumdiag(C \times X^T) + F \times Y^T + B \times Y^T \to \min \qquad (9)$$

Subject to the following 2 constraints:

- The first constraint indicates that the sum of the elements in row i of matrix X must be 1 (i=1,2,…,N). E is the column vector of all 1's.

$$X \times E = E \qquad (10)$$

- The second constraint indicates that the sum of elements in column j of matrix X must be less than or equal to p_j $(j = 0..M)$.

$$E^T \times X \le P \qquad (11)$$

In the matrix inequality of equation (11), the inequality relation is defined element by element.

3. Particle Swarm Optimization for OCWAN

3.1 Particle Swarm Optimization

Particle swarm optimization (PSO) is a stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy [4],[10], inspired by social behavior of bird flocking or fish schooling. It shares many similarities with other evolutionary computation techniques such as genetic algorithms (GA). The algorithm is initialized with a population of random solutions and searches for optima by updating generations. However, unlike the GA, the PSO algorithm has no evolution operators such as the crossover and the mutation operator.

In the PSO algorithm, the potential solutions, called particles, fly through the problem space by following the current optimum particle. By observing bird flocking or fish schooling, we found that their searching progress has three important properties. First, each particle tries to move away from its neighbors if they are too close. Second, each particle steers towards the average heading of its neighbors. And the third, each particle tries to go towards the average position of its neighbors. Kennedy and Eberhart generalized these properties to be an optimization technique as below.
Consider the optimization problem P. First, we randomly initiate a set of feasible solutions; each of single solution is a *"bird"* in search space and called *"particle"*. All of particles have *fitness values* which are evaluated by the *fitness function* to be optimized, and have *velocities* which direct the flying of the particles. The particles fly through the problem space by following the current optimum particles. The better solutions are found by updating particle's *position*.

In iterations, each particle is updated by following two "best" values. The first one is the best solution (*fitness*) it has achieved so far. (The fitness value is also stored.) This value is called *pbest*. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called *gbest*. When a particle takes part of the population as its topological neighbors, the best value is a local best and is called *lbest.*

PARTICLE SWARM OPTIMIZATION ALGORITHM

```
{ FOR each particle
        Initialize particle
  ENDFOR
  DO
     FOR each particle
        Calculate fitness value
        IF the fitness value is better than
        the best fitness value (pBest) in history
           Set current value as the new pBest
        ENDIF
     ENDFOR
        Choose the particle with the best fitness value of all the particles as the gBest (or Choose the particle with the best fitness value of all the neighbors particles as the lBest)
        FOR each particle
            Calculate particle velocity according
                 to(12)or (13))
            Update particle position according to 14)
        ENDFOR
   WHILE (STOP CONDITION IS TRUE)}
```

Fig.4. Particle Swarm Optimization Algorithm

After finding the two best values, the particle updates its velocity and positions with following equation (12) (which use global best gbest) or (13) (which use local best *lbest*) and (14).

$$\begin{aligned} v[] = v[] + c_1 * rand() * (pbest[] - present[]) \\ + c_2 * rand() * (pbest[] - present[]) \end{aligned} \qquad (12)$$

$$\begin{aligned} v[] = v[] + c_1 * rand() * (pbest[] - present[]) \\ + c_2 * rand() * (lbest[] - present[]) \end{aligned} \qquad (13)$$

$$present[] = present[] + v[] \qquad (14)$$

In those above equation, *rand()* is a random number between *0* and *1*; c_1 and c_2 are cognitive parameter and social parameter respectively. The stop condition mentioned in the above algorithm can be the maximum number of interaction is not reached or the minimum error criteria are not attained.

3.2 Solving the OCWAN based on PSO algorithm

In this section, we present application of PSO technique for the OCWAN problem. Our novel algorithm is described as follows. We consider that configurations in our algorithm are sets of *N* BSs and set of *M* MCSs.

1) Represent and decode a particle: The encoding of the configuration is by means of matrix *x*, say

$$x = (x_{ij})_{N\times M+1},\ \ (i = 1..N,\ j = 0..M)$$

where $x_{ij}=1$ means that the corresponding BS T_i has been connected to MSC site S_j, and otherwise $x_{ij}=0$ means that the corresponding BS T_i has been not connected to MSC site S_j. We use fully random initialization in order to initialize the population.

2) Initiate population: We use fully random initialization in order to initialize the population. We present *Particle_Repair Algorithm* to ensure that the particle *x* satisfies constraints in (10) and (11) show in Fig.5.

```
PARTICLE_REPAIR ALGORITHM ( $x = (x_{ij})_{N\times M+1}$ )
Input: The particle x
Output: The particle x will satisfies constraints
in (10) and (11)
{
FOR i=1..N
   $r_i$ = Number of 1s in row i
      IF $r_i$>1
            Select ($r_i$ -1) 1s randomly and
            removes them from row i
      ELSE IF Count$_i$<1
       Adds 1 1s in random positions in row i.
   ENDIF
ENDFOR
FOR j=0..M
      $c_j$ = Number of 1s in column j
      IF ( $c_j > p_j$ )
            Select ($c_j$ - $p_j$) 1s randomly and
            removes them from columnj
      ELSE IF ( $c_j < p_j$ )
       Adds ($p_j$ -$c_j$) 1s in random positions in
column j.
   ENDIF
ENDFOR}
```

Fig.5. Particle_Repair algorithm

After that, the particle *x* will have the sum of the elements in row *i* of matrix *x* must be 1 (*i*=1,2,…,*N*) and the sum of elements in column *j* of matrix *x* must be less than or equal to $p_j\ \ (j = 0..M)$.

3) Fitness function: The cost function of the particle *x* given by:

$$f_k = sumdiag(C\times k^T) + F\times Y^T + B\times Y^T \qquad \textbf{(15)}$$

In which, *Y* defined in (7) and (8).

4) Stop condition: The stop condition used in this paper is defined as the maximum number of interaction N_{gen} (N_{gen} is also a designated parameter).

4. Experiments and Results

For the experiments, we have tackled several OCWAN instances of different difficulty levels. There are 8 OCWAN instances with different values for *N* and *M*, and BS-connection cost matrix show in Table 1.

Table 1. The experimental of the problems tackled

Problem #	*Number of MSCs*	*Number of BSs*
#1	4	10
#2	5	20
#3	8	40
#4	10	80
#5	20	100
#6	40	150
#7	50	200
#8	60	250

We have already defined parameters for the PSO algorithm in Table 2 below:

Table 2. The PSO algorithm specifications

Population size	P = 1000
Maximum number of interaction	N_{gen} = 500
Cognitive parameter	c_1 = 1
Social parameter	c_2 = 1
Update population according to	(13) and (14)
Number of neighbor	K = 3

The experiment was conducted on Genuine Intel® CPU DuoCore 3.0 GHz, 2 GB of RAM machine. We ran experiment PSO algorithm, Exhaustive Search algorithm [5] and Heuristic algorithm [8] implemented using C language.

The experimental results of our algorithm was finally compared with others algorithm shown in Fig.6.

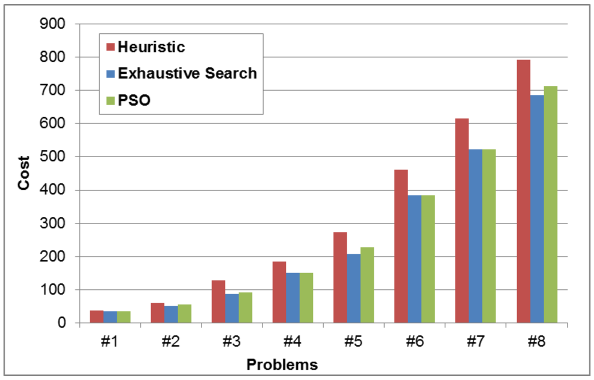

Fig.6. The results obtained in the OCWAN instances tackle

The results show that the objective function values of our algorithm has achieved a much better than a Heuristic algorithm and approximate good solutions of Exhaustive Search algorithm. But, the performance of our proposed algorithm is better than other algorithm.

The comparison of time processing shows in Fig.7.

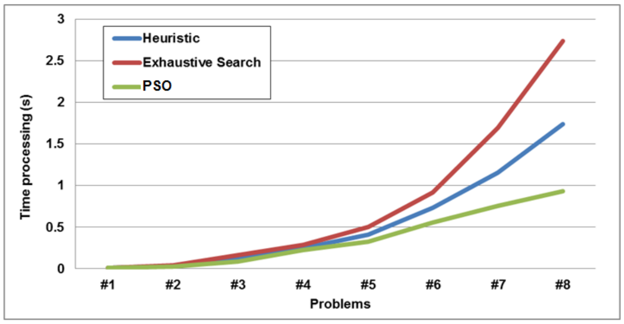

Fig.7. Comparison of time processing OCWAN instances tackle

5. Conclusion

In this paper, we have proposed a novel Particle Swarm Optimization (PSO) algorithm to finding the total cost of connecting the BSs to the MSCs, and connecting the MSCs to the LE called by the optimal centralized wireless access network. Numerical results show that performance of our proposed algorithm is much better than previous studies.

With a growing need for anywhere and anytime access to information and transaction, optimal capacity expansion of wireless networks to accommodate next-generation wireless service is our next research goal.

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Dac-Nhuong Le received the BSc degree in computer science and the MSc degree in information technology from College of Technology, Vietnam National University, Vietnam, in 2005 and 2009, respectively. He is a lecturer at the Faculty of information technology in Haiphong University, Vietnam. He is currently a Ph.D student at Hanoi University of Science, Vietnam National

University. His research interests include algorithm theory, computer network and networks security.

Gia Nhu Nguyen received the BSc degree in computer science and the MSc degree in information technology from Dannang University, Vietnam, in 1998 and 2006, respectively. He currently works in Duy Tan University, Danang, Vietnam. His research interests include algorithm theory, network and wireless security.