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Design of Telecommunication Networks by Evolutionary Strategy

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Abstract

The paper describes the application of the Evolutionary Strategy Methods for allocation capacity units in the telecommunication network (SDH or ATM) with given capacity of edges. The model of the network has been presented in a form of non-directed graph. The problem is discrete, integer valued and strongly constrained. In order to test the effectiveness of proposed method, three networks generated artificially and one 12-nodes real-network have been investigated. Two types of Evolutionary Strategy, $(\mu+\lambda)-ES$ and $(\mu,\lambda)-ES$ have been used and compared each other.

1 INTRODUCTION

This paper proposes an application of Evolutionary Strategy Algorithms to telecommunication networks design problems. The considered problem is of multicommodity flow type and consists in allocating capacity units in telecommunications network with fixed capacity of edges. An node-to-node capacity demand is associated with a set of admissible paths, on which capacity units of the demand can be allocated. The considered problem is to find allocation of all capacity units for each demand, such that capacity of edges are not exceeded. Evolutionary Algorithms use a non-linear penalty function as a fitness function. The algorithms optimize the fitness function. There have been attempts to solve similar problems using other algorithms, such as: Linear Programing Methods, Simulated Allocation and others [3, 6].

In section 2 the problem is introduced in details. Section 3 contains application of Evolutionary Algorithms. Such topics as chromosome structure, fitness function, problem - specific genetic operators are outlined. Section 4 contains results of experiments. There have been applied three networks generated artificually and 12-nodes network, which is concering a real network (a variant of the Polish Telecom interurban SDH network [5]. The last section concludes the paper and indicates some directions for future work.

2 PROBLEM FORMULATION

As a model of telecommunication network, a non-directed graph $G = (V, E, T)$ is considered, where:

- V is a set of nodes

- E is a set of edges (sets V and E are disjoint)
- $T = \{(v, e, w) : (v, w) \in V \times V, e \in E\}$ is a subset of $V \times E \times V$ determining relationships between nodes and edges:
  - $\forall e \in E \, \exists v, w \in V, \ (v, e, w) \in T$
    (each edge links two nodes)
  - $\forall e \in E \, \exists v, w \in V, \ (v, e, w) \in T \Rightarrow (w, e, v)$
    (edges are undirected)
  - $\forall e \in E \, \exists v, w \in V, \ (v, e, w) \in T \Rightarrow v \neq w$
    (there are no loops)
  - $\forall e \in E \, \exists v, w, u, t \in V, (v, e, w) \in T \wedge (u, e, t) \in T \Rightarrow (v \equiv u \wedge w \equiv t) \vee (v \equiv t \wedge w \equiv u)$
    (an edge cannot link two different pairs of nodes)

Consider the following notation:

- $P = \{p_{v,w} : (v, w) \in V \times V\}$ - set of paths, where each path is defined as a set of subsequent edges joining nodes, $p_{v,w} = \{e_i : e_i \in E, (v_i, e_i, w_i) \in T, \ v_{i+1} = w_i, \ i = 1, \ldots N_e, \ v_1 = v, \ w_{N_e} = w\}$ - N_e denotes the number of edges.
- A capacity demand $d = (v, w, P_{v,w})$ is characterised by:
  1. end nodes v and w;,
  2. the set of admissible paths $P_{v,w}$ (see coment below)
- $D = \{(v, w, P_{v,w}) : v, w \in V, P_{v,w} = \{p^i_{v,w} \in P, i = 1 \ldots N_p\}\}$ - set of demands, where N_p stands for the number of admissible paths for the demand $(v, w, P_{v,w})$ (see comment below),
- $l : E \longmapsto \mathcal{N}$ - function describing the weight (number of capacity units) of edges,
- $c : D \longmapsto \mathcal{N}$ - function of demand value,
- $a : P \longmapsto \mathcal{N}$ - function of demand allocation.

There is assumed, that for each pair of nodes $(v, w) \in V \times V$, there exists at least one path $p_{v,w}$ (i.e. $\forall (v, w, P_{v,w}) \in D, \ P_{v,w} \neq \emptyset$). In general, there may exist such paths $p_{v,w}$ joining nodes v, w that are not admissible (i.e. $p_{v,w} \notin P_{v,w}$).

The problem is described as follows:

Problem 1

Given :

- graph G,
- demands D,
- function $c : D \longmapsto \mathcal{N}$,
- function $l : E \longmapsto \mathcal{N}$

Find : function $a : P \longmapsto \mathcal{N}$

Such that :

- $\forall e_i \in E$,
  $\sum_{\{p_{v,w} \in P : (v_i, e_i, w_i) \in p_{v,w}\}} a(p_{v,w}) \leq l(e_i)$
- $\forall d = (v, w, P_{v,w}) \in D$,
  $\sum_{\{p^i_{v,w} \in P_{v,w}\}} a(p^i_{v,w}) = c(d)$ **(eq.)**

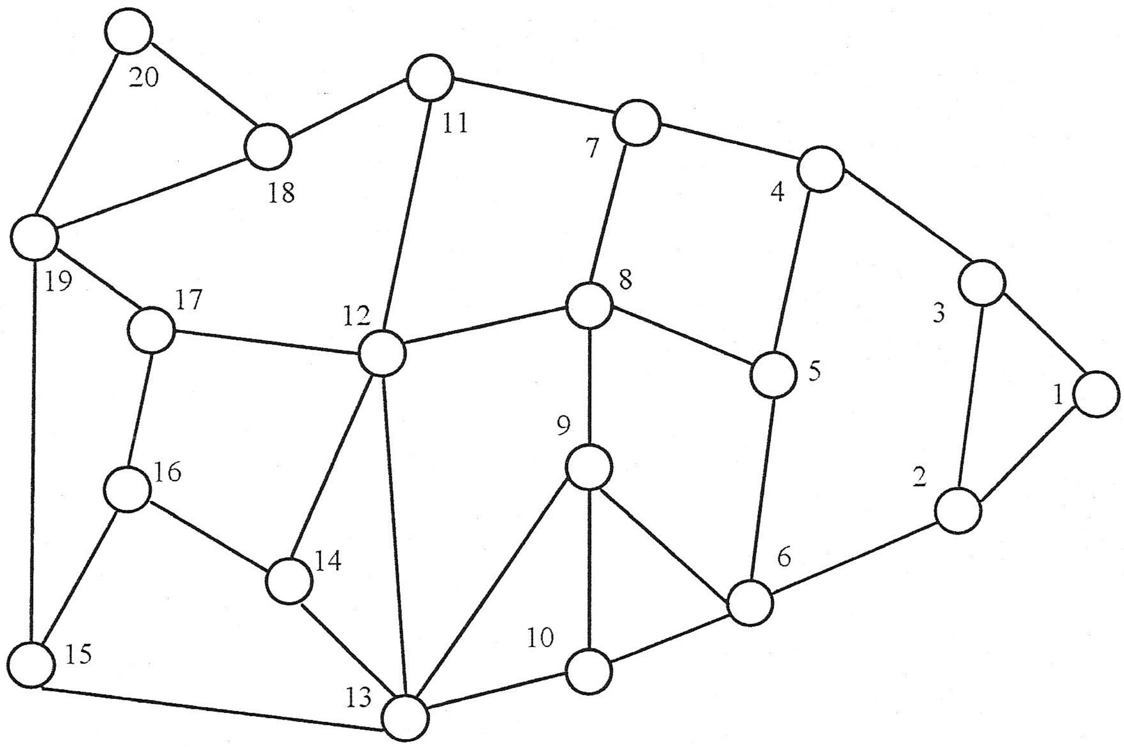

Figure 1: Example of network topology

Consider an example of allocation of any demand. In an example network topology presented in **Figure 1.** Let us allocate demand d_8. We have given:

1. $c(d_8) = 26$ (one capacity unit is equal 2Mbps in this case).

2.

$$\begin{aligned} d_8 = & (v_1, v_9, \{\{e_{1,2}, e_{2,6}, e_{6,9}\}, \\ & \{e_{1,3}, e_{3,4}, e_{4,10}, e_{10,9}\}, \\ & \{e_{1,2}, e_{2,6}, e_{6,8}, e_{8,9}\}\}) \end{aligned}$$

An example allocation: the first path is charged by value 12 (units of 2Mbps.), the second by value 8 and the last one by 6 units (edges are identifed by end node numbers). We can allocate this demand in the following way:
$a(\{e_{1,2}, e_{2,6}, e_{6,9}\}) = 12$
$a(\{e_{1,3}, e_{3,4}, e_{4,10}, e_{10,9}\}) = 8$
$a(\{e_{1,2}, e_{2,6}, e_{6,8}, e_{8,9}\}) = 6$

3 SOLUTION METHOD

In this section some details of the solution method and a genetic operators are described.

3.1 Fitness function

Consider the following penalty function:

$$f = \sum_{k=1}^{N_e} g(\min(0, l(e_k) - \sum_{i=1}^{N_d} \sum_{j=1}^{N_p(i)} x_{ij} \cdot \chi_{R_{ij}}(e_k))) \qquad (1)$$

where:

- $N_e = \|E\|$, is the number of edges,
- $N_d = \|D\|$, is the number of demands,
- $N_p(i) = \|P_{v_i,w_i}\|$, is the number of admissible paths for the i-th demand (v_i, w_i, P_{v_i,w_i}),
- $x_{ij} = a(p_j)$, where $p_j \in P_{v_i,w_i}$ stands for the j-th path in the set of admissible paths P_{v_i,w_i} for the i-th demand $d_i = (v_i, w_i, P_{v_i,w_i}) \in D$
- $R_{ij} = \{e_k \in E : (v_k, e_k, w_k) \in p_j,\ p_j \in P_{v_i,w_i},\ (v_i, w_i, P_{v_i,w_i}) = d_i\}$
- $\chi_A(x)$ is the characteristic function of set A
- $g(x)$ is a function; following the conclusions stated in [2] it have been chosen $g(x) = \log(1 + x)$.

Thus, the original **Problem 1** can be formulated as a constrained satisfiability problem. There is assumed that valid solution exist (the admissible region of the function domain is not empty). The original problem is solving by minimizing the penalty function (1). Obviously, $f(x) = 0$ implies solution to the original problem.

3.2 Chromosome encoding

For the equality constraints **(eq.)** there have been applied the following problem specific encoding method and problem - specific genetic operators. Each chromosome represents allocation of demands within the considered graph G. A chromosome consists of N_d vectors called demand realizations, each formed of $N_p(i)$ integer numbers. These vectors represent allocation of a single demand within admissible paths.

9	7	8	3	9	6	11	12	6	6	4	3	11	2	14	12	5	12	7	9	11
9	5	2	3	8	1	5	8	6	6		15	7	8	12	6	7	9	11	4	9
9	13	5	7		11	11	6	7	7		8	9					4	8	4	

Figure 2: An example chromosome.

For example, demand d_{10} (tenth column) is allocated by charging the first and the second admissible path with 6 capacity units, and the third admissible path is charged by 7 capacity units, etc.

3.3 Genetic operators

There have been introduced problem-specific genetic operators - mutation, and an intermediate crossover.

3.3.1 Mutation

Mutation is performed in the following way:

1. Build a set containing numbers of these path, where capacity is exceeded,

2. Assign values of "mutation allowability" for each allocation of the i-th demand,

3. Build another set M_f containing these demand allocation vectors, for which the mutation allowability is highest. Among them, choose the longest demand allocation vector,

4. Choose randomly j^*-th demand allocation vector from the set M_f. Calculate correction vector m_i, where

   - $m_{ij^*} = -\lfloor \xi_{[0,1]} x_{ij^*} \rfloor$
   - $\sum_{j=1}^{N_p(i)} m_{ij} = 0, \quad i = 1 \ldots N_d$

5. Add the correction vector to the demand allocation vector:

   - $x_i' = x_i + m_i$

There is worth stressing that mutation is performed for the "worst" demand allocation vector.

3.3.2 Intermediate crossover

During intermediate crossover a new offsppring chromosome is generated from randomly chosen parents in such way that the resulting demand allocation vectors are averages of their parentrs. Crossover is performed in the following way:

1. Choose randomly an averaging factor φ from $[0, 1]$

   - $\varphi = \xi_{[0,1]}$

2. Apply averaging to yield new offspring z_{ij}. Values of z_{ij} are real:

   - $z_{ij} = \varphi \cdot x_{ij}^1 + (1 - \varphi) \cdot x_{ij}^2$

3. Calculate integer part of z_{ij}:

   - $x_{ij}' = \lfloor z_{ij} \rfloor$

4. Calculate vector of residue ς as a sum of fractions:

   - $\varsigma_i = \sum_{j=1}^{N_p(i)} (z_{ij} - x_{ij}'), \quad i = 1 \ldots N_d$

5. Build random vectors of corrections m_i, such that

   - $\sum_{j=1}^{N_p(i)} m_{ij} = \varsigma_i, \quad i = 1 \ldots N_d$

6. Add the correction vectors:

   - $x_i'' = x_i' + m_i$

3.4 Algorithms

There are used two types of Evolutionary Strategy: $(\mu + \lambda) - ES$ and $(\mu, \lambda) - ES$. The sketches of algorithms are presented bellow:

```
procedure (μ + λ) − ES
begin
  t := 0
  initialize Pop(t)
  evaluate Pop(t)
  while (not termination-condition) do
  begin
    Offs(t) := recombine Pop(t)
    evaluate Offs(t)
    Pop(t + 1) := choosing the best (Pop(t) ∪ Offs(t))
    t := t + 1
  end
end
```

```
procedure (μ, λ) − ES
begin
  t := 0
  initialize Pop(t)
  evaluate Pop(t)
  while (not termination-condition) do
  begin
    Offs(t) := recombine Pop(t)
    evaluate Offs(t)
    Pop(t + 1) := choosing the best (Offs(t))
    t := t + 1
  end
end
```

'Initialize Pop(t)' generates in random way μ chromosomes which are considered as initial population. In *'evaluate Pop(t)'* there are computed the values of fitness function for each chromosomes from $Pop(t)$ population. *'Recombine Pop(t)'* gives an opportunity to create λ offspring chromosomes and create the offspring population $Offs(t)$. During the *'recombination'* step chromosomes undergo crossover and mutation. As a result of sucession step the best chromosomes have been chosen. It is deterministic operation and consist in choosing μ the best chromosomes among $\mu + \lambda$ (that is, $Pop(t) \cup Offs(t)$ - in the case of $(\mu + \lambda) - ES$) or among λ (that is, $Offs(t)$ - in the case of $(\mu, \lambda) - ES$) chromosomes.

4 EXPERIMENTS

There have been presented two groups of test data. The first group of data (P1,P2 and P3 in Tab.1) has been generated artificially, under condition rather restrictive constraints. Both sets concern the same network topology. The last example - $P4$ - was data concerning a real network (a variant of the Polish Telecom interurban SDH network [4]).

data	number of nodes	number of edges	number of demands	problem dimensionality
P_1	10	16	45	126
P_2	15	24	105	315
P_3	20	33	190	665
P_4	12	18	66	178

Table 1: Characteristics of the test data

Detailed results from the experiments are provided in Tab. 2. In the table $\mathcal{C}$ denotes the number of objective function evaluations to terminate the optimization procedure. Label $\mathcal{E}$ denotes the pecentage of valid solutions. Data were collected from 100 independent runs.

data	$(\mu+\lambda)-ES$		$(\mu,\lambda)-ES$	
	$\mathcal{C}$	$\mathcal{E}(\%)$	$\mathcal{C}$	$\mathcal{E}(\%)$
P_1	7400	100	16000	100
P_2	13600	100	17500	100
P_3	-14800	100	41000	100
P_4	1800	100	4200	100

Table 2: Results of experiments

5 CONCLUSIONS

The following conclusions can be stated:

1. There have been proposed Evolutionary Strategy Algorithms to find solutions for problems which arises form telecommunication networks design. The problem belongs to the NP class. It should be stressed that two considered types of Evolutionary Strategy had no problem at all, and solution was always found.

2. There have been used two types of Evolutionary Strategy, $(\mu+\lambda)-ES$ and $(\mu,\lambda)-ES$. The first type $(\mu+\lambda)-ES$ is more robust and reaches solution using much less

(several times less) objective function evaluations than the second type $(\mu, \lambda) - ES$. This indicates that the first type of Evolutionary Strategy performs better selective pressure.

3. Evolutionary Strategy Methods have one more important advantage: in practice, it is important to allocate demands as uniformly as possible. This postulate is implied by need for reliability of telecommunication networks - its fault-resistance. In the solutions produced by Evolutionary Algorithms, all demands are allocated almost uniformly over admissible paths.

There is planed to apply the Evolutionary Algorithms to solve other problems arising from the telecommunication networks design, such as:

- Design of network resistant to a path or link failure.

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References

[1] Arabas, J., "Evolutionary Algorithms with Varying Population Size and Variable Crossover Range". PhD Thesis, Warsaw University of Technology, Faculty of Electronics and Information Technology, Warsaw, Poland, 1995 (in Polish).

[2] Arabas, J. , Michalewicz, Z., "Genetic Algorithms for the 0/1 Knapsack Problem", in *Proc. Int. Symp. on Methodologies of Intelligent Systems ISMIS'94*, Charlotte, 1994.

[3] Kozdrowski, S., "Application of Genetic Algorithms in Network Design", *Proc. Transcom'95*, Žilina, Slovakia, 1995, pp. 239 – 243.

[4] Lubacz, J., Bursztynowski, D., Pióro, M., González-Soto, O., "A comparison of capacity protection mechanism for mesh SDH network" in *Telecommunication Review*, vol. 7, 1994, pp. 387–391 (in Polish).

[5] Lubacz, J., Bursztynowski, D., Pióro, M., Tomaszewski, A., "A Framework for Network Design and Management", in *COST 242 Document No. 1*, MC Meeting, Warsaw, October, 1993.

[6] Pióro, M., Gajowniczek, P., "Simulated Allocation — a Suboptimal Solution to the Multicommodity Flow Problem", *Proc. 11th UK Teletraffic Symposium*, Cambridge, 1994.

[7] Sakauchi, H., Nishimura, Y.& Hasegawa, S., "A Self - Healing Network with an Economical Spare - Channel Assignment", in *Proc. Globecom '90*, pp 438–443.