# MPLS NETWORK STRUCTURAL SYNTHESIS WITH APPLICATION OF MODIFIED GENETIC ALGORITHM

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***Abstract***: *The problem of MPLS networks structural synthesis is considered. The various modifications of Genetic Algorithms (GA) are investigated for this problem solution which differs in implementation of crossover and mutation procedures. The most adequate version of GA was elaborated and its investigations were carried out. The application to suggested GA for real problem of topological optimization of MPLS network is presented.*
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## Introduction

One of the most perspective network technologies is the MPLS (Multiple Protocol Label Switching). This technology uses different classes of service (CoS) for transmission of various information types (data, audio and video) and assures the corresponding quality of service (QoS) for corresponding CoS. QoS indices include: Packets Delay Time (PDT), Packets delay Variance (PDV) and Packets Loss Ratio (PLR). The important feature of MPLS is that it's easily integrates with Internet protocol stack TCP/IP. The appearance of MPLS technology required the necessity of optimal design methods of MPLS networks which would take into account the specificity of MPLS technology.

The main goal of this paper is to consider the problem of MPLS networks structure optimization, to elaborate and investigate the adequate method for its solution (modified genetic algorithm of structure synthesis under uncertainty).

## Problem statement

Let's consider the problem of computer network structure optimization with MPLS technology [Зайченко Е., 2008].

A set of networks nodes (so-called LSR ( Label Switching Routers) $X = \{x_j\}$ $j = \overline{1,n}$ - is given, their locations over territory, a set of channels $D = \{d_1, d_2, ..., d_k\}$ and their costs per unit length $C = \{c_1, c_2, ..., c_k\}$ , CoS (Class of Service) are defined, matrices of incoming demands are known for each Class of Service $H(k) = \|h_{ij}(k)\|$ $i, j = \overline{1,n}$ ; $k = 1, 2, ..., K$ , where $h_{ij}(k)$ is the k-th class flow rate which is to be transmitted from node I to node j (Mbits/sec).

Besides, desired values of QoS are set as the constraint on Mean Packet Time Delay for each CoS k $T_{зад,k}$ , $k = \overline{1,K}$

It's required to determine MPLS network structure as a set of channels, to find their capacities $\{\mu_{rs}\}$ and flows distribution for each class $F(k)=[f_{rs}(k)]$ so that to enable to transmit all the classes demands $H(k)$ with mean packets time delay $T_{cp}$ not exceeding given values $T_{зад,к}$ and Packets Loss ratio (PLR) not exceeding limitation on this value $PLR_k$, and total network cost should be minimal [Зайченко Е., 2008]. Let's construct a math model of this problem. It's necessary to find such network structure E, for which:

$$\min_{E\{\mu_{rs}\}} C_{\Sigma}(M)=\sum_{(r,s)\in E} C_{rs}(\{\mu_{rs}\}) \quad (1)$$

under constraints

$$T_{cp}(\{\mu_{rs}\};\{f_{rs}\})\le T_{зад,k},\ k=\overline{1,K} \quad (2)$$

$$f_{rs}<\mu_{rs} \text{ for all channels } (r,s) \quad (3)$$

$$\mu_{rs}\in D \quad (4)$$

$$PLR_k(\{\mu_{rs}\};\{f_{rs}\})\le PLR_{k\,çàä} \quad (5)$$

where $PLR_k(\{\mu_{rs}\};\{f_{rs}\})$ is a rate of lost packets for k-th class of flow $PLR_{k\,çàä}$ is a given constraint on this value.

This problem belongs to a class of so-called NP- difficult optimization problems. For its solution modified genetic algorithm is elaborated and investigated [Зайченко Е., 2008].

## Modified Genetic Algorithm for Network structure Synthesis

As it's well known GA consists of three procedures: crossover, mutations and selection [Згуровский, 2013]. But in this problem crossover and mutation procedures are made adjustable, so that strategic parameters are adapted in the process of algorithm run.

Define a channels matrix $K=\|k_{ij}\|$, where $k_{ij}=\begin{cases}1,\exists(i-j)\\0,\neg\exists(i-j)\end{cases}$, for each structure ( network). Then generate initial population of n different structures in a given structures class – multi-connected structures with connectivity factor 2. For synthesis we'll use semi-uniform crossover. Parent structures for crossover we select randomly with probability inverse-proportional to a cost function

$C_{\Sigma}$ (Ei(k)), to each parent matrix corresponds $K^i, i=1,2$. In the process of semi-uniform crossover each offspring gets one-half of parent's genes.

Crossover mask is represented as a matrix of the following form $M=\|m_{ij}\|$, где $m_{ij}=\begin{cases}0,p\ge p0\\1,p<p0\end{cases}$,

$p0=0.5$ - is a parameter, and a $p\in[0,1]$ is random.

Formally this process of crossover may be written as follows $E(k)'=\|e(k)'_{ij}\|=\begin{cases}(i-j)^1,k_{ij}{}^1=1,m_{ij}=0\\(i-j)^2,k_{ij}{}^2=1,m_{ij}=1\end{cases}$.

During crossover we generate only one offspring due to goal of maximization of algorithm productivity. In case of getting isolated subgraphs connect them with direct channels to a root. Further for obtained offspring – structure E(k)' solve the problems channels capacities assignment and flows distribution (problem CA-FD) and Fiona new channels capacities and flows distributions for all classes of service [Згуровский, 2013]. Then after comparison cost value for offspring and parents the we decide whether to introduce or not offspring structure E(k)' in a sequence of locally efficient structures 9 current population) П.

After crossover it's necessary to define mutation procedure. Note that basic algorithm suggested in [Зайченко Е., 2008] used the unconditional mutation procedure. Mutations consist of deleting or introducing some new channels in network structure. In the process of algorithm improvement the following schemes of mutations probability changes were suggested:

– Deterministic and adaptive change.

In deterministic version mutation probability is defined with application of time-variable function. As an example we change probability as follows

$$\sigma(t) = 1 - ct / T .$$

Note as time passes the probability decreases.

Note that main properties of such approach are:

1) Mutation probability change does not depend on the success of its application in genetic search;
2) A designer fully controls the probability changes due to certain formula;
3) Mutation probability change is fully predictable.

For the implementation of adaptive approach of mutation probability change we use Rechenberg rule [Згуровский, 2013]. In this case the rule for the mutation probability change will be as follows

$$\sigma(t) = \begin{cases} \sigma(t-1)/\lambda, \varphi(t-1) > 1/5 \\ \sigma(t-1)\lambda, \varphi(t-1) < 1/5 \\ \sigma(t-1), \varphi(t-1) = 1/5 \end{cases} ,$$

where $\varphi(t)$ is a per cent of good mutations, and $\lambda = 1.1$ is a learning factor.

Note that the main properties of this approach are the following:

1) Mutation probability change depends on the successfulness of its application in the process of genetic search;
2) Mutation probability change is non-predictable.

– Self-adjustable mutation.

Self-adjustable mutation may be implemented on the level of chromosome (network structures) and on the level of genes (channels) for should be given) mutation probability change rule (law) $\sigma(t)$, and then $\sigma(t)$ is coded in chromosome as:

$$\{Ek, \sigma(t)\} \text{ or } \{Ek = \|ek_{ij}\|, \|\sigma_{ij}(t)\|\} .$$

But this approach leads to crucial decrease in algorithm productivity and for our problem is not good alternative. Note that main properties of such approach are the following:

1) Mutation probability change is a result of natural choice;

2) The designer practically doesn't control this process;
3) Mutation probability change is non-predictable.

As a contra version to scheme with unconditional crossover and dynamic mutation the scheme with unconditional mutation and dynamic crossover was implemented.

In the process of algorithm improvement with unconditional mutation the following schemes of crossover probability change were investigated:

– Deterministic;

The implementation of deterministic scheme is based on hypotheses that on various search stages crossover may be more or less significant/ that's why as a function of crossover probability change is reasonable to choose non-monotonic function like such:

$$\sigma(t) = |\sin(t)|, \text{ где } 0 \le t \le T .$$

– Adaptive.

Define adaptive crossover as an operator probability of which decreases if a population is homogenous and increases if the population is sufficiently heterogenous one. As a measure of homogeneity/ heterogeneity take

$$C_\Delta = \max(C_\Sigma(E_i(k)) - C_\Sigma(E_j(k)),\ i \in [1,...,n], j \in [1,...,n], i \ne j ,$$

where $n = 3$ is a population size.

It's reasonable to suppose that in case of very like species in population crossover will be inefficient and vice versa. Thus in adaptive approach the rule of crossover probability change takes the form

$$\sigma(t) = \begin{cases} \sigma(t-1)\lambda, C_\Delta > C^* \\ \sigma(t-1)/\lambda, C_\Delta < C^* \\ \sigma(t-1), C_\Delta = C^* \end{cases},$$

where $C^*$ is a threshold value, and $\lambda = 1.1$ is a learning factor.

Self-adjusting crossover. The implementation of self-adjusting crossover is not reasonable due to substantial decrease of algorithm productivity like self-adjusting mutation.

## Experimental Investigations

The experimental investigations of various modifications of GA were carried out in which the efficiency of different variants of crossover and mutation procedures were explored and compared. The problem to be solved is a National Ukrainian MPLS network design. In process of experiments were varied sets of channels capacities, costs of unit channel length, demands matrices, given QoS values (PDT, PLR).

After series of experiments were carried out the following results were obtained:

1) A combination of unconditional crossover and dynamic deterministic mutation - this implementation proved to be one of the most successful - the increase of productivity up to 15%). This experiment confirmed the hypothesis that mutations play the essential role at the initial phase of search while at final stage the most efficient is to use crossover for finding optimal (Quasi-optimal) solution on the base of earlier obtained solutions.

2) The combination of unconditional crossover and dynamic adaptive mutation; this combination did not allow to reach stable decrease of algorithm run time.
3) The combination of unconditional crossover and dynamic self-adjusting mutation – this implementation is unreasonable as it essentially complicates the process of genetic search and leads to decrease of algorithm productivity – combination of unconditional mutation and:
4) Dynamic deterministic crossover: this implementation did not allow obtaining the stable increase in productivity.
5) Dynamic adaptive crossover: this implementation proved to be the most successful - the productivity increase is 20 - 22%.

By this the hypothesis that crossover operator has some positive properties which mutation operator does not have been confirmed. But its worth to note application of crossover operator is efficient only if the species in population are quite different.

As the illustration of experiments on Fig.1 the initial structure of MPLS network in Ukraine is presented while on Fig. 2 one of the optimal structures is presented obtained by modified genetic algorithm which uses the combination of dynamic adaptive crossover and unconditional mutation.

These results were obtained with test data close to real data. Note that after the application of modified GA total cut in network costs for optimized network structure comprised:

14250 thousand$ - 10023thousand. $ = 4227 thousand $,

that is by 30% less than the costs of initial network structure. It's very important that algorithm productivity was increased: this result was obtained with 22% less time than by basic GA.


**Figure 1** Initial MPLS network structure


**Figure 2** Optimized MPLS network structure

## Conclusion

The problem of MPLS computer networks structure design is considered.

Different genetic algorithms for its solution with various modifications of crossover and mutation procedures were investigated for its solution.

The most efficient GA for MPLS structure synthesis was determined and its application for Ukrainian MPLS network topological design is presented.

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