THE ANALYSIS AND OPTIMIZATION OF SURVIVABILITY OF MPLS NETWORKS

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Abstract: The problem of MPLS networks survivability analysis is considered in this paper. The survivability indexes are defined which take into account the specificity of MPLS networks and the algorithm of its estimation is elaborated. The problem of MPLS network structure optimization under the constraints on the survivability indexes is considered and the algorithm of its solution is suggested. The experimental investigations were carried out and their results are presented.

Introduction

Last years due to fast increase in volumes of the transferred information in computer networks, the necessity to transfer video, audio information and multimedia information, the need to develop new communication technology has appeared that is able to support the transmission of various information types (such as audio, video and data) with required quality of service at high speed.

Technology ATM (Asynchronous Transfer Mode) became the first technology providing integrated transfer of audio, video information and data. However, rigid restriction on the size of transferred cells - of 53 bytes, and also high cost of equipment, in particular ATM switch, precludes its wide usage. Therefore, in the late 1990's instead of it the MPLS technology (Multiprotocol Label Switching) appeared.

This technology gives the common transport mechanism for networks which use protocols TCP/IP, Frame Relay, X.25, ATM. It is based on introduction of streams of various classes of service (CoS), an establishment of priorities in service of various classes and maintenance of demanded quality of service (Quality of Service – QoS) for corresponding classes [1].

The important problem arising at designing of MPLS networks is the problem of the analysis and optimization of survivability indexes.

In E. Zajchenko's works the indicators of survivability for ATM networks have been defined and the method of the analysis of these indicators has been developed.

At the same time specificity of MPLS technology and, in particular, presence of various classes of service (Class of service) and introduction of their priority service do not allow to use directly methods and analysis algorithms of survivability indicators developed for data transmission networks and ATM networks for the analysis of survivability of MPLS networks.

Therefore, the purpose of the present work is development and research of the methods, analysis and optimization algorithms for survivability of MPLS networks.

Statement and model of the analysis of survivability problem

Following work [1] under *survivability of a system* we will understand its ability to keep the functioning and to provide performance of the basic functions (in the reduced volume) at the specified quality of service indicators.

As the basic purpose of a MPLS network is transfer of the specified sizes of input flows of various classes, survivability of MPLS network we estimate by size of the maximum flow which is possible to transfer in a network at failures of its elements - channels and nodes under preservation of the specified level of quality. of service.

There is MPLS network which is described by oriented graph $G=\{X,E\}$ where $X=\{x_j\}$ is a set of nodes,- $E=\{(r,s)\}$ -a set of communication channels (KC); μ_{rs} - capacity of channel (r,s)..

Let us admit, that in a network K classes of flows are transferred (K $=\widehat{1,6}$) (CoS) according to the matrix of requirements, $H(k)=\left\|h_{ij}(k)\right\|$ $i=\overline{1,N}$, $j=\overline{1,N}$ (Mbit/s). For each class k the quality of service indicator

(QoS) in the form of the specified value of an average delay $T_{cp,k}$ is introduced which is estimated by following expression [2]:

$$T_{cp,k} = \frac{1}{H_{\Sigma}^{(k)}} \sum_{(r,s)\in E} \frac{f_{rs}^{(k)} \sum_{i=1}^{k} f_{rs}^{(i)}}{\left(\mu_{rs} - \sum_{i=1}^{k-1} f_{rs}^{(i)}\right)\cdot\left(\mu_{rs} - \sum_{i=1}^{k} f_{rs}^{(i)}\right)}, \quad (1)$$

where $H_{\Sigma}^{(k)} = \sum_{i=1}^{n}\sum_{j=1}^{n} h_{ij}^{(k)}$, μ_{rs} - capacity of a communication channel (r,s), $f_{rs}^{(k)}$ - a flow value of the-k-th class in the channel (r,s).

It is required to define survivability indicators for the given network.

In work [2] for the analysis of indicators of MPLS networks survivability the following complex indicator has been suggested:

$$P\left\{H_{\Sigma}^{\Phi}(1) \ge r\% H_{\Sigma}^{0}(1)\right\}, P\left\{H_{\Sigma}^{\Phi}(2) \ge r\% H_{\Sigma}^{0}(2)\right\} ... P\left\{H_{\Sigma}^{\Phi}(k) \ge r\% H_{\Sigma}^{0}(k)\right\}, \quad (2)$$

where $H_{\Sigma}^{0}(k)$ - flow value of k -th class in failure-free network state;

$H_{\Sigma}^{\Phi}(k)$ is an actual flow value of class k in case of failures, r = (50÷100) % $k = \overline{1,K}$. Thus for an estimation of MPLS networks survivability the vector indicator of kind (1) is used.

As at failures of some channels or the nodes it is not known in advance, what would be the value of the maximum flow of each class at failures, the hypothesis that the general flow structure at failures remains is defined, i.e. the approximate parity on sizes of streams of various classes at failures should remain, namely:

$$H_{\Sigma}^{\Phi}(1) : H_{\Sigma}^{\Phi}(i) : H_{\Sigma}^{\Phi}(K) = H_{\Sigma}^{0}(1) : H_{\Sigma}^{0}(i) : H_{\Sigma}^{0}(K). \quad (3)$$

Algorithm of an estimation of survivability indicators of MPLS networks

Let's consider the MPLS network G = (X, E), consisting of elements (channels and nodes), subjected to environment influence in result of which they fail. It is supposed, that are set reliability characteristics of a network elements- factors of readiness of channels $k_{\Gamma r,s}$ and nodes - $k_{\Gamma r,s} . k_{\Gamma,i}$ $(r,s) \in E$ $i = \overline{1,n}$

Let us consider following failure states of network:

1) failure state 1 channel $Z_1 = \{Z_i\}$;
2) failure state 1 node $Z_2 = \{Z_j\}$;
3) failure state 2 channels : $Z_3 = \{Z_r\}$:
4) failure state 1 channel and 1node $Z_4 = \{Z_t\}$;
5) failure state 3 channels: $Z_5 = \{Z_s\}$.

Using model of an active environment, it is possible to define probability of each state $P\{Z_0\}$. For example, if Z_i is the state of channel, $(r_i s_i)$ failure then

$$P(Z_i) = (1 - K_{\Gamma,r,s}) \prod_{(r,s)\neq(r_i,s_i)} K_{\Gamma r,s} , \quad (4)$$

where $K_{\Gamma r,s}$ is a probability of the safe state of channel 1 $(r,s) \neq (r_i, s_i)$,$1 - K_{\Gamma r,s}$ - probability of a channel (r,s) failure.

In work [2] the algorithm of an estimation of survivability indicators of MPLS network has been suggested.

1. We calculate the general intensity of a flow in failure state for all classes of service:

$$H_{\Sigma}^{(0)}(1), H_{\Sigma}^{(0)}(2),..., H_{\Sigma}^{(0)}(K).$$

2. We simulate various failure states: Z_1, Z_2, Z_3, Z_4, Z_5.

For each of them we calculate probabilities $P(Z_i)$ according to (3).

3. We find the value of the maximum flow for all the classes in a condition. $Z_j : H_{\Sigma}^{\Phi}(k, z_j)\ k = \overline{1, K}$

For this purpose we use algorithm of a finding of the maximum flow which have been specially developed in the dissertation.

4. We calculate a complex survivability index for each class of service:

for the first class

$$P\left\{H_{\Sigma}^{\Phi}(1) \geq r\% H_{\Sigma}^{0}(1)\right\} = \sum_{Z_j} P(Z_j), \quad (5)$$

where summation in (5) is performed for all Z_j such that $H_{\Sigma}^{\Phi}(1) \geq r\% H_{\Sigma}^{0}(1)$;

for the k th class

$$P\left\{H_{\Sigma}^{\Phi}(k) \geq r\% H_{\Sigma}^{0}(k)\right\} = \sum_{Z_i} P(Z_i), \quad (6)$$

where summation in (6) is performed for all states Z_i :, $H_{\Sigma}^{\phi}(k) \geq r H_{\Sigma}^{(0)}(k)$

$H_{\Sigma}^{0}(k)$ is intensity of flow of k th class in faultless state of network;

$H_{\Sigma}^{\Phi}(k)$ - actual intensity of a flow of a class k in case of failures, r =(50÷100)%, $k = \overline{1, K}$.

where Z_i is such: that $H_{\Sigma}^{\phi}(r) \geq k H_{\Sigma}^{(0)}(r)$.

Let us construct the received dependences in co-ordinates

$P\{H_{\Sigma}^{\phi}(k)\}$ - $r\% H_{\Sigma}^{0}$ $P\left\{H_{\Sigma}^{\Phi}(1) \geq r\% H_{\Sigma}^{0}(1)\right\}, P\left\{H_{\Sigma}^{\Phi}(2) \geq r\% H_{\Sigma}^{0}(2)\right\} ... P\left\{H_{\Sigma}^{\Phi}(k) \geq r\% H_{\Sigma}^{0}(k)\right\}$

Statement of MPLS network optimization problem by survivability indicators

During designing networks by results of the analysis of its survivability indicators a problem of maintenance of demanded survivability level appears. It is natural, that this problem can be solved by reservation of its channels and nodes, structural optimization of a network and needs additional expenses.

Therefore, further we will consider statement of the network structural optimization problem by survivability indicators. [3].

Let there be MPLS network which is described by the oriented graph $G = \{X, E\}$ where $X = \{x_j\}$ is a set of network nodes, $E = \{(r, s)\}$ set of communication channels (KC); μ_{rs} - capacity of a channel.

Let us assume, that in the network K flows classes are transferred (To $=1,\widehat{6}$) (CoS) according to matrixes of requirements, $H(k) = \left\| h_{ij}(k) \right\|$ $i = \overline{1, N}$ ($j = \overline{1, N}$ Mbit/s). For each class k the quality of service indicator (QoS) in the form of the value of an average delay k $T_{cp,k}$. is set up. Let proceeding from a network functional purpose the following values of survivability indicators for the k th class flow are established k ; $P_{0зад}^{(k)}, P_{1зад}^{(k)}, ..., P_{5зад}^{(k)}$.

It is required to define such structure of a network for which for all classes K following restrictions on survivability level will be provided:

$$P\left\{H_{\Sigma}^{\phi}(k) \geq r\% H_{\Sigma}^{(0)}(k)\right\} \geq P_{kзa}, \ r = (50 \div 100)\%, \ k = \overline{1, K} \quad (7)$$

and additional expenses would be thus minimum.

We shall provide achievement of demanded level of survivability by introduction of corresponding reservation of the most responsible elements of a network (channels and nodes).

For an estimation of efficiency of channels and nodes reservation the following indicator is suggested:

a) for channels, $\alpha_{r_i s_i} = -\dfrac{\Delta P(Z_i)}{C_{r_i s_i}}$ (8)

where - Z_i a failure state of the channel $(r_i s_i)$;

$\Delta P(Z_i)$ - change of probability of the state Z_i after reservation, $C_{r_i s_i}$ is the cost of such reservation.

The value $\Delta P(Z_i)$ is estimated by the following formula:

$$P_{рез}(Z_i) - P(Z_i) = (P^2_{отк\,r_i s_i} \cdot \prod_{(r,s)\neq(r_i,s_i)} K_{\Gamma\,r,s} - P_{отк\,r_i s_i} \prod_{(r,s)\neq(r_i,s_i)} K_{\Gamma\,r,s} =$$
$$= -(1 - P_{отк\,r_i s_i}) \cdot P_{отк\,r_i s_i} \prod_{(r,s)\neq(r_i,s_i)} K_{\Gamma\,r,s} = -(1 - P_{отк\,r_i s_i}) \cdot P(Z_i) . \quad (9)$$

The similar formula is used for an estimation of nodes reservation.

Let us notice, that at failures of nodes, all ingoing and outgoing channels fail simultaneously. The indicator $\alpha_{r_i s_i}$ is used for a choice of prime elements (channels and nodes) for reservation. In work the following algorithm of MPLS network optimization by survivability indicators is offered.

Algorithm of MPLS networks optimization by survivability indicators

The algorithm consists of the same iterations, on each of which the next element - the channel or node is reserved.

1st iteration

1. For all channels and nodes we calculate an indicator $\alpha_{r_i s_i}$ by formula (8).

2. We choose channel (r^*, s^*) such that $\alpha_{r^* s^*} = \max\limits_{(r_i s_i)} \alpha_{r_i s_i}$

3. We reserve channel (r^*, s^*) and recalculate survivability indicators for all classes after reservation by the following formula:

$$P^H\left\{H^{\phi}_{\Sigma}(k) \geq r\% H^{(0)}_{\Sigma}\right\} = P\left\{H^{\phi}_{\Sigma}(k) \geq r\% H^{(0)}_{\Sigma}\right\} + \left|\Delta P(Z^*_i)\right|, \quad (10)$$

where $\Delta P(Z^*_i)$ is a change of probability state Z_i after reservation of the channel (r^*, s^*).

4. Check up conditions (11) (restrictions on survivability):

$$P^H\left\{H^{\phi}_{\Sigma}(k) \geq r\% H^{(0)}_{\Sigma}\right\} \geq P_{r,зад}^{(k)}, \ r = (50 \div 100)\%, \ k = \overline{1,K} . \quad (11)$$

If restrictions (11) are fulfilled for all r and all classes K then the end, otherwise we go to the 2nd iteration.

We repeat the specified iterations until the condition (11) will be held for all k and r. As on each iteration the values of survivability indicators raise, and their size is limited from top by value 1 the algorithm converges for a final number of iterations.

Experimental researches

The analysis of sensitivity of the received decision to a variation T_{cp}

All experiments were held for factors of readiness of the channels distributed normally at the interval 0.9 – 0.95, and for factors of readiness of the nodes distributed normally at the interval 0.95 – 0.99.

In the first series of experiments sensitivity of survivability indicators of the first class to a variation of restriction on an average delay T_{cp} was estimated. Corresponding results are presented in table 1 and on fig. 1.

Table 1

	T_{cp} = 0,01	T_{cp} = 0,05	T_{cp} = 0,15	T_{cp} = 0,7
P(100%)	0,352779	0,389927	0,410044	0,432404
P(90%)	0,352779	0,389927	0,410044	0,432404
P(80%)	0,482439	0,520454	0,539737	0,565827
P(70%)	0,483985	0,521005	0,541752	0,565827
P(60%)	0,484394	0,521005	0,543298	0,566516
P(50%)	0,484394	0,521005	0,545879	0,566516

In the given series of experiments sensitivity of survivability to a variation T_{cp} for the second class was estimated. Corresponding results are presented on fig. 2

As well as for the class 1 traffic, the variation T_{cp} strongly enough influences on survivability indicators, and at the further increase of T_{cp} the significant improvement of survivability indicators is not observed.

In the following series of experiments sensitivity of survivability to a variation for T_{cp} for the third class was estimated. Corresponding results are presented on fig. 3.

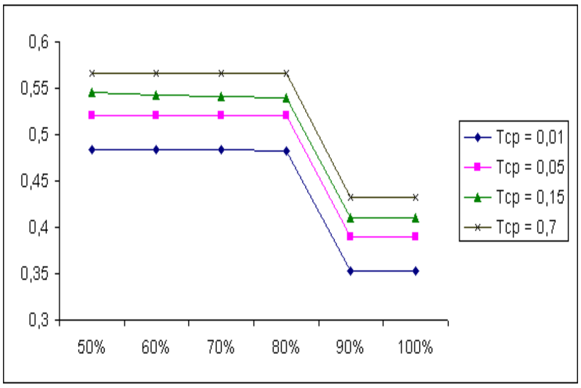

Fig. 1

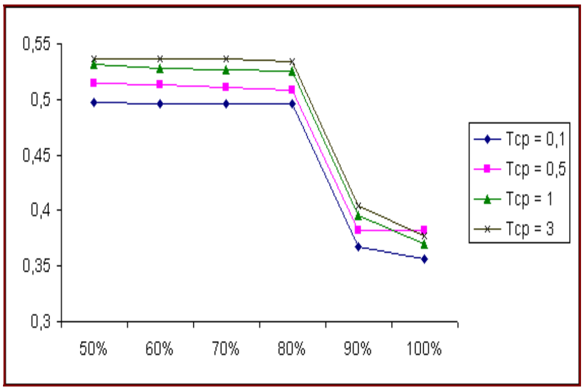

Fig. 2

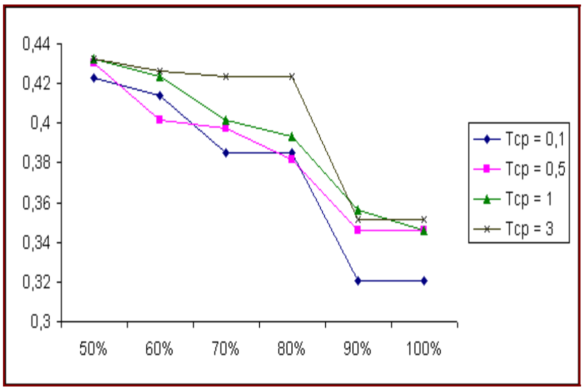

Fig. 3

The analysis of sensitivity of the received solutions to a variation of nodes and channels readiness factors

In the given series of experiments was estimated sensitivity of survivability indicators to a variation of reliable characteristics of network elements factors of readiness of channels and nodes.

Experiment №1. Factors of readiness of nodes are distributed normally on an interval [0,95 – 0,99], factors of readiness of channels – [0,9 – 0,95].

Experiment №2. Factors of readiness of nodes are distributed normally on an interval [0,95 – 0,99], factors of readiness of channels – [0,85 – 0,9].

Experiment №3. Factors of readiness of nodes are distributed normally on an interval [0,9 – 0,95], factors of readiness of channels – [0,85 – 0,9].

Experiment №4. Factors of readiness of nodes are distributed normally on an interval [0,9 – 0,95], factors of readiness of channels – [0,9 – 0,95].

Results for the traffic of class 1 are presented on table 4.

Table 4

	Exper. №1	Exper. №2	Exper. №3	Exper. №4
P(100%)	0,379308	0,212195	0,137087	0,21831
P(90%)	0,379308	0,212195	0,137087	0,21831
P(80%)	0,47672	0,244787	0,166213	0,302938
P(70%)	0,477463	0,24499	0,166213	0,302938
P(60%)	0,478882	0,24499	0,166299	0,303238
P(50%)	0,479821	0,245513	0,166557	0,303238

Conclusions

The problem of the analysis of survivability indicators of MPLS network, in case of failures of its elements-channels and nodes, is formulated.

1. Indicators of networks survivability are defined and the algorithm of their estimation considering the specificity of MPLS networks is offered.
2. The problem of optimization of networks by survivability indicators is formulated and the algorithm of its solution, allowing reaching preset values of survivability indicators is suggested at the minimum additional expenses.
3. Experimental researches of the offered analysis algorithms and optimization of MPLS networks are performed.

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