QoS Characteristics Providing in Network Traffic Balancing

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Abstract: Solving of the problem of quality characteristics providing QoS in MPLS-TE network with bypass routes of traffic transmission is proposed. By the nodal tensor method the value of packet delay along a traffic transmission route for the network with bypass routes of traffic transmission and without them is received and the results comparison of traffic balancing is conducted. It is shown, that in the network with the bypass routes of traffic transmission less time of packets delay is received. In this connection the balanced load of available network resources and its resiliency is provided.

1 INTRODUCTION

Modern transport packet network of multiprotocol switching according to the labels of MPLS-TE (Multiprotocol Label Switching Traffic Engineering) provides service packet traffic with the support for quality of service QoS (Quality of Service). MPLS-TE network functioning is based on the efficient use of available network resources, which is achieved by choosing the optimal route of traffic, procedures application of resource reservation and distribution network load, traffic balancing and application of mechanisms of preventing overloading and fault tolerance.

Ensuring the regulatory quality characteristic values of QoS in MPLS-TE network is performed by selecting the optimal route of traffic transmission by unidirectional tunnel TE-tunnel in the conditions of the rational application and downloading of network resources.

One of the solutions, that allows to ensure balanced load of network resources and its resiliency is the organization of bypass routes of traffic routing. This is due to the fact that during the operation of the network there is often a need to discharge certain routes, which loading is too significant.

Then, in order to balance traffic and in order to provide the required level of quality of service QoS, it is possible to use bypass (additional) pre-configured transmission route of traffic transmission.

Unlike fast rerouting of packages Fast ReRoute (FRR), which in the case of route failure allows in the network MPLS-TE to direct traffic to another pre-configured tunnel – TE-tunnel, chosen by the criterion of minimum packets delay, the application of bypass routes primarily supposes balancing of load and efficient use of network resources to provide QoS characteristics.

That's why the solution of quality characteristics problem of QoS in the MPLS-TE network with the organization of bypass routes of traffic transmission is considered by authors as the question of present interest.

Quite an important issue of using bypass traffic transmission routes is the mechanism of their choosing, which is determined by the number of nodes connecting paths, may be the shortest of all and so on. In this work as a criterion of choosing bypass routes the packet delay time is used.

To solve this problem it is advisable to use tensor methods to take into account the nature of the traffic stream and within a single tensor method simultaneously investigate the structural characteristics and functional properties of the network to meet the needs for appropriate quality of service characteristics.

Earlier, the authors obtained solution of traffic management problems in MPLS-TE network by node tensor method.

Under conditions of known values of intensities of network traffic and paths and the length of the output packet queue, its application allows to solve a significant class of traffic routing problems for networks of different topologies and technologies, by choosing a certain sequence of network nodes on set criteria specifics of a structure and network operation.

The aim of this work is solving the problem of providing quality characteristics of QoS in MPLS-TE network with bypass routes of traffic transmission and without them and the comparison of the results. This will allow effectively to apply and efficiently to load network resources, to provide balancing traffic in a network and to prevent possible overloads and routes failures.

2 TRAFFIC BALANCING IN MPLS-TE NETWORK UNDER CONDITIONS OF BYPASS ROUTES OF TRAFFIC TRANSMISSION

Let's consider the solving of quality characteristics QoS problems in the network under conditions of only main routes of traffic transmission by nodal tensor method.

Let's consider the output structure scheme of MPLS-TE network with ten paths of transmission that is shown on Figure 1.

The fragment of output network (Figure 1) is given as a graph G(N,V), where N = {N_j, j=1,5} – the set of vertices which are network nodes – routers, and V = {v_i, i=1,10} – set of arcs modelling network branches that are presented by network paths. In this case for the set fragment of output network only the main routes of traffic transmission are used.

We consider that the traffic transmission is performed in the direction from the network router N_1 to the router N_3 (on the structural scheme, the direction is shown by dash-and-dot line).

Let us set the main routes of TE-tunnel traffic transmission in the network, shown on the Figure 1: $N_1 \to N_3$, $N_1 \to N_2 \to N_3$, $N_1 \to N_5 \to N_4 \to N_3$, $N_1 \to \to N_6 \to N_5 \to N_4 \to N_3$, $N_1 \to N_5 \to N_2 \to N_4 \to N_3$, $N_1 \to \to N_6 \to N_1 \to N_6 \to N_5 \to N_2 \to N_4 \to N_3$, $N_1 \to N_2 \to N_4 \to \to N_3$, $N_1 \to N_6 \to N_5 \to N_2 \to N_3$.

To solve the set problem let we find the packets delay in T_v paths and on T_η nodes of the network, when between the nodes there are only basic routes of TE-tunnel traffic transmission by nodal tensor method.

We write the basic matrix of the pairs B_η according to network structure (Figure 1):

$$B_\eta = \begin{pmatrix} 0 & 0 & 0 & 1 & 0 & 1 & 0 & -1 & -1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & -1 \\ 0 & 1 & 1 & 0 & 0 & -1 & -1 & 0 & 0 & 0 \\ 1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \quad (1)$$

Let us define the length of the output packet queue, which is transmitted from router N_1 to router N_5 and is represented by tensor components of average length of packet queues H^{+}_{v} (th.pack):

$$H^{+}_{v} = \begin{pmatrix} 0 & 0 & 0 & 0 & 100 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}^{t}, \quad (2)$$

where t – is the sign of transportation.

The average traffic intensities L_v (th.pack/s) in the paths of network are known and given in Table 1.

Table 1: Average intensities values of traffic in the network paths without bypass routes of traffic transmission.

Number of path	1	2	3	4	5
L_v	700	500	300	850	0
Number of path	6	7	8	9	10
L_v	400	350	650	800	600

As a functional invariant equation, we use the formula of Little, which according to [3-4] in tensor presentation is:

$$h_i = l^{i\alpha}\, \tau_{i\alpha}, \quad i = 1,n, \quad (3)$$

where h_i – average length of packet queues in the i-th network path, l^i – average traffic intensity in the i-th network path, τ_i – average time of packets delay in i-th network path, n– number of paths, α – index of summarizing.

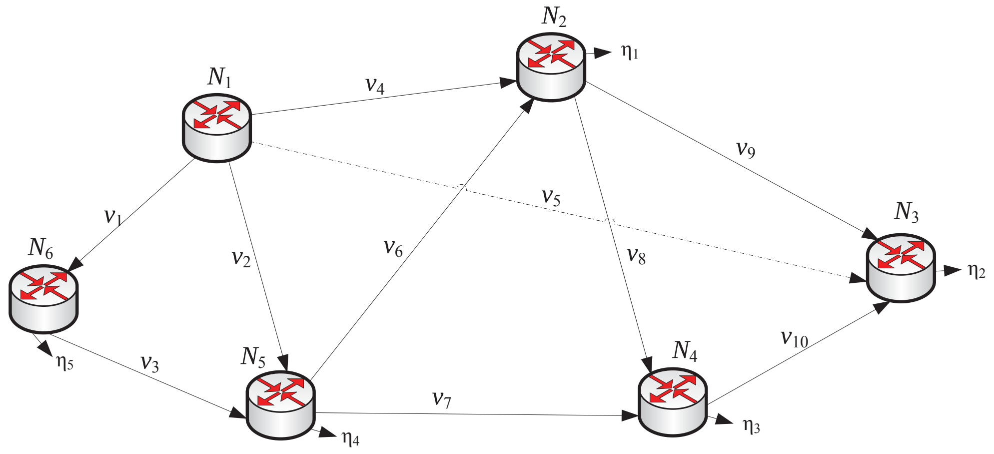

Figure 1: Block diagram of MPLS-TE network without bypass routes of traffic transmission.

Invariant equation (3) is presented in tensor form in the specified coordinate systems (SC) of branches and network node pairs:

$$H_\nu = L_\nu T_\nu, \quad H_\eta = L_\eta T_\eta, \qquad (4)$$

where H_ν, H_η – covariant tensors of average length of packet queues in the SC branches and node pairs respectively, T_ν, T_η – are covariant tensors of average packets delays in SC branches and node pairs, and L_ν, L_η – are covariant tensors of average intensities of traffic in SC branches and network node pairs respectively.

Tensor of packets time delay T_η in network nodes is defined by the formula (4), as:

$$T_\eta = (L_\eta)^{-1} H_\eta. \qquad (5)$$

The transformation of the tensors projections by changing the SC is carried out:

$$T_\nu = B^t_\eta T_\eta, \; H_\eta = B_\eta H^+_\nu, \; L_\eta = B_\eta L_\nu B^t_\eta, \qquad (6)$$

where B_η – matrix of basic node pairs, H^+_ν – tensor of output packets queue in the SC network branches.

Let us define loading of network nodes while transmitting output packet queue, by calculation of tensor projections of packets queue length H_η in SC network node pairs.

According to equation (6) and given expression (1) of basic matrix of nodal pairs B_η and expression (2) of tensor of packets queues of average length H^+_ν we get tensor of packets queue length in the network nodes:

$$H_\eta = \begin{pmatrix} 0 & 100 & 0 & 0 & 0 \end{pmatrix}^t. \qquad (7)$$

Let we find L_η tensor which components in SC nodal pairs determine the intensities of traffic of each network node.

Using the equation (6) and known average traffic intensities L_ν in network paths given in Table 1 and basic matrix of nodal pairs B_η given by the expression (1), we get:

$$L_\eta = \begin{pmatrix} 2700 & -800 & -650 & -400 & 0 \\ -800 & 1400 & -600 & 0 & 0 \\ -650 & -600 & 1600 & -350 & 0 \\ -400 & 0 & -350 & 1550 & -300 \\ 0 & 0 & 0 & -300 & 1000 \end{pmatrix}. \qquad (8)$$

Using expressions (5), (7) and (8), we find the value of the average delay of packets in each router of MPLS-TE network, by calculating tensor projections T_η in SC network node pairs:

$$T_\eta \approx \begin{pmatrix} 0{,}079 & 0{,}160 & 0{,}102 & 0{,}046 & 0{,}014 \end{pmatrix}^t \qquad (9)$$

where t – is the sign of transportation.

Let we define the value T_ν of packets delay for each path of the network according to the equation (6) in the SC network branches.

According to the obtained values of packets delay time for each network router given by tensor T_η (9) and known basic matrix of nodal pairs B_η, given by the expression (1) we obtain packets delay time T_ν in network paths.

The results are presented in Table 2.

Table 2: Value of average packets delay in network paths without bypass routes of traffic transmission

Number of path	1	2	3	4	5
T_v, c	0,014	0,046	0,032	0,079	0,160
Number of path	6	7	8	9	10
T_v, c	0,033	0,056	0,023	0,081	0,058

Taking into account that the value of packets delay is additive along the appropriate route let we find packets delay time in the network in the TE-tunnel for all set routes of traffic transmission.

The results of values calculations of average packets time delay in network nodes and paths which connect them in the case of absence the bypass routes of traffic transmission are shown in Figure 2.

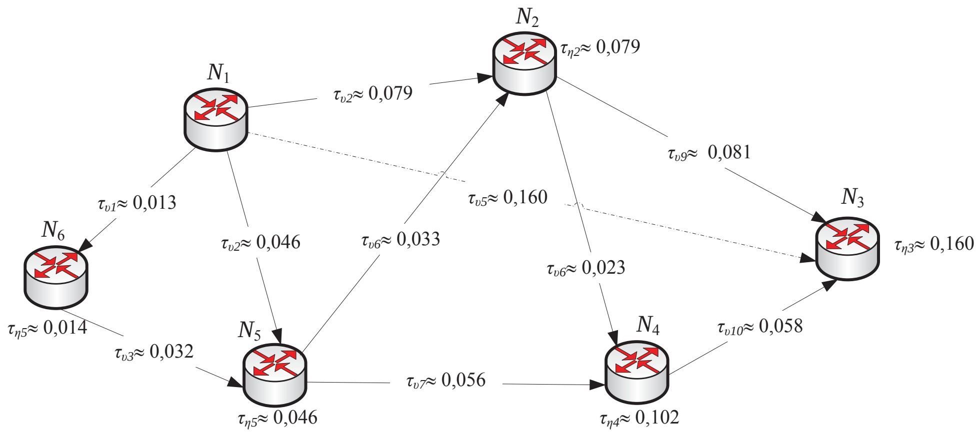

Figure 2: Results of packets delay calculations in the network without bypass routes of traffic transmission.

According to the conducted calculations (2-9) the values of packets delay time along different routes traffic transmission between set nodes pairs without bypass routes of routing are received. The results are given in Table 3.

Table 3: The values of average time of packets delay in the network routes without bypass routes of traffic transmission.

Route of traffic transmission	Number of branches ν (paths), that are included into the route	Value of average time τ of packets delay, s
$N_1 \rightarrow N_3$	ν_5	0,160
$N_1 \rightarrow N_2 \rightarrow N_3$	ν_4-ν_9	0,160
$N_1 \rightarrow N_5 \rightarrow N_4 \rightarrow N_3$	ν_2-ν_7-ν_{10}	0,160
$N_1 \rightarrow N_6 \rightarrow N_5 \rightarrow N_4 \rightarrow N_3$	ν_1-ν_3-ν_7-ν_{10}	0,160
$N_1 \rightarrow N_5 \rightarrow N_2 \rightarrow N_4 \rightarrow N_3$	ν_2-ν_6-ν_8-ν_{10}	0,160
$N_1 \rightarrow N_6 \rightarrow N_5 \rightarrow N_2 \rightarrow N_4 \rightarrow N_3$	ν_1-ν_3-ν_6-ν_8-ν_{10}	0,160
$N_1 \rightarrow N_2 \rightarrow N_4 \rightarrow N_3$	ν_4-ν_8-ν_{10}	0,160
$N_1 \rightarrow N_6 \rightarrow N_5 \rightarrow N_2 \rightarrow N_3$	ν_1-ν_3-ν_6-ν_9	0,160

3 TRAFFIC BALANCIING IN MPLS-TE NETWORK WITHOUT BYPASS ROUTESS OF TRAFFIC TRANSMISSION

Let we consider the solving of quality characteristic QoS providing problems in MPLS-TE network under condition when between the network nodes apart from basic routes there are additional routes of traffic transmission that allow to perform balancing the traffic and to prevent probable uploading routes failures.

Considering that the additional route has to be calculated simultaneously with basic one on the structural scheme of the network (Figure 3), let we set both basic and additional routes of traffic routing.

Let we consider the structural scheme of MPLS-TE network shown in Figure 3.

Let we set the network fragment in the form of multigraph G(N,V), where $N = \{N_j, j=1,5\}$ – the set of vertices which are represented by the network nodes – routers, and V = {v_i, i=1,15} – set of arcs that are modelling network branches presented by network paths, ten of which ($v_1 - v_{10}$) are basic and five ($v_{10} - v_{15}$) – bypass routes.

In the case when output network structure has not bypass routes of traffic transmission, the structure of network (Figure 1) is presented in the form of simple graph (graph without multiple edges).

But in the considered network there are bypass routes that's why it is reasonable to apply multigraph that allows describing network in which one and the same pair of vertices is connected by some arcs.

Then the basic matrix of node pairs B_η will have the form:

$$B_\eta = \begin{pmatrix} 0 & 0 & 0 & 1 & 0 & 1 & 0 & -1 & -1 & 0 & 1 & 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & -1 & 0 & 0 & 1 & 0 & -1 \\ 0 & 1 & 1 & 0 & 0 & -1 & -1 & 0 & 0 & 0 & 0 & -1 & -1 & 0 & 0 \\ 1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Known average traffic intensities L_v (th. pack/s) in the bypass paths of the network that are given in Table 4.

The results of calculations of the average packets delay in the network nodes and paths, which connect for the network with bypass routes of traffic transmission, are shown in Figure 4.

Table 4: Values of average traffic intensities in the paths with bypass routes of traffic transmission.

Number of path	11	12	13	14	15
L_v	450	600	300	500	200

According to carried out calculations (2-9), we obtained that the value of packets delay time along different routes of traffic transmission between given pairs of nodes is τ≈0,108 s in the case of additional routes of traffic transmission.

The results are given in Table 5.

Therefore, we obtain that the value of packets delay time in MPLS-TE network with bypass routes of traffic transmission between routers in TE-tunnels for different routes between set nodes pairs is the same and equals 0,108 s.

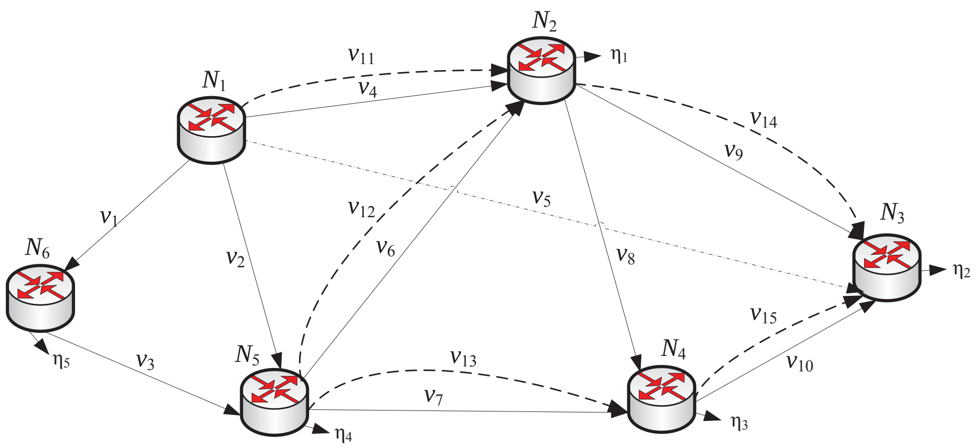

Figure 3: Structural scheme of MPLS-TE network with additional route of traffic transmission in the form of multigraph.

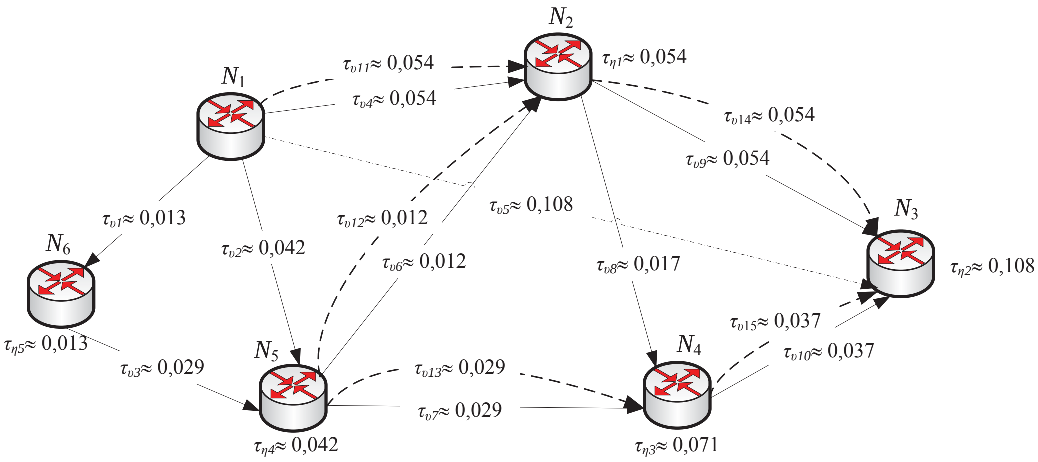

Figure 4: Results of calculations of packets delay time in the network with bypass routes of traffic transmission.

Table 5: Values of average packets delay time in the network with bypass routes of traffic transmission.

Routes of traffic transmission	Number of branches ν (paths), that are included into routes	Values of average time τ packets delay, sec
Basic routes		
$N_1 \to N_3$	ν_5	0,108
$N_1 \to N_2 \to N_3$	ν_4-ν_9	0,108
$N_1 \to N_5 \to N_4 \to N_3$	ν_2-ν_7-ν_{10}	0,108
$N_1 \to N_6 \to N_5 \to N_4 \to N_3$	ν_1-ν_3-ν_7-ν_{10}	0,108
$N_1 \to N_5 \to N_2 \to N_4 \to N_3$	ν_2-ν_6-ν_8-ν_{10}	0,108
$N_1 \to N_6 \to N_5 \to N_2 \to N_4 \to N_3$	ν_1-ν_3-ν_6-ν_8-ν_{10}	0,108
$N_1 \to N_2 \to N_4 \to N_3$	ν_4-ν_8-ν_{10}	0,108
Bypass routes		
$N_1 \to N_2 \to N_3$	ν_{11}-ν_{14}	0,108
$N_1 \to N_2 \to N_5 \to N_4 \to N_3$	ν_{11}-ν_{12}-ν_{13}-ν_{15}	0,108

4 COMPARISON OF TRAFFIC BALANCING RESULTS IN MPLS-TE NETWORK WITH AND WITHOUT BYPASS ROUTES OF TRAFFIC TRANSMISSION

Let we conduct the results comparison of characteristics performance in MPLS-TE network according to the criterion of the value of packets delay time for set routes in case of additional routes in the network of traffic transmission and case of its absence.

Received solution of set problem in the case of application of the same output data for the network structure, in which there are no bypass routes of traffic transmission, allow to get packets delay time $\tau \approx 0{,}160$ s, the same along all routes of traffic transmission is received.

Accordingly, for the network structure with bypass routes of traffic transmission, packets delay time is $\tau \approx 0{,}108$ s. and is also the same along all routes of traffic transmission.

It allows to state about reasonability of application of bypass routes of traffic transmission.

It is known, that when determining the packets delay along the traffic transmission route in MPLS-TE network, it is necessary also to consider not only packets delay in network paths, and also to take into account the value of packets time delay in network nodes.

Of course, the value of packets delay time in the nodes in MPLS-TE network depends on the functional features of equipment (volumes of buffer devices, mechanisms of organization and service of queue in the buffer devices), used protocols and other factors.

However, specifically packets delays in network nodes significantly affect the resulting value for quality of service QoS.

Therefore, we define the value of packets delay in the set traffic transmission routes in MPLS-TE network with additional directions and without them taking into account the received values of packets delay T_η in the network nodes (expression (9)).

For the network with basic routes of traffic transmission (Figure 1) the average time of packets delay τ_{delay} in the route taking into account delays in network nodes, is given in Table 6.

Table 6: Values of average packets delay time in the networks routes without bypass routes of traffic transmission taking into account delays in network nodes.

Routes of traffic transmission	Number of branches ν that are included into the route	Number of nodes that are included into the route	Value of average time τ_{delay} packets delay, s
$N_1 \to N_3$	ν_5	N_1, N_3	0,320
$N_1 \to N_2 \to N_3$	ν_4-ν_9	N_1, N_2, N_3	0,399
$N_1 \to N_5 \to N_4 \to N_3$	ν_2-ν_7-ν_{10}	N_1, N_5, N_4, N_3	0,468
$N_1 \to N_6 \to N_5 \to N_4 \to N_3$	ν_1-ν_3-ν_7-ν_{10}	N_1, N_6, N_5, N_4, N_3	0,482
$N_1 \to N_5 \to N_2 \to N_4 \to N_3$	ν_2-ν_6-ν_8-ν_{10}	N_1, N_5, N_2, N_4, N_3	0,547
$N_1 \to N_6 \to N_5 \to N_2 \to N_4 \to N_3$	ν_1-ν_3-ν_6-ν_8-ν_{10}	N_1,N_6, N_5, N_2, N_4, N_3	0,561
$N_1 \to N_2 \to N_4 \to N_3$	ν_4-ν_8-ν_{10}	N_1,N_2, N_4, N_3	0,501
$N_1 \to N_6 \to N_5 \to N_2 \to N_3$	ν_1-ν_3-ν_6-ν_9	N_1, N_6, N_5, N_2, N_3	0,459

For the set basic routes of traffic transmission and the network structure with bypass routes of traffic transmission (Figure 3) the time of packets delay τ_{delay} taking into account delays in the network nodes, given in Table 7, is received.

Thus, the value of packets delay time in the set routes of traffic transmission taking into account the delays in the network nodes is the same as for the basic and as for the bypass routes.

For example, for the route $N_1 \to N_2 \to N_3$ with bypass routes and without them, the time of delay is the same and equals $\tau_{delay} \approx 0{,}270$ s.

For example, for the route $N_1 \to N_5 \to N_4 \to N_3$ with bypass routes the time of delay $\tau_{delay} \approx 0{,}329$ s and without them $\tau_{delay} \approx 0{,}468$ s.

For example, for the route $N_1 \to N_2 \to N_4 \to N_3$ with bypass routes the time of delay $\tau_{delay} \approx 0{,}501$ s and without them $\tau_{delay} \approx 0{,}341$ s.

Table 7: Values of average time of packets delay in the network routes with bypass routes of traffic transmission taking into account delays in the network nodes.

Routes of traffic transmission	Number of branches ν that are included into the route	Number of nodes that are included into the route	Value of average time τ_{delay} packets delay, s
Basic routes			
$N_1 \to N_3$	ν_5	N_1, N_3	0,216
$N_1 \to N_2 \to N_3$	ν_4-ν_9	N_1, N_2, N_3	0,270
$N_1 \to N_5 \to N_4 \to N_3$	ν_2-ν_7-ν_{10}	N_1, N_5, N_4, N_3	0,329
$N_1 \to N_6 \to N_5 \to N_4 \to N_3$	ν_1-ν_3-ν_7-ν_{10}	N_1, N_6, N_5, N_4, N_3	0,342
$N_1 \to N_5 \to N_2 \to N_4 \to N_3$	ν_2-ν_6-ν_8-ν_{10}	N_1, N_5, N_2, N_4, N_3	0,383
$N_1 \to N_6 \to N_5 \to N_2 \to N_4 \to N_3$	ν_1-ν_3-ν_6-ν_8-ν_{10}	N_1,N_6, N_5, N_2, N_4, N_3	0,396
$N_1 \to N_2 \to N_4 \to N_3$	ν_4-ν_8-ν_{10}	N_1,N_2, N_4, N_3	0,341
$N_1 \to N_6 \to N_5 \to N_2 \to N_3$	ν_1-ν_3-ν_6-ν_9	N_1, N_6, N_5, N_2, N_3	0,325
Bypass routes			
$N_1 \to N_2 \to N_3$	ν_{11}-ν_{14}	N_1, N_2, N_3	0,270
$N_1 \to N_2 \to N_5 \to N_4 \to N_3$	ν_{11}-ν_{12}-ν_{13}-ν_{15}	N_1, N_2, N_5, N_4, N_3	0,383

5 CONCLUSIONS

1. The solution of quality characteristics providing problems of QoS in MPLS-TE network with bypass routes of traffic transmission and without them is suggested.

2. The comparison of traffic balancing results in the network is conducted:

– for the network structure, without bypass routes of traffic transmission (Figure 1), the value of average time of packets delay for different routes of traffic delivery (Table 3) between set nodes pairs that is τ≈0,160 s and is the same for all routes of traffic transmission in the network, is received;

– for the network structure with bypass routes of traffic transmission (Figure 3), the value of average time of packets delay for different routes of traffic delivery (Table 3) between set nodes pairs that is τ≈0,108 s and is the same for all routes of traffic transmission in the network, is received;

– the reduction of average time of packets delay for the network with bypass routes of traffic transmission allows to state about their application reasonability.

– thus in both cases, advantages of node tensor method, namely equality off average time of guaranteed packets delivery between given network nodes are preserved.

3. The values of packets delay time in the set routes of traffic transmission in MPLS-TE network with bypass routes of traffic transmission and without them taking into account the values of packets delay time in the network nodes are received:

– for the network with bypass routes of traffic transmission the value of packets delay for different routes of traffic delivery between set nodes pairs taking into account the values of packets delay in the network nodes (Table 7), where the time of packets delay is in the period of $\tau \in [0{,}270;0{,}407]$ s, is received;

– for the network without bypass routes of traffic transmission the values of packets delay time (Table 6) is $\tau \in [0{,}399;0{,}547]$ s;

– it is shown that in the network with bypass routes of traffic transmission the balanced loading of available network resources and its resiliency is provided.

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