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Enhanced Dynamic Load Balancing Algorithm in Computer Networks with Quality of Services[1]

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Abstract—Nowadays there is an increase in transfer volumes of audio, video and other types of multimedia content in modern computer networks (CN). Multimedia streaming and multicasting applications have limited jitter and end-to-end delay requirements and do not allow full providing of all necessary conditions for efficient data transmission on the Internet. To provide quality of service (QoS) of streaming applications Internet Engineering Task Force (IETF) proposed two QoS architectures: IntServ and DiffServ. However, these architectures have the limited ability of dynamical change in the movement of data flows and do not ensure compliance with all QoS requirements. Complexity in service of CN is often combined with incomplete compatibility of network decisions that involves dependence on the hardware manufacturers. The purpose of the work is the development of the enhanced dynamic load balancing algorithm in CN with QoS. The present work is dedicated to the simulation of software of dynamic load balancing processes. The results of the investigations of the offered algorithm on different topology of CN by 5 QoS-metrics are presented too. The assessment and comparison of the efficiency of the offered load-balancing algorithm with known analog such as Yen's algorithm including traffic engineering (TE) module are executed.

Keywords: computer networks, load balancing, quality of services, traffic engineering, delay, bandwidth, packet loss rate, jitter

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1. INTRODUCTION

Provision of high speed and reliable information exchange between nodes of computer networks (CN) in case of strict requirements to delay of information in the conditions of possible surges of traffic and local overloads of communication links is one of the major problems. The modern Internet technologies, such as VoIP and IPTV are especially critical on indicators of bandwidth, end-to-end delay, packet loss rate and jitter [1, 2]. In case of frequent updating of the routing information in widely known dynamic routing protocols such as OSPF and EIGRP it is necessary to rebuild completely routing tables of data flows or to work in the conditions of unreliable or irrelevant information about the status and characteristics of CN [3]. Different technologies and approaches to the classification and redistribution of the non-uniform data flows are widely applied to support of QoS on CN [4]. Recently there have been also new high-speed technologies and mechanisms of support of the required quality of network services considering different types of traffic. As a rule, these approaches are realized within the strategy by dynamic QoS-routing and multipath QoS-routing [5, 6]. Generally protocols of dynamic QoS-routing are based on Dijkstra's algorithm with computing complexity of $O(N^2)$, and protocols of multipath QoS-routing—on Yen's algorithm with complexity of $O(N^3)$, where N—number of nodes or routers in CN [7, 8]. Integration of multipath QoS-routing algorithms with load balancing algorithms allows redistributing more effectively data flows for support of QoS of multimedia streaming and multicasting applications.

In this work, the main attention is paid to development of mathematical model and enhanced dynamic load balancing algorithm (EDLBA) and its comparative analysis with Yen's algorithm including TE module (YATE). The proposed algorithm EDLBA using three coefficients: α, β, γ (α—coefficient of load balancing, β—deviation of the length of the minimum route from the length of the maximum route, γ—deviation of metric of the link, being in the minimum route, from metric of the link, being in the maximum route which consist concerning pair transition) allows redistributing and controlling QoS of multimedia

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streaming and multicasting applications more effectively. The optimization of process of dynamic load balancing with QoS is carried out on the basis of indicators of the route variation and the required value of delay jitter.

The main objectives of this work are:

- development of mathematical model of dynamic load balancing in CN with QoS;
- development of enhanced algorithm of dynamic load balancing in CN with QoS;
- development of dynamic load balancing software in CN with QoS.

This article has been as follows: the most actual works in this subject domain have been considered in section 2; the mathematical model of dynamic load balancing has been offered as well as the main QoS-parameters (bandwidth, delay, packet loss rate) and QoS-metrics (LARAC Metric, LARAC Cost Metric, Composite Metric) have been described in section 3; the flowcharts of EDLBA has been presented in section 4; the simulation results and comparison of the offered algorithm with popular approach (YATE) have been shown in section 5; the results analysis and the further research directions have been formulated in section 6; the efficiency of the offered algorithm has been given in the conclusion.

2. RELATED WORKS

Nowadays active scientific researches based on development of multipath QoS-routing strategy are carried out in CN for providing QoS of multimedia streaming and multicasting applications. The tasks of multipath QoS-routing are considered fully in the approaches of MCP, MCOP and CSP [6]. The protocols of multipath routing such as ECMP use changes of data flows for calculations and control of distribution of loading. The approach of redistribution of data flows (Traffic Engineering, TE) as extension of Yen's algorithm (YATE) is also used for load balancing. The review and the principles of TE module operation have been submitted in the work [9]. The algorithm including load balancing with multipath routing, which allows the routers to distribute loading along all paths depending on the current load of optimal route and reduces loss of data has been described in the work [10]. The development of new network technologies: software-defined networks (SDN) and OpenFlow protocol allows redistributing the data flows efficiently for providing QoS of multimedia streaming and multicasting applications [11–13]. The analysis of QoS-metrics and mechanisms in CN and SDN are considered in [14, 15]. The load balancing task for effective distribute data flows in SDN between a source-router and destination-router pair are offered in [16, 17]. The tensor model of multipath routing with load balancing for different classes of QoS is given in the work [18]. The multipath load balancing in SDN/OSPF hybrid network is given in the work [19]. This article proposes the development of mathematical model and enhanced dynamic load balancing algorithm in CN with QoS based on the development of the approach offered in the work [20].

3. DYNAMIC LOAD BALANCING WITH QOS

In this section, the mathematical model of dynamic load balancing in CN with QoS has been offered. The description of sensitivity of network applications on the passing flows on CN and settlement expressions for calculation of QoS-metrics has been also provided.

A. Mathematical Model

Within the solved task, the CN can be represented as directed weighed connected graph $\mathbf{G} = (\mathbf{V}, \mathbf{A}, \mathbf{W}, \mathbf{Z})$. Here **V**—a set of graph vertices (communication nodes or routers), $|\mathbf{V}| = \mathrm{N}$, **A**—a set of the arches of graph presenting communication links, $|\mathbf{A}| = \mathrm{M}$, **W**—a set of arches weights (metrics of communication links), **Z**—a set of network flows or QoS-services (applications, service data, etc.).

We designate $w_{i,j}$ as a route metric of the link connecting the nodes v_i and v_j. The node v_i is located lower than the node v_j in hierarchy of optimal routes tree. We define a set of routes to the node v_i from the initial node v_s through $\mathbf{R_i}$,where an element of a set $r_{i,k} \in \mathbf{R_i}$ is a set of the not repeating links $a_{i,j} \in \mathbf{A}$ forming together the route connecting v_s and v_i. We deliver to each $r_{i,k} \in \mathbf{R_i}$ in compliance the number equal to the sum of scales of the links entering it, i.e. cost or route metric of a path $c_{i,k} \in \mathbf{C_i}$, where $\mathbf{C_i}$ represents a set of estimates of optimal routes to the node v_i from the initial node v_s. A selector H returning an optimal route from a set $\mathbf{R_i}$ is defined in a set $\mathbf{R_i}$. In case there are some routes in $\mathbf{R_i}$ with the minimum cost, one of them gets out. An optimal route to the node v_i we designate as $r_i = H(\mathbf{R_i})$, the assessment of its route metric – c_i .

Table 1. Sensitivity of network applications to QoS-parameters in CN

Flow type	Sensitivity level of network applications to QoS-parameters			
	Bandwidth	Delay	Packet Loss Rate, PLR	Jitter
Speech traffic (VoIP)	Very low	High	Medium	High
E-commerce	Low	High	High	Low
E-mail	Low	Low	High	Low
Constant search in Internet (WEB, signalization)	Medium	High	High	Low
Exchange files (HTTP, FTP)	High	Low	Medium	Low
Streaming media	High	High	Medium	High
Multicasting	High	High	High	High

We establish for each QoS-service from a set $\mathbf{Z}$ a number of parameters: $w_{i,j}^{z}$—a route metric of z-traffic in communication link $a(i,j) \in \mathbf{A}$; s_z—router-source; t_z—router-destination. For an assessment of share of z-traffic proceeding in the link $a(i,j) \in \mathbf{A}$, we use the managing variable $x_{i,j}^{z}$. According to physics of the solved task on variables $x_{i,j}^{z}$, we impose the following restrictions:

$$0 \le x_{i,j}^{z} \le 1. \tag{1}$$

Metric minimization of routes in CN we computed based on QoS-parameters of bandwidth, delay and packet loss rate:

$$c_{k,t} = \min_{(i,j)\in \mathrm{E}} \sum_{z\in \mathrm{Z}} \sum_{(i,j)\in r_{k,t}} w_{i,j}^{k} x_{i,j}^{z}. \tag{2}$$

The arch capacity constraint B^z imposes a limit on the bandwidth $b_{i,j}^{\max}$ for each communication link $a(i,j) \in \mathbf{A}$:

$$\sum_{(i,j)\in A} B^z x_{i,j}^{z} \le b_{i,j}^{\max}. \tag{3}$$

The maximum acceptable value for the packet loss rate $P_{\mathbf{max}}^{\mathbf{z}}$ and delay $D_{\mathbf{max}}^{\mathbf{z}}$, imposes the limit for each z-traffic or QoS-service:

$$\sum_{(i,j)\in A} p_{i,j} x_{i,j}^{z} \le P_{\mathbf{max}}^{\mathbf{z}}; \tag{4}$$

$$\sum_{(i,j)\in A} d_{i,j} x_{i,j}^{z} \le D_{\mathbf{max}}^{\mathbf{z}}. \tag{5}$$

B. QoS-Parameters and QoS-Metrics

QoS-parameters in CN are considered from two perspectives: performance and reliability. Performance means delivering data flows over a determined time interval. The key performance parameters are: transmission delay, jitter, and bandwidth. Reliability depends on the accuracy of the transmitted data and the percentage of lost packets. Depending on the type of flows, the importance of a particular parameter increases (Table 1).

Multipath QoS-routing provides a selection of routes, which satisfies the QoS-requirements of a particular data flows. The chosen route can be different from shortest path. The process of routes determining involves knowledge of the requirements for QoS set by the data flows and information on available network resources. As a rule, during determining of the optimal and reserve routes in the multipath QoS-routing we take into account one of the network characteristics (bandwidth, transmission delay) or their combination (bandwidth and delay, delay and packet loss percentage, etc.) which form together QoS-metric.

The settlement expressions for calculation of QoS-metrics are given in Table 2.

Table 2. Settlement expressions for calculation of QoS-metrics

QoS-metrics	QoS 1	QoS 2	QoS 3	QoS 4	QoS 5
Settlement formula for metric calculation	OSPF Cost = 10^8/**Bandwidth**	**Delay** value, ms	LARAC Metric = **Bandwidth** + lambda·**Delay**	LARAC Cost Metric = (1−delta)·**Delay** + delta·**PLR**	**Composite Metric** value

The represented QoS-metrics are applied and used widely both in CN and in SDN.

4. ENHANCED DYNAMIC LOAD BALANCING ALGORITHM

The offered mathematical model of dynamic load balancing with QoS in CN corresponding algorithm was developed to confirm the correction. The comparative analysis of the EDLBA algorithm proves its efficiency in comparison with the known analog such as YATE algorithm with computing complexity $O(N^3)$. The computing complexity of the enhanced dynamic load balancing algorithm is $O(N^2)$. The flowcharts of the main and auxiliary procedures of the offered algorithm have been presented in Figs. 1–8.

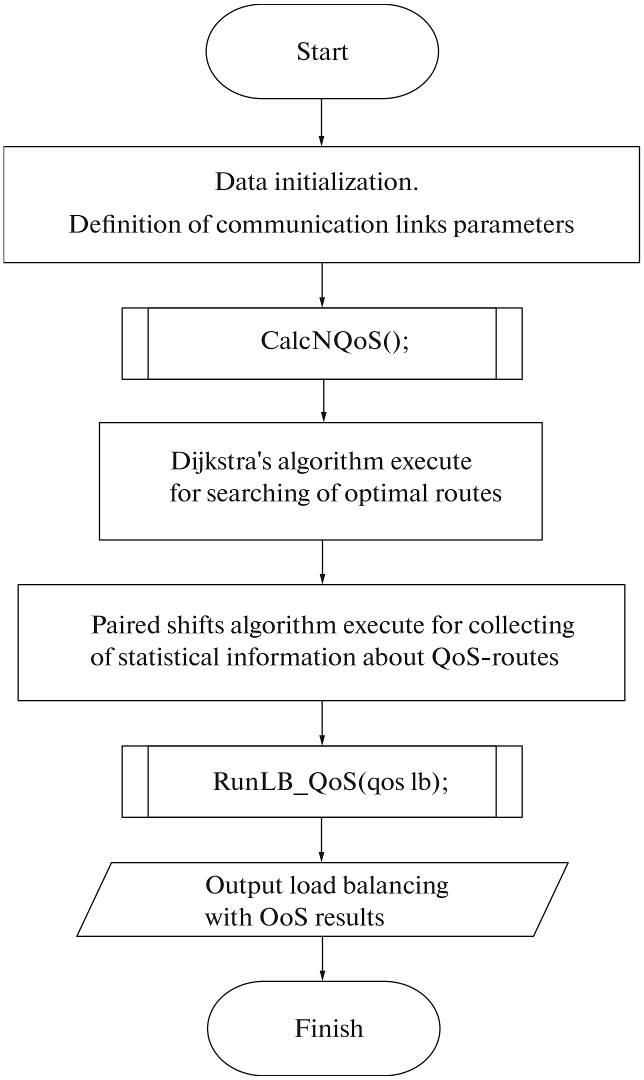


Fig. 1. Flowchart of the main procedure.

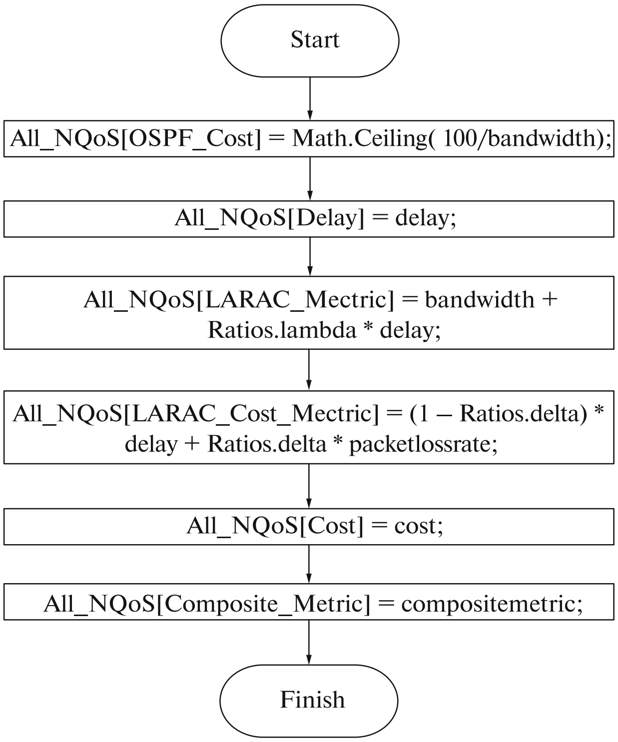


Fig. 2. Flowchart of the auxiliary procedure “CalcNQoS()”.

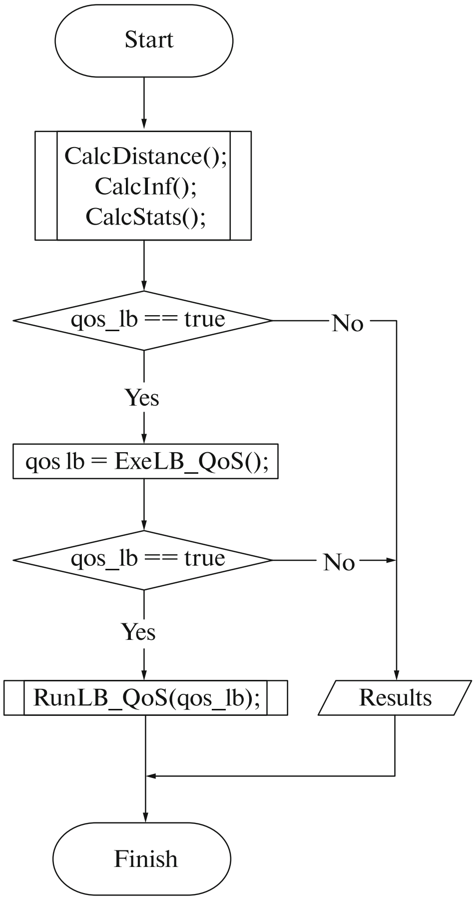


Fig. 3. Flowchart of the auxiliary procedure “RunLB_QoS(qos_lb)”.

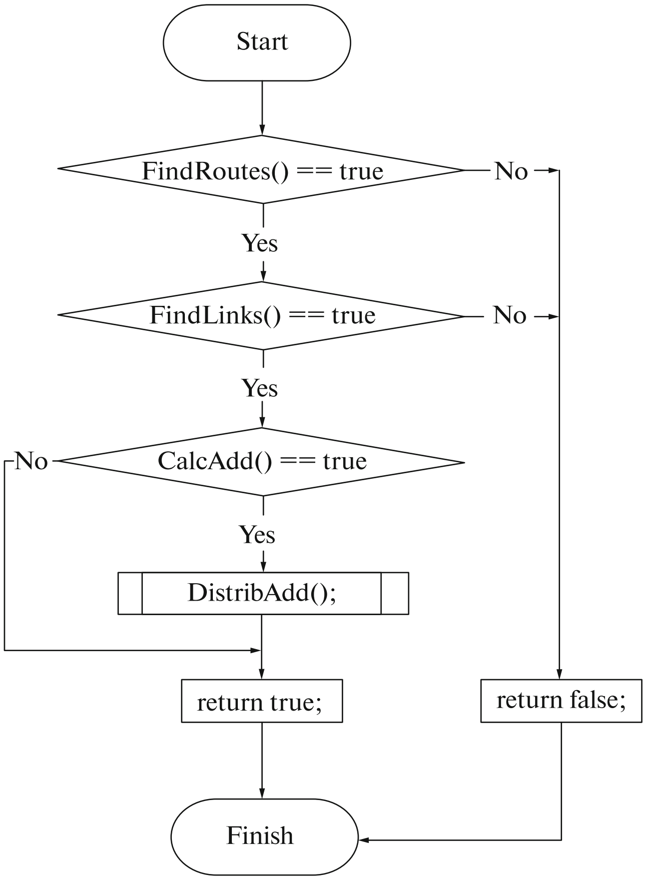


Fig. 4. Flowchart of the auxiliary procedure "ExeLB_QoS()".

5. SIMULATION RESULTS

The simulation software of dynamic load balancing processes in CN is developed to confirm the correctness of the offered algorithm. The offered algorithm of load balancing was carried out on different CN topology by 5 QoS-metrics. The program complex is developed in the C# programming language with use of .net Framework platform 4.5. and object-oriented programming approaches that will provide flexibility of the software at the possibility expense of the program addition with the new functions allowing to expand a complex of solvable tasks. The program complex interface and load balancing window are provided in Figs. 9, 10. The developed program complex allows: to make and delete the CN models, to set QoS-parameters of communication links (bandwidth, delay, packet loss rate, cost, composite metric), to execute load balancing of CN by 5 QoS-metrics, to save and open the CN models. For each communication link in CN a set of the QoS-parameters providing the required QoS has been established. The parameters values and QoS-metrics for any communication link in CN are given in Fig. 11.

Research results of Yen's algorithm including TE-module (YATE) and enhanced dynamic load balancing algorithm (EDLBA) have been represented in Figs. 12–15.

The topology of CN has: *N*—number of routers, *M*—number of links, *D*—diameter of graph, *CD*—common distance that is a total route metric of all available routes between a router-source and a router-destination, *R*—number of route, *Ds*—distance of the route, *I*—percent of information passing through the route, *AV*—average value of links entering in the route, *SD*—standard deviation of links entering in the route, *MxV*—max value link in the route, *MnV*—min value link in the route, *J*—percent of deviation value from length of an optimal route. Initial topology information and the results of algorithms work have been presented in Table 3.

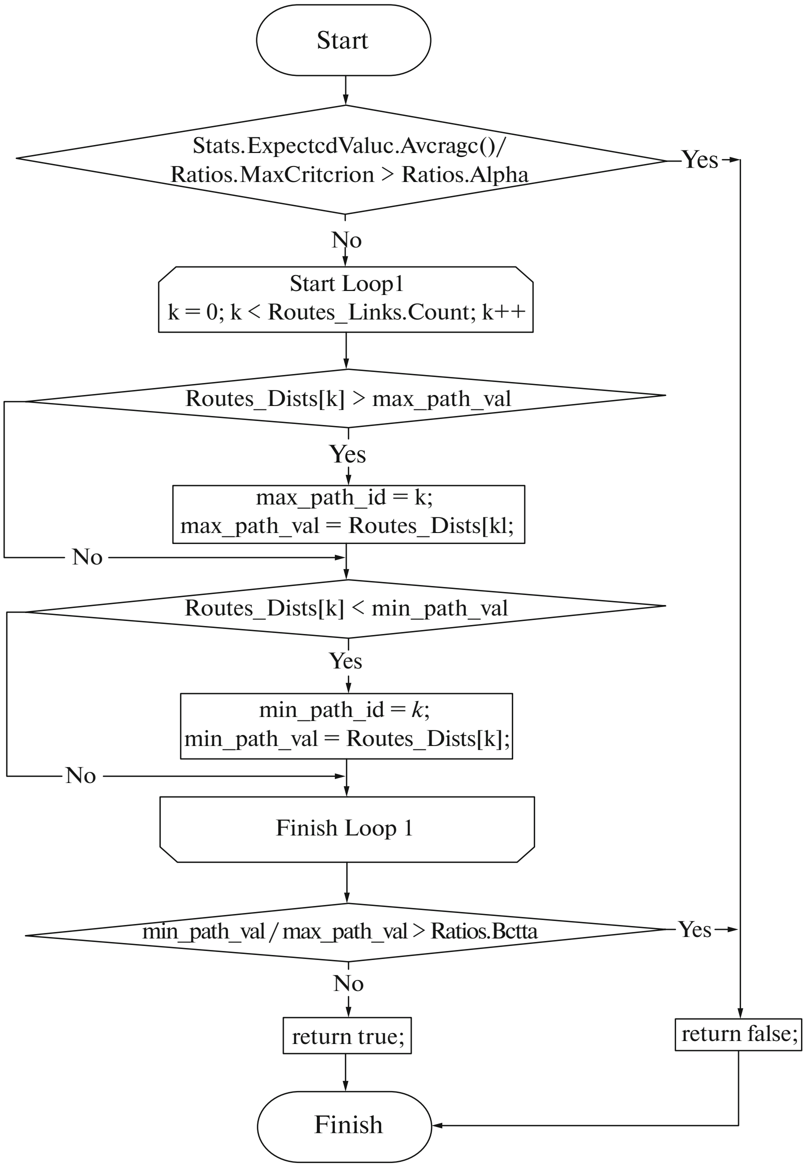


Fig. 5. Flowchart of the auxiliary procedure “FindRoutes()”.

6. RESULTS ANALYSIS AND FURTHER RESEARCH DIRECTIONS

The researches were conducted on different topology of CN including the topology given on Fig. 9. This topology consists of 14 routers and 23 communication links having such QoS-parameters as bandwidth, delay, packet loss rate, composite metric. Using EDLBA and YATE the routes, which correspond to the current QoS including one or several parameters of communication link were found. For example, for QoS 2 (Delay Metric) the initial jitter was made by 78% (Table 3). Having applied the YATE there was reduction of jitter to 69% (in case of $\alpha = 0.5$), and EDLBA to 19% (in case of $\alpha = 0.8$, $\beta = 0.9$, $\gamma = 0.9$). These results led to the efficiency increases of data transmission, losses of data packets in case of information transfer along the balanced routes.

The load balancing for QoS 3 (LARAC Metric) was calculated taking into account bandwidth and delay regulated by coefficient λ. This coefficient defines whether delay shall influence the resultant metric in case of computation of an optimal route. It was analytically proved that optimal and used at the moment the value of coefficient λ is 0.7. As shown in Table 4 that original jitter was equal to

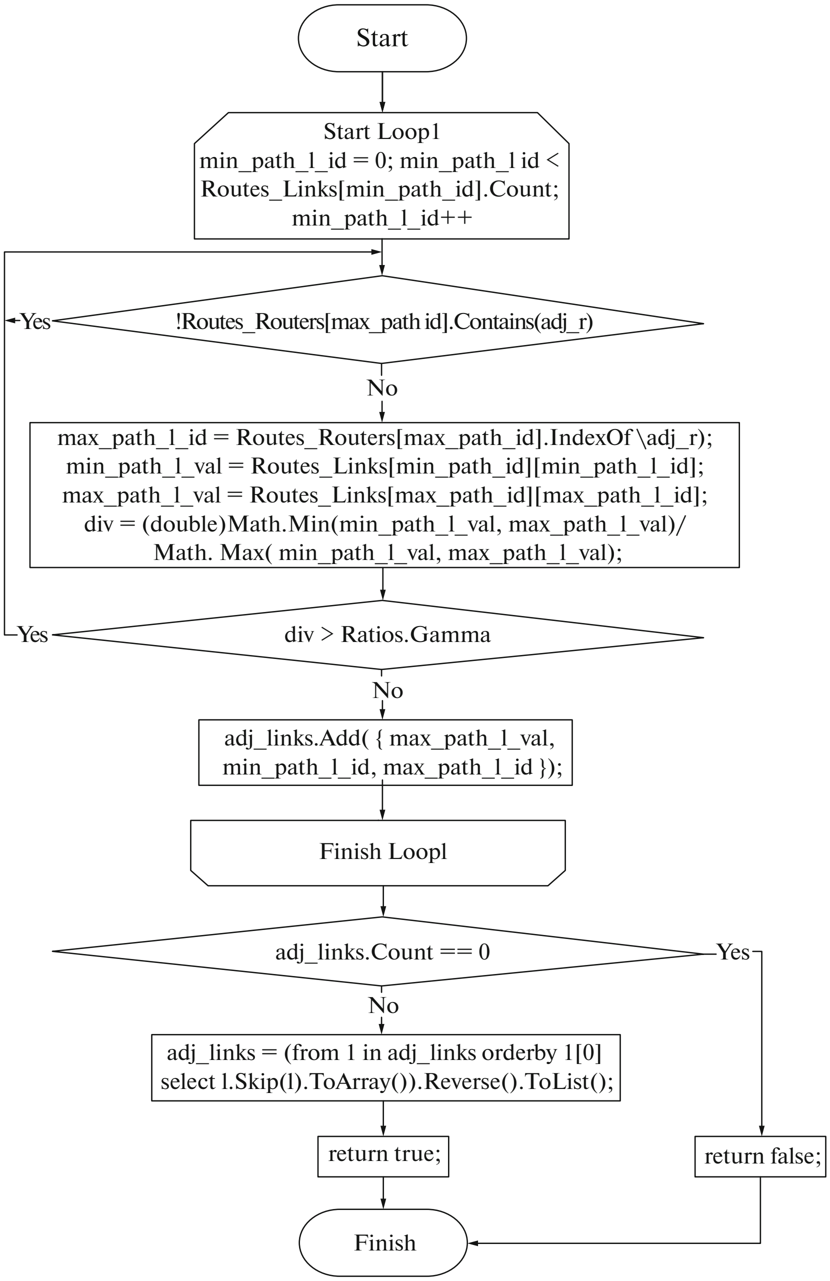


Fig. 6. Flowchart of the auxiliary procedure “FindLinks()”.

73% and the application of the balancing algorithms can decrease on: 10% (YATE) and for 67% (EDLBA).

The application of the load balancing for QoS 4 (LARAC Cost Metric) which is calculated taking into account delay and packet loss rate is regulated by coefficient δ. The coefficient defines the importance of one of two parameters on resultant metric at calculation of optimal route. It was analytically proved that optimal and used at the moment the value of coefficient δ is 0.8. Table 5 shows the initial deviation of the maximum route from optimal route equal to 64%, and after load balancing application this deviation on average decreases: for 10% (YATE) and for 50% (EDLBA).

The composite metric is a metric considering a set of different QoS-parameters. There are different methods of finding this metrics, the most widespread of which is the combination of the above-specified criteria. The composite metric is usually set manually by the network administrator and, gener-

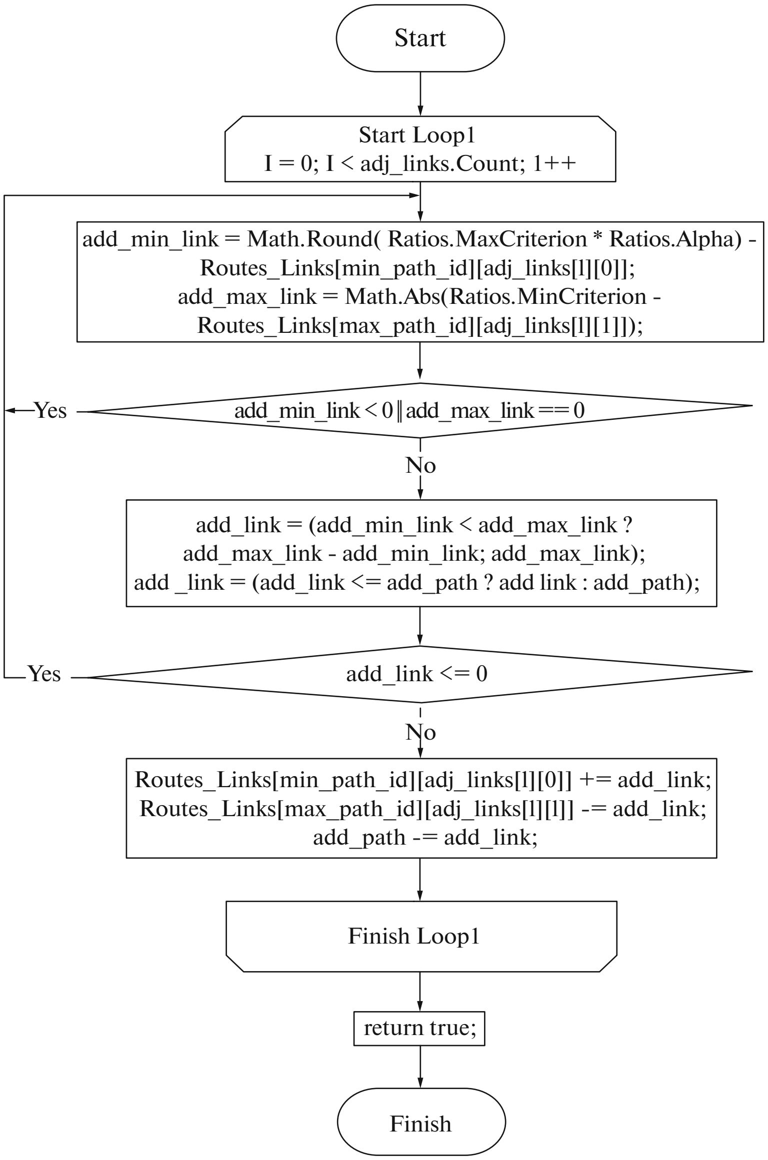


Fig. 7. Flowchart of the auxiliary procedure “DistribAdd()”.

ally, is served for debugging of incorrect operation of the load balancing algorithms. The composite metrics chosen for modeling are specified in Fig. 9. The results have been entered in Table 6 according to the following conclusion: the initial jitter is equal 65%, when using YATE is 56%, when using EDLBA is 17% that is a good indicator of efficiency of the offered algorithm.

Using of the offered approach allows to control data flows in CN more flexibly and to provide the required level of QoS of multimedia streaming and multicasting applications. Further it is supposed to use the approach offered in this work for data flow control in SDN. Researches of efficiency EDLBA in Mininet emulator are for this purpose conducted. Also within the pilot studies the hardware-software bench of dynamic load balancing of data flows in SDN on the basis of the equipment of HPE 2920-24G Aruba with support of OpenFlow protocol is designed. This experimental bench is planned to be used as a part of the campus network of RSREU. The received results of researches will be considered in the future scientific works.

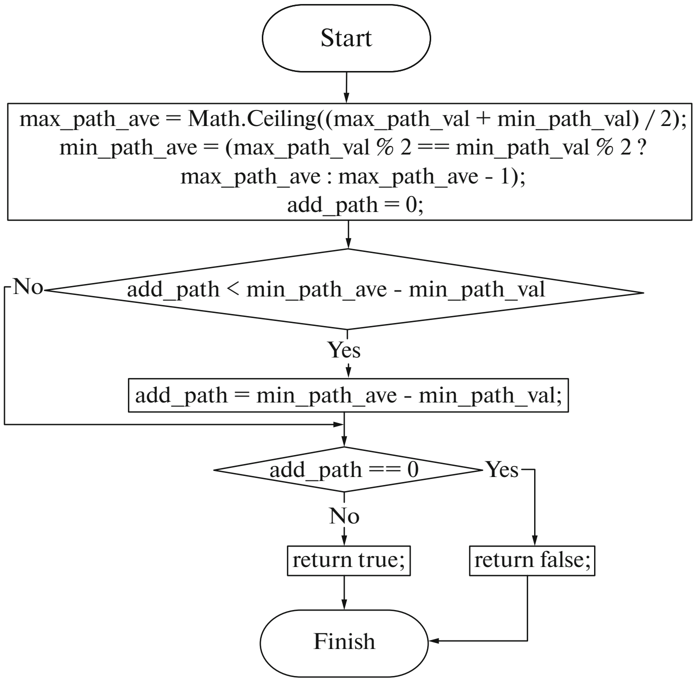
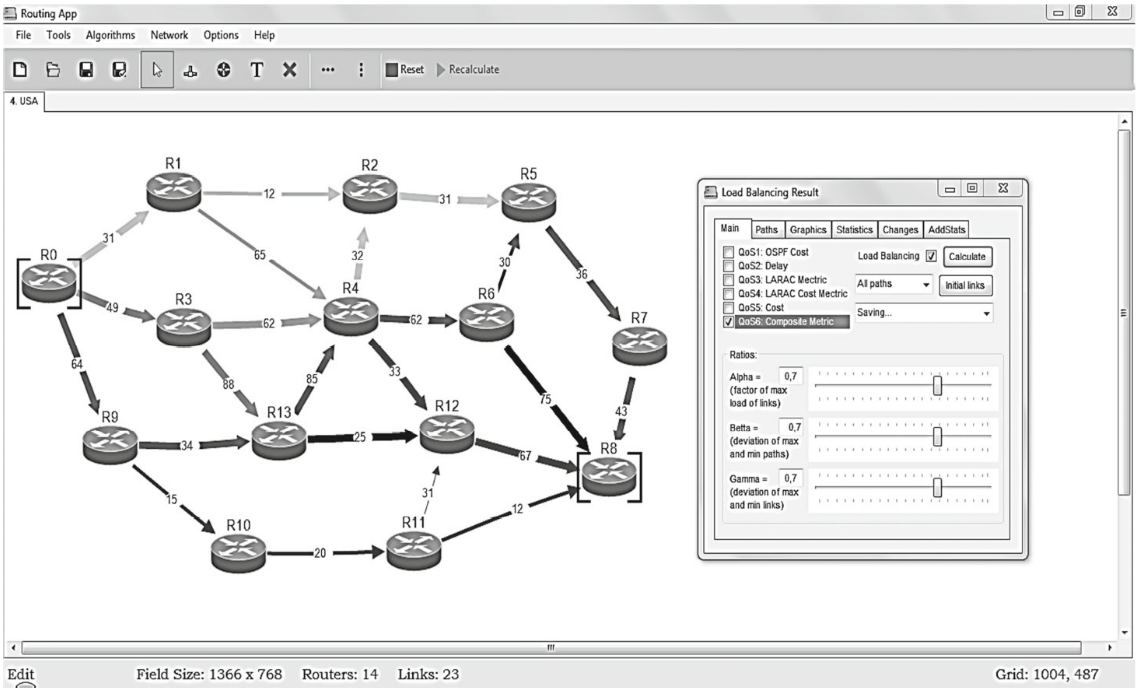


Fig. 8. Flowchart of the auxiliary procedure “CalcAdd()”.



☐ QoS1: OSPF Cost
☐ QoS2: Delay
☐ QoS3: LARAC Mectric
☐ QoS4: LARAC Cost Mectric
☐ QoS5: Cost
☑ QoS6: Composite Metric

Load Balancing ☑

All paths

Saving...

Ratios:

Alpha = 0,7 (factor of max load of links)

Betta = 0,7 (deviation of max and min paths)

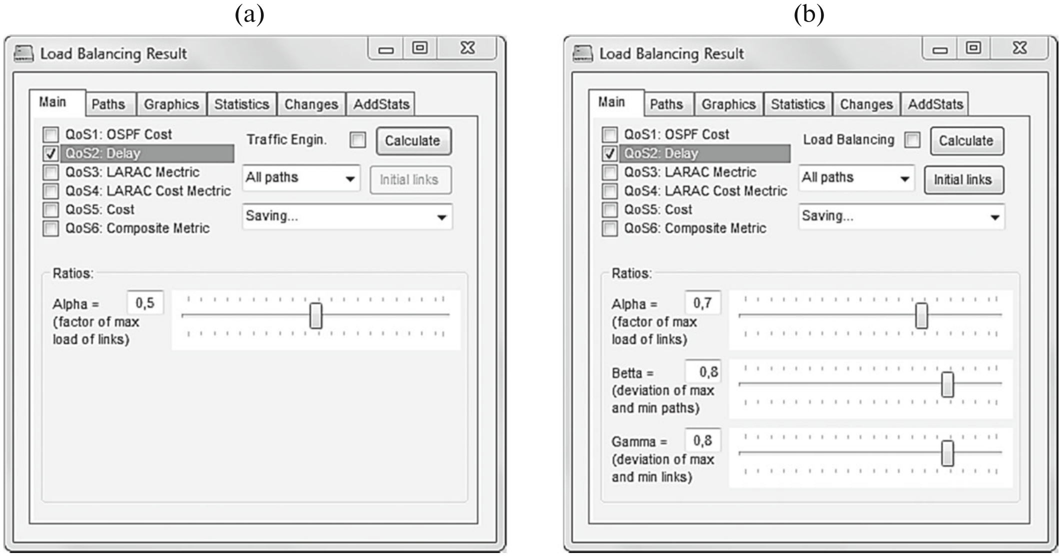
Gamma = 0,7 (deviation of max and min links)

Field Size: 1366 x 768 Routers: 14 Links: 23 Grid: 1004, 487

Fig. 9. User interface of the program system and executed dynamic load balancing.

7. CONCLUSION

The present paper presents the enhanced dynamic load balancing algorithm in CN with QoS. The development of this algorithm allows increasing generally for 33% high-speed performance of data transfer in comparison with the known YATE algorithm in case of updating of the routing information in CN.



(a)

☐ QoS1: OSPF Cost
☑ QoS2: Delay
☐ QoS3: LARAC Mectric
☐ QoS4: LARAC Cost Mectric
☐ QoS5: Cost
☐ QoS6: Composite Metric

Traffic Engin. ☐

Alpha = 0,5 (factor of max load of links)

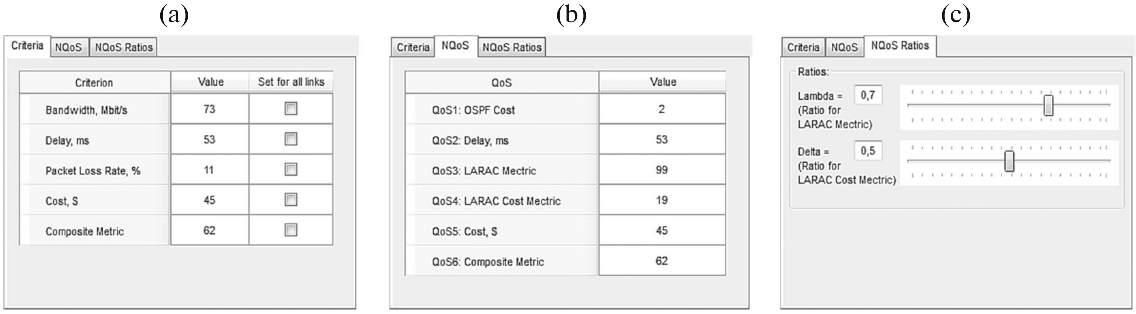
(b)

☐ QoS1: OSPF Cost
☑ QoS2: Delay
☐ QoS3: LARAC Mectric
☐ QoS4: LARAC Cost Mectric
☐ QoS5: Cost
☐ QoS6: Composite Metric

Load Balancing ☐

Alpha = 0,7 (factor of max load of links)
Betta = 0,8 (deviation of max and min paths)
Gamma = 0,8 (deviation of max and min links)

Fig. 10. Dynamic load balancing windows: (a) Window of Alpha coefficient control for YATE-module; (b) Window of Alpha, Beta, Gamma coefficients control for EDLBA.



(a)

Criterion	Value	Set for all links
Bandwidth, Mbit/s	73	☐
Delay, ms	53	☐
Packet Loss Rate, %	11	☐
Cost, $	45	☐
Composite Metric	62	☐

(b)

QoS	Value
QoS1: OSPF Cost	2
QoS2: Delay, ms	53
QoS3: LARAC Mectric	99
QoS4: LARAC Cost Mectric	19
QoS5: Cost, $	45
QoS6: Composite Metric	62

(c)

Lambda = 0,7 (Ratio for LARAC Mectric)
Delta = 0,5 (Ratio for LARAC Cost Mectric)

Fig. 11. QoS values of parameters and metrics for communication links: (a) – quality criteria value; (b) – QoS metrics value; (c) – coefficients value for QoS 3 and QoS 4 metrics.

Table 3. YATE and EDLBA for QoS 2 (Delay Metric)

Initial topology information $N = 14$, $M = 23$, $D = 4$, $CD = 1271$; $J = 78\%$							YATE				EDLBA			
							$\alpha = 0.4$; $J = 68\%$	$\alpha = 0.5$; $J = 69\%$	$\alpha = 0.6$; $J = 74\%$	$\alpha = 0.7$; $J = 78\%$	$\alpha = 0.7$, $\beta = 0.7$, $\gamma = 0.7$; $J = 42\%$	$\alpha = 0.7$, $\beta = 0.9$, $\gamma = 0.9$; $J = 33\%$	$\alpha = 0.8$, $\beta = 0.9$, $\gamma = 0.9$; $J = 19\%$	$\alpha = 0.8$, $\beta = 0.7$, $\gamma = 0.8$; $J = 31\%$
R	*Ds*	*I*, %	*AV*	*SD*	*MxV*	*MnV*	*Ds*/*I*, %	*Ds*/*I*, %	*Ds*/*I*, %	*Ds*/*I*, %	*Ds*/*I*, %	*Ds*/*I*, %	*Ds*/*I*, %	*Ds*/*I*, %
1	78	7	19.5	3.4	25	16	78/8	78/8	78/7	78/7	78/8	78/8	78/8	78/8
2	56	10	14	2.4	16	10	56/11	56/11	56/10	56/10	68/9	68/9	79/8	79/8
3	110	5	27.5	21.8	64	7	86/7	96/6	106/5	110/5	110/6	101/6	93/7	93/7
4	68	8	17	4.8	25	12	68/9	68/9	68/9	68/8	68/9	68/9	95/7	87/7
5	43	13	10.8	2.5	13	7	70/8	60/10	50/12	43/13	85/7	85/7	92/7	92/7
6	73	8	14.6	4.6	21	7	73/8	73/8	73/8	73/8	78/8	78/8	87/7	73/9
7	102	6	20.4	7.3	31	12	126/5	116/5	106/5	102/6	102/6	102/6	88/7	102/6
8	63	9	12.6	4.7	21	7	63/9	63/9	63/9	63/9	99/6	99/6	92/7	92/7
9	91	6	18.2	8.1	29	10	91/7	91/6	91/6	91/6	91/7	100/6	91/7	91/7
10	203	3	33.8	30.8	86	7	176/3	186/3	196/3	203/3	119/5	103/6	97/7	106/6
11	94	6	15.7	5.3	25	10	94/6	94/6	94/6	94/6	94/7	94/7	94/7	94/7
12	74	8	12.3	4	20	7	74/8	74/8	74/8	74/8	99/6	99/6	96/7	87/7
13	94	6	13.4	4.8	21	7	94/6	94/6	94/6	94/6	94/7	94/7	94/7	94/7
14	122	5	17.4	7.3	29	10	122/5	122/5	122/5	122/5	86/7	102/6	95/7	103/6

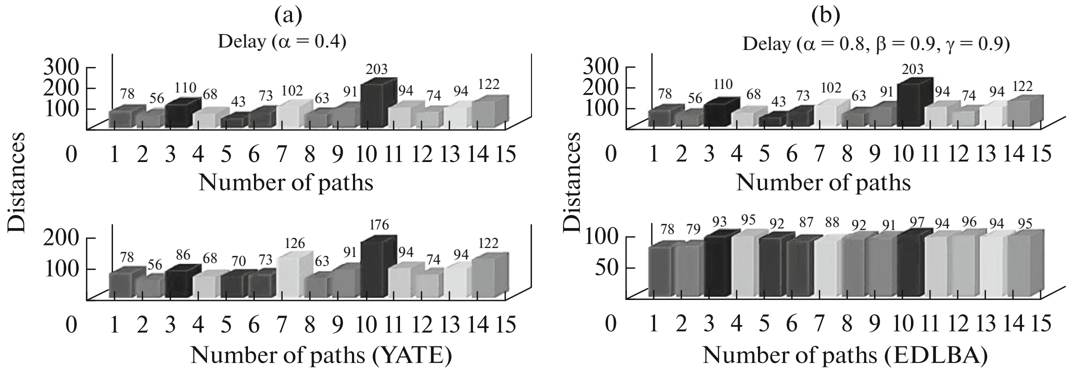


Fig. 12. QoS 2 (Delay Metric): (a) YATE (α = 0.4, *J* = 68%), (b) EDLBA (α = 0.8, β = 0.9, γ = 0.9, *J* = 19%).

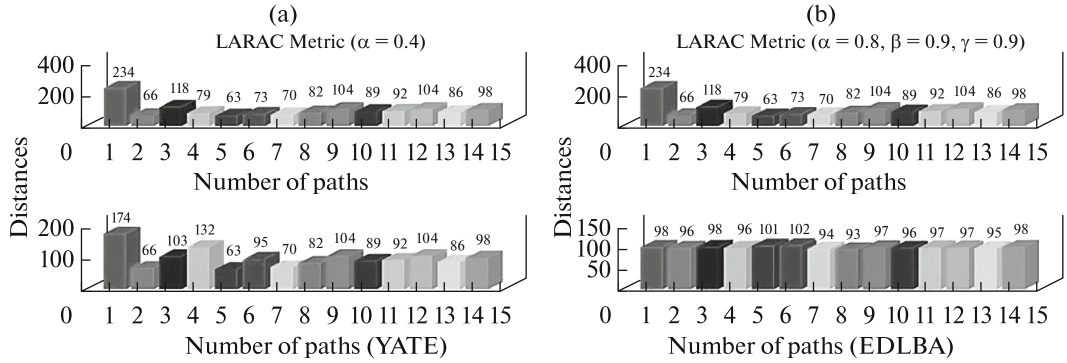


Fig. 13. QoS 3 (LARAC Metric): (a) YATE (α = 0.4, *J* = 63%), (b) EDLBA (α = 0.8,β = 0.9, γ = 0.9, *J* = 8%).

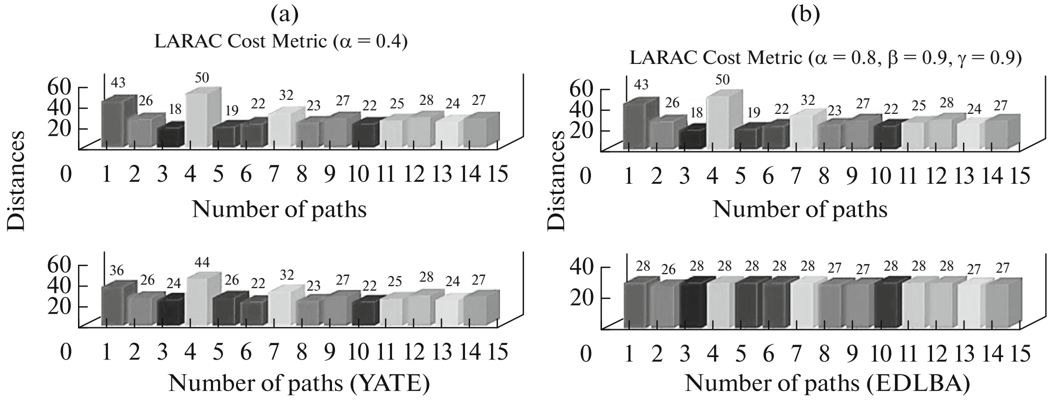


Fig. 14. QoS 4 (LARAC Cost Metric): (a) YATE (α= 0.4, *J* = 50%), (b) EDLBA (α = 0.8, β = 0.9, γ = 0.9, *J* = 7%).

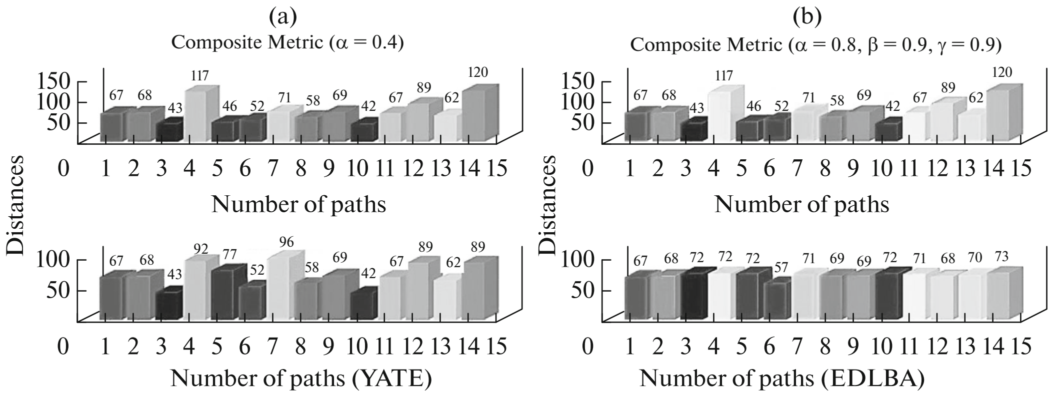


Fig. 15. QoS 5 (Composite Metric): (a) YATE (α = 0.4, *J* = 56%), (b) EDLBA (α = 0.8, β = 0.9, γ = 0.9, *J* = 21%).

Table 4. YATE and EDLBA for QoS 3 (LARAC Metric)

Initial topology information $N = 14$, $M = 23$, $D = 4$, $CD = 1358$; $J = 73\%$							YATE				EDLBA			
							$\alpha = 0.4$; $J = 63\%$	$\alpha = 0.5$; $J = 66\%$	$\alpha = 0.6$; $J = 69\%$	$\alpha = 0.7$; $J = 71\%$	$\alpha = 0.7$, $\beta = 0.7$, $\gamma = 0.7$; $J = 28\%$	$\alpha = 0.7$, $\beta = 0.9$, $\gamma = 0.9$; $J = 8\%$	$\alpha = 0.8$, $\beta = 0.9$, $\gamma = 0.9$; $J = 6\%$	$\alpha = 0.8$, $\beta = 0.7$, $\gamma = 0.8$; $J = 40\%$
R	Ds	I, %	AV	SD	MxV	MnV	Ds/I, %	Ds/I, %	Ds/I, %	Ds/I, %	Ds/I, %	Ds/I, %	Ds/I, %	Ds/I, %
1	234	3	58.5	43.8	120	17	174/4	189/3	204/3	219/3	115/6	97/7	98/7	115/6
2	66	9	16.5	6.3	27	10	66/10	66/10	66/10	66/10	94/7	96/7	96/7	89/8
3	118	5	29.5	30.5	82	7	103/6	156/4	148/4	133/5	104/7	98/7	98/7	98/7
4	79	8	19.8	7.9	28	7	132/5	79/8	79/8	79/8	93/7	93/7	96/7	113/6
5	63	10	12.6	2.9	15	7	63/10	63/10	63/10	63/10	84/8	99/7	101/7	69/10
6	73	9	14.6	4.1	21	8	95/7	80/8	73/9	73/9	106/6	98/7	102/7	106/6
7	70	9	14	7.2	27	7	70/9	70/9	70/9	70/9	107/6	99/7	94/7	113/6
8	82	8	16.4	6.4	27	8	82/8	82/8	82/8	82/8	82/8	99/7	93/7	82/8
9	104	6	17.3	7.7	28	7	104/6	104/6	104/6	104/6	104/7	97/7	97/7	104/7
10	89	7	14.8	8	27	7	89/7	89/7	89/7	89/7	89/8	96/7	96/7	89/8
11	92	7	13.1	7.2	26	7	92/7	92/7	92/7	92/7	92/7	98/7	97/7	92/7
12	104	6	14.9	6.9	26	8	104/6	104/6	104/6	104/6	104/7	95/7	97/7	104/7
13	86	7	12.3	6.6	27	7	86/8	86/7	86/7	86/7	86/8	95/7	95/7	86/8
14	98	6	14	6.6	27	8	98/7	98/6	98/6	98/6	98/7	98/7	98/7	98/7

Table 5. YATE and EDLBA for QoS 4 (LARAC Cost Metric)

Initial topology information $N = 14$, $M = 23$, $D = 4$, $CD = 386$; $J = 64\%$							YATE				EDLBA			
							$\alpha = 0.4$; $J = 50\%$	$\alpha = 0.5$; $J = 58\%$	$\alpha = 0.6$; $J = 64\%$	$\alpha = 0.7$; $J = 64\%$	$\alpha = 0.7$, $\beta = 0.7$, $\gamma = 0.7$; $J = 28\%$	$\alpha = 0.7$, $\beta = 0.9$, $\gamma = 0.9$; $J = 7\%$	$\alpha = 0.8$, $\beta = 0.9$, $\gamma = 0.9$; $J = 7\%$	$\alpha = 0.8$, $\beta = 0.7$, $\gamma = 0.8$; $J = 28\%$
R	Ds	I, %	AV	SD	MxV	MnV	Ds/I, %	Ds/I, %	Ds/I, %	Ds/I, %	Ds/I, %	Ds/I, %	Ds/I, %	Ds/I, %
1	43	4	10.8	6.6	21	4	36/5	40/5	43/4	43/4	31/6	28/7	28/7	31/6
2	26	7	6.5	0.9	7	5	26/7	26/7	26/7	26/7	26/8	26/8	26/8	26/8
3	18	10	4.5	1.7	7	3	24/8	20/9	18/10	18/10	28/7	28/7	28/7	28/7
4	50	4	10	5.5	20	5	44/4	48/4	50/4	50/4	28/7	28/7	28/7	28/7
5	19	10	3.8	1	5	3	26/7	22/8	19/10	19/10	31/6	28/7	28/7	31/6
6	22	8	4.4	1.2	6	3	22/9	22/8	22/8	22/8	28/7	28/7	28/7	28/7
7	32	6	5.3	1.8	7	2	32/6	32/6	32/6	32/6	32/6	28/7	28/7	32/6
8	23	8	3.8	1.6	6	2	23/8	23/8	23/8	23/8	23/8	27/7	27/7	23/8
9	27	7	4.5	2.3	8	2	27/7	27/7	27/7	27/7	27/7	27/7	27/7	27/7
10	22	8	3.7	1.7	6	2	22/9	22/8	22/8	22/8	28/7	28/7	28/7	28/7
11	25	7	3.6	1.3	5	2	25/8	25/7	25/7	25/7	25/8	28/7	28/7	25/8
12	28	7	4	1.5	6	2	28/7	28/7	28/7	28/7	28/7	28/7	28/7	28/7
13	24	8	3.4	1.4	6	2	24/8	24/8	24/8	24/8	24/8	27/7	27/7	24/8
14	27	7	3.9	1.6	6	2	27/7	27/7	27/7	27/7	27/7	27/7	27/7	27/7

Table 6. YATE and EDLBA for QoS 5 (Composite Metric)

Initial topology information $N = 14$, $M = 23$, $D = 4$, $CD = 971$; $J = 65\%$							YATE				EDLBA			
							$\alpha = 0.4$; $J = 56\%$	$\alpha = 0.5$; $J = 58\%$	$\alpha = 0.6$; $J = 62\%$	$\alpha = 0.7$; $J = 64\%$	$\alpha = 0.7$, $\beta = 0.7$, $\gamma = 0.7$; $J = 40\%$	$\alpha = 0.7$, $\beta = 0.9$, $\gamma = 0.9$; $J = 17\%$	$\alpha = 0.8$, $\beta = 0.9$, $\gamma = 0.9$; $J = 21\%$	$\alpha = 0.8$, $\beta = 0.7$, $\gamma = 0.8$; $J = 35\%$
R	*Ds*	*I*, %	*AV*	*SD*	*MxV*	*MnV*	*Ds*/*I*, %	*Ds*/*I*, %	*Ds*/*I*, %	*Ds*/*I*, %	*Ds*/*I*, %	*Ds*/*I*, %	*Ds*/*I*, %	*Ds*/*I*, %
1	67	7	16.8	4.8	22	9	67/7	67/7	67/7	67/7	67/7	67/7	67/7	67/7
2	68	7	17	7.9	30	9	68/7	68/7	68/7	68/7	68/7	68/7	68/7	68/7
3	43	10	10.8	4	16	5	43/11	43/11	43/11	43/10	72/7	72/7	72/7	72/7
4	117	4	29.2	22.1	65	10	92/5	102/5	112/4	117/4	88/6	73/7	72/7	77/6
5	46	10	11.5	4.9	20	8	77/6	67/7	57/8	47/10	79/6	71/7	72/7	67/7
6	52	9	13	5.4	20	5	52/9	52/9	52/9	52/9	52/9	60/8	57/9	52/9
7	71	6	14.2	8	30	8	96/5	86/5	76/6	71/6	71/7	71/7	71/7	71/7
8	58	8	11.6	5	16	5	58/8	58/8	58/8	58/8	58/8	69/7	69/7	69/7
9	69	7	13.8	7.9	29	8	69/7	69/7	69/7	69/7	69/7	73/7	69/7	69/7
10	42	11	8.4	3.1	14	5	42/11	42/11	42/11	42/11	69/7	69/7	72/7	81/6
11	67	7	11.2	5	20	7	67/7	67/7	67/7	67/7	67/7	67/7	71/7	67/7
12	89	5	12.7	7.3	29	7	89/5	89/5	89/5	89/5	70/7	70/7	68/7	68/7
13	62	7	8.9	3.7	15	5	62/7	62/7	62/7	62/7	62/8	70/7	70/7	62/8
14	120	4	17.1	22.2	71	5	89/5	99/5	109/4	119/4	79/6	71/7	73/7	81/6

The efficiency of the offered approach is confirmed by the comparative analysis with YATE algorithm on different topology of CN with using of 5 QoS-metrics.

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