Investigation of Tensor Approach for Providing Multimedia Quality in Infocommunication Networks

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Abstract. An approach based on a tensor mathematical routing model, due to which a given level of quality of experience is provided according to the Multimedia Quality indicator, is proposed in the paper. The QoE routing problem has been presented in the optimization form. The tensor formalization of the QoE routing model allowed obtaining the conditions for ensuring the specified values of Multimedia Quality in the analytical form, which were used as the main restrictions in solving the formulated optimization problem.

Keywords: multimedia quality, quality of experience, end-to-end delay, packet loss, tensor, routing.

1 Introduction

For the past few years, there has been a sharp increase of multimedia traffic in infocommunication networks. This is dictated by emergence of many multimedia services and applications provided to end users. In this regard, due to a shortage of the network resource in the existing infocommunication networks, a significant decrease in the Quality of Service (QoS) indicators occurs. Therefore, today the problem of providing the required values of several network indicators simultaneously – bandwidth, delay, jitter and packet loss [1-3] – is quite acute, especially when transmitting multimedia traffic.

In addition to assessing quality of service at the network level, today it is also necessary to evaluate the quality at the user level using the Mean Opinion Score, the so-called Quality of Experience (QoE) indicator. The use of QoE indicators allows to more adequately take into account the features of providing and assessing the quality of a multimedia service, taking into account not only the parameters of the transport network, but also the characteristics of the traffic generated by the application [4, 5, 8-14]. Providing specified values of QoE indicators is possible using routing tools. However, when solving QoE-based routing tasks, it is worth considering that MOS indicators, as shown in [6-8, 15-18], are a rather complicated and generally non-linear function of network performance indicators [9, 17]. Therefore, an approach based on the implementation of tensor models of QoS routing [5, 9], capable of providing specified values of the end-to-end bandwidth, delay, jitter and packet loss, is worth noting.

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Therefore, an approach is proposed based on the Routing Tensor Model with Providing MultiMedia Quality (MMq).

2 Routing Model for Assessment of Multi Media Quality

The main requirements for the developed Routing Model for assessment of Multi Media Quality should include ensuring maximum consideration of the features related to the processes of both multimedia traffic transmission and QoE assessment. Therefore, when transmitting multimedia traffic, the most stringent requirements are put forward not only to the average delay of packets and the probability of their loss along the calculated routes, but also to the issues of synchronizing the delivery of packets of audio and video flows transmitted in the same multimedia session [7].

In the framework of the proposed routing model, the structure of an infocommunication network is described using a one-dimensional simplicial complex (one-dimensional network) $S=(U,V)$, where $U=\left\{u_i, i=\overline{1,m}\right\}$ is a set of zero-dimensional simplexes – network nodes (routers), and $V=\left\{v_z=(i,j);\ z=\overline{1,n};\ i,j=\overline{1,m};\ i\neq j\right\}$ is a set of one-dimensional simplexes – network edges, where edge $v_z=(i,j)$ connects routers u_i and u_j.

Further, we agree that K is a set of multimedia sessions on the network. Then by k^{speech} we denote an audio flow, and by k^{video} we denote the video flow of the k th multimedia session. Then, in the course of solving the routing problem of the audio and video flows of the k th multimedia session, it is necessary to calculate a set of route variables $x_{i,j}^{k^{speech}}$ and $x_{i,j}^{k^{video}}$, each of which characterizes the fraction of the intensity of audio and video flows generated during the k th multimedia session and flowing in the link (i,j), respectively.

In order to implement the multipath routing strategy, the following restrictions are imposed on these route variables:

$$0\le x_{i,j}^{k^{speech}}\le 1 \text{ and } 0\le x_{i,j}^{k^{video}}\le 1. \qquad (1)$$

In addition to conditions (1), the routing variables are subject to restrictions represented by the conditions for conservation of audio and video flows on ICN routers. Therefore, for example, for the flow k^{speech}, these conditions, considering possible packet losses caused by the overload of the queue buffer, take the following form [4, 5, 21-24]:

$$\begin{cases} \sum\limits_{j:(i,j)\in V} x_{i,j}^{k^{speech}} = 1 \text{ if } k^{speech} \in K,\ u_i = b_k; \\ \sum\limits_{j:(i,j)\in V} x_{i,j}^{k^{speech}} - \sum\limits_{j:(j,i)\in V} x_{j,i}^{k^{speech}} (1 - p_{j,i}) = 0 \text{ if } k^{speech} \in K,\ u_i \neq b_k, u_i \neq d_k; a \\ \sum\limits_{j:(j,i)\in V} x_{j,i}^{k^{speech}} (1 - p_{i,j}) = \varepsilon^{k^{speech}} \text{ if } k^{speech} \in K,\ u_i = d_k, \end{cases} \tag{2}$$

where b_k and d_k are the source router and the destination router for packets of audio and video flows of the k-th multimedia session, respectively; $\varepsilon^{k^{speech}}$ is the fraction of rate of the audio flow k^{speech} serviced by the network, i.e. packets of which have been successfully delivered to the destination router; $p_{i,j}$ is the probability of packet loss on the j-th interface of the i-th router.

The conditions for video flow k^{video} conservation have a similar form (2)

$$\begin{cases} \sum\limits_{j:(i,j)\in V} x_{i,j}^{k^{video}} = 1 \text{ if } k^{video} \in K,\ u_i = b_k; \\ \sum\limits_{j:(i,j)\in V} x_{i,j}^{k^{video}} - \sum\limits_{j:(i,j)\in V} x_{i,j}^{k^{video}} (1 - p_{j,i}) = 0 \text{ if } k^{video} \in K,\ u_i \neq b_k, u_i \neq d_k; \\ \sum\limits_{j:(i,j)\in V} x_{i,j}^{k^{video}} (1 - p_{j,i}) = \varepsilon^{k^{video}} \text{ if } k^{video} \in K,\ u_i = d_k, \end{cases} \tag{3}$$

where $\varepsilon^{k^{video}}$ is the fraction of rate of the video flow k^{video} successfully serviced by the network.

The probability of packet loss, if the j-th interface of the i-th router is modeled by a queuing system with failures of the type $M/M/1/N$, can be calculated as follows:

$$p_{i,j} = \frac{\left(1 - \rho_{i,j}\right)\left(\rho_{i,j}\right)^{N_{i,j}}}{1 - \left(\rho_{i,j}\right)^{N_{i,j}+1}}, \tag{4}$$

where $\rho_{i,j} = \dfrac{\lambda_{i,j}}{\varphi_{i,j}}$ is the utilization coefficient of the j-th interface on the i-th router; $N_{i,j}$ denotes the maximum number of packets in the queue of the j-th interface on the i-th router; $\varphi_{i,j}$ denotes the bandwidth of the j-th interface of the i-th router measured in 1/s. $\lambda_{i,j}$ is the total rate of all flows of various multimedia sessions in the link $(i,j) \in V$ (1/s), which is calculated as:

$$\lambda_{i,j} = \sum_{k \in K} \left(\lambda^{k^{speech}} x_{i,j}^{k^{speech}} + \lambda^{k^{video}} x_{i,j}^{k^{video}} \right), \tag{5}$$

where $\lambda^{k^{speech}}$ and $\lambda^{k^{video}}$ are the average packet rates of the audio and video flows of the k-th multimedia session, respectively.

Then the rates of the lost packets of audio and video flows belonging to the k-th multimedia session on the j-th interface of the i-th router will be respectively determined as:

$$r_{i,j}^{k^{speech}} = \lambda_k^{speech\langle req \rangle} x_{i,j}^{k^{speech}} \, p_{i,j} \quad \text{and} \quad r_{i,j}^{k^{video}} = \lambda_k^{video\langle req \rangle} x_{i,j}^{k^{video}} \, p_{i,j} \tag{6}$$

The rate of successfully transmitted packets of audio $\lambda_{i,j}^{k^{speech}}$ and video $\lambda_{i,j}^{k^{video}}$ flows of the k-th multimedia session through the j-th interface of the i-th router is calculated as:

$$\lambda_{i,j}^{k^{speech}} = \lambda_k^{speech\langle req \rangle} x_{i,j}^{k^{speech}} (1 - p_{i,j}) \quad \text{and} \quad \lambda_{i,j}^{k^{video}} = \lambda_k^{video\langle req \rangle} x_{i,j}^{k^{video}} (1 - p_{i,j}) \tag{7}$$

To ensure control over the process of overloading links and queues taking into account (7), the following restrictions are introduced into the model structure [5]:

$$\lambda_{i,j} < \varphi_{i,j} \ , \ (i,j) \in V \, . \tag{8}$$

4 Conditions for Providing MultiMedia Quality in Infocommunication Network

The main requirement when implementing QoE routing is to meet the conditions for ensuring a given level of MultiMedia Quality. In accordance with the ITU-T Recommendation G.1070 [7], the requirements for MultiMedia Quality (MM_q) are generally defined as

$$MM_q^{<req>} \geq MM_q \, , \tag{9}$$

where

$$MM_q = m_1 MM_{SV} + m_2 MM_T + m_3 MM_{SV} MM_T + m_4 \, , \text{ at } \ 1 \leq MM_q \leq 5 \, . \tag{10}$$

where $MM_q^{<req>}$ are the requirements for the MultiMedia Quality level; MM_{SV} denotes the quality of transmission of audiovisual information; MM_T denotes degradation in quality due to delays and desynchronization of processes for transmitting audio and video flow packets; m_i denotes coefficients depending on the size of the display and the purpose of communication [7]. The task is to support the possibility of analytical calculation of the MM_q indicator in order to fulfill the conditions (9) for each multimedia session during the routing of each pair of audio and video flows. For clarity, the index k, i.e. the number of such a session, will be omitted during further transformations.

Moreover, the terms included in (10), as well as the transmission quality of audio (S_q) and video flows (V_q), are the functions of the average end-to-end delays of packets of audio (T_S) and video (T_V) flows, the probabilities of losing packets of audio (P^S) and video (P^V) flows in the network, and are determined in accordance with the recommendation [7]. For example, the transmission quality of audiovisual information MM_{SV} is determined using the following expressions:

$$MM_{SV} = m_5 S_q + m_6 V_q + m_7 S_q V_q + m_8 \text{, at } 1 \le MM_{SV} \le 5 . \tag{11}$$

$$MM_T = \max\left\{AD + MS, 1\right\} \text{, at } 1 \le MM_T \le 5 . \tag{12}$$

$$AD = m_9 (T_S + T_V) + m_{10} , \tag{13}$$

$$MS = \begin{cases} \min\left[m_{11}(T_S - T_V) + m_{12},\ 0\right], \text{ if } \mathrm{T}_S \ge T_V, \\ \min\left[m_{13}(T_V - T_S) + m_{14},\ 0\right], \text{ if } \mathrm{T}_S < T_V, \end{cases} \tag{14}$$

where MS is the coefficient which takes into account the desynchronization between the sound and the image; AD is the parameter reflecting the effect of average delays of packets of audio (T_S) and video (T_V) flows.

Based on (14), we can conclude that during QoE routing it is important to ensure maximum closeness of T_S and T_V values for audio and video flows of each multimedia session. Then, in accordance with the recommendation [7], the presented expressions, in this case similar to (11)-(14), can be used to form restrictions of the type (7) based on the known required level of Quality of Experience $MM_q^{<req>}$. The main problem in the MM_q calculation is the definition of expressions for finding the values of the end-to-end delays T_S and T_V, as well as the probabilities of packet loss P^S and P^V for audio and video flows, respectively. These indicators directly depend on the route variables (1), traffic characteristics and network parameters. Therefore, based on the model (1)-(6), the expressions for calculation of P^S and P^V will take the form:

$$P^S = 1 - \varepsilon^{k^{speech}} , \tag{15}$$

$$P^V = 1 - \varepsilon^{k^{video}} . \tag{16}$$

To derive analytical expressions for determining T_S and T_V taking into account the results obtained in [5, 9, 21], it is advisable to use the functional of tensor modeling of routing processes in infocommunication networks.

5 Tensor Formalization of Routing Model with Providing Multimedia Quality

In accordance with the methodology for tensor modeling of an ICN proposed in [5, 9, 21], the network structure determines the anisotropic space formed by many loops and node pairs. The dimension of this space is determined by the total number of branches (communication links) in the network and is equal to n. Moreover, each independent path (branch, loop, or node pair) determines the coordinate axis in the space structure. As a rule, an ICN is modeled by a connected one-dimensional network, i.e. it contains one connected component, then the cyclomatic number μ and the rank ϕ of the network determine, respectively, the number of basis loops and node pairs, for which the following expressions are true:

$$\mu = n - m + 1, \qquad \phi = m - 1, \qquad n = \phi + \mu. \tag{17}$$

In the selected space when transmitting packets of each pair of audio and video flows generated during the k th multimedia session, the infocmmunication network can be represented by a mixed bivalent tensor

$$\Omega = T \otimes \Lambda, \tag{18}$$

where $\otimes$ is the tensor multiplication operator, and the components of the tensor Ω are the monovalent covariant tensor of average packet delays T and the monovalent contravariant tensor of flow rates Λ in the coordinate paths of the network.

In the framework of the proposed model (1)-(8), when the interface is modeled by a queuing system with failures of the type $M/M/1/N$, the average packet delay in an arbitrary ICN communication link for both audio and video flows is approximated by the expression

$$\tau = \frac{\rho - \rho^{N+2} - (N+1)\rho^{N+1}(1-\rho)}{\lambda(1-\rho^{N+1})(1-\rho)}. \tag{19}$$

Moreover, in accordance with the postulate of G. Kron second generalization [25] and the results of [5, 9, 21], expressions (18) written for each of the network links determine the following vector-matrix equation:

$$\Lambda_v = G_v T_v, \tag{20}$$

where Λ_v and T_v are the projections of the tensors Λ and T, respectively, in the coordinate systems of the branches represented by the n-dimensional vectors of the flow rate and average packet delay in the communication links; $G_v = \left\| g_v^{ij} \right\|$ is a diagonal $n \times n$ matrix, the elements of which correspond to the branches (links) of the network and are calculated as an example of servicing the audio flow according to the expression [25]

$$g_v^{ii} = \frac{\lambda_i \,(1-(\rho_i^v)^{N_i^v+1})(1-\rho_i^v)\lambda_i^v}{\rho_i^v - (\rho_i^v)^{N_i^v+2} - (N_i^v+1)(\rho_i^v)^{N_i^v+1}(1-\rho_i^v)}\,, \tag{21}$$

where the index i indicates the belonging of a particular interface parameter to the link $v_i \in V$; λ_i is the total rate of all flows of various multimedia sessions in the link $v_i \in V$ (4); λ_i^v denotes packet rate of the considered audio flow in the link $v_i \in V$. The projections of the tensors of the average packet delays and flow rates in the coordinate system of the loops and node pairs are connected by the expression similar to (20):

$$\Lambda_{\pi\eta} = G_{\pi\eta} T_{\pi\eta}\,. \tag{22}$$

According to the inverse tensor attribute, the tensor G is a twice contravariant metric tensor, the projections of which are transformed as follows when the coordinate system of its consideration is changed:

$$G_{\pi\eta} = A^t G_v A\,, \tag{23}$$

where $G_{\pi\eta}$ is the projection of the tensor G in the coordinate system of loops and node pairs; A is the $n \times n$ covariant transformation matrix; $[\cdot]^t$ is the transposition operation. As shown in [5, 25], the matrix $G_{\pi\eta}$ can be represented as a block structure, i.e.

$$G_{\pi\eta} = \begin{Vmatrix} G_{\pi\eta}^{\langle 1\rangle} & | & G_{\pi\eta}^{\langle 2\rangle} \\ --- & + & --- \\ G_{\pi\eta}^{\langle 3\rangle} & | & G_{\pi\eta}^{\langle 4\rangle} \end{Vmatrix}, \quad G_{\pi\eta}^{4} = \begin{Vmatrix} G_{\pi\eta}^{\langle 4,1\rangle} & | & G_{\pi\eta}^{\langle 4,2\rangle} \\ --- & + & --- \\ G_{\pi\eta}^{\langle 4,3\rangle} & | & G_{\pi\eta}^{\langle 4,4\rangle} \end{Vmatrix},$$

where $G_{\pi\eta}^{\langle 1\rangle}$ and $G_{\pi\eta}^{\langle 4\rangle}$ are the square submatrices of the sizes $\mu \times \mu$ and $\phi \times \phi$, respectively; $G_{\pi\eta}^{\langle 2\rangle}$ is the submatrix of the size $\mu \times \phi$; $G_{\pi\eta}^{\langle 3\rangle}$ is the submatrix of the size $\phi \times \mu$; $G_{\pi\eta}^{\langle 4,1\rangle}$ is the first element of the matrix $G_{\pi\eta}^{\langle 4\rangle}$; $G_{\pi\eta}^{\langle 4,2\rangle}$ is the second element of the matrix $G_{\pi\eta}^{\langle 4\rangle}$ of the size $1 \times (\phi - 1)$; $G_{\pi\eta}^{\langle 4,3\rangle}$ is the third element of the matrix $G_{\pi\eta}^{\langle 4\rangle}$ of the size $(\phi - 1) \times 1$; and $G_{\pi\eta}^{\langle 4,4\rangle}$ is the fourth element of the matrix $G_{\pi\eta}^{\langle 4\rangle}$ of the size $(\phi - 1) \times (\phi - 1)$.

In the framework of the tensor description of the infocommunication network in the context of the multipath routing strategy [5, 17, 21], the average end-to-end delay of the audio flow packets can be calculated as:

$$T_S = \frac{\lambda^{k^{speech}} \varepsilon^{k^{speech}} - G_{\pi\eta}^{\langle 4,2 \rangle} \left[G_{\pi\eta}^{\langle 4,4 \rangle} \right]^{-1} \Lambda_{\eta-1}^{k^{speech}}}{G_{\pi\eta}^{\langle 4,1 \rangle} - G_{\pi\eta}^{\langle 4,2 \rangle} \left[G_{\pi\eta}^{\langle 4,4 \rangle} \right]^{-1} G_{\pi\eta}^{\langle 4,3 \rangle}}, \tag{24}$$

where $\Lambda_{\eta-1}^{k^{speech}}$ is the rate vector of lost packets on the interfaces of routers, the coordinates of which are determined by the expression:

$$\lambda_\eta^i = \sum_{j=1}^{m} \lambda^{k^{speech}} x_{i,j}^{k^{speech}} p_{i,j} . \tag{25}$$

The average end-to-end delay of video flow T_V packets is determined in a similar way and calculated as:

$$T_V = \frac{\lambda^{k^{video}} \varepsilon^{k^{video}} - G_{\pi\eta}^{\langle 4,2 \rangle} \left[G_{\pi\eta}^{\langle 4,4 \rangle} \right]^{-1} \Lambda_{\eta-1}^{k^{video}}}{G_{\pi\eta}^{\langle 4,1 \rangle} - G_{\pi\eta}^{\langle 4,2 \rangle} \left[G_{\pi\eta}^{\langle 4,4 \rangle} \right]^{-1} G_{\pi\eta}^{\langle 4,3 \rangle}}, \tag{26}$$

where $\Lambda_{\eta-1}^{k^{video}}$ is the intensity vector of the lost packets of the video flow on the interfaces of the routers, the coordinates of which are determined similarly to expression (25). In the course of solving the multipath QoE routing problem, a condition related to maximizing the overall performance of the infocommunication network was selected as a criterion for the optimality of the obtained solutions [21]:

$$\max_{x,\varepsilon} \sum_{k \in K} \left(\lambda^{k^{speech}} \varepsilon^{k^{speech}} + \lambda^{k^{video}} \varepsilon^{k^{video}} \right), \tag{27}$$

if there are restrictions (1)-(3), (5), (8) taking into account their detalization in (9)-(27).

6 Investigation of Tensor Approach for Providing Multimedia Quality

To assess the adequacy of the proposed model (1)-(27) and the demonstrativeness of the obtained calculation results, we will solve this problem for a fragment of the infocommunication network as shown on Fig.1. Assume that the network under investigation consists of sixteen routers and twenty-four communication links, indicating their capacity (1/s) in the gaps of the links.

Let the packet speech k^{speech} and video k^{video} flow be transmitted between the first and sixteenth routers with the following QoE requirements:

$\lambda_k^{speech\langle req\rangle} = 100$ 1/s, $\lambda_k^{video\langle req\rangle} = 300$ 1/s, $MMq^{\langle req\rangle} \geq 3.5$, when some users dissatisfied [6].

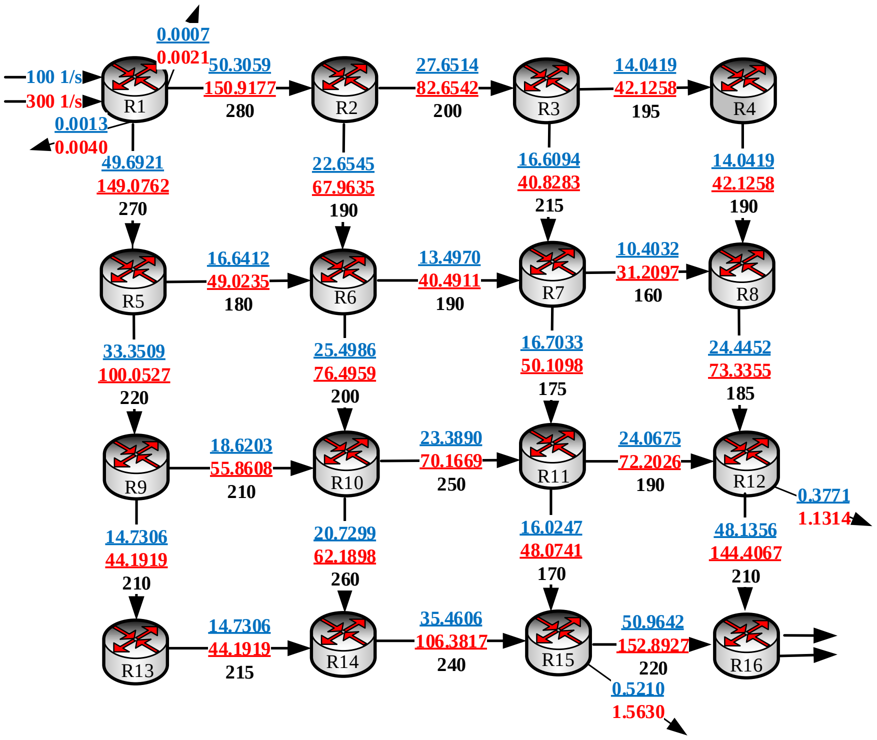

Fig. 1. The routing order of a flow of audio and video packets that is transmitted

As a result of the calculations (see *Table 1*), which quantitatively meet the requirements for ensuring the level of Multimedia quality in the network (9) at $MMq^{\langle req\rangle} \geq 3.5$, the following values have been obtained:

$$MMq = 3.5455,$$

at $MM_{SV} = 3.3634$; $MM_T = 3.9149$; $T_s = T_v = 0.0976$ s; $P^S = P^V = 0.009$.

Thus, the analysis of the effectiveness of the proposed approach for QoE-routing of multimedia packet flows for different network topologies and flow characteristics has been also conducted in the work. The efficiency has been estimated by the amount of link resource used by the network while meeting the established requirements for multimedia quality.

The results were compared with the solutions that were obtained using two classes of flow-based routing models:

- the flow-based model based on the bandwidth metrics, by analogy with the EIGRP and OSPF protocols [9];
- the flow-based routing model based on the load balancing and principles of Traffic Engineering [13, 14].

Table 1. Results of solving the problem of providing MMq.

Link	Example	QoE requirements: $\lambda_k^{speech\langle req\rangle} = 100$ 1/s, $\lambda_k^{video\langle req\rangle} = 300$ 1/s, $MMq^{\langle req\rangle} \geq 3.5$			
	$\varphi_{i,j}$, 1/s	Calculation results for the speech flow		Calculation results for the video flow	
		$\lambda_{i,j}^{k\,speech}$, 1/s	$r_{i,j}^{k\,speech}$, 1/s	$\lambda_{i,j}^{k\,video}$, 1/s	$r_{i,j}^{k\,video}$, 1/s
(1,2)	280	50.3059	0.0007	150.9177	0.0021
(1,5)	270	49.6921	0.0013	149.0762	0.0040
(2,3)	200	27.6514	0	82.6542	0
(2,6)	190	22.6545	0	67.9645	0
(3,4)	195	14.0419	0	42.1258	0
(3,7)	215	16.6094	0	40.8283	0
(4,8)	190	14.0419	0	42.1258	0
(5,6)	180	16.6412	0	49.0235	0
(5,9)	220	33.3509	0	100.0527	0
(6,7)	190	13.4970	0	40.4911	0
(6,10)	200	25.4986	0	76.4959	0
(7,8)	160	10.4032	0	31.2097	0
(7,11)	175	16.7033	0	50.1098	0
(8,12)	185	24.4452	0	73.3355	0
(9,10)	210	18.6203	0	55.8608	0
(9,13)	210	14.7306	0	44.1919	0
(10,11)	250	23.3890	0	70.1669	0
(10,14)	260	20.7299	0	62.1898	0
(11,12)	190	24.0675	0	72.2026	0
(11,15)	170	16.0247	0	48.0741	0
(12,16)	210	48.1356	0.3771	144.4067	1.1314
(13,14)	215	14.7306	0	44.1919	0
(14,15)	240	35.4606	0	106.3817	0
(15,16)	220	50.9642	0.5210	152.8927	1.5630

The proposed approach of QoE-routing of multimedia packet flows ensured the fulfillment of multimedia quality requirements when using an average of 20-27% less link resource than the flow-based model based on the bandwidth metrics. When comparing with the routing model organized on the principles of Traffic Engineering, the gain ranged from 14-17% to 22-25% depending on the features of the network topology and the bandwidth of the communication links. The biggest gain corresponded, firstly, to the use of networks with a heterogeneous topology when the connectivity of different routers was significantly different. Secondly, the network was heterogeneous, that is, different communication links had significantly different bandwidth. The obtained results of the efficiency analysis determine the corresponding field of practical application of the obtained solutions, which are presented by the method of QoE-routing of multimedia flows.

7 Conclusions

The paper proposes an approach based on the tensor mathematical routing model, due to which a given level of Quality of Exprience is provided according to the Multimedia Quality indicator. The model underlying this solution belongs to the class of flow-based routing models based on the conditions for implementing the multipath routing strategy (1), flow conservation taking into account possible losses at the network nodes (2), (3) and preventing overloading of communication links (8). The novelty of the proposed solution is to ensure that in the course of solving the routing problem, the Multimedia Quality conditions are fulfilled (9). Due to the tensor formalization of the QoE routing model, it was possible to obtain the conditions for ensuring the specified values of Multimedia Quality (15), (16), (24), (26) in the analytical form, which were used as the main restrictions in solving the formulated optimization problem. This was achieved due to the possibility of analytical calculation of the quality of service indicators: packet loss probabilities for audio (15) and video (16) flows, as well as the average end-to-end packet delay (24), (26) for the same flows transmitted within the multimedia session. At the same time, obtaining expressions (24) and (26) linking the end-to-end QoS-indicators, network parameters and flow characteristics was possible using the tensor research methodology. In the framework of this approach, the ICN was modeled for each multimedia session by the divalent mixed tensor (18) presented in a discrete space determined by the network structure.

To investigate the proposed approach, the functionality of the MatLab package was used. The calculation performed on a fragment of the infocommunication network allowed to evaluate the adequacy and effectiveness of the proposed approach, in which the end-to-end QoS indicators were calculated. Based on these indicators, it was possible to control the influence of the time desynchronization in the delivery processes of packets of audio and video flows on Multimedia Quality. The proposed approach, in comparison with existing solutions, allows using an average of 20-27% less link resource than the flow-based model based on using bandwidth metric, and 14-17% up to 22-25% less when comparing with the routing model organized on the basis of the Traffic Engineering principles.

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