QUALITY OF SERVICE ENSURING USING DYNAMIC TENSOR MODEL WITH SUPPORT OF DIFFERENT FLOW CLASSES IN TELECOMMUNICATION NETWORKS

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Dynamic tensor model with support of different flow classes in telecommunication networks for ensuring QoS proposed. QoS multipath routing model represented. Tensor model based on geometrization and tensor generalization of differential equations of network state, which adequately describe network links utilization and average packet delays. Results of research the proposed dynamic tensor model have shown that using this model allows more accurately calculate the value of average packet delay, especially in the case of high utilization of network interfaces, that can be useful in network resource allocation to flows of different classes.

A distinctive feature of modern telecommunication networks (TCN) is a high dynamics of information exchange processes. Network state (interface utilization, packet delay) changes in real time within dozens – hundreds of milliseconds. Therefore, prospective protocols and traffic management mechanisms should be based solely on dynamic models of network state. This primarily concerned to models that describe the processes of routing and queue management on network interfaces. In this regard, the proposed dynamic tensor TCN model that describes multipath routing process providing quality of service simultaneously over multiple quality of service (QoS) parameters.

Within the multipath routing model structure of TCN described by one-dimensional network $S=(U,V)$, where $U=\{u_i, i=\overline{1,m}\}$ is a set of network nodes (routers), and $V=\{v_z=(i,j); z=\overline{1,n}; i,j=\overline{1,m}; i\neq j\}$ is a set of edges. Here the edge $v_z=(i,j)\in V$ models z-th link connecting i-th and j-th routers. Assume that capacity $\varphi_{(i,j)}$ is known for every link (i,j) and measured in packets per second (1/s).

The result of routing problem solving is calculation of the set of routing variables $x_{(i,j)}^{k_p}$, each of which characterizes the fraction of intensity of the k-th flow of p-th class ($p=\overline{1,P}$, $k_p\in K_p$, $K_p\in K$, where K is the set of flows in network, and K_p is the set of flows of p-th class) from i-th node to j-th node through the appropriate j-th interface.

For the purpose of TCN nodes overload prevention it is necessary to meet the condition of flow conservation on the source, transit and destination nodes, respectively, which can be written in the form [1]:

$$\begin{cases} \sum\limits_{j:(i,j)\in V} x_{(i,j)}^{k_p} = 1, \; k_p\in K_p, \; i=s_{k_p}; \\ \sum\limits_{j:(i,j)\in V} x_{(i,j)}^{k_p} - \sum\limits_{j:(j,i)\in V} x_{(j,i)}^{k_p} = 0, \; k_p\in K_p, \; i\neq s_{k_p}, d_{k_p}; \\ \sum\limits_{j:(j,i)\in V} x_{(j,i)}^{k_p} = -1, \; k_p\in K_p, \; i=d_{k_p}, \end{cases} \qquad (1)$$

where s_{k_p} and d_{k_p} are source and destination nodes of the k-th flow of p-th class.

For implementation of multipath routing strategy with load balancing the control (routing) variables must satisfy the following condition

$$0 \le x_{(i,j)}^{k_p} \le 1 . \tag{2}$$

The precondition for controllability of routing is capacity constraint, i.e. the condition $\rho < 1$ (where $\rho = \lambda / \varphi$ is link utilization):

$$\sum_{k_p \in K_p} \lambda_{req}^{k_p} x_{(i,j)}^{k_p} \le y_{(i,j)}^{p} \varphi_{(i,j)} , \quad (i,j) \in E , \tag{3}$$

where $\lambda_{req}^{k_p}$ is average intensity of the k-th flow of p-th class, incoming to the network; $y_{(i,j)}^{p}$ is control variable, characterizing fraction of capacity $\varphi_{(i,j)}$, allocated to flows of p-th class ($0 \le y_{(i,j)}^{p} \le 1$). This value is the required packet rate and one of the QoS metrics.

In solving the routing problem should be minimized the following objective function:

$$J = \sum_{(i,j)\in E} \sum_{p \in P} \sum_{k_p \in K_p} h_{(i,j)}^{x_p} \cdot x_{(i,j)}^{x_p} + \sum_{(i,j)\in E} \sum_{p \in P} h_{(i,j)}^{y_p} \cdot y_{(i,j)}^{p} , \tag{4}$$

where $h_{(i,j)}^{x_p}$ is routing metric of the link between i-th and j-th TCN nodes; $h_{(i,j)}^{y_p}$ is the metric of throughput allocation to flows of different classes.

For obtaining a tensor model of the TCN let us introduce anisotropic space structure constructed by the set of circuits and node pairs (Fig. 1). The dimension of this space is determined by the total number of links in the network. Within the scope of tensor generalization as a dynamic model of changes the state of TCN router interface was chosen the mathematical model, based on the use of nonlinear differential equation system of the network state obtained by the Pointwise Stationary Fluid Flow Approximation (PSFFA) [2, 3]. According to this approximation the average packet delay on the network router interface changing as follows:

$$\frac{d\tau_{(i,j)}^{p}(t)}{dt} = 1 - \varphi_{(i,j)}^{p} \left(\frac{\tau_{(i,j)}^{p}(t)}{\lambda_{(i,j)}^{p} \tau_{(i,j)}^{p}(t) + 1} \right), \tag{5}$$

where $\varphi_{(i,j)}^{p} = y_{(i,j)}^{p} \varphi_{(i,j)}$ is the links (i,j) throughput, allocated to flows of p-th class; $\lambda_{(i,j)}^{p} = \sum_{k_p \in K_p} \lambda_{req}^{k_p} \cdot x_{(i,j)}^{x_p}$ is the total intensity flows of p-th class in (i,j) link.

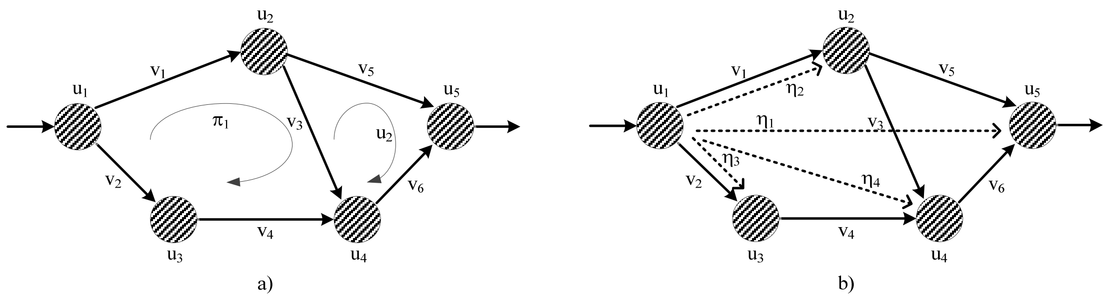

Fig. 1. Tensor model of Telecommunication Network: a) set of circuits; b) set of node pairs

As a result of geometrization the TCN structure, based on tensor generalization of expression (5), the metric tensor has become a function of time and for each link has the next form:

$$g_v^{ij}(t) = \lambda_v^i(\varphi-\lambda)\cdot[(\varphi\cdot W(0,-(\lambda\cdot\mathbf{exp}(-(\lambda+(t- \\ -(\lambda+\varphi\cdot\mathbf{ln}(\mathbf{exp}(-(\lambda\cdot(\tau_0\lambda-\tau_0\varphi+1))/\varphi)\cdot \\ \cdot(\tau_0\lambda-\tau_0\varphi+1)))/(\varphi-\lambda)^2)\cdot(\varphi-\lambda)^2)/\varphi))/\varphi))/\lambda+1]^{-1}, \quad (6)$$

where $W(\cdot)$ is Lambert W function; $\mathbf{exp}(\cdot)$ is exponential function; τ_0 is the average delay at the interface at initial time.

Then under the tensor model for solving problem of providing QoS in TCN for specified quantitative requirements for average packet delay and packet rate analytical conditions of QoS ensuring are following:

$$\lambda^{req} \le \left(G_{\pi\eta}^{\langle 4,1\rangle}(t) - G_{\pi\eta}^{\langle 4,2\rangle}(t)\left[G_{\pi\eta}^{\langle 4,4\rangle}(t)\right]^{-1} G_{\pi\eta}^{\langle 4,3\rangle}(t)\right)\tau_{req}, \quad (7)$$

where form and content of matrices $G_{\pi\eta}^{\langle \ldots \rangle}(t)$ depend on the network structure, link capacities and packet service disciplines [4, 5].

Results of research the proposed dynamic tensor model have shown that using this model allows more accurately calculate the value of average packet delay, especially in the case of high utilization of network interfaces. For example, if the interface utilization is from the range of ρ=0.63...0.82, the error varied from 15% to 40%, which in practice reveals usually in not effective allocation of network (link and buffer) resource to flows of different classes.

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