THE NODAL TENSOR MODEL FOR QOS ESTIMATION OF COMMUNICATIONS NETWORKS

Ponomarev D.

Siberian State Aerospace University,
Russia.

E-mail: : dupon@sibsau.ru

Abstract

The main characteristics of QoS are estimated usually by methods of queuing theory. However, in the application to nets queuing theory considers processes for each of the systems (switches, routers, servers etc.) without taking into account the network topology. On the other hand, graph theory uses the topology for network analysis but cannot consider arrival and service processes in network systems. Tensor analysis of networks allows to provide an estimate of QoS characteristics with taking into account both the arrival and service processes and the network topology.

This work presents the nodal tensor model as a tool for QoS analysis in the communications networks. In these models, the main systems of the communications network represented as single-line queuing systems (but and other types of queuing systems can be used). Models formed in accordance to the types of networks. The proposed models allow estimating the QoS characteristics for the individual routes and the entire network. Moreover, these models can be used to optimize the communications networks.

Communications networks have a complex structure of connections between a large number of networks elements. These structure and elements provide the transmission and processing of information flows through the formation of transmission paths called routes. For multimedia streams, routes are set in such a way that quality of service (QoS) of information flows is provided, and network congestion is avoided. This task is mainly solved by applying the methods of queuing theory. However, many factors complicate the solution of this task by classical methods of queuing theory. Some of them are a dynamic structure of connections and a large number of routes.

This work presents the model for the estimation of QoS characteristics by applying of tensor analysis. The base of tensor model is invariant equation whose components (in this work, are flow and service intensities, utilizations but can be use and other) change linearly when the transition occurs from one coordinate system to another. This transition means transition from one network structure to another. Thus, researched characteristics (for communications it is mean delay, losses etc.) are determined from geometric presentation of these characteristics in such coordinate system where it can be found simple without using complex methods. Tensor method was used for QoS estimation of NGN in [1,2] but the other models were applied.

The basis of tensor analysis is a geometric representation of network characteristics as a vector. Network restructuring results in a vector transformation. According to Kron's theory, geometric object is a mathematical or physical object which is represented as set of matrices for an infinite number of coordinate system [3]. Representations related via transition or transformation matrix. The set of an infinite number of transformation matrices is a transformation tensor. Equation is invariant if all its components are geometric objects. It means that the equation is rightly for an infinite number of physical systems [3]. Thus, invariant equation is valid for any systems of this nature. For communications, tensor analysis can be based on different relations (mean queue, traffic intensity etc.), for example, Little's law [1,2].

In this work, the relation between load and flow intensity is used. Then, load ρ, flow intensity λ, service time t and service intensity μ are components of invariant equation: $\rho = \lambda t$ or $\lambda = \mu\rho$. Infinite number of representations these components for different coordinate systems is a geometric object. The transformation matrix C (or A) is used for transition from one coordinate system to another. Thus, invariant equation is a set of representations for different coordinate systems. This set consists of vectors and tensors (vectors of load ρ and flow intensity λ; tensors of service time t and service intensity μ).

In this work, a method of the network analysis is based on the following assumptions [4]. First, the same intensity (λ is the average arrival rate) of information flows causes the same load (ρ) of network nodes when the network structure change, but service intensities are constant. Consequently, the relationship can be defined as:

$$\rho\lambda = \rho'\lambda' , \qquad (1)$$

where variables with apostrophe refer to one structure of network and variables without apostrophe refer to another structure. Second, any connection of network nodes does not change anything in the process of the information flow service. Then, the communications network analysis is defined by the primitive element identification and its properties determination [3,4]. In this work, the primitive element is a queuing system that is a model of network interface, node or route. Third, the network connections change is not to result in qualitative changes of processes that proceed in primitive elements, but causes only quantitative changes.

We can determine QoS characteristics with the specified structure of network and intensities of information flows. The main characteristics of the QoS estimation are the probability of packet loss and the mean delay. These characteristics are functions of a load: $p_{loss} = f(\rho)$ and $T_{delay} = f(\rho)$, where ρ depends on the flow intensity and, therefore, queuing system (QS) loads are determined by the distribution of traffic. Thus, main QoS characteristics can be determined for an each route of information flow or for a whole network as: $p_{loss} \approx \sum_{i=1}^{m} p_{loss,i}$ (in case of low losses); $T_{delay} = \sum_{i=1}^{m} T_{delay,i}$ (m is a number of QS in a network). Hence, a load calculation of nodes allows estimating QoS characteristics.

For tensor analysis using, the nodes of the communications network are represented as a queuing net. Queuing system of this net is a model of individual physical interface of information transmission system (input/output interfaces). This interface is represented as a single server QS, but, in some cases, we can use multi-server QS. Type of the QS is defined by service procedures of a real system. QS has characteristics: t is a service time and μ is a service intensity (it is the average service rate).

In dependence of type of network connections tensor analysis defines two main kinds of network models: the mesh model and the node model. The mesh model is used if a network has closed paths, and in contrary the nodal model is applied if a network has not closed paths. Then, the traffic distribution can be found with used equations: $\rho = \lambda t$ (for mesh models) or $\lambda = \mu\rho$ (for node models). The decision of these equations allows determining the distribution of loads or flow intensities. Consequently, we can estimate of QoS characteristics as a function of obtained distribution. According to tensor analysis of networks [3] a model of communications network is the initial network. Further, initial network transformed into primitive network by decomposition of network elements. Decomposition is to break the connections between QS. Thus the expression (1) defines a relation between initial and primitive networks.

The nodal method of the tensor analysis of communications networks uses the nodal type of network. In this case, the transformation matrix A is defined from the correspondence between QS utilizations in the initial network ρ and QS utilizations in the primitive network ρ': $\rho' = A\rho$. Thus, the equation form for the nodal method is [4]:

$$\left(A^T \mu' A\right)\rho = A^T \lambda' . \qquad (2)$$

Algorithm of nodal method is a simple. First, "nodal" loads are defined for initial networks (for example, Fig.1b: $\rho_a, \rho_b, \rho_c, \rho_d$ etc.) Second, the initial network is divided into a separate QS. Third, the matrix A is determined. Accordance between "nodal" and QS loads determines elements of matrix A. For example, in Fig.1b: $\rho_1 = \rho_a$ and $\rho_2 = \rho_b - \rho_a$. Therefore, for first string of matrix A: $A(1,a) = 1$ and others equal '0'; for the second string: $A(2,a) = -1$, $A(2,b) = 1$ and others equal '0'. Analogous, elements of other strings are determined.

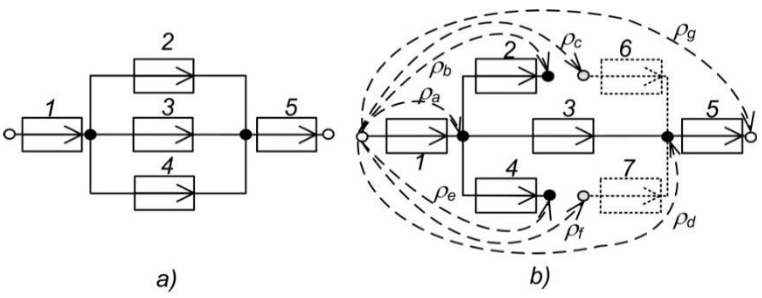

Fig.1. The model of the IMS network

Further, equation (2) is solved for variable ρ. Then, initial network system utilizations ρ are determined as: $\rho_{branch} = A\rho$. It allows estimating QoS characteristics. Also, the flow intensity for each QS can be found as: $\lambda_{branch} = \mu_{branch}\rho_{branch}$. Thus, we can get the traffic distribution of the network.

For the demonstration of the nodal method, we consider the model of the information processing in the IMS (IP multimedia subsystem). The main elements of the IMS are: HSS (Home Subscriber Server); control function objects (CSCF - Call Session Control Function: P-CSCF (Proxy-CSCF), I-CSCF (Interrogating-CSCF)) and others [5].

In the Fig.1a, the model is presented for the IMS network: QS1 is a model of the P-CSCF service process; QS2, QS3, QS4, QS5 are models of I-CSCF$_1$, I-CSCF$_2$, I-CSCF$_3$ and HSS respectively. Thus, there is SIP message-passing model for part of IMS network. Flow intensities for QS are determined by procedures of SIP message exchange in IMS network.

This model is transformed to the nodal form (Fig.1b) with disconnection of closed paths (QS2-QS3; QS3-QS4) because closed paths should not be in the nodal model. In this case, imaginary queuing systems (QS6, QS7) are included for retaining of the sum of flow intensities in node: $\lambda_5 - \lambda_2 - \lambda_3 - \lambda_4 = 0$. Thus, for imaginary systems: $\lambda_2 = \lambda_6$, $\lambda_4 = \lambda_7$. Hence, the sum of flow intensities in the node is: $\lambda_5 - \lambda_6 - \lambda_3 - \lambda_7 = 0$. Therefore, in further analysis, "nodal" loads are set for all nodes: $\rho^T = (\rho_a \quad \rho_b \quad \rho_c \quad \rho_d \quad \rho_e \quad \rho_f \quad \rho_g)$.

According to (2), it is necessary to determine the relationship between loads of the initial network and the primitive network in order to obtain the matrix A (this matrix is not presented here because it has high dimensionality and sparseness). To solve the matrix equation (2), service and flow intensities must be set. In this model, the QS1 is one traffic generator in this network so all flow intensities can be determined through λ_1 by setting the coefficients p_i that define the part of the input traffic in the i-th queuing system. For given network, relationships between flow intensities are: $\lambda_1 = \lambda_2 + \lambda_3 + \lambda_4$, $\lambda_5 = \lambda_3 + \lambda_6 + \lambda_7$, $\lambda_2 = \lambda_6$, $\lambda_4 = \lambda_7$.

Thus, the coefficients p_2, p_3, p_4 define the traffic distribution because $p_2 + p_3 + p_4 = 1$ (hence $p_3 = 1 - p_2 - p_4$) and $\lambda_2 = p_2\lambda_1 = \lambda_6$, $\lambda_3 = p_3\lambda_1$, $\lambda_4 = p_4\lambda_1 = \lambda_7$.

Thus, the solution of equation (2) is obtained by setting the intensity λ_1, probabilities p_i and intensities of service μ_i ($i = 1 \ldots 7$ and $\mu_6 = \mu_2$ and $\mu_7 = \mu_4$ because QS6, QS7 are imaginary systems). Probabilities p_i are defined by percentage of traffic incoming to I-CSCF$_1$, I-CSCF$_2$ and I-CSCF$_3$.

Further, we used the following values: $\lambda_1 = 9$, $\mu_1 = \mu_5 = 10$, $\mu_2 = \mu_6 = 8$, $\mu_3 = 10$, $\mu_4 = \mu_7 = 12$, type of QS is $M/M/1$. Probability varying changes the traffic distribution that results to the changing of delay. The Fig.2 presents the average network delay as a function of p_2 for differ values p_4. The figure shows that some value p_2 results in a minimum value of delay. Thus, the node distribution probability $(p_2 \quad p_3 \quad p_4)$ is a vector that is provide the management of the traffic distribution to ensure the specified average delay for the whole network.

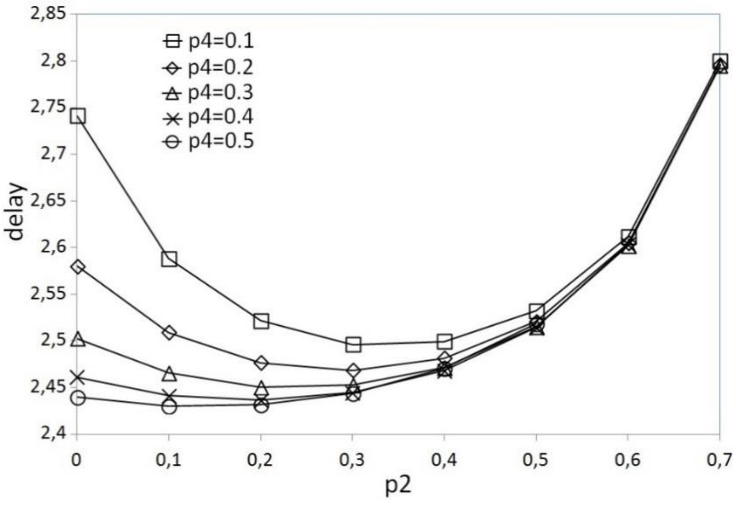

Fig. 2. Average network delay as a function of p_2

In conclusion, we would like to note the following. The analysis of the modern communications network is a very complex task. The solution of this task is complicated by many factors some of them are a dynamic hanging of network topology, large number of information routes, a dynamic distribution of network flows etc. Classical methods are difficult to solve the task of the network analysis especially for WAN.

Unlike methods of queuing theory, the tensor approach allows to obtain a solution without some complex operations: the poor formalize procedure of taking complex differential-difference equations; solving of set of differential-difference equations; finding of normalization constant; changing of the differential-difference equations set when the network topology changed. Besides, tensor approach has some advantages. First, it is a good formalize method for the computer-aided design of communications network. Second, it is an invariant under the network topology and scale. Third, it captures the interaction arrival streams and network topology.

The main tensor models of the communications networks are a mesh model and nodal model. For communications networks, the nodal model more preferred because this model allows estimating of QoS with standard input data (an intensity of sources of traffic and a service intensity of systems). Besides, the nodal model can be use for the traffic distribution and its optimization (for example, for traffic engineering). The tensor models of both types allow estimating the different characteristics of the communications networks: delay, probability, loss etc.

Thus, the tensor models provide the possibility of QoS estimation for networks of almost any scale (from LAN to WAN) and enable to solve the tasks of management of the communications networks. Moreover, these models can be used for optimization of the communications networks to improve the level of service.

Bibliography

1. *Strelkovskaya I.V., Solovskaya I.N.* Tensor method of traffic management problems solving with service quality network parameters maintenance // Eastern European journal of enterprise technology. – 2011. – No 5(53). – P. 37-51. (In Russian).

2. *Lemeshko A.V., Drobot O.A.* A multipath QoS routing model for multi-service telecommunication network // Radio-technique: All-Ukrainian interdepartmental. Scientific and Technical digest. – 2006. – №144. – P. 16-22. (In Russian).

3. *Kron G.* Tensor analysis of networks. – London : MacDonald, 1965. – 635 p.

4. *Ponomarev D.* Research of packet networks characteristics with using node method of tensors analysis // Software & Systems. – 2009. - No. 4. – P. 65-69. (In Russian).

5. *Poikselka M., Mayer G.* The IMS: IP Multimedia Concepts and Services, 3rd edition. – London : John Wiley & Sons, 2009. – 560 p.