Research of Queue Management Model That Includes Congestion Avoidance Mechanism

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***Abstract* — The following paper presents queue management model that includes congestion avoidance mechanism and suitable for using on telecommunication network nodes. Within the proposed model on a network node consistently was solved Congestion Management and Congestion Avoidance tasks. At the same time general queue management task was reduced to solving of optimization problem. Within the congestion avoidance mechanism packets were dropped in order to prevent node buffer and link overload. Proposed mathematical model was investigated with analytical modeling methods.**

Keywords—queueing; congestion management; congestion avodance; modeling

I. Introduction

Improving the quality of service (QoS) for users flows is one of the important direction of development and improvement of telecommunications nowadays. Queue management solutions play an important role among a range of measures to ensure QoS, they allow to improve such characteristics as jitter, delay, number of dropped packets (packet loss) without substantial modernization the existing network [1]. In turn, characteristics and effectiveness of technological solutions in the management of queues depend on the mathematical models and methods that they contain.

Those congestion control mechanisms that are applied today (First In First Out – FIFO, Priority Queuing – PQ, Custom Queuing – CQ, Weighted Fair Queuing – WFQ, Class-Based Fair Queuing – CBWFQ), have several disadvantages, including static nature (the need of administrator intervention for configuration), inability for adaptation, inconsistency with other methods of queue management, such as congestion avoidance mechanisms (Random Early Detection – RED, Weighted Random Early Detection – WRED, Random Exponential Marking – REM, Adaptive virtual queue – AVQ, Stochastic fair Blue – SFB), that can neutralize advantages of both the first and second groups of algorithms [2]. In this connection the study of new queue management approaches at both wire and wireless telecommunication network nodes looks relevant.

This work presents mathematical queue management model main feature is which is the agreed solution of the following tasks in terms of one mathematical model for improving quality of service of users flows:

- flows distribution among queues (Congestion Management);
- bandwidth allocation for serving packets of each queue;
- preventive limitation of the queue length (Congestion Avoidance).

II. Queue Management Model That Includes Congestion Avoidance Mechanism

Within the proposed model a_i ($i=\overline{1,M}$) – rate of the flow of i-th class, that comes to telecommunication network node, M – total number of flows; b_j ($j=\overline{1,N}$) – bandwidth, allocated for serving packets from j-th queue, N – total number of queues; x_{ij} – a part of flow of i-th class that was directed into j-th queue. Feature of the model is the possibility to manage number of dropped packets of flow of i-th class for preventive limitation of the queue length with usage of variable α_i.

The general scheme of the proposed model is shown on Fig. 1.

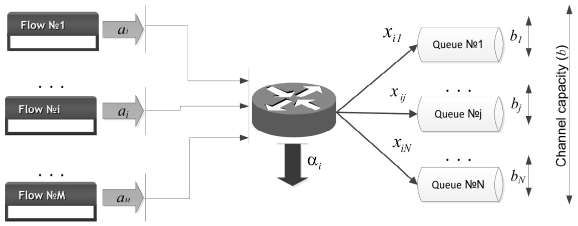

Fig. 1. The general scheme of the proposed model

The input interface of the network node receives M flows with different rate, priority, length and arrival time distribution. In case of link congestion indication a part of the packets going to be dropped to implement preventive queue length limitation. The rest of the packets will be distributed among N queues according to the calculation results of the proposed model. Bandwidth will be allocated for each queue to ensure the quality of service for flows received by the node.

While solving the problem of queue management it is necessary to determine the order for serving packages (x_{ij}), bandwidth allocation for each queue (b_j), and also number of dropped packets (α_i). Then the vector of the variables can be conveniently represented in the following form:

$$\vec{X} = \begin{bmatrix} x_{ij} \\ \alpha_i \\ b_j \end{bmatrix}. \quad (1)$$

The dimension of the $\vec{X}$ vector is determined by the amount of flows entering the interface and the number of allocated queues.

In accordance to the physics of the problem being solved x_{ij} can possess only two values – either 0, or 1, i.e. flow of one class can be served only within one queue:

$$x_{ij} \in \{0,1\}. \quad (2)$$

Following restrictions imposed on components α_i and b_j of the X vector:

$$0 \le \alpha_i \le 1, \quad (3)$$

$$0 \le b_j \le 1. \quad (4)$$

While calculating $\vec{X}$ (1) it is necessary to invoke minimum of some cost function:

$$\min_{x_{ij}, \alpha_i, b_j} \vec{c}^{\,t} \vec{X}, \quad (5)$$

that characterizes the relative costs of queues management. Components of the vector c:

$$c = \begin{bmatrix} c_{ij} \\ c_{\alpha_i} \\ c_{b_j} \end{bmatrix}, \quad (6)$$

where c_{ij} – penalty coefficient for serving flows of i-th class by j-th queue; c_{α_i} – penalty coefficient for dropping packets of flow of i-th class; c_{b_j} – penalty coefficient for bandwidth allocation for j-th queue.

The main cause of the packet loss in telecommunication network is the buffer overflow of the network devices caused by the lack of available bandwidth to serve incoming traffic. In case of using Tail drop mechanism there is a danger of nonuniform flows distribution, that can lead to global synchronization effect. Probabilistic packets dropping, that is used in the Congestion Avoidance mechanisms, helps to avoid this problem. Providing network nodes congestion indication before queue overflows, Congestion Avoidance mechanisms are able to provide smaller queue length than in the case of the Tail drop mechanism, which reduces the packet delay.

In the proposed model the part of flow of i-th class, that was dropped on network node is determined by the variable α_i. In order to ensure the controllability of the proposed model it is necessary to ensure following condition:

$$\sum_{j=1}^{N} x_{ij} + \alpha_i = 1 \; (i = \overline{1, M}). \quad (7)$$

Condition (7) allows introduction of the preventive queue length limitation mechanism in the proposed model. Approach proposed in this paper is also investigated in the traffic management tasks for routing [3].

In order to prevent queue overload during the flow distribution it is important to satisfy the condition:

$$\sum_{i=1}^{M} a_i x_{ij} < b_j, \quad (8)$$

where a_i – rate of the flow of i-th class, that came to the network node to be served.

Solutions obtained from the use of model (1)-(8) should provide adaptive nature of queue length limiting. In case of node overload, from one hand, restricted first of all should be low-priority flows, on the other hand – flows, which are sources of node overload. In addition, the process of queue length limiting should be adaptive preventing thereby appearance of global overloading effect. Therefore whithin the proposed model (1)-(8) important task is to study the effect of a separate network settings on the nature of traffic restriction substantiating selection of values of certain parameters of the model. This primarily concerns the choice of the numerical values and the ratio of penalty coefficients (6) in the objective function (5), responsible for the penalty for flows distribution between queues or possible packet loss.

III. RESEARCH OF THE PROPOSED MODEL

Research of the proposed model was based on the results of analytical modeling. For the laboratory research of the models the approach described in [4] can be used. Optimization of criterion (5) within the constraints (2)-(4),(7)-(8) was solved using the package Optimization-Toolbox of Matlab 7 environment. In this paper we studied in details the preventive aspect of limiting the length of the queue. Efficiency solutions for flow distribution and allocation of bandwidth are investigated in [5-8]. For example, to solve the queuing problem using the proposed model following initial data was taken (Fig. 2).

The input for the network node was traffic that consists of five flow with following rate: $a_1 = 1 - 500$ 1/s, $a_2 = 160$ 1/s, $a_3 = 235$ 1/s, $a_4 = 200$ 1/s, $a_5 = 98$ 1/s. Let the rate of the first flow varies from 1 to 500 1/s, while rate of the rest of flows remains constant. For serving flows suggested to use three queues. Link capacity was 1200 1/s. Number of unknown variables thus was 23.

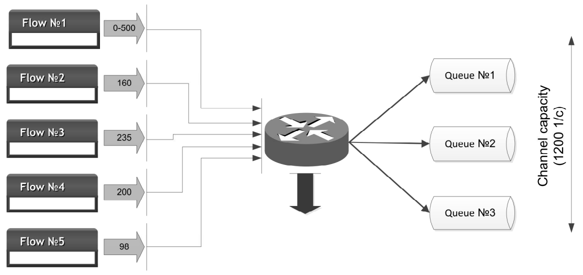

Fig. 2. General scheme of the experiment

Results showed that in case of selecting penalty coefficients c, where $c_{ij} << c_{\alpha_i}$, queue length limit is observed only under conditions of link overload, when incoming traffic rate exceeds link capacity. In the case when the penalty for packet loss less then penalty for the distribution of packets between queues ($c_{\alpha_i} < c_{ij}$) then packet loss observed on node, even if there is enough free bandwidth resources. Thus, there is a need to justify the choice of the ratio of the penalty coefficients c_{ij} and c_{α_i} , that is independent complicated enough task. 1-st flow packet loss probability characteristic depending on the flow rate presented on Fig. 3, when penalty coefficients ratio $c = c_{ij} / c_{\alpha_i} \approx 1:200$, $1:300$, $1:400$.

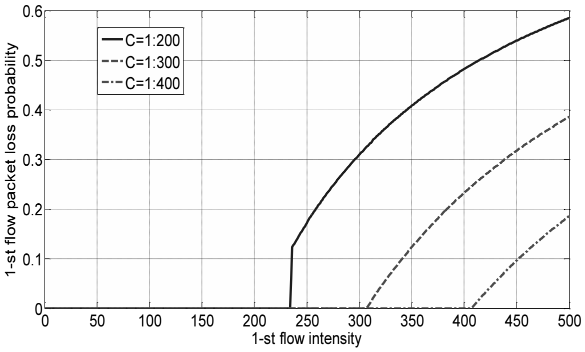

Fig. 3. 1-st flow packet loss probability characteristic depending on the intensity

Fig. 3 shows that for this structure optimal value of the ratio of penalty coefficients is $c = c_{ij} / c_{\alpha_i} \approx 1:300$, when dropping of packets occurred only in the zone of high interface utilization (1000-1200 1/s).

IV. CONCLUSION

Paper presented queue management model with preventive limitation of the queue length suitable for telecommunication netwrok nodes. This allowed to unite under a single model solution of the flow distribution problem (Congestion Management) and queue length management (Congestion Avoidance). Agreed solution of those tasks allows effective queue management to improve the quality of service of user flows.

The proposed model was solved by linear programming methods, which allows to use it on the equipment with low computing power.

According to results of modeling the research was performed (Fig. 3) and rationale for the selection of penalty coefficients (3) was shown.

Further development of the proposed model is possible in the direction of accounting larger number of quality of service indicators.

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