# Research of Goal Coordination Method for Congestion Management on Telecommunication Network Nodes

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*Abstract* - **The paper presents the hierarchical concept of congestion management on the telecommunications network nodes in which the method of goal coordination is determined. Proposed model is suitable for network nodes with multiprocessor or multi-core architecture. Convergence of the proposed model is investigated.**

*Keywords* - **Congestion management, Hierarchical queues, Goal coordination.**

## I. INTRODUCTION

Improvement of the quality of service (Quality of Service, QoS) within growing number of user requests currently is an important task for modern telecommunication networks. This paper presented to enhance quality of service for users flows. Existing technology congestion management solutions are not able to provide all of the growing need for quality of service for new information society. Most of the control actions have static nature, i.e. require administrator intervention in the network settings configuration.

Relevance of research is in the need of adaptation of mathematical models for modern telecommunication hardware. Model of a hierarchical structure is proposed, which implements the goal coordination principle which is suitable for multi-processor, multi-core systems.

## II. TWO-LEVEL HIERARCHICAL QUEUING MODEL

Modern telecommunications network has a large distributed structure, transition to distributed, cloud-based technologies taking place that require compliance with the principles of agreement, elements coordination in their work. Hierarchical structures (queues) best suited for scaling the network in case of increasing the number of flows that need to be served. This mathematical tool allows more efficient use of multi-core (processor) system, when a shared resource is distributed and each CPU engaged in solving maintenance tasks for its group of queues.

Queue management task require determination of the multiple flows distribution between queues, and defines the order of serving packet flows with given intensity. In order to improve the scalability of the queue management solutions the two-level functional hierarchy of calculations has been determined:

- at the lower level - the required distribution of flows and bandwidth allocation to be calculated independently for each macro-queue for flows that comes from the access network;
- at the upper level - solutions obtained on lower level for each queue are coordinated in order to prevent probable network link overload.

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

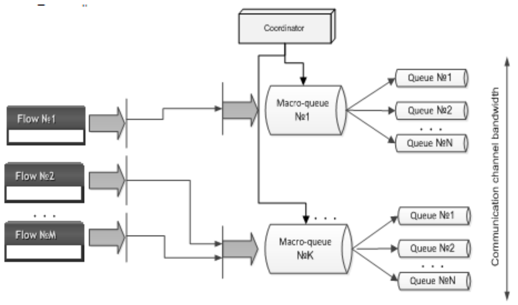


Fig. 1. The general scheme of the two-level hierarchical queuing model

As shown on Fig. 1 $M$ flows enter network node, they all have different intensity, priority, packet length, inter-arrival time distribution. Depending on the configuration of access lists on a network node flows distributed among $K$ macro-queues. Each macro-queue served by separate processor or core. Flow distribution between queues within macro-queue calculated parallel. Coordinator's task is to ensure that the sum of bandwidth allocated to macro-queues does not exceed link bandwidth.

Consider variables $x_{ij}^r$ and $b_j^r$ to be search for each $r$-th macro-queue. $x_{ij}^r$ describes the intensity of $i$-th flow that was directed into $j$-th queue of $r$-th macro-queue. $b_j^r$ determines bandwidth allocated for j-th queue of $r$-th macro-queue.

According to the physical content of the variable $x_{ij}^r$ it can take only two values, either 0 or 1, i.e.:

$$^{r} \in \; 0,1 \qquad , \tag{1}$$

condition should be met:

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$$\sum_{r=1}^{K}\sum_{j=1}^{N_r} x_{ij}^r = 1\,(\,i=\overline{1,M}\,), \qquad (2)$$

Condition (2) must be met for each $i$-th flow that enters macro-queue to be served. The intensity of all flows that need to be served should not exceed available bandwidth. To prevent link overload the following condition should be satisfied:

$$\sum_{r=1}^{K}\sum_{j=1}^{Nr}\sum_{i=1}^{M} a_i x_{ij}^r \le b\,, \qquad (3)$$

where $a_i$ – intensity of the $i$-th flow, that comes to router for serving; $b$ – link bandwidth.

The criterion of optimality is selected to minimize the average queue length at the node:

$$\min_{x,b} F\,,\ F = \sum_{r=1}^{K}\sum_{j=1}^{N_r}\left[\frac{\rho_j^r}{1-\rho_j^r} - \rho_j^r\right], \qquad (4)$$

where $\rho_j^r = \dfrac{\sum_{i=1}^{M} x_{ij}^r}{b_{ij}^r}$ – bandwidth utilization of the queue.

In order to move to a more flexible, scalable hierarchical queuing model, the centralized formulation of the problem of flow distribution and bandwidth allocation must be submitted in decomposition form by the number macro-queues with the possibility of coordination of results at each macro-queue.

It should be taken into account that it is impossible to met condition (3) within decentralized calculation of variables on each individual macro-queue. The reason is that the flow distribution for each macro-queue is calculated based only on the information it has about the received packet and link bandwidth, without knowing results of flow distribution and bandwidth allocation on other macro-queues. In order to prevent link overloading the coordinator will use following constraint:

$$\sum_{i=1}^{M}\sum_{j=1}^{N_r} a_i x_{ij}^r \le b - \sum_{\substack{s=1\\ s\ne r}}^{K}\sum_{i=1}^{M}\sum_{j=1}^{N_r} a_i x_{ij}^s\,, \qquad (5)$$

Solution of the optimization problem associated with the minimization of the function (4) was the basis of the proposed hierarchical queuing model. Then, according to theorem of strict duality of conditional extremum problems turning to the problem of unconditional extremum, following equality take place:

$$\min_{x,b} F = \max_{\mu} \Phi\,,$$

determined in accordance with the formula (5) dual function as follows:

$$\Phi(\mu) = \{\min_{x,b} L(x,b,\mu)\}\,,$$

where

$$L = \sum_{r=1}^{K}\sum_{j=1}^{N_r}\left[\frac{\rho_j^r}{1-\rho_j^r} - \rho_j^r\right] + \sum_{r=1}^{K}\vec{\mu}_r^{\,t}(B_r\vec{x}_r + \sum_{\substack{s=1\\ s\ne r}}^{K} B_s\vec{x}_s - b) \quad (6)$$

On the upper level of hierarchical queuing model, whose main task is to coordinate the solutions obtained at the lower level, performed modification of Lagrange multipliers vector implementing following gradient procedure:

$$\mu_r(\alpha+1) = \mu_r(\alpha) + \nabla\mu_r\,, \qquad (7)$$

where $\nabla\mu_r$ – gradient of the function, that was calculated using results obtained on the lower level of hierarchy, i.e. the problem of flow distribution and bandwidth allocation for each specific $r$-th macro-queue ($r \in K$):

$$\nabla\mu_r(x_{ij}^r, b_j^r) = \sum_{r=1}^{K} B_r\vec{x}_r - b\,. \qquad (8)$$

With proposed flow-based model goal coordination principle was the most reasonable to be used. It defined order for consideration of macro-queue interaction constraints and also distribution of calculation tasks between levels of hierarchy. In the course of solving variables $x_{ij}^r$ and $b_j^r$ should be calculated directly using processors of each macro-queue. Analysis and coordination of bandwidth allocation is performed by coordinator (upper level of hierarchy) using Lagrange multipliers $\vec{\mu}_r$ (Fig. 2).

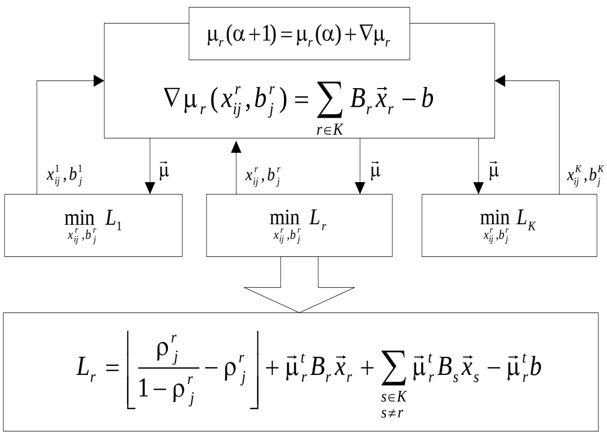


Fig.2. Two-level hierarchical queuing model

Imitational modeling approaches were used to get convergence results of the proposed mathematical model (Fig.3). The figure shows that with an increase of the Lagrange multipliers vector ($\mu_r$) the sum of bandiwdth allocated to macro-queues ($\sum_{r=1}^{K} B_r\vec{x}_r$) decreased until it intersected the line which describes link bandwidth.

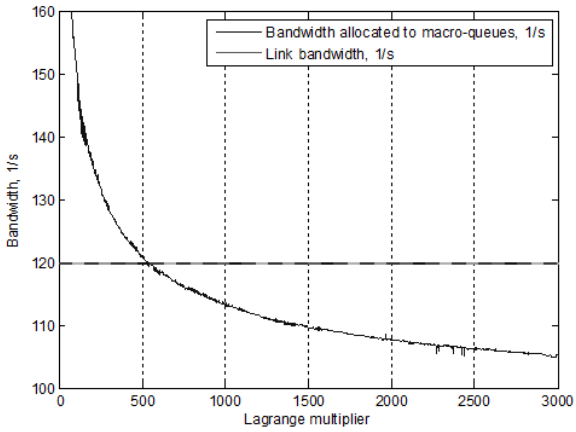


Fig.3. Convergence results of the proposed hierarchical model

Values of sum of bandwidth allocated to macro-queues lower link bandwidth satisfy (5). The figure shows that the value $\mu_r$ which satisfies the condition (5) should be in the range of 510 or higher (in this example). If we take $\mu_r$ at once large enough we will meet constraints, but will get high values of the average queue length, because the less bandwidth we will allocate to flow the more queue length we will get. Our task is to find vector multipliers $\mu_r$ at the intersection of curves (Fig. 3) so that fit into the constraints and fully use of available bandwidth, thus minimizing the average queue length

## III. Conclusion

This paper proposes a two-level hierarchical queuing model for queue management at telecommunication network nodes. The model is based on the goal coordination method, and queue management problem has been reduced to optimization task presented in the decomposition form. When solving the queue management problem this allowed to make this process more adequate (systemic), giving a higher quality of congestion control, adapting it to modern multiprocessor architecture of network nodes.

The proposed mathematical model suitable for solving resource allocation problems in distributed, multi-core, multi-processor, multi-module systems. Use of parallel processors for calculations on the first level of the hierarchy increased the speed of finding the optimal solution. Convergence study showed the need to find such a coordinating vector, which would provide the maximum bandwidth usage.

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