A Queue Management Model on the Network Routers Using Optimal Flows Aggregation

T.N. Lebedenko, A.V. Simonenko, Fouad Abdul Razzaq Arif

Abstract - **The paper presents the flow-based queue management model on telecommunication networks routers based on optimal flow aggregation and packets distribution in queues. The novelty of the model is that with flows distribution in queues it is carried out its aggregation based on flows and queues classes comparison within the analysis of the set of classification indicators.**

Keywords - **Telecommunication Network, Quality of Service, Model, Queue, Router, Traffic Rate, Overload, Flow Rate, Packets.**

I. Introduction

The development of modern telecommunication networks and technologies is submitted to one important goal – improving the quality of service (QoS) for users. The analysis [1-8] shows that the numerical values of the main parameters of Quality of Service (average delay, jitter, packet loss probability) is mainly determined by the effectiveness of solving problems of buffer resource management in telecommunication network (TCN), i.e., queues of packets organized on the routers interfaces.

Providing differentiated quality of service implemented on solving next interrelated problems [1-8]:

– packet classification and marking;
– creation and configuration of the queues system on the interface;
– distribution of packets on queues interface;
– determining the order queue servicing;
– allocation of the interface bandwidth between separate queues;
– preventive (prior) limiting of a queue length.

II. Queue Management Model on the Network Routers Using Optimal Flows Aggregation

The proposed work based on the results obtained in the works [1, 3]. In order to give an adequate description of the process let us suppose that router interface supports M flows with the following known characteristics:

Tatyana N. Lebedenko - Kharkov National University of Radio Electronics, Lenin Ave., 14, Kharkov, 61166, UKRAINE, E-mail: tatyana.n.lebedenko@gmail.com
Alexander V. Simonenko - Kharkov University of Air Force, Sumskaya St., 77/79, Kharkov, 61023, UKRAINE,
E-mail: 28186@mail.ru
Fouad Abdul Razzaq Arif - Al Iraqi University, Adamiya, Baghdad, IRAQ.
E-mail: fdshaikley@yahoo.com

a_i is the rate of the i-th flow that goes to the service router;

$K_i = \{k_i^l, l = \overline{1, L}\}$ is a set of parameters of the i-th flows that are used for network traffic classification within implemented transport technology in TCN, where L is the total number of parameters for traffic classification.

Based on the analysis of multiple parameters $\{k_i^l, l = \overline{1, L}\}$ suppose, that for each i-th flow is determined the class k_i^f, which is a function of the elements of the set K_i. In general, this function can be non-linear, for example, in [2] this dependence was in the form

$$k_i^f(p_i, d_i) = \frac{p_i}{\nu \cdot d_i}, \quad (i = \overline{1, M}), \tag{1}$$

where p_i and d_i are the values of the packet priority and packet length respectively for the i-th flow, ν is some normalization coefficient, that should smooth out the difference in order of priority values (0 ÷ 7) and the packet length in bytes.

In general, the value of k_i^f is dimensionless and we assume that k_i^f is normalized within the range of zero to one. The most important flow will have the class value is equal to one, i.e. $k_i^f = 1$. Than the class smaller the value of k_i^f will be closer to zero.

Suppose that received on the router interface packets should be allocated between N queues during Congestion Management solving problems when calculating the set variables of the second type $x_{i,j}$ $(i = \overline{1, M}, j = \overline{1, N})$. Each variable $x_{i,j}$ characterizes the part of i-th flow that serves by the j-th queue. For Resource Allocation solving problems it is necessary to calculate the set of variables b_j. Let b_j $(j = \overline{1, N})$ be a part of bandwidth of the outgoing transmission path which is allocated to the j-th queue of queues $(j = \overline{1, N})$. Suppose, that the number of flows is greater than the number of supported on the interface queues, i.e. obtain inequality

$$M > N. \quad (2)$$

By analogy with the flow (packages) classification, we assume that in the queue management system also established queue classes, as is done, for example, in the CBQ, CBWFQ and LLQ mechanisms. Then, each to the j-th queue deliver the class k_j^q $(j=\overline{1,N})$, which is similar to a flows class k_i^f also is a dimensionless quantity, varying between 0 (exclusive) to 1 (inclusive). In practice, the packets of the same flow are sent to the same queue, therefore, in accordance with the physical meaning of the solved problem the variable $x_{i,j}$ is Boolean:

$$x_{i,j} \in \{0,1\}. \quad (3)$$

Further limitations (3) on the control variables $x_{i,j}$, imposed the condition of flow conservation on the router interface:

$$\sum_{j=1}^{N} x_{i,j} = 1, \quad (i=\overline{1,M}). \quad (4)$$

Condition (4) ensures that all i-th flows packets will be directed to one of the queues, organized on the considered interface.

The variables b_j are positive real values, which also applied constraint system

$$0 < b_j, \quad (j=\overline{1,N}). \quad (5)$$

where b is the total interface bandwidth of outgoing transmission path defined by the type of used telecommunication technology. Compliance with conditions (5) defines the correct interface bandwidth distribution between the separate queues.

The constraint that prevent overloading the queue is the main feature of this model. Then it is necessary to satisfy the condition:

$$\sum_{i=1}^{M} a_i x_{i,j} < b_j, \quad (j=\overline{1,N}). \quad (6)$$

Thus, the total flows rate that are directed to the service in j-th queue, should not exceed bandwidth interface that is allocated for that queue.

The condition (6) is not sufficient to prevent a queue buffer overload along its length because the flows rate that arrive into one or another queue has random and non-stationary nature. So, for each j-th queue denote $\overline{n}_j$ and n_j^{max} $(j=\overline{1,N})$ its current length (in the packet) and the maximum capacity respectively [1,3-5]. Then the conditions of handling during congestion avoidance (6), supplemented by the conditions congestion avoidance queues along their length:

$$\overline{n}_j \le n_j^{max} \quad (j=\overline{1,N}), \quad (7)$$

where the value $\overline{n}_j$ depend on the statistical characteristics of the flow, the selected packets service discipline and from allocated interface bandwidth interface to that queue. Calculation expression variants for the evaluation $\overline{n}_j$ are shown in [4].

While developing and complementing the ideas of the Traffic Engineering Queues concept into the structure of the model, we introduce some several additional conditions that regulate the issues of providing balanced loading of queues

$$k_j^q \overline{n}_j \le \beta, \quad (j=\overline{1,N}), \quad (8)$$

where β is the upper dynamically controlled threshold of queue length. The physical meaning of the conditions (8) is that to a created on the interface queue were loaded in a balanced manner. Moreover, than the higher the queue class (k_j^q), the smaller length it should have.

Calculation of the control variables $x_{i,j}$, b_j и β will be provided in the course of solving the optimization problem associated with the minimization of the objective function of the form:

$$F = \sum_{i=1}^{M}\sum_{j=1}^{N} h_{i,j}^x x_{i,j} + \beta, \quad (9)$$

where $h_{i,j}^x$ is stated value (metric) of i-th flow packet services using a j-th queue. The physical meaning is that the calculation of the control variable should lead to minimizing the total cost of network resources using, where the first term is responsible for the procedure for the use of the queue buffer, and the second term is the interface bandwidth.

Eq. (9) corresponds to minimization of the upper limit of queue length on the router, weighted with respect to such characteristics of the flow as the length of the packet and its priority.

It is important to note that the criterion for the direction of one or another flow in a certain queue is the best match (commensurate) of their classes k_i^f and k_j^q.

Then, in the framework of improving the model (3) - (9) it is proposed that the metric calculated using the formula (10), which is responsible for the distribution of packet flows by queues and, when the condition (2) is done

$$h_{i,j}^x = w_x^b (k_i^f - k_i^q)^2 + 1, \quad (i=\overline{1,M}, j=\overline{1,N}). \quad (10)$$

Thus, the metric $h_{i,j}^x$ is a nonnegative quantity, and directly dependent on square of the distance between the classes of separate flows and queues. The option w_x^b allows adjust the final impact on the numerical value of the objective function (9) namely its first and second term. The proposed model with newly introduced formalisms (1), (2), (8) - (10) allows to provide an agreed problems solution by flows aggregation and distribution of the queues as well as the distribution of interface bandwidth between supporting queues. The novelty of this model lies in the flows distributions on the queues with flows aggregation. Moreover, the aggregation is performed by comparing the flows and queues classes.

III. Investigation of Proposed Queue Management Model

With the proposed model was performed the analysis of queue management on the router interface. Input data and results of investigation performed are shown in Table 1, where the number of flows is eight ($N = 8$) and the number of queues is five ($M = 5$), interface bandwidth is 100 1/s ($b = 100$) and w_x^b =100.

TABLE 1

INPUT DATA AND RESULTS OF INVESTIGATION FOR $N = 8$, $M = 5$ AND $b = 100$

Flow characteristics			Queue parameters
N	FC	a_f (1/s)	M
2	0,1206	4,9740	1
4	0,2262	18,4249	
7	0,2518	10,9513	
8	0,2904	2,0207	
1	0,4820	11,5705	2
5	0,3846	13,6922	
3	0,5895	15,4571	3
6	0,5830	6,4477	
-	-	-	4
-	-	-	5

Table 2 contains a detailed description of the queue parameters for the same input data.
For convenience of description, introduce some notation:

N is flow number; M is queue number; FC is flow class; QC is queue class; a_f is the average flow rate; a_q is the average flow rate in the queue; B is dedicated bandwidth; A/M queue length – Average / Maximum queue length.

TABLE 2

QUEUE PARAMETERS

FOR $N = 8$, $M = 5$ AND $b = 100$

M	QC	a_q (1/s)	B	A/M queue length
1	0,2500	36,3709	41,135	3,75/9
2	0,4375	25,2626	30,659	3,857/6
3	0,6250	21,9047	28,205	2,700/4
4	0,8125	0	0	0
5	1,0000	0	0	0

The average queue length is determined by the modeling of the interface by queuing system M/M/1 [2]. The upper dynamically controlled threshold of queue length is equal $\beta = 1{,}6875$. The flow aggregation was carried out in accordance with the similarity of their classes and a queue class, which they were sent.
Table 3 and Table 4 contains input data and results for sixteen flows, ten queues. Interface bandwidth is 100 1/s and for the upper dynamically controlled threshold of queue length is $\beta = 5{,}9735$. The average queue length modeling by the same queuing system.

TABLE 3

INPUT DATA AND RESULTS OF INVESTIGATION FOR $N = 16$, $M = 10$ AND $b = 100$

Flow characteristics			Queue parameters
N	FC	a_f (1/s)	M
3	0,1270	7,4269	1
6	0,0975	0,3348	
11	0,1576	6,9669	
16	0,1419	0,2984	
-	-	-	2
7	0,2785	7,9606	3
-	-	-	4
8	0,5469	8,7562	5
14	0,4854	1,6049	
5	0,6324	6,1476	6
-	-	-	7
1	0,8147	3,9540	8
15	0,8003	6,6192	
2	0,9058	8,5850	9
4	0,9134	8,9952	
9	0,9575	6,3631	10
10	0,9649	7,1038	
12	0,9706	3,6771	
13	0,9572	6,1451	

TABLE 4

QUEUE PARAMETERS

FOR $N=16$, $M=10$ AND $b=100$

M	QC	a_q (1/s)	B	A/M queue length
1	0,1111	15,0270	15,302	53,761/
2	0,2099	0	0	0
3	0,3086	7,9606	8,3526	19,354
4	0,4074	0	0	0
5	0,5062	10,361	11,175	11,801
6	0,6049	6,1476	6,7173	9,8746
7	0,7037	0	0	0
8	0,8025	10,573	11.842	7,4439
9	0,9012	17,580	19,921	6,6281
10	1,0000	23,289	26,691	5,9735

The analysis showed the usage of queue mathematical management model allowed using the minimum required number of queues. In both cases some of the queues won't used. It was happened because the queues didn't have the flows with respective classes. For data from Table 1 and Table 2 it was fourth and fifth queues. For data from Table 3 and Table 4 it was second, fourth and seventh queues.

IV. CONCLUSION

Thus, the given work proposes the mathematical queue management model based on optimal flow aggregation and packets distribution in queues on the routers of Next Generation Networks for ensuring maximum differentiation quality of service (DiffServ).

Flows aggregation process optimization depending on the ratio of the number of flows and queues as well as their classes allows to reduce the number of supported queues from 15-18% to 25-33% without reducing the level of quality of service differentiation of users flows, which helps to reduce the time for packets processing on the interface and minimization of the end-to-end packet delay within the network in a whole.

In addition, this model saved an important feature with respect to the implementation of the requirements of Traffic Engineering Queues concept, related to ensuring a balanced queues workload along their length. Using the proposed model allows to optimize the process of flow aggregation, distribution of packets in separate queues and allocation of interface throughput for queues, giving the solution a high level of consistency.

Minimizing the number of supported queues without compromising QoS leads to a proportional time reduction takes to packets processing on the router interface in a particular queue. Within the shown example it was possible to reduce the number of using queues by 40% for five queues and eight flows and by 30% for ten queues and sixteen flows respectively.

REFERENCES

[1] O. Lemeshko, M. Semenyaka, and O. Simonenko, “Researching and designing of the Dynamic adaptive queue balancing method on telecommunication network routers,” *XIIth International Conference The experience of designing and application of CAD systems in microelectronics*, pp. 204-207, February 2013 [Proceedings of XIIth CADSM`2013, Ukraine, p. 480, 2013].

[2] S. Álvarez, "QoS for IP/MPLS networks," *in Cisco Press*, 2006, pp. 299.

[3] O. Lemeshko, and M. Semenyaka, “Research of Queue Management Model That Includes Congestion Avoidance Mechanism,” First International IEEE Conference Problems of Infocommunications. Science and Technology, pp. 42-44, October 2014 [*Proceedings of PICS&T*-2014, Ukraine, p. 203, 2014].

[4] O. Lemeshko, A.S. Ali, and M. Semenyaka, “Results of the Dynamic Flow-Based Queue Balancing Model Research,” Modern Problems of Radio Engineering, Telecommunications and Computer Science, pp. 318-319, February 2012 [*Proceedings of the international Conference TCSET’2012*, Ukraine, p. 552, 2012].

[5] O. Lemeshko, and M. Semenyaka, “Researching of mathematical models based on optimal control approaches for congestion control in telecommunication network,” East-West Design & Test Symposium (EWDTS’2012), pp. 341-344, 2012 [*Proceedings of the international Conference EWDTS’2012*, Ukraine, p. 448, 2012].

[6] Y. Li, S. Panwar, and C.J. Liu, “On the Performance of MPLS TE Queues for QoS Routing,” *Simulation series*, vol. 36, part 3, pp. 170-174, 2004.

[7] V. Michopoulos, L. Guan, G. Oikonomou, and I. Phillips, “A Comparative Study of Congestion Control Algorithms in IPv6 Wireless Sensor Networks,” *International Conference on Distributed Computing in Sensor Systems and Workshops (DCOSS)*., pp. 1-6, 2011.

[8] A.P. Silva, S. Burleigh, C.M. Hirata, and K. Obraczka, “Congestion control in disruption-tolerant networks: a comparative study for interplanetary networking applications,” 9th ACM MobiCom workshop on Challenged networks (CHANTS'14), pp. P. 65-68., 2014 [*Proceedings of the 9th ACM MobiCom workshop on Challenged networks, 2014*].