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FLOW-BASED BALANCING SOLUTION OF TRAFFIC POLICING

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Abstract – *The paper proposes a flow-based model of load balancing with a consistent solution of traffic profiling tasks and multipath routing in conditions of network operation close to overloading. The mathematical model is represented by algebraic equations and inequalities of network condition: the conditions for implementing multipath routing, the equations of flow conservation, the conditions for preventing overloading of communication links and the network as a whole, as well as the conditions for balancing possible service failures on the network edge. The model describes a multi-flow case, which allowed simulating variants of simultaneous joint transmission of packets of several heterogeneous flows between different pairs of network routers. Using the proposed model, the load balancing problem was reduced to the solution of the optimization problem of linear programming. At the same time, the criterion was the minimum of the upper dynamically controlled failure threshold for all flows in the network as a whole. A number of numerical examples demonstrated the efficiency and adequacy of the proposed model and the effectiveness of the final solutions. The study of load balancing processes using the proposed model showed that the restriction of the intensity of flows at the network edge is adaptive: flows with greater intensity have been limited to a greater extent. It is their role in the emerging network overloading that was crucial. The development of the proposed approach is seen in the consideration of the case of differentiated flow restrictions on the network edge, taking into account their key parameters affecting the QoS level, for example, a priority and length of packets, IP and MAC addresses, TCP/UDP port numbers, etc.*

Анотація – *В роботі запропонована потокова модель балансування навантаження при узгодженому рішенні задач профілювання трафіка і багатошляхової маршрутизації в умовах функціонування мережі, близьких до перевантаження. Математична модель представлена алгебраїчними рівняннями і нерівностями стану мережі: умовами реалізації багатошляхової маршрутизації, рівняннями збереження потоку, умовами запобігання перевантаження каналів зв'язку та мережі в цілому, а також умовами балансування можливих відмов в обслуговуванні на кордоні мережі. Модель описує багатопотоковий випадок, що дозволило розглядати варіанти спільної передачі пакетів одночасно декількох різнорідних за своїми характеристиками потоків між різними парами маршрутизаторів мережі.*

Аннотация – *В работе предложена потоковая модель балансировки нагрузки при согласованном решении задач профилирования трафика и многопутевой маршрутизации в условиях функционирования сети, близких к перегрузке. Математическая модель представлена алгебраическими уравнениями и неравенствами состояния сети: условиями реализации многопутевой маршрутизации, уравнениями сохранения потока, условиями предотвращения перегрузки каналов связи и сети в целом, а также условиями балансировки возможных отказов в обслуживании на границе сети. Модель описывает многопотоковый случай, что позволило рассматривать варианты совместной передачи пакетов одновременно нескольких разнородных по своим характеристикам потоков между различными парами маршрутизаторов сети.*

Introduction

The main challenges in modern Telecommunication Networks (TCN) concern with providing Quality of Service (QoS) in conditions of network overload. TCN overload can significantly increase such parameters as packet delay, jitter and packet loss. The main reason of the transport TCN overload is not failures of reliable communication equipment, but

excessive load on the network. In this regard, it is special demands to traffic shaping arise that are responsible for regulation of the incoming packets rate to the transport network [1].

Performance of Traffic Shaping (TS) and Traffic Policing (TP) mechanisms are mainly determined by effectiveness of mathematical models and methods which they based on [2]. Currently used schemes in TS/TP like Token Bucket and Leaky Bucket are relevant to heuristic solutions which do not satisfy the demands in relation to differentiation of quality of service and consistent work with other traffic management mechanisms, for example, routing protocols, because of their main responsibility about serving the critical network load. Due to the streaming nature of modern network traffic the future models and methods of traffic shaping are tend to be flow-based [3-6].

In the field of streaming modeling there are known several approaches to combined mathematical description of multipath routing and traffic shaping processes [5, 6]. However the problem of traffic shaping for the case of overloaded network operation wasn't previously studied. In addition, it is important that the process of limiting the flow rate in traffic shaping must be of balanced (fair) manner, i.e. all flows shaped differentially in accordance with the concept of Traffic Engineering (TE) [7, 8]. Therefore, the actual scientific problem seems related to the development of mathematical models of multipath routing and balancing the flow of rejections in telecommunication network overload conditions.

I. Flow-based balancing solution of traffic policing

Within the study the model proposed in [5], [6] taken as a basis. In routing model the network structure is represented by weighted oriented graph $G = (V, E)$, where V is a set of vertices (routers), and E is a set of graph arcs (links). Every link $(i, j) \in E$ is weighted by the parameter $c_{i,j}$ characterizing the throughput of the modeling communication link. Let S_k and D_k be source and destination nodes of the k-th flow, and r^k (bps) be the k-th flow rate from the set K. Quantity $x_{i,j}^k$ is a control variable, which characterizes the part of k-th flow of the link $(i, j) \in E$. In accordance with the physics of the multipath routing problem being solved the following restrictions for the variables are needed:

$$0 \le x_{i,j}^k \le 1. \tag{1}$$

For the purpose of network nodes overload prevention it is necessary to meet the condition of flow conservation on the nodes (source, transit and destination) [5, 6]:

$$\begin{cases} \sum_{j:(i,j)\in E} x_{i,j}^k - \sum_{j:(j,i)\in E} x_{j,i}^k = 1 - y^k, \ i = S_k; \\ \sum_{j:(i,j)\in E} x_{i,j}^k - \sum_{j:(j,i)\in E} x_{j,i}^k = 0, \ \ i \ne S_k, D_k; \\ \sum_{j:(i,j)\in E} x_{i,j}^k - \sum_{j:(j,i)\in E} x_{j,i}^k = y^k - 1, \ i = D_k, \end{cases} \tag{2}$$

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where y^k is a control variable too, which characterizes the part of k-th flow denied of service on the edge router (S_k); S_k is a source node; D_k is a destination node.

There are also some constraints associated with rejection variables in relation to their physical meaning and implemented strategy of load balancing:

$$0 \le y^k \le \alpha, \tag{3}$$

$$0 \le \alpha \le 1, \tag{4}$$

where α is dynamically managed upper bound of rejections for all flows in a whole network.

Also, to prevent the communication links overload the next conditions must be met:

$$\sum_{k \in K} r_k \cdot x_{i,j}^k \le c_{i,j}, \quad (i,j) \in E. \tag{5}$$

With realization of single path routing flow conservation condition (2) converted to the form:

$$\begin{cases} \sum_{j:(i,j)\in E} x_{i,j}^k - \sum_{j:(j,i)\in E} x_{j,i}^k = 1, \ i = S_k; \\ \sum_{j:(i,j)\in E} x_{i,j}^k - \sum_{j:(j,i)\in E} x_{j,i}^k = 0, \ i \ne S_k, D_k; \\ \sum_{j:(i,j)\in E} x_{i,j}^k - \sum_{j:(j,i)\in E} x_{j,i}^k = 1, \ i = D_k, \end{cases}$$

while conditions of prevention communication links overload (5) substituted by system of nonlinear constraints:

$$\sum_{k \in K} (1 - y^k) \cdot r_k \cdot x_{i,j}^k \le c_{i,j}, \quad (i,j) \in E.$$

In solving the routing and policing problems it is reasonable to minimize the following objective function:

$$J = \alpha \to \mathbf{min}. \tag{6}$$

Using the criterion (6) provides balanced denials of service at the network edge for all user flows. Thus, within the proposed model (1)-(6) consistent solution of problems of multipath routing with traffic policing rejection balancing converged to solution of the linear programming optimization problem with optimality criterion (6) in the presence of constraints (1)-(5).

II. Research of traffic policing balancing

Within the investigation, consider an example of routing the two flows with varying rate, which make the network overload (Fig. 1). Suppose that a network structure consists of six nodes and eleven links. On a network links are given their throughputs (1/s) shown on a Fig. 1. The source of the first flow is first router, while fifth router is the source for the second flow. Destination of the packets of first and second flows is the third router.
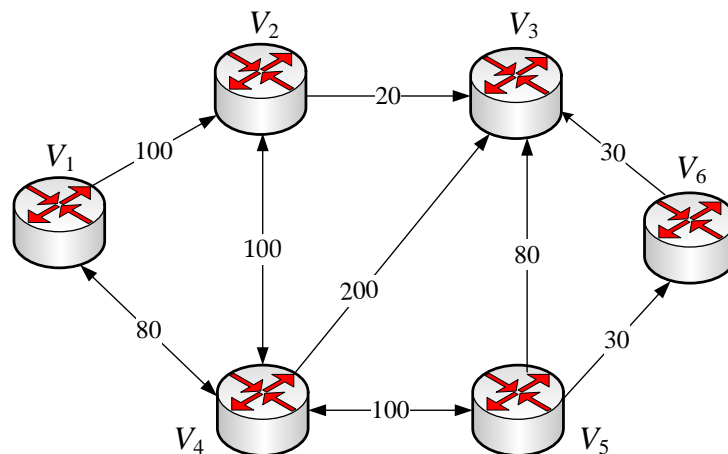

Fig. 1. Example of network structure

Fig. 2 shows an example of solving problem of multipath routing and balancing the flow of rejections in conditions of telecommunication network overload: rates of first and second flows are both 200 1/s. On communication links (Fig. 2) in the numerator of fraction is specified the first flow rate, and in the denominator the rate of the second flow.
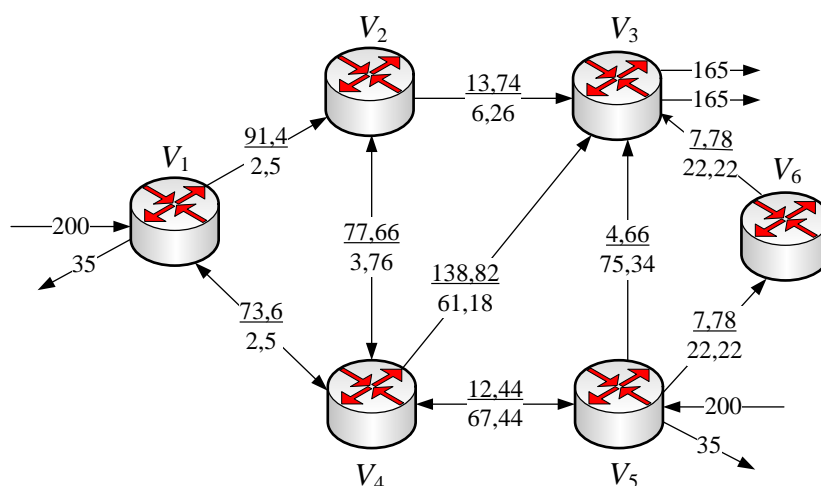

Fig. 2. Results of solving routing and policing problem with flow rates $r_1 = r_2 = 200$ 1/s

As a result of consistent solution of routing and rejections balancing problem both flows have been limited by the same rate of access equal to 35 1/s, while the destination node (third router) received packets with the rate of 165 1/s. In this case, the dynamically managed upper bound of rejections for these flows is equal to $\alpha = 0{,}175$.

In the case when flow rates are different, for example, $r_1 = 200$ 1/s and $r_2 = 150$ 1/s, the nature of rejections also changed (see Fig. 3). More rejections appeared in the first flow with higher rate, which mainly affected the occurrence of network overload. First flow packets received by a third router with rate of 180 1/s, and packets of the second flow received with rate of 138,45 1/s. Thus, in the second case, the dynamically managed upper bound of rejections for these flows is equal to $\alpha = 0{,}1$.
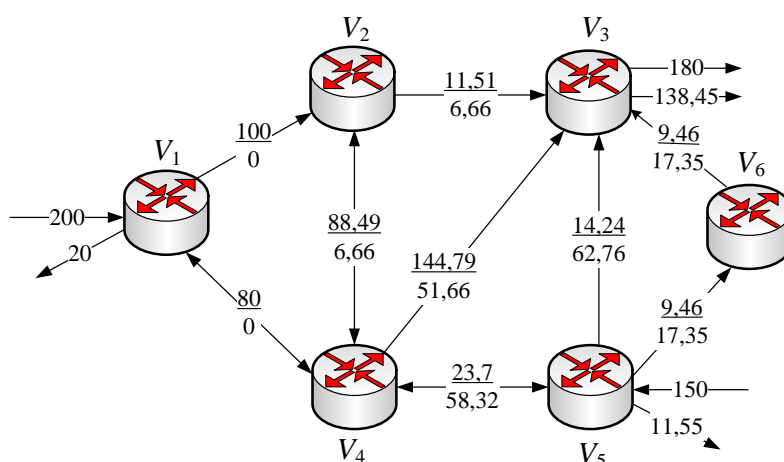

Fig. 3. Results of solving routing and policing problem with flow rates $r_1 = 200$ 1/s, $r_2 = 150$ 1/s

However, in both cases during flows routing network links were not overloaded. This result was achieved by adaptive limiting rates of each of the incoming flows.

Conclusions

To ensure the specified level of service quality with minimum use of available network resources should be possible a consistent solution of problems of traffic management, where the key problems are routing and traffic shaping. Routing defines the procedure for the distribution of flows within the network, while the traffic shaping is responsible for restriction of incoming flow rates at the network edge. Thus, the general function of these processes is to prevent network overload.

In the study proposed the flow-based model of multipath routing with traffic policing rejection balancing, which is represented by algebraic equations and inequalities of network state, such as conditions for implementation of multipath routing (1), flow conservation equations (2), conditions of overload prevention in communication links and a whole network (5), as well as balancing conditions of possible denials of service at the network edge (3), (4). The model describes a multiflow case, allowing simulation of concurrent transmission diverse by characteristics packet flows between different pairs of network routers.

Within the proposed model (1)-(6) consistent solution of problem of multipath routing with traffic policing rejection balancing converged to solution of optimization problem of linear programming with the optimality criterion (6) in the presence of constraints (1)-(5). Besides, as criterion was chosen the minimum of dynamically managed upper bound of rejections for all flows in a whole network. For solving the mentioned above linear programming problem can be used the following methods: simplex algorithm of Dantzig, criss-cross algorithm, ellipsoid algorithm, projective algorithm of Karmarkar, and path-following algorithms.

In the case of single path routing optimization problem associated with minimization of expression (6) belongs to the class of nonlinear programming due to the fact that prevention overload conditions will take the nonlinear character.

Numerical examples of multipath routing with traffic policing rejection balancing problem solving confirmed the adequacy and effectiveness of the proposed solution. Investigation of processes of multipath routing with traffic policing rejection balancing using the proposed model (1)-(6) showed that the flow rate restriction on the network edge has an adaptive nature: flows with higher rate limited to a greater extent, because of their responsibility on network overload.

Further development of proposed approach is seen in differentiated restriction of flows at the network edge based on their key parameters affecting the level of QoS, such as priority and packet length, IP and MAC-addresses, TCP/UDP-ports and others.

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