Traffic Type Influence
on Performance of OSPF QoS Routing

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Abstract—Feasibility studies with QoS routing proved that the network traffic type has influence on routing performance. In this work influence of self-similar traffic for network with DiffServ architecture and OSPF QoS routing has been verified. Analysis has been done for three traffic classes. Multiplexed On-Off model was used for self-similar traffic generation. Comparison of simulation results was presented using both relative and non-relative measures for three traffic classes. Results were commented and analyzed. The basic conclusion is that performance for streaming and best-effort class for self-similar traffic is higher than performance for the same class with exponential traffic (Poisson). The other important conclusion is relation between performance differences and offered traffic amount.

Keywords—DiffServ, exponential traffic, network performance, OSPF routing, packets networks, QoS, self-similar traffic.

1. Introduction

Modern telecommunication networks are using many different technologies. The most important technology and the most developed at the time are packet networks. Unfortunately existing packet networks don't guarantee quality. That is why modern convergent technologies are challenging for telecommunication operators. Quality of Service (QoS) guarantee is necessary. One of the basic examples of QoS ensuring solution is DiffServ architecture with QoS routing.

Studies in packet networks proved that traffic in packet networks have self-similar character [1]. Unfortunately until now studies of self-similar traffic were focused on single services device [2], [3], [4] or devices connected in a chain. There was no research for networks with many routers and DiffServ architecture in real network structure.

In this paper performance of networks with QoS routing and DiffServ architecture for different network structures with self-similar traffic was analyzed. Network performance with exponential offered traffic and self-similar offered traffic was compared. Results for exponential offered traffic for OSPF routing were captured from existing work [5]. Results for self-similar traffic were obtained in this study. The simulation model is based on model from [5].

The paper is organized into six sections. Section 2 describes routing algorithm and realization of DiffServ architecture. Section 3 describes two traffic types: exponential offered traffic and self-similar offered traffic. In this part self-similar offered traffic model used for simulation model

is described. Section 4 describes simulation model, its structure and features. Section 5 describes the simulation and presents the results. In this section also conclusions are presented and explained. Section 6 presents summary and description of next studies steps.

2. OSPF QoS Routing

The studied networks use OSPF routing algorithm and within this Dijkstra algorithm [6] to determine shortest route between source and destination router. This algorithm is sometimes called Shortest Path First (SPF). There are identical routes for all traffic classes in simulation model. Metric used for SPF algorithm implementation is metric from classical implementation of OSPF. This is product of constant number and inverse link capacity.

Simulation model fully implemented DiffServ architecture, where routers are divided into edge routers and core routers. Core routers handle and send packets with defined politics only. Edge routers define traffic class of packet and accept or discard traffic stream. Edge routers have also core routers functions. In this implementation of edge routers, decisions about acceptance or rejection of streams are based on actual network load. This algorithm is described in detail in [5].

Method of handling packets depends on the traffic class in DiffServ architecture. If edge router accepts packet, packet class is marked and information about it is saved in header. Next edge routers make decisions about traffic class and packet handling method on the basis of packet class information saved in header.

3. Traffic Type: Exponential
and Self-Similar

Exponential offered traffic is short range dependent (SRD). This traffic is easy to simulate.

Self-similar offered traffic is long range dependent (LRD). Between events in this traffic there are dependencies in short and long time scale. Hurst coefficient [7] represents level of this dependency. Range of Hurst coefficient value for network traffic is between 0.5 and 1. Network traffic with Hurst coefficient equal to 0.5 is SRD traffic, and an example of this traffic realization is exponential offered traffic. Network traffic with Hurst coefficient greater than 0.5 and less than 1 is self-similar traffic [7].

Multiplexed On-Off model was used for self-similar offered traffic modeling. This model is multiplexing many two state streams. In first state, called On, packets are generated with constant time interval. Packets aren't generated in second state, which is called Off. On state time is determined through Pareto distribution, Off state time is determined through exponential distribution. This model is described in detail in [8].

4. Simulation Model

Simulation model is based on the model described in detail in [5]. It allows verifying performance of the networks with different QoS routing algorithm and different offered traffic types. Model was implemented using discrete event network simulator called Omnet++ [9]. The implementation has been provided using standard STL C++ libraries and functions. This model fully implements DiffServ architecture. As an addition to the model from work [5] self-similar offered traffic generator has been added. This self-similar traffic generator is implemented using the multiplexed On-Off streams.

Model consists of three basic network components: edge routers, core routers and central module. The central module component is used for data storage. It is combined with all network routers via virtual connections which are used for routing tables transfer. The global object shares also the interface which can be used for communication between the object and edge/core routers. The object stores also information about the network topology and all Link State Protocol information. Edge and core routers deliver the functions specified according to the DiffServ architecture. Both routers service systems are the same and specified by the DiffServ architecture. Service systems consist of two queuing policies Priority Queuing (PQ) and Weighted Fair Queuing (WFQ). Streaming traffic is attached to first queue of PQ and contains very short buffer just for few packets (REM model). This particular buffer should be no longer than 5 packets. Two other traffic classes (elastic, best effort) are directed to WFQ with ω_{AF} and ω_{BE} weight parameters respectively. The output from WFQ is directed to second input of PQ without additional buffering. Buffers length for elastic traffic should be not too long due to QoS constraint given to this class [10]. Best effort buffer is not set to a large value to omit resources waist. Packets are generated independently in edge router for all three traffic classes. The single generator of traffic class generated packets to all possible edge routers (all relations). Each generator is described by the time periods distribution between next generated packets, like uniform, exponential, Pareto, etc. Edge routers are at the same time traffic receivers. Hurst coefficient of self-similar traffic for three traffic classes can set independently in this model. Each edge router is connected with only one core router. The capacity of links connecting edge and core router is much larger than the capacity of links in the core (not to cause bottleneck here). The core router is similar to the edge router with the difference that it does not include the traf-

fic generator block and traffic receiver block. Core routers do not generate packet but just process the packets and forward them to the output links according to the routing tables.

AC function to keeps QoS in this model is realized through acceptance or rejection stream in edge router. These operations are needed because of the required QoS and limit packets in network. First packet in each stream is initial packet. If edge router receives it, router calculate path for stream first based on SPF algorithm. In next step router verifies QoS parameters: delay (IPTD – IP Time Delay), delay variation (IPDV – IP Delay Variation), loss ratio (IPLR – IP Loss Ratio). These parameters are verified for end-to-end link based on the current network state for streaming class. In terms of capacity there is a check for all intermediate links in the path if all of them include the required bandwidth amount. The QoS parameters values are taken from [10]. If verified path meets above values then stream is accepted, and path is saved in route table and next in packet headers, else stream is rejected. Saving this information in header is needed for simulation process.

5. Results of Studies

5.1. Simulation Parameters and Scenarios

Simulation model has been applied for three structures with different connections density. The structures are Sun, NewYork and Norway [11]. Connections density is defined as number of links between routers divided by number of routers. NewYork structure is network with maximum connections density equal 3.06. Sun structure is network with least connections density equal 1.5. Connections density of Norway structure is between Sun and NewYork and is equal 1.89. In this paper results for Sun, Norway and NewYork are presented.

For each structure the simulation has been done with forty different traffic classes proportions. For each ten proportion: level of best-effort traffic class is constant (1–10, 11–20, 21–30 and 31–40), level of streaming traffic class is increase and level of elastic traffic class is decrease. These proportions are presented in Table 1. For example, for first proportion: 1% offered traffics are stream traffic, 19% traffics are elastic traffic and 80% traffics are best-effort traffic. The length packet for each traffic class is constant and for streaming traffic class is equal 160 bytes, for elastic traffic class is equal 500 bytes and for best-effort traffic class is equal 1500 bytes.

Buffer length for streaming traffic class is equal 5 packets (REM model), for elastic traffic is equal 10 packets, for best-effort traffic class is equal 50 packets. Input weight for handling of elastic class in WFQ is set to 0.4 and input weight of best effort class is set to 0.6.

The simulation time was set to 3600 s. For each traffic class proportion and each structure the simulations has been repeated six times, with exception Sun structure. For this structure simulation was done twelve times. These number of repetitions is required to get appropriate confidence intervals.

Table 1
Proportions of traffic

No. of proportion	Stream traffic	Elastic traffic	Best-effort traffic
1	0.01	0.19	
2	0.03	0.17	
3	0.05	0.15	
4	0.07	0.13	
5	0.09	0.11	0.8
6	0.11	0.09	
7	0.12	0.08	
8	0.13	0.07	
9	0.14	0.06	
10	0.15	0.05	
11	0.02	0.28	
12	0.06	0.24	
13	0.1	0.2	
14	0.12	0.18	
15	0.14	0.16	
16	0.16	0.14	0.7
17	0.18	0.12	
18	0.2	0.1	
19	0.24	0.06	
20	0.28	0.02	
21	0.05	0.35	
22	0.08	0.32	
23	0.12	0.28	
24	0.14	0.26	
25	0.18	0.22	
26	0.24	0.16	0.6
27	0.28	0.12	
28	0.32	0.08	
29	0.34	0.06	
30	0.35	0.05	
31	0.1	0.4	
32	0.13	0.37	
33	0.16	0.34	
34	0.18	0.32	
35	0.2	0.3	0.5
36	0.24	0.26	
37	0.28	0.22	
38	0.32	0.18	
39	0.38	0.12	
40	0.4	0.1	

The result of simulation is network performance for each structure and for each traffic proportion. The performance is the number of packet processed by network.

Hurst coefficient for stream, elastic and best effort is 0.9. This value is results of study technical publications on self-similar traffic. Analyze of the Hurst coefficient of stream traffic, VoIP traffic, is in the work [12]. The Hurst coefficient of elastic traffic, MPEG traffic, is presented in [13]. Study of the Hurst coefficient of best effort traffic is shown in [1].

5.2. Relative and Non Relative Measure

The simulation results are presented using two measures: non relative and relative. Non relative measure described amount of serviced packets in network for each traffic class. This amount in one network structure, for each proportion, for one traffic class shows in one figure. The relative measure is described by parameter

$$A_{rel} = \frac{A_{SS} - A_{exp}}{A_{exp}}. \qquad (1)$$

In Eq. (1) A_{exp} is the mean amount services packet for exponential offered traffic for each traffic class for one structure, A_{SS} is the mean amount packet for self-similar offered traffic for each traffic class, for one structure. This measure can show relative differences between performance network with self-similar offered traffic and network with exponential offered traffic. Values of this measure, for one network structure, for each traffic class proportion, for one traffic class or combination of traffic class are presented in one figure.

5.3. Results

In Figs. 1–10 are presented results for Sun structure. In first five diagrams are presented results in non-relative measure. Next five presents results in relative measure. In Figs. 11–20 are presented results for Norway structure, and in Figs. 21–30 results for New York structure was shown in the same layout as for Sun structures.

First, results in non-relative measure are described. In Figs. 1–5 are presented results in amount packet serviced over network for traffic class: streaming, elastic, best-effort, aggregate streaming and elastic traffic and aggregate all traffic for Sun structure. For most traffic proportions for streaming, elastic and best-effort traffic confidence intervals of network performance for exponential offered traffic and self-similarity offered traffic are separable. Only for several proportions for elastic traffic confidence intervals overlap. For aggregate measures is similar, for the most traffic proportions the confidence intervals are separable.

For New York structure non-relative measures are presented in Figs. 21–25. For this structure, just as Sun one the most confidence intervals are separable. Only for elastic traffic almost all confidence intervals are overlap. The same results are for Norway structures, for which results presented in Figs. 11–15, only for elastic traffic almost all confidence intervals are overlap.

All other results based on relative measures. For Sun structures these results presented in Figs. 6–10, for New York in Figs. 26–30 and for Norway in Figs. 16–20.

First the results for Sun structures for streaming, elastic and best-effort traffic are described. Results for aggregate traffic are described as the second ones in this paper. For self-similar offered traffic performance is higher about 30% comparing to exponential offered traffic for the stream traffic class. For elastic traffic class confidence intervals are overlap and comparing results is impossible. For best-effort traffic class, performance for self-similar offered
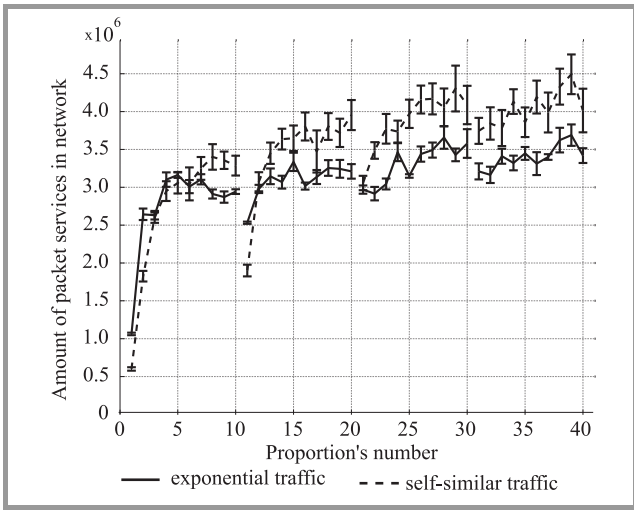
Fig. 1. Streaming class packet services for Sun network structure with exponential and self-similar offered traffic.
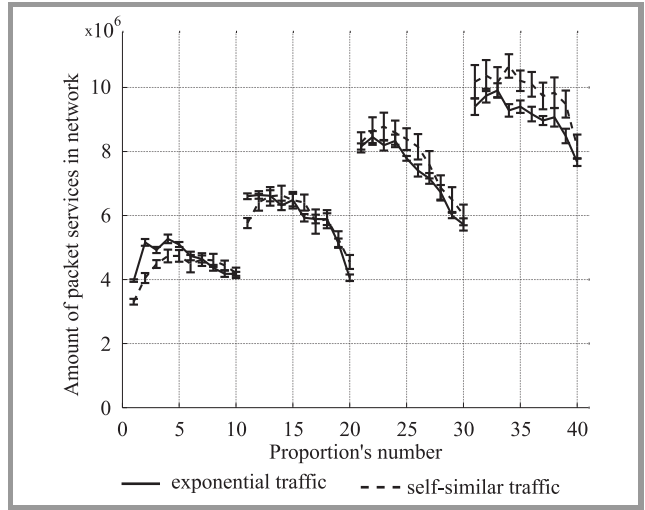

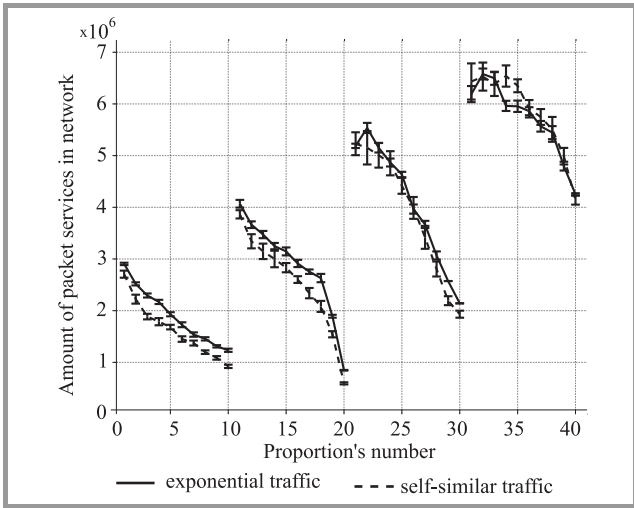**Fig. 2.** Elastic class packet services for Sun network structure with exponential and self-similar offered traffic.
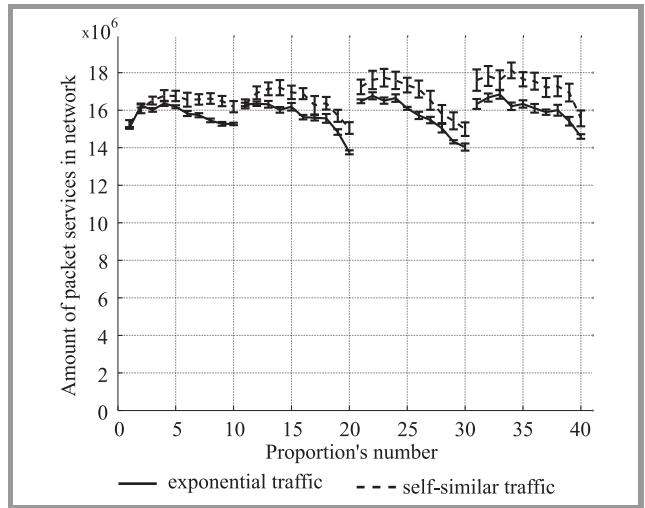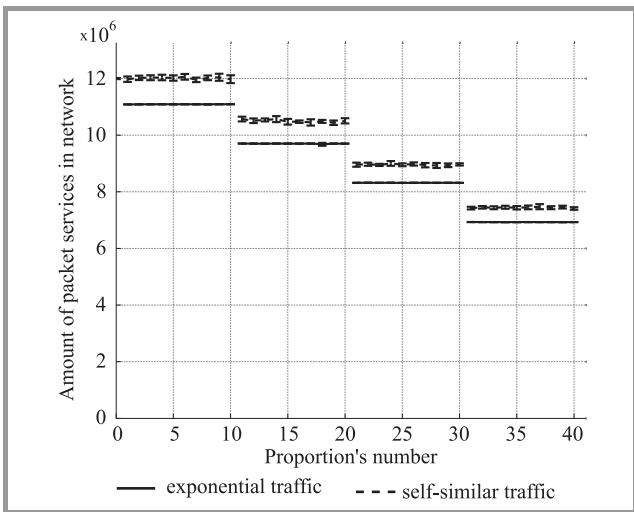

Fig. 3. Best-effort class packet services for Sun network structure with exponential and self-similar offered traffic.
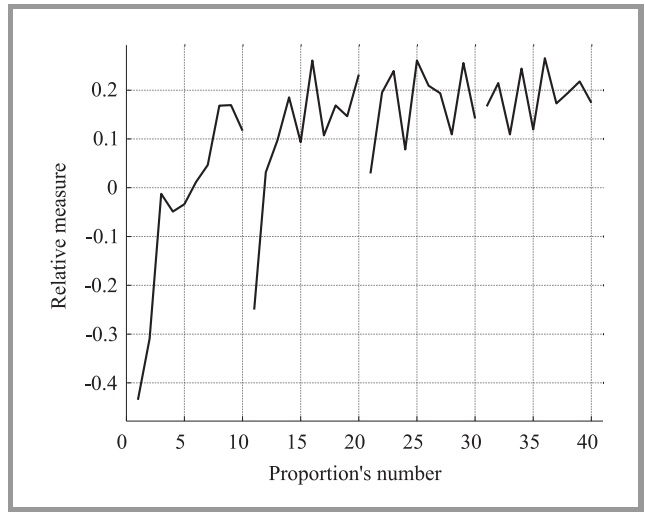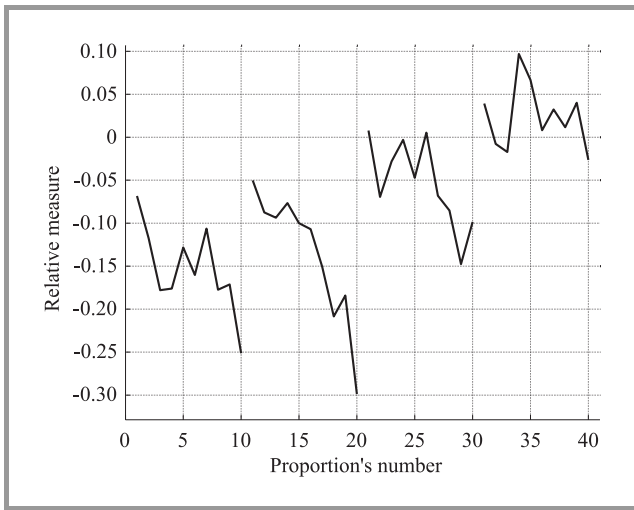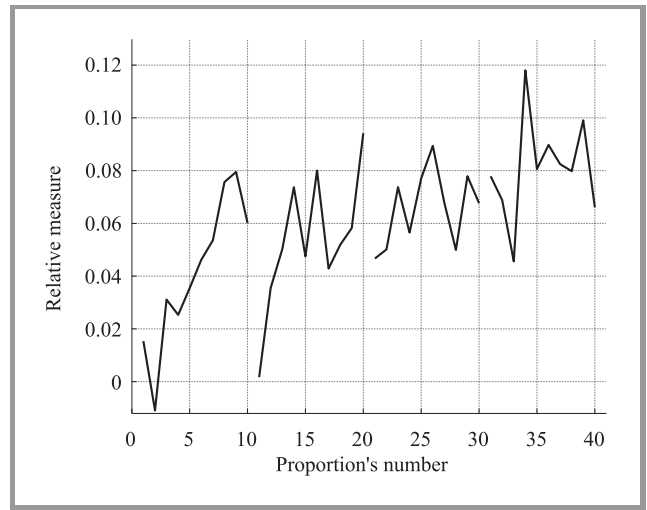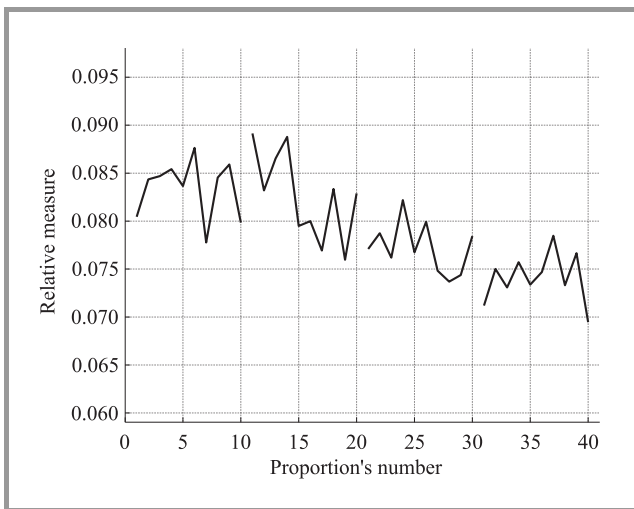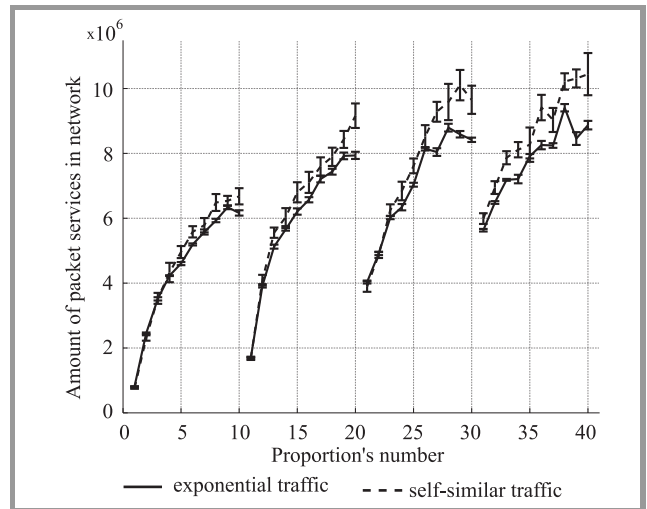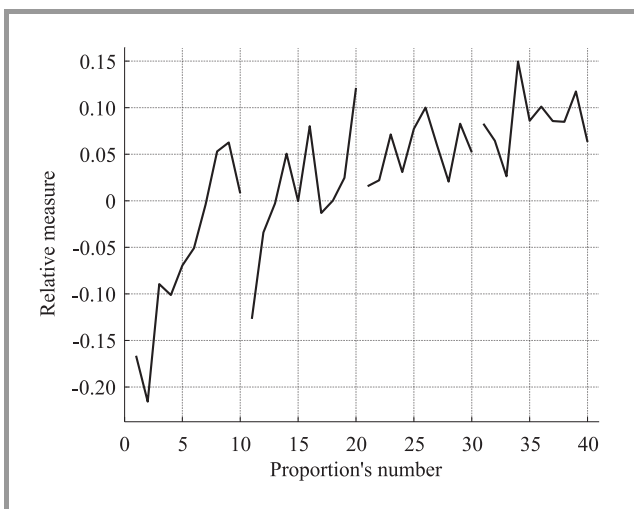

Fig. 4. Streaming and elastic class packet services for Sun network structure with exponential and self-similar offered traffic.
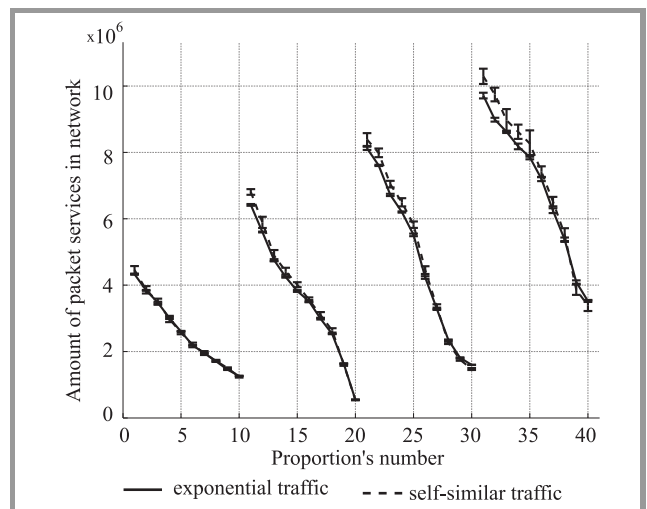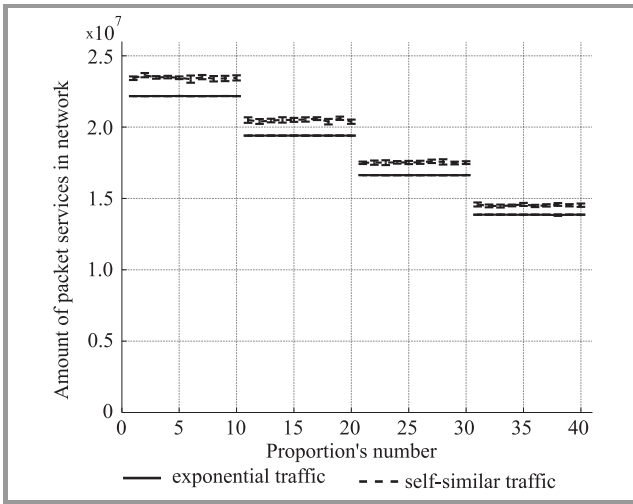

Fig. 5. All packet services for Sun network structure with exponential and self-similar offered traffic.

Fig. 6. Streaming class packet services for Sun network structure with exponential and self-similar offered traffic.

Fig. 7. Elastic class packet services for Sun network structure with exponential and self-similar offered traffic.

Fig. 8. Best-effort class packet services for Sun network structure with exponential and self-similar offered traffic.
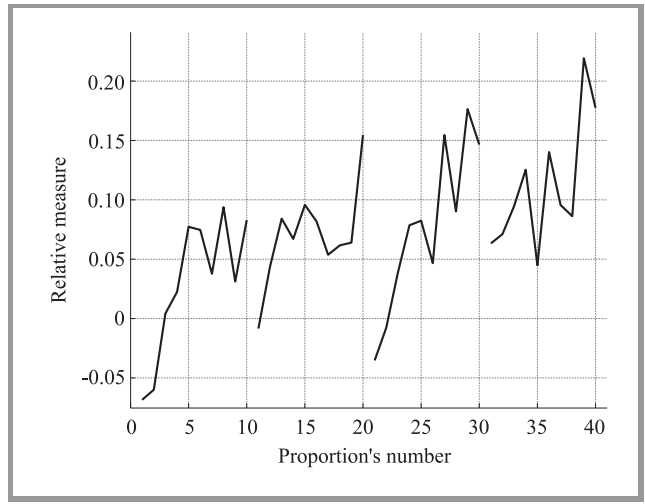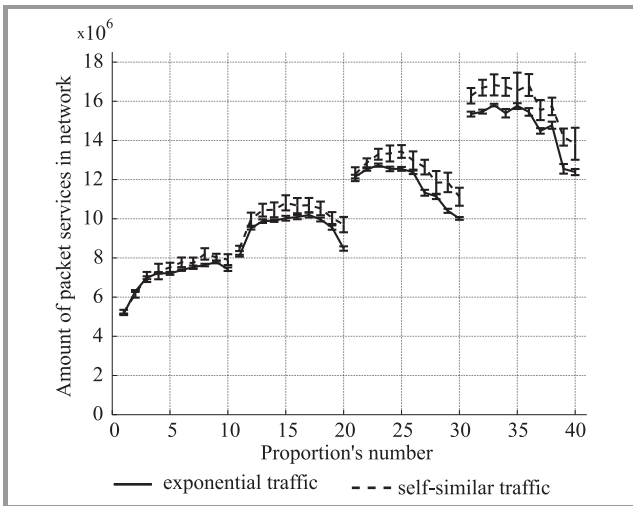

Fig. 9. Streaming and elastic class packet services for Sun network structure with exponential and self-similar offered traffic.

Fig. 10. All packet services for Sun network structure with exponential and self-similar offered traffic.

Fig. 11. Streaming class packet services for Norway network structure with exponential and self-similar offered traffic.
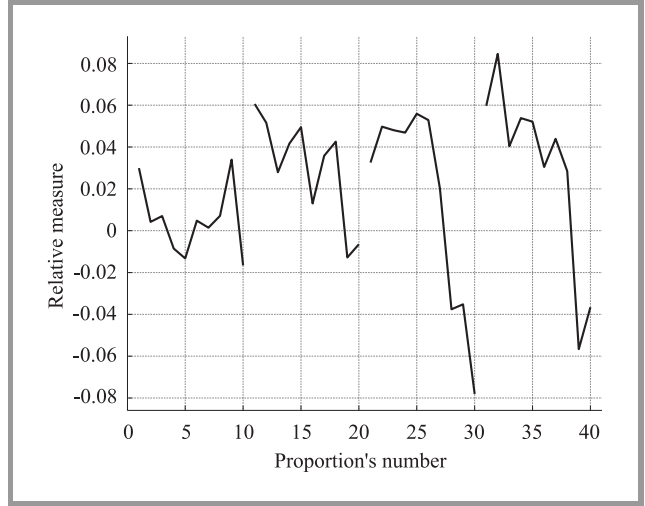

Fig. 12. Elastic class packet services for Norway network structure with exponential and self-similar offered traffic.
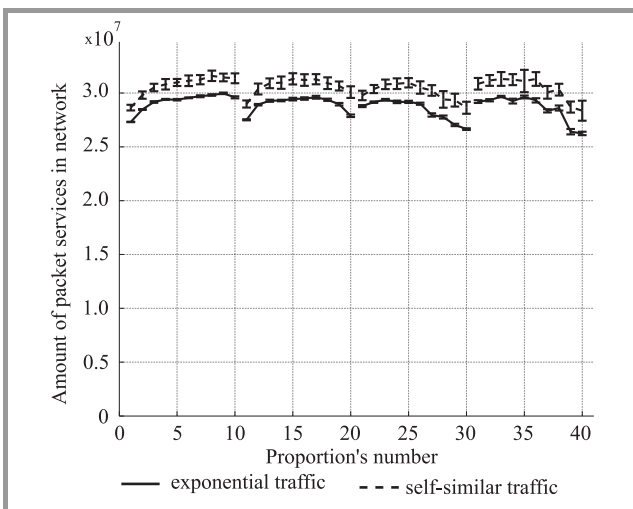
Fig. 13. Best-effort class packet services for Norway network structure with exponential and self-similar offered traffic.

Fig. 14. Streaming and elastic class packet services for Norway network structure with exponential and self-similar offered traffic.

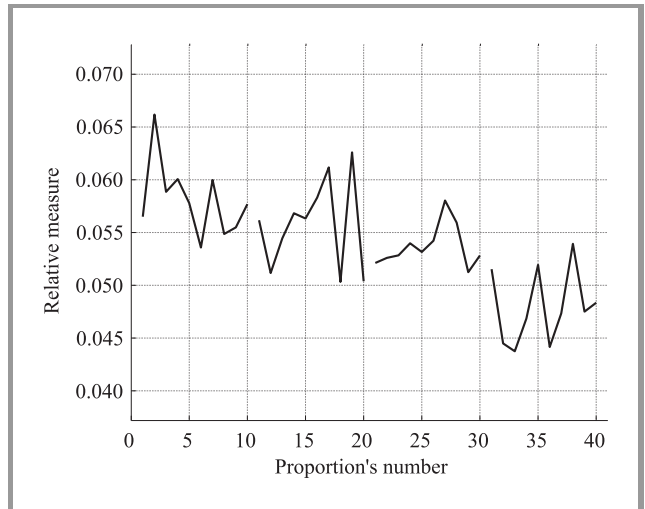**Fig. 15.** All packet services for Norway network structure with exponential and self-similar offered traffic.

Fig. 16. Streaming class packet services for Norway network structure with exponential and self-similar offered traffic.

Fig. 17. Elastic class packet services for Norway network structure with exponential and self-similar offered traffic.

Fig. 18. Best-effort class packet services for Norway network structure with exponential and self-similar offered traffic.
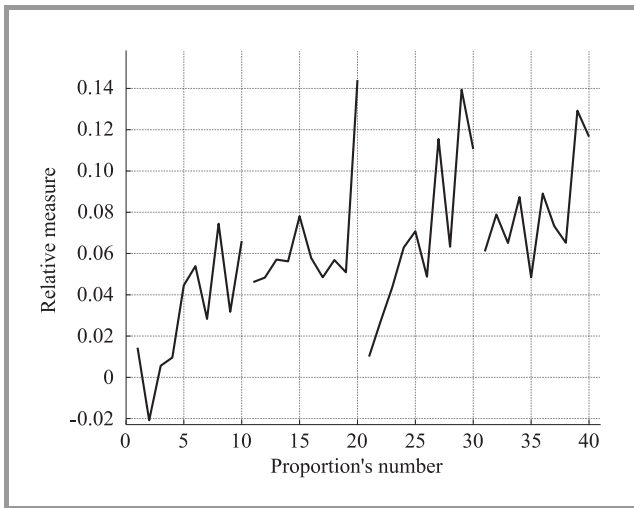
Fig. 19. Streaming and elastic class packet services for Norway network structure with exponential and self-similar offered traffic.
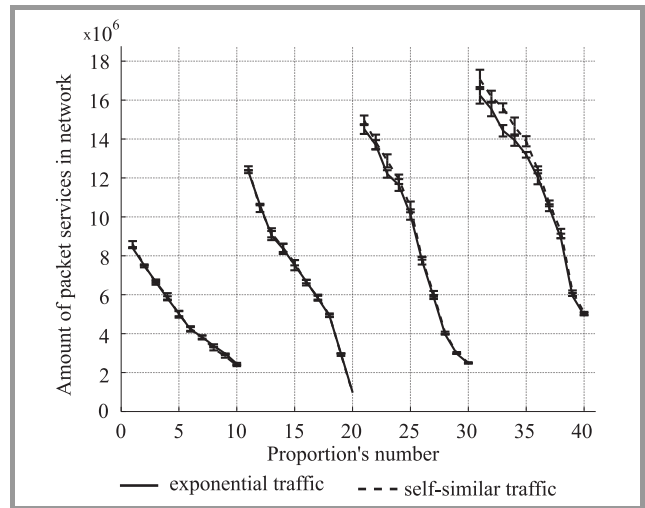

Fig. 20. All packet services for Norway network structure with exponential and self-similar offered traffic.

Fig. 21. Streaming class packet services for New York network structure with exponential and self-similar offered traffic.

Fig. 22. Elastic class packet services for New York network structure with exponential and self-similar offered traffic.
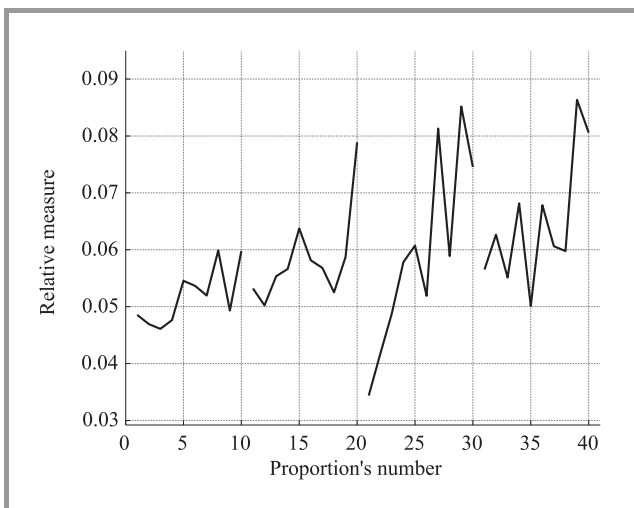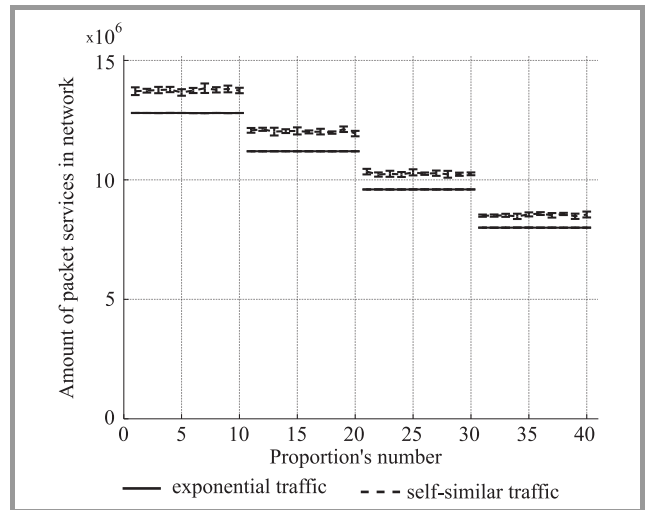

Fig. 23. Best-effort class packet services for New York network structure with exponential and self-similar offered traffic.
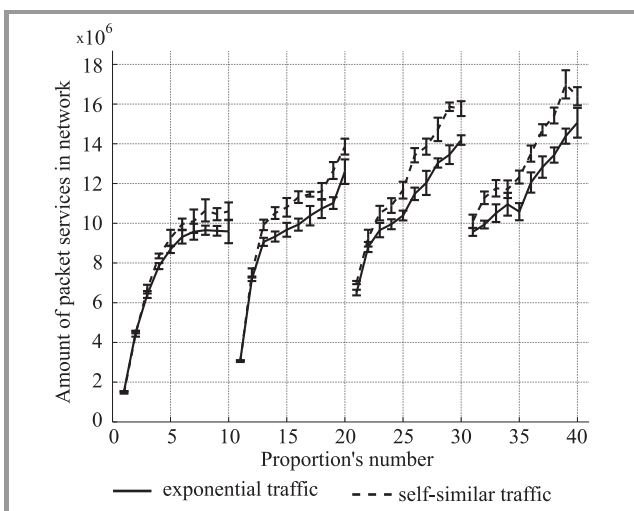

Fig. 24. Streaming and elastic class packet services for New York network structure with exponential and self-similar offered traffic.

Fig. 25. All packet services for NewYork network structure with exponential and self-similar offered traffic.

Fig. 26. Streaming class packet services for NewYork network structure with exponential and self-similar offered traffic.
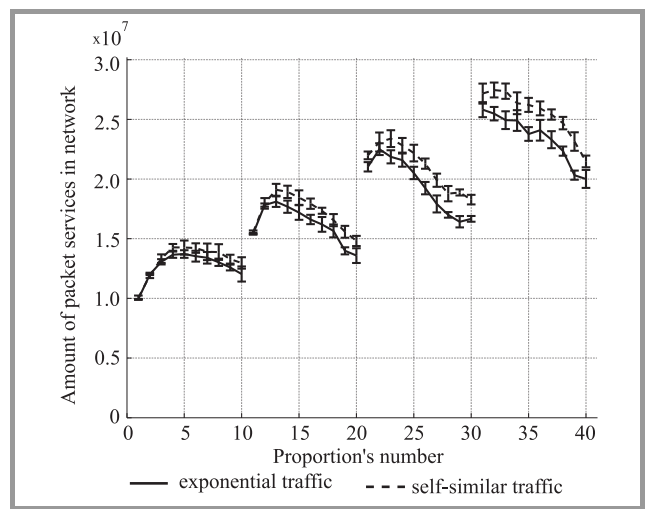

Fig. 27. Elastic class packet services for NewYork network structure with exponential and self-similar offered traffic.

Fig. 28. Best-effort class packet services for NewYork network structure with exponential and self-similar offered traffic.

Fig. 29. Streaming and elastic class packet services for NewYork network structure with exponential and self-similar offered traffic.
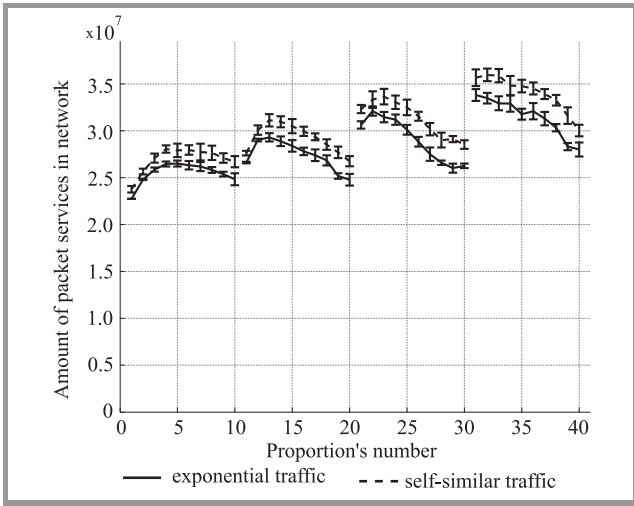

Fig. 30. All packet services for NewYork network structure with exponential and self-similar offered traffic.
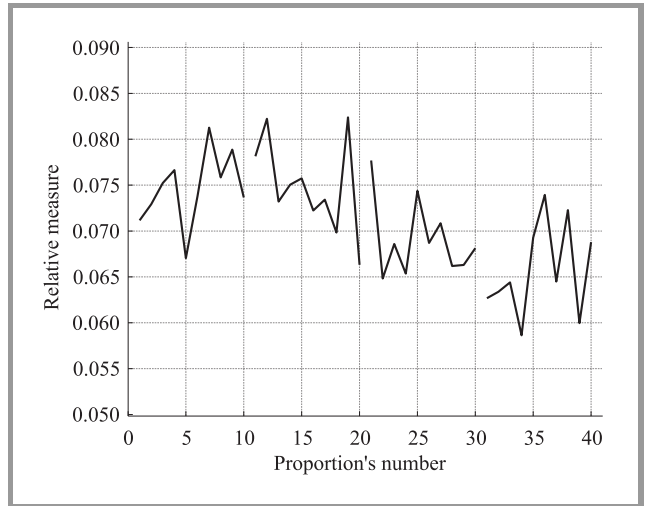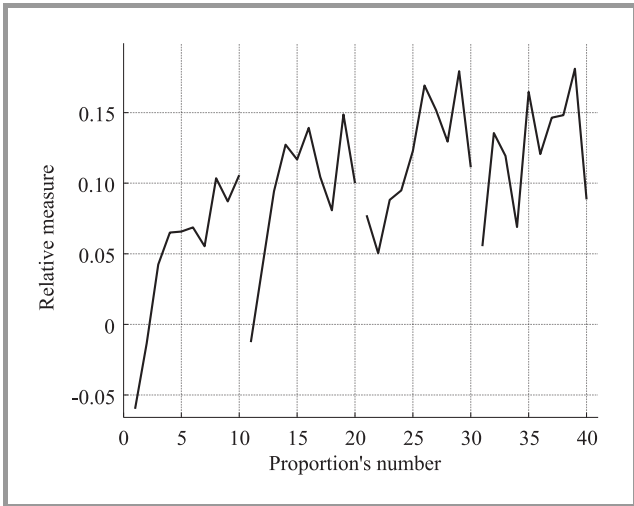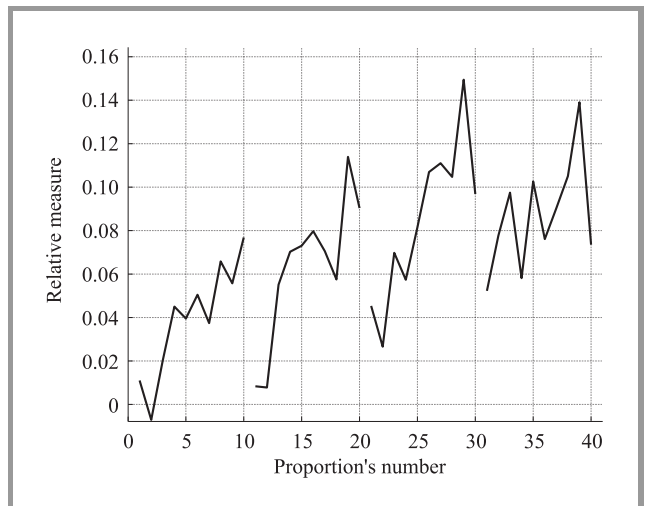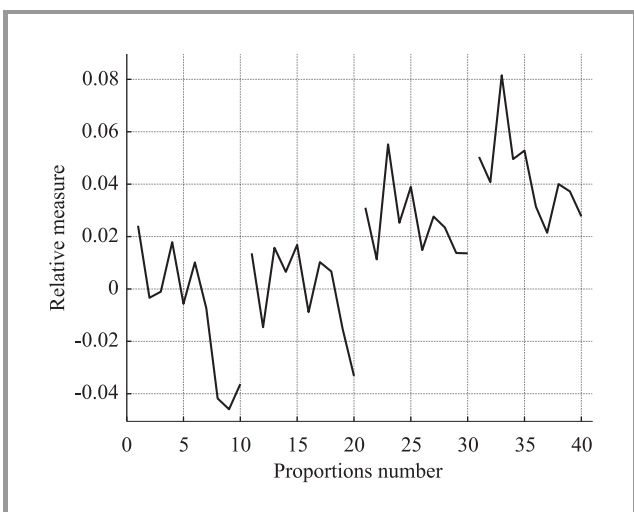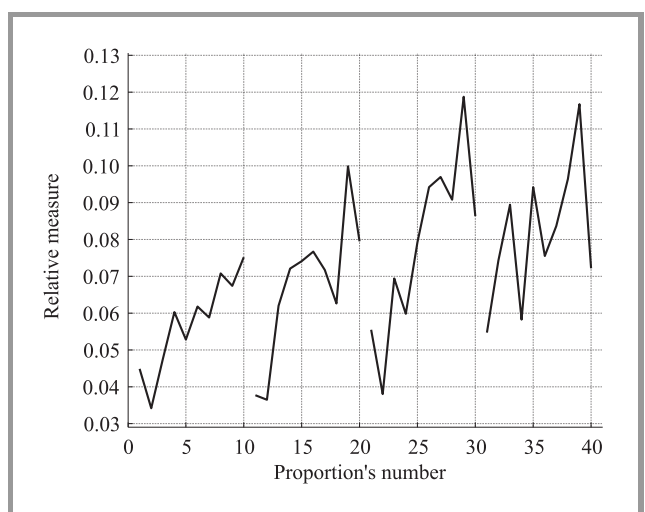
traffic is higher about 7% in comparison to exponential offered traffic.

The same conclusions are for Norway and NewYork structures. Results for Norway structure for traffic class: streaming, elastic and best-effort, aggregate streaming and elastic and aggregate all traffic are presented in Figs. 11–15. Results for NewYork structure for traffic class: streaming, elastic and best-effort, aggregate streaming and elastic and aggregate all traffic are presented in Figs. 21–25. Major difference between results for NewYork or Norway and Sun structure is performance growth in percentage for streaming traffic class. Maximum performance is 22% higher for Norway structure and maximum growth performance is 18% for NewYork one. Result of this analysis is the proposal – difference of performance for streaming traffic class depends on connections density. If density grows then the network performance difference is lower. This statement is confirmed in relative measure. Similar results are for best-effort traffic class, but difference is less, and it is more visible in relative measure.

Now the results for aggregate traffic will be described. For NewYork and Norway structure with aggregate streaming and elastic traffic, more traffic is serviced by network with self-similar offered traffic than by network with exponential offered traffic. Maximum performance growth between network with self-similar traffic and network with exponential traffic is equal to 15% for NewYork structure and 14% for Norway structure. For Sun, which is the smallest one for some proportions there is lower network performance for self-similarity traffic than for exponential.

The results for aggregated traffic for all proportions, for all structures prove higher network performance for network with self-similar traffic than network with exponential one. Other kind of analysis is trend analysis of relative measure. Result of this analysis show impact of amount of offered traffic and the traffic character for network performance. Results for Sun structure are presented first. Difference of performance between network with self-similar offered traffic and network with exponential one, for streaming traffic class is higher while using higher offered traffic. The same results are for best-effort traffic class. The performance difference for elastic traffic class requires additional comment. If there is a visible gain on performance difference between network with self-similar offered traffic and network with exponential offered traffic, it is higher with growth amount elastic traffic class. In case of lower performance difference between networks with self-similar offered traffic and network with exponential offered traffic, this is decrease with decrease amount elastic traffic class. Equivalent conclusions are for Norway and NewYork structures and results for these structures are presented in Figs. 26–30 and Figs. 16–20.

Important result is trend analysis of relative measure for aggregate traffic and at the same time analysis of non-relative measures for streaming traffic. Larger amount of serviced packet for streaming traffic caused also gain within relative measure for aggregated traffic. Next conclusion is – if offered traffic had a self-similar character more traf-

fic was serviced with increasing streaming offered traffic than for exponential character of offered traffic. A similar conclusion is for aggregated streaming and elastic traffic. Network can service more streaming and elastic traffic of self-similar traffic type than exponential traffic type with increasing streaming traffic amount in the network.

6. Summary

The main conclusion is that higher network performance was noticed for streaming and best effort traffic class for self-similar offered traffic type than for exponential offered traffic type. Important is also higher network performance for aggregate traffic for self-similar traffic type. Difference of performance for elastic and best-effort traffic class depends on connections density. If network density is growing the difference on network performance lowers. Other conclusion is the relation between different performance gain and increase of the offered traffic, but this relation is complex and may depend on buffers length and connection density. To fully confirm this thesis further research is required.

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