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Research and development of effective managing algorithms in admission control systems for telecommunication networks

Summary of the doctoral thesis

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CONFIRMATION

I confirm that the work contained in the Dissertation submitted by me to Riga Technical University for the Doctor's Degree in Engineering is my own original work and has not previously been submitted by me for a degree at this or any other University.

Mihails Kulikovs ....(Signature)

Date: ....

The promotion work is written in English, contains introduction, 6 chapters, conclusions, references, 112 figures, 200 pages in total. A list of references consists of 175 publication titles.

Abstract

The main purpose of the present research is the development of managing algorithms in the control system that admits data flows to communication resources, thus providing the required quality of service.

The algorithms covered in the study are admission control and flows redistribution, the algorithms of resources redistribution and maximization of system load that lead to fulfillment of quality of service requirements.

The research resulted into elaboration of recommendations regarding optimization of admission control system functioning. In order to test the recommendations an OPNET modeling system has been applied.

General description

Theme relevance: The research relevance and applicability is supported by current situation of resources. They argue [69] that by 2011 the necessity for resources will dramatically outreach the volume of existing global network. These predictions have been presented by Nemerset Research laboratory. The current work aims for the development of algorithms and programs of effective usage of network resources.he current work aims for the development of algorithms and programs of effective usage of network resources.

The objective: The main task of the present study is the elaboration of effective methods to manage data flows and distribute the resources in the systems controlling the admission of flows into the network. Effectivity is reached by optimizing the usage of the communication system resources such as buffer size and throughput of a connection channel. The most effective usage of resources happens when optimization tasks needed for the calculation of buffer size/throughput ratio are solved. At the same time Quality of Service (QoS) requirements has to be fulfilled and the system costs are at its' minimum.

Research method: Theoretical estimations are used to realize the objective. Analytical and digital models have been elaborated and form a base for optimization tasks solutions. Theoretical calculations get proved by results gained in the course of simulation experiments. For the experiments an Measurement-Based Admission Control (MBAC) model has been created in OPNET Simulation Framework.

Results and scientific novelty: The managements of the flows is executed in real time mode. Therefore, the optimization procedure ought to produce the solutions as quick as possible. It can be realized only by analytical model that describes a commuting nod. The author is unaware of any analytical model which can be used for the description of the commuting nod with self-similar character of the incoming traffic which actually prevails in modern networks. The investigation has showed a commutation system with a specified incoming flow can be successfully replaced by the model with group incoming data flow where the number of packets in the group is set by the coefficient of geometrical distribution.

Using analytical solution the author has developed the algorithm that makes possible the estimation of the optimal ratio of the communication system buffer size and the throughput of the output channel at the stage of elaboration taking into account the specified requirements for packet loss probability and a known ceiling of incoming flow intensity. It has been shown that the elaborated algorithm can be applied for flows management at the time of admission control system functioning in real time mode.

The author has proved the results that earlier has been shown in several publications. They argued that measurement based admission control is more efficient than the system solely based on previously declared parameters. The absence of recommendations regarding the measurement procedure made the author to develop them so it would be possible to choose the window length of the measurements and frequency measurements in traffic of self-similar character. The generated recommendations can be applied for traffic measurements of the previously adjusted connections and the newly admitted ones.

It goes without saying that before confirmation for the incoming flow connection the capacity of system load has to be detected. It includes evaluation of the parameters of previously adjusted connections. In MBAC system it can be implemented on the basis of previously adjusted connections parameter measurements. Having assessed the information gained during the measurements, the author has discovered the optimal size of the sample.

The research paper shows that the sample size can vary in a wide range without affecting the accuracy of traffic parameters estimation.

Admission control algorithm based on the probability of packet loss is in the focus of this research. The loss probability is estimated taking into account the parameter if traffic self-similarity (H). In order to fasten the pace of the decision making about admission to the system, the previously estimated table data have been suggested for use. Parameters γ and H can be compared using the queuing models of group and self-similar traffic without restricting the buffer size. H parameter reflects traffic self-similarity more accurately than the group traffic parameter γ. Thus, the author suggested t using the analytical group model at the stage of system design. Admission control in real time mode is performed using a digital system model of commutation with self-similar incoming traffic.

An admission control algorithm based on the probability of packet loss has been elaborated. Loss probability gets estimated taking into account the traffic self-similarity parameter (H). In order to raise the speed of making a decision about admission to the system, the author has proposed to use previously calculated table data. The parameters can be compared using the queuing models of bursty and self-similar traffic without including restrictions for buffer size. Nevertheless, the H parameter reflects the self-similarity of traffic more accurately than the bursty traffic parameter. Therefore, the author has proposed the analytical group model for use at the stage of system design, while admission control in real-time mode is implemented using the digital model of commutation system with self-similar incoming traffic.

The present paper proves that during the decision making about the flow admission one has to take into account the influence of statistical multiplexing on the parameters of the exiting traffic. The author shows that statistical multiplexing provides a substantial advantage for the speed of transferring the self-similar data flows. Also, the algorithm that creates a possibility to raise the network performance (admitted connections number) maintaining the quality of service parameters (P_{Loss}).

The analysis of problem of managing the flows belonging to the same priority class resulted in the elaboration of the algorithm that dispatching these flows.

Research practical application possibilities: The research resulted in several practical applications for MBAC systems which allow t increase its efficacy significantly. The recommendation has been tested by imitation testes in OPNET system. Using imitation enables fast testing and immediate realization of algorithms. During the course of work the author has developed an MBAC module for imitation OPNET packet which can be easily embedded into the physical commutation system.

Propositions:

- The optimal buffer size and throughput together with the algorithm of estimating the set packet loss probability minimize the summarized system costs.
- The method of estimation the adoptive evaluation and sampling periods provides the possibility for decreasing the estimation error and false decision making.
- An additional channel multiplexing possibility with the decrease of packet arrival rate of bursty flow with keeping guarantee of packets lost probability.
- The method including the optimal dispatching of the same priority class flows allows to improve the quality of service.
- The algorithm of the system resources reallocation, such as buffer size and throughput, allows lowering the overall costs while securing the quality of service requirements.

Validation and introduction of the research results: The main propositions have been presented, discussed and received appreciation at eleven international conferences.

1. 2010 IEEE Region 8 International Conference on Computational Technologies in Electrical and Electronics Engineering SIBIRCON-2010, Irkutsk Listvyanka, Russia, July 11-15, 2010
2. 14^{th} International Conference ELECTRONCS 2010// Kaunas, Lithuania, May 18-20, 2010
3. The 19^{th} Annual Wireless and Optical Communication Conference// Shanghai, China, May 14-15, 2010
4. The Fifth Advanced International Conference on Telecommunications AICT 2009// Venice/Mestre, ITALY: IARIA, May 24-28, 2009
5. The 13^{th} International Conference ELECTRONCS// Kaunas, Lithuania, May 13, 2009
6. IADIS International Conference Telecommunications, Networks and Systems 2008// Amsterdam, Netherlands, July 22-24, 2008
7. World Congress on Science, Engineering and Technology// Paris, France, July 4-6, 2008
8. The 14^{th} Conference on Information and Software Technologies IT 2008// Kaunas, Lithuania, April 24-25, 2009
9. The 12^{th} International Conference ELECTRONCS// Kaunas, Lithuania, May 21, 2009
10. RTU 48^{th} International Science Conference// Riga, Latvia, October 11-13, 2007
11. The 11^{th} International Conference ELECTRONCS// Kaunas, Lithuania, May 13, 2009

Publications: The research results have been published in seventeen publications having international quotations.

1. Mihails Kulikovs, Ernests Petersons, Sergeys Sharkovsky. Integral measurement process of incoming traffic for measurement-based admission control// Proceedings of the 2010 IEEE Region 8 International Conference on Computational Technologies in Electrical and Electronics Engineering SIBIRCON-2010, pp. 183-186

2. M. Kulikovs, S. Sharkovsky, E. Petersons. Comparative Studies of Methods for Accurate Hurst Parameter Estimation// ELECTRONICS AND ELECTRICAL ENGINEERING No. 7(103), 2010

3. Mihails Kulikovs, Ernests Petersons, Sergeys Sharkovsky. Adaptive Traffic Measurement for MBAC System// Proceedings of 2010 19th Annual Wireless and Optical Communications Conference (WOCC 2010), pp. 354-358

4. M. Kulikovs and E. Petersons,Optimal Dispatching of the Flows Falling in the Same Priority Class// Automatic Control and Computer Sciences, 2010, Vol. 44, No. 1, pp. 42-46. ©Allerton Press, Inc., 2010.

5. Куликовс, Э. Петерсонс, Оптимальная диспетчиризация потоков, принадлежащих одному классу // АВТОМАТИКА И ВЫЧИСЛИТЕЛЬНАЯ ТЕХНИКА. 2010. No.1. С.58-64.

6. Alfreds Asars, Mihails Kulikovs, Ernests Petersons. Buffer Size and Output Bandwidth Optimization in a MBAC system// Automatic Control and Computer Sciences, Vol. 43, No. 5, pp. 241-246.

7. А. Асарс , М. Куликовс, Э. Петерсонс. Оптимизация объема буферной памяти и пропускной способности выходного канала в MBAC системе. //АВТОМАТИКА И ВЫЧИСЛИТЕЛЬНАЯ ТЕХНИКА. N5, 2009, pp.24-31

8. Mihails Kulikovs, Ernests Peterson. Real-Time Traffic Analyzer for Measurement-Based Admission Control// Proceeding of the 2009 Fifth Advanced International Conference on Telecommunications, 24-28 May 2009, Venice/Mestre, Italy, pp 72-75

9. Mihails Kulikovs. Statistical parameters estimation of the self-similar input traffic for the Measurement-based Admission Control// Scientific Proceedings of Riga Technical University in series "Telecommunications and Electronics". -Riga, 2008, pp 37. - 42.

10. M.Kulikovs, E.Petersons, Modeling the On-line Traffic Estimator in OPNET// ELECTRONICS AND ELECTRICAL ENGINEERING No. 7(95) 2009, pp. 82-86

11. М. Куликовс, Э. ПЕТЕРСОНС. Оценка параметров имитационной модели системы доступа в сеть самоподобных входных потоков.// АВТОМАТИКА И ВЫЧИСЛИТЕЛЬНАЯ ТЕХНИКА. N2, 2009, pp. 47 - 56

12. M. Kulikovs and E. Petersons Parameter Estimations in a Model Imitating a Network Admission System with Self-Similar Arrival Streams// Automatic Control and Computer Sciences, 2009, Vol. 43, No. 2, pp. 88-95. ©Allerton Press, Inc., 2009.

13. Kulikovs M., Petersons E. Remarks Regarding Queuing Model and Packet Loss Probability for the Traffic with Self-Similar Characteristics// Proceeding of World Academy of Science, Engineering and Technology. Volume 30,PWASET, 2008, pp. 537- 543.

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15. Kulikovs M., Petersons E. Packet Loss Probability Dependence on Number of ON-OFF Traffic Sources in OPNET// ELECTRONCS AND ELECTRICAL ENGINEERING. 5. E2008, 2008, pp. 77-80 Kaunas

16. Kulikovs M., Petersons E. Estimation of buffer overflow probability by OPNET// Conference Proceedings. 14th Conference on Information and Software Technologies. - Kaunas, Lithuania: Tehnologija, 2008. pp. 145-149.

17. Asars A., Petersons E., Kulikovs M. Modeling of measurement based admission control algorithm, using OPNET// Scientific Proceedings of Riga Technical University in series "Telecommunications and Electronics". -Riga, 2007, pp 16-21

The results gained in the course of work have been used in the following projects:

1. RTU ZP-2006/10: Development of telecommunications systems simulation models for research and education 1.06.2006 - 31.12.2006

2. RTU V1308: Analysis and modeling of intelligent wireless data transmission network in transport system 1.10.2007 - 15.009.2008

3. LZP Nr. 04.1260: Network resources distribution for securing quality of service in self-similar load environment 2004. - 2008.g

4. LZP Nr. 06.1963 Development of adaptive methods and algorithms to process complex information with the purpose of raising the accuracy of a vehicle localization determination

5. VPP, Nr. V7408.2 Real stand elaboration for the estimation of traffic in computer networks and optimal regulation of connections with mobile

6. VPP, V7552.2: Data saving model development. Research and implementation of the dispatching algorithm 01.01.2009 - 31.03.2009

7. VPP, V7552.2: Research of the measuring model with statistical and dynamic parameters 01.01.2009 - 31.12.2009

Thesis size and structure: The dissertation consists of an introduction, five chapters, conclusion exposed on 201 pages and containing 17 tables, 112 pictures. Also, the paper contains a list of literature used composed of 175 items and 4 appendixes.

The relevance and urgency, as well as the direction and purpose of the current research is justified in the introduction.

In the first chapter the author presents the results of investigation regarding the models that describe traffic. The well-know models of self-similar traffic generation in systems of communication networks imitation modeling. On the basis of analysis the author has produced the recommendations on generation of self-similar traffic in imitation systems.

The second chapter is dedicated to the review of queuing models with group incoming flows. It contains a convenient digital estimation model of a queue with an interval between packets being distributed according to Pareto law, request service being distributed according to the exponential law, one serving nod and a limited buffer size ($P/M/1/K$). Here, the analytical expressions for the queuing model with group incoming of packets of exponential service performed by single nod are described ($M^X/M/1/K$). Also, the author reviews the studies that prove that the $M^X/M/1/K$ model in load range typical for telecommunication systems is similar to $P/M/1/K$ model in terms of digital values of queue parameters. The suggested model has been extended in the frames of the current work.

IP protocol development was not intended for quantitative delivering of quality of service guarantees. Real - time applications expansion has dramatically increased the necessity for ensuring QoS constraints. The third chapter contains the description of different methods that make possible the fulfillment of QoS requirements.

Recently, a solution called MBACmeasurement-based admission control has become widely spread for securing statistical quality of service guarantees. The fourth chapter contains a detailed description of this model. MBAC does not have to be aware of a priori parameters of the connected source as they are often difficult or impossible to describe. MBAC receives the characteristics of parameters of already connected flows through measurements. In order to make a decision regarding the flow admission, the measured values of flows parameters are used together with the basic description of the requesting flow.

In the fifth chapter the recommendations regarding commutation systems equipped with MBAC are presented. They can be divided into two groups. The first one includes the recommendations applied during the stage of communication systems design. Recommendations of solutions to the issues that appear during the functioning of the system go to the second group. The chapter cites the selection of the optimal buffer size and bandwidth of the throughput channel under the minimal costs and maintaining the quality of service parameters set at the time of system design.

In the second group of questions a method of measuring the traffic with adaptive sampling frequency and measurement window is introduced. This method guarantees a more accurate measurement of traffic of different kinds, including the bursty traffic. The author has described the measurement method of a number of possible flows under the condition of maintaining the QoS requirements and maximizations of exiting channel load in the mode of statistical multiplexing.

The developed algorithm of the dynamic redistributions of resources when besides the performance measurements, costs measuring is used too. The same chapter presents the algorithm that realizes the function of the optimal dispatching of the flows that have the same priority level of service.

All the propositions mentioned above have analytical and numerical argumentation that can be found in corresponding sections.

In order to test the overall solution that takes into account all the improvements, a programming and simulation framework, OPNET has been used. The sixth chapter is dedicated to the description of MBAC realization in OPNET. Block scheme, structural analysis of data flows, description of results used for testing, scenarios and modeling results are presented in this chapter. Separate modules of MBAC can easily be incorporated into the physical realization of commutation system.

Analysis of results, discussion and plans for further research are demonstrated in the last chapter.

Appendix contains the calculated table data of the needed buffer size, main parameters of the queuing model of bursty character, results gained by different flow management methods and the main definitions used in the paper.

Extended summary

Introduction

For the last years the character of services offered to Internet users has changed crucially. Multimedia services have become dominating over traditional plain text (web, mail) and data (ftp) services. Hence, one can argue the evolution of Internet has occurred. In particular, two fields have evolved:

- Traffic - its parameters have changed
- Services - multimedia applications began requiring quality of service guarantees

As far as traffic development is concerned, bursty flows has become prevailing over traditional Poisson ones [30, 3]. In this kind of traffic packet income time distribution comply with long-tail distribution, Pareto for example. Analysis has shown that this traffic can be characterized by self-similarity property. It results in keeping statistical parameters under varying time scales. The author has reviewed the issue of the artificial creation and analysis of trace of self-similar character in the systems that simulate the communication systems.

Traffic with self-similar property has dramatically influences network performance. It increases delays and packet loss probability [60, 20, 43]. The negative effect of self-similar traffic on network performance may be significantly reduced by the means of decreasing overloads of communication system elements.

One of the options to reduce overloads during the network operation is taking into account traffic characteristics on the stage of design when structural network units such as buffer size and bandwidth are being chosen [67, 5, 54, 68, 55, 19, 18, 4]. Usually optimal values of network structural units' parameters are chosen employing a queuing model. Due to self-similar character of traffic, the traditional queuing models are not suitable.

Therefore, the author has made an investigation of queuing models that match the qualities of modern traffic. During the study, the author has identified a queuing model that is convenient for making the numerical computations. It has packet arrival process characterized by Pareto distribution low, requests service is distributed according to exponential law; it has one service node and limited memory size K - $P/M/1/K$.

Also, the author has found the model that encompasses the *analytical* expressions for the queue parameters with bursty income of flows, exponential service by single node ($M^X/M/1/K$). Queue parameters values of $M^X/M/1/K$ model are similar to those in the $P/M/1/K$ model encountered in common load range of telecommunication systems. The model has been further developed and added by analytical expressions for the average queue length ($\bar{K}$) and average packet service waiting time ($\bar{W}$) under the limited buffer size assumption.

On the basis of analytical expressions for the system with bursty flow income the author gives recommendations regarding the estimation of structural units of the system such as buffer size and bandwidth with specified P_{Loss} and minimal cost such as buffer size and bandwidth of output channel. These recommendations are useful during the selection of sizes of communication system elements at the stage of design.

Another option to reduce the overload of structural elements and the whole system is employing the algorithms that manage the flows. The managing algorithm is dedicated to provision of QoS guarantees to network clients.

A large part of the present work is devoted to the recommendations about design of managing algorithms. There are several problems in design of managing algorithms:

- Functional
- Structural
- Technological

The functional problems are related to the development of decision making methods of management. Hereby, management is considered to be the decision making process regarding the necessary QoS guarantees.

In this work it is assumed that QoS requirements have to be satisfied in the End-to-End (e2e) mode. This mode includes the fulfillment of the requested QoS along the entire way from the data source to the destination.

For that case in order the specified QoS are guaranteed it is important that a newly incoming flow does not violate QoS guarantees for the existing flows. Therefore, Connection Admission Control (CAC) has to become the main target function of the managing algorithm [52, 64] while the new connection may be supported by the network only if it has the requested resources, requirements to quality of service for the existing connections are met and under the condition the new connection does not disturb them.

For real time applications, interactive video for example, it is impossible to estimate the resources that might be needed in advance. For this reason the required resources are raised so one could be confident in fulfillment of QoS. This action has caused the failure of CAC that uses the requirements set by the flows for utilization evaluation, for example, the requirements to bandwidth. Such CAC is called Parametric-based Admission Control (PBAC), as it uses application traffic parameters for admission control. PBAC can be easily realized. However it provides low network utilization due to the raised requirements.

In the present work it is suggested to use CAC that gets the information about utilization directly from the performed measurements of the existing flows. Such an approach is called MBAC and recently it has become popular in provision of QoS guarantees [31]. In this work a new structural and functional MBAC scheme is proposed.

Measurement and evaluation of both existing and incoming traffic parameters module is one of MBAC structural elements. Further, the description of main problems encountered by the author during elaboration of this module is given.

The first problem is functional and being applied to MBAC, concerns measurements. Data measurements and processing for clarification of system load is a complicated task due to traffic being bursty [16, 15, 38, 25].

The author suggests using an adaptive method when evaluation interval and measurement frequency depend on the traffic character. It allows reducing the amount of errors and decreasing the load on the managing system that stems from the measurement process.

In search of the compromise the author has proposed using an adaptive approach that denotes observation period and sampling period dependence on the traffic character. The suggested adaptive measuring method allows not only reducing the number of errors in traffic measurements, but what is extremely important when real time mode is employed - reducing the managing system load related to the measuring process.

The second problem during the process of managing algorithms design is a structural problem caused by maximum usage of the limited network resources. In the work the author presents the studies and recommendations regarding usage maximization of the limited system resources while QoS guarantees are met.

The best usage of the limited resources can be reached by the algorithm of optimal dispatching proposed by the author. The proposed and described algorithm solves the dispatching problem when flows belong to the same priority class under the limited resources.

The third problem of the managing algorithm is the technological one. Its solution effects the cost of the managing system. It is known that the parameters of flows quality of service depend on bandwidth of outcoming channel and buffer size of the communication node [62, 35]. As it has been mentioned above, the author offers recommendations about optimal calculation of structural system units values at the stage of design. The same techniques can be used to solve the task of optimal resource reallocation in the process of system functioning.

It is important to mention that all the above recommendations have analytical basis. In order to test them the author has realized the MBAC model in simulation framework OPNET. Modeling results have shown that introduction of some recommendations produces substantial performance improvement.

Chapter 1 Traffic characteristics

Elaboration of admission control model is not possible without understanding of traffic character. Therefore, the first chapter is dedicated to the review of existing traffic models. The models of artificial data flows are regarded in particular details as they will be used in simulative modeling

The link/source model is an approach to resource management. Along with the evolution in technology traffic characteristics has significantly changed. After the [51, 17, 21] show that in a packet-based network, models of the traffic are now also best represented by heavy tail distributions firstly proposed link/source models [28, 11, 42, 24, 13] have been replaced with suitable multi-fractal models [40, 56, 57].

It is obvious that the network traffic models must be developed together with analysis techniques and evolution of the network traffic itself. The source model does not provide assure means of required resource for traffic with complicated and less-tractable properties. Instead of a link/source model, the model that could taken into account the interacting with a network and suitable for characterizing elastic traffic. Such network model was supported in [66, 6, 14, 53, 26, 46, 41]. The detailed description of Web browsing, File transfer, VoIP and Video Conferences traffic models are described in the present work.

Following part of the chapter is dedicated to description of the modern self-similar traffic parameters, generation ways and its analysis.

The main characteristic parameter for the self-similar processes is the Hurst parameter - it shows the self-similarity level. The value $H = 0.5$ indicates the absence of self-similarity, while high (close to 1.0) values of H show a high degree of self-similarity.

A stationary process X with finite mean $\eta = \mathbf{E}X_i < \infty$ and variance $\sigma^2 = VarX_i < \infty$ is called exactly second-order self-similar with parameter $0 < \beta < 1$ if an autocorrelation function $R(k)$ is represented as follows:

$$R(k) = \frac{1}{2}\left((k+1)^{2-\beta} - 2k^{2-\beta} + (k-1)^{2-\beta}\right) \tag{1}$$

Parameter β and the Hurst parameter H are related as $H = 1 - \beta/2, \frac{1}{2} < H < 1$. An autocorrelation function $R(k)$ of self-similar process is presented on Fig. 1

As has been shown in [1, 2, 36, 45, 47, 48, 49] the self-similarity has a negative influence on the network performance. Namely, due to presence of burst traffic in several time-scales leading to an increase in end-to-end delay packet delays and their losses [34, 65, 27, 33].

In the present research the simulation of the self-similar traffic is based on the ON/OFF model that originally was suggested by Mandelbrot [39]. The ON/OFF model was chosen for our simulation as it has been shown in the literature that self-similar network traffic can be generated by multiplexing several sources of Pareto-distributed ON- and OFF- periods [50]. Each source sends bursts with random duration distributed by Pareto distribution. The traffic generated by individual sources is independent and identically distributed.

The second model is a simplified ON/OFF model where every batch of packets contains exactly one packet, and the time intervals between the packet arrivals are described by the Pareto distribution, i.e., Fractal Renew Process with Pareto distributed packets arrival time.

The conducted by author investigation of the generated streams shows that the traffic where the packet inter-arrival times are distributed according to the Pareto law is not ergodic. The generated streams where packet arrives according to ON/OFF model are not ergodic also. The experiments allowed the author to choose the correct evaluation of a correlation interval:

$$\tau_k = \frac{1}{2}\frac{S(0)}{R(0)}, \tag{2}$$

where $R(0)$ is the autocorrelation function at zero shift, and $S(0)$ - spectral density at zero frequency.

The estimated autocorrelation function suggests that the behavior of the generated stream agrees qualitatively with the theoretical results (Fig. 2a and Fig. 2b).

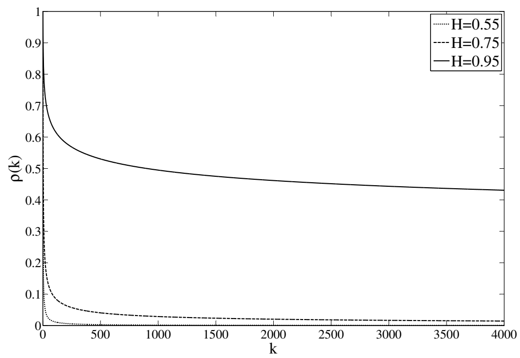
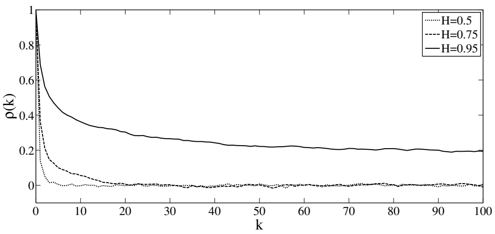


Figure 1: The autocorrelation function of the self-similar processes with the different H parameter

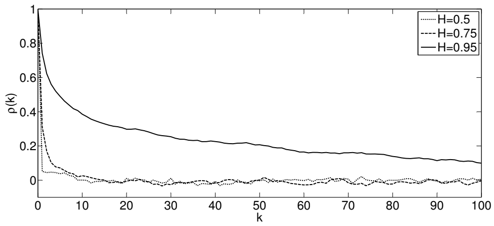
Chapter 2 Buffer size evaluation

One of the important structural elements of network nodes is buffer capacity that can keep packets of incoming flows. Buffer size has to be determined taking into consideration the limits of the packet loss probability of incoming flows in case the bandwidth is not sufficient.

Starting with the work by Norros [45] and continued in [22, 63, 60, 20, 43] stated that the buffers needed at switches and multiplexers must be bigger than those predicted by traditional queuing analysis.



(a) The short autocorrelation function of the centered Fractal Renewal Process



(b) The short autocorrelation function of the centered ON/OFF Process

Figure 2: The short autocorrelation functions

Due to the self-similar nature of traffic the traditional queuing models are not suitable as in order to gain analytical solutions they were built on the assumption about Poisson character of the incoming flow ($M/M/1/K$) or about unlimited resources (e.g. buffer size - $P/M/1$). The absence of analytical expressions for the models with self-similar character of traffic is determined by the lack of Laplace transform for the long tail distribution. The chapter presents $M^X/M/1/K$ and $P/M/1/K$ queuing models that suit modern packet switched networks.

Firstly the queuing model $P/M/1/K$ is describes. The model represents a numeric algorithm of necessary queue size calculation given the preset parameters of the incoming traffic, requests' service intensity and the requested guaranteed loss level. In the present study the analytical expression for the derivative of the Laplace transform of the Pareto PDF is used according to [58]. Later it is used with a purpose to calculate the asymptotic packet loss probability that can be written as following:

$$P_{Loss} = \left(1 - \frac{\alpha(\alpha-1)}{\rho} M^{\frac{\alpha}{2}-1} e^{\frac{M}{2}}\right) \left[\sqrt{M} W_{-\frac{\alpha+1}{2},-\frac{\alpha}{2}}(M) - W_{-\frac{\alpha}{2},\frac{1-\alpha}{2}}(M)\right] \sigma^K \qquad (3)$$

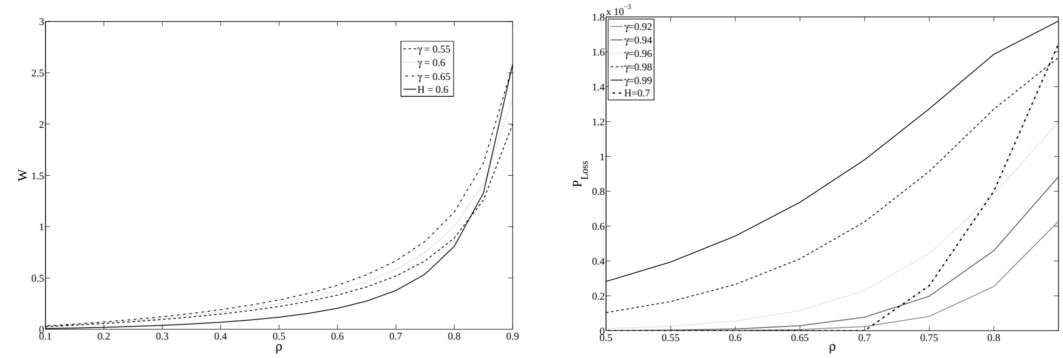
where $M = \frac{(\alpha-1)(1-\sigma)}{\rho}$ and $W_{\eta,\xi}(\phi)$ - Whittaker's function.

Author has examined the equation and has built relations that are represented on Fig. 4a. The Fig. 4a presents the relation between utilization, buffer size and packet loss probability for different Hurst parameter of the queuing system evaluated according to [58].

It is commonly considered that a linear increase in buffer sizes will produce nearly exponential decreases in packet loss, and that an increase in buffer size will result in a proportional increase in the effective use of transmission capacity. As it can be seen in the Fig. 4a self-similar traffic do not hold these assumptions.

The disadvantage of that model is the lack of expression to calculate such a parameter as average time of packet staying in the queue. Most importantly, this expression demands iterative digital calculations that will take long time.

The queuing model with a bursty incoming of requests gives a possibility to solve that



(a) The mean time the packet stays within the system for $M^X/M/1$ and $P/M/1$ queuing models

(b) The packet loss probability for $M^X/M/1$ and $P/M/1$ queuing models

Figure 3: Comparison of $P/M/1/K$ and $M^X/M/1/K$ queuing models parameters

problem. It holds the following assumption: it has Poisson incoming group flow, the group packets size is geometrical law distributed with γ geometrical coefficient that characterizes the number of packets in the burst, exponential service time variance law and one server. Moreover the $M^X/M/1/K$ model is given that has similar characteristics as the model described earlier. The difference between models $M^X/M/1/K$ and $P/M/1/K$ is small in a wide range of the utilization coefficients of the system ρ that can be seen in Fig. 3a and Fig. 3b.

This fact gives a possibility to use the analytical expressions of the model $M^X/M/1/K$ in further chapters where optimization tasks will be discussed.

According to [9], the packet loss probability for the $M^X/M/1/K$ model can be written as following:

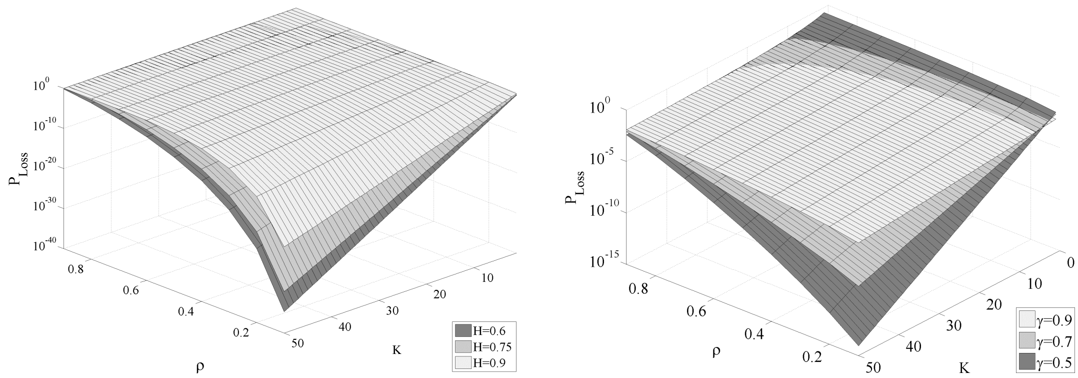
$$P_{Loss} = \frac{(1-\rho)(\gamma + (1-\gamma)\rho)^{K-1}((1-\gamma)\rho}{1-\rho(\gamma + (1-\gamma)\rho)^{K}} \tag{4}$$

In Fig. 4b the packet loss probability within the system for $M^X/M/1/K$ queuing model is presented.

An average packet number in $M^X/M/1/K$ system can be evaluated by improving the previous results [9] and can be represented as follows:

$$\bar{K} = \frac{K+1}{(\rho+\gamma-\rho\gamma)^{K+1}-1} - \frac{K(1-\rho-\gamma+\rho\gamma)+1}{(1-\rho)(\gamma-1)} \tag{5}$$

Fig. 5 presents the graphs of relationships between the average queue length, system utilization, burstyness and buffer size. It can be seen that there is a certain buffer size (K_{opt}) that is sufficient for provision of the average queue length. That means that calculating the system resources parameters in communication systems there is no sense to equip the system with the buffer size larger than K_{opt}. Similar approach can be applied whilst making decision



(a) The relation between utilization, buffer size and packet loss probability for different Hurst parameter estimated according to [58]

(b) The packet loss probability in the system $M^X/M/1/K$

Figure 4: Packet loss probability for $P/M/1/K$ and $M^X/M/1/K$ queuing models

about resources allocation in the dynamic system mode.

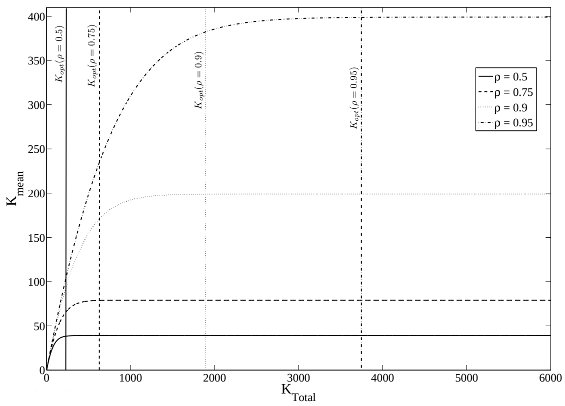


Figure 5: The mean number of Jobs in System for the $M^X/M/1/K$ queue model with $\gamma = 0.95$

As it has been mentioned in the introduction and proved in the present chapter, consideration of the traffic character at the stage of its design during the selection of structural units size such as buffer size, allows decreasing the overloads of the system. Next chapter presents a mechanism that can be used for increasing the performance of network.

Chapter 3 Quality of Service in Integrated-Service Networks

The purpose of QoS is the enhancement of service availability and throughput capability at minimal delays and elimination of jitter and losses [61, 37]. The chapter presents overview of QoS schemes elaboration. IntServ, DifServ and IntServ over DiffServ are described. Scheme examination serves for the purpose of emphasizing the necessity for the application of solutions developed by the author.

In the process of quality of service guarantees provision it is important the new flow does not ruin the promised quality guarantee which already exists in the network. For this reason it is necessary to have the mechanism that will fulfill CAC [52, 64].

The function is realized in IntServ scheme, that is orientated for long-lived unicast or multicast flows. The author proposed a new method to regulate the number of competing flows. A difference of this method lies in consideration of self-similarity of the modern traffic and the optimal usage of available resources.

As the realization of IntServ is a rather complicated task developers from Internet engineering Task force (IETF) has suggested a DiffServ model. In this model the services with the same requirements are combined into one aggregated flow. It receives the necessary level of service in comparison to other flows. In case of congestion the packets of lower priority will be discarded in favor of the higher priority. To implement such schema IETF proposed DiffServ architecture [44, 10].

The proposed scheme does not describe the mechanisms that allow regulation of the number of competing flows belonging to the same priority class. It can cause the disturbance of quality of service guarantees. In dissertation the author solves the issue of dispatching the flows with similar level of priority.

A hybrid architecture has been suggested to escape the disadvantages of IntServ and DiffServ [8]. This architecture, IntServ over DiffServ, offers Scalable admission control methods for IP networks. In the IntServ over DiffServ schema, IntServ is used in access networks, while DiffServ is used in the backbone network. The solutions also may be applied to IntServ over DiffServ scheme. The proposed by author solutions also may be applied to IntServ over DiffServ scheme.

In present work the end-to-end QoS guaranty model will be used. This mode assumes fulfillment of necessary QoS requirements along the entire way from the data source to the destination. In this case it is important to make sure the new data flow does not violate QoS guarantees of the existing flows. CAC function can be used for this purpose. The next chapter describes the process of decision making about admission on the basis of measurements of network load, and does not need *a priori* description of the flows. The access control of this kind is named MBAC.

Chapter 4 Measurement-Based Admission Control

For the last years the MBAC [32, 31, 29, 23] is widely used for providing statistical service guarantee.

In this case the guarantee of QoS parameters occurs on the basis of *combination* of the measured traffic parameters (intensity of the received requests, variance and so on) and those requested by user [12].

As Fig. 6 shows the MBAC mechanism consists of several parts. The highest level of processes specification, the MBAC mechanism, can be described by the following processes:

- incoming flow traffic measurements,
- parameters estimator,
- admission decision algorithm - policy.

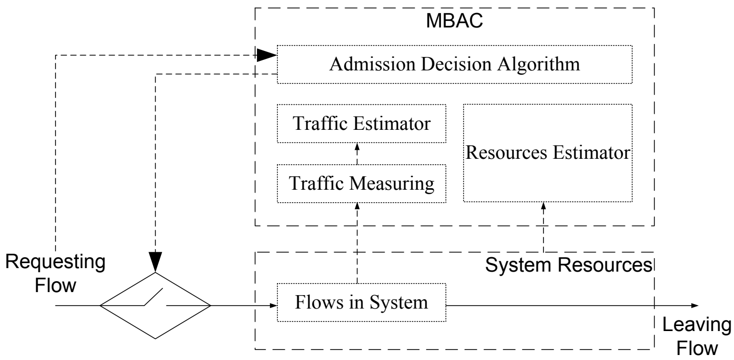


Figure 6: Model of Measurement-Based Admission Control

Description of each module is presented in respective section. The main contribution of the chapter is presenting a number of different MBAC algorithms, noting the fundamental premise upon which each are based. The investigation of the existing literature studying of MBAC has shown the absence of recommendation for the measurement procedure of modern traffic characterized by a high level of burstyness which is critical for the further evaluation of its parameters and correct decision making. The author solves the question regarding the selection of parameters of the measuring function such as observation period and sampling interval that allows decreasing the possibility of making an error in traffic parameters evaluation.

Next chapter presents evaluation of MBAC parameters and presents suggestions for efficiency improving.

Chapter 5 MBAC parameters evaluation

As it has been noted in the introduction, in order to raise the MBAC systems performance, the author proposes to use the following improvements, formulated in the form of recommendations and algorithms:

- recommendations regarding the selection and redistribution of system resources such as buffer size and bandwidth of the output channel;
- recommendations of using a new adaptive approach for measurements;
- admission control algorithm providing a high load of the communication system and securing the parameter of quality of service such as packet loss probability;
- algorithm of optimal dispatching of the flows belonging to the same priority class.

The current chapter demonstrates the proposed solutions related to the improvement of MBAC system performance.

Buffer Size and Output Bandwidth Optimization in a MBAC System: We consider a packet switched system using the example of a data hub (switch) with i inputs and one output. We use λ_i to denote the intensity of the packet flow arriving to the hub through the i-th input ($i = 1, \bar{M}$).

The hub has a buffer of size K^* and the maximal bandwidth of the output is μ^* while the part of resources K_0 and μ_0 are already occupied. Hence, $K^* - K_0 = K$ and $\mu^* - \mu_0 = \mu$ are involved in the decision-making process on allocating the sought buffer size for the arrival traffic.

The arrival traffic can have optimal values of the buffer size K_{opt} and the bandwidth μ_{opt} allocated for it, for which the packet loss probability P_{Loss} does not exceed the given level. To find these optimal values we minimize the cost functional

$$C = c_1\mu + c_2 K, \tag{6}$$

where c_1 is the cost of the unit bandwidth, and c_2 is the cost of the unit buffer..

To find the optimal values μ_{opt} and K_{opt}, we form the Lagrangian:

$$L = c_(\mu_0+\mu)+c_1(K_0+K)+\delta[(1-P_{Loss}-(1-\epsilon)]+\lambda(\mu_0+\mu-\mu^*)+\beta(K_0+K-K^*), \tag{7}$$

where δ, λ and β are the undetermined Lagrange multipliers, and ϵ - and ϵ is the upper admissible value of the loss probability.

We find the derivatives of the Lagrangian with respect to several variables, set them equal to zero, and solve the system of equations

$$\begin{cases} \dfrac{\partial L}{\partial \mu} = 0 \\ \dfrac{\partial L}{\partial K} = 0 \end{cases} \tag{8}$$

In order to solve the task, the model $M^X/M/1/K$ studied in Chapter 2 can be used. There is an analytical probability of packet loss expression (Eq. 11). To simplify the solving procedure in the beginning we remove the resource limitations.

Then, to optimize the system's parameter, we can differentiate and zero out Lagrangian (9). This yields the optimality condition for the allocation of the bandwidth μ and the buffer size K - (10)

$$L = c_1\mu + c_2K - \delta[(1 - P_{Loss}) - (1 - P^*_{Loss})], \tag{9}$$

where δ is the undetermined Lagrange multiplier, and $(1 - P^*_{Loss})$ is the given restriction on the probability of the loss-free packet transmission.

$$\frac{\partial\Phi}{\partial\mu}\frac{1}{c_1} = \frac{\partial\Phi}{\partial K}\frac{1}{c_2} = -\frac{1}{\delta}. \tag{10}$$

where the packet loss probability is:

$$P_{Loss} = \Phi(\lambda, \mu, K). \tag{11}$$

From the Eq. 10 follows the rule of the optimal bandwidth and buffer size allocation: "the decrease in the loss probability P_{Loss} per unit of cost should be the same for both types of resources viz. the bandwidth μ and the buffer size K".

We find the derivatives of the packet loss probability $P_{Loss} = \Phi(\lambda, \mu, K)$ with respect to μ and K:

$$\frac{\partial\Phi}{\partial\mu} = \frac{\lambda(\gamma-1)\left(\frac{\lambda+\mu\alpha-\gamma\lambda}{\mu}\right)^K}{\left[\mu - \lambda\left(\frac{\lambda+\mu\alpha-\gamma\lambda}{\mu}\right)^K\right]^2}\times$$
$$\times\frac{\left[\lambda^2\left(\frac{\lambda+\mu\alpha-\gamma\lambda}{\mu}\right)^K - K\lambda^2 + \mu^2\alpha + \gamma\lambda^2 - \lambda^2 - 2\mu\alpha\lambda + K\alpha\lambda^2 + K\mu\lambda - K\mu\alpha\lambda\right]}{(\lambda+\mu\alpha-\gamma\lambda)^2} \tag{12}$$

and

$$\frac{\partial\Phi}{\partial K} = \frac{\lambda ln\left(\frac{\lambda+\mu\alpha-\gamma\lambda}{\mu}\right)(\mu-\lambda)(\gamma-1)\left(\frac{\lambda+\mu\alpha-\gamma\lambda}{\mu}\right)^{K-1}}{\left[\mu - \lambda\left(\frac{\lambda+\mu\alpha-\gamma\lambda}{\mu}\right)^K\right]^2} \tag{13}$$

We can construct two surfaces $\frac{\partial\Phi}{\partial\mu}\frac{1}{c_1}$ and $\frac{\partial\Phi}{\partial K}\frac{1}{c_2}$ in the three-dimensional space depending on μ and K'. The intersection of these two surfaces is presented in Fig. 7 and yields the optimal solution that corresponds to Eq. 10

We can apply the optimization rule obtained to the case of adjusting the system's parameters dynamically with the restrictions on the available resources taken into account. Allocating an additional bandwidth or increasing the buffer size used in the communication system

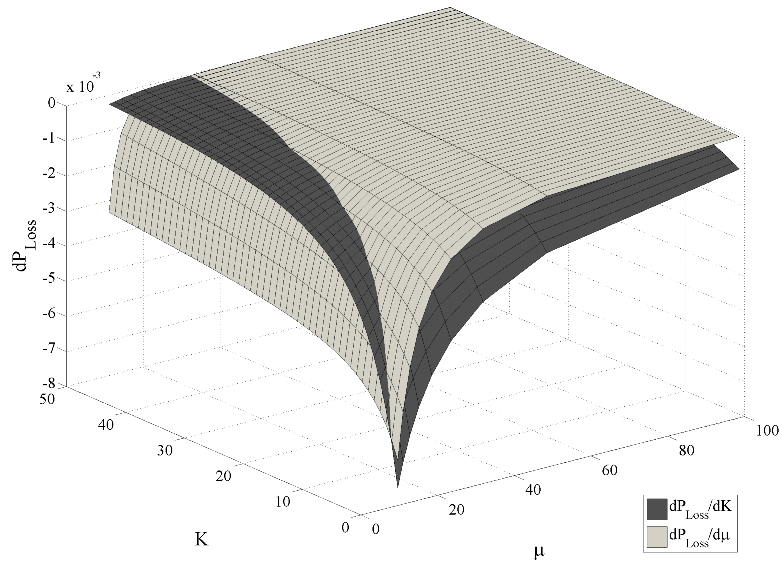


Figure 7: $\frac{\partial \Phi}{\partial \mu}\frac{1}{c_1}$ and $\frac{\partial \Phi}{\partial K}\frac{1}{c_2}$ surfaces for $\rho = (0.1..0.9)$ represented by the inter-arrival rate $\lambda = 10$ and the coefficient of the geometric distribution $\gamma = 0.9$

for the particular traffic flow, we reduce the loss probability $P_{Loss} = \Phi(\lambda, \mu, K)$. However, this makes the communication system's costs grow; therefore, we need to allocate resources so that relation (Eq. 14) is minimal:

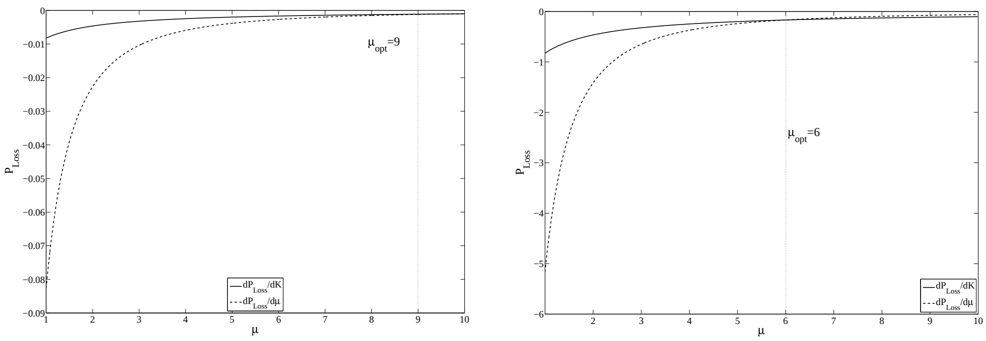
$$\frac{\Delta P^i_{Loss}}{P^*_{Loss}} / \frac{c_i}{C}. \tag{14}$$

Here ΔP^i_{Loss} is the decrease of the loss probability caused by the allocation of the i-th resource, P_{Loss} is the packet loss probability prior to the resource allocation, C is the cost of the communication system prior to the resource allocation. Making successive decisions based on Eq. 14, we reduce the packet loss probability. We continue to perform these steps until $P_{Loss} \leq P^*_{Loss}$. If a new traffic flow arrives and the resource allocation does not ensure the given packet loss probability, the traffic is denied access.

show the curves of the derivatives of the packet loss probabilities with respect to K (dP_{Loss}/dK) and μ ($dP_{Loss}/d\mu$) depending on such parameters as the packet arrival intensity (λ), the coefficient of the geometric distribution (γ), the packet processing intensity (μ), and the buffer size. Using the graphs Fig. 8a and Fig. 9a we can find the optimal solution without taking into account the cost coefficients, and the graphs in Fig. 8b and Fig. 9b show the optimal solution for the coefficients taken into account.

In this case the cost coefficients c_i were chosen for memory cost and units of the speed of data transmission down to the data of 2009. A crossing point of curves on the graph corresponds to the optimal solution.

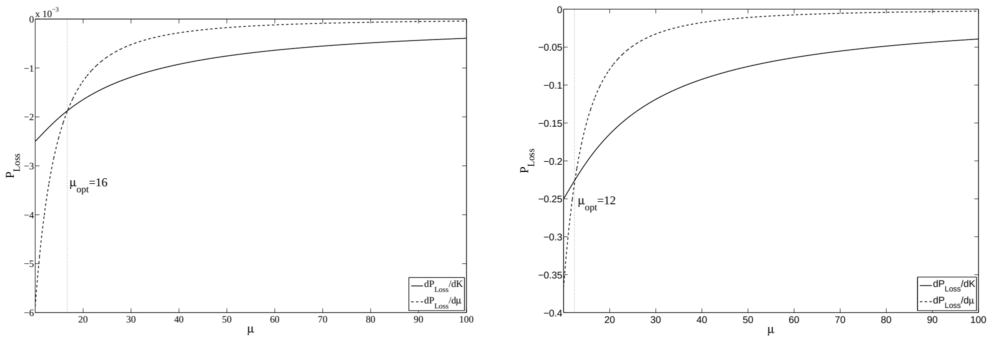
There are several cases where one can apply the results of solving the optimization prob-



(a) Optimal output bandwidth μ_{opt} without taking into consideration the price of resources

(b) Optimal output bandwidth μ_{opt} with taking into consideration the price of resources

Figure 8: Optimal output bandwidth μ_{opt}. $\lambda = 1$, $K = 1$



(a) Optimal output bandwidth μ_{opt} without taking into consideration the price of resources

(b) Optimal output bandwidth μ_{opt} with taking into consideration the price of resources

Figure 9: Optimal output bandwidth μ_{opt}. $\lambda = 10$, $K = 10$

lem for the parameters of the communication system:

1. In the course of designing the system, until there are no restrictions on the resources, we can choose the optimal value of the buffer size K^* and the optimal output bandwidth μ^* if the total intensity Λ of the arrival data traffic is known.

2. To make a decision on whether the new traffic with the *a priori* known intensity Λ_2 can be admitted.

3. Another case deals with the simultaneous request for resources from at least two competing traffic flows. In this case, we choose the priority traffic flow as a result of solving the optimal traffic control problem.

The second structural element of MBAC is a measuring block. A study focused on the determination of parameters of this block is presented in the dissertation.

An integral measuring process of the incoming traffic parameters in MBAC system: The intensity of incoming packet flow and self-similarity parameter of incoming traffic need to be estimated so that calculation of outgoing channel load and buffer capacity is possible. These operations have to be done for further decision about allowance of the flow to the system with limited resources, e.g. bandwidth and buffer capacity.

The incoming flow is analyzed by accumulating data about it during the periods of time T. Using these periods the system shows the results of incoming flow analysis which are further used to take a decision about the new flow access to the system.

The measurements of the flow parameters are taken during the discrete time periods Δt and can be denoted as $x(i)$, where i is Δt period. It has to be mentioned that besides the last time period the system accumulates data about any parameter during a longer time period too. Thus, there is a probability this fact can be used.

The target parameter is intensity of incoming flow λ_i at period i. The flow intensity as well as the other incoming flow parameters is declared by the source at the moment of request about available network channel resources. The value declared in the request, the incoming flow intensity, for example, is not known for sure and get assigned roughly.

According to [70] and [71] the optimal evaluation value of the parameter is:

$$a_{opt} = \frac{1}{r} \sum_{i=}^{r} a_i. \tag{15}$$

alternatively it can be presented as:

$$a_{opt}(r) = a^*_{opt}(r-1) + \frac{1}{r} \left[a_r - a^*_{opt}(r-1) \right]. \tag{16}$$

The later equation leads to the algorithm of parameter evaluation: on another r step of observation the optimal value of the parameter turn into mathematical expectation of the parameter gained at the previous $r-1$ stage of observation, plus the correction that is equal to: $\frac{1}{r}(a_r - a^*_{opt}(r-1))$. Thus, in the end of time period T the described approximation procedure results the formation of data about a parameter or parameters in the system.

In order to reduce the errors of parameters evaluation, first of all an observation interval T has to be determined. For example, it cannot be too long as the character of the current traffic may change suddenly and the system will not be able to note that change. Therefore we assumed that appropriate value for the period T can be the correlation interval τ_k while the flow can change its statistical parameters after this interval.

The second parameter of MBAC has to be the period Δt. If it is high, a high uncertainty in the evaluation of the flow parameters appears. The most accurate option is the observation of each incoming packet that is impossible due to time losses of processing [59, 16].

The definition of the time period has to take into account the flow character as this is observed in the self-similar traffic [7]. Using recommendations of the present work the following suggestions are proposed. Based on Eq. 17 it is possible to build the $I(x, y)$ curve family dependence on Θ with various Δt. According to Fig. 10a - Fig. 10b it is possible to determine the period between the countdowns Δt^* while $I(x, y)$ are at their max:

$$I(x,y) = \frac{1}{2}\left\{1 + (t-\Theta)^{2H}\left[1 - \frac{[t^{2H} + (t-\Theta)^{2H} - \Theta^{2H}]^2}{4t^{2H}(1-\Theta)^{2H}}\right]\frac{(\Theta - \Delta t)}{b}\right\} \tag{17}$$

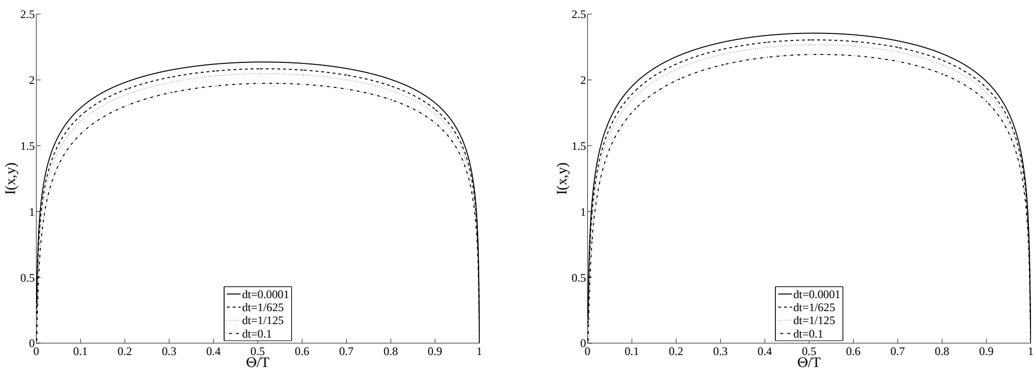
where $I(x, y)$ is the information volume that is gained during the measurements for time Θ previous to the moment t; H - Hurst parameter; and $b = (\Theta - \Delta t)\sigma_z^2$, where σ_z^2 is the variance of packets number at single measurement.

From the graphs it is seen that the value of Θ, resulting in $I(x, y) \to max$, lies in a wide range: it cannot be very small $\Theta < 20\%$ or too large $\Theta > 80\%$, starting from the last evaluation of parameters T_i and finishing with the moment of making the decision - T_Z.

There is no necessity to expect the end of the period T at the incoming of a new flow. The evaluation of the working flow can be done using the accumulated data from periods $\Theta << T$ on the basis of the Eq. 17:

Building the relationship $I(x, y)$ from Θ (period needed to check and process the measurements), it can be seen that $I(x, y) \to max$, if Θ is $\frac{1}{2}$ of the moment of the last accumulated measurements.

The constructed graph (Fig. 10a - Fig. 10b) shows that the necessary period of measurements and processing decreases while the self-similarity coefficient H increases. It is logical, as with the increase of H, flow correlation grows too. Therefore the flow can be observed using the shorter period of time.



(a) $H = 0.75$ (b) $H = 0.95$

Figure 10: $I(x, y)$ depending on Θ with various Δt

Next, the case of MBAC *starting phase* is presented. The system starts to receive the requests for access of the first flow. For the unknown flow the initial observation period S

and sampling period δ are choosing. We assume the worst case which the Poisson character of the flow is, i.e. it is not correlated.

If the declared intensities of the flow λ are known, the period δ between the countdowns can be taken as equal to correlation period of Poisson flow that is equal $\delta = \frac{1}{\lambda}$.

The larger the observation period S is, the more accurate are the measurements. The measurements error $\beta = \frac{D}{(m-1)}$, where D is the process variance and m is the number of measurements ($m = \frac{S}{\delta} = S\lambda$). Poisson process variance represents $D = R_x(0) = 1$. Measurements error can be expressed in the following way:

$$\beta = \frac{D}{m-1} = \frac{1}{S\lambda - 1} \approx 1/S\lambda. \tag{18}$$

The resulting graph of the observation and measurements process looks as it is shown on Fig. 11

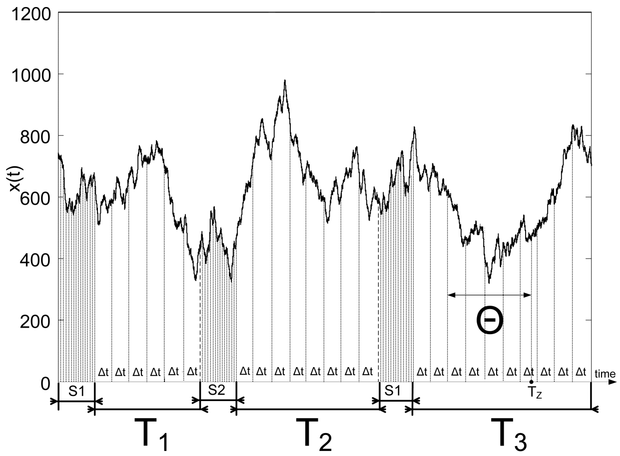


Figure 11: An integral measurement process of incoming traffic for MBAC.

At the initial stage of research that studies the flow with the length S, the observation are taken in the period $\delta << \Delta t$, i.e. in the periods between the incoming packets. Further, on the basis of gained statistics, the correlation coefficient τ_k which equals T_1 gets calculated. After the period T_1 ends, the flow analysis for time S is commenced again and a new correlation period is calculated, as well as a new period T_2 is assigned.

If before the end of period T_2 a new flow at the moment T_Z tries to enter the system, than on the basis of data gained for the past period Θ that can be estimated using the formula (Eq. 17) the parameters of the current flow and resources remained for the new flow connection to the system are clarified.

The next MBAC block is "Admission Decision" which makes a decision about the admission of a new flow to the system on the basis of the requested and available resources.

Resource Allocation Method for Admission Control Algorithm: The present section concentrated on resource allocation in communication networks in order to assure specific packet loss probability for requested new connections.

The framework of the model consists of the multiple same QoS priority sources .Traffic of multiple sources goes through the switch where the multiplexing is performed (Fig. 12). It is important to mention that the probability that arrival rate of the aggregated traffic would be equal to peak rate of the individual source approaches tends to zero. That is why it is possible to gain high network utilization while saving the QoS packet loss guaranties.

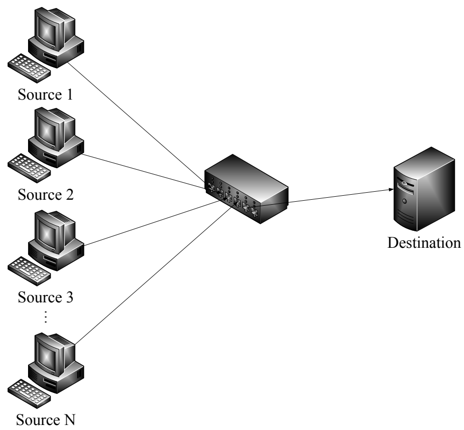


Figure 12: The framework of the model

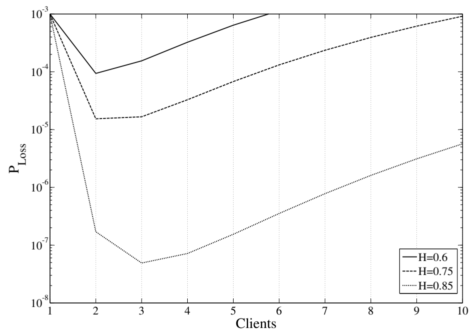
The traffic shaping is integrated into the switch. We considered the shaper policy as follows: if the limited resources of switch are not sufficient to guaranty the requested packet loss probability, then traffic shaper decreases the bandwidth of every established connection. For the case with multiple sources of the same QoS priority level it means that the bandwidth available for an individual source is inverse to the number of sources.

Fig. 13a shows the P_{Loss} probability for the individual connection according to [58]. The packet inter-arrival rate decreases proportionally to the number of established connections. The buffer size of each source gets allocated proportionally to the number of connections in reference to initially estimated.

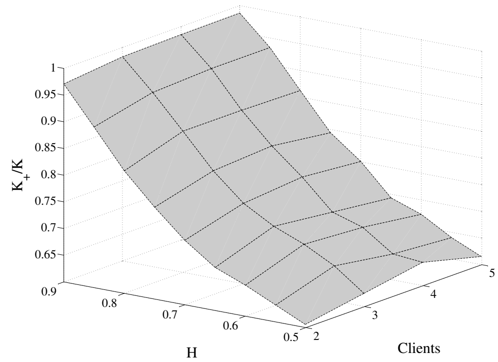
It can be seen that packet loss probability decreases when the arrival rate decreases proportionally to the number of clients, and allocated memory decreases according to arrival rate, hence $P_{Loss}^{\Sigma} = \sum_{i=1}^{ClientNumber} P_{Loss}$ for the multiplexed traffic of established client's connections decreases too. In the work is demonstrated that greater the gain from the multiplexing could be achieved for the high utilization, or for the traffic with high long-range dependence parameter - H.

Fig. 13b illustrates the gained buffer capacity during the traffic aggregation.

The advantage we gain of this result is the connection of more clients with the defined



(a) Packet loss probability for the source with decreasing inter-arrival rate proportional to the connected clients for the one client with arrival rate corresponding to $\rho = 0.5$



(b) The buffer capacity during the traffic aggregation for $\rho = 0.75$

Figure 13: The gain from statistical multiplexing

packet loss guaranty. In other words, we can have more available buffer memory for newly arrived connections. For such "free" resources we use the "over-utilization" term. Thus, it is possible to control the channel resource distribution, slowing down the incoming flows on the basis of Service Level Agreement (SLA) between a client and a provider.

In modern communication nodes DiffServ scheme is used for securing the quality of service guarantees. Firstly, the QoS of high priority flows is being provided. However, in the same class of priorities the flows vary in its statistical characteristics. During the present research work the algorithm of optimal dispatch of the same priority class flows has been developed. The algorithm helps to resolve the task of choosing a flow that can be connected while having no enough resources for securing all the flows with the necessary level of quality service.

Optimal Dispatching of the Flows Falling in the Same Priority Class: In order to manage the flows effectively , its classes have been introduced and the corresponding priorities. The task of resources allocation is complicated in the case when two or more flows of the same priority class arrive to the entrance. Let's give a consideration to a concentrator with n flows with arrival intensity λ_i $(i = \overline{1,n})$ at the entrance. Each flow at the outputting channel is provided with channel resources: service intensity μ_i $(\frac{1}{sec})$. Each flow is characterized by variance coefficient of service time v_i. Each i-th flow creates load for the concentrator and the outputting channel ($\rho_i = \frac{\lambda_i}{\mu_i}$) of the summarized $\rho = \sum_{i=1}^{n} \rho_i$.

The concentrator has the buffer size of r packets which is divided into zones so that volume r_i is allocated to each flow. It is suggested that service discipline of flows with relative priorities, that is in case of the buffer memory being fully loaded, the income flows get lost irrespective of its priority.

In accordance with [72], the probabilities of the packet losses for the flow of the k-th priority (the first priority is assigned to $k = 1$) are known:

$$P_{Loss_k} = \frac{\rho_{\Sigma_k}}{\rho_k} \frac{1 - \rho_{\Sigma_k}}{1 - \rho_{\Sigma_k}^{\frac{2r_k}{1+v_k^2}+1}} \rho_{\Sigma_k}^{\frac{2r_k}{1+v_k^2}}, \tag{19}$$

where $\rho_{\Sigma_k} = \sum_{i=1}^{k} \rho_i$, r_k - is the capacity of the buffer region for the k-th flow.

The flow priority should be determined by the following algorithm. Consider two flows $n = 2$. The first flow is assigned the highest priority $k = 1$. The packet loss probability for this flow is

$$P_{Loss_1} = \frac{1 - \rho_1}{1 - \rho_1^{\frac{2r_1}{1+v_1^2}+1}} \rho_1^{\frac{2r_1}{1+v_1^2}}. \tag{20}$$

The packet loss probability for the flow with the second priority is

$$P_{Loss_2} = \frac{\rho_1 + \rho_2}{\rho_2} \frac{1 - (\rho_1 + \rho_2)}{1 - (\rho_1 + \rho_2)^{\frac{2r_2}{1+v_2^2}+1}} (\rho_1 + \rho_2)^{\frac{2r_2}{1+v_2^2}}. \tag{21}$$

where $r_2 = r - r_1$, and r is the total buffer storage capacity of the communication node.

The total probability of the packet loss for two flows is

$$P_\Sigma = 1 - (1 - P_1)(1 - P_2) \approx P_1 + P_2 \tag{22}$$

Take the ranking of the flows as unknown and therefore assume that there are two flows A and B that produce the loads ρ_A and ρ_B.

Consider two cases: the case a is when the priority is given to flow A, and the case b is when the priority is given to flow B. If $P^a_{Loss_\Sigma} < P^b_{Loss_\Sigma}$ then the priority should be given to the flow with the index A, and vice versa.

In order to simplify the comparison procedure, one can take the variation coefficients as equal: $v_A^2 = v_B^2 = 1$. Consider the case of $\rho_A << 1$, while $\rho_B \to 1$, and assume that $r_A = r_B = r_x$. Then, the probability of losses can be estimated as

$$P_\Sigma^1 \cong \rho_A^{r_x} + \frac{\rho}{\rho_B} \frac{1 - \rho}{1 - \rho^{r_x+1}} \rho_x^r. \tag{23}$$

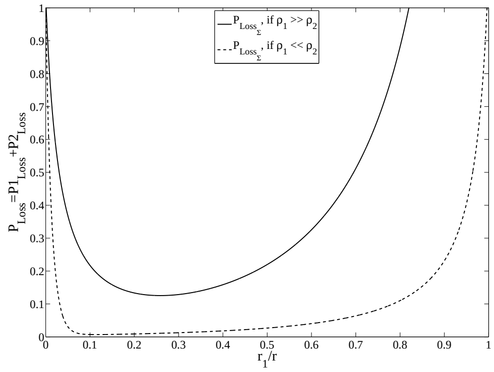
If $\rho_A \to 1$, and $\rho_B << 1$ then:

$$P_\Sigma^2 \cong \frac{1 - \rho_A}{1 - \rho_A^{r_x+1}} \rho_A^{r_x} + \frac{\rho}{\rho_B} \frac{1 - \rho}{1 - \rho^{r_x+1}} \rho_x^r. \tag{24}$$

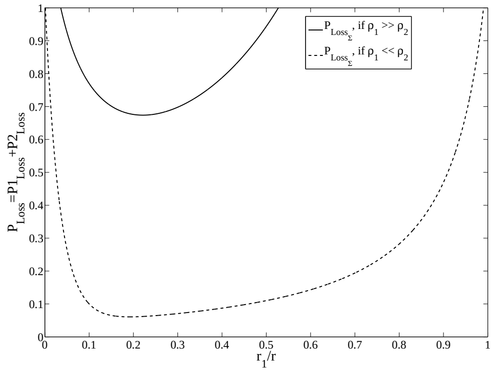
In the second case, the first addend is changed by the factor $\frac{1-\rho_A}{1-\rho_A^{r_x+1}}$, and the second one by the factor $\cong \frac{1}{\rho_B}$.

Reasoning from this, the second strategy of assigning the priorities is disadvantageous. Hence follows the conclusion: the priority should be given to the flow that produces less communication system load.

This conclusion is supported by the plot given in Fig. 14a The advantage of giving the priority to the flow that produces a smaller load becomes more evident with the increase in the loads' ratio, as well as with the increase in the servicing time variation (Fig. 14b).



(a) $v_1 = v_2 = v = 1$



(b) $v_1 = v_2 = v = 2$

Figure 14: Total probability of the packet loss. The load produced by the first flow equals 0.8 and that by the second flow, 0.1, where $r = 31$. The solid line stands for the priority being given to the first flow, and the dashed one, to the second flow.

To determine the optimum buffer storage capacity $r_i^*(i = \overline{1,n})$ for competing flows the dependency of the ratio of the storage capacity provided to the first flow to the total storage capacity $(r_{opt}/K(\rho))$ can be constructed.

The optimal value of the buffer storage capacity allocated to the preemptive flow is determined from a family of plots similar to the ones presented in Fig. 14a and Fig. 14b The absence of an analytical expression for computing the optimal value r_{opt} makes us either use a previously computed table of optimal values or employ numerical methods.

Simulation framework OPNET is used for testing some of the previously mentioned recommendations. Further, the basic description and structure of block scheme of the proposed complex of algorithms for the realization of $iMBAC$ orientated for the self-similar traffic.

Chapter 6 Simulation of Intellectual MBAC system

The developed $iMBAC$ module can be described using the following three submodules:

1. Measurement module that fixes the inflow of packets to the system. At the moment of income the analysis of it's header occurs. Than a belonging to the current session gets

determined. In case it is found, the information about the packet header is transferred to the third module, the one which accommodates the measurements. If the packet does not belong to any of existing connections, the packet require a new connection establishment. In this case the requirements for quality guarantees are transmitted to the second module. The schema of the submodule is depicted in Fig. 15

2. The module that decides whether to support the incoming connection. It calculates the capability of the communication system to provide the quality guarantees necessary for the new connection without diminishing the quality of service of the existing connections. The decision is made on the base of accumulated statistics about system utilization. In case the support can be provided, the packet that initializes the connection gets forwarded and the information about it is sent to the third module. The schema of the submodule is depicted in Fig. 16.

3. The measurement accumulating module. Receiving the information from the previous modules it makes a decision about the necessity of saving this information to provide the decision taking module with correct statistics. As it was described above, only the accumulation of those data that overcome the borders of the previously accumulated data correlation interval is needed for accurate statistics. The schema of the submodule is depicted in Fig. 17

In order to verify the conclusion and recommendations MBAC module for simulation OPNET environment has been developed. For MBAC function realization in OPNET a Real-Time Traffic Analyzer (RTTA) module has been integrated. The main objective of RTTA is traffic capturing, sniffing and store. It consists of two cross-dependent sub-modules: traffic measurement and traffic estimator. The model presented is characterized by low system overheads for real-time traffic parameters estimation and can be used either within IntServ or DiffServ approaches.

Data are being processed as described in Fig. 18. Fig. 18 depicts a major data flow diagram of the data processing. This diagram presents a holistic view of the MBAC model. *Data Capturing* deals with measurement of the established flows. The responsibility of the *Analyze* is to estimate traffic parameters of the measured traffic. The function of a *Forecasting* module is to predict the network traffic. The *Decision Enforcement* module implements admission control functions. Admission decision is enforced basing on the estimated and forecasted traffic parameters. Decision enforcement regarding the packet affects if the packet will be transmitted or dropped.

In the proposed model a noticeable reduction of the overheads is achieved by *Data Capturing* process. The *Packet Analyze* module analyzes the head of the packet. If the packet belongs to the data session with ”captured” status then the information about the packet will be collected in *STORE* object. Otherwise the information of the packet will be ignored. We

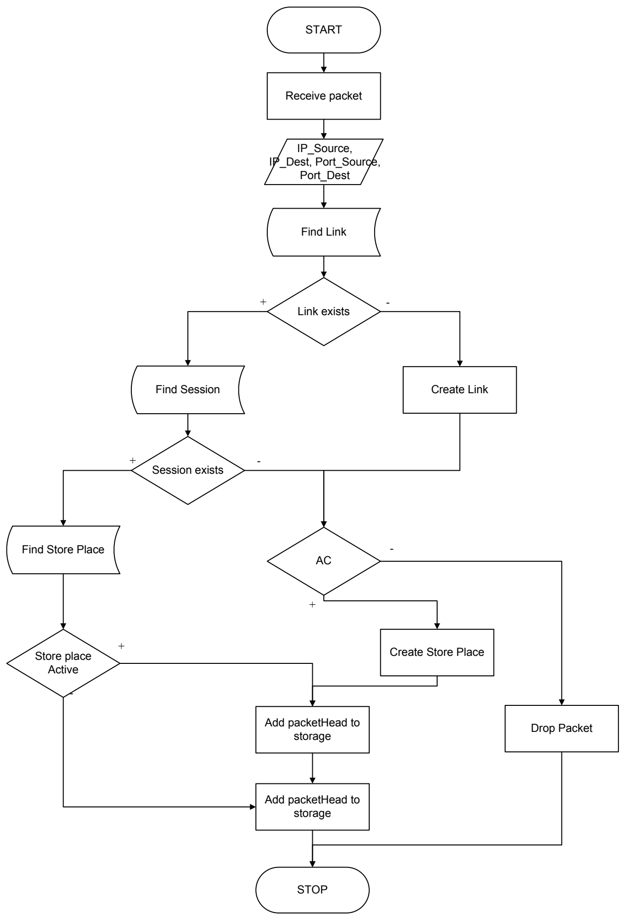


Figure 15: iMeasurements

suggest creating interrelated *Data Capturing* and *Analyze* components in the way that estimated parameters have impact on the measurement process.

The capturing process is depicted on the Fig. 19a diagram. The responsibility of *Force Capturing* component is to control corresponding time and correlation interval.

The model was designed taken into account that the parameters estimation could be applicable to the session or to the whole link. It corresponds to the Object that is transmitted to the *Data Estimator* and is depicted in the Fig. 19b

We suggest organizing *STORE* data storage element in the native network way where a variety of packets belongs to one session, whereas variety of session belongs to the link. The network equipment could have more than one link connection. Packet heads of the same session and on the same correlation interval are collected to the same Packet Head Collection (PHC). Variety of PHC with the same session ID fully describes the characteristics of a session. And finally, the variety of the sessions with the same link ID can fully describe link characteristic. An example of object-oriented implementation is presented in Fig. 20

Further, the description of scenarios used for testing of the proposed methods.

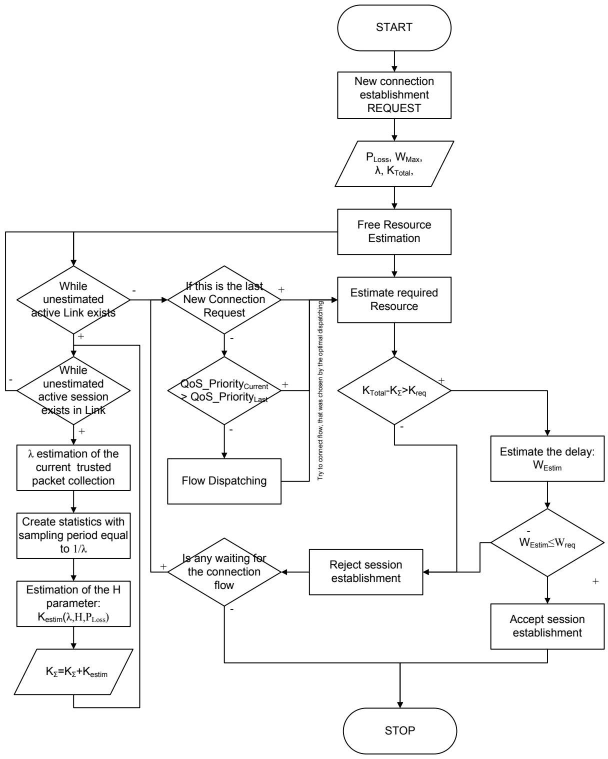


Figure 16: iAdmission Control

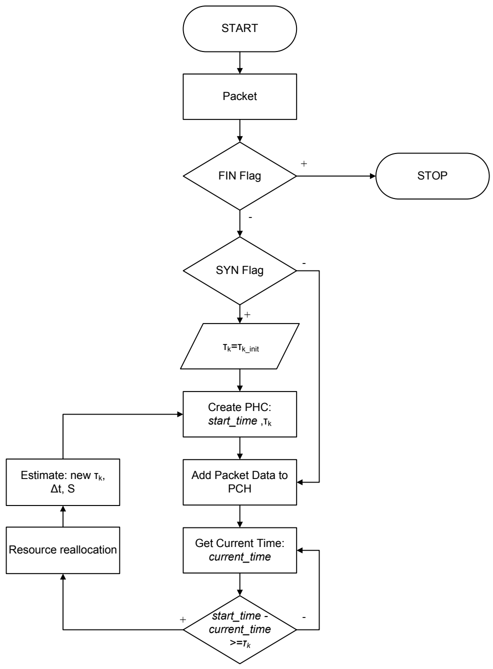


Figure 17: iPHC

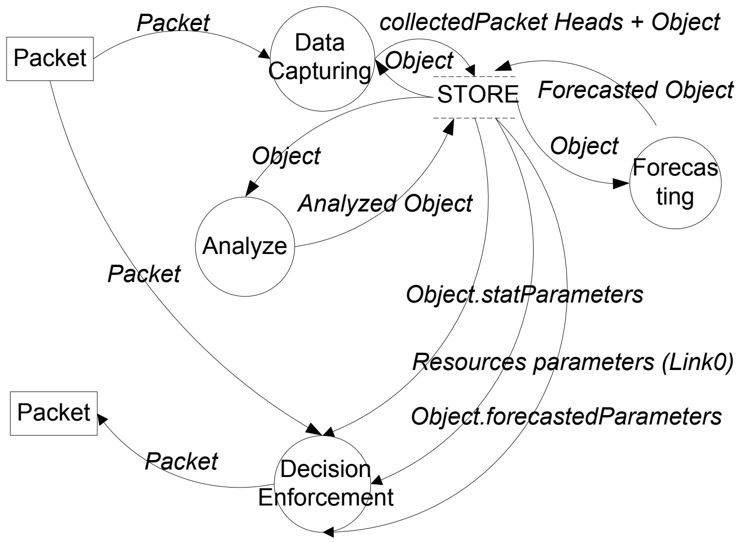
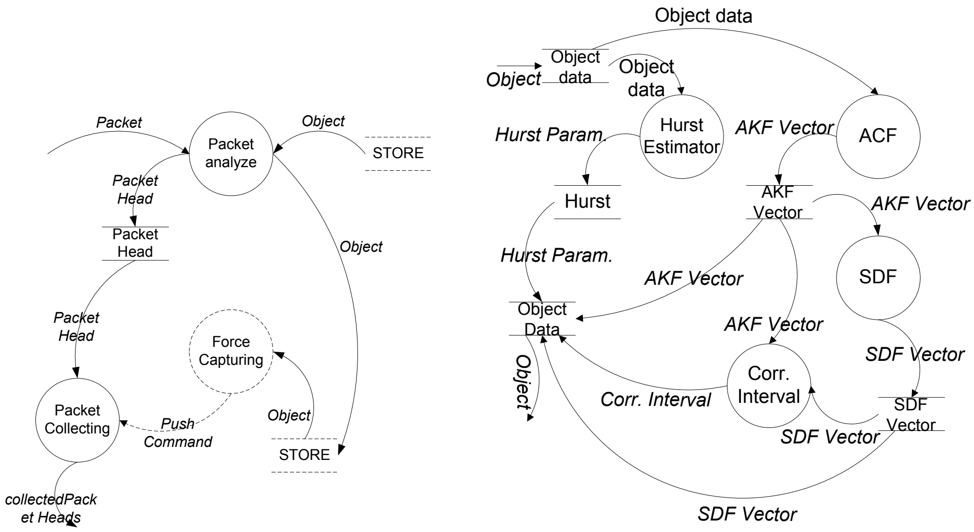


Figure 18: Data processing DFD



(a) Data capturing DFD

(b) Data analyzing DFD

Figure 19: Data flow diagram

Fig. 21 presents the structural scheme of the scenario telecommunication network. For testing of the effectiveness of recommendations for the managing MBAC algorithm switch parameters, in particular bandwidth, were chosen as understated on purpose.

The modality of MBAC model utilized allows adding another measurement, estimation and policy algorithms effortlessly.

The current version realized the following estimator and policy algorithms:

- Simple policy Policy of AC-AR (P-AR) based on the system load coefficient

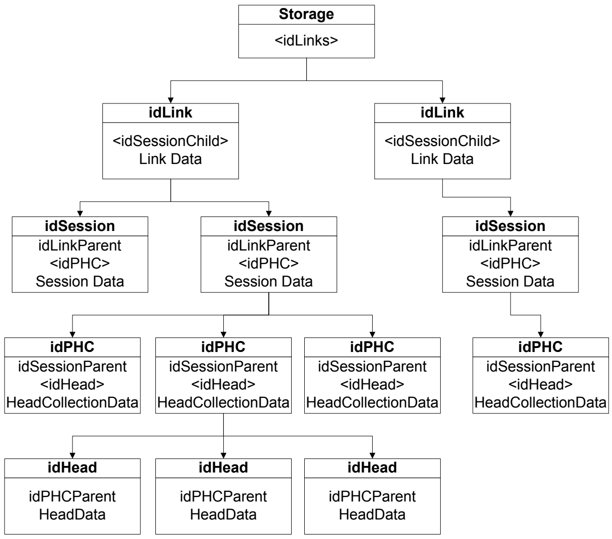


Figure 20: The storage hierarchy

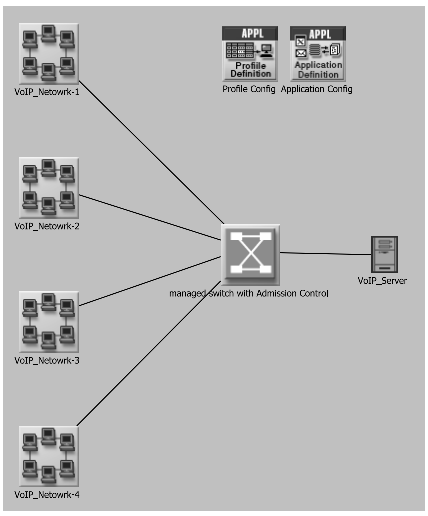


Figure 21: The OPNET Project for VoIP Scenario

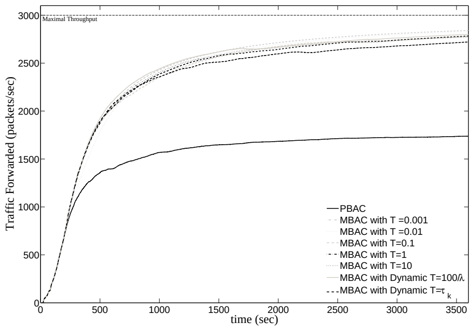
- Utilization parameter is estimated according to the Instantaneous Utilization (E-IU) method

The model realizes 4 measurement algorithms:

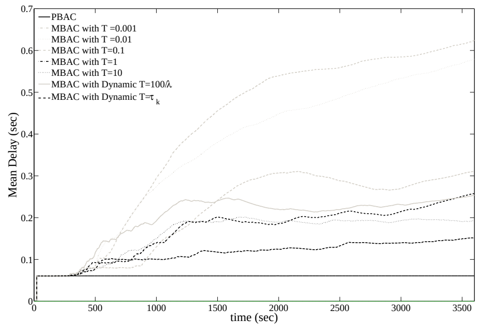
- Static - measurement interval is set before launching and remains unchanged all the time during the simulation.
- Dynamic - measurement interval is chosen depending on the intensity of the incoming flow.
- Second dynamic method where measurement interval equals the correlation interval.

- Third dynamic method is the advanced version of the previously mentioned one. The improvements regard system load decrease related to the measurements.

Results: Fig. 22a and 22b present the modeling results and dynamic of changes of the average throughput and packet delay in the queue at the central managed switch. Simulated were the following admission control methods with simple policy P-AR and E-IU estimator.



(a) The mean value of throughput

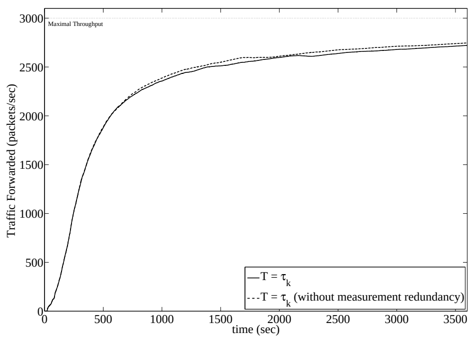


(b) The mean value of delay in queue

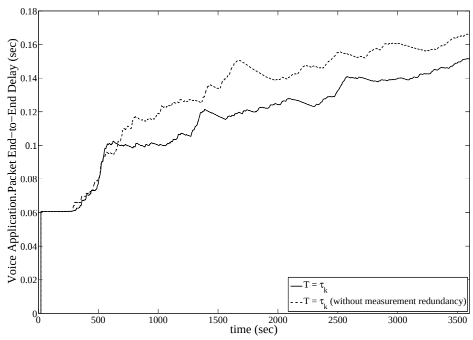
Figure 22: The mean values for different AC mechanisms

The comparative results of network performance under the usage of managing algorithm with measurement window equaling correlation interval with the same algorithm but decreasing the redundancy of measurements are described following.

Fig. 23a shows that for both cases the number of active sessions and utilization are very close. From Fig. 23b we can conclude that whilst the measurement redundancy decreases, the delay increases, however it remains acceptable. Evaluating the simulation results, we can argue that such an approach reduces the number of necessary measurements for $\approx 17\%$.



(a) The Traffic Forwarded by managed switch



(b) The End-to-end Delay of Voice Application

Figure 23: The comparison of proposed methods

The results match the hypothesis that the best results can be gained while adaptive to traffic parameters window measurement is applied. The best window measurement equals correlation interval $T = \tau_k$. Also, simulation results prove that the costs of the correlated traffic, related to measuring process, can be decreased.

Chapter 7 Conclusions

The work presents the recommendations for development of managing algorithms that provide the increase of network performance while ensuring quality of service guarantees.

The specialty of the proposed algorithms is that they take into account the bursty character of the traffic. Using the queuing model with the bursty incoming flow, the algorithm of choosing the optimal size of structural units of the telecommunication system, such as buffer size and bandwidth, has been elaborated. It allows choosing the structural unit at the stage of designing the communication system under the specified P_{Loss}, thus - minimizes the expenses.

The work has presented recommendations how the mentioned algorithm may be applied to minimize the costs during the exploitation of the communication system. It can be achieved by resource redistribution so that the most expensive resource is used minimally.

Bursty traffic negatively influences the network performance. Interconnection of several flows of group character into one produces a substantial gain, because of the low probability that the bandwidth will equal the sum of the peak speeds of the separate flows. Thus, the network utilization can be enhanced under the condition when the service guarantees at P_{Loss} parameter are met, as the gain from the flows connection can be used for additional flows.

It has been claimed that the bursty traffic negatively influences the network performance. Also, multiplexing several flows with bursty character into one produces a significant gain, as the probability that the used bandwidth represent the sum of peak rates of the individual flows is very low. Therefore, the network utilization can be advanced by fulfilling quality guarantees respectively to P_{Loss} due to the benefit gained from combining the flows which can be used for connection additional flows.

The connection of the flow is possible only in case of sufficient number of resources. The work provides the algorithm of choosing the connected flow in the situation when there are no enough resources for connection of all the same priority simultaneously incoming flows. In order to estimate available resources it is suggested to use direct system load measurement. The recommendations for choosing the measurements window and sampling period are developed in the work. In addition, the recommendations regarding the decrease of the system load which is directly related with the measurement process can be found in the research.

The proposed recommendations were tested using the logical and structural MBAC scheme which has been realized in modeling framework OPNET. The modeling results have confirmed the recommendations elaborated previously.

Further research: The recommendations and results of the present work give significant scope for future work and especially in wireless environment.

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