Relations between ATM traffic parameters and quality of multimedia transmission – an experimental approach

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Abstract — In the paper, we present the results of research of MPEG-2 streams transmission through CBR and VBR channel in ATM network. We applied not only experimental and measurement methods but analytical ones as well. A description of the proposed measurement station includes: installed hardware, created software and prepared experimental data. Next, we present the applied measurement method. In the following section, we define a term of the quality of multimedia transmission. The measurement results were compared with the results of the analytical station model. We proposed a functional description of dependence between ATM traffic parameters, video stream bit rate, and quality of multimedia transmission.

Keywords — multimedia transmission, quality of service, traffic parameters, MPEG-2, ATM, CBR and VBR.

1. Introduction

Applications of real-time multimedia services like videoconferences or video on demand has been lately widely discussed. Such services require much more bandwidth than traditional data transmissions. In the case of multimedia transmissions, besides the bandwidth, the important factors are: low loss rate, bounds of end-to-end delay, and delay variation. On the other hand, a lot of users should share network resources. Network operators ought to find a compromise between a number of users and quality of transmission. Network technology employed to real-time multimedia transmission has to guarantee quality of service (QoS). Currently, the only one native technology assuring QoS on a large topographically area is asynchronous transfer mode (ATM). There are two categories of services in the ATM for real-time communication: constant bit rate (CBR) and variable bit rate (VBR). The both categories are described by combination of traffic parameters and QoS parameters called a traffic descriptor. The CBR traffic descriptor is simpler than the VBR traffic descriptor but the VBR category is potentially more efficient than its CBR counterpart in terms of network resources utilization. Additionally, the traffic descriptors are not always easy to understand clearly for end users who pay operators for their services. Moreover, it is difficult to predict traffic descriptors of encoded multimedia streams.

In this paper we propose an application of relative simply functional dependencies for efficiently bandwidth management in ATM networks. The obtained dependencies were drawn from experimental results. In our experiments we transmitted MPEG-2 streams both in CBR and in VBR ATM channels. The MPEG-2 streams were classified into various categories. Moreover, we made an analytical model of the station to compare with measurement results. The found dependencies can be an alternative for complex analytical and statistical models.

2. Testbed and samples of streams

The experimental research was performed on a testbed configured in the Laboratory of Computer Multimedia Systems at the Institute of Theoretical and Applied Informatics of PAS. The station included the server providing video on demand service, three workstations as clients of this service with prepared measurement software and an ATM network analyser. The components were connected through an ATM network built with three switches. Samples of multimedia streams we prepared on the encoding workstation with a built-in real-time MPEG-2 coder. The schema of the station is shown in Fig. 1.

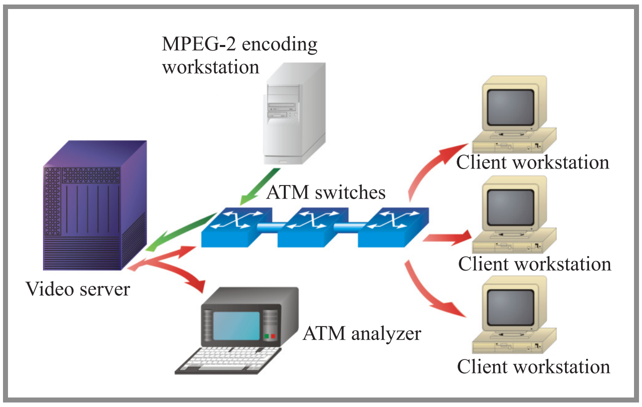

Fig. 1. The schema of the testbed and information flows.

We made use of software, called the Oracle Video Server, to build the station. Its most important feature is an access to stored MPEG streams in the real-time [7]. We took advantage of this feature and we wrote software to collect measurements automatically. The software is composed of two parts called transmitter and receiver. The transmitter reads a stream from a disk (possibly it separates audio and video streams) and sends it to the receiver in the real-time. The receiver stores delivered data, especially time stamps of received frames with 10^{-6} s precision, for statistical analysis and prepares general statistics. The structure of the software and an information flow is presented in Fig. 2.

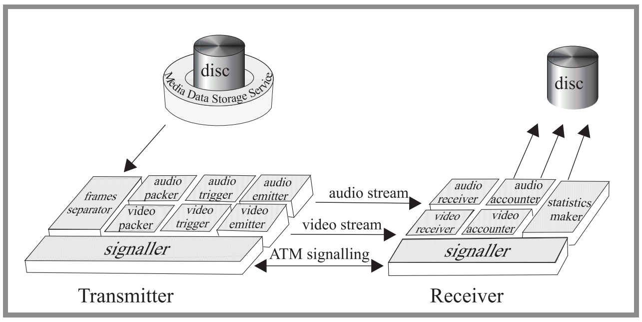

Fig. 2. The structure of the transmitter and the receiver programs and information flow between them.

For the experiments we prepared samples of different kind of multimedia streams. We classified them from the point of view of their contents. There were:

– video clip,

– sport (a football match),

– action film,

– news,

– cartoons,

– talk show,

– slow-motion sequence.

In our work we applied the main profile and the main level (MP@ML) of MPEG-2 encoding. The samples were encoded with both constant and variable bit rate [3]. The samples had the bit rate varying from 2 to 15 Mbit/s. For the CBR streams, we modified a value of the peak bit rate, for the VBR streams we changed a value of the average bit rate while the peak bit rate remained constant: 15 Mbit/s. We prepared 112 samples of the streams each of 10 minutes playtime. A source for the samples was the PAL system, so each sample consisted of 15 000 frames.

3. Measurement method

There are two methods to measure cell delay and cell delay variation [1, 2]: the two-points method and the one-point method. The first method requires synchronized clocks on input and output of a communication channel because a measurement is made on both ends of channel. In the second method, time is registered only on the output of channel. Therefore, the one-point method is simpler to implement. A disadvantage of the one-point method is that it is sensitive to congestion in the network or to contract violation. If there is not congestion in the network, both the methods are equivalent. To apply the one-point method we had to prepare dedicated experiments. We added an extra bandwidth during the connection setup procedure. To set the value of this bandwidth we used an experimental approach. For video streams the value of "extra bandwidth" was 5% of the base bandwidth. In the experiments, we used the ATM analyser, which allowed us to observe losses and delays of cells. The concept of measurement is shown in Fig. 3.

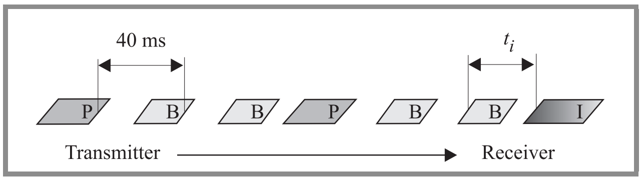

Fig. 3. The concept of measurement in the implemented one-point method.

4. Quality of multimedia transmission

There are two fundamental parts in a multimedia path that determine of quality of multimedia communication: one is independent and the other is dependent on transmission. The first part includes: acquisition, encoding, decoding, and presentation. The second part is related to transmission of encoded multimedia streams with real-time relations. In our work we investigated only the second part. In this part quality of multimedia communication depends on: end-to-end delay, delay variation, and error tolerance.

Our software collects the time stamps of received video frames. We made use of them to calculate the average time space between frames; afterwards we estimated the variation and the standard deviation of this time interval. In our experiments we did not notice any frame losses because we had applied "the extra bandwidth", so we assumed that in our case the measure of quality of multimedia transmission is the standard deviation of frame delay.

5. Model of testbed

To compare with the experiments, we prepared a simple analytical model of the testbed to verify the obtained results.

The model works as follows:

– number of packets for one video frame is calculated;

– amount of control data (packets and cells headers, trailers, AAL data) for the frame is calculated;

– packet series with single frame (or a previous frame is continued) are sent every 40 ms;

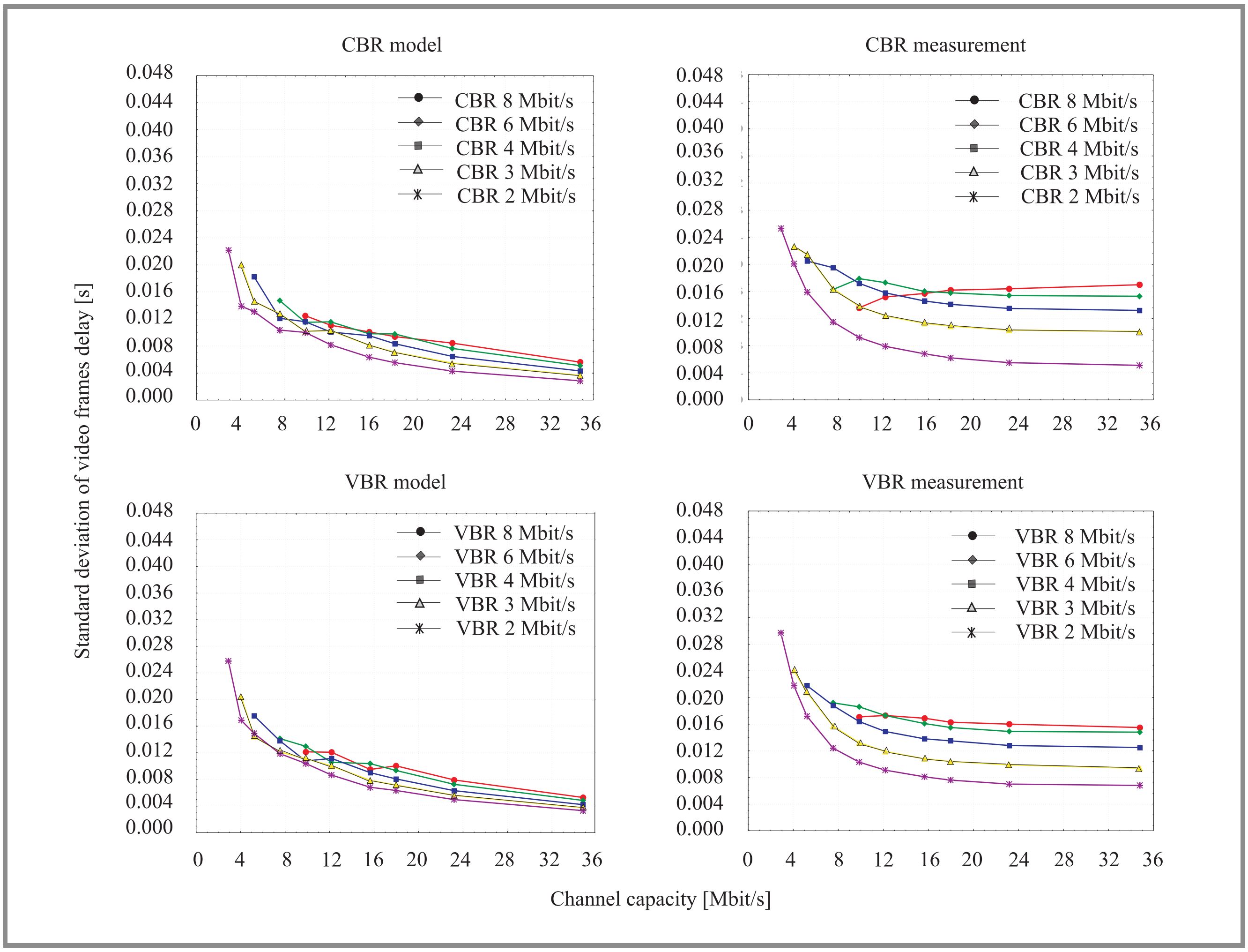

Fig. 4. The standard deviation of frames delay from the model and from measurements for CBR and VBR news streams.

- transmission time of the video frame and the burst size are calculated relating to the applied bandwidth;
- the above algorithm steps are repeated for all video frames;
- the average burst size is calculated and the standard deviations of video frames delay and of burst size are estimated.

6. MPEG-2 streams transmissions through CBR channel

In the experiments with CBR channel we were looking for dependencies between the traffic parameters, the video stream bit rate and quality of multimedia transmission expressed by standard deviation of video frames delay. In case of CBR connection there is only one traffic parameter called peak cell rate (PCR). We divide the experiments into two parts. The first part concerns the experiments with the model of the station; the second one regards practical experiments. We made use of seven kinds of the multimedia streams encoded both as CBR and as VBR with 2, 3, 4, 6 and 8 Mbit/s bit rate. We applied 376 octets packet size.

In Figs. 4, 5 we present some selected results of the experiments. They illustrate the dependence between the standard deviation of video frames delay and the channel capacity. The pictures on the left side of the figures show the results of model experiments, the pictures on the right side show the results of measurements. The upper pictures concern CBR streams, the pictures on the bottom concern VBR streams. In Fig. 4 the results are classified by stream bit rate and in Fig. 5 we present the results according to the types of stream contents.

In the figures we see that the value of the standard deviation is increasing together with growing video stream bit rate. The biggest differences are for the streams with a low bit rate (2, 3 Mbit/s). The results are similar for a higher stream bit rate. We observe a threshold about 18 Mbit/s. Increasing the bandwidth over the threshold has a weak influence on the standard deviation of frames delay. We

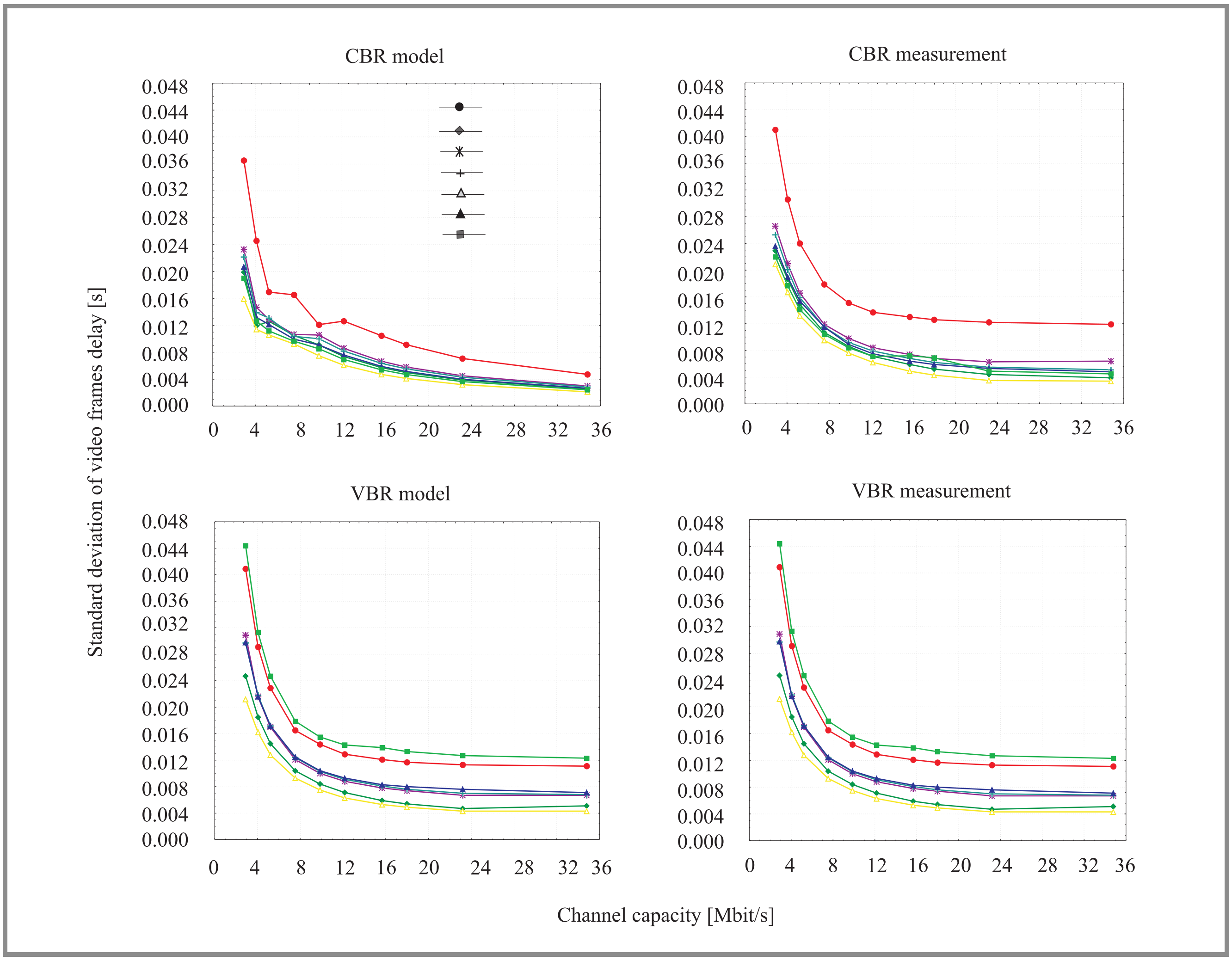

Fig. 5. The standard deviation of frames delay from the model and from the measurements for CBR and VBR 2 Mbit/s bit rate streams.

notice a strong hold of the increasing bandwidth for the streams with lower bit rate.

The comparison of the results illustrates adequately impact of operating system mechanism and communication mechanism (before all the "traffic shaper" mechanism) upon the standard deviation of frames delay. The mechanisms "shape the curves" and augment values of the standard deviation.

In the second part of the experiments, we were looking for dependence between the value of PCR and the quality of multimedia transmission. After heaving performed some initial experiments we set the hypothesis that the dependence may be expressed as a linear combination of functions depending on modified parameters in the experiments:

$$f_{\mathrm{CBR}}(x,y) = f_{\mathrm{NS}}(x) + f_{\mathrm{PCR}}(y), \tag{1}$$

where f_{CBR}, f_{NS}, f_{PCR} – the standard deviation of video frames delay [s], x – video stream bit rate [Mbit/s].

The goal of the next research was verification of this hypothesis. We made use of the nonlinear regression methods to check dependences using the following functions:

$$f_1(x,y) = a_1 \mathrm{arctg}\,(a_2 \ln x + a_3) + \\ + b_1 \mathrm{arctg}\,(b_2 \ln y + b_3) + c\,, \tag{2}$$

$$f_2(x,y) = a_1 \mathrm{arctg}\,(a_2 \ln x + a_3)^2 + \\ + b_1 \mathrm{arctg}\,(b_2 \ln y + b_3)^2 + c\,, \tag{3}$$

$$f_3(x,y) = a_1 \mathrm{tgh}(a_2 x + a_3) + \\ + b_1 \mathrm{tgh}(b_2 y + b_3) + c\,, \tag{4}$$

$$f_4(x,y) = \frac{1}{a_1 + a_2 x} + \frac{1}{b_1 + b_2 y} + c\,, \tag{5}$$

$$f_5(x,y) = \frac{a_1}{a_2 + \sqrt{a_3 x + a_4}} + \frac{b_1}{b_2 + \sqrt{b_3 y + b_4}} + c\,, \tag{6}$$

$$f_6(x,y) = \frac{a_1}{a_2 + \mathrm{e}^{a_3 x}} + \frac{b_1}{b_2 + \mathrm{e}^{b_3 y}} + c\,, \tag{7}$$

$$f_7(x,y) = \frac{a_1}{a_2 + e^{a_3 x + a_4 x^2}} + \frac{b_1}{b_2 + e^{b_3 y + b_4 y^2}} + c\,, \qquad (8)$$

where a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4, and c are function parameters.

We applied the coefficient of determination of regression model (R2) in evaluation of approximation results. However, we took note not only of values for single approximation but the values for all types of streams approximated by the defined function. Among functions listed above we obtained the best results of approximation for the function f_6 stated by formula (7).

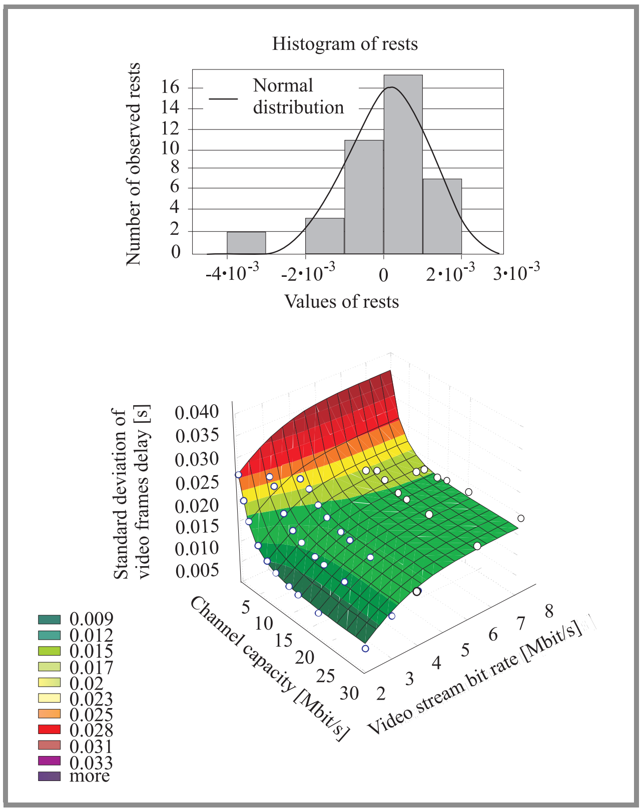

Fig. 6. The standard deviation of frames delay according to video stream bit rate and channel capacity for CBR streams.

For example, in Fig. 6 we present the area for the CBR streams. The formula (9) describes this area. On the X axis is video stream bit rate, on the Y axis is channel capacity, and on the Z axis is the standard deviation of video frames delay. The histogram of rests after the approximation is in the upper left corner of the figure. It is presented to take into account the quality of approximation. The rests which have values close to zero are the most numerous:

$$f_C(x,y) = \frac{1}{-41{,}75 - 10{,}12\,e^{0{,}879x}} + \\ + \frac{1}{-45{,}34 + 55{,}94\,e^{0{,}185y}} + 16{,}21 \cdot 10^{-3}\,. \qquad (9)$$

The functions can be applied to interpolate in range from 2 to 8 Mbit/s for the video stream bit rate and from 2.9 to 34.8 Mbit/s for the channel capacity. The functions are defined for these ranges.

7. MPEG-2 streams transmissions through VBR channel

In the experiments with VBR channel we were looking for dependencies between the traffic parameters, the video stream bit rate, and the quality of multimedia transmission similar to the experiments with CBR channel. However, in the case of VBR connection there are three traffic parameters called: peak cell rate, sustainable cell rate (SCR), and maximum burst size (MBS). After observation of some initial experiments we set the hypothesis that the dependence may be written in a form of a linear combination of functions depending on modified parameters in the experiments such as in the CBR channel case:

$$f_{\mathrm{VBR}}(v,x,y,z) = f_{\mathrm{PCR}}(v) + f_{\mathrm{MBS}}(x) + \\ + f_{\mathrm{SCR}}(y) + f_{\mathrm{NS}}(z)\,, \qquad (10)$$

where f_{VBR}, f_{PCR}, f_{MBS}, f_{SCR}, f_{NS} – the standard deviation of video frames delay [s], v – traffic parameter PCR [c/s] (cells per second), x – traffic parameter MBS [c], y – traffic parameter SCR [c/s], z – the average video stream bit rate [Mbit/s].

The experiments we divided into three parts:

1) finding dependence between MBS, SCR, and the quality of multimedia transmission;

2) finding dependence between MBS, SCR, the average video stream bit rate, and the quality of multimedia transmission;

3) finding dependence between MBS, SCR, PCR, the average video stream bit rate, and the quality of multimedia transmission.

In the first part we approximate the estimated standard deviation of video frames delay. In order to approximate this parameter we use the same functions as in CBR channel experiments. We applied also the same method of evaluation. The best results of approximation we got for function f_4, Eq. (5). For example, in Fig. 7 we present plane for the news streams described by formula (11):

$$f_{\mathrm{CBR}}^{News}(x,y) = \frac{1}{382 + 0.231x} + \\ + \frac{1}{62.56 + 3.098 \cdot 10^{-3} y} - 2.129 \cdot 10^{-3}\,. \qquad (11)$$

On the X axis is MBS, on the Y SCR and on the Z axis is the standard deviation of video frames delay.

In the next part, we extended the function f_4 to include of the video stream bit rate in approximation (12):

$$f_V(x,y,z) = \frac{1}{a_1 + a_2 x} + \frac{1}{b_1 + b_2 y} + c_1 e^{-c_2 z} + d\,. \qquad (12)$$

As before, we approximated the estimated standard deviation of video frames delay. The formula (13) formulates the

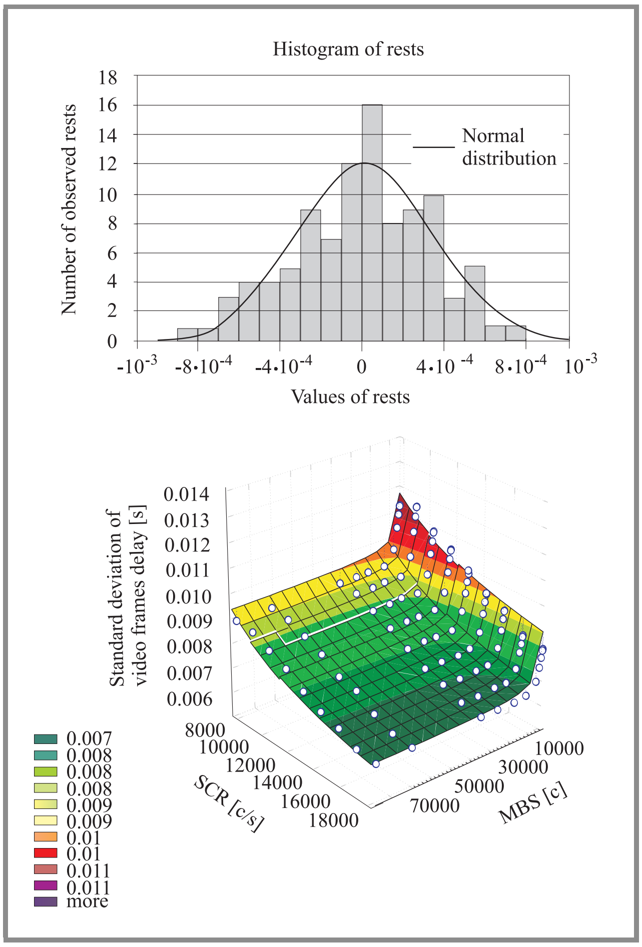

Fig. 7. The standard deviation of frames delay according to MBS and SCR for the news stream with 2 Mbit/s average bit rate.

searched dependence for the selected news streams:

$$f_{\mathrm{VBR}}^{News}(x,y,z) = \frac{1}{504.9+0.218x} + \\ + \frac{1}{58.93+8.629\cdot 10^{-3}y} + \\ +48.20\cdot 10^{-3}\mathrm{e}^{-7.274\cdot 10^{-3}z} - 45.68\cdot 10^{-3}\,. \quad (13)$$

In the third part of experiments we were looking for dependence between values of PCR and the quality of multimedia transmission. We performed the experiments for two values of MBS: 171 and 17100 cells. We set values of SCR according to the video stream bit rate. The results of the experiments are illustrated in Fig. 8.

We observe a threshold in the figure. The threshold appears clearly for the higher value of MBS. Additional experiments showed that the threshold appears for values of PCR equal to doubled values of SCR. We decided that we could use this dependence (14) in the following discussion and would not extend the approximating function:

$$\mathrm{PCR} = 2\cdot \mathrm{SCR}\,. \quad (14)$$

To make use of economical properties of the VBR category of service we should know efficiency combination of values

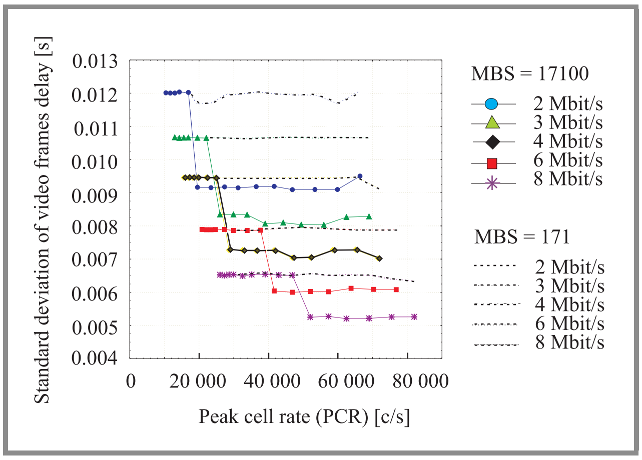

Fig. 8. The standard deviation of frames delay as a function of PCR.

of traffic parameters. The effective use of band-width depending on the values of traffic parameters has been already researched. The proposed dependences are based on queueing analysis and they are called: the effective bandwidth. In our discussion we applied the effective bandwidth prepared by Elwalid and Mitra and described in formulas (15–18).

$$\delta = -\ln \mathrm{CLR}, \quad (15)$$

$$\gamma = \mathrm{PCR}, \quad (16)$$

$$\eta = \frac{\mathrm{PCR}}{\mathrm{ABS}}, \quad (17)$$

$$\lambda = \eta\,\frac{\mathrm{SCR}}{\mathrm{PCR}-\mathrm{SCR}}, \quad (18)$$

$$\beta = \frac{\lambda\gamma}{\lambda+\eta} + \frac{\delta\lambda\eta\gamma^2}{Buf\cdot(\lambda+\eta)^3}, \quad (19)$$

where CLR – cell loss ratio, ABS – average burst size.

It is important that in the equations for the effective bandwidth we use the ABS parameter while the applied in ATM network traffic descriptor is the parameter MBS. Therefore, we should define some relationship between them before we apply the effective bandwidth. For example, we can apply with the limited domain normal distribution whose the maximum value of arguments is equal to MBS and the mean value is equal to ABS. We made use of the burst sizes collected using the station model to define the dependence between ABS and MBS. We applied a lognormal distribution to do it. Having the equations for the quality of multimedia transmission (12, 14) and for "the effective bandwidth" (19) we can solve them numerically in order to answer various practical questions. For example, what values should have the traffic parameters to utilize efficiently the bandwidth while the standard deviation of video frames delay should not have value greater then 8 ms.

8. Conclusions

In this article, we discuss possibility of using an experimental approach to allocate better bandwidth to the real-time MPEG-2 streams transmissions. We investigated transmission features for both CBR and VBR connections. In the experiments we applied the MPEG-2 streams with various type of contents, encoding, and bit rate. We proved that the dependence between the quality of multimedia transmission and the traffic parameters can be described as a line combination of functions depended on the modified parameters. Finally, we proposed application of the effective bandwidth together with our formulas for efficiently bandwidth utilization. They can be applied, for example, while negotiations between an end-user and his Internet Service Provider.

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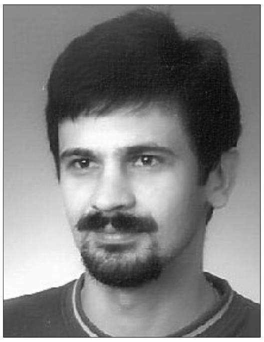

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