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Resource Allocations Protocols Impact on MPEG Sequence Quality

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Abstract

MPEG-2 video compression is the standard retained for video applications. Two encoding schemes are defined: open-loop and closed-loop. In this paper, some characteristics of the two MPEG encoding schemes are studied. We observe through the carried experiments that, with the same mean rate, open-loop encoding quality is better and less variable than closed-loop encoding quality. The ITU and ATM-Forum have defined ATM transfer capabilities in order to transport a wide variety of traffic classes. The impact of ATM contracts on the quality of a MPEG sequence is investigated. We show that the sequence quality is less damaged by reducing image size at the encoder level with ABT/DT contract than by a random cell loss inside the network with rt-VBR contract. Finally, we present a novel mechanism for real-time video transmission over ATM networks based on the elastic version of ABT/DT contract.

Keywords

MPEG, sequence Quality, ATM traffic contracts, resource allocation, FRP, ABT

1 INTRODUCTION

Performance and Management of Complex Communication Networks
T. Hasegawa, H. Takagi & Y. Takahashi (Eds.)

The development of multimedia applications relies on the deployment of broadband integrated services data networks (B-ISDN) such as ATM and the improvement of video compression techniques. The MPEG-2 video compression standard defines a generic video coding method for a wide range of application, bit rates, resolution, quality and services (ISO/IEC1994). To achieve a high compression ratio and then reduce the required resources for video transmission over broadband networks, the redundancy in natural video sequences needs to be removed as much as possible. MPEG compression is achieved through different techniques : discrete cosine transform (DCT), movement prediction and compensation, quantization and variable length coding (Huffman coding) (Le Gall 1991). DCT method reduces spatial redundancy while movement prediction and compensation removes the temporal redundancy. Combination of quantization and Huffman coding contributes to most of the compression. Researches on the video transmission over B-ISDN have emphasized on the quantization phase. Traffic characteristics depend enormously on the method adopted during this phase. With a constant quantization parameter, the encoding is called open-loop encoding or VBR encoding. The traffic is sporadic and makes the optimization of resource allocation a hard task for the network operator. MPEG Test Model 5 (MPEG-TM5) (ISO/IEC 1993) proposes a method regulating the quantization parameter so as to obtain a constant throughput at the exit of the encoder. The coding is called closed-loop encoding or CBR encoding. Constant bit rate connection is suitable for the transmission of this traffic over an ATM network. However, closed-loop encoding leads to a variable quality while the open-loop encoding induces a near-constant quality. This claim is verified through some results presented in this paper. Multimedia applications requires the guarantee of a good quality by the encoder and the network. Open-loop encoding was then retained for this work. Compression techniques reduce the redundancy in the data to be transmitted thus making multimedia applications also sensitive to data loss. Transport of multimedia data over ATM networks has to be reliable.

According to the International Telecommunication Union (ITU, formerly CCITT) (I371 1995) and the ATM-Forum (ATMForum 1996), the user negotiates a contract with the operator before establishing a connection. Through this contract, the user specifies the characteristics of its traffic, the required quality of service and selects an ATM transfer capability. Video transmission under real time constraints on ATM networks requires the optimization of resource allocation in the network and the guarantee of an acceptable quality by the user. Three ATM transfer capabilities are candidates for the real time video transmission : Constant bit rate (CBR), real-time variable bit rate (rt-VBR) and ATM block transfer (ABT).

The sporadic nature of open-loop MPEG traffic makes CBR contract leads to under-utilization of allocated resources or to a waiting time to the level of the network access. rt-VBR contract would have to allow the operator to profit from statistical multiplexing and thus to increase the number of accepted connections. However, statistical multiplexing gain implies random cell loss in the network. Cell loss can damage the quality of an image and some times all a sequence of images. Note that the encoder have to regulate the quantization parameter so as to be true to the previously negotiated contract (peak rate, sustainable cell rate, maximum burst size).

Different works evoked the possibility to transmit the video through a preliminary reservation of resources (Boyer 1992, Grossglauser 1995, El Henaoui 1996). The protocol we have retained (Gara 1996a) rests on the utilization of the ABT with delayed transmission (ABT/DT) contract or the Fast Reservation Protocol with delayed transmission (FRP/DT) (Tranchier 1993). The basic idea of FRP/DT is to decompose the transmitted data into block. Each block is sent at a constant rate which is negotiated with the network resource management. Before the transmission of a block, the source send a reservation request. With the elastic version of this protocol, the reserved bandwidth can be less than the requested bandwidth by the application. The encoder has to be adapted to take into account this bandwidth reduction. The idea is to look for the best quantization parameter so that the size of the compressed image or the set of images fit the reserved bandwidth. In section 2, a relation between the quantization parameter and the size of an image is proposed.

The utilization of this approach with rigid real time constraints requires first an estimation of the necessary resources for the transmission of an image, a set of images (two, three, . ..) or a group of pictures (Gara 1996b).

We observe through the experiments we have carried that the degradation of the quality of a video sequence following a loss of cells with a rt-VBR contract is more important than the degradation caused by size reduction of one or several images with an ABT/DT contract.

The remainder of this paper is organized as follows. In Section 2, we present some characteristics of a MPEG traffic. The choice of suitable contract for real time video transmission is discussed in Section 3. The impact of rt-VBR and ABT/DT contracts on sequence quality is studied in Section 4. Section 5 introduces a novel mechanism for video transmission. Finally, Section 5 concludes the paper.

2 SOME CHARACTERISTICS OF MPEG TRAFFIC

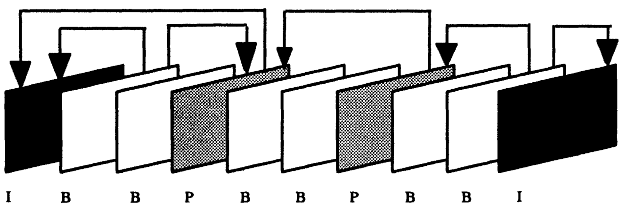


Figure 1 Structure and dependencies in a GOP.

MPEG algorithm decomposes the video sequence into group of pictures (GOP). Three types of images are defined: I, P and B. I Images are obtained by spatial compression (DCT). P and B Images are obtained through a temporal compression. Images P are coded as a function of a previous image (image I or P). Images B are coded according to a previous image (image I or P) and a next image (image I or P) (see Figure 1). Each image is divided into slices composed of macro-blocks. The number of blocks (8 lines x 8 samples) inside a macro-block depends on the adopted chrominance format.

The characteristics of a MPEG traffic are related to the different stages of the compression scheme (see Figure 2). We will be interested mainly in the phase of quantization. The quantization is a technique of compression with a loss of information.

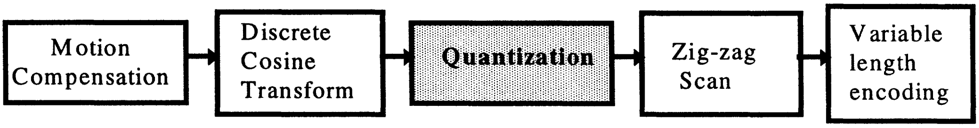


Figure 2 Different stages of the compression.

Quantified coefficients are obtained by an integer division of DCT coefficients by a quantization matrix modulated by a quantization parameter. Quantization matrix is defined before the transmission of the sequence in order to minimize the degradation of the sequence quality. On the other hand, quantization parameter can be adjusted for each macro-block. The number of bits representing the DCT coefficients is reduced and the number of null coefficients is increased.

When the MPEG bit stream needs to be transmitted over a fixed rate channel, closed-loop encoding scheme is applied. A channel buffer is usually used to smooth out the bit stream. In order to prevent channel buffer from overflow or underflow, MPEG-TM5 proposes a rate control method. The quantization parameter is adjusted on a macroblock-by-macroblock basis according to the channel buffer fullness and a block spatial activity measure. A fuller buffer will require a larger quantization parameter while a nearly empty buffer will lead to a much smaller quantization parameter.

Open-loop encoding leads to variable bit rate. The quantization parameter is maintained constant all along the sequence. Many researches assume that the quality of the sequence is near-constant with a constant quantization parameter. Recently, the concept of constant-quality encoding has been introduced in (Dalgic 1995) and further developed in (Dalgic 1996). The proposed scheme called "constant Quality variable bit rate" (CQ-VBR) achieves a constant quality; however this comes at the cost of more sporadic traffic as compared to the open-loop encoding scheme.

Next, we present some characteristics of a MPEG sequence. We investigate a relation between the quantization parameter with the size of compressed image and the quality of the video sequence. We will be based on a 220 images of a basketball sequence captured at a rate of 25 images/s. The GOP was composed of 12 frames and 2 B-pictures between every reference picture (I or P frames). The MPEG encoder has been developed by MPEG Software Simulation Group[1].

[1] The MPEG encoder developed by MPEG Software Simulation group is available via anonymous ftp from: ftp.mpeg.org/pub/mpeg/mssg/ .

2.1 Image size variation

We have carried some experiments to study the image size variation for both CBR and VBR encoding. The basketball sequence was first encoded in VBR with different values of the quantization parameter. For CBR encoding, the encoding rate was positioned to mean rates obtained through VBR encoding. The obtained results are presented in Table 1.

The period of time used to calculate peak rates for VBR encoding is one video frame time (40 ms). A longer averaging time (2 or more frames) would reduce peaks caused mainly by I frames but will increase the end-to-end transmission delay. We noticed that, for the same mean rate, the mean of quantization parameter for CBR encoding can be approximated by the VBR quantization parameter.

Table 1 Rates and quantization parameter for CBR and VBR encoding

VBR encoding				CBR encoding		
Q	mean rate (b/s)	peak rate/mean rate	Mean rate x Q x 10^{-6}	mean rate (b/s)	$\overline{Q}$	σ_Q
15	11 544 178	1.72	173.16	11 544 178	15.5	3.6
20	8 774 867	1.74	175.50	8 774 867	20.4	4.9
25	7 041 465	1.75	176.04	7 041 465	25.4	6.2
30	5 869 802	1.82	176.09	5 869 802	30.3	7.4
35	5 016 612	1.89	175.58	5 016 612	35.3	8.6
40	4 382 997	1.96	175.32	4 382 997	40.1	9.6
45	3 888 937	2.03	175.00	3 888 937	44.9	10.7

2.1.1 MPEG VBR

To adapt the quantization parameter to the amount of reserved bandwidth with the elastic version of ABT/DT contract, we investigate a relation between the quantization parameter and the size of an image. From table 1, we note that for VBR encoding, the product mean rate by the quantization parameter is approximately constant (175.24 ± 1%) :

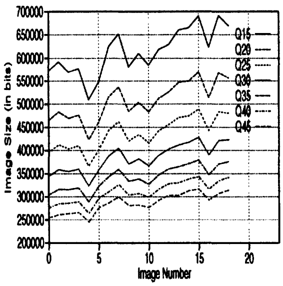
$$Tseq_{Q1} \times Q_1 \approx Tseq_{Q2} \times Q_2 . \qquad (1)$$

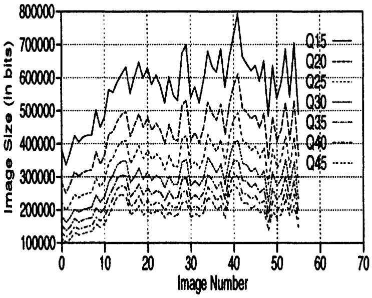
where $Tseq_Q$ is the mean rate of the sequence encoded in VBR with a constant quantization parameter Q . The mean rate seems to be inversely proportional to the quantization parameter.

In (Hamdi 1995), a relation between the size of a GOP and the quantization parameter was proposed:

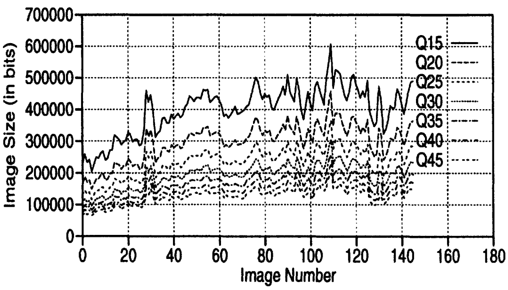
$$TGOP_{Q1}(k) \times Q_1 \approx TGOP_{Q2}(k) \times Q_2 . \qquad (2)$$

where $TGOP_Q(k)$ is the size of the kth GOP coded in VBR with a constant quantization parameter Q. We note from the carried experiments that approximation (2) is valid (maximum relative error is 3%).





a) Images I *b) Images P*



c) Images B

Figure 3 Size of images of the Basketball sequence encoded in VBR

Figure 3 traces the size of images obtained by VBR encoding the basketball sequence for different values of the quantization parameter. Through this figure, we notice that the reduction of the size of an image is proportional to the increase in quantization parameter.

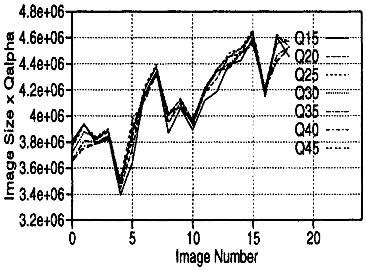
We propose to test the approximation (2) at the image level. Note $T_Q(k)$: the size of the image k encoded in VBR with the quantization parameter Q.

We observe through Figure 4-b that for each image k of type P :

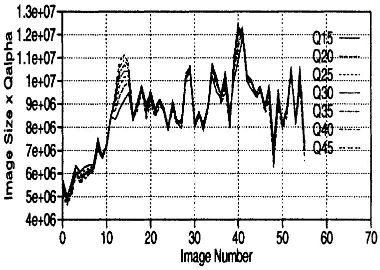
$$T_{Q1}(k) \times Q_1 \approx T_{Q2}(k) \times Q_2 \quad (3)$$

with a mean relative error of 2% and maximum relative error of 6%.

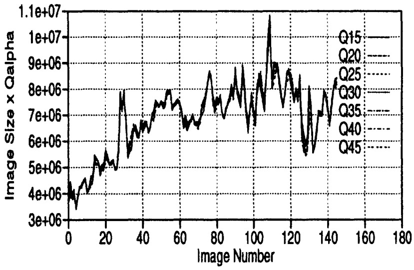
Unfortunately, for I images, the maximum relative error was 13% and the mean error was 10%. For B images, the maximum relative error was 9% and the mean error was 3%.



a) Images I, α=0.70



b) Images P, α=1.00



c) Images B, α=1.05

Figure 4 Product $T_Q x Q^{\alpha}$ - VBR encoding

Then, we have generalised the relation (3) and investigated the following relation :

$$T_{Q1}(k) \times Q_1^{\alpha} \approx T_{Q2}(k) \times Q_2^{\alpha} \text{ with } \alpha > 0 . \quad (4)$$

For I images, with $\alpha = 0.70$, the maximum relative error was 2% (see Figure 4-a). For B images, with $\alpha = 1.05$, the mean relative error was 1% and the maximum relative error was 7% (see Figure 4-c). This relation should be tested for other video sequences.

If the size of an image, quantized first with Q_1, should be decreased, the image have to be quantized with Q_2 obtained through this relation :

$$Q_2 \approx \left(\frac{T_1}{T_2} \right)^{\frac{1}{\alpha}} \times Q_1 . \quad (5)$$

It seems that the size of an image or its entropy is inversely proportional to the quantization parameter.

2.1.2 MPEG CBR

For CBR encoding, the user has to specify the encoding rate. Quantization parameter is regulated through MPEG-TM5 in order to be true to the specified constant encoding rate (see Figure 5).

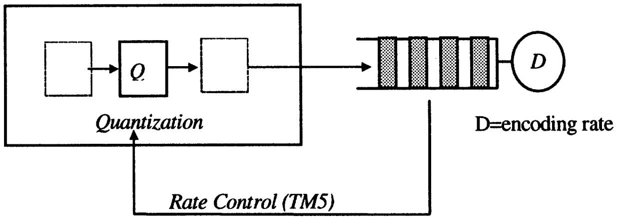


Figure 5 MPEG CBR encoder

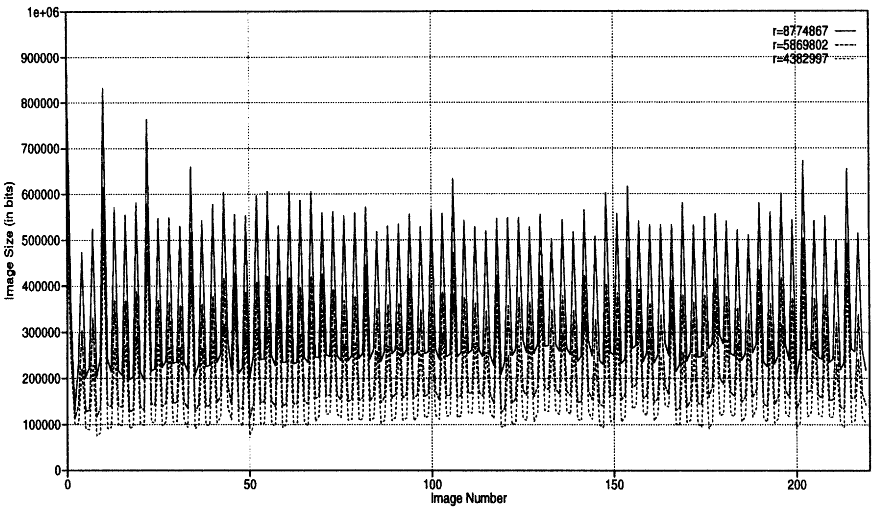


Figure 6 Size of images of the Basketball sequence coded in CBR

Figure 6 traces the size of images obtained by CBR encoding of the basketball sequence for different values of the encoding rate parameter. We emphasize on the fact that MPEG CBR traffic is constant at the output of the encoder but variable inside the encoder. Our experiments shows that image peak size is more than twice the image mean size. To obtain a constant throughput, the MPEG traffic is buffered inside the encoder. The image size variation leads to a waiting time inside the encoder (see Figure 7).

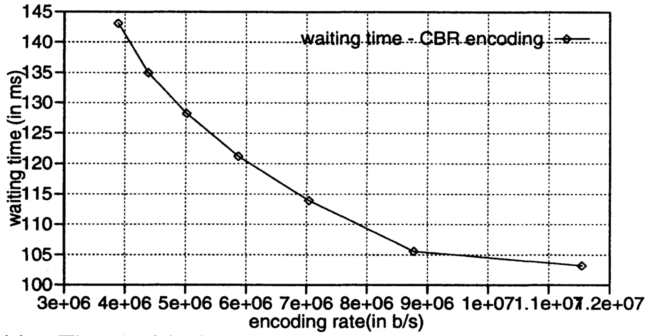


Figure 7 Waiting Time inside the encoder- CBR MPEG encoding

2.3 Sequence Quality

The great interest related to the transmission of numerical animated images on B-ISDN carried forward the study of the quality of images. Video quality assessment plays fundamental role in development of video compression techniques. Peak signal to noise ratio (PSNR) is one of the most well known and widely used quality metrics for video (Netravali 1988). New measures of the quality of the compression are proposed:

- measure of quality of the Institute for Telecommunication Science in Colorado (Webster 1993).
- MPQM developed by the Laboratory LTS at EPFL (Van 1996).

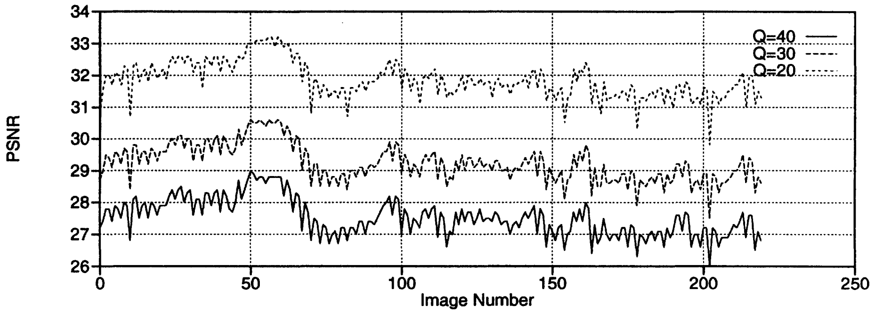


Figure 8...Quality of a sequence coded in VBR

Being not able to have these tools, we will be based in our study on PSNR parameter.

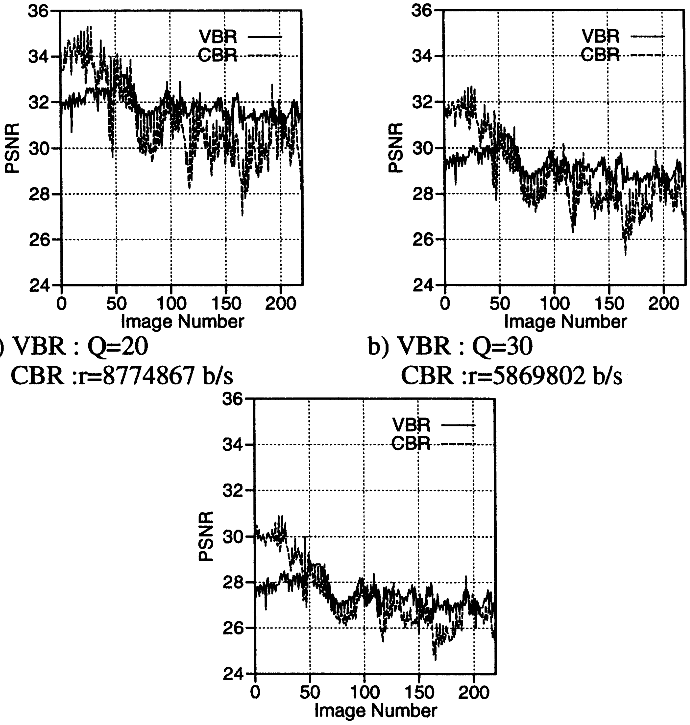
For an image composed of N pixels, the PSNR is calculated as follows:

$$PSNR = 10 \times \log_{10} \frac{255^2}{\sigma^2} \text{ with } \sigma^2 = \frac{1}{N} \sum_{i=1,N} (o_i - r_i)^2,$$

o_i : value of pixel i in the original image (before encoding),

r_i : value of pixel i in the displayed image (the image was first encoded at the sender and then decoded at the receiver).

Through Figure 8, we observe that the quality of a VBR MPEG encoding is near-constant and that the smaller the quantization parameter is the better the quality of the sequence is.



a) VBR : Q=20
CBR :r=8774867 b/s

b) VBR : Q=30
CBR :r=5869802 b/s

c) VBR : Q=40
CBR :r=4382997 b/s

Figure 9 Quality of a sequence coded in VBR and CBR

We observe through Figure 9 that CBR encoding leads to a variable quality compared to VBR encoding. The compression achieved at movement prediction and compensation step is effective if the continuation of images presents a similarity. The VBR encoding takes into account scene activity variation within a sequence. The size of the compressed images increases following a scene change. On the other hand, CBR encoding allocates the same size to each GOP and doesn't adapt therefore to scene activity. In this case, quality is degraded.

We notice through Figure 10 that for a same average rate, the average quality of VBR encoding is better than the average quality of CBR encoding.

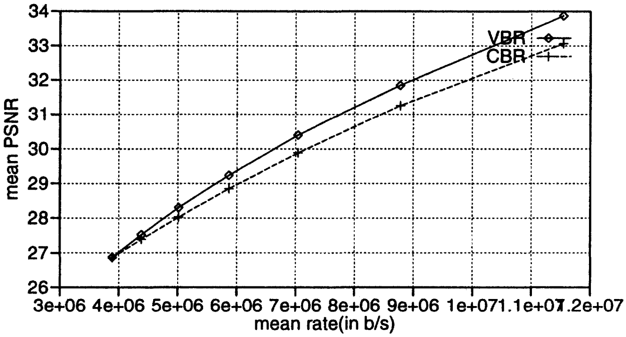


Figure 10 Mean quality versus mean rate

Note F the distribution function of the quality of the sequence. We have defined the following parameters to estimate the minimal quality, the maximal quality and the variation of the quality with the quantile $10^{-\alpha}$ for a sequence coded with MPEG :

$$MinQuality(\alpha) = Max\left\{x / F(x) = 10^{-\alpha}\right\}$$

$$MaxQuality(\alpha) = Min\left\{x / F(x) = 1 - 10^{-\alpha}\right\}$$

$$QualityVariation(\alpha) = MaxQuality(\alpha) - MinQuality(\alpha)$$

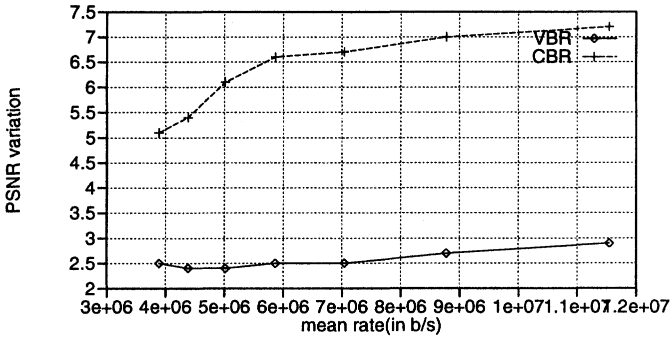


Figure 11 Quality variation versus mean rate

Figure 11 traces quality variation with a quantile 10^{-2}. We noted that CBR encoding quality is by far more variable than VBR encoding quality. The minimal quality guaranteed by VBR encoding is better than CBR encoding. To obtain the same minimun quality obtained by VBR encoding, the mean rate of CBR encoder should be once and a half the mean rate of VBR encoding (Figure 12).

For the continuation of the work, we have retained the VBR encoding so as to insure to the user the best possible quality.

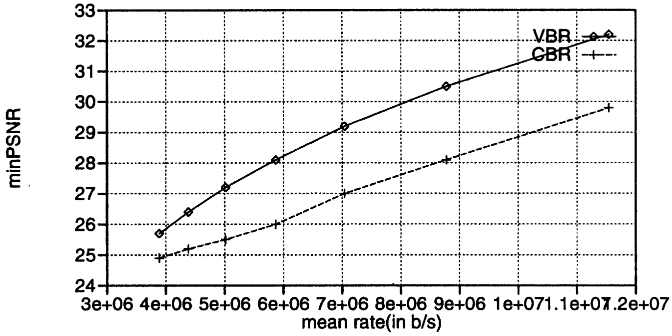


Figure 12 Minimum Quality versus mean rate

3 ATM CONTRACTS FOR REAL TIME MPEG TRANSMISSION

Three ATM contracts are candidate for real-time video transmission : CBR, rt-VBR and ABT. Note, that according to the ITU and the ATM-Forum Available Bit Rate contract (ABR) will not be able to guarantee end to end transmission delay (I371 1995, ATMForum 1996).

With CBR contract, a constant bandwidth is allocated to the connection all along the transmission. MPEG VBR traffic is sporadic. The allocation of the peak rate would induce under-utilization of allocated bandwidth. In the other hand, the allocation of a bandwidth less than the peak rate would induce a waiting time to the level of the network access and eventually to cell loss.

The contract rt-VBR proposed by the ATM-Forum and called statistical bit rate (SBR) by ITU is based on statistical multiplexing. Different works introduce the notion of equivalent bandwidth estimated by connection or by a group of connections. The equivalent bandwidth defines the size of the bandwidth to reserve to one or several connections while guaranteeing them a certain rate of cell loss (Guérin 1991). These studies show that the number of accepted connections should be small in order to obtain a low loss rate . The gain in statistical multiplexing is important only if the rate of loss accepted by the connection is higher.

The ABT contract defined by the ITU is based on FRP protocol (I371 1995, Boyer 1992, Tranchier 1993). Data are decomposed in blocks. Each block is transmitted with a constant rate. The traffic is constant at each step. The transmission of a block requires a preliminary reservation of necessary resources. A reservation request sent by the transmitter can be accepted if necessary resources are available. In the opposite case, the reservation fails. However, a rate equal to the sustainable cell rate can be guaranteed to the user. According to the elastic version of the contract, the reserved bandwidth is equal to the available bandwidth in the network. The failure of a bandwidth reservation induces an increase in compression rate of an image or a group of images.

The choice of one of the two contract rt-VBR or ABT has to take into account the impact of cell losses (with rt-VBR) and the reduction of the size of images (with ABT) on the quality of a video sequence.

4 IMPACT OF CELL LOSS AND SIZE IMAGE REDUCTION ON THE QUALITY OF A SEQUENCE

With rt-VBR contract, the user can tolerate some cell loss rate. Suppose that m cells are lost while image k is transmitted. The requested bandwidth for the transmission of the image k is noted as B_k^{conf}. With the elastic version of ABT/DT, the reserved bandwidth, noted as B_k^{res}, would be:

$$B_k^{res} = B_k^{conf} - \frac{m \times sizeof(ATMcell)}{frame\ rate} \quad \text{where } sizeof(ATMcell) = 53\,bytes.$$

4.1 Impact of Cell Loss with rt-VBR contract

Cells are lost independently of the cell content. If a lost cell belongs to the sequence header, all the sequence is lost. Similarly if the lost cell belongs to the header of a GOP, all the images of this GOP are lost and so on.

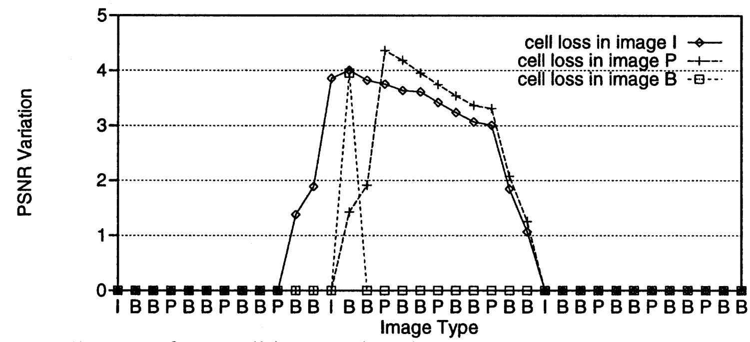


Figure 13 Impact of one cell loss on the PSNR

We have studied the PSNR variation in the case of a loss of one cell in the different types of images: I, P and B (see Figure 13). The lost cell wasn't related to any header and was located at the beginning of the 10th slice (An image is composed of 36 slices). A cell loss in a reference image (I or P) causes a degradation in the reference image and in all the images coded relatively to it. The impact of a cell loss in B image isn't propagated.

4.2 Reduction of the size of an image with the elastic version of ABT/DT contract

With the elastic version of ABT/DT contract, the reserved bandwidth may be less than the requested bandwidth to send an image. The encoder should increase the rate of the compression by adjusting the quantization parameter (see II.1). In order to reduce the size of an image by 53 bytes, we increased by one the quantization parameter.

Our objective is to compare the impact of ABT and rt-VBR contracts on the same video traffic. Let's note *Relative(k)* the set of images coded relatively to the image *k*. Our experiments have shown that the size of some images belonging to the set *Relative(k)* may increase once the quantization parameter of the image *k* is increased from the value Q_1 to Q_2. This can lead to a different traffic. To avoid this problem, we positioned the quantization parameter of all the images belonging to the set *Relative(k)* to Q_2.

Figure 13 and Figure 14 show that the degradation following the loss of a cell is ten times greater than the damage caused by equivalent image size reduction.

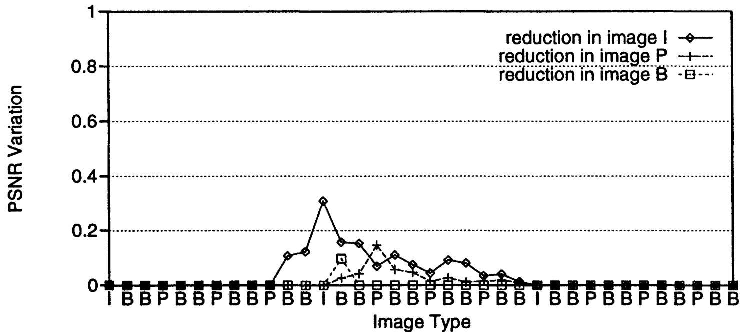


Figure 14 Impact of image size reduction on the PSNR

Size reduction of an image I induce the greatest degradation of the sequence. Note Q_1 the initial quantization parameter of the image I. The image size reduction is achieved with the quantization parameter Q_2 with $Q_1 \prec Q_2$. In fact, the quantization parameter of all the images encoded relatively to this I image will be Q_2.

So as to evaluate the variation of the quality following this reduction, we have studied the variation of the PSNR following an increase in quantization parameter for all the sequence. Figure 15 traces PSNR variation for different $\frac{Q_2}{Q_1}$ ratios. Given one ratio, the PSNR variation is approximately the same for each image. We noticed also that PSNR degradation doesn't vary linearly with the ratio $\frac{Q_2}{Q_1}$.

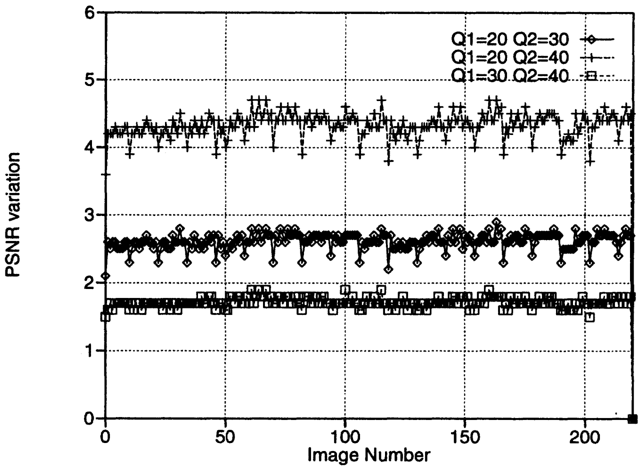


Figure 15 Impact of image size reduction

We have estimated the mean and the standard deviation of PSNR degradation evaluated at each image for different $\frac{Q_2}{Q_1}$ ratios. Figure 16 allows us to establish the next approximation:

$$PSNR_{Q_1}(i) - PSNR_{Q_2}(i) \approx 15 \times Log_{10}\left(\frac{Q_2}{Q_1}\right) \text{ where:} \quad (6)$$

$PSNR_{Q_1}$: quality of the image i encoded with the quantization parameter Q_1,

$PSNR_{Q2}$: quality of the image i encoded with the quantization parameter Q_2 with $Q_1 \prec Q_2$.

Figure 15 and Figure 16 show that for $\frac{Q_2}{Q_1} = 2$, the PSNR variation is approximately equal to 4.5. Figure 14 attests that only one cell loss caused a PSNR variation of the same magnitude. According to the approximation (4), the size of the image is reduced to approximately the half. This means that reducing the size of an image to the half can lead to the same PSNR variation following just one cell loss.

We observe through the carried experiments that the quality variation change as a logarithmic function of image size reduction. This means that an image size reduction may lead to a small decrease in the PSNR of the image. In order to minimize sequence quality degradation, ABT contract should be investigated to support real-time video transmission. In the next section, a mechanism based on this contract is proposed.

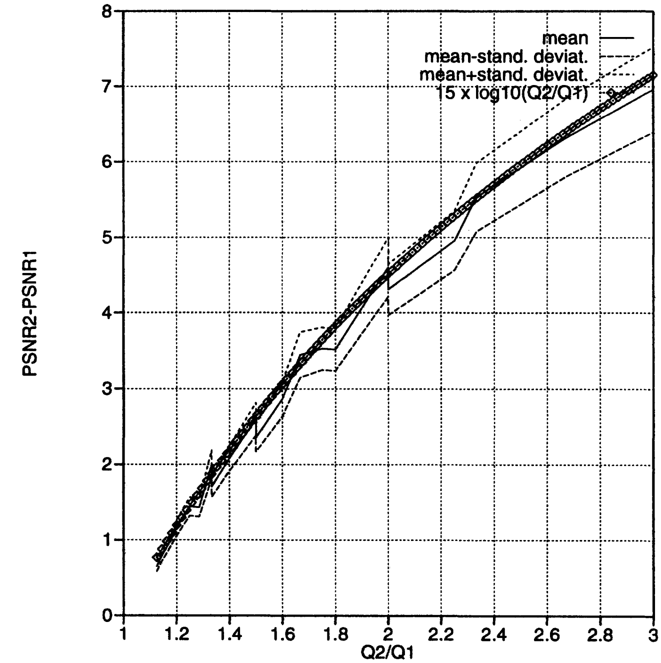


Figure 16 PSNR variation versus the ratio $\frac{Q_2}{Q_1}$

5 A PROPOSAL OF A NEW RESOURCE ALLOCATION MECHANISM FOR VIDEO TRANSMISSION

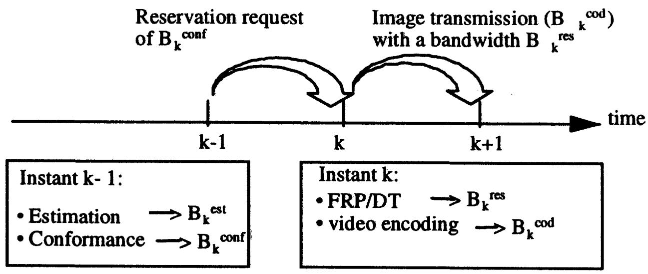


Figure 17 Periodic allocation with resource estimation

We have adopted the solution presented in the Figure 17. This mechanism is based on FRP/DT protocol. The requested bandwidth for the transmission of an image is estimated. The source send for each image a reservation request. If the reserved bandwidth is less than the requested one, we increase the quantization parameter using the approximation (5) so that the size of the image fits the reserved bandwidth. The different steps of our mechanism are listed below:

- Period k - 1:

Step 1: The image k is encoded first with a reference quantization parameter noted as Q_{ref} . The requested bandwidth for the transmission of the image k is noted B_k^{est} .

Step 2: Contract conformance: This estimation can be modified by the source to guarantee the conformity to the negotiated ABT/DT contract with the operator. The new value is noted as B_k^{conf} .

Step 3: Submit to FRP/DT unit a reservation request of the bandwidth B_k^{conf} .

- Period k:

Step 4: The FRP unit provides the value of the reserved bandwidth for the period k. This value is noted as B_k^{res}. According to the elastic version of ABT/DT, this value is larger than the sustainable cell rate and less than or equal to the requested bandwidth: $SCR \le B_k^{res} \le B_k^{conf}$.

Step 5: Encoder regulation: If the reserved bandwidth is equal to the requested bandwidth, the image is sent. In the other case, the image should be requantified. The quantization parameter is modified with the approximation (5).

Step 6: Transmission of image k.

This solution can be generalized to allow the transmission of a set of images or a GOP.

6 CONCLUSION

In this paper, we have studied MPEG VBR and CBR traffics. We noted that MPEG VBR traffic provides a better quality than CBR MPEG traffic. We have compared the impact of rt-VBR and ABT/DT contracts on the quality of a MPEG sequence coded in VBR. We find that the quality of sequence is less damaged by image size reduction than by cell loss. Finally, we have presented a mechanism for video transmission under real time constraints based on the elastic version of the ABT/DT contract.

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BIOGRAPHY

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