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Shaping of video traffic to optimise QoS and network performance

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Abstract

A method of shaping the video traffic within the video encoder is proposed. At the intraframe coded frames, where the maximum number of bits are generated, the coder constrains its generated bit rate through a leaky bucket mechanism. A sliding window is also used to maximise network utilisation without violating any of the traffic parameters declared at the call set-up. The impact of the shaping mechanism on both coding and network performance are studied. It is shown that for video sequences with scene cuts, shaping the video traffic under a certain peak-to-mean ratio optimises both network performance and perceived image quality.

Keywords

Traffic and Congestion Control

1 INTRODUCTION

ITU-T has proposed ATM as the mechanism for multiplexing/switching in the future B-ISDN (ITU-T 1991). A key challenge in the ultimate success of ATM is to define and implement a congestion control strategy that provides an efficient sharing of network resources among different services with diverse traffic characteristics. Such a congestion control comprises of three sections, namely control of access of the customers to network resources, policing the traffic flow of each user and protection of the Quality of Service (QoS) against possible fluctuations of the traffic flow above the channel capacity .

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Video services are expected to share a large portion of the traffic handled by ATM networks. A critical aspect of VBR coding and transmission is the real-time constraints for VBR video data. The network has to ensure the on time delivery of data, while on the other side the encoder has to provide the appropriate shaping functions in order to improve the channel performance. This shaping function can be used by the encoder to regulate its traffic at the ingress of the network.

The paper is structured as follows: Part 2 describes the policing functions/(UPC) methods for policing a service in an ATM network. Part 3 presents the UPC methods proposed for regulating video services. Part 4 gives the impact of the proposed scheme on the network performance. Part 5 investigates its impact on the perceived image quality. Finally, conclusions are given in Part 6.

2 POLICING FUNCTION/USAGE PARAMETER CONTROL (UPC)

After the connection is established, the network has to monitor the conformity between the declared and the actual cell stream parameters at the ingress of the network. This is enforced to protect the network resources from possible malicious or erroneous users who may exceed the traffic volume declared at the call set-up and thus overload the network. This function called user parameter control (UPC) is performed at the user network interface/ network network interface (UNI/NNI) for each existing virtual path/virtual circuit (VP/VC), controlling its traffic flow based on the declared traffic parameters. If a VP/VC is detected violating the agreement, its cells can either be discarded or tagged for later discard when congestion arises. The policing function can be characterised by the following attributes (BAE, 1991), (IEEE, 1991), (IEEE, 1992):

I) The UPC mechanism should be selective with respect to the policed parameters. It should be able to distinguish the trade off between traffic fluctuations during normal operation from real traffic violations.

II) It should respond rapidly to parameter violations.

III) The mechanism should be simple and flexible to implement.

Some of the most common policing techniques involve leaky bucket and window mechanisms. Leaky bucket (Niestegge, 1990) is a virtual buffer (bucket) with a constant service time, as is illustrated in Figure 1a. Once the buffer becomes full a violation is detected. The service rate of the virtual buffer corresponds to the rate to be policed (for example, peak bit rate (PBR) or mean bit rate (MBR)) assuring that UPC algorithm tolerates fluctuations caused by cell delay variation (CDV) or burstiness. The size of the bucket is determined by the maximum burst length that the user is allowed to submit to the network. Another implementation of the leaky bucket is to control the traffic flow by a means of tokens (Sidi, 1989). A queuing model for this method is shown in Figure 1b. An arriving cell enters the bucket after it has received a token pool. If no tokens are available, a cell must wait in the queue until a new token is generated. Tokens are generated at a fixed rate corresponding to the bit rate to be policed.

A window is a fixed time interval, defined as a number of time slots in an ATM VP, which is used to measure the number of cells within this time interval (Bae, 1991), (IEEE, 1991), (IEEE, 1992), (Roberts, 1992). There are two versions of window mechanisms, namely jumping window and moving/sliding window, as shown in Figure 2. The jumping window consists of non-overlapping consecutive time intervals that counts the number of cells delivered from a source within the interval. A new interval starts immediately at the end of the preceding interval where the associated counter is reset to zero. In the moving window, the window slides continuously through the time. Thus, the arrival time of each cell is stored and a counter is incremented by one for each new arrival. Exactly T time units after an arrival of an accepted cell, the counter is decreased by one.

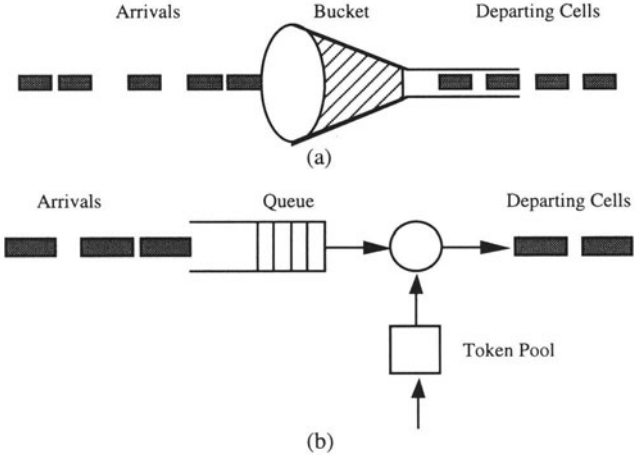


Figure 1: Schematic representation of leaky lucket.

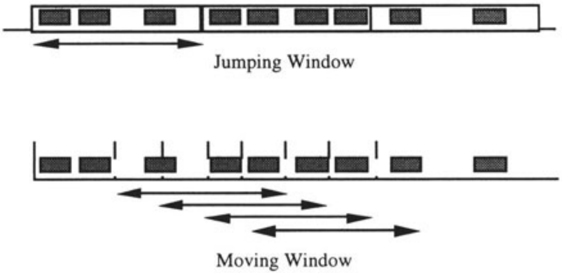


Figure 2: Schematic representation of window mechanisms.

3 EMPLOYMENT OF POLICING MECHANISMS IN VIDEO SERVICES

Much attention has been paid to the implementation of the policing functions in packet video. Such attention stems from the fact that real time services, such as video, prefer to constrain the generated traffic according to the declared MBR and PBR such that no penalty is imposed from the policing function. Such penalty may lead to deterioration of the QoS due to the discard of cells which are important for the reconstruction of the pictures at the decoder. The policing function is normally imposed at the UNI. Once a violation from a source is detected, cells from that source may be discarded or tagged for later discard. As an option a feedback from the UNI to the source can be set up to regulate the traffic as required.

Ratheb (1993) has studied the impact of the policing functions on video services. His studies show that efficient policing can be achieved by restricting the PBR to a reasonable value. Among the leaky bucket, moving and jumping windows, the leaky bucket exhibits better performance than the window mechanisms. Policing of the MBR seems not to be realistic for either of the mechanisms due to the large bucket/window requirements. This is because observations have shown that cell losses occur in clusters and for a given policed rate, the size of the bucket/window has to be extremely large.

The imposition of UPC can badly damage QoS of those services violating their traffic descriptors. This is more pronounced in an interframe coded video, where loss of one cell may propagate through several video frames. It would be beneficial to the user himself to control his generated bit rate prior to being penalised by the network operator. This is because if the encoder codes pictures at a lower bit rate and image quality is temporarily degraded, since the decoder without cell loss can track the encoder, the picture quality can be improved later. On the other hand if cells are lost due to the network policing, since the decoder can not track the encoder, the picture quality will remain poor for a long time, which is very objectionable.

Harasaki and Yano (1993) have used a leaky bucket to police both PBR and MBR. They have demonstrated that the leaky bucket size should be quite long (possibly as long as several seconds) but not prohibitively long from network designers' point of view, in order to allow constant picture quality for most of the time during a long video program.

Kawashima and Tominaga (1993) have used a sliding window to police the MBR. This method utilises variability of bit rate under the constraints by the UPC and its influence on the QoS. It has been reported that transmission of video under this mechanism shows significantly better image quality than the conventional constant bit rate (CBR) transmission in scene changes. In addition, when the sliding window is small (10 to 30 frames) image quality is very poor in the areas of pictures with zooming or panning. We have adopted a more integrated approach where a shaping mechanism is used to police the declared traffic parameters and adjust the actual bit stream accordingly, such that both network and codec performance is optimised.

4 IMPLEMENTATION OF THE SHAPING MECHANISM

The proposed shaping mechanism imposes two constraints in the generated bit rate. The first constraint deals with the shaping of PBR and the second is concerned with the control of MBR. Thus, the objective of the shaping mechanism is the best usage of the available resources provided by the network operator, while at the same time the user tries not to violate the contract declared at the call set-up. These constraints are described in the following sub-sections.

4.1 Shaping/Smoothing of the PBR

Video codecs for ATM networks are VBR oriented. The bit rate variation is a function of scene content and motion of moving objects. The PBR (the maximum number of bits in one frame period) is normally generated at scene cuts, where the pixels are coded with an intraframe method. In this study, an H.261 standard video codec was used, where images are interframe coded using motion compensation for greater compression. At scene changes, the encoder switches to an intraframe mode, generating its PBR. The bit rate can be regulated by adjusting the quantiser step size. For example in the reference model simulation coder (RM8, 1989), the quantiser step size can be changed at the start of each group of pictures (GOB) or at one third of them (11 macroblocks) (ITU, 1990). This technique in conjunction with the rate smoothing buffer is employed in circuit switched network applications to deliver constant bit rate video into the channel.

The proposed strategy for the shaping of the PBR is to employ two virtual buffers. The first buffer performs like a leaky bucket and its occupancy is used as a feedback to the encoder to control the quantiser step size. Note that increase (decrease) in the quantiser step size results in the decrease (increase) in the generated bit rate. The second buffer counts the total number of bits generated within the scene cut frame. A threshold value, s, is imposed at the counter to control the quantiser step size further whenever is necessary. The dimensions of both buffers are equal to the PBR declared at the call set-up.

The method employed in RM8, was used to detect a scene cut by comparing the variances of intraframe and interframe coded macroblocks. Then, if in the first few GOBs (e.g. 2-3 GOBs) the majority of the macroblocks are intraframe coded, it can be assumed that the whole frame will be intraframe coded, i.e. detection of a scene cut. This introduces $\left(\frac{1}{6},\frac{1}{4}\right)$ of a frame delay, corresponding to almost 6-9 ms in a 30 Hz video. At scene cuts, where the codec switches to the intraframe mode, the quantiser step size is adjusted at the start of the frame. Since the aim of the peak constraint is the reduction of the PBR which occurs at scene cuts, then the quantiser step size has to be increased. It was found experimentally that a good starting point is to set the quantiser step size q_p to $1.5 \times q_{int}$,where q_{int} is the quantiser step size during the interframe coding mode. In our experiments, q_{int} was set to 12. While coding the scene cut frames, the quantiser step size is adjusted every 11 macroblocks based on the fullness of the leaky bucket. The adjustment of the quantiser step size is controlled, based on RM8 where the quantiser step size q_{sc}, is :

$$q_{sc} = 2 \times \mathrm{INT}\left(\frac{32 \times b_i}{b_{max}}\right) + 2 \tag{1}$$

where b_i denotes the leaky bucket fullness after coding each macroblock and b_{max} is the control buffer dimension determined by the targeted PBR. The initial leaky bucket content is calculated from (1), such that quantiser step size is q_{int}. The leaky bucket is filled up with the rate of generated data at each macroblock, but it is emptied at rate $\frac{\mathrm{PBR}}{396}$ at every macroblock (there are 396 macroblocks in each frame). Once the buffer content reaches the threshold s, the quantiser step size is further adjusted by :

$$q_{sc} = q_p \times b_{av} \times \left(\frac{1 - \frac{\text{coded MB}}{\text{total MB}}}{b_{\max} - \textit{leaky}\ \text{bu}\textit{cket}\ \text{level}}\right) \tag{2}$$

where b_{av} is the target mean bits/frame. It was found, that a threshold of $s = 0.7 \times b_{max}$ is a good indication of the fullness of the virtual buffer that controls the generated bit rate in the scene cut.

4.2 Control of the MBR

The shaping of the PBR itself is insufficient to yield a reliable control mechanism since the other important parameter declared during the call set-up is the MBR. The encoder should employ a method such that MBR is neither underestimated nor overestimated. Underestimation would lead to cell loss while overestimation would be poor utilisation of the network resources that the user has paid for. For this purpose, a sliding window may be employed to monitor the short term MBR which is used as a guideline to estimate the long term MBR. For the target MBR of b_{av} bits/frame, the expected bit rate within the window of size w frames is $w \times b_{av}$. The actual generated bit rate, w_{sum}, within this interval is:

$$w_{sum} = \sum_{i=1}^{w} f_i \qquad (3)$$

where f_i is the generated bit rate at frame i. Thus, at any time instant, the deviation, d_{ev}, of the actual sum from the expected one within the window is:

$$d_{ev} = (w \times b_{av}) - w_{sum} \qquad (4)$$

which is used to code the new frame.

To code a new frame, the window is shifted by one frame. The frame which is dropped out of the window with bit rate f_{rem}, is added to the deviation bit rate to estimate the allowable bit rate for coding the new frame f_{new} as:

$$f_{new} = d_{dev} + f_{rem} \qquad (5)$$

The quantiser step change Δq for the new frame in the window is calculated by normalising f_{new} to the b_{av}:

$$\Delta q = \frac{b_{av} - f_{new}}{b_{av}} \qquad (6)$$

Thus the quantiser step size for the new frame, q, is derived from:

$$q = q_{\min} + \Delta q \qquad (7)$$

To preserve the characteristics of VBR coding, the upper bound of the quantiser is crucial. If the variation in the quantiser step size is quite large, it may degrade the picture quality. In addition, the overall consistency of picture quality is affected. On the other hand, small variation in the quantiser step size may cause w_{sum} to exceed $w \times b_{av}$. Thus, in order to compromise the above effect, Δq is limited to a maximum of four while the lower bound of q is set to q_{min}. The newly adjusted quantiser step size is used to code the next frame. No further transition in the quantiser step size is allowed within the next frame to obtain consistency within the frame.

5 THE IMPACT OF TRAFFIC SHAPING ON THE DECODED IMAGE QUALITY

A typical video sequence containing several scene cuts was used to evaluate the effect of the traffic shaping on the decoded image quality. A fixed quantisation step size of 12 was used to code the sequence. Figures 3 and 4 illustrate the cell generation and the PSNR profiles respectively for the video sequence under study.

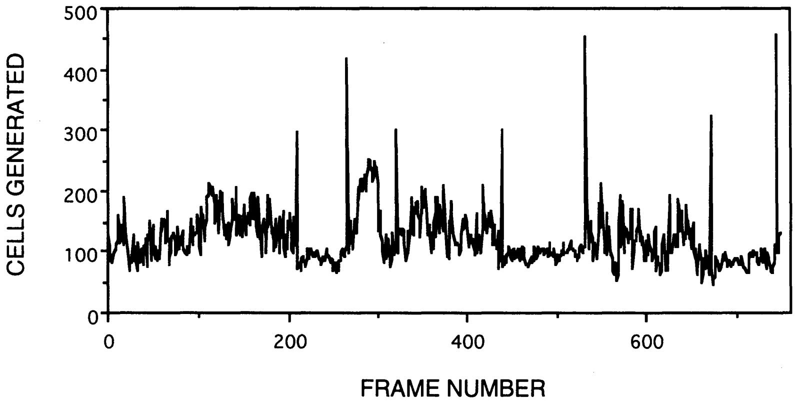


Figure 3: Bit Rate profile of a typical video trace with several scene cuts coded with an H.261 video codec.

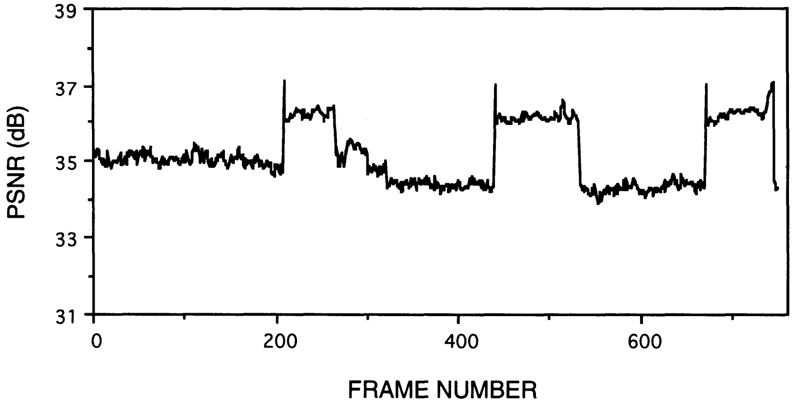


Figure 4: PSNR of a typical video trace with several scene cuts coded with an H.261 video codec.

At a fixed quantiser step size (q=12) the picture quality is almost constant. Small quality variation is due to the scene dependency of coded video. The sequence was also coded under the shaping constraints. The impact of the shaping constraints on the bit rate and PSNR is demonstrated below.

5.1 Peak To Mean (P/M) ratio

For a given MBR, the constraint imposed on the PBR reduces P/M. Figure 5 illustrates the cell generation profile of the video trace when P/M is reduced from its unconstrained value (3.5) to 2.5. Due to the PBR constraint, PSNR is degraded at the scene cuts, as illustrated in Figure 6.

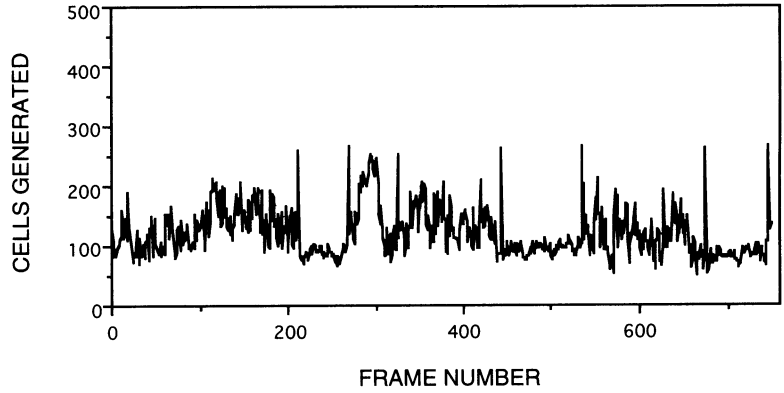


Figure 5: Bit Rate profile of a typical video sequence under the shaping mechanism.

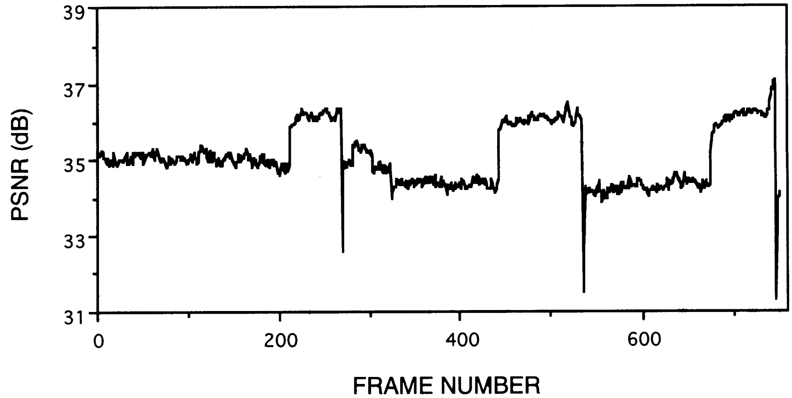


Figure 6: PSNR of a typical video sequence under the shaping mechanism.

The allowed degradation is picture dependent and is subject to the visibility threshold of the observer. The drop in the bit rate at scene cuts, causes the bit rate in the subsequent frames to sustain in a high level until the MBR converges to its long term average. The smaller the P/M (larger constraint imposed in the PBR), the worse is the degradation in the PSNR at scene cuts. Since in normal TV programmes the scene cut frequency is small (1 every 5-9 s (Hughes, 1993)), the constraint imposed on PBR does not alter the MBR significantly.

5.2 Window Size

The window size determines the number of frames used to calculate the short term MBR. It has been suggested (Kawashima, 1993) that a selection of window in the range of 50 to 150 video frames would give good estimation of the MBR while at the same time image quality does not degrade in scenes of panning or zooming. The results have shown that by using different window sizes for a given PBR and MBR, variation in the overall PSNR is not significant, as Figure 7 illustrates.

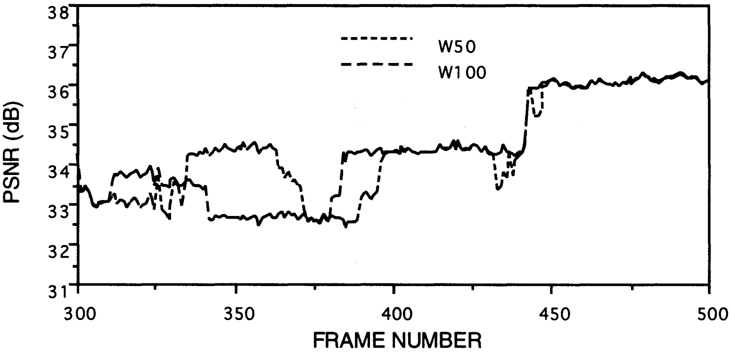


Figure 7: Effect of window size on the PSNR of a typical video under the shaping mechanism.

No constraints are imposed on the bit rate up to the point where the window is full assuming that there are no scene cut frames in this period. When the coder starts controlling the bit rate, the MBR for the overall traffic tends to converge towards the long term mean, as illustrated in Figure 8. In addition, once the user selects an appropriate window size in the range of 50-150 frames, the window size has no impact on the generated bit rate as illustrated in Figure 9.

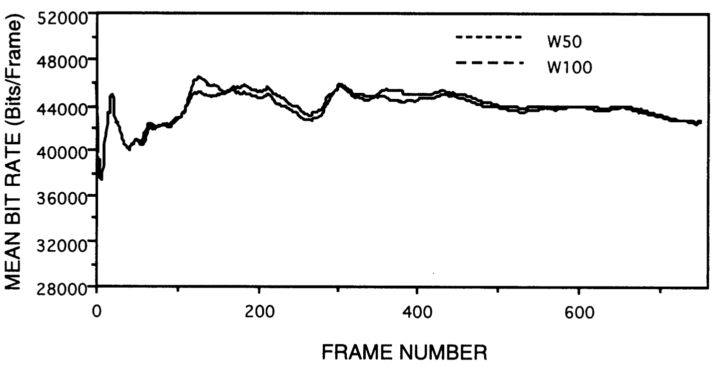


Figure 8: Effect of the window size on the MBR of a typical video under the shaping mechanism.

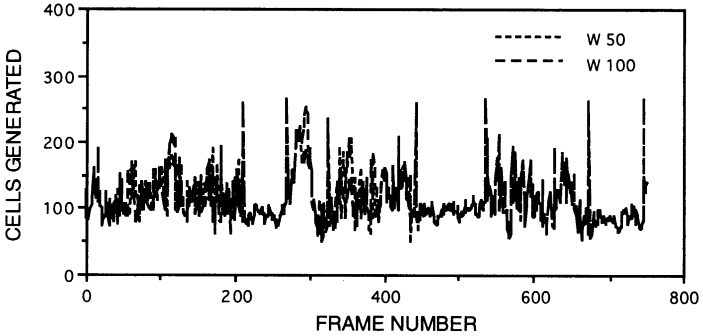


Figure 9: Effect of the window size on the bit rate of a typical video under the shaping mechanism.

6 THE IMPACT OF TRAFFIC SHAPING ON THE NETWORK PERFORMANCE

Although the reduction of the peak bit rate at the intraframe coded frames, leads to poorer PSNR at these frames, it is expected that it will ease network congestion reducing the cell loss rate. To study this improvement, a single multiplex of eight homogeneous video sources was considered. An 8-cell size buffer was used at the input of the multiplex to withstand simultaneous cell arrivals from the eight sources (one cell per channel). A FIFO policy was employed to serve the buffer.

The output of the encoder generates bits per macroblock. Every 44 bytes of video data were packetised into the payload of ATM cells and a list of interarrivals of video cells was generated. Each sequence was considered as a circular linked list of homogeneous video sources. An event driven simulation was adopted for the generation of the traffic of each video source. For each video source a different offset point (randomly selected) in the list was used to ensure that all sources are not identical on a cell by cell basis. The distances between the starting points were taken larger than 10 frames such that correlation between cell generation was made small.

It was observed that reducing the PBR or (P/M) decreases the cell loss rate. This is because lowering P/M reduces the burstiness of the incoming data at the intraframe coded frames and the small multiplexing buffer is less flooded. However at much lower values of P/M, the cell loss rate rises again. This is due to the fact that although image quality at scene cuts is impaired, the interframe errors (due to coding distortions) in the subsequent frames remain high for a few frames, till all the coding errors are cleared. Thus, the limited multiplexed buffer is subject to a flow of data for a longer time. Therefore, there should be an optimum value for P/M, where the cell loss rate is the smallest. Figure 10 illustrates the cell loss rate for various network loadings when P/M is reduced from its unconstrained value of 3.5 to 2.0 . The smaller the loading factor, the larger becomes the difference in cell loss ratios for different P/M ratios. For example at 50% network load, the optimum P/M ratio for this sequence is 2.25. For such P/M ratio, the cell loss is less than 1/6 of the unconstrained video. As network load increases, more cells face the full buffer and thus the difference in cell loss ratios decreases.

The optimum value of P/M shown in Figure 10 can also be justified from an investigation of the burstiness of the generated data under various P/M ratios. Here we define burstiness as the number of generated cells per macroblock. Figure 11 illustrates the mean values of burstiness for various P/M ratios, showing that P/M of 2.25 has the least burstiness.

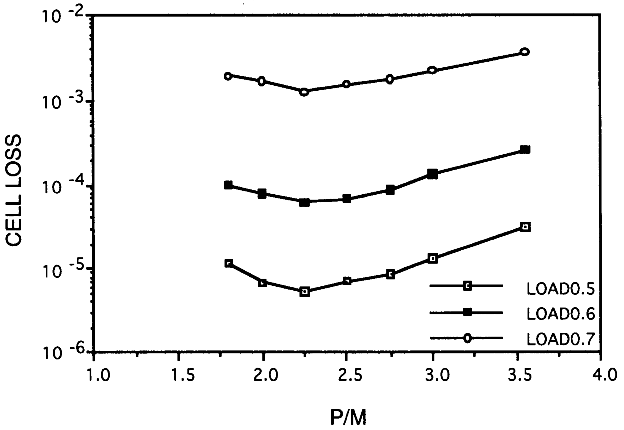


Figure 10: Cell loss rate for different P/M ratios at various network loads.

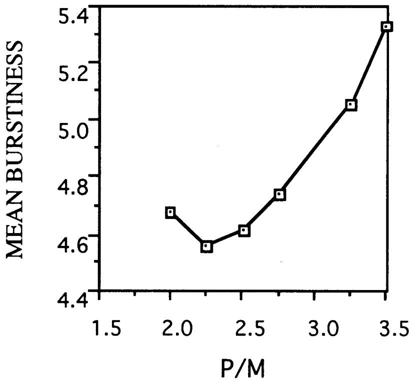


Figure 11: Mean burstiness of the generated video at different P/M ratios.

7 THE IMPACT OF TRAFFIC SHAPING ON THE QoS OF VIDEO SERVICES

The video sequence with the characteristics of Figure 10 was used to evaluate the PSNR of the coded pictures under the uncontrolled and the optimum constrained P/M ratios. As Figure 10 shows, for the uncontrolled P/M value of 3.5 and multiplex buffer size of eight cells, the cell loss rate at network load of 0.5 , is almost 4×10^{-4}. This value for the optimum constrained P/M value of 2.25 is nearly 6×10^{-5}, which is about 6 times smaller than that of the uncontrolled case. Assuming that cell loss occurs in clusters and are confined within a frame, then for the 750 frames sequence under study the cell loss rates in a particular frame are almost 2.7×10^{-1} and 4.5×10^{-2} for uncontrolled and optimum constrained P/M ratios respectively. Two cases were examined: cell loss at a scene cut (intraframe coded) frame and cell loss at a interframe coded frame

7.1 Cell Loss in a Scene Cut Frame

Figure 12a illustrates a scene cut picture frame of the sequence under the uncontrolled P/M ratio. The scene cut frame of the sequence was exposed to 27% cell loss. Although picture quality in the non-lossy areas is good, the artefacts due to cell loss are very disturbing. Due to the interframe nature of the codec and the fact that the encoder is unaware of the cell loss, in the decoded images the artefacts will propagate through the image sequences and can last for a long time, as shown in Figures 13a and 14a, which display the picture at one frame and five frames respectively after the lossy scene cut frame. These artefacts can be cleared when the entire frame is updated with intraframe coded information (Ghanbari, 1993). Figure 15 illustrates the propagation effects of cell loss for the sequence under study. At the instant of the cell loss the image quality drops from its nominal value of 36 dB to 26 dB. It may take several frames for the decoder to completely recover from the lost cells of one frame. For example in the H.261 codec,

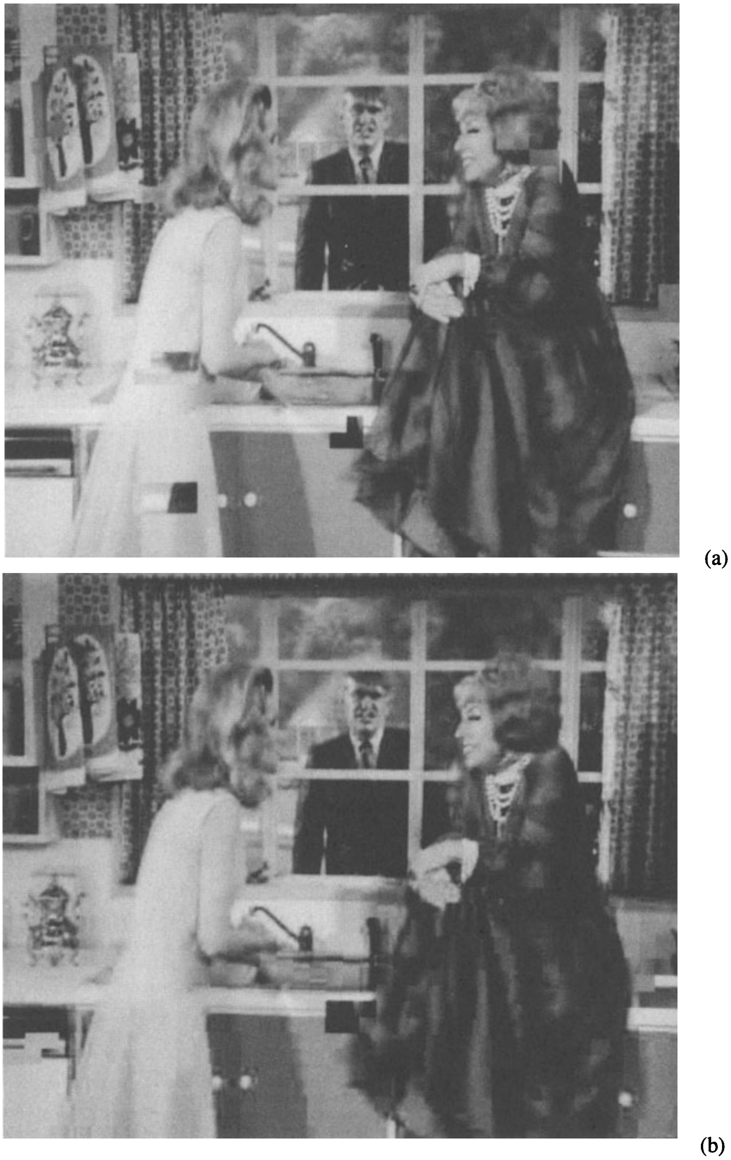


Figure 12 A scene cut frame with a cell loss rate of a) 27% unconstrained and b) 4.5% optimum constrained.

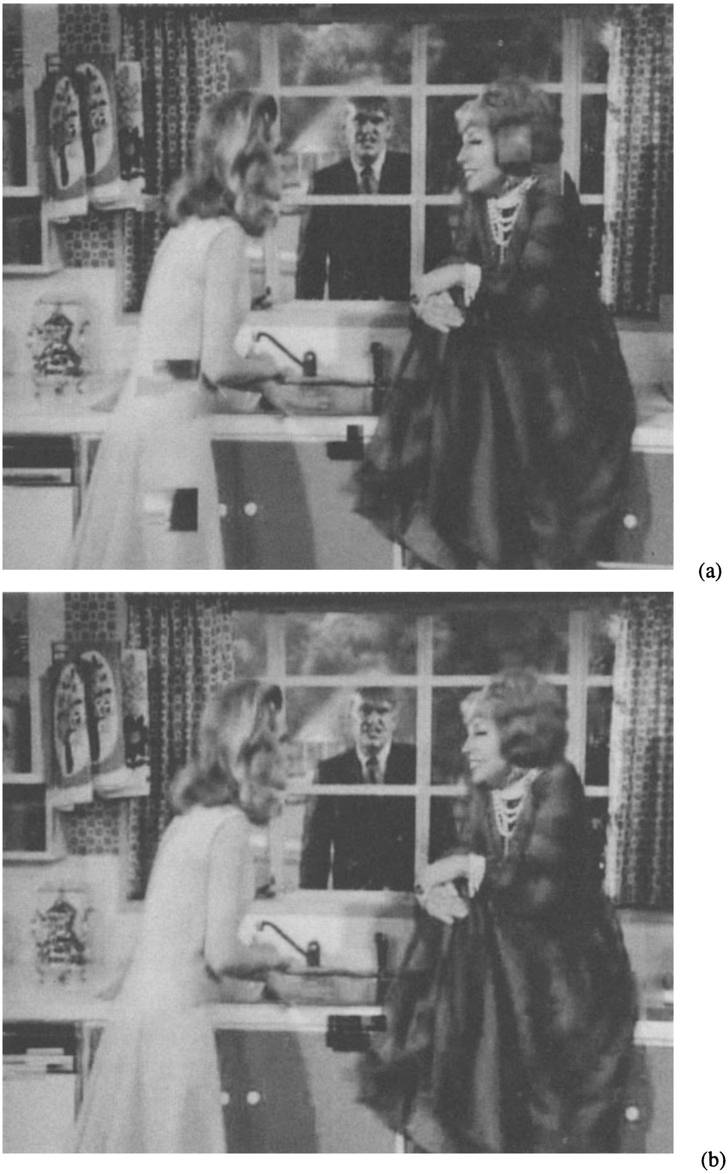
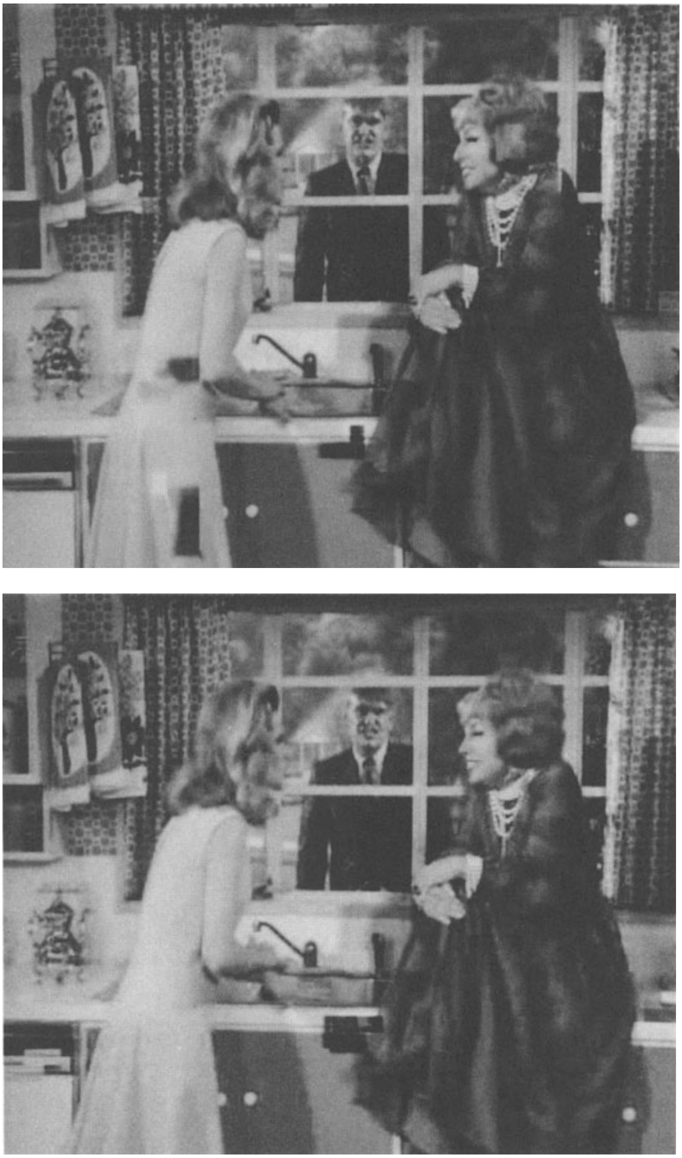


Figure 13 Cell loss at one frame after the lossy scene cut frame , a) unconstrained and b) optimum constrained.



(a)

(b)

Figure 14 Cell loss at five frames after the lossy scene cut frame , a) unconstrained and b) optimum constrained.

since at least 3 macroblocks in a frame are intraframe coded, it may take 132 frames (nearly 5-6 s) till the effect of cell loss can disappear.

The same scene cut frame under the constrained P/M of 2.25 ratio was exposed to 4.5% cell loss. Figure 12b shows the quality of the image at the scene cut, where the cell loss occurred first. It is not surprising that due to smaller cell loss rate, the picture quality is better than that of Figure 12a. In Figure 12b apart from the cell loss artefacts, picture quality in non-lossy area, due to the constraint on the PBR, is poor. However, impairments due to the bit rate constraint (larger quantiser step size) do not appear worse than the cell loss artefacts. At one frame after the scene cut, the quantiser step size is set back to its nominal value. Since the decoder is aware of this change, the picture quality, which was impaired due to the bit rate constraint, improves back to normal. Figure 13b and 14b illustrate the pictures at one frame and five frames respectively after the lossy scene cut frames, where the effect of the bit rate constraint distortion is removed, but that of the cell loss is still present. These pictures in the non-lossy areas exhibit the same quality of the uncontrolled case of Figure 12a. Considering that image sequences are displayed at rates of 25-30 frames per second, the temporary impairments due to the PBR constraint is hardly noticeable, but that of cell loss, similar to the uncontrolled case can last for a long time, till the whole frame is updated, as shown in Figure 15. Since the cell loss in this case is small, the PSNR of the sequence with cell loss is not significantly different from that of without cell loss at scene cuts. However, subjectively the cell loss artefacts are more disturbing than the coding distortions.

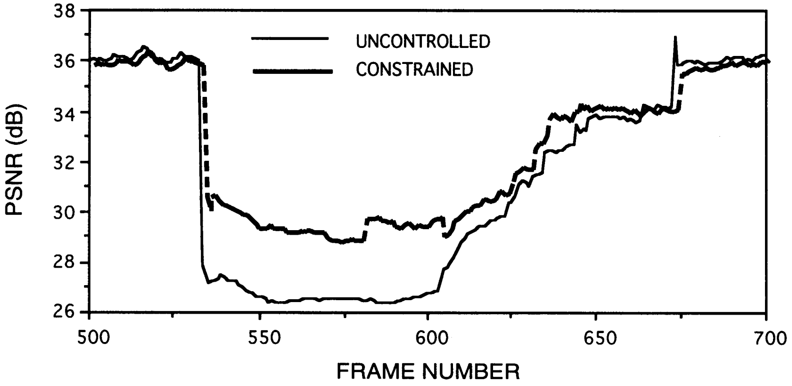


Figure 15 PSNR of the reconstructed video after the occurrence of cell loss at a scene cut.

7.2 Cell Loss in a Non-scene cut Frame

Similar to the scene cut experiment, it was assumed the lost cells are only confined in one interframe coded picture. Figure 16 illustrates the PSNR of the decoded sequence and Figures 17a and 17b show the image quality of a single interframe coded picture at the instant of cell loss for both unconstrained and constrained P/M ratios. Due to smaller cell loss rate under the constrained P/M, the picture degradation is very marginal. The artefacts caused by the cell loss are less disturbing than those of the scene cut frames due to the fact that lost cells do not carry significant information. Furthermore, in the constrained P/M there are no coding impairments in the non-lossy areas since no constraint is imposed on coding of this frame.

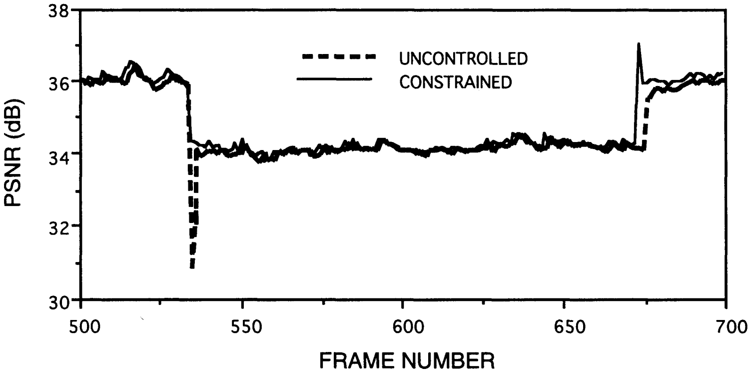


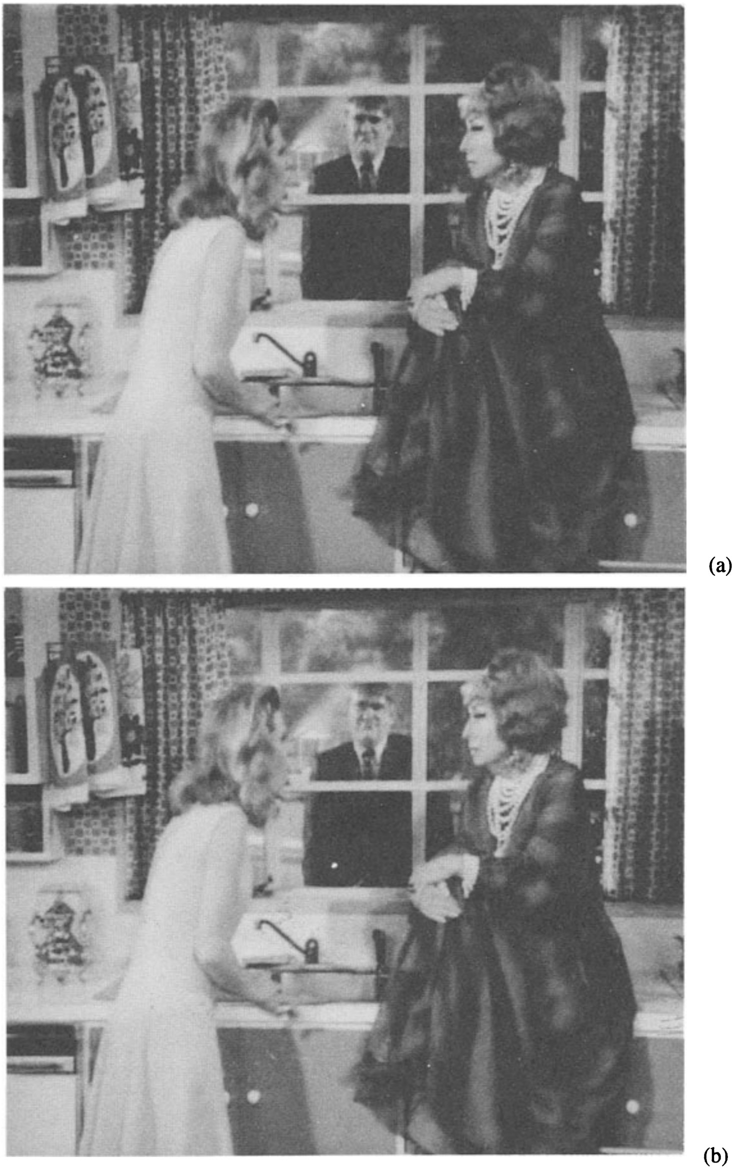
Figure 16: PSNR of the reconstructed video after the occurrence of cell loss at an interframe coded frame.

8 CONCLUSIONS

A method of shaping the video traffic generated by an H.261 type VBR video codec was proposed. The proposed mechanism incorporates a control function to regulate both mean and peak bit rates. At the intraframe coded frames, where the PBR are generated, the video encoder limits its generated bit rate through a leaky bucket mechanism. The bit rates are controlled by adjusting the quantiser step size of the encoder. The adjustment of the quantiser step size is based on the comparison between the actual generated bit rate and the target bit rate within a specified window duration. Decision on the adjustment is made at the start of each video frame. By defining MBR, PBR (P/M ratio), the encoder is able to select a minimum suitable quantiser step size for coding.

It was demonstrated that there is an optimum value of PBR for a given MBR (optimum P/M), where both network and perceived image quality are optimised. This PBR is less than the unconstrained PBR generated by video codecs, and is the value that can be declared by the user.

From the coding point of view, the performance of the shaping mechanism under optimum selection of its parameters, is better than the uncontrolled method both subjectively and in terms of PSNR. It was shown that for a typical video incorporating scene cuts the cell loss rate can be as low as one sixth of the unconstrained methods at low link utilisation.



(a)

(b)

Figure 17 A non-scene cut frame (interframe coded) with cell loss rate of a) 27% unconstrained and b) 4.5% optimum constrained.

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