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TITLE: A Comparison Study of VBR vs CBR for Conversational Video Services

PURPOSE: Proposal

Abstract

The advantages and new capabilities offered by VBR video transmission are described. The flexibility of VBR in particular, may be exploited to achieve efficient utilisation of network resources and cost savings for the user. The results of an investigation into relative efficiency of channel utilisation between VBR and CBR, based on the network model recently developed by the Experts Group, are next reported. The study was carried out for a long videoconferencing test sequence and employed both subjective and objective criteria in the assessment of picture quality. The results for the subjective comparison showed an advantage for VBR. It is stressed that consideration of VBR over CBR should take into account the full range of benefits offered by VBR transmission, and not be focussed exclusively on the statistical multiplexing gain.

1. Introduction

Video codecs have traditionally featured constant bit rate (CBR) transmission, mainly due to the requirement of synchronous transmission on existing transmission networks. The output of a compressed video source is however naturally varying and, to attain a fixed-rate output stream, a rate-smoothing buffer is usually employed and the quality of picture dynamically varied. The new ATM network (B-ISDN) however has been developed especially for asynchronous data transport and has therein the capability to directly communicate the variable-rate data from the video source.

In the following the advantageous features and some potential capabilities of variable bit rate (VBR) video transmission are first presented. This is followed by a report on a comparison study of VBR vs CBR, carried out at Telecom Australia Research Laboratories. The objective of the study was to determine the relative efficiency of network utilisation, in terms of number of sources which can be multiplexed on to the network of given capacity. The results for a long conversational (videoconferencing) test sequence are presented. A long sequence is essential to sufficiently capture the lulls and peaks of activity in a conversational session. The results showed a favour for VBR in terms of statistical multiplexing gain for the more important subjective approach at network capacity of 140 Mbits/sec.

2. VBR Advantages and Capabilities

Variable bit rate (VBR) video transmission offers potential advantages over conventional constant bit rate (CBR) transmission. It can provide intrinsic performance advantages and its flexibility may be exploited to achieve more efficient and economical network usage whilst providing the user with new and improved service features.

2.1 Enhancement of Quality of Service

In a VBR system the picture quality is not varied in order to sustain a constant output rate. The picture quality therefore remains constant or nearly constant throughout transmission, irrespective of motion activity or spatial detail in the scene. This implies that for the first time users need no longer put up with the varying picture quality intrinsic in CBR transmission, where often picture degradation becomes noticeable during periods of large motion activity. The elimination of the rate smoothing buffer in a VBR system can also significantly reduce end-to-end delay, which is large for existing CBR conversational video systems. Excessive delay is objectionable in an interactive conversational service and any significant reduction is highly desirable. As both consistency of picture quality and improved delay performance are subjectively attractive characteristics a VBR coder can therefore potentially provide a higher quality of service (QOS) on the ATM network, compared with similar services provided by CBR coders.

2.2 Efficient Representation of Source Information

The VBR transmission of data as produced by the video source coder implies that data is transmitted only as necessary for representation of the picture content. At times of low temporal activity unnecessary transmission of data is avoided, and when there is excessive motion the data rate correspondingly rises to convey the extra information. This matching of transmission rate with picture information content can lead to greater efficiency of video communication. For conversational sequences VBR may for example exploit the natural pattern of alternating talk-listen activity. During listening periods the amount of coded information can be expected to be low. In a two-way connection usually one party will be listening whilst the other is talking, and the aggregate of forward and return channel rates may therefore be significantly reduced. This effect is expected to be most pronounced where a single subject is participating at each end of the video conversation.

2.3 Flexible Bandwidth Characteristic

Additionally and quite importantly, VBR offers flexibility of bandwidth during a transmission which may be utilised to provide new video service features. This flexibility allows the average transmission rate to be altered during a call, within the peak value allocated at call set-up. This can for example be utilised to offer the customer the opportunity to select a lower mean rate i.e. stronger compression, as he perceives the picture to be less detailed (e.g. single talking head), or contain less degree of motion activity, potentially leading to reduced transmission cost. The amount of transmitted data may also be dynamically reduced to match the display window size and, in a retrieval service, during browsing of the video database. The method of tariffing will be a key consideration in realising these benefits.

3. Comparison Study

The advantages and potential capabilities of VBR make it attractive for adoption as the standard transmission method for video on B-ISDN. To aid the assessment a more quantitative understanding of the relative performance of VBR over CBR is valuable and this requirement was identified in the first meeting of the Experts Group. A comparison study has been carried out at Telecom Australia's Research Laboratories to investigate the efficiency of network utilisation of VBR and CBR systems. The experimental procedure and first results of this study are reported in the following sections and appendices. It is stressed that the results are valid for the network model and combination of test factors and conditions employed in the study. A different combination or model may yield different results.

3.1 Approaches to Comparison

In the comparison study the ratio of number of channels for VBR and CBR which can be multiplexed on to the B-ISDN as represented by a network model, is obtained for equal picture qualities. This ratio is also referred to as Statistical Multiplexing Gain (SMG), the comparison model is shown in Fig.AVC-38/1. Two approaches were employed in the study.

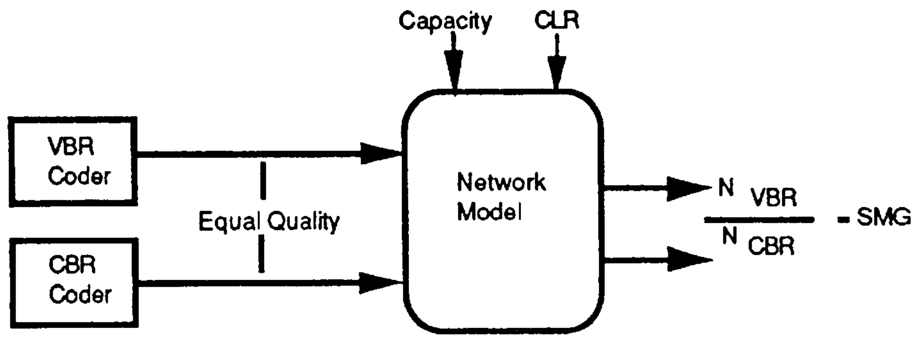

Fig. AVC-38/1 Comparison Model

In Approach 1 an objective measure of picture quality is employed which is the average value of frame Signal-to-Noise Ratio (SNR) over the test sequence. The peak normalised SNR is used.

In Approach 2 a subjective assessment of picture qualities was made based on an AB comparison test. The test subjects consisted of research engineers who are not involved in the study and who are not video experts. The selection of test material, testing procedure and resulting scores are described in Appendix B. From the subjective tests the equality of picture quality was established, and the SMG was computed from the parameters of the two picture sequences and network model.

3.2 Network Model and Source Coder

The network model employed in the study is a slightly modified version of the B-ISDN model developed at the first meeting of the ATM Video Experts Group. A refinement has been made on the equation for computation of cell loss ratio (Appendix C) and some comments on the its realistic applicability are also included.

The source coder employed in the comparison study is based on CCITT H.261 Experts Group's Reference Model 8 (RM8). Temporal pre-filtering and spatial post-filtering were applied in the processing. For VBR mode the buffer is eliminated and no external control of quantisation is applied. In the experiments different mean rates for VBR are generated entirely by varying the quantiser step size. This implies the VBR quality may be obtained at only discrete levels corresponding to the valid values of step size.

A test sequence of 5000 frames (3.3 minutes) was employed in the study. The frame rate is 25 fps, and spatial resolution is CIF (288 lines x 352 pixels). In the output display CIF frames are repeated to provide 50 Hz interlaced format fields. The test sequence was originally recorded on S-VHS tape, taken from a live videoconferencing session in Telecom Australia's Sydney studio. The test sequence shows four participants seated horizontally behind a table. The amount of static background is estimated at about 80%.

3.3 Rate Measurements

Measurements for peak rate and mean rate were made at the output of the VBR coder. The mean rate is the average bit rate over the entire test sequence. The measuring window for the peak rate is one frame. As the network model defines rates for statistical multiplexing with this measuring window, a buffering and delay of at least one frame is implied.

In the comparison study the range of mean bit rates investigated was 100-500 kbits/sec, which reflects the typical operating range of CIF-quality videoconferencing services. The network capacity employed in the comparison is 140 Mbps which is taken to be representative of the B-ISDN access channel capacity.

4. Results of Experiments

The detailed results of the comparison study are given in Appendix A. On the basis of objective measure employing the average frame SNR, a positive gain of SMG was obtained for higher operating mean rates of the VBR coder at cell loss ratios of 10^{-3} and 10^{-4}. At lower cell loss ratios no statistical multiplexing gain was observed. The SNR is however a poor measure of picture quality and these results are more of academic interest.

Based on subjective assessment a clear advantage for VBR was found from the study. In the range of operating rates investigated, when the output sequences from the VBR and CBR coders were determined to be subjectively equal, positive gains of SMG were obtained for cell loss ratios at and greater than 10^{-9}. As may be expected the SMG increased with higher cell loss ratio. An increase of SMG may also be obtained by increasing the amount of buffering to achieve a lower peak-to-mean ratio, and incurring increased delay.

5. Conclusions

The first results of the comparison study demonstrated an overall performance gain for VBR compared with CBR in respect of network utilisation, for the combination of conversational test sequence and set of assumed conditions. The subjectively-based comparison showed a significant statistical multiplexing gain at the network capacity of 140 Mbps and across a range of cell loss ratios. Further experiments are ongoing to determine the performance for a wider range of test material.

The statistical multiplexing gain should not however be employed exclusively as the basis for judgment in considering the choice of VBR or CBR for video transmission on B-ISDN. VBR potentially offers new and attractive capabilities which may be appropriate for the next generation of video services on B-ISDN. VBR removes the artificial constraint of fixed-rate transmission from a compressed video source, the output of which is naturally variable. Consequently a stable picture quality may be offered in the future generation of video services. The flexibility of VBR transmission allows for the introduction of powerful features which can result in more economic service delivery and more efficient network usage. The support of the new capabilities will require new functionalities in signalling protocols, and early advice by the Experts Group to the network designers will better ensure their successful implementation.

Appendix A. Results of Comparison Study

1. Number of Channels

Fig. AVC-38/A1 shows the typical bit rate profile from the VBR coder for the test sequence (measuring window of a frame) shown here for a quantisation step size of 8. The mean rate at this step size is 139 kbps. The straight line graph for a CBR coder at 256 kbps is included. The SNR profiles (frame SNR) of these two coders are compared in Fig. AVC-38/A2. The near constant quality of the VBR coder is clearly evident, whilst SNR fluctuations of about 6 dB corresponding to motion activity were observed for the CBR case. Similar patterns of fluctuation were observed for CBR coder operation at other rates.

In this investigation the SMG is obtained and compared for a range of operating rates between 100 kps and 500 kbps, to determine the performance for CIF-quality videoconferencing services.The mean rates for the VBR transmissions corresponding to the legitimate values of quantiser step sizes are shown in the third column of Table AVC-38/A1. In practice it is likely that some limit of peak rate will be imposed at a particular operating mean rate. In the calculations of number of VBR channels for various values of cell loss ratio, it is assumed that there is a peak rate limit for each of the VBR transmissions, which is set to four times the mean rate, i.e. the peak-to-mean ratio is set at 4 for the computations. To realise this constant peak-to-mean ratio, a buffer is introduced at the output of the coder and over the measuring window of a frame, a maximum is imposed on the number of bits taken out of the buffer for transmission. This has no effect on the picture quality but an additional variable delay is introduced from the buffering. The buffer is assumed to have sufficient capacity to absorb all statistical variations of data rate.

Using the B-ISDN Network Model, the number of channels which can be multiplexed for a number of values of cell loss ratio (CLR) with a network capacity of 140 Mbps, are shown in the final column. This rate may be taken as representative of a typical B-ISDN channel capacity.

As a comparison the number of multiplexed channels is calculated for a channel capacity of 30 Mbps, and displayed in the penultimate column of the table. The sensitivity of number of multiplexed channels to magnitude of CLR is seen to be greater at the lower network capacity. For example, at a step size of 8, the percentage increase in number of channels when the CLR increased from 10^{-9} to 10^{-6} is 53%, compared with 22% at 140 Mbps.

2. Results for Approach 1 - Statistical Multiplexing Gain for Equal SNRs

The objective comparison of the two coders, based on SNR, is shown in Fig. AVC-38/A3. The solid curve plots the SNR variation with bit rate for the CBR coder based on measured SNRs at a number of points. For the VBR coder the number of VBR channels which may be multiplexed onto the 140 Mbps network is first computed for each of these step sizes for four values of CLR (final column, Table AVC-38/A1), assuming a constant peak-to-mean ratio of 4. The equivalent average bit rate is then calculated as the network capacity divided by the number of channels. Using this equivalent average rate the points for the 4 cell loss ratios are plotted on the graph.

For each value of SNR of the VBR coder shown on the graph the positions of points to the right of the CBR curve indicate higher equivalent rates over CBR for equivalent quality i.e. fewer channels, or less efficient network utilisation. Point positions to the left of the CBR curve indicate a positive statistical multiplexing gain. The distance between the points and the CBR curve of course indicates the relative efficiency of channel usage of the two coders, and the ratio of the end-points of the distance, VBR to CBR bit rates, give the statistical multiplexing gain.

The values of statistical multiplexing gain (SMG) are shown in the penultimate column of Table AVC-38/A2. The graph-interpolated CBR rates for equal SNRs corresponding to VBR step sizes of 6 and 8 were taken to be 225 kbps and 139 kbps respectively. The upper bound for the number of VBR channels is given in the top row of results for each step size. This corresponds to the perfect statistical multiplexing case, and is simply given by the network capacity (140 Mbps) divided by the mean rate. The SMG increases with VBR coder mean rate and comparable or better channel utilisation was observed for high cell loss ratios of 10^{-4} and 10^{-3}. At lower cell loss ratios the SMG showed a negative gain i.e. more CBR channels may be multiplexed on the network .

3. Results for Approach 2 - Statistical Multiplexing Gain for Subjectively Equal Qualities

The results of Approach 2 based on subjective comparison of quality are shown in the final column of the Table AVC-38/A2. The procedure and results of the subjective testing are given in Appendix B. Two AB comparison tests were performed using the VBR coders operating with step sizes of 6 and 8. In each test the picture quality was compared with the output of a 256 kbps CBR coder.

A unanimous scoring was obtained for the step size of 6 which indicates a distinctly superior quality for VBR at this step size (mean rate of 181 kbps) over the 256 kbps CBR coder. This implies the SMG is at least equal to the ratio of the number of VBR channels at this mean rate to the number of CBR channels at 256 kbps. The least SMG values are shown in Table AVC-38/2.

For the second test using the VBR coder for 139 kbps mean rate the result was no clear preference for either coder. This can be taken to mean an approximate equality of picture quality. On this basis the SMG was computed as the ratio of the number of VBR channels at this VBR mean rate, and the number of multiplexed CBR sources at 256 kbps. The results are shown in the last column of Table AVC-38/A2. A positive gain in SMG was attained for the set of CLRs which ranged from 1.37 to 1.67 for CLRs of 10^{-9} to 10^{-6} respectively. Even allowing for some tolerance of accuracy in the subjective testing, VBR clearly has the advantage.

4. Influence of Peak-to-Mean Ratio (or Buffering Delay)

The choice of peak-to-mean ratio for the VBR transmission impacts on the delay, from the buffering needed to limit the number of output bits per measuring period. Alternatively if the buffer size is fixed in order to limit the delay, the peak-to-mean ratio may vary. Fig. AVC-38/A4 shows a plot of typical variation of peak-to-mean ratio against an increasing size of buffer in number of macroblocks (VBR coder with step size of 8). The first frame of the sequence has been excluded to avoid distortion of results. As the buffer decreased from a frame (396 macroblocks) the peak-to-mean ratio increased gradually, but below 100 macroblocks the rise became quite rapid. In practice the minimum buffering would be for a single ATM cell (48 bytes).

The effect of increasing peak-to-mean ratio on SMG is shown in Table AVC-38/A3 for VBR step size of 8 and at 140 Mbps network capacity. As expected the SMG decreased with increasing peak-to-mean ratio, and at the peak-to-mean ratio of 32, a negative gain was attained by the VBR coder. Thus a shorter buffering delay may be obtained at the expense of sacrificing channel utilisation.

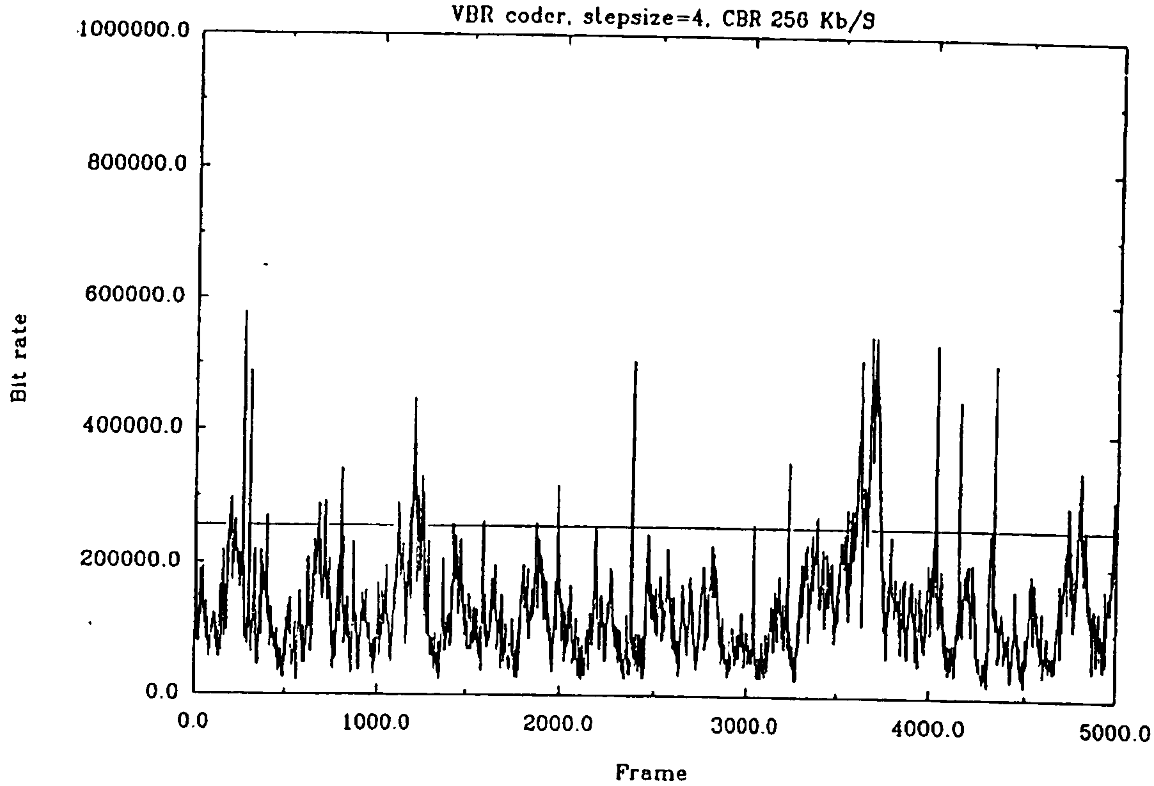

Fig. AVC-38/A1. Bit rate profiles (VBR coder: Step-size=8, mean rate = 139 kbps, measuring period = 1 frame; CBR: 256 kbps).

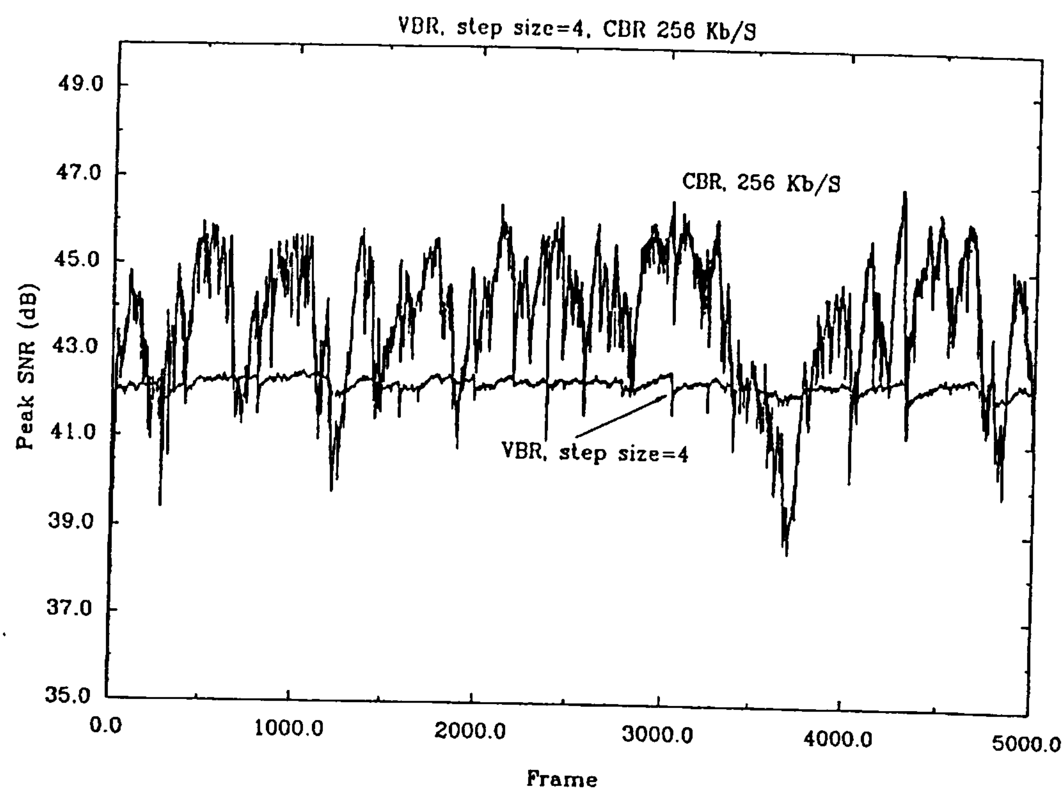

Fig. AVC-38/A2. SNR profiles (VBR coder: Step-size=8, mean rate = 139 kbps, measuring period = 1 frame; CBR: 256 kbps).

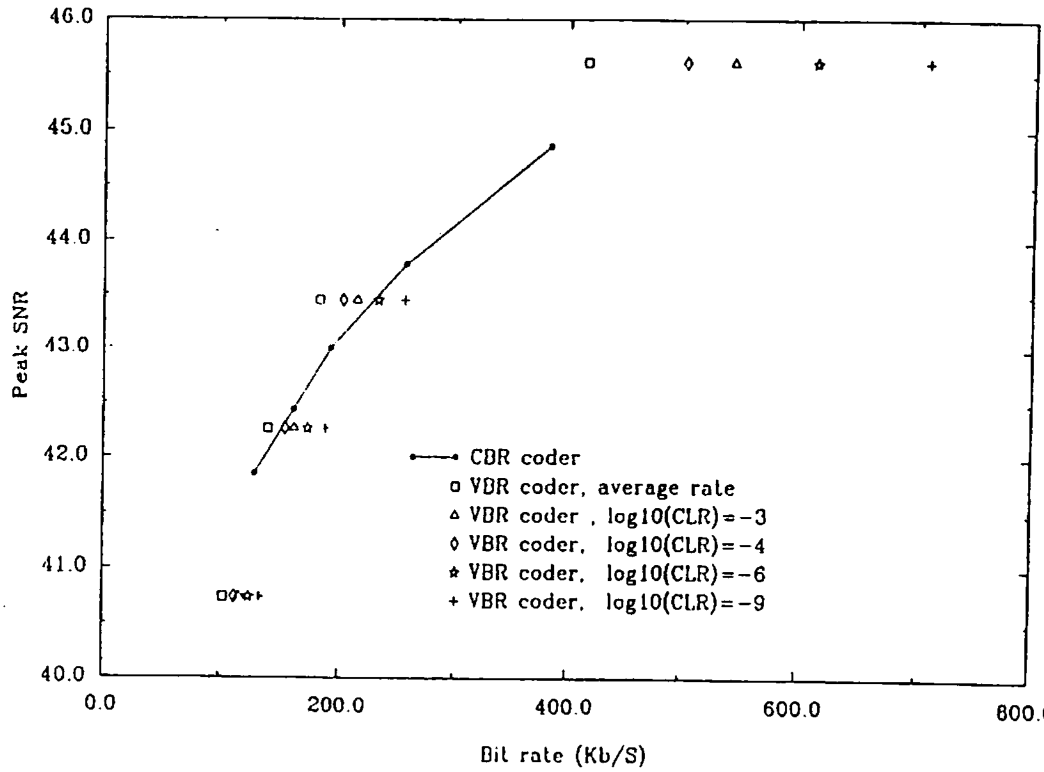

Fig. AVC-38/A3. VBR - CBR Comparison.

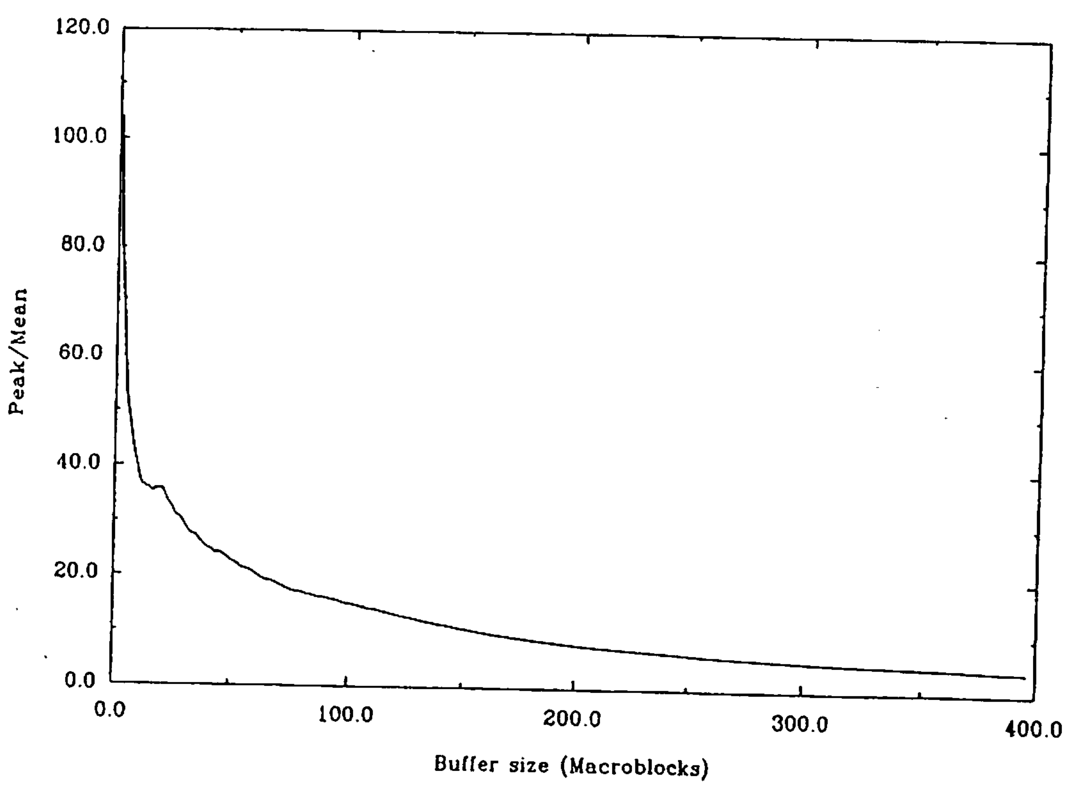

Fig. AVC-38/A4. Peak/Mean Ratio vs Buffer Size (Step-size=8, CLR: 10^{-6}).

Step size	SNR (dB)	Mean Bit rate (KbpS)	Peak Bit rate (Kbps)	Cell Loss Rate (log10)	No. of channels (30 MbpS)	No. of channels (140 MbpS)
4	45.61	415	1660	-3	44	279
				-4	37	258
				-6	29	228
				-9	21	198
6	43.45	181	724	-3	123	688
				-4	110	652
				-6	93	604
				-9	76	551
8	42.26	139	556	-3	168	914
				-4	153	872
				-6	131	814
				-9	110	750
10	40.74	103	412	-3	237	1252
				-4	218	1202
				-6	191	1134
				-9	164	1058

Table AVC-38/A1. Number of channels (VBR) for 30 and 140 MbpS network capacities.

VBR Step size	SNR (dB)	Mean Bit Rate (Kbps)	Cell Loss Rate (log10)	No. of VBR channels	SMG, Equal SNR	SMG, Equal quality (subjective)
6	43.45	181	Bound	770	1.24	> 1.41
			-3	688	1.11	> 1.26
			-4	652	1.05	> 1.19
			-6	604	0.97	> 1.11
			-9	551	0.89	> 1.01
8	42.26	139	Bound	1005	1.10	1.84
			-3	914	1.00	1.67
			-4	872	0.95	1.60
			-6	814	0.89	1.49
			-9	750	0.82	1.37

Table AVC 38/A2. VBR - CBR comparison for equal objective and subjective qualities assumes 140 Mbps network capacity.

Peak/ Mean	Buffer length (MBs)	SMG, Equal SNR	SMG, Equal quality (subjective)
4	396	0.89	1.49
8	205	0.78	1.31
16	71	0.65	1.08
32	11	0.48	0.80
64	4	0.30	0.49

Table AVC-38/A3. The Effect of Peak/Mean Ratio on SMG (step size=8, CLR=10e-6).

Appendix B. Subjective Tests

1. Compilation of Subjective Sequence

This appendix describes the method used to carry out subjective testing on a long video sequence. It was inappropriate to present the entire sequence in view of its long period (3.3 minutes) and a representative shorter sequence was needed. In order to keep the comparison fair the subjective test sequence should somehow reflect the activity in the original long sequence. Typically the CBR coder output shows long periods of relatively high picture quality interspersed with periods of relatively poor quality. Therefore a straight mix of 50:50 of good and bad quality sections in the test sequence would not be representative of the original long sequence. The difficulty is to determine the appropriate ratio and select the sections.

In the comparison study, the subjective test sequence was constructed using two short segments of the original long sequence consisting of a "good" section in which the quality is relatively high e.g. having small amount of motion, and a "bad" section where quality is relatively poor e.g. having high temporal activity. First the ratio of "good" and "bad" frames in the original long sequence is determined and an objective measure is obtained of the quality for the sets of "good" and "bad" frames. Then the same ratio is applied on the desired duration of subjective test sequence to determine the lengths of good and bad segments in this sequence. A selection is then made of contiguous good and bad segments from the original sequence. The objective quality of the segment is taken to be as close as possible to that of the sets of good and bad frames in the original sequence.

The SNR profile of the CBR coder output gives an indication of the activity of the original long sequence, and is used to determine the ratio of good to bad lengths in the original sequence. Thresholds for "good" and "bad" classification are derived from the average SNR of a VBR coder. The average SNR is obtained for the good and bad frames. The selection of good and bad segments employed a smoothed version of the CBR coder's SNR profile. The step-by-step procedure is as follows:

1) The frame SNR profile of the 256 kbps CBR coder was first smoothed using an averaging interval of 40 frames

2) Two limits are established based on the average frame SNR of the VBR coder for step size of 6 (mean rate 181 kbps)
   upper limit: VBR SNR + 1.5dB
   lower limit: VBR SNR - 1.5dB

3) The following values are computed:
   Ngood- the number of CBR coder frames with SNR above the upper limit
   dBgood - the average value of frame SNR for these frames
   Nbad - the number of CBR coder frames with SNR below the lower limit
   dBbad - the average value of frame SNR for these frames

4) Two segments of the test sequence are then selected such that in one segment the CBR quality is superior to the VBR quality and the reverse is true for the other segment. The ratio of the lengths of the good to bad segments in the CBR case is Ngood/Nbad.

5) It was decided to use a 300-frame sequence for viewing. The number of frames in the good and bad segments were determined from Ngood/Nbad. The average SNR for the good CBR segment is selected to be equal to dBgood, whilst that for the bad segment is selected to be equal to be dBbad. A contiguous segment satisfying the average SNR value and number of frames was found for each case.

From this procedure the following segments were selected for viewing in the subjective tests:
   Good segment: frames 3000 to 3199
   Bad segment: frames 3550 to 3650

The two segments were concatenated to give a 12-second (300-frame) test sequence and CBR and VBR qualities were presented to the subjects in an AB comparison test. The test sequences were presented sequentially, CBR followed by VBR.

2. Results of Subjective Testing

TEST1: 256 kbps CBR coder versus 181 kbps mean VBR coder (i.e. step size = 6)

number of subjects preferring CBR - 0

number of subjects preferring VBR - 5

total number of subjects - 5

TEST2: 256 kbps CBR coder versus 139 kbps mean VBR coder (i.e. step size = 8)

number of subjects preferring CBR - 4

number of subjects preferring VBR - 3

number of subjects who cannot see any difference - 3

total number of subjects - 10

Appendix C. Network Model

The network is represented by a single multiplex, as shown in figure AVC-38/C1, with N sources. The sources are *independent* and *identically distributed.* The rate of a source is assumed to be a *Bernoulli* random variable that has a value P when it is on and 0 when off. The probability of it being on is p . Hence the mean rate is $p{\cdot}P$. The distribution of the multiplexed sources is therefore *binomial.* The network is assumed to be *memoryless* with a capacity C . If the instantaneous rate of the multiplex is X then $X > C$ implies cell loss at a rate X-C. If $X<C$ no cell loss occurs. Using these assumptions it is straight-forward to obtain the *cell loss ratio* (CLR) as a function of the source and network parameters.

$$CLR = \frac{\sum_{x=\lceil C/P \rceil}^{N} (P \cdot x - C) Pr(X = P \cdot x)}{\sum_{x=0}^{N} P \cdot x \cdot Pr(X = P.x)} \qquad \text{(C.1)}$$

where $Pr(X=Px)$ is the probability that the multiplexed rate is Px. Note that $\lceil x \rceil$ is used to denote the next integer greater than x. This expression is the ratio of the average loss rate to the average rate of the multiplex. Since X is a binomial random variable the probability is given by

$$Pr(X = P \cdot x) = \binom{N}{x} p^{x} (1-p)^{N-x} \qquad \text{(C.2)}$$

In this expression x can be interpreted as the number of sources which are on and therefore transmitting at a rate P. Implicit in this expression is an assumption that the network operates with 100 % efficiency when the total rate exceeds capacity. This might be slightly optimistic. More conservative assumptions can be applied by replacing (Px - C) with some other representative non-linear loss function. For example you might assume that as the multiplex rate increases the network efficiency decreases and at some point complete congestion occurs giving a loss of Px . For the purposes of this contribution we will use the expression given. Using this model it is possible to obtain curves for the CLR as a function of the number of sources for a given channel capacity, peak rate and mean rate, or the channel utilisation as a function of peak to mean ratio for a given cell loss and peak rate.

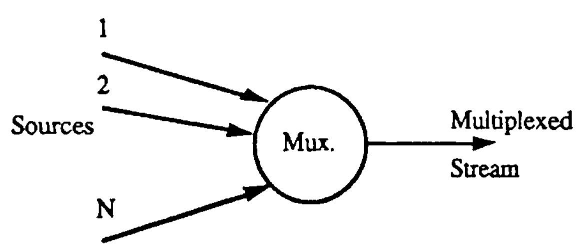

Figure AVC-38/C1. Single stage multiplex.

Although this result has been obtained using similar source and network model assumptions to those used to generate the CLR function proposed in the November 1990, SGXV ATM experts meeting the results can be quite different. The ATM experts group cell loss formula [1],[2] is an approximation to the probability

$$Pr(X > C) = \sum_{x=\lceil C/P \rceil}^{N} Pr(X = P \cdot x) \qquad \text{(C.3)}$$

This expression could be called the congestion probability since it is the probability that the instantaneous rate of the multiplex exceeds the channel capacity. It is not obvious how this probability is related to cell loss and indeed the two expressions give results which differ by up to two orders of magnitude. The congestion probability provides a pessimistic estimate of cell loss.

An important question is how realistic is the evaluation of channel utilisation provided by this model. There are clearly many simplifications. One obvious omission is buffering in the network model. Studies of channel utilisation which include buffering have been carried out [3],[4]. Analysis of networks with buffering requires queueing theory. If buffering is included then it is also necessary to enhance the source model since the distribution is no longer an adequate characterisation. Time dependencies, usually expressed through the autocorrelation function, must also be quantified. Inclusion of buffering will enhance the statistical multiplexing gain predicted from the model if the sources are uncorrelated (in time) since it will act to smooth out rate variations. It is not clear at this stage what buffer length assumptions would be appropriate for B-ISDN though it is likely that switch buffer lengths will be kept to a minimum. Sources in which the rate is bursty (i.e., significant correlation over time) will not obtain the same improvements when buffering is introduced. Burstiness is an important source parameter which is being considered, along with peak and mean, by CCITT SGXVIII for channel allocation and policing, hence it may be necessary to study its effect. One could also consider enhancing the distributional model of the source. For example a continuous model, or a more sophisticated discrete model which has multiple states, could be proposed. However, since CCITT SGXVIII are only considering very simple methods for allocating channels on the B-ISDN, which are based on peak and mean, it is unprofitable to consider improved distributional models.

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