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Title: VBR MPEG Bit-rate Characteristics

Purpose: Information and discussion

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1. Summary:

This contribution presents some recent bit-rate data for variable bit-rate (VBR) MPEG-1 compatible video for ATM applications. Variable bit-rate MPEG is an alternative to constant bit-rate (CBR) for certain ATM-based multimedia networking and teleconferencing scenarios. The VBR mode of ATM is of special interest in systems requiring resource sharing via statistical multiplexing, low latency, integrated multimedia transport, etc. Accordingly, understanding and characterization of the source bit-rate process is an important pre-requisite for the design of ATM systems supporting MPEG-based VBR video.

Four test video sequences (Flower Garden, Mobi, Table Tennis and Recap) totaling over 3000 frames of video, were encoded using an open-loop VBR encoder following MPEG-1 syntax. The results presented include: (i) the frame-by-frame bit-rate, probability density function and autocorrelation plots for each test sequence, (ii) image quality in terms of Signal-to-Noise Ratio (SNR), versus average and peak bit-rate, (iii) the effect of different peak rate control levels on the image quality, (iv) a comparison of CBR versus VBR image quality for the same average bit-rate.

2. VBR MPEG characteristics:

2.1. Introduction

The VBR bit-stream was obtained by encoding CCIR 601 video sequences using the MPEG-1 compatible, MPEG VBR encoder shown in Figure 1. In the open-loop mode, a triplet of quantization steps (one for each frame type) is initially selected based on a target image quality and remains fixed during open-loop operation mode. In this study, N=9, and M=3, (N is the distance between I pictures, and M is the distance between P pictures).

2.2. Time Plots, distributions and autocorrelation:

The bit-rate statistics of representative scenes have been collected to characterize the open-loop VBR MPEG-1 encoder. Figure 2 presents plots of frame bit-rate vs. time for the four test sequences used. For a specified quantization scale triplet, the mean bit-rate is an indicator of scene complexity; thus, from Figures 2, Mobi sequence is the most complex scene, followed by Recap, Table Tennis and finally Flower Garden. It is observed that the three bit-rate levels corresponding to the I, P and B frame types, are distinguishable in the plots. Stationarity may be assumed for smooth pan and zoom scenes such as Mobi (Fig 2a) and Flower-garden (Fig 2b). In these scenes, segments of the bit-rate trace look statistically alike. On the other hand, scenes like Recap and Table-tennis have sudden changes in activity levels and are not stationary. Table Tennis (Fig 2c) contains fast camera panning and a few scene changes characteristic of sports material. Recap (Fig 2d) is an ensemble of scenes and contains sudden scene changes; it is characteristic of commercial and music clip broadcasting video material.

Figure 3 shows a short-term trace of the frame bit-rate for one of the test sequences (Mobi); this plot clearly shows the three different activity levels corresponding to each frame type, and the I,B,P periodicity inherent to the MPEG encoder. Figure 4 presents the probability distribution function (pdf) for a test sequence (Mobi); the distribution of frames among I, P and B types and the relative average size of each frame type is shown. Figure 5 presents the pdf for each frame type. Note that I frame bit-rates (Fig 5a) are distributed around two mean values with a rather small standard deviation. Bit-rates for P and B frames are more spread out. Figure 6 presents the correlogram for the same test sequence; since the bit-rate time series contains periodic fluctuations, the autocorrelation presents the same oscillations at the same frequency. Although higher order Markovian models could capture the periodicity in the bit-rate trace and match the sequence correlogram closely, partially independent modeling of the encoding states (I, P and B frames) by using more compact (fewer parameters) models is also possible.

2.3. Video Quality vs. Bit-Rate

Table 1 presents the codec output bit-rate and SNR as a function of the I,P,B quantization step triplet selected, for a representative CCIR 601 video sequence (Mobi). These results may be useful for selection of VBR encoder parameters given the image quality/bit-rate scenario required by an application. Note that the quantization step triplets have been empirically selected to give reasonably uniform video quality for various target bit-rate regimes, and are not claimed as optimum selections. A general rule is that the quantization scale for I frames should be the finest, followed by the one for P frames (since these frames are referenced the most when differential coding is performed); while the quantization scale for B frames is the coarsest one.

quantizer triplet (qI,qP,qB)	Average Bit-Rate in Mbps (Overall)	Average Bit-Rate in Mbps (I frames)	Average Bit-Rate in Mbps (P frames)	Average Bit-Rate in Mbps (B frames)	Peak Rate in Mbps	Average SNR in dB
2, 5, 5	28.0	56.4	27.8	23.1	69.0	40.0
3, 4, 6	26.1	44.2	34.4	20.3	54.0	39.0
4, 5, 8	21.1	36.9	29.4	15.6	45.3	37.0
6, 7, 12	15.2	28.0	22.9	10.5	34.5	34.0
8, 9, 16	12.0	22.7	18.9	7.8	28.2	32.0
12, 15, 20	8.9	16.8	12.4	6.4	21.0	30.2
12, 15, 25	7.7	16.8	12.4	4.6	21.0	29.5
14, 17, 30	6.5	14.8	3.6	3.6	18.0	28.6

Table 1 : VBR encoder bit-rate and SNR vs. quantization step for Mobi Sequence

Figure 7 presents the SNR versus the average and peak open-loop bit-rates for a particular test sequence. The results in Table 2 below provide a summary of the variation of the bit-rate and SNR among different test sequences when VBR encoded with the same quantizer triplet (qI=12, qP=15, qB=20).

Test Sequence	Length (Frames)	Average Bit-Rate (in Mbps)	Burstiness (Peak/Average)	SNR (dB)
flower garden	800	5.45	2.85	32
mobi	900	8.9	2.33	30.2
table tennis	734	4.3	4.4	32.3
recap	810	7.1	3.54	35.3

Table 2 : VBR Codec Outputs for different test sequences for qI=12, qP=15 and qB=20.

2.4. Peak Rate Control (Traffic Shaping)

The objective of peak rate enforcement at the video encoder is to avoid the effects of ATM network policing on VBR video quality. Acting at the source level, peak rate control provides a mechanism for staying within agreed-upon ATM network VBR bit-rate parameters without severe degradations in image quality due to cell loss. The peak control method considered here is a frame level self-policing scheme based on two-pass encoding. The first pass is a detection phase that emulates open-loop operation by using the pre-established quantization scale. If the obtained bit-rate level is below the pre-established peak threshold, the bit-stream representing the encoded frame is sent to the ATM network (and transmitted as a sequence of cells with appropriate inter-cell spacing). However, if the number of bits resulting from encoding the frame exceeds the peak level, a second encoding pass of the frame takes place using a suitably determined larger quantization scale.

Table 3, presents performance results for an implementation of peak rate control on the four different test sequences. Note that when contrasted with open-loop performance (see Table 2), at the 1.5 * Average Bit-Rate policing level, the Peak-to-Average ratio is reduced, in average, by 10% while the SNR is reduced, in average, only less than 1%. Figure 8, shows the open loop versus policed bit-rate. Figure 9, compares the SNR performance of the open loop and the peak policed bit-stream.

	Peak = 1.5 * Average Bit-Rate for Open loop			Peak = 2.0 * Average Bit-Rate for Open loop			Peak = 2.5 * Average Bit-Rate for Open loop		
Seq.	Av. Rate	Peak / Average	Average SNR	Av. Rate	Peak / Averag.	Average SNR	Av. Rate	Peak / Average	Average SNR
f.g	5.34	2.5	31.9	5.42	2.56	32.1	5.44	2.67	32.2
mobi	8.63	2.0	30.1	8.1	2.23	30.2	8.71	2.38	30.2
recap	6.83	3.3	34.16	7.0	3.2	34.9	7.13	3.27	35.0
t.t.	4.12	4.0	32.0	4.2	3.91	32.3	4.14	4.0	32.2

Table 3: performance results of the peak rate control mechanism

3. Comparison of VBR and CBR MPEG

In order to assess the potential image quality and/or efficiency benefit of VBR MPEG, a simple comparison with CBR is given in this section. The VBR encoder using the quantizer scale set qI=12, qP=15 and qB=20, is compared with a (500 ms rate buffered) CBR version rate controlled to operate at the same average bit-rate. Figure 10, contrasts the frame-by-frame bit-rate process out of the CBR MPEG-1 encoder and out of the open loop VBR MPEG-1 encoder (for the Table-tennis sequence). Figure 11, presents the corresponding SNR variation of both modes. Table 4 below gives a summary of encoder performance for alternative VBR and CBR encoding modes (for the test sequence: Table Tennis).

	Av. Bit Rate (Mbps)	Peak/Average	Av. SNR (dB)	SNR Variance (dB)
VBR Mode	4.3	4.4	32.2	1.16
CBR Mode	4.3	3.7	30.4	14.78

Table 4: Comparison of VBR vs. CBR performance for the same test sequence (Table Tennis)

From the above results, as expected from earlier studies, it is observed that tne VBR mode does provide a higher average SNR at the same average bit-rate as the CBR codec. In addition, the VBR achieves a very low SNR variance of the order of 1 dB^2(i.e., constant quality), as compared with the large 15 dB^2variance obtained for the CBR encoder. While these results demonstrate some of the advantages of VBR encoding, a more complete comparison must also account for higher VBR overhead due to adaptation headers and network admission control margins.

4. Cell loss resilience & its impact on VBR mode

Referring to an earlier MPEG/CCITT document, (Regis Saint Girons, et. al. "Transport and Error Concealment for MPEG-2", AVC-139), it has been shown via detailed simulations that the type of MPEG encoded video under consideration can tolerate cell loss rates of the order of 10^{-5} to 10^{-3} (depending on service quality requirements) with one-layer ATM transmission, specialized adaptation and decoder error concealment. With two layer augmentation (as in the MPEG-based AD-HDTV system, "Advanced Digital Television: Prototype Hardware Description" FCC WP1 Certifcation Document, Feb. 1992), the cell loss threshold can be further improved to the region of 10^{-1} to 10^{-2}. Thus, resource shared (statistically multiplexed) operation of VBR MPEG encoders characterized above may be useful and feasible in certain ATM networking scenarios, since the cell loss rate targets are fairly realistic (i.e., 10^{-3} -10^{-5}), rather than more difficult to achieve reference levels such as 10^{-9}.

5. Figures

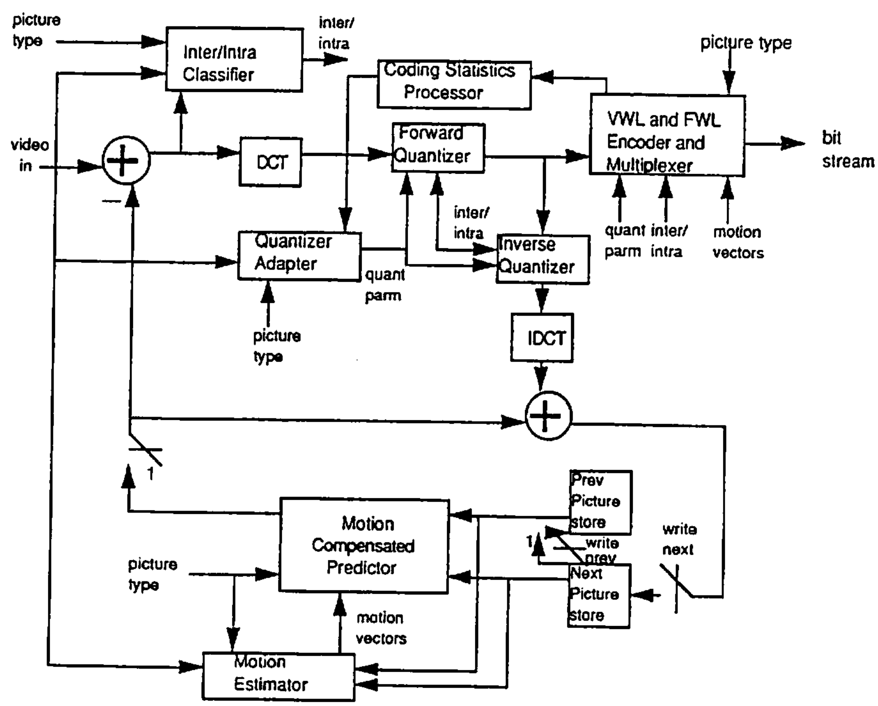

Figure 1: Block Diagram of typical MPEG-1 VBR Encoder

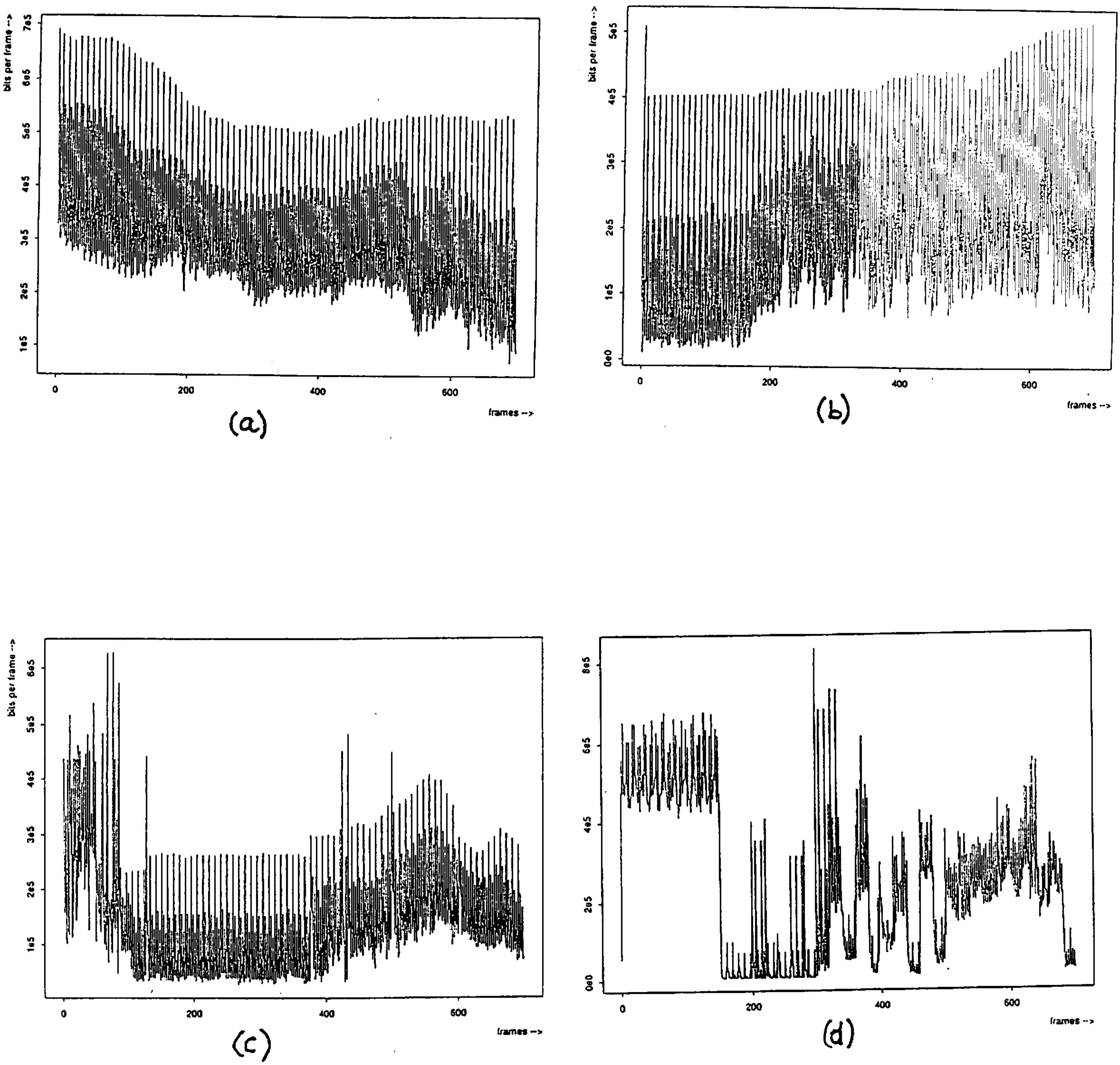

Figure 2: Bits per Frame for (a) Mobi, (b) Flower Garden, (c) Tabel Tennis, (d) Recap

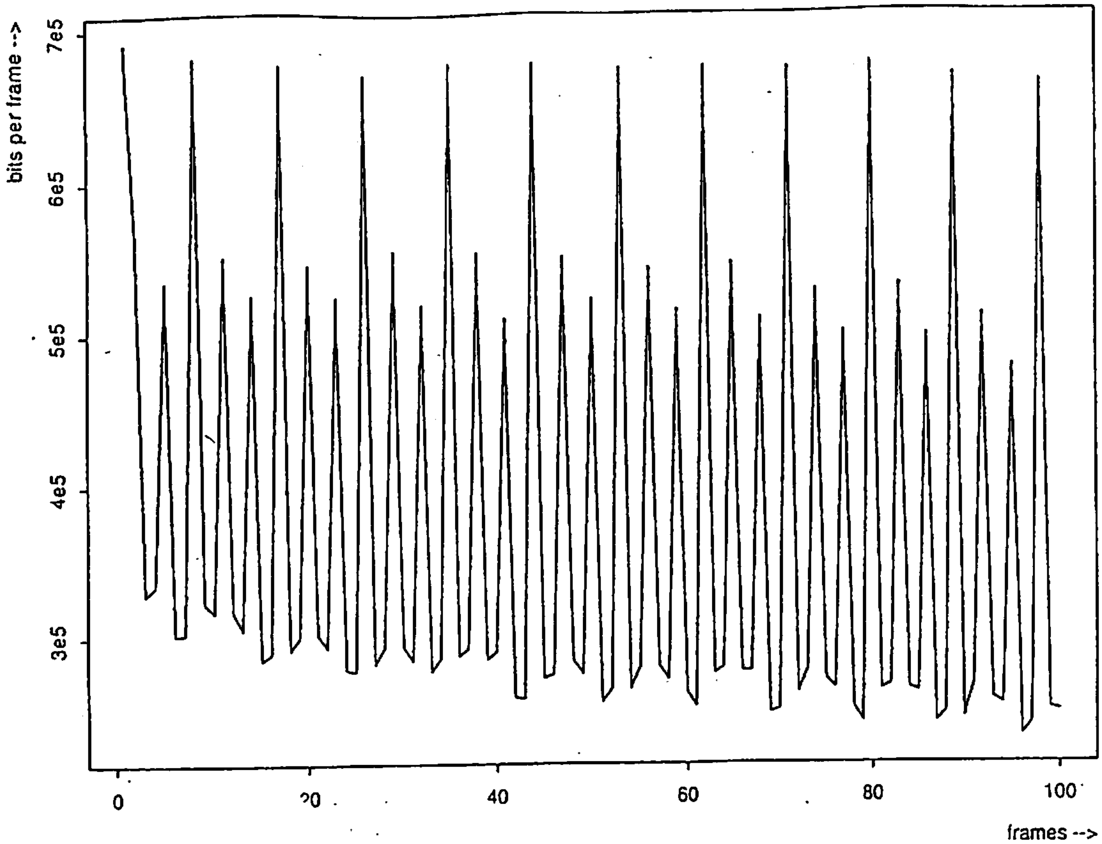

Figure 3: Expanded plot of the instantaneous bit-rate (Mobi sequence)

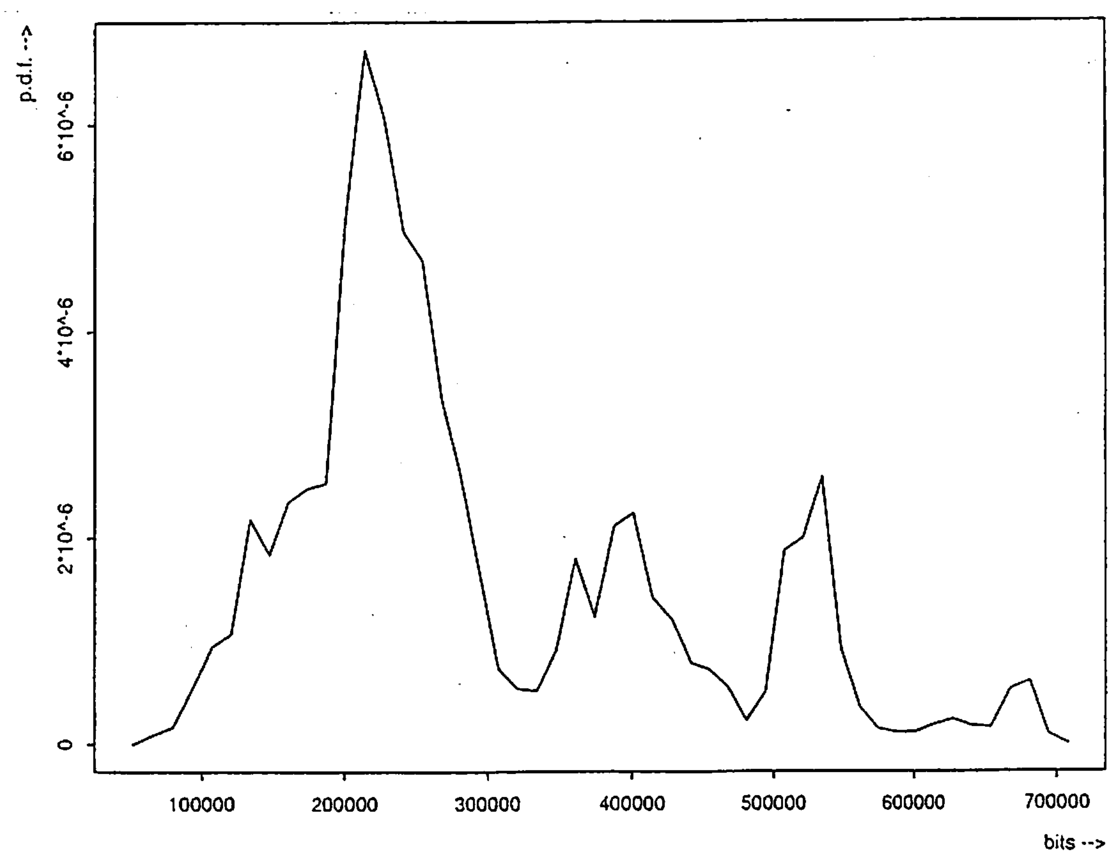

Figure 4: Bits per Frame distribution (Mobi sequence)

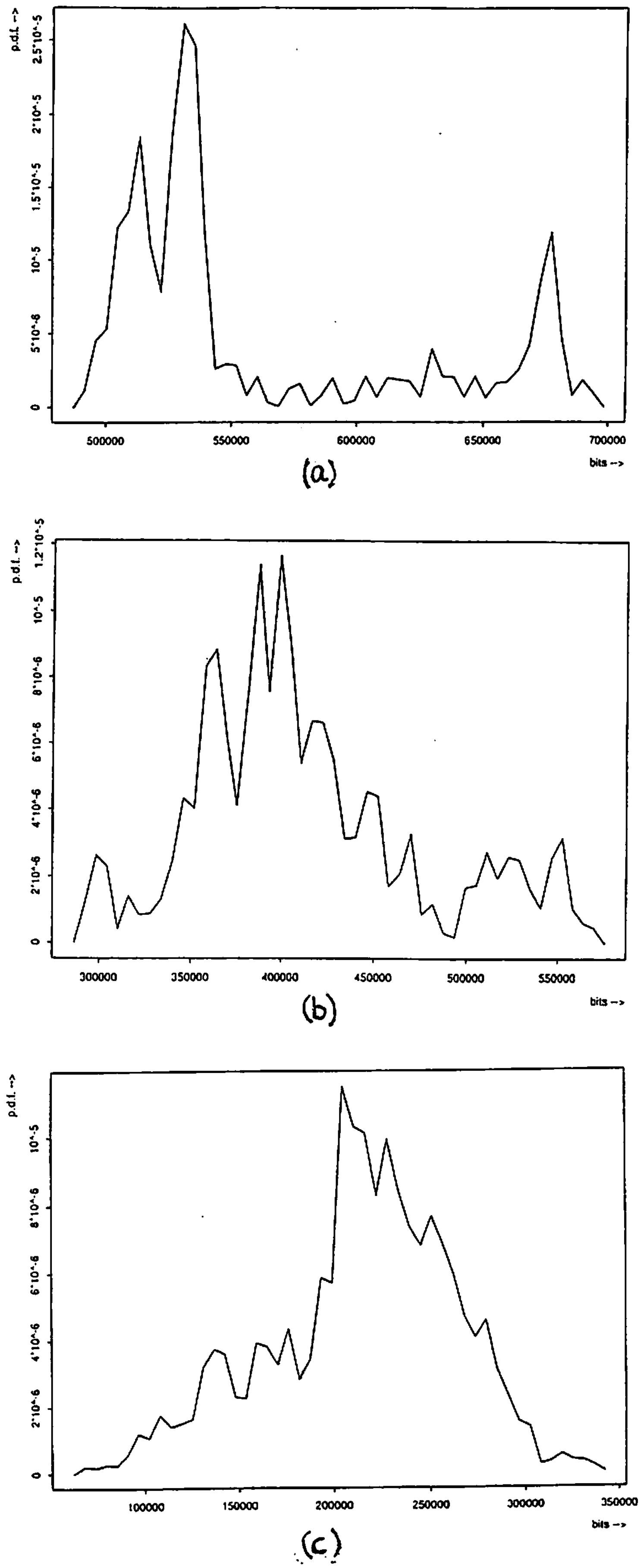

Figure 5: Distribution of Bits per frame Type (a) I frames, (b) P frames, (c) B frames

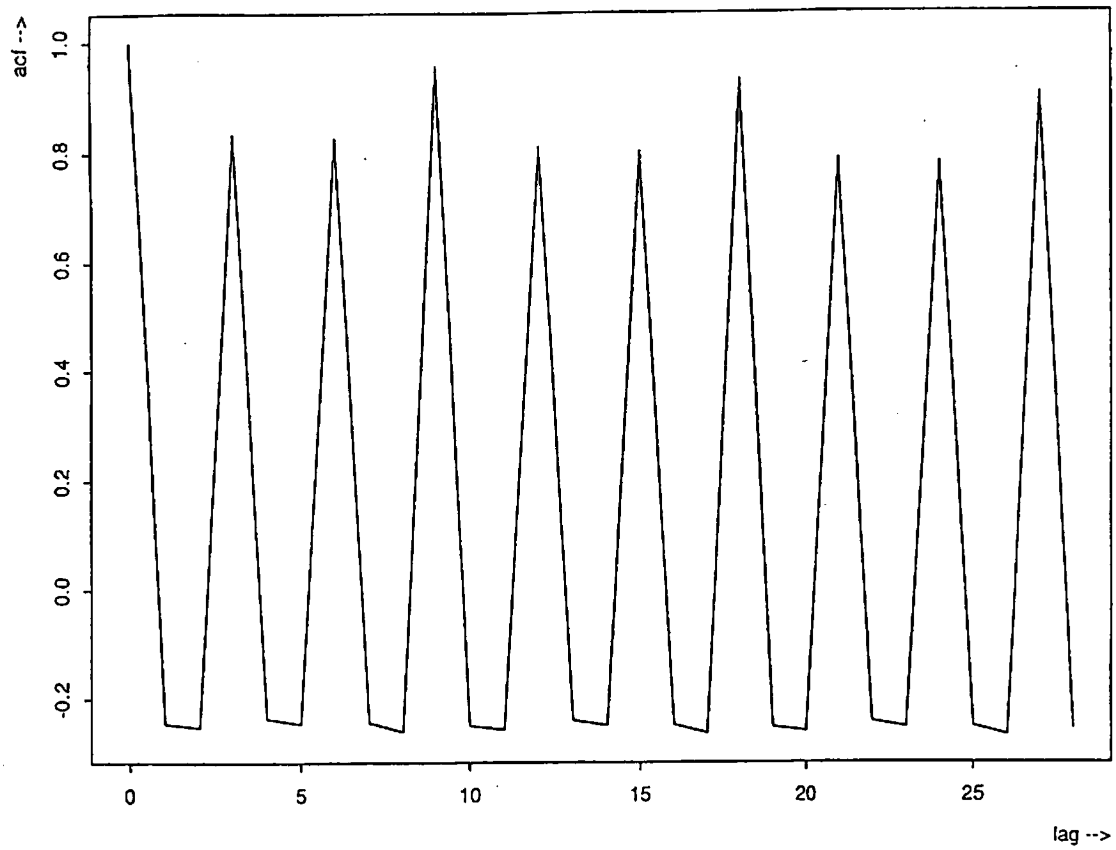

Figure 6: Correlogram Plot (Mobi Sequence)

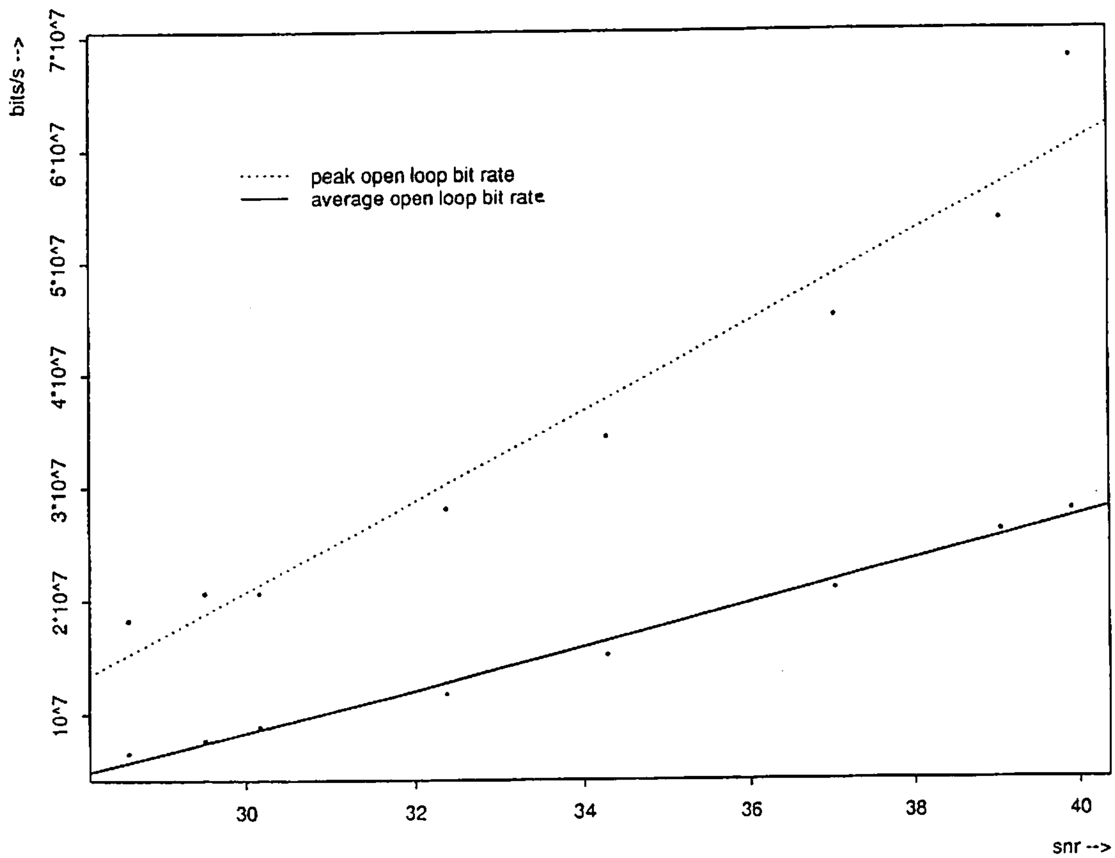

Figure 7: SNR vs. Average and Peak Open loop bit-rate (Mobi Sequence)

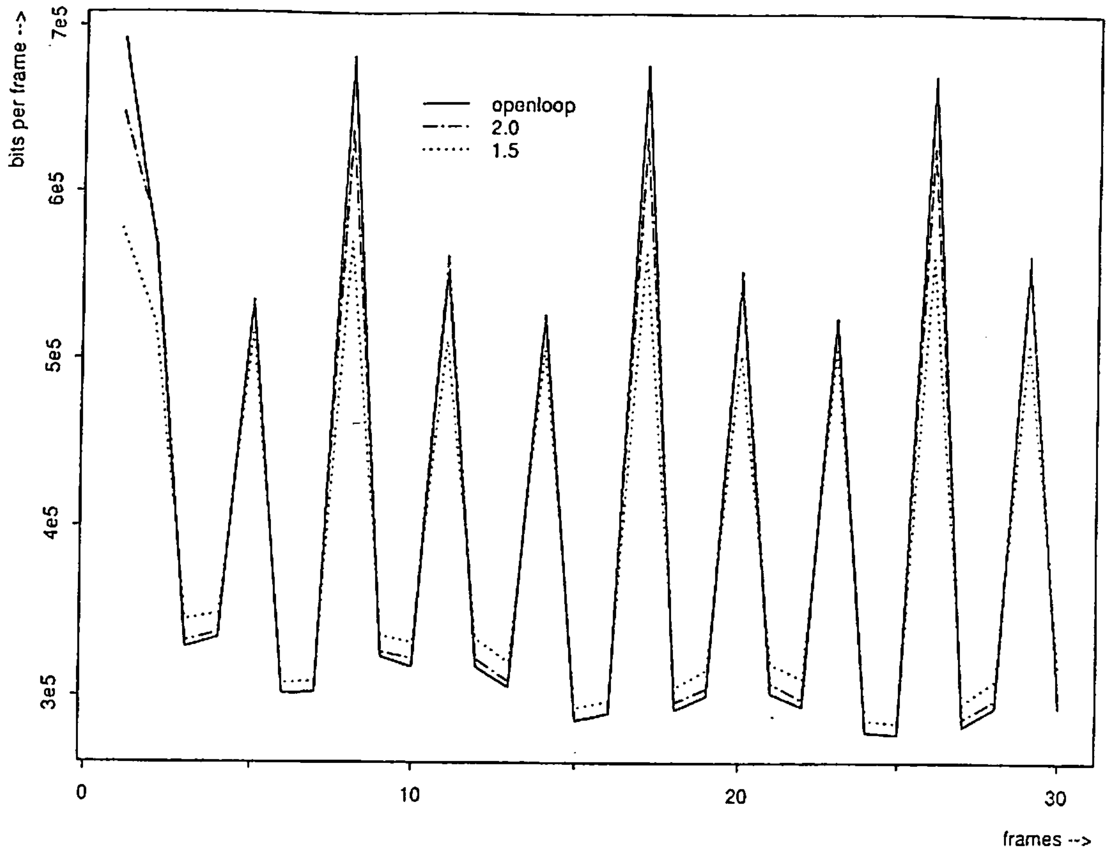

Figure 8: Open-Loop vs. Peak-Policed Instantaneous Bit-Rate

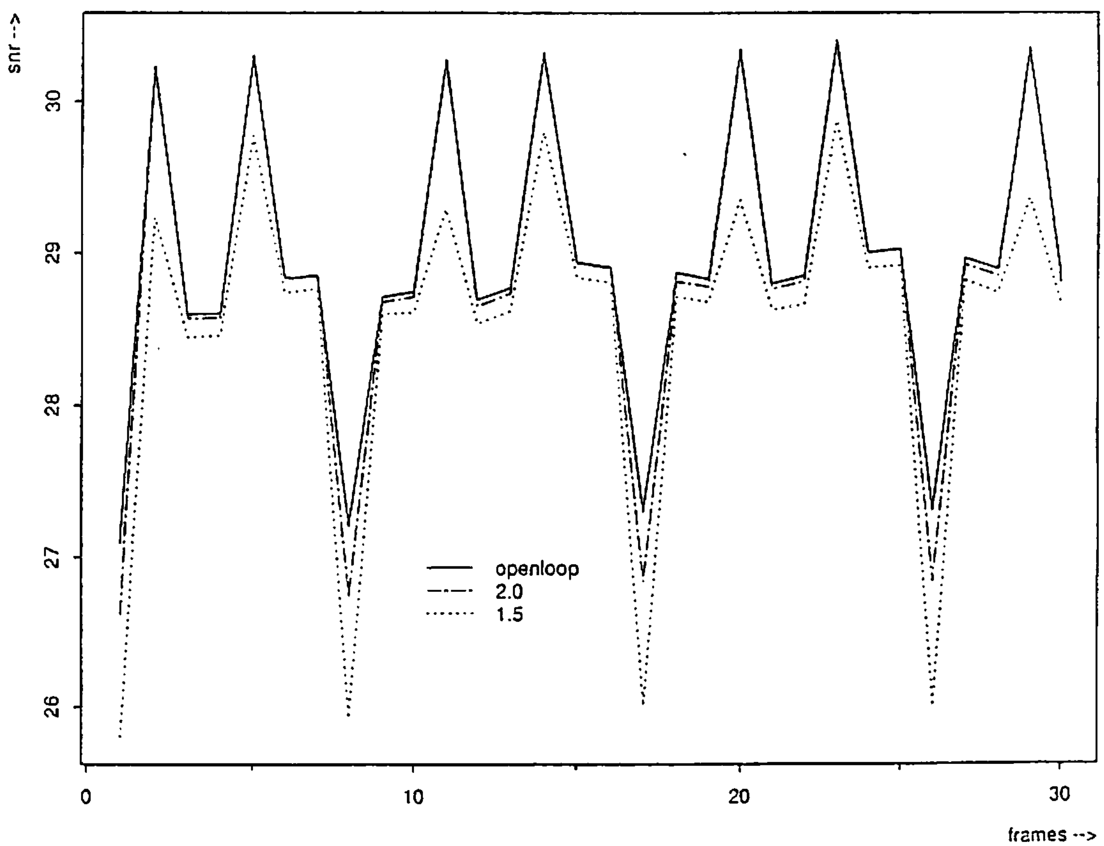

Figure 9: Open-Loop and Peak-Policed VBR SNR Performance

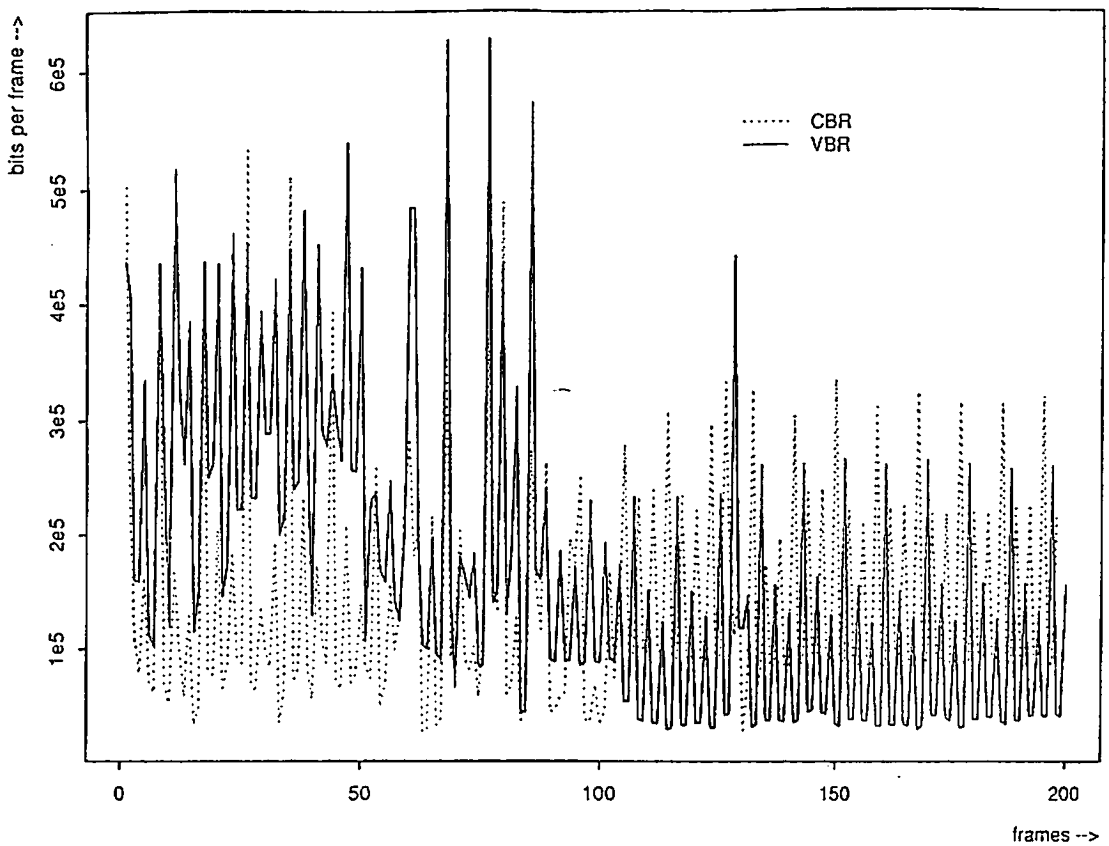

Figure 10: Bitrate Process: VBR vs. CBR for the same Average Bit-Rate (Table-Tennis)

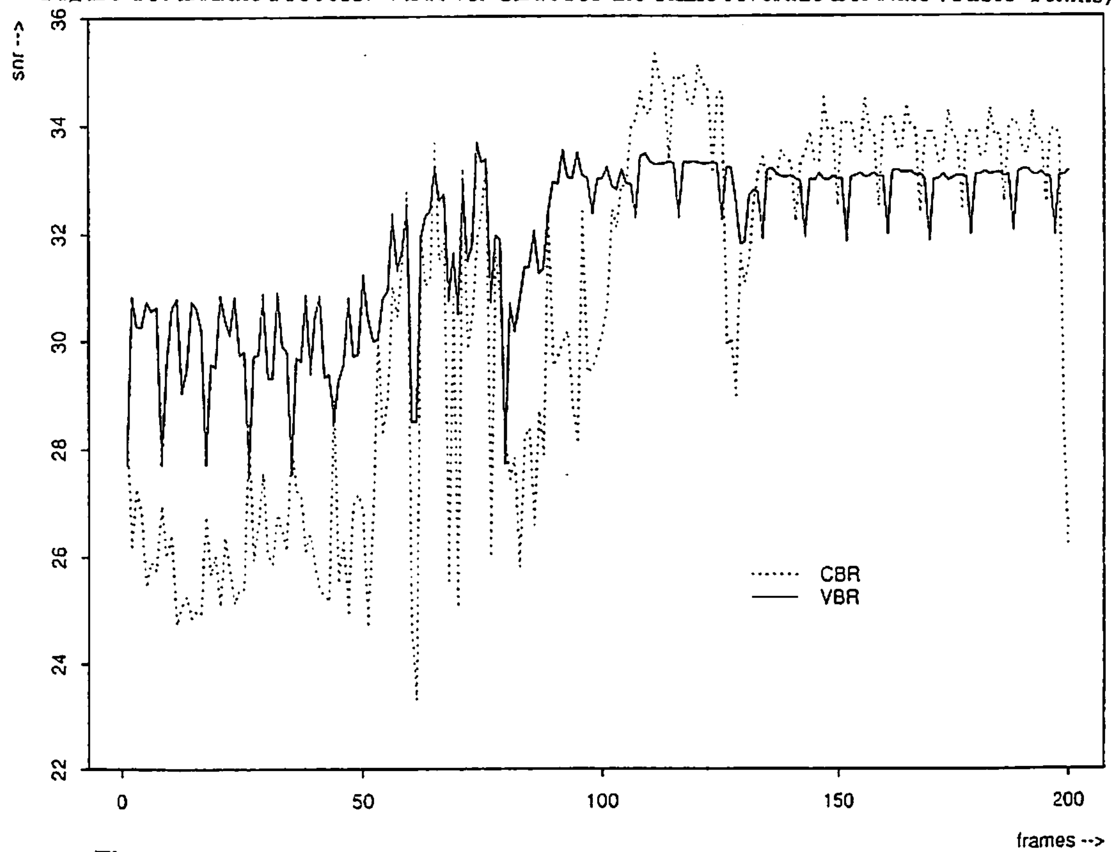

Figure 11: SNR : VBR vs. CBR for the same Average Bit-Rate (Table-Tennis)