STATISTICALLY MULTIPLEXING/RE-MULTIPLEXING

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ABSTRACT

This paper presents a statistically multiplexing/re-multiplexing system for both uncompressed and pre-compressed digital video signals. The system consists of encoders and transcoders plus a joint rate control engine. Hence, it is able to handle both the uncompressed digital video signals and the pre-compressed video bit streams. Specifically, encoders encode the uncompressed video signals while transcoders transcode the pre-compressed video bit streams. The rate control engine dynamically distributes the channel capacity among the programs according to the program relative complexities. Computer simulation results are reported.

1. INTRODUCTION

With recent advance in digital video compression, such as MPEG-2 [1], and digital transmission, it is possible to deliver several digitally compressed video programs in the same bandwidth presently occupied by a single analog TV channel.

Fig. 1 shows a multi-program transmission environment where several programs are coded, multiplexed and transmitted over a single channel. Clearly, these programs have to share the channel capacity. In other words, the aggregate bit rate of the programs has to be equal to, or less than, the channel rate. This can be achieved by controlling either each individual program bit rate (independent coding) or the aggregate bit rate (statistical multiplexing, or stat mux [2,3]). In independent coding, rate control can only be performed across the time and spatial dimensions of a program. However, in stat mux, control is extended to an additional dimension, that is, the program dimension, implying more freedom in allocating the channel capacity among programs and therefore more control of picture quality among programs as well as within a program.

Furthermore, it should also be noticed that more and more pre-compressed video materials, such as films, are becoming available these days. In addition, some applications may require to unbundle the statistically multiplexed video signals and re-multiplex (stat remux) some of them with other video streams. Hence, it is desirable that a stat mux system is able to handle not only the uncompressed video signals, but also the pre-compressed video signals. The problem with the pre-compressed video materials is that they could be pre-encoded at any bit rate, either constant (CBR) or variable (VBR). In order to include the pre-compressed video bit streams in a stat mux system, the rates of the pre-compressed video bit streams have to be *changeable* while multiplexing.

This paper presents a stat mux/remux system for both pre-compressed and uncompressed video signals. The system consists of both encoders and transcoders, as shown in Fig. 2. To squeeze the incoming programs into a given channel, the stat mux/remux system either encodes them by using encoders if they are in raw pixel data, or transcode them by using transcoders if they are in compressed bits. Ideally, the input programs should share the channel capacity (bits/s.) according to their relative complexities. That is, more complex programs are assigned more bits and less complex programs less bits. The stat mux/remux system implements a joint rate control that manages the bit allocation among the incoming programs.

The paper is organized as follows. Section 2 introduces the concept of transcoding by presenting two rate-conversion transcoder architectures for MPEG bit streams. Performance comparisons of the two architectures with direct MPEG are also provided in terms of PSNR. Section 3 describes the stat mux/remux system and reports its performance.

2. TRANSCODER ARCHITECURES

A straightforward rate-conversion transcoder for MPEG bit streams can simply be a cascaded MPEG decoder and encoder, as shown in Fig. 3. In the cascaded-based transcoder, the decoder decodes the input compressed MPEG bit stream, reconstructing the video signal, and the encoder re-encodes the reconstructed video signal, generating a new bit stream. The desired rate of the new bit stream can be achieved by adjusting the coding parameters, such as quantization parameter, Q_2, in the encoder. Note that the quatization parameter, Q_1, embedded in the pre-compressed bit stream is decodable, but not changeable. The main concern with the cascaded-based transcoder is its implementation cost: one full MPEG decoder and one full MPEG encoder.

The cascaded-based transcoder could be simplified if the picture types (I, P or B) in the incoming pre-compressed bit stream can remain unchanged during transcoding. Maintaining the picture types also means maintaining the temporal processing of macroblocks (MB) in each picture (intra, inter, forward, backward, or interplative). Because of the similarity between the original and reconstructed video signals, the motion vector (MV) fields embedded in the pre-compressed bit stream should be reasonable good for the reconstructed video signal. Hence, the MV fields can be used for the MC in the encoder, implying that motion estimation (ME) -- the most expensive operation in the encoder can be removed. Fig. 4 shows a cascaded-based transcoder without ME where the MV fields decoded from the decoder are re-used in the encoder.

In evaluating the cascaded-based transcoder architectures, experiments were carried out for a number of video sequences for different rate conversions. Table 1 shows the results, in terms of PSNR, for two sequences of *Market* and *Trapeze* for two different rate conversions (15 → 3 Mbits/s and 6 → 3 Mbits/s.). For comparison purpose, the PSNRs for direct MPEG at the same final rate of 3 Mbits/s. are also provided in Table 1. Direct MPEG can be considered as benchmark for transcoder. Transcoder introduces an additional quality loss, as compared to direct coding, because the signals passing through a transcoder are actually quantized twice. From Table 1, it should be noted that transcoder without ME in the encoder actually performs nearly as well as with ME.

The reconstructed video sequences at the same final bit rates were viewed side by side for subjective assessment. There were virtually no perceptual differences found between two cascaded-based transcoders with and without ME, implying that cascaded full decoder/encoder can be replaced by cascaded transcoder without ME. GI developed a transcoder architecture for MPEG-2 bit streams derived from the cascaded-based transcoder with re-use of motion vector fields. It has been shown theoretically that its performance is identical to the cascaded-based transcoder with re-use motion vector fields (Fig. 4). But, its architecture is much simpler than the cascaded-based transcoder, and it actually saves many function blocks and memories, as compared to the cascaded-based transcoders (Fig. 3 and 4).

2. STAT MUX/REMUX

A stat mux/remux system is developed for both uncompressed and pre-compressed video programs. Fig. 5 shows the main architecture of the system consisting of both encoders and transcoders. Encoders are used to encode the uncompressed digital video signals while transcoders to transcode the pre-compressed video bit streams. The stat mux/remux system implements a joint rate control scheme, which dynamically distributes the channel capacity over programs according to the program relative complexities. This means that given a fixed channel, the rate assigned for a program not only depends on the program own complexity, but also others. Specifically, at each frame, each MPEG encoder/transcoder l receives a target number of bits, T_l, from rate control engine, as shown in Fig. 5. The MPEG encoder/transcoder then encodes/transcodes the frame at that rate by adjusting the coding parameters, such as, quantization parameter. The average quantization parameter, Q_l, used for a frame and the resulting number of compressed bits, R_l, generated for the frame are then sent to the rate control engine. The product of Q_l and R_l can be considered as a frame complexity measure, and used to update the complexity measure for the corresponding picture type. The rate control engine in turn determines a new target number of bits for the next coming frame of each program based upon the type of the frame, types of other frames in the same program and in other programs, as well as the set of the updated picture complexity measures. Joint rate control with dynamic bit allocation can work with the programs of different GOP structures, and it can also address the possible future changes in the program GOP structures. The bits generated from MPEG encoders and transcoders are multiplexed in Mux engine and moved into encoder buffer for transmission.

Experiments were conducted with joint coding of eight video programs at a total bit rate of 24 Mbits/s, or 3 Mbits/s per program on average. The eight programs include film materials, news, sports, and MPEG2 test sequences. All the eight programs have a resolution of 720x480 pixels and a frame rate of 30 frame/s. interlaced with a color-sampling ratio of 4:2:2. Five of them were pre-compressed at 15 Mbits/s. and the rest three were the uncompressed video sequences. Table 2 shows the processing engine used for each program. The stat mux/remux system (Fig. 5) in experiments therefore had five transcoders and three MPEG encoders *running* simultaneously. Two different GOP structures were chosen for the eight programs, that is, GOP(N=15,M=3) and GOP(N=12,M=3) where N is the GOP length and M is the distance between two P pictures. Table 3 shows the GOP structures for each program. For comparison purpose, the eight programs are also independently encoded/transcoded at a rate of 3 Mbits/s. That is, the uncompressed video sequences are encoded by MPEG-2 encoders, and the pre-compressed video bit streams are transcoded by MPEG transcoders, separately.

Table 4 gives the bit rates in Mbits/s. for the eight programs for both independent and joint coding. Note that these bit rates were averaged over a certain number of frames per program. Hence, they were slight higher than the actual rates as the last GOP may contain less number of P/B pictures that usually use less bits than I picture. From Table 4, it should be seen that by independent coding, all the eight programs were, more or less, coded at the same rate of 3 Mbits/s while the bit rates by joint coding could be very different, depending upon the corresponding program complexity. For example, sequence Mobile used more 4 time as many bits as sequence News.

Table 5 shows the average PSNR (dB) for the eight programs for both independent and joint coding. The PSNR for more complex sequences are increased significantly, but at the expense of the PSNR of less complex sequences. However, it should also be realized that the quality loss for the well-coded sequences with very high PSNR might not be as visible as the quality gain for those complex sequences with low PSNR. The quality variation among the eight programs by using joint coding is seen to be much smaller than that by independent coding.

Fig. 6 shows the PSNR with respect to frame number for independent coding, which demonstrates a big difference in quality (up to 17 dB) among the eight programs. For some individual programs, the PSNR may vary considerably from frame to frame (e.g. football1503.snr). On the other hand, joint coding significantly narrows down the difference in quality among the program, as shown in Fig. 7. In fact, the PSNRs for the eight programs are maintained within a range of less than 9 dB, as compared to a quality difference up to 17 dB for independent coding (Fig. 6). Furthermore, it should also be noticed that the PSNR for each individual program by joint coding tends to be more stabilized than by independent coding.

4. CONCLUSIONS

The paper presented a stat mux/remux system with encoders and transcoders. The system is able to handle both pre-compressed and uncompressed video signals. Specifically, the uncompressed video signals are encoded by encoders while the pre-compressed video bit streams are transcoded by transcoders. The rate control engine manages the bit allocation among the input programs. The computer simulation results demonstrated that the stat mux/remux system indeed achieved a relatively uniform quality among programs as well as within a program.

REFERENCE CITED

1. ISO/IEC (MPEG-2), "Generic coding of moving pictures and associated audio", March, 1994.

2. M. Perkins and D. Arnstein, "Statistical multiplying of multiple MPEG-2 video programs in a single channel", SMPTE Journal, Sept. 1995.

3. E. Nakasu, K. Aoki, R. Yajima, Y. Kanatsugu and K. Kubota, "A statistical analysis of MPEG-2 picture quality for television broadcasting", SMPT Journal, Nov. 1996.

Table 1. PSNR in dB

MPEG/Transcoder	Market	Trapeze
Direct MPEG at 3 Mbits/s	34.85	35.42
15 → 3 Mbits with ME	34.43	35.16
15 → 3 Mbits/s without ME	34.37	34.91
6 → 3 Mbits/s with ME	33.71	34.59
6 → 3 Mbits/s without ME	33.72	34.56

Table 2. Processing Engine

	News	Market	Flower	Football	Mobile	Movie	Tennis	Trapeze
Process	MPEG	Trans.	MPEG	Trans.	MPEG	Trans.	Trans.	Trans.

Table 3. GOP Structures

	News	Market	Flower	Football	Mobile	Movie	Tennis	Trapeze
N	15	15	12	15	12	15	15	15
M	3	3	3	3	3	3	3	3

Table 4. Bit Rate in Mbits/s

	News	Market	Flower	Football	Mobile	Movie	Tennis	Trapeze
Joint	1.31	1.70	3.63	3.95	5.65	1.78	3.84	2.40
inde.	3.03	3.04	3.05	3.02	3.04	3.02	3.01	3.01
Δ	-1.72	-1.34	0.58	0.93	2.61	-1.24	0.83	-0.61

Table 5. PSNR in dB

	News	Market	Flower	Football	Mobile	Movie	Tennis	Trapeze
Joint	37.81	32.81	29.22	33.85	27.87	36.55	30.98	33.93
Inde.	41.06	35.94	28.35	31.63	25.16	38.44	30.23	35.15
Δ%	-7.91	-8.70	3.07	7.02	10.77	-4.92	2.48	-3.47

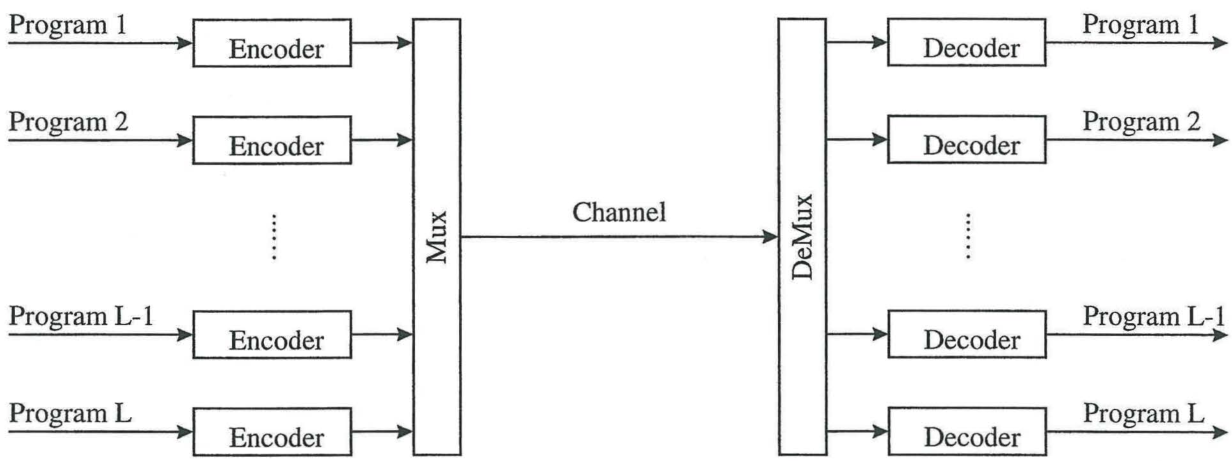

Figure 1. Multi-program transmission: Several programs are coded, multiplexed and transmitted over a single channel.

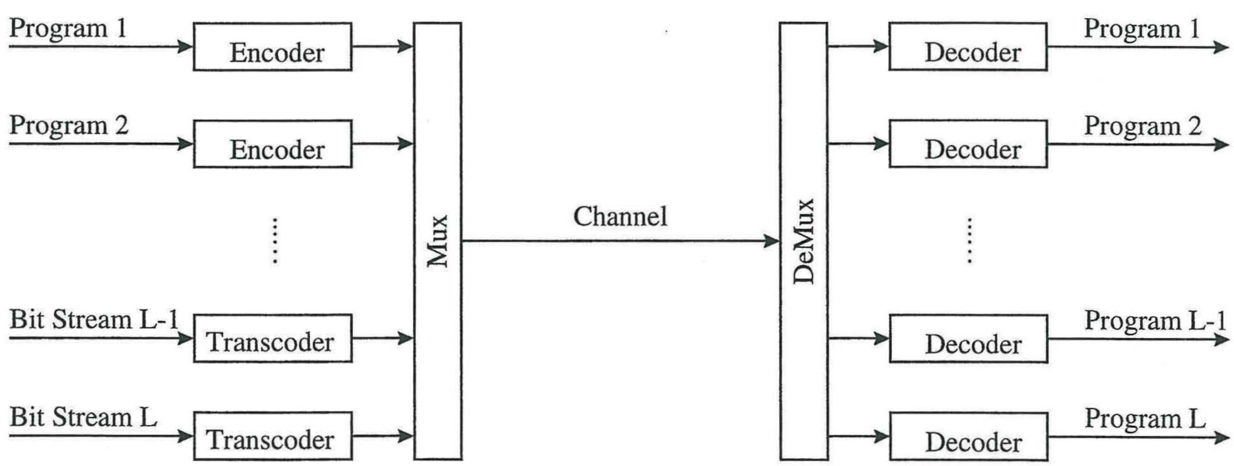

Figure 2. Multi-program transmission: the inputs can be either compressed or uncompressed video programs.

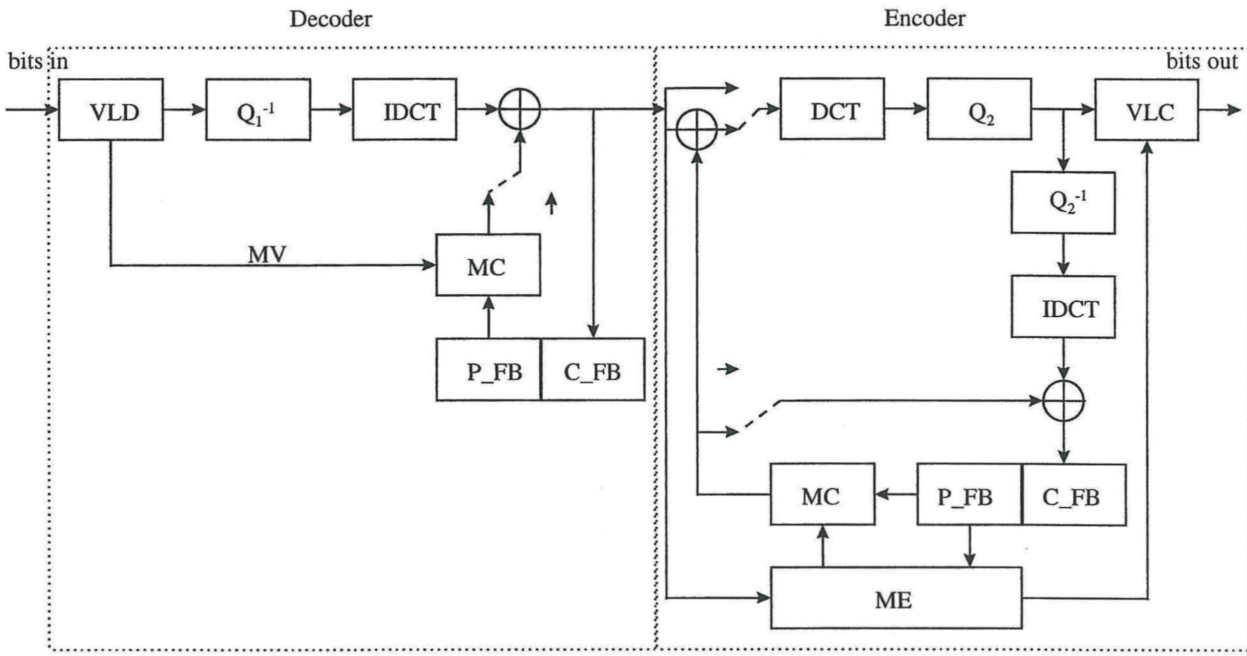

Figure 3. Cascaded MPEG decoder/encoder.

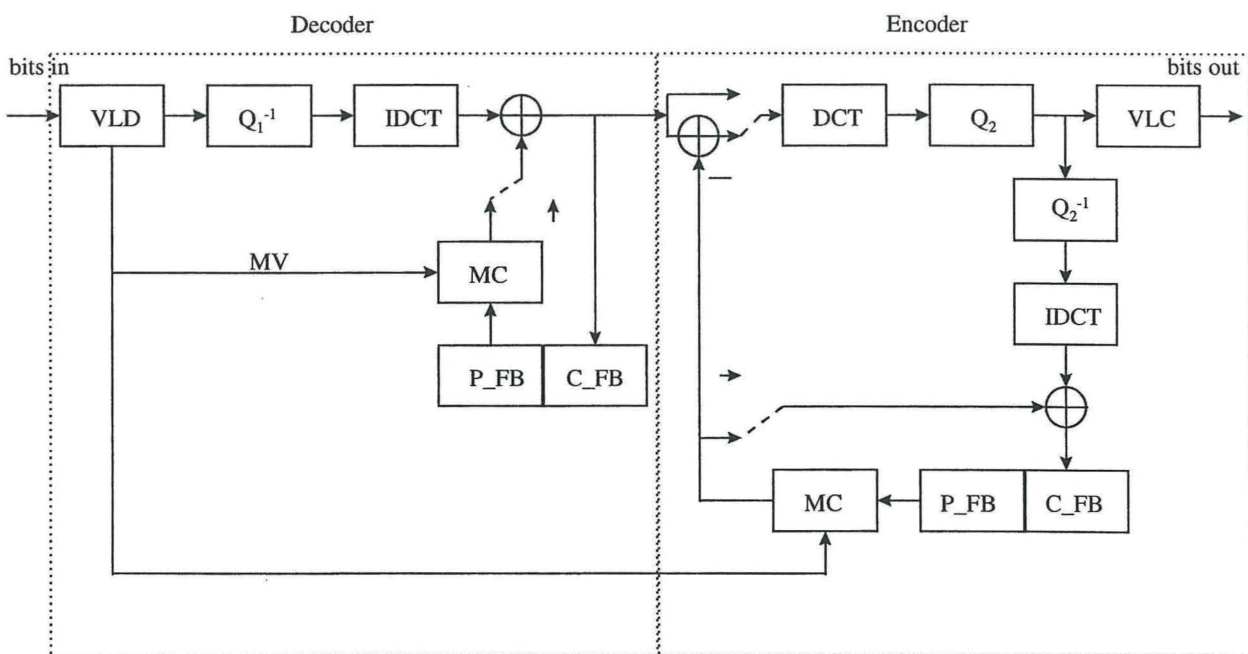

Figure 4. Cascaded MPEG decoder/encoder without ME.

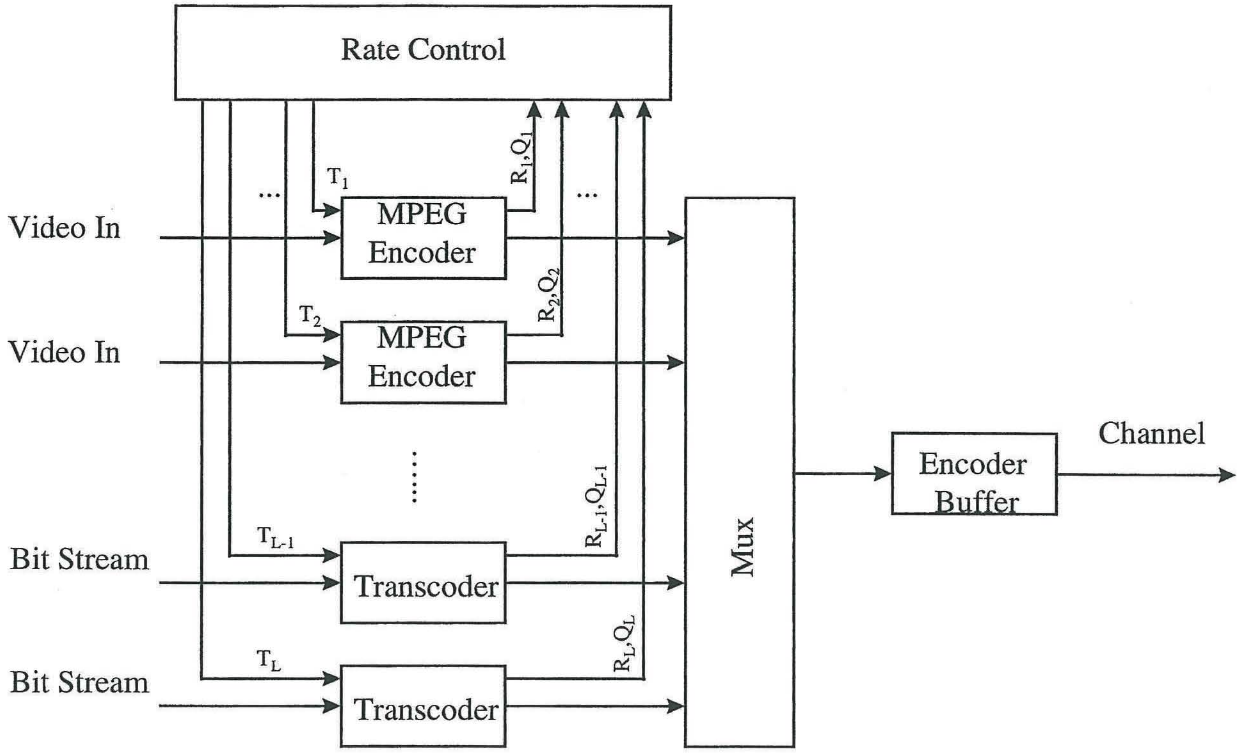

Figure 5. Block diagram of a stat mux/remux system for both pre-compressed and uncompressed video signals.

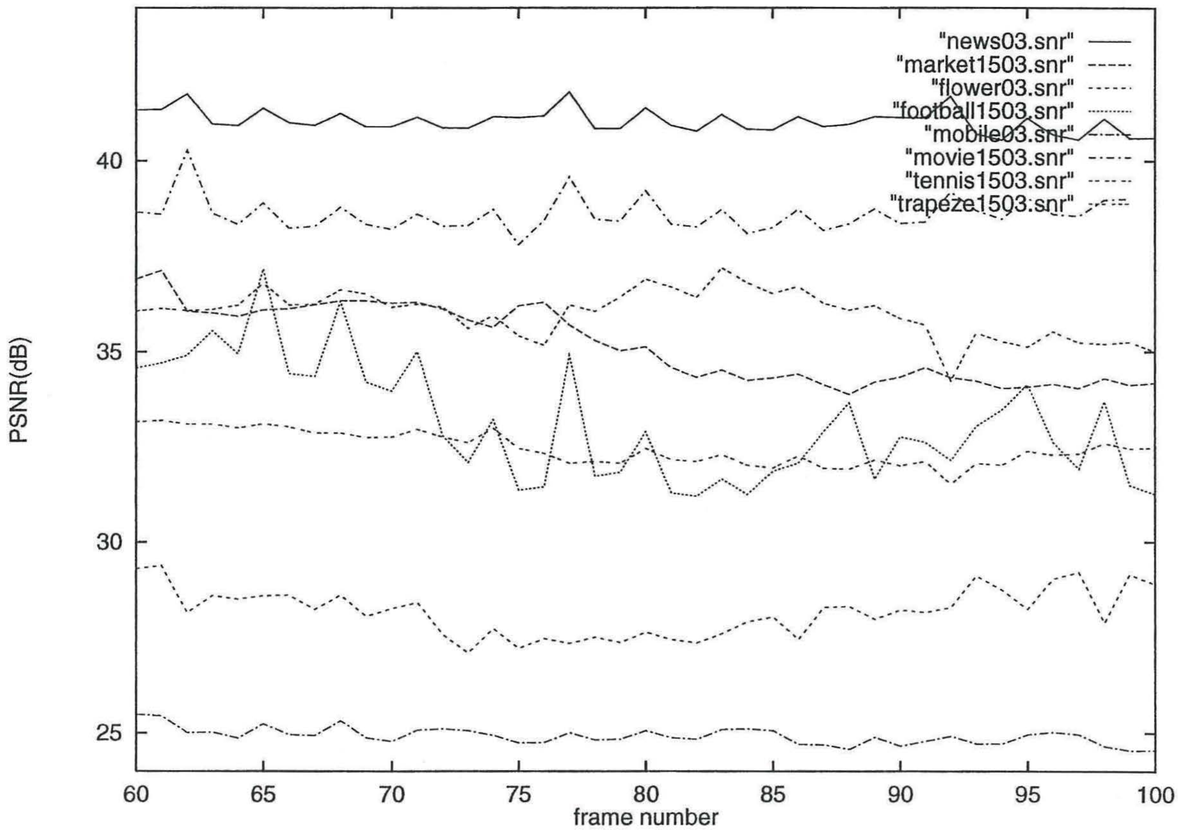

Fig. 6. The PSNR by independent encoding/transcoding for the eight test sequences where "...03.snr" means direct MPEG at 3 Mbits/s and "...1503.snr" means transcoding from 15 Mbits/s to 3 Mbits/s.

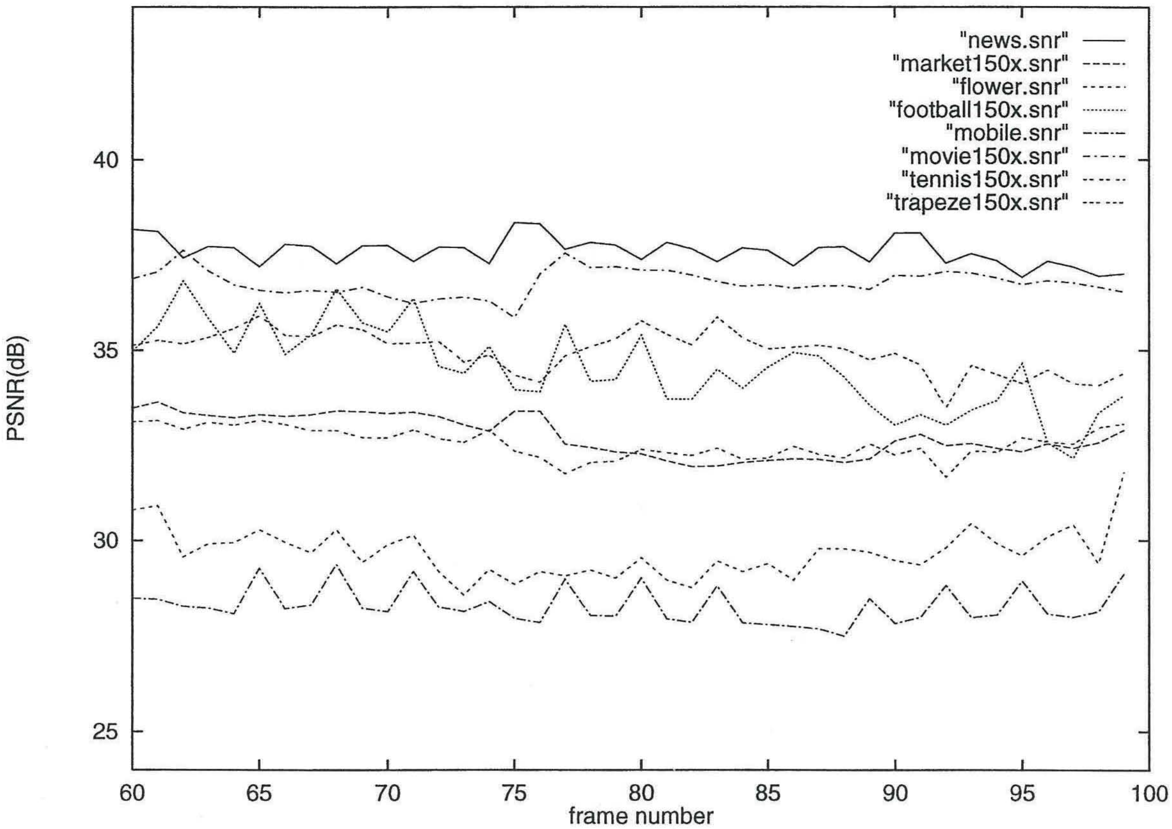

Figure 7. The PSNR by stat mux/remux for the eight test sequences where "... .snr" means uncompressed video signals and "...150x.snr" means pre-compressed video bit streams at 15 Mbits/s.