DBS 응용을 위한 다채널 MPEG 비디오의 연합 비트율-왜곡 제어

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요 약

MPEG2 압축 비디오 채널의 버퍼링에 의한 비트율-왜곡 제어 방법이 DBS(디지탈 직접위성방송)에의 응용을 위해 고려되었다. 엔코더의 코딩 변수와 버퍼 점유 상태에 약간의 제약을 두어 한 GOP 블록 내에서 제한적인 가변 비트율(VBR)를 허용해주는 다채널 소스의 연합 비트율-왜곡 제어 알고리듬을 제안하였다. VBR 부호화기를 사용하지 않는 고정 비트율 채널을 통한 비디오 전송의 주요 단점은 영상 수신시 화질이 급격히 변화는 결과를 대처하지 못하여 균일하지 않은 주관적 화질 열화를 발생하게한다. 이같은 효과를 극소화하기 위해 한 GOP 블록 단위로 각 소스의 버퍼링에 의한 비트율-왜곡 제어는 국부적인 프레임에 기초한 비트율 제어 방법보다 다채널 압축 프로그램을 통계적 다중화할 때 버퍼상태를 직접 궤환하여 전체적인 비디오 시퀀스에 걸친 비트율을 제어함으로써 전체 비용 함수를 최소화하는 방법을 찾고자 한다. 실험 결과는 기존의 고정 비트율 제어 방법에 비해 화질 개선과 자원 절약을 나타내준다.

A Joint Rate-Distortion Control of Multichannel MPEG Video for DBS Applications

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ABSTRACT

Buffered rate-distortion control method of MPEG 2 compressed video channel is considered for DBS applications. A joint rate-distortion control algorithm of multichannel sources is proposed to control overall picture quality by putting some constraints on encoder's quantization parameters and buffer occupancy state to allow a limited variable bitrate (VBR) coding within a GOP block. A major drawback for video transmission over a conventional fixed rate channel without using VBR encoder is that received picture quality varies greatly, resulting in non-uniform subjective visual impairments. In order to minimize these effects buffered-constrained rate-distortion control within a GOP block level finds an optimal solution in a combined rate-distortion sense by permitting a VBR encoding over larger image sequences rather than local intra-frame based rate control with the aid of the direct feedback of the buffer state into the cost measure when multichannel programs are statistically multiplexed. Results indicate some quality gains and resources savings over the conventional constant bit rate method.

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1. Introduction

Studies on source bit regulations occurring when transmitting Variable Bit Rate (VBR) bit stream over Constant Bit Rate (CBR) channel have been done by using buffered compression algorithm in [1, 2, 3]. Conventional buffer control schemes proposed by Ortega et. al. and Shoham et. al. [3, 6] do not use a global rate-distortion measure over the entire sequence block to formulate the strategy for rate-distortion control. Recently a formal description of the buffer control algorithm has been developed in a rate-distortion sense [1]. Bitrate of digital image encoder (e.g. MPEG 2) using VLC (Variable Length Coding) varies depending on image content being analyzed. So in case where constant bitrate transmission is used, variable bitrate sources generated during encoding process have to be regulated using buffered control mechanism. Conventional coding schemes, which are applied to MPEG and motion JPEG, control bitrate in a sense of macro block level for transmission of encoded digital images. Therefore this causes image quality distortion due to improper control of bitrate and due to lack of a global control of bitrate.

In order to better adapt to image content changes as well as program channel's statistics, statistical multiplexing and buffering schemes are used to minimize variations of image quality by sharing bandwidth resources allocated in each transponder and by allowing variable program source channel capacity. This approach to increase bandwith efficiency was addressed in [1] at program source level. In our case, some constraints on encoder's quantization parameters were imposed to permit a *limited* variable bitrate coding at a GOP (Group of Pictures) block level rather than a macro block (MB) level or an entire video sequence level. A new dynamic buffer control algorithm to be proposed will provide a suboptimal solution for minimization of a combined cost of R-D (Rate-Distortion) as compared to the optimal buffer-constrained bit allocation method[4]. Although the proposed algorithm does not provide the optimal performance, it can be implemented much simpler than the optimal one and its computaional complexity is relatively low to others[1, 2, 3, 4]. Section Ⅱ introduces conventional as well as the proposed buffer control algorithm for buffered compression and bitrate regulation in multichannel video sources. Section Ⅲ shows some experimental results for two different scenarios: first experiment deals with a joint rate-distortion control in JPEG-like coding environment and second experiment shows some preliminary results for buffered rate-distortion control of multichannel MPEG2 video sources for DBS application. Finally in section Ⅳ conclusions are drawn.

2. Buffered Compression and Bitrate Regulation

A. Conventional bitrate control methods

Buffer is absolutely needed to absorb an instantaneous bitrate change of VBR coder for transmission over a constant bitrate channel (CBR) environment. Coding scheme using an adaptive quantization requires an effective buffer control algorithm for optimal bit allocation that minimizes a joint R-D cost measure for consecutive N macro blocks. Implementation methods of buffer control algorithm in a R-D sense can be divided into optimal dynamic programming method and suboptimal fast approximation method. The dynamic programming method provides an optimal buffer control solution by tracing all possible cost paths using the trellis minimization tree diagram, but it also gives heavy computational burden to implement the algorithm. Fast approximation algorithms like Largangian optimization or controlled Lagrangian optimization were proposed to reduce computational complexity involved in efficient buffer control as well as image quality control[6, 7].

B. Buffer Control Using an R-D Criterion

The conventional method for distribution of digital

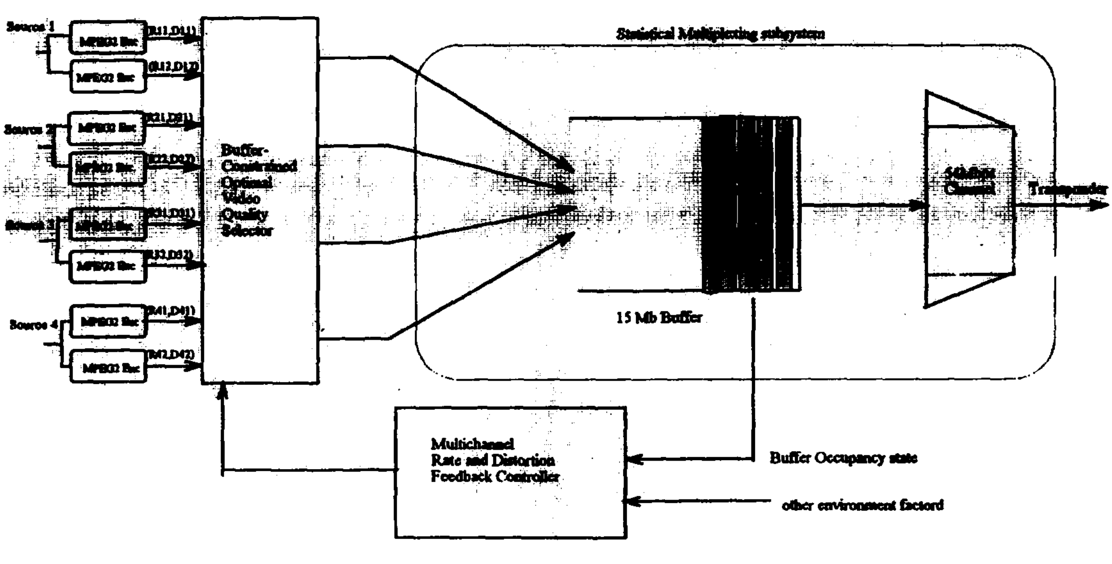
TV via delivery media such as Direct Broadcasting Satellite (DBS), cable and fiber is based on constant bitrate transmission of compressed video. In this paper we assume a typical DBS broadcasting scenarios where four video programs compressed by MPEG-2 encoder share equal portion of a 30Mbps (Video part only) satellite transponder so that each channel of program sources must be compressed at 7.5Mbps or less. Since four channels are statistically multiplexed per transponder and transmitted through constant bitrate channel, major encoding parameters related to bitrate must be adjusted according to buffer occupancy. Resources sharing in buffered multiplexing environments can be accomplished by controlling the rate of MPEG (MP@ML) compressed video program sources for each GOP block.

Given are four program channels as shown in Fig. 1. Two compressed video bit streams are generated per channel depending on the previous buffer state. The compressed video bit streams for a GOP block unit from each source program are input at a time to the multiplexer and the multiplexed buffer generates bit streams at a constant transmission rate. Thus multiplexer output requires buffer control scheme to avoid overflow/underflow.

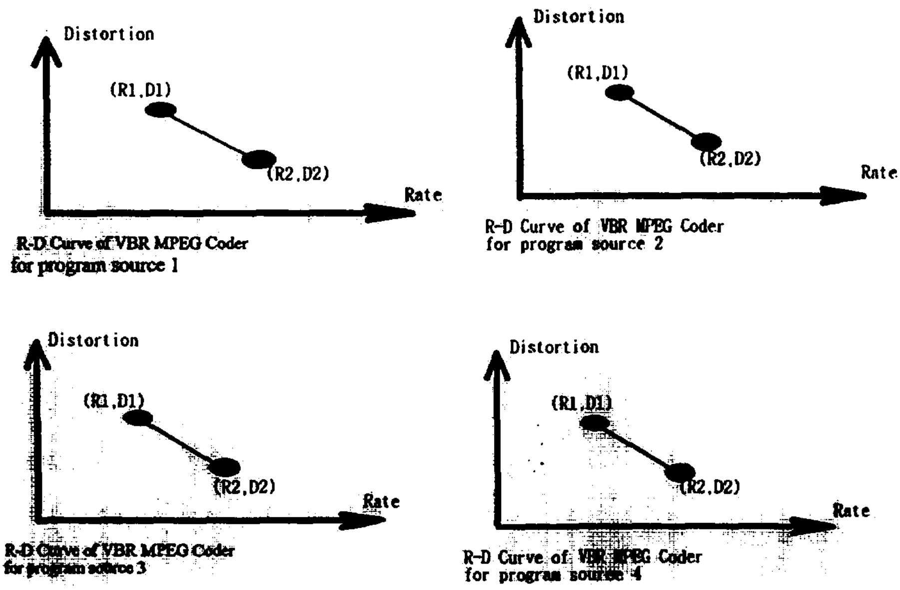
Individual encoder's rate and distortion characteristics are shown in Fig. 2 Two encoding bit streams are available in a GOP block unit for a single source program. Possible combinations of individual quantizers for each GOP block for 4 channel sources can have as many as 16 R-D composite points as shown in Fig. 3. The proposed multichannel R-D feedback controller searches for a minimum cost solution among admissible combinations that enable an optimal buffer constrained bandwidth reallocation for given GOP block.

C. Optimal Buffer Control

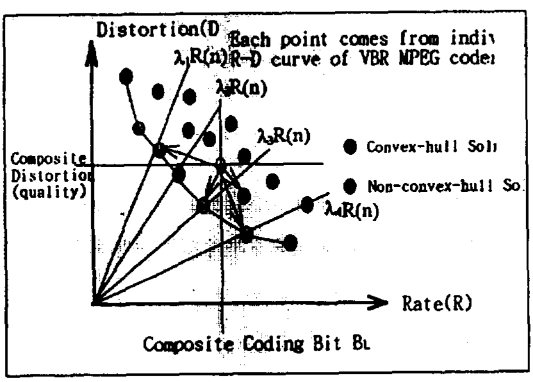
For given coding bit budgets, one tries to get high quality image transmission by minimizing distortion associated with image by buffering and using multiple quantizers. Total distortion and rate of an information source(in our case one GOP block) sequence $\{x(n)\}_{n=1}^{N}$, are denoted by $D(n)=\sum_{n=1}^{N} d(x(n))$ and $R(n)$



(Fig. 1) System function diagram of multichannel video bitstream multiplexing



(Fig. 2) Individual rate-distortion characteristics of VBR video encoder



(Fig. 3) Composite rate-distortion characteristics for a given quantizer set

$=\sum_{n=1}^{N} r(x(n))$, respectively, where $\{d(x(n)), r(x(n))\}$ is a set of points in distortion-rate curve which is determined by given budget and minimization algorithm of distortion sum measure. From rate-distortion theory[8], we know that rate $R(n)$ depends on distortion $D(n)$. In practice, the distortion is determined by selected quantizer and the rate is determined by the entropy coder. For instances, if we take a finer quantizer, the $D(n)$ and $R(n)$ values get smaller and larger, respectively. On the other hand, if a coarser quantizer is used, the $D(n)$ and $R(n)$ values become larger and smaller, respectively.

We now consider an optimal buffer control problem [3] as belows:

$$\min_{R(n)} \{\sum_{n=0}^{N} D(n)\}$$

$$\text{subject to } 0 \le B(n) \le B_{max}, \text{ for all } n = 1, 2, 3, \cdots, N \quad (1)$$

with the buffer update

$$B(n) = B(n-1) + r(n) - \gamma, \quad (2)$$

where $r(n)$ is inputing bits from source, γ is the transmission rate of buffered content and the initial state of buffer is $B(0) = B_{init}$. It is assumed in this formulation that there is an explicit relationship between distortion $D(n)$ and rate $R(n)$ and thus we can always find a quantizer which provides the pair $\{D(n), R(n)\}$ which satisfies this explicit relationship. As described in [3], this formulation can be solved using dynamic programming method, however, the computational complexity increases exponentially with n. Thus it can't be used in practice. We propose a practical solution to buffer state control with much less computational complexity.

D. Controlled Lagrangian Fast Algorithm

The optimal buffer control algorithm via dynamic programming approach can not be used in practice because of its computational burden. To overcome this difficulty, fast algorithm based on an optimal bit allocation method was proposed by Ortega et al. [3]. Here we propose an alternative method of buffer control by a direct feedback control of the buffer occupancy state called the controlled Lagrange multiplier method[7]. In the case where there is no buffering constraint and only a desired total bit budget (or channel capacity) has to be met, well known optimal bit allocation techniques have been documented [6]. In general, bit regulation of the finite buffered case will be limited by the constraints imposed by the buffer underflow/overflow conditions. An optimal algorithm using dynamic programming method known as the Vieterbi algorithm is described in [4] along with their fast algorithms using Lagrange multiplier method. Even though this algorithm renders a fast solution to budget-constrained buffer control, the Lagrange multiplier λ must be iteratively found for each block. Unfortunately a solution for given rate budget may not exist for any λ. In order to apply buffered compression idea to bandwidth resources sharing, a multichannel joint rate-distortion controller of the buffered statistical multplexer has to be designed by taking more bits from the encoder sources that will suffer less degradation of image quality. Design issues will include: for given rate budget in each GOP block what is a best bitrate adjustment using a combined total cost minimization algorithm? Now we consider a new method of buffer control by a direct feedback of the buffer state into Lagrange multiplier λ. Let us define a combined cost function with time-varying λs:

$$T_\lambda(n) = D(n) + \lambda(n) R(n) \tag{3}$$

An individual distortion(mse) and rate(bps) at each GOP block depends on a selected quantizer among avaliable quantizer set. For a given value of $\lambda(n)$, we can adjust $R(n)$ and $D(n)$ that minimize $T_\lambda(n)$. Eventually controlled total distortion and rate can be found by searching for best quantizer set based on the $\lambda(n)$, where $\lambda(n)$ represents the current buffer state. The λ value controls the slope of distortion-rate (D-R) curve. In other words, if buffer becomes full, the value of λ becomes large and it renders a small value of rate $R(n)$. Thus by incorporating the state of buffer ocupancy to the value of λ in the combined cost function, we can obtain a buffer control algorithm which is called "controlled Lagrange multiplier (CLM) method" as follows:

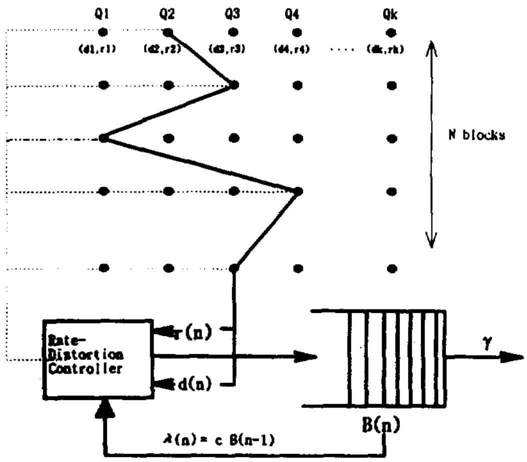
$$\min_{\{R(n),\, D(n)\}} \{D(n) + \lambda(n) R(n)\}, \tag{4}$$

where the updating rule is represented as a function of buffer state by

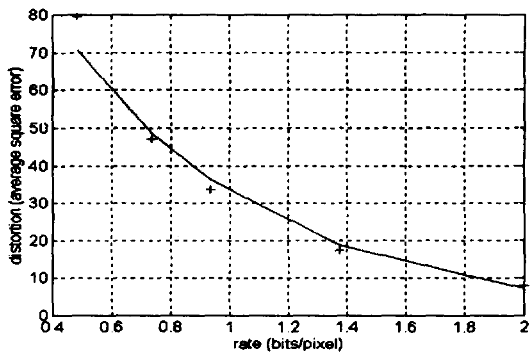
$$\lambda(n) = cB(n-1), \quad c > 0, \tag{5}$$

and $B(n)$ is given by (2). This is illustrated using Fig. 3 which shows dynamic determination of operational RD points by adjusting the parameter $\lambda(n)$ depending on the previous buffer occupancy state. The CLM method dynamically finds the suboptimal path that minimizes a combined total cost $T_\lambda(n)$ for consecutive N GOP blocks by feeding back the buffer occupancy state into the λ updating rule as illustrated in Fig. 4.

This concept is illustrated using Fig. 3 which shows dynamic determination of operational R-D points by adjusting the parameter λ according to (3). The CLM



(Fig. 4) Suboptimal path finding by minimization of a combined total cost T(e(t), r(t)) at consecutive N blocks



(Fig. 5) Average distortion and rate points for five pairs of quantizer and entropy coder and its EDR curve which is fitted from five (D, R) points.

method dynamically finds the suboptimal path that minimizes a combined total cost for multichannel program sources (in our case 4 channels are used) in the n-th GOP block by feedback of the buffer state. The computational complexity of this λ updating rule is quite low compared to others, e.g. ref. [1] and the performance is not affected by the GOP length of program source as long as minimum bitrate for each source is maintained.

3. Experimental Results

For first experiment, an image source $x(n)$ of size 256×256 is divided into 8×8 subblocks which is JPEG coded by changing scale factor to obtain associated distortion and rate points for subblcoks (see Fig. 5). The number of quantizers used in the experiment is five.

In simulations, the three methods are applied to the same sequence of image subblocks and results are summerized in Table 1 -2 and Fig. 4. In Table 1, the total rates and performance indecies of the sequence of image block for each method are given. The performance index is defines by

$$S = \frac{\text{the sum of distortions for each method}}{\text{the sum of distortions for the direct bit allocation method}}$$

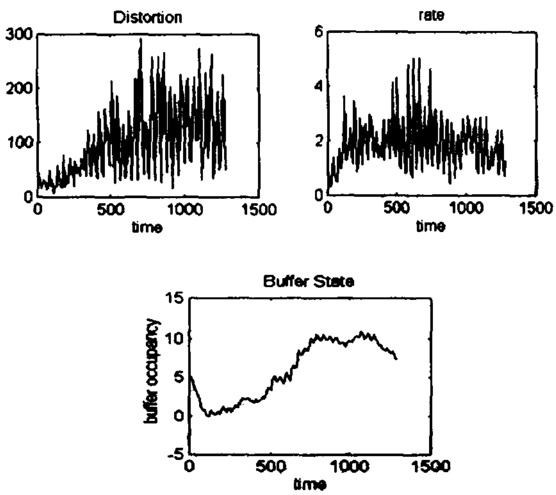
As we would expect, the performance index for the optimal bit allocation method is larger than the others. To reduce the overhead occuring from switching a pair of quantizer and entropy coder in the CLM method, the same pair of quantizer and entropy coder can be used over successive m blocks. As we see in Table 2, the performance index is decreasesd as the number of merging blocks m increases. As shown in Fig. 6, the

〈Table 1〉 Performance index and total rate for various methods (Note: the overhead bits in the CLM and the optimal bit allocation methods are excluded)

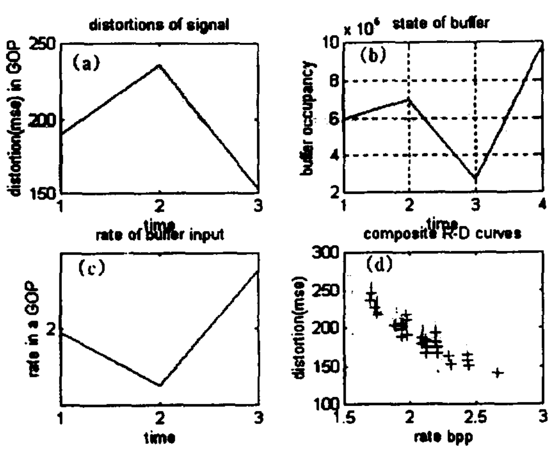
buffer control method	CLM	optimal bit allocation	direct bit allocation
performance index S	1.0005	1.2677	1.0000
total rate (bits)	949.7	952.9	952.6

〈Table 2〉 Performance index and total rate for CLM method with different numbers of merged blocks m for buffer cintrol (Note: the overhead bits are excluded)

buffer control method	m=1	m=4	m=8	m=16
performance index S	1.0005	0.9727	0.9517	0.9992
total rate (bits)	949.7	952.34	954.38	972.14



(Fig. 6) The CLM buffer control method with the equilibrium state of buffer $B^* = 5$ and $\gamma = 0.9303$ (a) the sequence of distortions (b) the sequence of rates and (c) the states of buffer occupancy.



(Fig. 7) Rate-distortion and buffer state

buffer occupancy state is well controlled without causing any buffer underflow and/or overflow.

For second experiment, video bit streams were generated according to MPEG 2 MP●ML. Program sources for experiment are "Bicycle", "Flower Garden", "Football", and "Mobile & Calendar" consisting of 27 frames, respectively. Bit streams with 6 Mbps and

〈Table 3〉 Average rate(bps) and distortion(mse) values for 3 GOP blocks

MPEG 2 MP●ML N=9, M=3	GOP 1		GOP2		GOP3	
Sources	6Mbps (R, D)	9Mbps (R, D)	6Mbps (R, D)	9Mbps (R, D)	6Mbps (R, D)	9Mbps (R, D)
Source 1	(0.44, 62.02)	(0.67, 38.19)	(0.38, 83.72)	(0.57, 50.53)	(0.39, 80.64)	(0.58, 49.28)
Source 2	(0.43, 39.35)	(0.66, 23.05)	(0.38, 58.27)	(0.58, 34.55)	(0.39, 55.56)	(0.57, 33.37)
Source 3	(0.45, 27.18)	(0.67, 18.40)	(0.37, 37.43)	(0.57, 22.03)	(0.39, 36.78)	(0.59, 22.37)
Source 4	(0.43, 97.52)	(0.66, 61.87)	(0.37, 90.47)	(0.56, 56.69)	(0.39, 76.14)	(0.58, 47.23)

* source 1 : Bicycle, source 2 : Flower Garden, source 3 : Football, source 4 : Mobile&Calendar

9 Mbps bitrate are generated with GOP size = 9 and frame distance between I picture and P picture = 3. Average bitrate R and distortion (mse) D were computed over 3 GOP blocks. Table 3 shows average bitrate and distortion for 3 GOP blocks of program sources coded according to the aforementioned conditions.

An optimal composite rate and distortion is shown in Fig. 7 (a) and Fig. 7 (b) for each GOP block which was found out of 16 possible combinations by using the proposed buffer control algorithm. Fig. 7 (c) represents multiplexer buffer occupancy state evolving over time (i.e. GOP block). Initial buffer state can be set around the middle of total buffer capacity and here set to 6 Mbits. Length of video sequences used in the experiment is only 3 GOP blocks and may not be large enough to confirm a long-time behavior of the buffer state and examine image complexity(Please refer [3] as to the stability and long-term behavior of the proposed algorithm.). But we can see that the current buffer state which is input to mux buffer is regulated according to increase or decrease of the previous bitrate. Fig. 7 (d) represents all possible (R, D) points that can be produced for 3 GOP blocks.

In order to compare the performances of the proposed algorithm to that of the fixed rate encoder we define distortion performance index as $S_{GOP}=\frac{MSE_2}{MSE_1}$, where MSE_1 and MSE_2 represents mean square error computed by the proposed algorithm and the fixed rate algorithm, respectively. When compared to the fixed rate (7.5 Mbps) encoder, performance index of the proposed method is 0.91, 0.93, and 0.89, respectively, for 3 GOP block. About 10% less distortion for the fixed bitrate is obtained and implies that more information bits can be added if equal quality is permitted. In this paper we simply tested the possibilities of resources sharing for short GOP blocks by taking a global view of the problem of buffered rate and distortion control of MPEG 2 compressed video channels with hope of better video quality for DBS applications.

4. Conclusions

A feedback control algorithm for a buffer-constrained adaptive quantization is proposed. The proposed buffer control algorithm demonstrated the stability of the buffer state occupancy under a given buffer size and (exponential) average distortion-rate curve. The very low computational complexity as opposed to the optimal method enabled fast approximation based on recursive feedback of the buffer state occupancy in the parameter λ.

The proposed joint rate-distortion control method is applied to DBS application statistically multiplexing in GOP unit of multichannel program sources per tranponder. Preliminary results show that 4-channel MPEG 2 compressed video programs can be configured in a more bandwidth efficient manner to provide a better average picture quality.

The results derived in this paper are the groundwork for future development on this problem. A preliminary experimental results indicate that the proposed multichannel rate-distortion control can be used to transmit more data on an example 30 Mbps transponder with roughly equal picture quality of the fixed rate 4-channel encoder. A more practical design on the MPEG-2 encoder requires two-pass parallel processing bit stream generator for bandwidth reallocation among sources.

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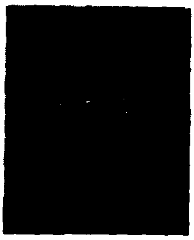

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