Rate Allocation of Equal Image Quality for MPEG-4 FGS Video Streaming

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ABSTRACT

This paper proposes a new rate allocation method for MPEG-4 fine granularity scalable (FGS) video streaming, with which the received image quality can be smoothed during the streaming period. Although average bit rate allocation is quite simple, the image's quality changes greatly between frames, which will result in quality fluctuation and degrade the streaming quality. In this paper the bits are allocated to those frames according to their rate-distortion curve in order to obtain the same objective quality. Fast rate allocation algorithm of equal image quality is implemented based on Newton search method, which is much faster than linear search method. It is important to realize fast rate allocation for bit-stream truncating in practical video streaming applications. To validate the performance of proposed rate allocation method, other three relevant methods are compared with different sequences at different bit-rate, such as average bit rate allocation, rate allocation with equal slope of rate-distortion curve, grouping rate allocation. In comparison, the proposed rate allocation method achieves the best performance among four tested methods. The fluctuating of distortion between two adjacent frames is reduced to about 0.3dB, which is much less than other methods. The quality's variation is less than 1.0dB over the buffered video frames in one shot. The speed of proposed fast rate allocation algorithm is also measured, which is about 60 times faster than that of real time, thus this method is feasible in video streaming application.

1. INTRODUCTION

Multimedia streaming is widely applied in entertainment and commercial area through the Internet or Wireless networks. It has been attained much attention from research and industry, such as MPEG [11] and Internet Streaming Media Alliance [12]. Currently, three incompatible proprietary solutions offered by RealNetworks, Microsoft, and Apple companies dominate the Internet streaming software market. Although there are so many applications existing, video streaming is still facing two challenging problems caused by substantial transmitting channel: packet loss and fluctuation of available bandwidth. Third-generation mobile communication system (3GPP/3GPP2) will become a transmission network for streaming applications. Bursting bit-error is a serious problem in such wireless streaming. All these difficulties are described in [1]. Scalable coding seems a hopeful solution to deal with time-varying transmission bandwidth. Discrete wavelet transform (DWT) based scalable coding is proposed in [9], but block DCT transform based scalable coding achieve much success for its good performance and low complexity, good compatibility [3][8][10]. MPEG-4 streaming profile [2] provides a flexible solution for available bandwidth fluctuation. In this profile, fine granularity scalable (FGS) coding [3][4] is used to compress source video into a scalable bit-stream, which can be truncated arbitrarily. Bit plane coding is the main feature of FGS coding, and it can provide good scalability. The received image can be enhanced gradually with progressive available bandwidth increasing. MPEG-4 streaming profile FGS reference software [5] provides a uniform rate allocation method to adapt the streaming bit-stream to current available bandwidth, but this simple method does not consider the rate distortion relationship of different frames, thus it causes fluctuated image quality among different frames with equivalent bits . Large fluctuation of image quality will eventually degrade the streaming service quality. JPEG2000 [6] provides an effective rate control method considering rate-distortion function of all coded blocks. The bit rate is allocated in terms of the equal slope of rate-distortion curve. But it emphasizes the effectiveness of allocated bits, and cannot get the equivalent image quality over all coded blocks. Wang et. al. [7] proposed a rate allocation method for progressive fine granularity scalable (PFGS) coding [10]. But the performance of this method cannot get satisfying for its coarse assumption that the distortion is similar if different frames are truncated at the same bit plane. From the rate-distortion curve of FGS coding, we can see there is still large distortion's variation existing even at the same bit plane in different frames. As we have known, the variable bit rate (VBR) video coding aims to obtain the same quality on every encoded frame with different allocated bits, and it outperforms constant bit rate (CBR) video coding, which aims to get the smooth bit-rate with fluctuated image quality. However VBR will result in limited bit-rate fluctuation. This paper proposes a new rate allocation method for MPEG-4 FGS to balance the image quality according to each frame's rate distortion relationship. Fast rate allocation algorithm with equal image quality is also implemented for practical streaming applications.

The left of this paper is organized as follows. The proposed rate allocation method of equal image quality and fast allocation algorithm is described in section 2. Section 3 presents the experimental simulation results and some relevant rate allocation methods are also compared. Finally we give some conclusions of this paper in section 4.

2. Equal image quality RATE ALLOCation Method

MPEG-4 FGS coding consists of a base-layer (BL) and multiple enhancement-layers (ELs). The base-layer is encoded with MPEG-4 single layer coding (MPC), which provides the basically guaranteed image quality assuming that the bottleneck bandwidth is higher than BL's bit-rate, and the enhancement-layer can provide enhanced quality in fine granularity with bit plane coding. In other words, the decoder can start decoding and displaying the image after receiving a very small amount of data. As more data is received, the quality of the decoded image is progressively enhanced until the complete information is received. Fig.1 illustrates this kind of video scalable coding structure. Compared with non-scalable methods, single-layer's hybrid codec, the biggest disadvantage of SNR scalable coding is that the encoder does not know the decoded bit-rate at the decoder, however it must support the bit-stream can be decoded at any bit-rate above base layer bit-rate. If the encoder select a reconstructed image decoded at a higher unwarranted bit-rate above BL's, decoder maybe cannot get the perfect reference if bandwidth is lower than that encoder has used, and this kind of reference's mismatch will cause drifting error due to motion compensation loop at the decoder side. Performance will degrade within lower bit-rate range. So MPEG-4 FGS only utilizes a reconstructed image decoded at very low bit-rate as motion compensation reference, which limits its coding efficiency and results in large quality fluctuation in base-layer. For consecutive frames, the number of bit planes used in ELs coding may be different because the quality of base-layer varies in a large range. In MPEG-4 FGS streaming application, BL coding usually applies rate control such as TM5 or MP4 method [4] in order to meet the given lower bit rate. Fig.2 shows the rate-distortion curves of ELs from different frames' coding. They are different obviously and vary in a quite large range. Therefore uniform rate allocation will cause large quality fluctuation. Thus it is important to balance the image quality by means of rate allocation in ELs. This paper proposes a rate allocation method according to each frame's rate-distortion curve, which can get the same distortion with different rate allocated. Bit-rate will fluctuate with such rate allocation for MPEG-4 FGS, but the buffers at sender and receiver sides can absorb the limited bit-rate fluctuation.

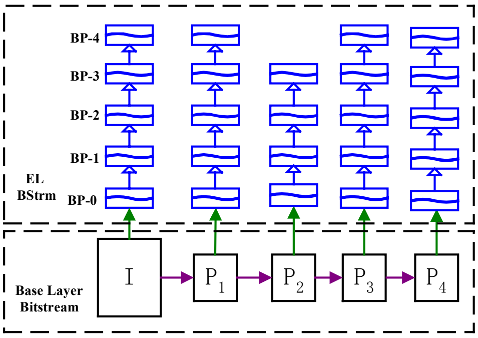


Figure 1. Architecture of MPEG-4 FGS coding. "EL BStrm" represents enhancement layer bit-stream. "BP" represents bit plane, and "BP-0" is the bit plane consisting of first most significant bit (MSB-0) of residues to be coded.

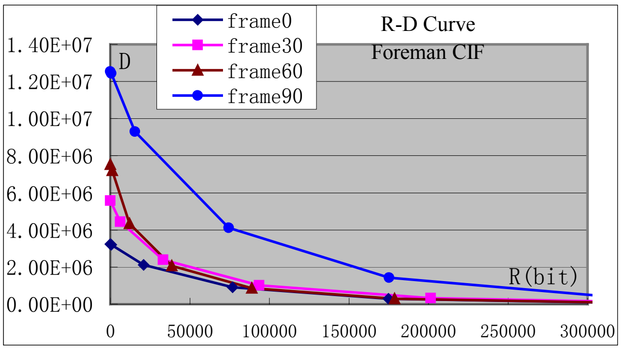


Figure 2. Rate-Distortion curve of MPEG-4 FGS EL's coding.

2.1. Rate Allocation Method

Proposed rate allocation method aims to smooth the decoded image's quality over the video clip, such as group of pictures (GOP) belonging to one shot, whose length is determined by the size of streaming buffer, subject to a bit-rate constraint. Let R_i denote the rate allocated for the i-th frame and D_i denote the corresponding distortion. The equal quality rate allocation can be formulated as the following constrained optimization problem:

$$D_i = D \quad \text{s. t.} \quad \sum_{i=1}^{N} R_i = R_c,$$

where D is the optimal distortion, N is total frame number of the group and R_c is the given bit-rate. Newton search method can solve such problem for $D_i(R_i)$ is monotonous. We rewrite above optimization problem to the following equation:

$$F(D) = \sum_{i=1}^{N} R_i(D) - R_c \tag{1}$$

Then the aim is to solve the equation:

$$F(D) = 0 \tag{2}$$

Referring to Newton search principle, the expected D can be found with the following iterative calculation. Once we get D_k at step k, then $F(D)$ near to D_k can be expanded using Lagrange with first order approximation:

$$F(D) \approx F(D_k) + (\sum_{i=1}^{N} dR_i(D_k)/dD)(D - D_k) \tag{3}$$

D_{k+1} is the root of Equation 2:

$$D_{k+1} = D_k - F(D_k) \ /(\sum_{i=1}^{N} dR_i(D_k)/dD) \qquad (4)$$

The optimal D is found until the absolute value of $F(D)$ is less than the predefined threshold.

2.2. Fast Equal Image Quality Rate Allocation Algorithm

The optimal rate allocation algorithm must be very fast and efficient. The streaming server should do rate allocation real-time according to current available bandwidth. We develop a fast equal image quality rate allocation algorithm for practical streaming applications. Much side information can be saved during encoding process because the encoded bit-stream is created off-line in MPEG-4 FGS streaming. Fig. 3 depicts the structure of MPEG-4 FGS bit-stream. An auxiliary file is created in compression, which includes the frame header's position, each encoded bit plane position, the distortion and the differential of rate-distortion of every bit plane. In this paper, the distortion is measured with residues' mean square error (MSE). Truncating bit-stream can be completed very fast at the given bit-rate with the reference information of frame header's position. The fast algorithm is presented as follows.

Some variables are defined as: k denotes the current iteration step number. D_k is the current distortion of frame. F_k denotes the value of function $F(D_k)$ in Equation 1. *MaxNum* is the predefined maximum iteration step number. *MinDiff* is the predefined threshold of rate allocation error. If the difference between allocated rate and given rate is less than *MinDiff*, then stop rate allocation process.

Step 1: Initialization: $k = 0$, $D_k = D_0$, $F_k = F(D_0)$.

Step 2: Calculate temporary distortion value D_{temp} and rate difference value F_{temp} at next step according to Equation 4 and Equation 1.

$$D_{temp} = D_k - F(D_k) \ /(\sum_{i=1}^{N} dR_i(D_k)/dD) \ ; \quad F_{temp} = \sum_{i=1}^{N} R_i(D_{temp}) - R_c$$

Step 3: If (Sign(F_k) and Sign(F_{temp}) is different) Then
  $D_{k+1} = (D_k + D_{temp})/2$;
  $F_{k+1} = F(D_{k+1})$;
 Else
  $D_{k+1} = D_{temp}$;
  $F_{k+1} = F_{temp}$;
 EndIf
 $k = k + 1$;

Step 4: If ((k < *MaxNum*) and (abs(F_k) > *MinDiff*)) Then goto Step 2;
 Else stop.
 End If

Sign(F_k) is the sign of value F_k: $\quad \text{Sign(v)} = \begin{cases} 1 & ,if \ v \geq 0 \\ -1 & ,if \ v < 0 \end{cases}$

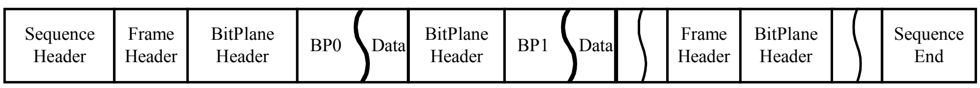


Figure 3. Structure of MPEG-4 FGS bit-stream.

3. SIMULATIONS

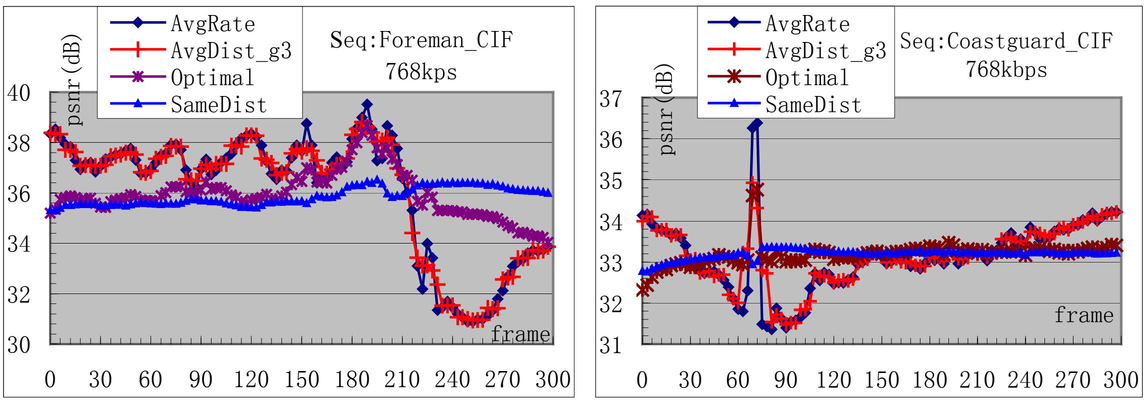
MPEG-4 test sequences are used in the simulations. The encoding frame rate is 10 fps. The first frame is I frame and the subsequent frames are all P frames. The base-layer bit-stream is 128kbps for CIF or SIF resolution, 32kbps for QCIF resolution with TM5 rate control method. Table 1 lists all these sequences and some experimental conditions. Four kinds of rate allocation methods have been applied to create 768kbps(CIF resolution) and 160kbps(QCIF resolution) bit-stream. Fig.4 is curves of the decoded PSNR of Y component versus frame number. Table 2 shows the PSNR fluctuations of decoded frames between two adjacent frames with four different rate allocation methods. Our proposed equal quality rate allocation yields the smallest fluctuation. Average rate allocation has serious quality fluctuation between two adjacent frames. In Fig.4, "AvgRate" is uniform rate allocation method provided by MPEG-4 reference software [5]. "AvgDist_g3" is the method with n being 3 in [7]. "Optimal" is equal slope rate allocation method in [6]. "SameDist" is rate allocation of equal image quality proposed in this paper. On the average, the maximum fluctuation between two neighboring frames allocated by AvgRate method is larger than 1.5dB, but the fluctuation of our method "SameDist" is only 0.3dB, which is smallest among four methods and it is negligible. On the other hand, over the whole video sequence about 10 seconds long, the quality fluctuates within 5-10dB for "AvgRate" method. "AvgDist_g3" is almost same with "AvgRate". "Optimal" is better than the former two, but it still fluctuates in 5dB. "SameDist" shows impressive performance on this aspect for the quality's fluctuation is limited in 1dB. Fig. 5 shows the rate versus frame curve for News sequence with three methods except Average rate method. The rate fluctuation of equal quality rate allocation is less than 10% of average rate, which can be smoothed by the buffer at sender and receiver.

Table 1. Test sequences

Sequence	Source Format (Frame Rate)	Total Frames	Base-Layer Bit-Rate (kbps)	Coding Frame Rate (fps)	Base-Layer Rate Control
1.Foreman	CIF (30fps)	300	128	10	TM5
2.Coastgurad	CIF (30fps)	300	128	10	TM5
3.Stefan	SIF (30fps)	300	128	10	TM5
4.Table-tennis	SIF (30fps)	300	128	10	TM5
5.News	CIF (30fps)	300	128	10	TM5
6.Carphone	QCIF (30fps)	300	32	10	TM5

Table 2. Quality Fluctuation of Rate Allocation between two adjacent frames

Sequence	AvgRate		AvgDist_g3		Optimal		SameDist	
	Average fluctuation	Max diff.	Average fluctuation	Max diff.	Average fluctuation	Max diff.	Average fluctuation	Max diff.
Foreman CIF	0.41	2.21	0.25	2.16	0.16	0.84	0.05	0.39
Coastgurad CIF	0.22	4.90	0.16	1.59	0.09	1.65	0.02	0.35
Stefan SIF	0.19	0.80	0.13	1.13	0.10	0.72	0.03	0.17
Tabletennis SIF	0.17	1.62	0.14	1.62	0.11	0.64	0.04	0.42
News CIF	0.09	0.74	0.06	0.67	0.03	0.17	0.02	0.09
Carphone QCIF	0.25	1.71	0.19	2.47	0.14	0.47	0.05	0.17



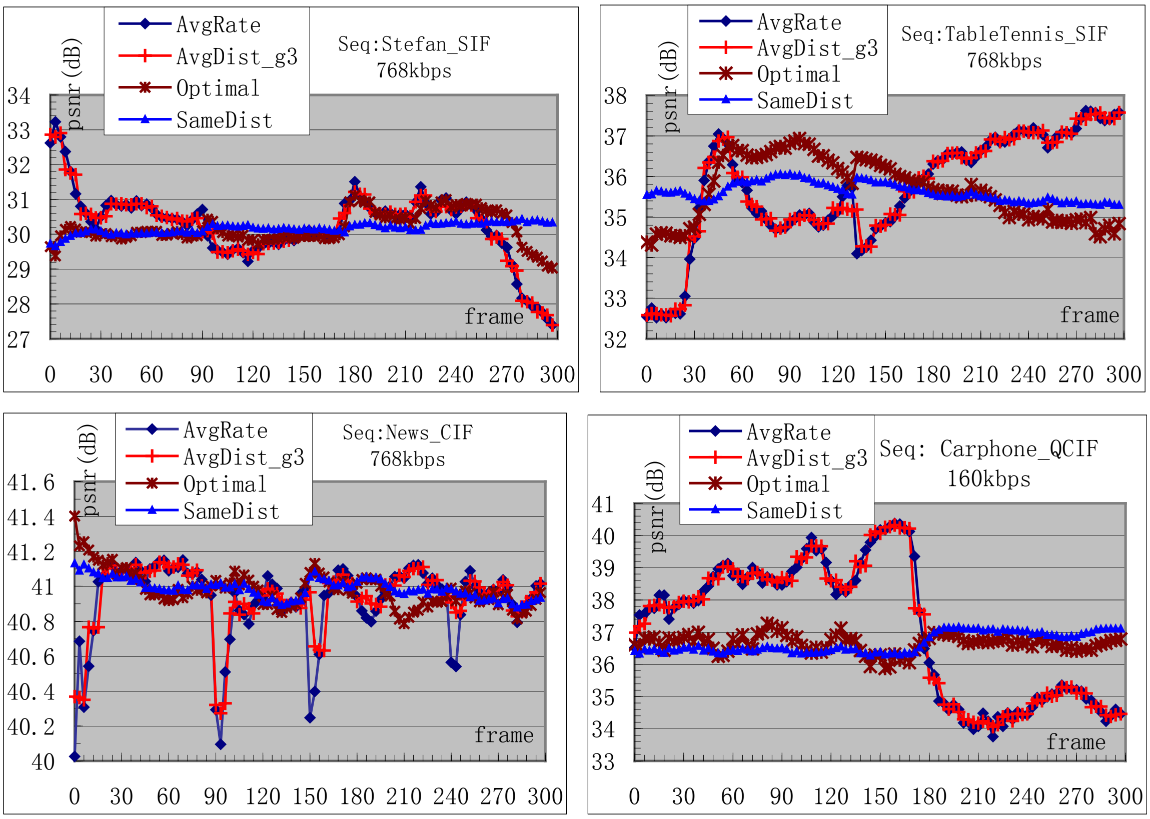


Figure 4. PSNR versus Frame Curves

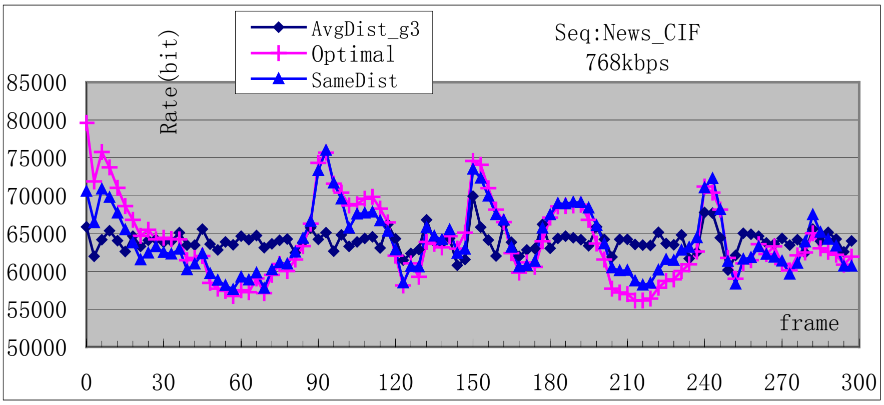


Figure 5. Rate versus Frame Curve: Average rate for FGS enhancement layer is 640kbps.

4. CONCLUSIONS

Equal image quality rate allocation method for MPEG-4 FGS video streaming is proposed in this paper. The consecutive frame's quality is smoothed with different allocated bits. The total average rate is still constrained to current available bandwidth. Although there is rate fluctuation to some extent, the buffer of sender and receiver can smooth small fluctuation of allocated rate, thus it is negligible. Compared with other three existing rate allocation methods, the proposed rate allocation method has an impressive performance. The quality fluctuation of adjacent frames is less than 0.3dB, but the other three methods have large fluctuation till 1.5dB. With proposed rate allocation method, the quality of streaming service can be improved. In streaming application, rate allocation method cannot consume much resource of streaming server in order to get higher throughput of service, and there is also some real-time requirements. Thus fast rate allocation algorithm is important. Newton search method is utilized to accelerate rate allocation process. Through these efforts, our proposed rate allocation method is quite practical for video streaming. The quality fluctuation among the video clip in one shot is less than 1.0dB, which is much smaller than that of uniform rate allocation (up to 5-10dB) method.

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