IMPROVED RATE ALLOCATION METHOD BASED ON SLIDING WINDOW FOR FGS VIDEO BIT-STREAM

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ABSTRACT

This paper proposes an improved rate allocation method based on sliding window for FGS video bit-stream. It can allocate rate for every frame in FGS video bit-stream rapidly to smooth video quality under dynamical channel condition. The paper formulates FGS rate allocation problem under the time-varying channel condition using sliding window to record available network bandwidth. Under the constrained bandwidth, the proposed method first allocates rates in advance and creates a reference window by solving the problem of constant quality constrained FGS rate allocation. Then by refreshing reference and sliding window, rate allocation of other frames can be solved rapidly. Theoretical analysis and simulation results for the method demonstrate its low complexity and high performance.

1. INTRODUCTION

With the network video applications growing rapidly, the objective of video coding has somewhat converted from storage to transmission. MPEG FGS (Fine Granular Scalability) coding[1] is recently proposed and adopted as amendments to the MPEG-4 standard. Compared with traditional scalable coding solutions, FGS video bit-streams are more suitable for network transmission. Through a bit-plane coding method of DCT coefficients in enhancement layer (EL), FGS allows the EL bit-stream to be truncated at any point. Thus FGS bit-stream can be adaptively adjusted to meet the largely changed bandwidth in Internet.

To best utilize FGS codec video bitstream, rate allocation method is needed to assign bits to each frame, and at the same time, to maximize the visual quality and smooth the quality fluctuation. The simplest one is called uniform method, which allocates uniform EL bits for each frame in the bit-stream. Although uniform method is simple to implement, it may bring large quality fluctuation and degrade the overall quality. Then there are many other rate allocation schemes proposed in the literature[2][3][4]. The objective of these methods is mainly to allocate rates to constrain the FGS video in constant quality under constant network bandwidth. Considering the dynamic channel condition, Philippe de Cuetos[5] develop heuristic algorithm, however, without taking R-D characteristics into account, it could not effectively smooth the video quality and get the optimal video quality. Zhang[3] proposes sliding window approach, however, the iterate algorithm it adopted seems to have too high complexion to be applied in the real-time application.

In this paper, improved method is proposed to effectively solve the rate allocation problem of FGS video bit-stream under dynamic bandwidth condition. The method firstly allocates rates of frames in the sliding window in advance and creates a reference window by finding the solution of the constant quality constrained FGS rate allocation problem, which uses piecewise linear interpolation RD relationship, and bisection search algorithm. Then the rate allocation of following frames is solved rapidly by refreshing the reference window and sliding window. The condition of out-of-bit-plane rate is also built and used to avoid the phenomenon of allocated rates out of the same bit plane. Our theoretic analysis and simulation results both verify this method is more simple and effective than the default uniform and former sliding window approach.

The rest of this paper is organized as follows. In section 2, the paper formulates the FGS rate allocation problem under the dynamical channel condition. The improved rate allocation method is proposed in section 3. Then theoretical analysis and discussion are given. Simulation results demonstrate good performance of the proposed method in section 5.The conclusions are presented in section 6.

2. PROBLEM FORMULATION

Constant quality constrained rate allocation problem is always formulated as minimizing the sum of absolute quality differences between adjacent frames under a bit constraint[2][3]. Considering time-varying network condition, sliding window approach[3] is commonly adopted to smooth the available bandwidth.Then the rate allocation problem under dynamical channel condition could be solved by optimizing the following formulation at each definite time t.

$$minJ = \sum_{i=w_2}^{w_N} |D_i(R_i) - D_{i-1}(R_{i-1})| s.t. \sum_{i=w_1}^{w_N} R_i \leq W(t) \tag{1}$$

Where D_i and R_i are respectively the distortion and rate of frame i, N is the size of sliding window, w_1 and w_N are the first and last frame number in sliding window, $W(t)$ denotes the available bandwidth at time t, J is the cost function.

To solve the problem, R-D curves of all frames in the sequence should be obtained. R-D curves can both be represented using parametric [4] and non-parametric [3] representations. As pointed out in [3], most parametric representations are not accurate over a large range of R. In this paper, we will focus the discussion on non-parametric representation, specifically a piecewise linear model using R-D samples.

The solution of repeatedly optimizing the formulation (1) by iterative algorithms presented in [3], which is named as M-iterate algorithm in this paper, has large computation complexion, especially when it should apply to long or multiple FGS codec video sequences. It has to take iterate computation a large number of times for all the frames in a scene.

3. IMPROVED RATE ALLOCATION METHOD DESCRIPTION

The motivation of the proposed method is to reduce the computation complexion by establishing a direct algorithm instead of iterative one. The method employs a sliding window and proposes a reference window to realize this objective.

Sliding window records current available bandwidth for all the frames in it. Reference window records the rate of per frame under a definite distortion. The bandwidth expressions of sliding window $W(t)$ and reference window $W_{ref}(t)$ are formulated as (2) and (3).

$$W(t) = \begin{cases} N * R_c(t)/F_s & \text{if } t = 1 \\ W(t-1) - R(t-1) + R_c(t)/F_s & \text{if } 1 < t < M \end{cases} \tag{2}$$

$$W_{ref}(t) = \begin{cases} W(t) & \text{if } t = 1 \\ W_{ref}(t-1) - R_{ref}(t-1) & \\ \quad +R_{ref}(t+N-1) & \text{if } 1 < t < M \end{cases} \tag{3}$$

Where N be the size of the sliding and reference window. $R_c(t)$ is the available network bandwidth at t frame time. $R(t)$ is allocated rate at t frame time. F_s denotes the source frame rate and M is total frame number of one scene. $R_{ref}(t-1)$ and $R_{ref}(t+N-1)$ are the rate of frame $(t-1)$ and $(t+N-1)$ under a same definite distortionD_{ref}.

These windows could be changing on per frame or several frames basis. In this paper, we consider the former condition. Then the proposed method could be described as following steps.

step1. Let $t = 1$, initialize the bandwidth of a sliding window by $(2)$and take it as a bit-rate constraint.

step2. Under the bit-rate constraint, solve the formulation(1) using bisection search algorithm. This is called rate allocation in advance.

Thus the optimal distortion D_{ref} and allocated rates $R_{ref}(t+i)(i = 1 \sim N)$ is obtained in advance. The real allocated rate at current time $R(t)$ equals to $R_{ref}(t)$.

step3. Let $t_{ref} = 1$, create a reference window and initialize its bandwidth by(3).

step4.Let $t = t+1$,$t_{ref} = t_{ref}+1$, update the bandwidth of sliding window and reference window.

$R_{ref}(t+N-1)$ under the reference distortion D_{ref} should be computed by using the R-D relationship of frame $(t+N-1)$, before it slides into reference window.

step5. Calculate the real allocate rate for current frame using following formulation.

$$R(t) = R_{ref}(t) + (W(t) - W_{ref}(t))/N \tag{4}$$

step6.Check the condition of out-of-bit-plane rate true or false. If false, the real allocated rate of current time $R(t)$ is obtained, then return $step4$. and compute the rate for next frame; if the condition is true, then return step $step2$. and make rate allocation in advance over again.

The condition of out-of-bit-plane rate is described as follow. The bit plane No of every real allocated rate at the current time $PlaneNo(t)$ will be computed and conserved. When $PlaneNo(t) = PlaneNo(t-1) = \ldots = PlaneNo(t-N_{obp}+1) \neq PlaneNo(t-N_{obp})$, we name the condition of out-of-bit-plane rate is true; else false. N_{obp} is a parameter which is induced to avoid acute and unstable jitter of the network bandwidth.

4. THEORETICAL ANALYSIS AND DISCUSSION

4.1. Feasibility analysis

M-iterate algorithm is one of the optimal rate allocation methods for the formulation(1). The analysis in this part would show the proposed method is equivalent with M-iterate method under some observations of the R-D curves.

The notations used in the analysis are summarized as follows: $R_{w_1}(t), R_{w_2}(t) \ldots R_{w_N}(t)$ and $R_{ref_1}(t), R_{ref_2}(t) \ldots R_{ref_N}(t)$ are separately allocated rates of per frame in sliding window and reference window at time t; $a_{w_1}, a_{w_2} \ldots a_{w_N}$ and $b_{w_1}, b_{w_2} \ldots b_{w_N}$ are separately slopes and sections of R-D curves in the same bit-plane for frames in sliding window.

The R-D curves discussed in this paper are approximated by piecewise linear interpolation, as shown in $Fig.1$. Many

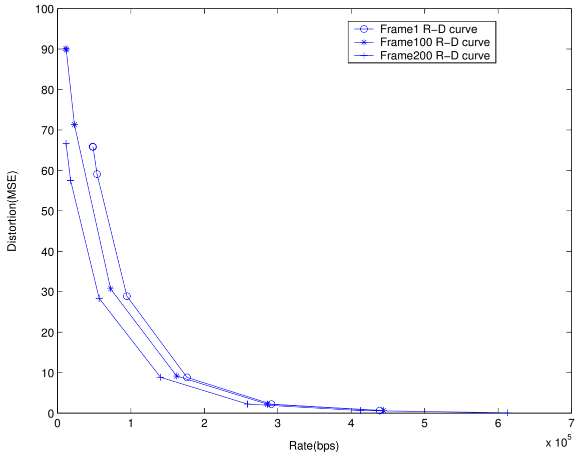

Fig. 1. Real R-D curve and R-D bit-plane point sampling

R-D curves of the FGS video bit-streams are investigated, and the investigated R-D curves in the same bit-stream have similar behaviors. We list two basic observations about statistical characteristics of the investigated MPEG-4 FGS bit-stream as follows.

$Observation1$: Under the same distortion, the allocated rates of frames in the sliding window are mostly in the same bit-plane.

$Observation2$:Within the same bit-plane, the slopes of R-D curves, belonging to frames in the sliding window, are roughly equal to each other. It is formulated as $a_1 \doteq a_2 \doteq \ldots \doteq a_N$.

From $Observation1$, the allocated rates of frame in sliding window would satisfy the following formulation.

$$\left\{ \begin{array}{l} W(t) = R_{w_1}(t) + R_{w_2}(t) + \ldots + R_{w_N}(t) \\ D(t) = a_{w_1} * R_{w_1}(t) + b_{w_1} = \ldots = a_{w_N} * R_{w_N}(t) + b_{w_N} \end{array} \right. \quad (5)$$

Then we have the real allocated rate of current time

$$R(t) = R_{w_1}(t) = \frac{W(t) - \sum_{i=2}^{N}(b_{w_1} - b_{w_i})/a_{w_i}}{1 + \sum_{i=2}^{N} a_{w_1}/a_{w_i}} \quad (6)$$

At the same time, the allocated rates of frames in reference window would satisfy the following formulation.

$$\left\{ \begin{array}{l} W_{ref}(t) = R_{ref_1}(t) + R_{ref_2}(t) + \ldots + R_{ref_N}(t) \\ D_{ref} = a_{ref_1} * R_{ref_1}(t) + b_{ref_1} \\ \quad\quad = \ldots = a_{ref_N} * R_{ref_N}(t) + b_{ref_N} \end{array} \right. \quad (7)$$

We will also obtain

$$R_{ref}(t) = R_{ref_1}(t) = \frac{W_{ref}(t) - \sum_{i=2}^{N}(b_{ref_1} - b_{ref_i})/a_{ref_i}}{1 + \sum_{i=2}^{N} a_{ref_1}/a_{ref_i}} \quad (8)$$

When $D(t)$ and D_{ref} are in the same bit-plane, we get $a_{w_i} = a_{ref_i}$,$b_{w_i} = b_{ref_i} (i = 1 \ldots N)$. Then with the $Observation2$, we obtain expression (4): $R(t) = R_{ref}(t) + (W(t) - W_{ref}(t))/N$.

The analysis above shows real allocated rate and reference rate have simple relationship shown in (4) under the definite condition. Thus this simple formulation can be used in place of M-iterate method to reduce the computation.

However, the channel condition is time varying, and sometimes change largely. Demanded rates of adjacent frames may not be in the same bit-plane, which leads to the situation that $D(t)$ and D_{ref} are not in the same bit-plane. Then in the proposed method, the condition of out-of-bit-plane rate is induced. When the condition is true, it can be determined that the network bandwidth possibly changes a lot durably. Then the reference rate in the reference window need to be reestablished. The parameter N_{obp} is established to avoid acute and unstable jitter of the network bandwidth.

4.2. Analysis of computation complexion

The computation complexion of proposed method is largely smaller than M-iterate method. In both methods, the major time-consuming part is the computation of R-D function, bit-plane No and searching for optimal distortion. Assume the average time of finding R and bit-plane No for a given D are approximately same and it can be set to T. Assume the average frequency of the optimal search is P, the total number of frames in one scene is M. The frequency of the condition of out-of-bit-plane rate satisfied is m.

The computation quantity of M-iterate method is $M * P * N * T$, and that of proposed method is $((m + 1) * P * N + (2M - 1)) * T$. Experientially, m is well smaller than M and N would be large enough to smooth video quality. Then the proposed method has much lower computation complexity than M-iterate method.

The efficiency of M-iterate method is largely determined by parameter P, which is concerned with the selection of initialized value. Meanwhile, the efficiency of M-iterate method is also critically perceptive with the size of sliding window. The proposed method solves the above problem. It avoids the complex search computation and size of sliding window has also little concern with its efficiency, which would enhance the performance of sever very much.

5. SIMULATION RESULTS

In order to validate the effectiveness of the proposed method, the simulation compares proposed method with the default uniform method and M-iterate method. The dynamical channel condition is generated by network simulation ns2, which is shown in $Fig.2$. In the simulation, coast CIF sequence is encoded using MPEG-4 FGS coding. The BL is encoded with TM5 rate control at $128kbps$ at $10fps$ with the first frame is I by all the P frames. The window size N equals

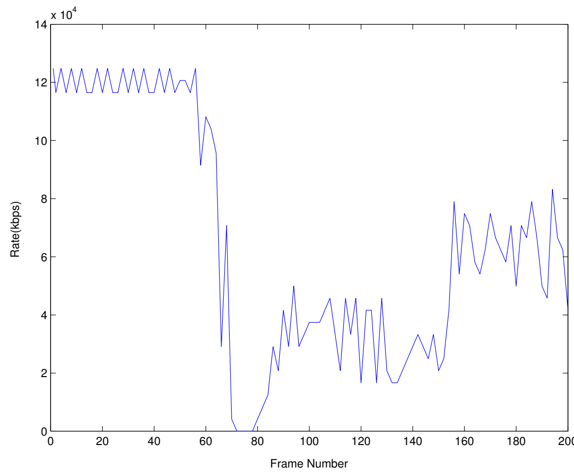

Fig. 2. Network bandwidth

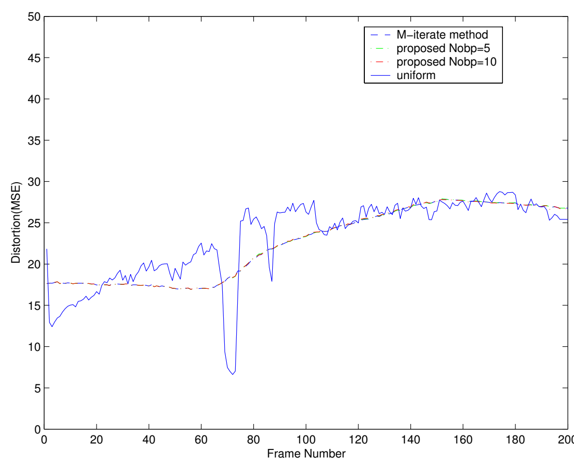

Fig. 3. Distortion curves per frame for different methods

100. $Fig.3$ shows the actual distortion curves by three methods, and $Table1$ compares relative indexes. All the algorithms are executed on a PC with Intel P4 1.5GHz CPU in this simulation.

The results indicate M-iterate and proposed method have much better performance in video quality fluctuation and distortion than uniform method. M-iterate method has best video quality smoothness. The difference of average video quality fluctuation between M-iterate and proposed method is very small, which is commonly imperceptible to human. When N_{obp} equals to 10, the fluctuation of proposed method is about 7 percent larger than M-iterate method, and when N_{obp} equals to 10, the percent decreases to about 2. However, the computation quantities of the proposed methods are both more than 90 percent lower than M-iterate method. The simulation also shows influence of the parameter N_{obp} on the results. The larger N_{obp} is, the larger video quality fluctuation is, but the less computation complexion is.

method	Average fluctuation	Average Distortion	Computation time(s)
Uniform	0.8086	23.0551	0.01
M-iterate	0.0878	22.5401	36.853
Proposed ($N_{opt} = 5$)	0.0897	22.5515	2.9840
Proposed ($N_{opt} = 10$)	0.0945	22.5560	2.2030

Table 1. relative index for three methods

6. CONCLUSION

The paper proposes an improved FGS rate allocation method based on sliding window under dynamic network bandwidth. The method uses the similarity of per frame R-D characteristic in same scene, and creates a reference window to accelerate the process of FGS rate allocation. Our theoretical analysis and simulation results show the method could smooth video quality well and have much lower complexion, comparing with former methods.

7. REFERENCES

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