An Integrated Rate Control Scheme for TCP-friendly MPEG-4 Video Transmission

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***Abstract*—Delivering MPEG-4 real-time video over the Internet needs to employ rate control schemes both in compression and transport domain. In addition to rate matching requirement between two schemes to ensure TCP-friendliness, the demand of smoothness also has significant impact on media quality. In this paper, we propose an integrated rate control scheme for MPEG-4 video transported by TCP-friendly rate control (TFRC) protocol. The experimental results show the successful integration with relatively low rate variation for video coding. Reduced frame skipping indicates the improved temporal quality while the flickering artifact possibly caused by rate variation is decreased through PSNR test.**

Keywords: rate control, MPEG-4 video, TFRC

I. INTRODUCTION

Rate control plays an important role in delivering MPEG-4 video over the Internet due to the timing constraint of video playback and network bandwidth variation. The method of rate control can be interpreted in two perspectives: one of them is from the compression perspective. Scalable rate control (SRC) in the MPEG-4 standard is such mechanism to satisfy the desired data rate by setting a sequence of quantization parameters (QP) of video frames and allowing variable frame-skip [5]. The other is from transport perspective, also known as flow control which attempts to minimize network congestion and the amount of packet loss in transmission. A new transport protocol, datagram congestion control protocol (DCCP), has been proposed to support congestion-controlled flows of unreliable datagrams for delay-sensitive applications, such as streaming media and telephony [1]. DCCP applies an appropriate rate adaptation mechanism, TCP-friendly rate control (TFRC) [2], to media traffic. TFRC aims at the fair bandwidth sharing with TCP. Additionally, relative to the TCP's abrupt sending rate changes, TFRC has the smoother sending rate for media transmission.

It is necessary to integrate compression and transport rate control for the transmission task of MPEG-4 video. However, there is a tradeoff between TCP-friendliness and media quality [4]. The implication of such integration is that data generation rate and network sending rate must be closely matched. Regarding TFRC as a rate adjustment process with the dynamic adjustment interval, the interval, during which the rate can be viewed as constant, is determined by the packet loss event and the variable RTT. Typically, timing mismatch exists between the adjustment interval of TFRC transport service and GOP period of video encoding process. Furthermore, the oscillation of TFRC transmit rate is still too abruptly variant for video encoding. The rate matching requirements could be difficult to achieve. As a result, the fairness of bandwidth distribution might fail and the perceptual quality might be demeaned as well.

Additionally, rate control in constant bit rate (CBR) channel, such as MPEG-4 SRC, does not fit for TFRC acted as a dynamic rate adjustment process. Generally, the QP of I-frames keeps unchanged for consistent spatial quality, which may cause an instant buffer-level surge [3]. Therefore, the buffer level will overflow and a continuous number of frames need to be skipped when the desired data rate decreases. This might degrade the temporal quality, which could annoy human eyes, since the smoothness is important for real-time video streaming. Even if the buffer does not overflow, the high buffer level means that the following P-frames have to sacrifice their quality at low data rate and this may cause the quality flickering artifact.

In this paper, we propose an integrated rate control scheme for TCP-friendly MPEG-4 video transmission. For the oscillation of TFRC transmit rate, a rate smooth algorithm is used to smooth the TFRC rate, and then sends the smoothed rate to the MPEG-4 rate control mechanism as the request data rate. In the application layer, the MPEG-4 encoder obtains the request data rate every GOP, and adaptively allocates the data rate of the I-frame to reduce the continuous skipping of the subsequent P-frames. Our goal is to improve the temporal quality based on the requirement of dynamic data rate.

This paper is organized as follows. Section 2

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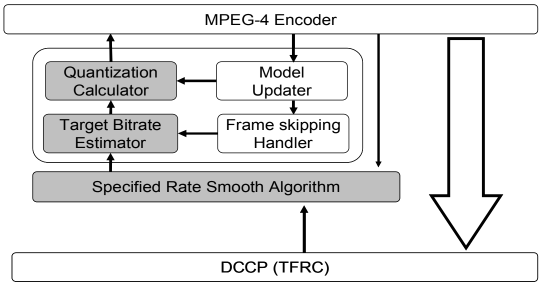

Figure 1. Integrated rate control scheme

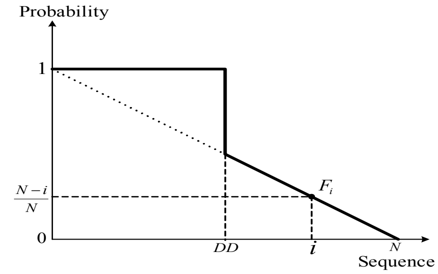

Figure 2. Weighted frame compensation probability

introduces the system architecture of our scheme. The rate smooth algorithm and the adaptive rate allocation for I-frames are then presented. The experiment results are given in section 3. Finally, we conclude this paper in section 4.

II. Integrated Rate Control Scheme

Fig. 1 illustrates our integrated rate control scheme with the MPEG-4 encoder, rate control mechanism and the transport protocol at the sender side. The MPEG-4 encoder encodes the video stream and passes it through the underlying layer, namely the DCCP/IP, for network transmission. TFRC is assumed to determine the data rate injected into the network based on the feedback information from the corresponding receiver. For every GOP, the rate control mechanism receives smoothed TFRC rate by the rate smooth algorithm as its request rate. The rate control mechanism is the modified version of the original MPEG-4 SRC. In SRC, as the target bit-rate estimator retrieves the present request rate, it allocates the data rate for P-frame and then sends the rate to the quantization calculator. The quantization calculator would compute the desirable QP based on the allocated data rate of P-frame, and the encoder compresses the frame using the calculated QP. After the encoder finishes compression, the model updater updates R-D model parameters based on the encoding results, and the frame skipping handler would check whether the buffer is over the threshold to determine if the next frame will be skipped. Based on the aforementioned SRC only for P-frame, the proposed scheme establishes a model for I-frame. The model adaptively allocates the data rate of the I-frame and calculates its QP for encoding.

A. Rate smooth algorithm

The oscillation of TFRC transmit rate is inappropriate for video coding with timing mismatch between rate control schemes of two domains, the rate matching requirement is thus difficult to achieve. Given the current TFRC transmit rate R_i and transport buffer size B, the smoothed rate R_{sm} as request data rate for video coding is:

$$R_{sm} = (1-\alpha)\times R_{sm} + \alpha\times R_i + C(B_{th} - B_{use})$$

where α is the weighting factor ($0\leq\alpha\leq1$), B_{th} is buffer threshold, B_{use} is buffer useness and C is weighting buffer factor ($0\leq C\leq1$). Both B_{th} and B_{use} are represented in packets since TFRC for video transports application data by packets based on the mean packet size measurement. The former part of equation above is the weighting average of the smoothed rate and TFRC transmit rate with parameter α. The latter part considers the rate matching through buffer useness for the TFRC transport and video data generation. The underflow in transport buffer can lead failed fairness promise for TFRC and lower bandwidth sharing might be received to degrade the user's perceived quality.

B. Adaptive rate allocation

1) Weighted Frame Compensation Probability

Given the request rate, the desired data rate per GOP is first allocated. The expected size of each frame is then calculated by the rate control mechanism. While data rate of I-frame occupies much encoding buffer space, many subsequent P-frames are thus skipped in order to conform to the request rate. The skipped frames can be classified into two categories: frames following I-frame are directly dropped (DD) in contiguous way and other dropped frames. Since the former P-frames are used as reference by many subsequent P-frames in one GOP, P-frames that are closer to I-frame should be assigned to larger coding weight to ensure that the prediction of subsequent frames is based on referenced frames with better quality. Fig. 2 shows the weighted compensation probability of P-frames. Denote N as the amount of video frame in a GOP, for frame sequence i, the corresponding weight F_i is:

$$F_i = \begin{cases} 1 & (\text{if skipped}, \; i \leq DD) \\ \dfrac{N-i}{N} & (\text{if skipped}, \; i > DD) \\ 0 & (\text{if not skipped}) \end{cases} \quad (1)$$

Therefore, the percentage needed to be compensated by I-frame for GOP k can be obtained by:

$$CP(k) = \sum F_i(k) \quad (2)$$

2) I-frame Scale Rate Allocation

The rate allocation of I-frame aims at reducing continuous frame skipping to improve temporal quality as the request rate for video encoding is dynamically changed. For current GOP k, let $R_{req}(k)$ be the request data rate in GOP k from R_{sm}, the ideal data rate of I-frame without frame skipping can be showed as:

$$\text{ideal } r(k) = r(k) - \frac{R_{req}(k) - r(k)}{N-1} \times CP(k) \quad (3)$$

where N is total frames in a GOP and $r(k)$ is data rate of I-frame for GOP k. $(R_{req}(k)-r(k))/(N-1)$ denotes the average data rate of each P-frame in GOP k and thus the compensation portion of I-frame would be further multiplied by $CP(k)$. Then, for next GOP (k+1), the data rate of I-frame can be predicted by a proportional expression:

$$r(k+1) = \frac{\text{ideal } r(k)}{R_{req}(k)} \times R_{req}(k+1) \quad (4)$$

3) Adaptive Quantization Approximation for I-frame

After the data rate of I-frame is acquired, the next step is to calculate the corresponding quantization parameter Q which could encode the most nearest desired data rate r. Due to the time constraint of real-time video streaming, the computation overhead is thus critical. To relieve the complexity, the quantization for I-frame can be approximated by:

$$Q(k+1) = Q(k) r(k) / r(k+1) \quad (5)$$

where $Q(k)$ is the quantization parameter of GOP k. In [6], eq. 5 has been showed to be useful in GOP scale for MPEG-1. We thus take three different kinds of test sequences, namely Akiyo, Foreman, and Stefan, to show the approximation error of eq.5 for I-frame scale. From all combinations of the Q-R relationship of I-frame-(k) and I-frame-($k+1$) in test sequences (QP=1~31), the statistical distribution shows the 80% cumulative error probability can be obtained in 30% approximation error for all sequences.

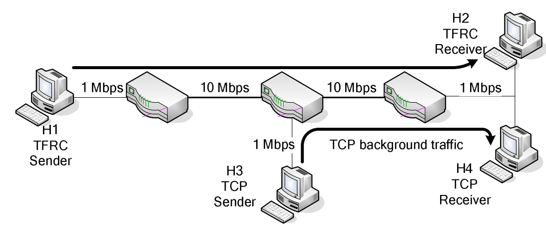

Figure 3. Experiment set-up

III. EXPERIMENTAL RESULTS

As Fig. 3 shown, the experimental environment contains four hosts and three Cisco 2600 routers. Each link connecting two nodes is labeled with its respective link bandwidth. The proposed scheme is implemented in H1 with TFRC. The source of TFRC comes from the experiment code [7]. The test sequence ‘Stefan’ in QCIF format is encoded with 30 f/s and GOP 30. Video stream flows to H2. We compare the result of the modified rate control with adaptive rate allocation with the original MPEG-4 VM rate control. In addition, two TCP flows from H3 to H4 are generated to observe the result of bandwidth competition between TFRC and TCP flows.

A. Rate smooth

The experiment is conducted for 120 seconds by setting $\alpha = 0.125$ and $C = 0.5$. The test sequence is looped for video encoding. Since the slow-start phase of TFRC would double its sending rate to rapidly compete for available bandwidth, only the congestion-avoidance phase is considered to observe the rate matching requirements (30s~120s). Fig. 4 shows the buffer useness of TFRC transport service from 0s to 80s. Regardless of the unavoidable buffer underflow in slow-start phase, the request rate is appropriate for TFRC transport service to preserve TCP-friendliness. Table 1 shows the coefficient of variation (CoV) for data rate of TFRC and request rate from the rate smooth algorithm. The data rate injected into network has relatively large CoV. Note that the variation of TFRC in data rate is generally smaller than TCP to exhibit its smooth-changing feature. With TCP flows, CoV of TFRC data rate further decreases. In both cases, the request rate has small CoV to benefit video coding for stable perceptual quality.

B. Adaptive rate allocation

To verify the adaptive rate allocation with the test sequence, the experiment changes link capacity from 1 Mbps to 128Kbps between hosts and routers. The remainder of experiment set-up is unchanged. In this case, the data rate of TFRC may be still larger than the encoding rate while QP of all frames is set to the

Table 1. Coefficient of variation

	Without TCP	With TCP
Data rate	0.651	0.385
Request rate	0.235	0.099

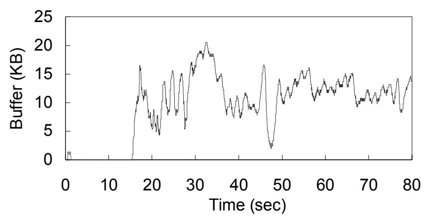

Figure 4. Buffer useness of TFRC transport

minimum. Fig. 5 top shows the result of bit rate comparison. Given the target bit rate obtained from request rate, the modified rate control can be more approximate to target rate than original SRC, which is helpful to achieve rate matching requirements. Fig. 5 middle and bottom shows the result of weighted frame dropped ratio (WFDR) and PSNR value to observe the temporal quality, respectively. Each dropped frame calculates its quality degradation effect D_i by (1+weight $\times$ (i-1)) where i is the sequence number of contiguous dropped frame and weight is set to 0.2. Then WFDR is obtained by (Σ D_i / N) where N is total number of frames in a GOP. As contiguous dropped frame increase, the WFDR increases. The modified rate control with adaptive rate allocation has relatively low WFDR and the PSNR comparison also shows the stable perceptual quality. On the contrary, the original SRC presents the flickering artifact to annoy human eyes while video stream is in service.

IV. Conclusions

This paper presents an integrated rate control scheme for MPEG-4 real-time video with TCP-friendly congestion control transport service. The proposed scheme comprises the specific rate smooth algorithm to reconcile the conflict between video encoding and TFRC transport, and the adaptive rate allocation to reduce contiguous frame drops. The experimental results show the proposed scheme supports rate matching requirements to preserve TCP-friendliness as well as improved temporal quality for video streaming.

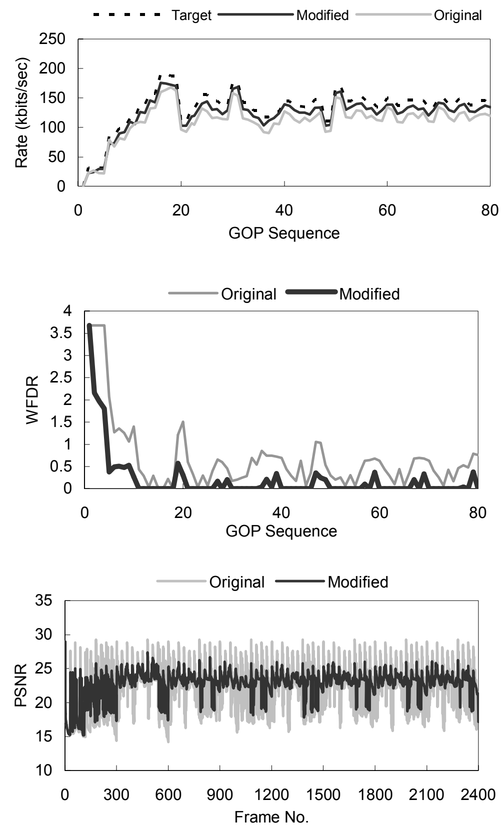

Figure 5. Performance comparisons. top: bit rate; middle: WFDR; bottom: PSNR

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