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A Control of Channel Rate for Real-time VBR Video Transmission

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Abstract

Recent studies on the Constant Bit Rate and Variable Bit Rate transmissions have mainly focused on the frame by frame encoder rate control based on the quantization parameter With the existing approaches it is difficult to guarantee a consistent video quality Also, the rate control overhead is too high for the real-time video sources In this paper, a channel rate allocation scheme based on the control period is proposed to transmit a real-time video, in which the control period is defined by a pre-specified number of frames or group of pictures At each control period, video traffic information is collected to determine the channel rate at the next control period The channel rate is allocated to satisfy various channel rate constraints such that the buffer occupancy at the decoder is maintained at a target level If the allocated channel rate approaches the level at which the negotiated traffic descriptions may be violated, the encoder rate is decreased through adjusting quantization parameters in the MPEG encoder In the experimental results, the video quality and the overflow and underflow probabilities at the buffer are compared at different control periods Experiments show that the video quality and the utilization of network bandwidth resources can be optimized through the suitable selection of the control period

1. Introduction

Recent progress on the standardization of high-speed networking and digital video technologies has led to active commercial development of various video services such as video conferencing,

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videophone, and TV broadcast. The video output generated by Moving Picture Experts Group (MPEG) coder is intrinsically variable bit rate (VBR) for most practical compression algorithm [6] The VBR nature of compressed video gives rise to a motivation for establishing networks which allow video transmission at variable bit rate while providing the quality of service (QoS) guarantees such as cell loss, cell delay, and cell delay variation. An asynchronous transfer mode (ATM) network [4] is an example of a network architecture, which would allow this type of VBR transmission

In this paper, we consider VBR transmission of a real-time video over ATM networks To provide reliable and consistent video quality, it is very important to effectively manage network resources including buffers and channel bandwidth. We propose a channel rate allocation schemel for real-time VBR video such that consistent video quality is guaranteed

Recent studies related to the video transmission can be classified into two categories; constant bit rate (CBR) transmission and VBR transmission. In the CBR transmission [1, 3, 5, 9], it is assumed that the channel rate for a video source is constant Given the constant channel rate, which is negotiated between a user and a network, the MPEG encoder adjusts the source coding rate based on the quantization parameters. In [9], a source encoding rate control is proposed based on the adjustment of the quantization parameter When the encoder buffer occupancy level is in potential overflow region, the MPEG encoder increases quantization parameter (Q) to decrease the source output rate In the opposite case, Q is decreased to improve the quality of VBR videos. In [5], the required channel rate for a video source is estimated in the CBR transport Luo and Zarki [3] present the relationship between picture quality and encoder rate control for different combinations of channel bandwidth, buffer size, and quantization rate In [1], a source rate control algorithm is presented based on the leaky bucket controller However, CBR transmission for VBR video suffers from disadvantages such as variable video quality and relatively high transmission cost.

In the study of VBR transmission [2, 7, 8], a joint control of encoder rate and channel rate is considered to maintain the end-to-end delay of transmitted videos in the appropriate level that is suitable to reliable display. In [7], the authors present conditions to ensure that the video encoder and decoder buffers do not overflow or underflow when a channel transmits a VBR video In [8], it is shown that increasing the delay in the video buffers decreases the necessary peak bandwidth and significantly increases the number of calls that can be carried by the network. In [2], the source encoder rate and the channel rate are jointly selected to ensure that real-time video display at the decoding end is possible. However, these studies of VBR transmission have mainly focused on the source encoder rate control Also, the video transmission is controlled on the frame by frame basis In addition, the decoder buffer occupancy is not considered Thus the probability of overflow or underflow in the decoder buffer may tend to increase

In this paper, we propose a channel rate control scheme for a real-time video over ATM networks To allow picture quality of video sources to be uniform, it is assumed that the MPEG encoder generates each frame by using a set of constant quantization parameters In particular, the proposed scheme is based on the control period, which is defined by a pre-specified number of frames or group of pictures (GOPs) During a control period, each frame is transmitted onto the network at a constant channel rate. The channel rate for control period is determined by the traffic information collected during the previous control period. The channel rate is allocated to satisfy various constraints. To decrease the probability of overflow and underflow at decoder buffer, a constraint that limits the occupancy of the decoder buffer at a target level is included. If the allocated channel rate approaches the level at which the negotiated traffic descriptions may be violated, the encoder rate is decreased through adjusting quantization parameters in the MPEG encoder

This paper is organized as follows. Section II describes the VBR video transmission model and channel rate constraints for video transmission over ATM networks In Section III, the concept of control period and the related optimization model are presented for the channel rate control. In Section IV, we propose a channel rate control algorithm. In Section V, the performance of the proposed scheme is compared with different control periods. Section VI concludes this paper

2. VBR Video Transmission System

2 1 Video Transmission System

[Figure 1] shows an end-to-end model for real-time VBR video over ATM networks. The MPEG encoder processes the raw video source and passes the bitstream to the encoder buffer The MPEG bitstream consists of units of group of pictures (GOPs) containing an Intra (I) picture, Predictive (P) pictures and bidirectional or interpolated (B) pictures Typically, the target quantization parameter is set to be 3 for I frame, 4 for P frame and 6 for B frame, respectively [9]. A GOP pattern is IBBPBBPBBPBB for GOP size of 12 and two GOPs are transmitted for a second over ATM networks. Thus one frame period corresponds to 1/24 seconds [6] At the end of the i-th frame period, $E(i)$ cells for the i-th frame are fed into the encoder buffer.

During the same frame period, the network interface inside the video terminal chooses a variable channel rate $\lambda(i)$ to transmit cells from the encoder buffer onto the ATM network. The network interface prepares the cell stream for ATM delivery by segmenting data into cells and adding appropriate ATM adaptation layer The VBR traffic profile is defined through a set of traffic descriptors such as the peak rate, the sustainable rate, and the maximum burst size. These parameters are referred to as source traffic descriptor (STD) [4]. The network admits a VBR connection based on its declared STD. Once the connection is established, it is expected that the terminal device will comply with the declared STD.

The network may enforce the declared STD using a leaky bucket (LB) based network policing mechanism in the network interface. The LB is specified by three parameters (λ_p, λ_s, LB_{max}), which are the peak rate, the sustainable rate, and the LB size, respectively LB_{max} is the maximum size of a LB counter. When a cell arrives and the counter is less than LB_{max}, the cell can be sent immediately to the network. The counter is then incremented by one When the counter is equal to LB_{max}, any arriving cell is either dropped or marked as a low-priority cell. While the counter is positive, it is decreased at a constant rate λ_s. Note that a larger LB_{max} allows more bursty traffic to pass. The LB parameters are negotiated and agreed upon by both video source and network.

After a transmission delay, cells will arrive at the decoder buffer and will be re-assembled and sent to the decoder after a prespecified system delay of L frame period [2, 7, 8]. In Figure 1, the occupancy or fullness of the encoder and decoder buffers are denoted by $B^e(i)$ and $B^d(i)$, respectively.

2.2 Channel Rate Constraints

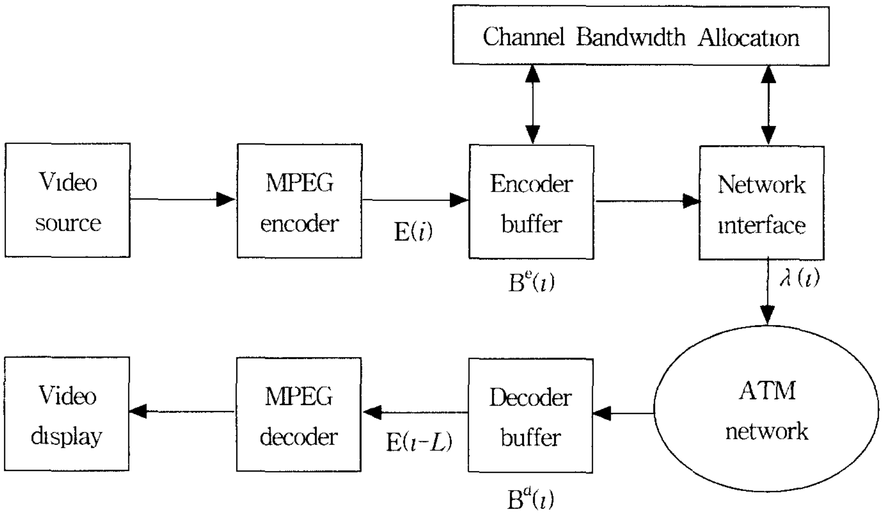
Differently from the existing studies, we in this paper will not address a detailed encoder rate control between the MPEG encoder and the encoder buffer. This is because the main objective of the paper is to provide a channel rate such that the encoded data arriving at the encoder buffer are transmitted as entirely as possible onto the network. Thus, we focus our attention on the control of channel rate for a given encoder rate.

To prevent cell drop, encoder buffer overflow, decoder buffer overflow and underflow, LB overflow, and the channel rate should be strictly constrained. Thus constraints are imposed on $\lambda(i)$ for the frame period i. The channel rate allocation is to choose the channel transmission rate $\lambda(i)$ to satisfy these constraints. The related constraints on the channel transmission rate $\lambda(i)$ are explained in [9] and summarized as follows.

First, the encoder buffer occupancy $B^e(i)$ is determined by the buffer state of previous period i-1, the encoder rate $E(i)$, and channel rate $\lambda(i)$ as follows.

$$B^e(i) = B^e(i-1) + E(i) - \lambda(i),$$
$$0 \le B^e(i) \le B^e_{max}. \qquad (1)$$

The encoder buffer underflow is actually not a concern. It is included only because it is not necessary for the channel rate $\lambda(i)$ to be greater than $B^e(i-1) + E(i)$.



[Figure 1] End-to-end VBR video transmission system

The decoder buffer underflow is mandatory, since at the end of the i-th frame period all E($i-L$) cells of the ($i-L$)th frame have to be in the decoder buffer and ready for decoding. The decoder buffer constraint is given by

$$B^d(i) = B^d(i-1) + \lambda(i) - E(i-L),$$
$$0 \le B^d(i) \le B^d_{max} \qquad (2)$$

Finally, the leaky bucket overflow condition requires

$$LB(i) = \max\{0, LB(i-1) + \lambda(i) - \lambda_s\},$$
$$LB(i) \le LB_{max}. \qquad (3)$$

Note that LB underflow is not a constraint We can also include the following peak rate constraint:

$$\lambda(i) \le \lambda_p \qquad (4)$$

The peak rate constraint implies that the instantaneous channel rate with which a source can transmit cells onto a network should not exceed the peak rate λ_p, which is negotiated between a user and a network. Note that the standard ATM LB mechanism employs both the peak rate (4) and the sustainable rate (3) constraints simultaneously

3. Modeling of the Control of Channel Rate

The channel rate constraints described in the previous section are based on the frame-by-frame control In the frame-by-frame control mode, a different channel rate may be allocated for each frame Ideally, this is a desirable approach because the traffic amount is changed very rapidly and irregularly along the usual MPEG frame sequences.

In the frame-by-frame control mode, however, it is generally agreed that the control overhead is too high because the channel rate allocation is required too frequently, i.e., for each frame period, 1/24 second [3, 5, 6]. In addition, such an approach is not realistic in real-world networks because the round trip delay for the rate control is usually more than one frame period.

Thus we introduce a control period for the control of channel rate. The control period (CP) may be defined by a number of frames or GOPs. A fixed channel rate is employed for all frames during the control period, and such a channel rate is determined in the previous control period Note that the proposed model includes the case of frame-by-frame control by setting CP to be just one frame period.

3.1 Control Period

The control period (CP) is defined by a number of frames or GOPs, during which a constant channel rate is assigned to the video source. By letting CP be the duration of the control period, same channel rate λ is assigned during the control period, i. e., $\lambda(j) = \lambda$ for frames $j = i, i+1, \ldots, i + CP - 1$. For example, for the control period of three frame periods, the channel rate $\lambda(j) = \lambda$ is employed for the three frame periods Ideally, the control period may be set to be one frame, which is called the frame-by-frame control. The frame-by-frame control, however, requires too much overhead for the control of channel rate. In addition, such a short control period seems to be not suitable to MPEG video traffic, which is very irregular for each frame I, P, and B For the irregular MPEG traffic, we thus recommend a CP with integer multiple of the size of GOP as a reasonable choice

For a real-time VBR video, we cannot obtain current traffic information related to the variables in the equations (1)-(4), described in Section II. Thus we use traffic information at the control period t-1 to determine the channel rate $\lambda(t)$ for the control period t At current frame period i, variables related to the channel rate constraints for the control period t are defined as follows

$$E(t) = \frac{1}{CP} \sum_{j=i-CP}^{i-1} E(j) \tag{5}$$

$$B^e(t-1) = \frac{1}{CP} \sum_{j=i-CP}^{i-1} B^e(j) \tag{6}$$

$$B^d(t-1) = \frac{1}{CP} \sum_{j=i-CP}^{i-1} B^d(j) \tag{7}$$

$$LB(t-1) = \frac{1}{CP} \sum_{j=i-CP}^{i-1} LB(j) \tag{8}$$

Among these equations, note that the equation (5) represents an estimate for the encoding cell rate for the control period t, which is based on the assumption that traffic pattern of E(t) is nearly the same as that of E(t-1) for a short control period We note that a larger control period is easy to implement, but it has a disadvantage that the traffic fluctuation of a video source is not properly reflected on the channel rate The other variables $B^e(t-1)$, $B^d(t-1)$, and LB(t-1) in equations (6), (7), and (8) are simply a collection of the data during the control period t-1

3 2 Optimization Model

Based on the variables and constraints, we formulate the optimization model for the control of channel rate To decrease the probability of underflow and overflow at decoder buffer the following is employed as the objective function

$$\text{Minimize} |B^d(t) - B^d_{target}|, \tag{9}$$

where B^d_{target} can typically be employed as 1/2 B^d_{max}. This objective function has the effect of maintaining the decoder buffer occupancy at a target level Now, the controls of channel rate (Problem CR) is formulated at each control period t as follows,

(Problem CR)

$$\begin{array}{ll} \text{Minimize} & \text{Minimize } |B^d(t) - B^d_{target}| \\ \text{subject to} & 0 \leq B^e(t) \leq B^e_{max} \qquad (10) \\ & LB(t) \leq LB_{max} \\ & \lambda(t) \leq \lambda_p \end{array}$$

where

$$\begin{aligned} B^e(t) &= B^e(t-1) + E(t) - \lambda(t) \qquad (11) \\ B^d(t) &= B^d(t-1) + \lambda(t) - E(t-L) \\ LB(t) &= \max\{0, LB(t-1) \\ &\qquad + \lambda(t) - \lambda_s\} \end{aligned}$$

4. Channel Rate Control Algorithm

We first derive the feasible range of the channel bandwidth $\lambda(t)$ to be transmitted onto ATM networks. The following lemma determines the range of the bandwidth $\lambda(t)$.

Lemma 1 In problem CR, the feasible region of $\lambda(t)$ is given as follows,

$$\max\{0, B^e(t-1) + E(t) - B^e_{max}\} \leq \lambda(t) \leq \min\{B^e(t-1) + E(t), LB_{max} - LB(t-1) + \lambda_s, \lambda_p\}$$

Proof Clear from constraints (10) and (11).

In Lemma 1, we denote the maximum and minimum values of feasible $\lambda(t)$ by λ_{max} and λ_{min}, respectively That is,

$$\lambda_{max} = \min\{B^e(t-1) + E(t), LB_{max} - LB(t-1) + \lambda_s, \lambda_p\}$$

$$\lambda_{min} = \max\{0, B^e(t-1) + E(t) - B^e_{max}\}$$

In the lemma, the feasible region of $\lambda(t)$ may be empty, I. e., $\lambda_{max} < \lambda_{min}$. This situation occurs when the source traffic violates the negotiated parameters such as λ_s, λ_p, and LB_{max}. As an example of $\lambda_p < B^e(t-1) + E(t) - B^e_{max}$, then, the encoder rate $E(i)$ should be decreased for each frame i in the transmission period of control period t by increasing the quantization parameters in the MPEG encoder, which will result in the degradation of video quality

The problem CR can be easily solved due to the linearity of the objective function $|B^d(t) - B^d_{target}|$. Note that λ_{target}, which is defined as

$$\lambda_{target} = B^d_{target} + E(t-L) - B^d(t-1),$$

is a channel rate for which the objective function becomes zero. Then the following lemma characterizes the optimal channel rate

Lemma 2 The optimal channel rate $\lambda(t)$ of the problem CR is given as follows,

Case 1. If $\lambda_{min} < \lambda_{target} \leq \lambda_{max}$, then $\lambda(t) = \lambda_{target}$,
Case 2 If $\lambda_{min} > \lambda_{target}$, then $\lambda(t) = \lambda_{min}$,
Case 3 If $\lambda_{target} > \lambda_{max}$, then $\lambda(t) = \lambda_{max}$

Until now we assumed that the source MPEG encoder generates a frame by using a set of fixed quantization parameters to guarantee consistent video quality. However, when a user's traffic exceeds the negotiated traffic parameters, the network needs to constrain the encoder rate by increasing the quantization parameters. In this case, the quality of the video may be degraded instantaneously by the control of the excess video traffic The quantization parameter based control of encoder rate is also necessary to prevent the overflow or underflow of the buffers In this paper, we propose the following quantization parameter adjustment, which is based on the channel rate obtained by the channel rate control algorithm

By dividing the interval between λ_p and λ_s into three regions as

Low channel rate $\lambda_s \leq \lambda \leq \lambda_l$
Normal channel rate : $\lambda_l \leq \lambda \leq \lambda_h$
High channel rate : $\lambda_h \leq \lambda \leq \lambda_p$

the quantization parameter value Q(t+1) at control period t+1 may be increased or decreased depending on the channel rate λ at period t. In other words, when λ at period t is low (high) rate, then Q(t+1) is decreased (or increased) by Q compared to Q(t) Otherwise, when the channel rate is normal at t, the same quantization rate is used at t+1.

Based on the discussion of this section, the channel rate control algorithm at each control period t is summarized as follows;

Step 1 Obtain the data $B^e(i)$, $B^d(i)$, $E(i)$, $LB(i)$ for each frame i during the control period t-1.
Step 2. Use the equations (5)-(8), to obtain the input data $B^e(t)$, $B^d(t)$, $E(t)$, and $LB(t)$
Step 3 Obtain the feasible range of $\lambda(t)$ based on Lemma 1
Step 4. Set $\lambda(t)$ as one of λ_{min}, λ_{max} or λ_{target} based on Lemma 2
Step 5 For the $\lambda(t)$ obtained, perform the quantization parameter adjustment, if required
Step 6 Stop.

Until now, we have presented an optimal channel rate control algorithm, which is based on the concept of control period In the algorithm a channel rate is obtained such that the objective function of the proposed model is minimized under some channel rate constraints.

5. Experimental Results

In case that the network provider employs the channel rate control based on control period, it is one of the very interesting issues to select a suitable control period, and to analyze an impact on the video quality by the selected control period. In this section, we examine the performance of video quality, based on the proposed channel rate control algorithm. In the experiments, we show that the video quality, control overhead and network bandwidth resources can be optimized through the selection of a suitable control period.

The "Star-Wars"[10] sequence is employed for our test, which includes dramatic scene changes enough to examine the control period-based channel rate algorithm. The test data set represents the frame data rate encoded by the MPEG standard. The source material contains quite a diverse mixture of material ranging from low complexity/motion scenes to those with very high action. The test data consists of 150,000 integers, representing the number of bits per video frame. The original film is coded with 24 frames per second. Thus a frame period corresponds to 1/24 second. The sequence of MPEG I, P, and B frames used in a GOP is IBBPBBPBBPBB. The length of the movie is approximately 2 hours. The source traffic profile can be characterized by the peak cell rate, 482 cells/frame and the sustainable cell rate, 38 cells/frame, where one cell includes frame information of 48 bytes. Thus peak to average ratio is 482/38 = 12.7, which implies that the video source's traffic consists of rapid scene changes.

To test the proposed algorithm, the related system variables are set as follows,

$\lambda_p = 482$ cells/frame, $\lambda_s = 38$ cells/frame, $B^e_{max} = B^d_{max} = LB_{max} = 13 \times \lambda_s$, and $L = 3$ frame periods.

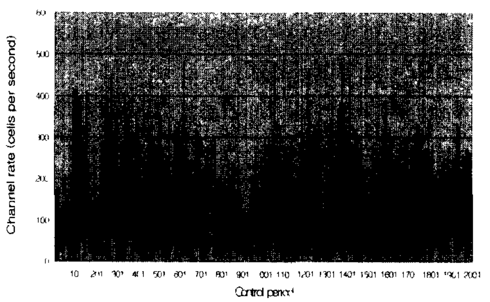
The performance of the proposed algorithm is tested with the following three metrics.

(1) trace of $\lambda(t)$ at different control period,
(2) the video quality at different control period,
(3) overflow and underflow probability of decoder buffer at different control period.

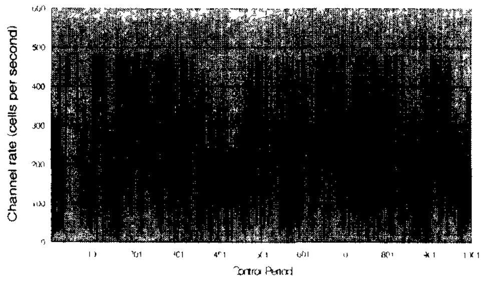
With the first metric, we analyze the relationship between resource utilization and control overhead. The second metric is defined by the ratio between target encoder rate and the encoder rate to be adjusted by the quantization parameter control. The third one is measured by the frequency of overflows or underflows at the decoder buffer.

[Figure 2, 3 and 4] show the performance of the transmitted channel rate, overflow and underflow probability at the decoder buffer, and video quality, respectively. In [Figure 2], the traces of channel rates are shown at CP = 1/2 GOP, 1 GOP, 2 GOPs, and 4 GOPs over totally 1000 GOP periods. From the figure, it is clear that the shorter period controls the variable fluctuation of traffic source more adaptively. The utilization of channel bandwidth can be compared with CP = 1/2 GOP and CP = 4 GOPs. Note in [Figure (d)] that most of the controlled channel rates are near at the peak cell rate (482 cells/second), while the bandwidth in case of Figure (a) is far below the peak. This bandwidth gain is obtained at the cost of the frequent updates of channel rates. Thus a suitable control period is necessary for the tradeoff between resource utilization and the overhead of channel rate controls

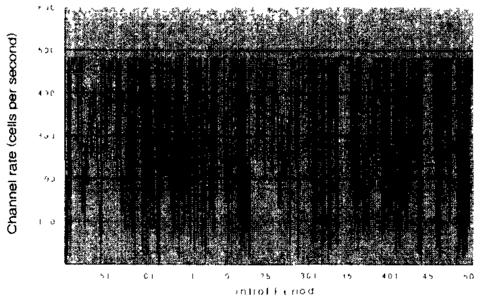
(a) CP=1/2 GOP



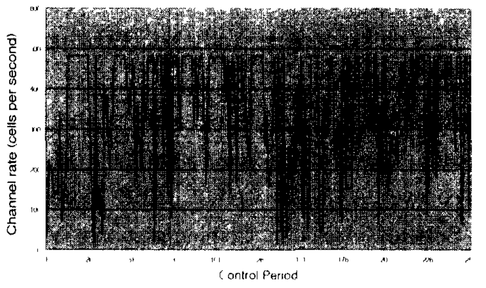
(b) CP = GOP



(c) CP = 2 GOP

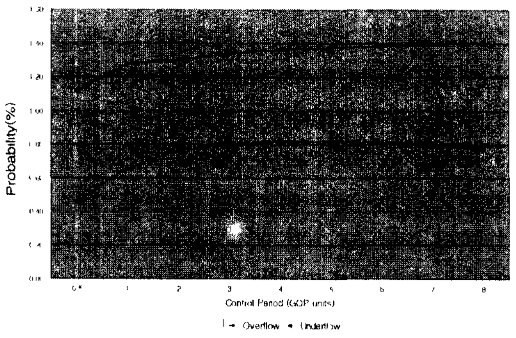


(d) CP = 4 GOP



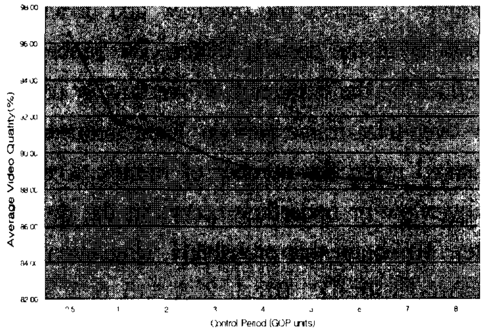
[Figure 2] Variation of Channel Rates with different control periods

[Figure 3] shows the overflow and underflow probability at the decoder buffer. The probability is defined by the frequency of overflow or underflow over total frame periods. Each frequency is measured using the number of frames at which the overflow or underflow occurs in the decoder buffer. To obtain this probability, simulations are performed with CP = 0.5, 1, 2, 3, 4, 5, 6, 7, and 8 GOPs. In the figure, it is shown that the overflow and underflow is sensitive to the control period CP ≤ 3 GOPs



[Figure 3] Overflow and underflow probability at decoder buffer

[Figure 4] shows the video quality at different control periods. In the figure, the video quality is determined by the amount of encoder rate, which should be decreased by the quantization parameter adjustments for the original encoder rate based on Q_{target}. For example, 97% video quality with CP = 0.5 GOP implies that 3% of the original encoder rate should be decreased. The quantization parameter adjustment is required since the channel rate is controlled based on the encoder rate or previous period. From the figure, the video quality is degraded as the control period gets longer. This is because the longer control period cannot suitably reflect the dramatic traffic fluctuations.



[Figure 4] Video quality at different control periods

6. Conclusions

In this paper, a channel rate control algorithm is proposed to transmit a real-time video, which is based on the control period In each control period, traffic data are obtained to determine the channel rate for the next period. The channel rate is controlled to satisfy various channel rate constraints. The encoder rate is also adjusted based on the channel rate determined at previous control period If the channel rate approaches the level at which the negotiated traffic descriptions may be violated, the encoder rate, at the next control period, is decreased through adjusting quantization parameters From the experiments, we know that the video quality, control overhead and network bandwidth resources can be optimized through the selection of a suitable control period.

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