# ON-LINE DYNAMIC BANDWIDTH ALLOCATION FOR VBR VIDEO TRANSMISSION

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## ABSTRACT

To guarantee quality of service (QoS), the requirements for video transmission, such as delay and cell loss rate (CLR), are very stringent. These constraints are difficult to meet if high network utilization is desired. In this paper, on-line dynamic bandwidth allocation algorithms, in which the bandwidth is adjusted based on the current frame size, are proposed to improve the bandwidth utilization. When the bandwidth deviation is large enough, the bandwidth renegotiation process is triggered. Compared with CBR service, network utilization can be improved significantly for the same CLR. In general, to achieve a very low CLR and high bandwidth utilization, the renegotiation frequency may become high. Algorithms, which are proven to be effective in reducing the renegotiation frequency while keeping the bandwidth utilization at a reasonable level, are also proposed.

**Key words:** video transmission, dynamic bandwidth allocation, quality of service, MPEG, frame delay

## 1. INTRODUCTION

The main design objective of emerging broadband networks is to provide high speed transmissions of a wide range of quality of services. Video is becoming the major component of broadband network traffic, and therefore, an efficient video traffic transmission mechanism is important to network operators. Bit streams of video traffic produced by a codec are naturally VBR (variable bit rate). For example, the ratio between peak and average bit rate may be as large as 12 for the *Star Wars* video sequence. It is very difficult to meet the QoS parameters (such as delay and cell loss ratio) for such kind of traffic while keeping high network utilization.

There is a trade-off between provisioning video transmission over constant bit rate (CBR) service and variable bit rate (VBR) service, namely, complexity versus QoS. Transmission over CBR requires less complex network management but at the cost of varying video quality and network efficiency while that over VBR can provide QoS but at the cost of more complex network management.

Dynamic bandwidth allocation approach (or Renegotiated CBR) is an alternative for improving network utilization, that allow users to dynamically reserve or adjust network resources. When there is not enough reserved resource for the user to transmit its traffic, a renegotiation is initiated to ask for more. If the reserved resource is more than enough, some bandwidth can be released. In such a way, network utilization can be improved significantly.

One major class of dynamic resource management algorithms is based on parameter measurements. Several measurement based dynamic bandwidth allocation algorithms, which initiate their renegotiation processes based on the actual measurement of CLR or user parameters (UPs), have been proposed [5],[2].

In [2], the CLR is calculated up to the current period, and the service rate for the next period is adjusted based on the current CLR. Owing to the difficulty for assessing the CLR on line and the indirect relationship of the current CLR and UP with the future bandwidth requirements, these approaches are not effective enough to enhance QoS and improve network utilization.

Another major class of algorithms are based on prediction techniques. User parameters or bit rates are predicted on-line based on the available information, and resources are allocated based on the predicted results. It is important to predict these parameters accurately so that network resources can be used efficiently.

In [4], the UPs, such as peak rate and sustained rate,

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are adjusted for every GOP (group of picture). UPs could be inherently inaccurate because they are calculated from previous GOPs. To reduce the buffer size, the source quantization step is adjusted on line. The major drawback of this algorithm is that the user parameters (peak rate, sustained rate, and burst length) need to be renegotiated for each GOP, which is a big burden to network management.

Adas [1] proposed to use adaptive linear prediction to support dynamic bandwidth reallocation. It was claimed that by predicting the average bit rate of the next GOP and allocating bandwidth based on the predicted results, the network utilization can be improved by a factor of 1.9-3.0 [1]. Since the bit rate variation is very high, it is very difficult to predict the average bit rate for the next GOP accurately, and the prediction error can be very large. It often appears that when the actual bitrate reaches a peak, the predicted result reaches a valley. Only when the bit rate changes remain small, the predicted results are close to the actual bit rate. The prediction errors become very large when bit rate changes significantly. If the bandwidth is allocated based on such kind of results, the bandwidth utilization or CLR can not be improved efficiently.

If the renegotiation is triggered by video sources, no prediction is needed, even for real-time video delivery because only one or two frames need to be held. One or two frame holding time is acceptable for real-time video delivery. Our earlier proposed algorithms [6] which allocate bandwidths based on scene changes require a holding time of (variable) scene lengths, and thus only applicable to pre-recorded video. In this paper, new on-line dynamic bandwidth allocation algorithms, which require only one to two video frame holding time, are proposed for real-time video delivery. The bandwidth is allocated based on the value of the bandwidth deviation from the currently allocated bandwidth.

The paper is organized as follows: in section 2, a bandwidth allocation algorithm based on frame size difference is introduced. In section 3, an algorithm based on frame size of I frame is introduced to reduce renegotiation frequency. An algorithm that can improve bandwidth utilization while keeping the renegotiation frequency low is introduced in section 4. Conclusions are drawn in section 5. Simulation results are presented in respective sections.

## 2. DYNAMIC BANDWIDTH ALLOCATION FOR REAL TIME MPEG VIDEO TRANSMISSION

As pointed out earlier, if the renegotiation is initiated by the video source (or codec), it is easier to realize a more effective bandwidth allocation algorithm because the immediate frame size is known before transmission.

Suppose the current transmission rate is $R$ bits per second, the size of the frame that will be transmitted is $S$ bits, and the frame refresh rate is $N$ frame per second. The bandwidth allocation can be done in the following way:

- if $|R - N \times S| < \delta$, transmission rate $S$ is kept unchanged,
- $R = S \times N$, otherwise,

where $\delta$ is the threshold.

The value of $\delta$ affects the bandwidth utilization, the size of the buffer needed, renegotiation frequency, and cell loss ratio. In order to increase bandwidth utilization and decrease CLR, the value of $\delta$ should be small. To achieve a small number of renegotiations, the value of $\delta$ should be large enough. To evaluate the effect of $\delta$, an ATM switch with limited buffer size is simulated for different values of $\delta$, as shown in Figure 1.

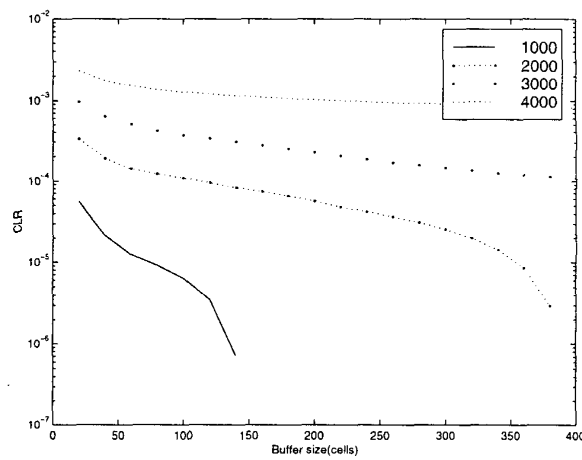


Figure 1: CLR versus buffer size for different values of $\delta$ using dynamic bandwidth allocation.

From the figure, in order to achieve satisfactory CLR, the value of $\delta$ should be small, implying that a large number of renegotiations is needed. When the buffer size is large enough, CLR decreases rapidly, implying that buffering is effective in reducing CLR, which is difficult to achieve by CBR service. The actual bandwidth allocation for $\delta = 1000$ is shown in Figure 2. The renegotiation frequency and bandwidth utilization for different thresholds are illustrated in Table 1

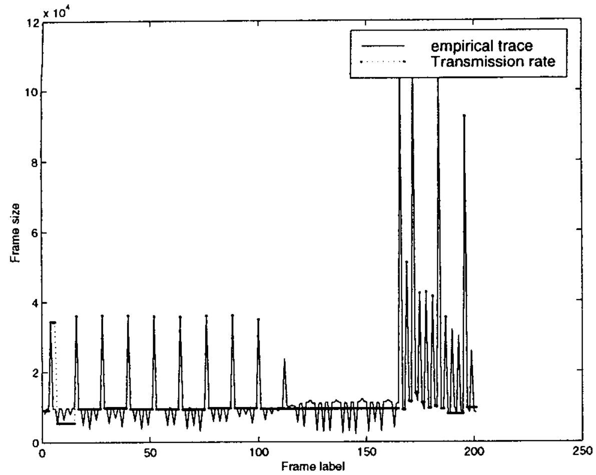


Figure 2: Actually allocated bandwidth.

Table 1: The number of renegotiations and bandwidth utilization.

| $\delta$ | 1000 | 2000 | 3000 | 4000 |
|---|---|---|---|---|
| FREQ. | 71007 | 67229 | 63557 | 60197 |
| Util. | 0.9992 | 0.9988 | 0.9986 | 0.9982 |

## 3. REDUCING THE NUMBER OF RENEGOTIATIONS

Although the bandwidth utilization has been improved by dynamic bandwidth allocation, the renegotiation is still a big burden to network management. To reduce the renegotiation frequency while keeping the bandwidth utilization reasonably high, an algorithm based on I frames is introduced in this section.

Through the analysis of the MPEG video trace we find that I frames often have large frame sizes, and B frames have small frame sizes. Most of the time, when I frame size changes significantly, P and B frame sizes also change significantly, implying that the increase or decrease of I frame size often indicates the increase or decrease of P and B frame sizes, and therefore, we can base on I frames to allocate bandwidth to improve QoS and network utilization.

To allocate bandwidth, the algorithm requires to hold I frames to determine the size of I frames. When I frame size changes significantly, a renegotiation can be triggered to ask for reallocation of bandwidth.

Suppose the I frame of the $kth$ GOP is just ready to be transmitted. Let $I_k$ be the size of the I frame of the $kth$ GOP and $R$ be the transmission rate for the previous GOP, $\delta$ be a threshold, then the dynamic bandwidth allocation algorithm can be stated as follows:

- if $|I_k - R/N| < \delta$, then the transmission rate remains unchanged.
- if $|I_k - R/N| \geq \delta$, then $R = I_k \times N$,

where $N$ is the number of frames needs to be transmitted per second.

The negotiation frequency can be reduced significantly because only I frames need to be checked. Since the size of I frame is the largest in a GOP most of the time, the bandwidth allocated is very close to the largest one needed for the transmission of frames in the GOP, and therefore the CLR can be kept small. The negotiation frequency and bandwidth utilization are tabulated in Table 2 while the CLR for different values of $\delta$ are shown in Figure 3. The results demonstrate that the renegotiation frequency can be reduced significantly.

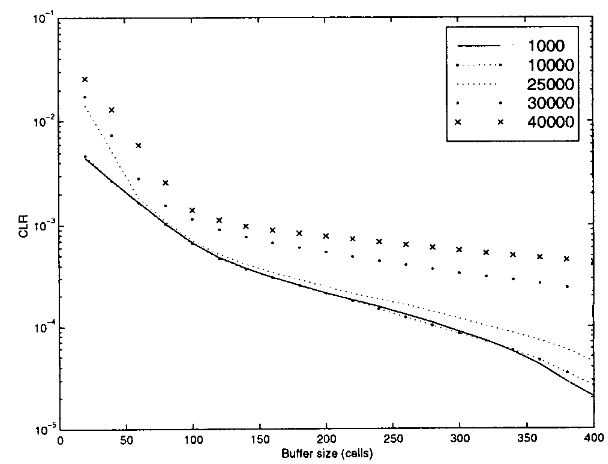


Figure 3: CLR versus buffer size for different value of $\delta$.

The actual bandwidth allocated when $\delta = 3000$ is shown in Figure 4. From the table and figures, the CLR almost remains unchanged even when $\delta$ changes significantly, implying that the number of renegotiations can be reduced significantly without deteriorating the CLR performance.

## 4. INCREASING BANDWIDTH UTILIZATION

As mentioned early, most of the time, I frames have the largest frame size in the respective GOPs, i.e, most of

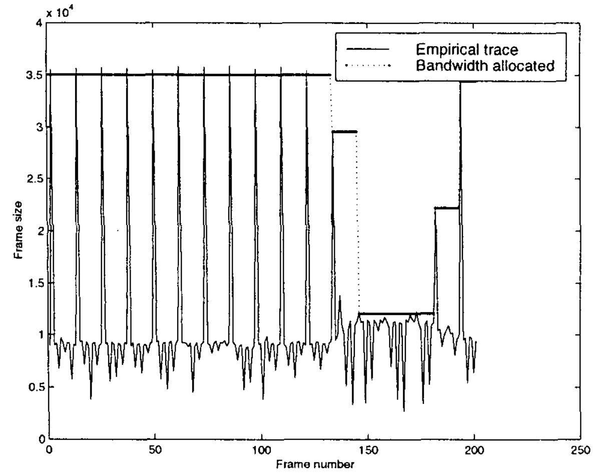


Figure 4: Actually allocated bandwidth when $\delta$=3000.

Table 2: The number of renegotiations and bandwidth utilization.

| $\delta$ | 1000 | 10000 | 150000 | 20000 |
|---|---|---|---|---|
| FREQ. | 9208 | 2479 | 1694 | 1211 |
| Util. | 0.2584 | 0.2583 | 0.2588 | 0.2589 |

the time the bandwidth is not used efficiently. From the analysis of the empirical trace we can see that the difference between B frames for each GOP is not large. We can use this characteristic to increase bandwidth utilization.

Again suppose that $I_k$ is the size of the I frame of the $kth$ GOP, $B_k$ is the size of the B frame immediately following the I frame in the $kth$ GOP, and $R$ is the transmission rate for the previous GOP, and $\delta$ is the threshold. Assuming these two frames are ready for transmission, the dynamic bandwidth allocation algorithm can be altered as follows:

- if $|B_k + \alpha(I_k - B_k) - R/N| < \delta$, the transmission rate remains unchanged.
- otherwise, $R = [B_k + \alpha(I_k - B_k)] \times N$,

where $\delta$ is still the threshold, and $\alpha$ is a parameter which can be used to adjust the trade off between CLR and bandwidth utilization.

In general, the value of $\alpha$ should be less than one in order to have high bandwidth utilization. The value of $\alpha$, however, can be larger than one if very good CLR performance is needed. The CLR performance for different

Table 3: The number of renegotiations and bandwidth utilization.

| $\delta$ | 1000 | 7000 | 11000 | 19000 |
|---|---|---|---|---|
| FREQ. | 8113 | 2482 | 1611 | 763 |
| Util. | 0.3511 | 0.3508 | 0.3503 | 0.3515 |

$\alpha$ and $\delta$ are shown in Figures 5 and 6. The renegotiation frequency and bandwidth utilization for $\alpha = 0.7$ are shown in Table 3. The actual bandwidth allocated for the case $\delta = 9000$ and $\alpha = 0.8$ is shown in Figure 7.

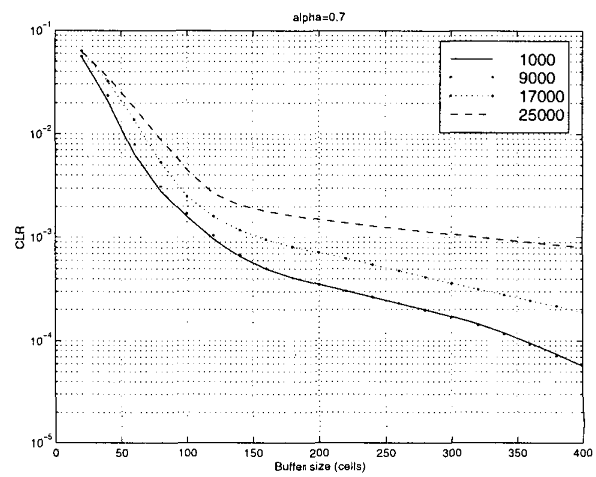


Figure 5: CLR performance versus buffer size and $\delta$, $\alpha = 0.7$.

## 5. CONCLUSIONS

In this paper, three algorithms have been proposed to renegotiate bandwidth on line to increase bandwidth utilization and reduce CLR. It has been shown by simulations that the bandwidth utilization can be improved significantly, and the renegotiation frequency can be reduced to only several hundreds. The algorithms are applicable to deliver real-time video.

## 6. REFERENCES


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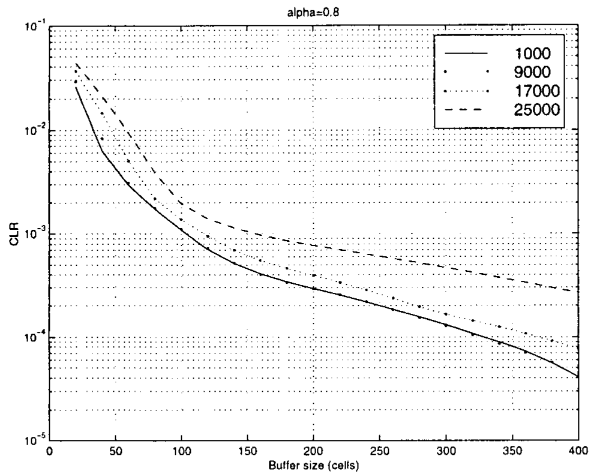


Figure 6: CLR performance versus buffer size and $\delta$, $\alpha = 0.8$.

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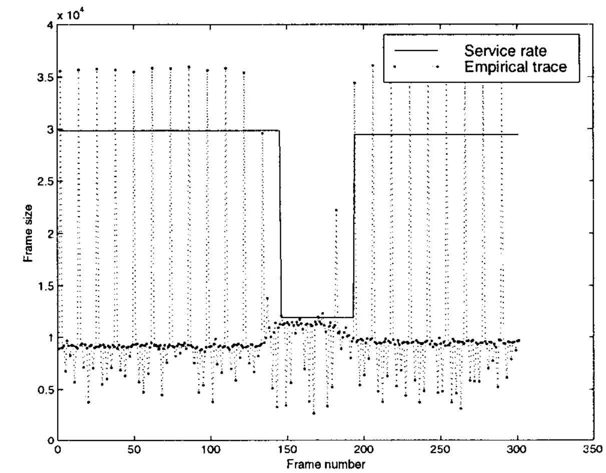


Figure 7: Actually allocated bandwidth when $\delta$=9000 and $\alpha$=0.8.