Dynamic Bandwidth Allocation for VBR Video Traffic Based on Scene Change Identification

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Abstract

To guarantee quality of service (QoS), the requirements of 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, dynamic bandwidth allocation algorithms, in which scene change identification is incorporated, are proposed to improve the bandwidth utilization. The bandwidth allocated for each scene is based on the maximum and mean bandwidth of the scene. When a scene change is identified, a new negotiation process is triggered, and the bandwidth is reallocated.

1. Introduction

The main design objectives of emerging broadband networks is to provisioning high speed transmissions for 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 of the peak-to-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) of 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 Constant Bit Rate) is an alternative for improving network utilization, allowing 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 the cell loss ratio (CLR) or user parameters (UPs), have been proposed [5][2].

In [2], the CLR was calculated up to the current period, and the service rate for the next period was 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, sustain rate, were adjusted for every GOP (group of picture). UPs can be inherently inaccurate because they were calculated from previous GOPs. To reduce the buffer size, the source quantization step was adjusted on line. The drawback of this algorithm is that the user parameters (peak rate, sustain rate, and bursty 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. The number of renegotiation needed is also very large.

All these bandwidth allocation algorithms measure or predict parameters on the line. The source information, or *a priori* information, is not exploited. For video, the source information is available to the network, and it can help to ease network management. Based on the belief that source information should be used to manage network resource, a new algorithm, in which a renegotiation process is initiated only when a scene change occurs, is proposed here. It is applicable to prerecorded video. It is well known that bit rate changes dramatically only when scene change occurs, and thus, renegotiation is necessary only at that time. Intuitively, the renegotiation frequency should be lower compared with those proposed in [1][4]. The CLR is guaranteed to be zero if the maximum bandwidth for every scene can be satisfied.

The paper is organized as follows. Section 2 introduces the method to identify scene changes. Section 3 describes the bandwidth allocation algorithm based on scene change identification. The method to improve bandwidth utilization is proposed in Section 4. Simulation results are also presented for respective proposed algorithms in these sections.

2. Scene Change Identification

A representative portion of an empirical video trace is plotted in Fig. 1. The vertical axis represents the number of bits per frame, and the horizontal axis represents the corresponding frames. It is clear that the data record appears to be composed of stationary segments. The average bit rate of each segment changes abruptly from one segment to another. Visually, these abrupt transitions coincide with scene changes [3].

To detect scene changes in the empirical trace, the algorithm introduced in [3] is adopted. A scene change is declared if the change of the number of bits between successive frames exceeds certain threshold in a sustained manner. Denote X_n as the number of bits in the nth frame, and J_{min} the threshold. Define J_n as:

$$J_n = \begin{cases} 1 & |X_n - X_{n-1}| > J_{min}, \\ 0 & otherwise. \end{cases} \qquad (1)$$

The indicator function for the nth frame is then given by

$$S_n = \begin{cases} 1 & \begin{array}{l} if\ J_n = 1, J_{n-1} \neq 1, \\ J_{n-2} \neq 1, \cdots, J_{n-L_{min}} \neq 1 \end{array} \\ 0 & otherwise, \end{cases} \qquad (2)$$

where L_{min} is the minimum scene length in frames. The frame whose indicator function is one corresponds to a scene change. It was empirically determined [3] that for the *Star Wars* video, $J_{min} = 5000$, and $L_{min} = 2$.

3. Dynamic Bandwidth Allocation Based on Scene Changes

For MPEG coded video movies, the ratio of peak to average rate may vary significantly from segment to segment. If CBR service is used to transmit MPEG video traffic, it is difficult to guarantee QoS while keeping bandwidth utilization high. For instance, network utilization will be low if the bandwidth is allocated to a value equal to the peak rate, while the delay or the CLR will be high if average bit rate is allocated.

It is intuitive that the bit rate does not vary much during a scene, as shown in Fig. 1, and hence, low CLR, small delay, and high network utilization can be expected. Based on this premise, the following dynamic bandwidth allocation algorithm is proposed:

1. Identify the scene change.
2. If scene change occurs, determine the maximum bandwidth needed (which can be found in advance for stored video).
3. Initiate a negotiation process for the maximum bandwidth for this scene.
4. Go to Step 1.

The maximum bandwidth for every scene should be determined and stored beforehand. During the retrieval process, if a scene change is detected, the maximum bandwidth for the new scene can be read and the bandwidth can be allocated for this scene.

Let C be the maximum number of bits that can be transmitted by the channel, and M be the total number of bits transmitted. The bandwidth utilization factor is defined as:

$$\rho = \frac{M}{C}. \tag{3}$$

For the *Star Wars* video, if peak bit rate is used in CBR service, the utilization factor is 0.0842. Using the proposed method, the utilization factor becomes 0.1962 (an improvement by a factor of 2.3). Compared with the methods proposed by Reininger et al.[4] and Adas [1], our method can achieve a reduction of the renegotiation frequency by a factor of 7 with zero CLR and no delay [1].

[1]Since [4] and [1] are based on prediction, zero CLR can hardly be achieved unless very large buffer is used.

4. Improving Bandwidth Utilization

The algorithm introduced above achieves zero CLR at the expense of bandwidth utilization. The bandwidth utilization can be improved with buffer. To improve network utilization, the following procedure is proposed.

1. Identify the scene change.
2. If scene change occurs, determine the mean bandwidth **B** of this scene.
3. Initiate a negotiation process to acquire bandwidth $\beta\mathbf{B}$ for this scene, where $\beta > 1$ is a constant.
4. Go to Step 1.

The average bandwidth for each scene should be determined off-time. For stored video traffic, it is very easy to find the average bit rate of each scene.

Suppose that the movie has N scenes. B_i is the mean frame size of the ith scene, and L_i is the number of frames in the ith scene. Then,

$$M = \sum_{i=1}^{N} L_i B_i \tag{4}$$

$$C = \sum_{i=1}^{N} \beta L_i B_i \tag{5}$$

and

$$\rho = \frac{M}{C} = \frac{\sum_{i=1}^{N} L_i B_i}{\sum_{i=1}^{N} \beta L_i B_i} = \frac{1}{\beta}, \tag{6}$$

where M is the total number of bits of the movie, and C is the maximum number of bits that the source can transmit. It is clear that the bandwidth utilization is the reciprocal of β.

Video trace *Star Wars*[2] was used in our simulations. The data file for the trace consists of 174,136 integers, whose values are frame sizes (bits per frame). The largest frame has 185267 bits, and the smallest one has 476 bits. This is a good representative movie sequence for benchmark comparison, with scenes ranging from low complexity/motion to high and very high actions.

[2]The MPEG-1 coded data were the courtesy of M.W.Garrett of Bellcore and M.Vetterli of UC Berkeley.

In Fig. 2, the relationship between CLR and buffer size is illustrated for different values of β. The value of β varies from 2 to 9, from top to bottom, with a step size of 0.5. When β is larger than 9, the CLR becomes zero for any buffer size. The curve at the top corresponds to $\beta = 2$. Compared with CBR service, CLR can be reduced by an order of 2-3 using our proposed techniques with a fixed buffer size and bandwidth utilization. Likewise, with fixed CLR and bandwidth utilization, the buffer size can be reduced by a factor of 2-4.

5. Conclusions

Several dynamic bandwidth allocation algorithms have been proposed for pre-recorded video. Simulations demonstrate that bandwidth utilization can be improved by a factor of 2 to 5, the buffer size can be reduced by a factor of 2 to 4, and the CLR can be reduced by an order of 2 to 3. Zero CLR with no delay can be achieved while the network utilization can be improved by a factor of 2.3. The proposed algorithms can be efficiently used for video delivering.

References

[1] A. M. Adas, "Using Adaptive Linear Prediction to Support Real-Time VBR Video Under RCBR Network Service Model," *IEEE/ACM Transactions on Networking*, vol. 6, pp. 635–644, 1998.

[2] E. W. Fulp and Douglas S. Reeves, "Dynamic Bandwidth Allocation for VBR Sources," in *On-Line Proc. IEEE RTSS Workshop on Resource Allocation Problems in Multimedia Systems*, Washington, DC, Dec. 3 1996, http://www.cs.unc.edu/~jeffay/mmwrkshp96.html.

[3] B. Melamed and D. E. Pendarakis, "Modeling Full Length VBR Video Using Markov Renewal Modulated TES Models," *IEEE/ACM Transactions on Networking*, vol. 5, pp. 600–612, February 1998.

[4] D. Reininger, M. Ott, G. Michelitsch, and G. Welling, " Dynamic Bandwidth Allocation for Distributed Multimedia with Adaptive QoS," in *On-Line Proc. IEEE RTSS Workshop on Resource Allocation Problems in Multimedia Systems*, Washington, DC, Dec. 3 1996, http://138.15.10.21/paper/96-N-011 or http://www.cs.unc.edu/~jeffay/mmwrkshp96.html.

[5] K. Shiomoto, S. Chaki, and N. Yamanka, "A Simple Bandwidth Management Strategy Based on Measurements of Instantaneous Virtual Path Utilization in ATM Networks," *IEEE/ACM Transactions on Networking*, pp.625–634, 1998.

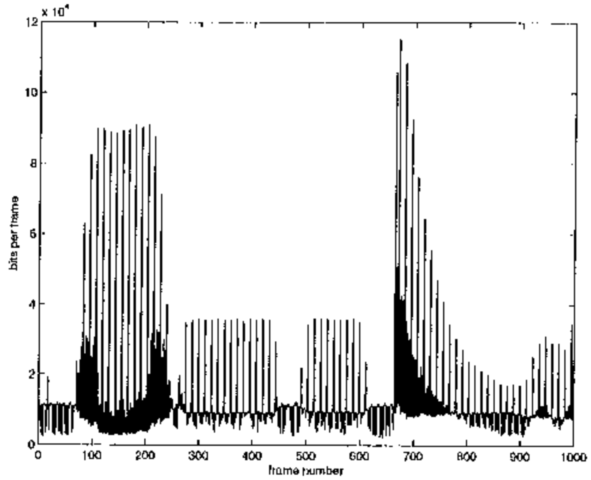

Figure 1. Video traffic of *Star Wars*

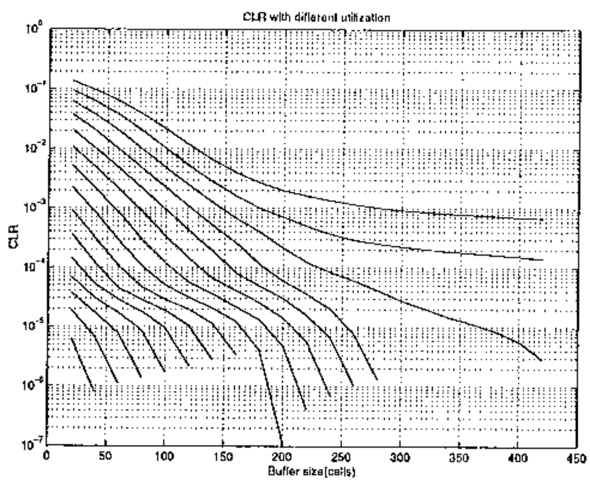

Figure 2. CLR versus buffer size under different network utilization factors; β varies from 2 to 9 from top to bottom with a step size of 0.5.