Content-based Dynamic Resource Allocation for VBR Video in Bandwidth Limited Networks

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Abstract

In bandwidth limited access networks, dynamic resource allocation can increase the link utilization and decrease the required network buffering. In this paper, we propose a new policy in which the *visual content* of video is used to determine the bandwidth needed for its transmission. The policy is based on a novel framework of content-based video traffic modeling, introduced in [5]. Based on simulation results, the proposed content-based dynamic resource allocation scheme has shown that reduction of 55% to 70% in network resources, as compared to existing approaches (e.g. RVBR and RCBR), could be reached.

1 Introduction

Emerging video applications have increased the demand for reliable heterogeneous communications, which are able to guarantee a full range of the quality of service (QoS) requirements. Due to the constant picture quality of variable bit-rate (VBR) video, it is expected that it will be an important traffic class in future packet networks. The architecture to support QoS should be flexible enough to deal with the complicated VBR traffic characteristics (e.g., high bandwidth and burstiness, multiple-time scale property, long-range dependency, etc.) and communication media characteristics (e.g., bandwidth limitations, constant/variable link capacity, etc.).

The focus of this work is on the QoS support for multiple time-scale sources (e.g., VBR video) in bandwidth limited networks. To satisfy QoS, the long-range dependent sources must reserve a transmission rate near their peak rate for the entire session duration [1]. Given the high burstiness of VBR sources, a peak rate bandwidth reservation scheme would lead to very low network utilization. To increase the network utilization, applications may decide to soften the QoS requirements or to allow dynamic bandwidth reservation. This approach is taken in *dynamic resource allocation* (DRA), in which bandwidth is reserved for relatively short time intervals only (i.e., at burst time-scale), and the amount of reserved bandwidth depends on the source's activity during that time interval. While providing an important functionality of congestion control in terms of individual stream protection, the DRA is a scheme for statistical multiplexing at the burst layer [2]. Small probabilities of source blocking are allowed, when resources are temporarily not available (e.g., shared resources are used by other competing sources).

While the advantage of DRA technique is well known, its efficiency depends on selection of renegotiation strategies (e.g., determining instants at which resource renegotiation should take place) and the estimation and prediction of the bandwidth for the corresponding reservation interval. For example, many real-time DRA schemes utilize traffic prediction models that are based solely on a single prediction indicator (bit-rate). For that reason, their effectiveness is limited [3, 4].

The main contribution of this work is to define an approach to solve the problem of limited efficiency of real-time DRA scheme. We propose the use of a *Content-based Video Resource* (CVR) model [5] in order to determine the renegotiation intervals and corresponding resource requirements. The principal idea behind this approach is motivated by the correlation between the visual content and bandwidth requirements of video stream. The CVR model reflects the process of generation of VBR video streams, giving an intuitive insight into the video traffic characteristics by capturing causes (e.g. visual content) of its non-stationary behavior.

The rest of the paper is organized as follows. Section 2 is devoted to the theoretical basis and the structure of the CVR model. In Section 3 the system model of content-based DRA and the function of its components is described. In the last section, the results of trace-driven simulations are analyzed and the advantages of the content-based DRA are shown.

2 CVR model

Inefficient DRA techniques may cause high frequency of the renegotiation requests and result in processing bottleneck. To circumvent this bottleneck, it is preferable to generate renegotiations at relatively long time intervals (in order of seconds). In other words, it is sufficient to capture the video bit-rate at slow time scale that usually corresponds to scenes. Note that scenes are typically the source of the non-stationarity that was found in the VBR traces while the character of the bit stream at individual scene is quasi-stationary and can be approximately modeled by stationary stochastic process [7].

The *Content-based Video Resource* (CVR) model, which is depicted in Figure 1, represents the VBR video at inter- and intra-scene layers. The inter-scene layer models the visual content and captures the video stream non-stationarity while the intra-scene layer captures the stationary behavior within the scene. The visual content is a result of the complete video production process (i.e., shot composition, scene editing, object motion, etc.). The particular characteristics of the bit stream within the scene are due to the video compression mechanism. The inter- and intra-scene layer partition is called as the "separation principle" [5]. It is reflected by the CVR model's two independent parts: *Video Structure* (VS)

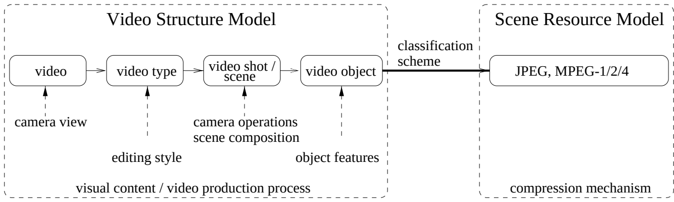

Figure 1: Content-based Video Resource model.

model and *Scene Resource* (SR) models.

The VS model is independent of compression scheme. It assumes that a video can be partitioned into a sequence of non-overlapping segments, which are called scenes. The boundaries between the segments are determined by the changes in the visual content of the video. The scene visual content is expressed in terms of quantized visual features. For example, the visual features may include the number of major video objects, the type of camera motion, and the attributes of each video object (e.g., size, motion speed and visual complexity). The video content information can be extracted from the compressed video stream in real time [6] or supplied directly by a digital video camera and associated scripts.

The SR model is sensitive to compression scheme. It characterizes video scene in terms of bandwidth requirements. For the purpose of dynamic resource allocation, a relatively simple stationary traffic model can describe the video stream at the scene level*. Because of its ability to characterize the source burstiness at different time scales, a Deterministic Bounding Interval Dependent (D-BIND) model [4] was chosen at intra-scene layer.

The essential component of the CVR model is a novel *object-based scene classification scheme* that simplifies the complex relationship between the visual content and resource requirements, which is generally complicated to be expressed in closed form. The classification scheme is based on the idea that scenes with "similar" visual content require "similar" resources. Therefore, scenes with "similar" content can be classified into same basic scene class. In other words, the classification scheme represents the connection between the VS and SR models. The classification scheme of MPEG-2 VBR video stream can be found in [5].

3 Content-based DRA system

Figure 2 depicts a real-time content-based DRA system that controls the multiplexer at the Network Interface Card (NIC). Its main component is a single *Network Resource Manager* (NRM). Its function is a buffer/link QoS control that includes both the Call Admission Control (CAC) and the Dynamic Resource Control (DRC). Each stream has its own *Source Rate Control* (SRC) agent that regulates transmission of the VBR video stream.

Figure 3 depicts the content-based SRC that is based on CVR model. The input to the SRC is a VBR traffic stream, which is generated by an encoder in real time or retrieved from a video storage system. First, the stream is analyzed by the

*With the accuracy adequate to video content extraction.

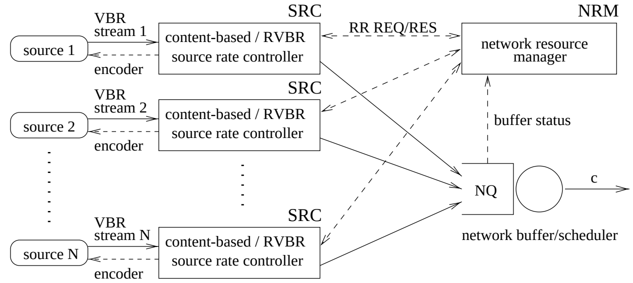

Figure 2: Content-based / RVBR DRA system.

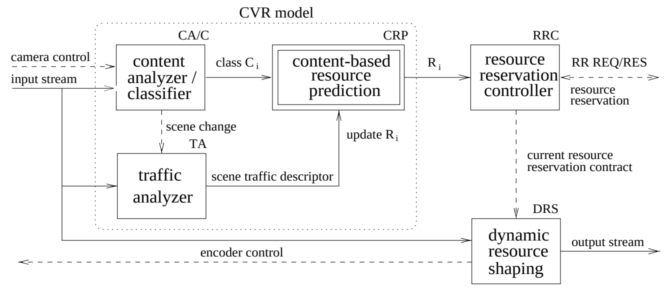

Figure 3: Content-based source rate controller.

content analyzer/classifier, which segments the video stream into individual scenes. Given the scene classification scheme, each scene is assigned into one of the basic scene classes. For each individual scene, the *traffic analyzer* measures the scene traffic descriptor that is used to predict bandwidth requirements of future scenes with "similar" visual content. The *content-based resource prediction* is an important part of the content-based SRC as it predicts the resource requirements for a scene directly from its class. At the beginning of new scene, the predicted resource requirements are used by the *resource reservation controller* in its decision whether to increase or decrease the resources. The *dynamic resource shaping* polices and dynamically transcodes the video stream to enforce its conformance to the current network resource contract.

4 Simulation results

The performance study of various DRA schemes was based on trace-driven simulations. The results were obtained using single 54000-frame-long trace (30 minutes) of the MPEG-2 encoded movie Forrest Gump [8]. Although only one trace was used, it consisted of over 300 different scenes. Figure 2 depicts a model of entry node multiplexer, with service rate of $c = 45$ Mbps and FCFS scheduling policy. The experiments were conducted using the renegotiation blocking probability of 10^{-2}.

Using the link utilization curves, the following DRA schemes were compared: content-based CB-rt and CB-nrt; frame-based; RVBR-rt and RVBR-nrt [4]; and RCBR-rt [3]. Note that suffixes "-nrt" and "-rt" indicate non real-time and real-time schemes respectively. The link utilization is defined as the ratio of the number of streams that are admitted under the given DRA policy to the maximum number of streams

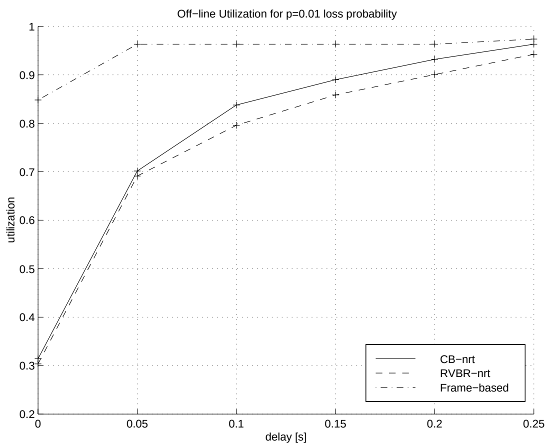

Figure 4: Effectiveness of off-line DRA schemes.

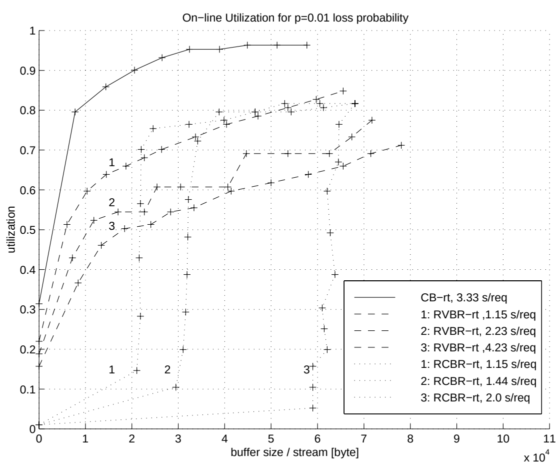

Figure 5: Effectiveness of on-line DRA schemes.

that are admitted under the mean rate admission policy.

Figure 4 depicts the link utilization corresponding to three off-line video DRA schemes. Note that the effect of network buffering was present in all DRA schemes. The network buffering is able to smooth the source bit-rate, resulting in an increase of network utilization.

As expected, the utilization of the frame-based scheme was superior and established an upper bound on the network utilization. The high link utilization of the frame-based scheme is due to its ability to extract statistical multiplexing gain of both short and long time-scale variations of the VBR video source. Unfortunately, the frame-based scheme is not practical because it creates the bottleneck in the NRM due to a high frequency of renegotiation. The utilization of both CB-nrt and RVBR-nrt schemes were asymptotically approaching the utilization of the frame-based scheme. However, at large delays the CB-nrt scheme has shown only 5% improvement compared to the RVBR-nrt scheme. Given simulation conditions, this leads to the conclusion that both schemes have “similar” performance characteristics.

Figure 5 depicts link utilization of RVBR-rt and RCBR-rt schemes for three different renegotiation frequencies and compares them to the CB-rt scheme (mean renegotiation frequency of 3.3 s). Note that contrary to other schemes, the RCBR-rt scheme does not use the shared network buffer as the streams are separately buffered before entering the network multiplexer [3].

It was found that the best real-time performance was achieved with CB-rt scheme, which has shown a sharp increase in utilization from 31% (no buffering) to 95% at the buffer of 20 Kbytes/stream. The superior performance of CB-rt scheme can be explained by improved resource prediction accomplished by detecting the natural discontinuities in the source bit-rate based on the visual content. As expected, in the range from static to frame-based dynamic resource allocation, the performance of both RVBR-rt and RCBR-rt schemes depend heavily on renegotiation frequency. Furthermore, their utilization were lower than CB-rt, even when their renegotiation frequencies were higher. For example, RVBR-rt scheme has shown utilization of 67% (buffer of 20 Kbytes/stream) even for a very high renegotiation rate (1.2 s/request). The RCBR-rt scheme has shown very low utilization at small buffer sizes per stream, but its utilization increased sharply at large buffer sizes. This effect and low performance of RCBR-rt scheme can be explained by its separate buffering.

5 Conclusion

While the simulation results show the advantage of using a visual content of the video in DRA, more research needs to be conducted to show its advantage in general. However, we believe that given content-based nature of the model, the similar results can be expected for other types of VBR video, including those streams, encoded using other compression mechanisms.

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