Simple VBR Harmonic Broadcasting (SVHB)

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Abstract

One way to broadcast a popular video is to partition the video into segments, which are broadcasted on several streams periodically. The approach lets multiple users share streams; thus, the stress on the scarce bandwidth can be alleviated without sacrificing viewers' waiting time. One representative approach is the Harmonic Broadcasting (HB) scheme, which can broadcast a video using multiple streams by having new viewers wait no longer than $\theta(\frac{L}{N})$ time, where L is the length of a video, and N is the number of segments. In comparison with other segmented schemes, the HB scheme requires minimum bandwidth. However, the scheme mainly supports transmission of CBR-encoded videos. In this paper, we propose a simple VBR harmonic broadcasting (SVHB) scheme for VBR-encoded videos. Unlike the HB scheme, the SVHB scheme guarantees continuous playout. Additionally, the scheme improves the variable bandwidth harmonic broadcasting (VBHB) scheme in bandwidth consumption, maximum buffer requirements, and maximum required disk transfer rate. Some bounds on the bandwidth consumption, the buffer requirements, and the required disk transfer rate are also developed.

Keywords: Hot-video broadcasting, video-on-demand (VOD), variable-bit-rate (VBR)

1 Introduction

With the advancement of broadband networking technology and the growth of processor speed and disk capacity, video-on-demand (VOD) services have become possible [9][11]. A VOD system is typically implemented by a client-server architecture, and may easily run out of bandwidth because the growth in bandwidth can never keep up with the growth in the number of clients. This results in tremendous demand for computing power and communication bandwidth on the system.

To alleviate the stress on the bandwidth and I/O demands, many alternatives have been proposed by sacrificing some VCR functions, or known as near-VOD services. One way is to broadcast popular videos. According to [2], 80% of demands are on a few (10 or 20) very popular videos. Because the server's broadcasting activity is independent of the arrivals of requests, the approach is appropriate to popular or hot videos that may interest many viewers at a certain period of time. One way to broadcast a popular video is to partition the video into segments, which are broadcasted on several streams periodically. The schemes [1][3][4][5][6][7][8][13][16][17][19] share a similar arrangement. A video server divides a video into segments that are simultaneously broadcasted on different data streams. One of these streams transmits the first segment in real time. The other streams transmit the remaining segments according to a schedule predefined by the scheme. When clients want to watch a video, they wait first for the beginning of the first segment on the first stream. Thus, their maximum user waiting time equals the length of the first segment. While the clients start watching the video, their set-top boxes (STB) or computers start downloading enough data from the other streams so they will be able to play the segments of the video in turn.

The simplest broadcasting scheme is the staggered broadcasting [1]. The server allocates K streams to transmit a video. Its maximum viewers' waiting time is L/K, where L is the video length. The pyramid broadcasting [18] partitions a video into increasing size of segments and transmits them on multiple streams of the same bandwidth. It requires less bandwidth than the staggered broadcasting under the same maximum waiting time. The fast broadcasting (FB) [3] divides a video into a geometrical series of 1, 2, 4, …, 2^{K-1}. Its maximum waiting time is $\frac{L}{2^K-1}$. In comparison with the staggered broadcasting and the pyramid broadcasting, the FB scheme obtains shorter waiting time.

The new pagoda broadcasting (NPB) scheme [13] is a hybrid of the pyramid broadcasting and the fast broadcasting. It partitions a video into fixed-size segments and maps them into data streams of equal bandwidth at the proper decreasing frequencies. Accordingly, the NPB scheme obtains shorter waiting time than the FB scheme. The recursive frequency splitting (RFS) scheme [16] further improves the NPB scheme in waiting time by using a more complex segment-to-stream mapping. The harmonic broadcasting (HB) scheme [5] first divides a video into several segments equally, and further divides the segments into sub-segments according to the harmonic series. Yang, Juhn, and Tseng [20] proved that the HB scheme requires the minimum bandwidth under the same waiting time. An implementation of the FB scheme on IP networks was reported in [21].

The above schemes assume that videos are encoded in constant-bit-rate (CBR). Accordingly, they cannot support variable-bit-rate (VBR) videos well. Some schemes were proposed to address this problem. The periodic broadcasting with VBR-encoded video (VBR-B) [15] integrates the pyramid broadcasting scheme with the techniques of the GoP smoothing, server buffering, and client prefetchig to transmit VBR videos. Based on the VBR-B, the trace adaptive fragmentation (TAF) scheme [10] takes the trace of each video into account to predict the bandwidth requirements, and then uses complex techniques to smooth the bandwidth consumption. The variable bandwidth harmonic broadcasting (VBHB) [14] first divides a VBR video into fixed size segments. The first and second segments are broadcasted at the transmission rate guaranteeing on time delivery of all frames. All other segments are divided into equal-size sub-segments, which are distributed in the way of the cautious harmonic broadcasting (CHB) scheme [12].

In this paper, we propose a simple VBR harmonic broadcasting (SVHB) scheme for VBR-encoded videos. It is systematic and simple in concept. A VBR video is divided into multiple equal-length segments by time. Each segment is further equally divided into sub-segments by size. The scheme then broadcasts sub-segments at constant bit rate in the way of the HB scheme; thus, the total required bandwidth is constant. The SVHB scheme is the same as the VBHB scheme in segment partition and the maximum viewers' waiting time under the same video length and number of segments.

The SVHB scheme mainly differs from the VBHB scheme in two areas. First, the SVHB scheme and the VBHB scheme are based on the HB scheme and the CHB scheme, respectively. Second, the schemes employ different approaches to ensure continuous playout. The SVHB scheme requires clients to receive a segment completely before playing it. That is clients cannot receive and play a segment concurrently. In contrast, the VBHB scheme allows clients to receive and play a segment synchronously. The scheme derives the maximum bandwidth requirements for the first segment and leaves the second segment undivided such that video data can be played continuously. Finally, the SVHB scheme improves the VBHB scheme in bandwidth consumption, maximum buffer requirements, and maximum required disk transfer rate at the cost of longer average viewers' waiting time.

The rest of this paper is organized as follows. In Section 2, we present the SVHB scheme for VBR videos. Some analysis and simulation results are presented in Section 3. We make brief conclusions in Section 4.

2 Harmonic Broadcasting Scheme for VBR Videos

2.1 Harmonic Broadcasting Scheme

To help understand the new scheme, we first review the HB scheme in the literature. Suppose we equally divide a video into N segments. The segments are denoted by S_1, S_2,..., S_N in sequence. Segment S_i is further divided into i sub-segments equally, denoted by $S_{i,1}$, $S_{i,2}$,..., $S_{i,i}$. We then allocate N streams, denoted by $C_1,\ldots,C_N$, to broadcast the video segments. C_i is responsible for distributing all the sub-segments of S_i sequentially and periodically. Suppose the bandwidth required for C_1 is equal to the data consumption rate b of the video. Because S_i is divided into i equal-size sub-segments, the

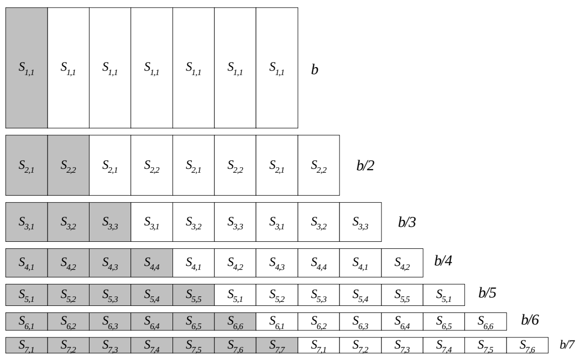


Figure 1: An example for the stream allocation for the harmonic broadcasting scheme.

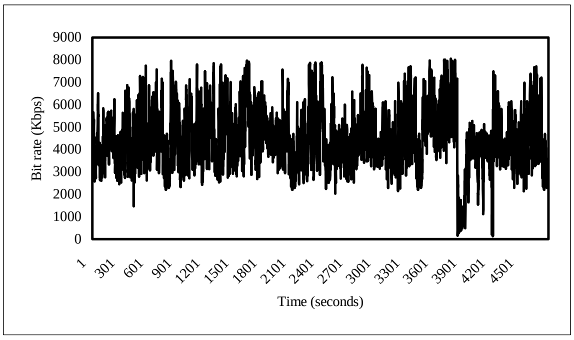


Figure 2: The data consumption rate of the video, Jurassic Park III.

bandwidth required for C_i is $\left(\frac{1}{i}\right)\times b$. Therefore, the total required bandwidth is the summation of the first N terms of harmonic series, equal to $\sum_{i=1}^{n}\left(\left(\frac{1}{i}\right)\times b\right)$. Figure 1 illustrates the stream allocation for a video with seven segments by the HB scheme.

2.2 Simple VBR Harmonic Broadcasting

Figure 2 shows the data consumption rate of a MPEG-2 video, Jurassic Park III. The variance of the rate is very large, and so is its required bandwidth. If we directly partition a VBR video into multiple segments, and then distribute the segments using the HB scheme. Video servers may easily stop their video services because the disk transfer rate and bandwidth requirements exceed their capabilities. In addition, clients probably cannot receive the video data in time when the networks cannot satisfy the peak bandwidth requirements.

To eliminate the variance of bandwidth requirements for VBR videos, we propose the simple VBR harmonic broadcasting (SVHB) scheme. The SVHB scheme and the HB scheme differ in two areas.

- Asynchronous download and playout for a segment. The data consumption rate of a VBR video varies with time so the rate is probably larger than its data transfer rate. In the HB scheme, a client receives and plays a segment concurrently; thus, the video playout may be blocked when the consumption rate is larger than the transfer rate. To ensure the continuous playout, the SVHB scheme requires a client to buffer a segment completely before playing it. That is the client cannot receive and play a video segment concurrently. This restriction causes the SVHB scheme having larger average waiting time than the HB scheme; however, the two schemes have the same maximum waiting time.
- Hybrid division by length and size. The SVHB scheme divides a VBR video into segments by length, and then further divides the segments into sub-segments by size. The scheme transmits each sub-segment at constant bit rate on each stream. Thus, the variance of required bandwidth is zero.

On the server side, the SVHB scheme involves the following steps.

1. A video is equally divided into N segments by length. Suppose S_i is the i*th* segment of the video, and its size is s_i. The concatenation of all the segments constitutes the whole video, $S = S_1 \bullet S_2 \bullet \ldots \bullet S_N$. S_i is then divided into i equal-size sub-segments. Suppose $S_{i,j}$ is the j*th* sub-segment of S_i. The concatenation of all the sub-segments constitutes the whole segment, $S_i = S_{i,1} \bullet S_{i,2} \bullet \ldots \bullet S_{i,i}$. The size of $S_{i,j}$ is $\frac{s_i}{i}$.
2. The video server broadcasts the sub-segments of S_i on stream i sequentially and periodically at constant bit rate. Figure 3 illustrates the distribution of a video, which is divided into eight equal-length-but-unequal-size segments. In the figure, the rectangles represent the segments of the video, and the area reflects the size of a segment.

At the client end, suppose there is plenty of disk space to buffer portions of the playing video. For watching a video, the following steps are involved:

1. Download all of the sub-segments concurrently during each time slot.
2. To ensure a segment was buffered completely before its use, we delay the

playout a period of time. If the client begins to download the video segments at t_0, the video can be played in the order of $S_1 \bullet S_2 \bullet \ldots \bullet S_N$ at $t_0 + \frac{L}{N}$.

3. Stop loading data from networks when we have received all of the segments.

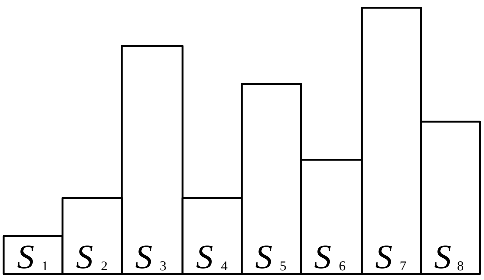
3 Analysis and Comparison

3.1 Viewers' Waiting Time

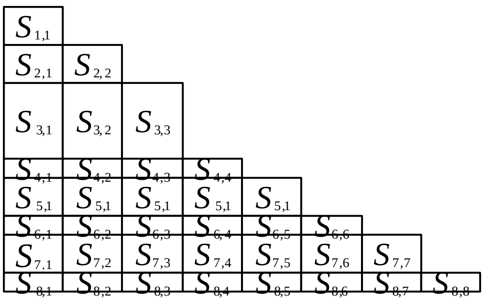
Suppose the client has enough disk space to buffer portions of the playing video on disk. The viewer's waiting time comes from the access time of video segments on networks. To ensure continuous playout, the access time of a segment cannot be larger than its length. Thus, the viewers' waiting time δ is equal to the length of a segment.

$$\delta = \frac{L}{N} \qquad (1)$$

Thus, the SVHB scheme has longer average waiting time than the VBHB scheme. However, their maximum waiting time is the same.



(a) The video segments



(b) The segment arrangement by the SVHB scheme

Figure 3: An example for video distribution by the SVHB scheme.

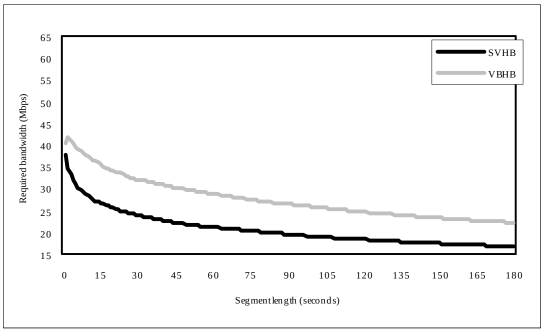


Figure 4: The required bandwidth versus segment length in the movie, Jurassic Park III.

Because the video server broadcasts the sub-segments of S_i on stream i sequentially and periodically, the required bandwidth B_i on stream i is equal to $\frac{S_i}{\delta i}$. The total required bandwidth is $\sum_{i=1}^{N} B_i = \frac{1}{\delta} \sum_{i=1}^{N} \frac{S_i}{i}$.

Given a bandwidth allocation B, the access time δ_B equals the transferred data size over the bandwidth; thus, $\delta_B = \frac{1}{B} \sum_{i=1}^{N} \frac{S_i}{i}$.

Figure 4 depicts the bandwidth requirements for the movie, Jurassic Park III, using the SVHB scheme and the VBHB scheme. The video is encoded by MPEG-2. Its length and size is 4800 seconds and 2.66 Gbytes. With the increasing of segment length, the number of segments decreases so the number of the required streams (or the required bandwidth) becomes small. The figure also indicates that the required bandwidth for the SVHB scheme is smaller than that for the VBHB scheme. It reflects the segment partition by the HB scheme is more efficient than that by the CHB scheme.

3.2 Buffer Requirements

The client needs to buffer portions of the playing video on disk because the arrival rate of the video data is larger than the consumption rate. In addition, the client merely buffers same video data once. Suppose the time that a client begins to receive video data is t_0. During $t_0 + (i-1)\delta$ to $t_0 + i\delta$, the sub-segments that come from

$C_i, C_{i+1}, \cdots, C_N$ need to be buffered. Let

$$I_i = \sum_{j=i}^{N} \frac{s_j}{j}, \text{ where } 1 \le i \le N. \quad (2)$$

represent the size of the increasing data that are written into the buffer by the client during this time interval. During the same interval, the client consumes previous received segments because the client cannot download and play a segment concurrently. Let

$$O_1 = 0, \text{ and}$$

$$O_i = s_{i-1}, \text{ where } 2 \le i \le N+1 \quad (3)$$

represent the output size of the data that are read out from the buffer by the client during $t_0 + (i-1)\delta$ to $t_0 + i\delta$. Let Z_i represent the size of the required buffer during $t_0 + (i-1)\delta$ to $t_0 + i\delta$. At $t_0 + \delta$, all the data that come from $C_1, C_2, \cdots, C_N$ need to be buffered. Hence, we obtain

$$Z_1 = I_1, \text{ and}$$

$$Z_i = Z_{i-1} + I_i - O_i, \text{ where } 2 \le i \le N. \quad (4)$$

During $t_0 + N\delta$ to $t_0 + (N+1)\delta$, the client stops downloading the data, and begins consuming the last segment. There is no write requirement, and all the buffered data will be consumed during this interval. Hence, we obtain $I_{N+1} = 0$ and $Z_{N+1} = 0$.

According to equations (2), (3), and (4), we can calculate $\{Z_1, Z_2, \cdots, Z_N\}$ for a fixed N. From equation (1), we can obtain $N = \frac{L}{\delta}$; thus we can derive the relationship between the max $\{Z_i \mid i = 1, \cdots, \frac{L}{\delta}\}$ and the segment length δ. Figure 5 depicts the curve for the movie, Jurassic Park III. The figure indicates the SVHB scheme requires less buffer than the VBHB scheme.

3.3 Disk Transfer Rate

According to the storage requirements, the disk transfer rate requirements can be broken into write requirements and read requirements. From equation (2), the write requirements during $t_0 + (i-1)\delta$ to $t_0 + i\delta$ are

$$W_i = \frac{1}{\delta} \sum_{j=i}^{N} \frac{s_j}{j}, \text{ where } 1 \le i \le N, \text{ and}$$

$$W_{N+1} = 0. \quad (5)$$

The read transfer rate is equal to the data consumption rate. Because the video is VBR-encoded, the rate varies with time. For simplicity, we merely consider the maximum consumption rate of each segment. Let b_{S_i} represent the rate of S_i. During t_0 to $t_0 + \delta$, the read transfer rate is zero because the client cannot download and play the first segment concurrently. Let

$$R_1 = 0, \text{ and}$$

$$R_i = b_{S_{i-1}}, \text{ where } 2 \le i \le N+1 \quad (6)$$

represent the maximum read transfer requirements during $t_0 + (i-1)\delta$ to $t_0 + i\delta$. Thus, the maximum disk transfer rate requirements are

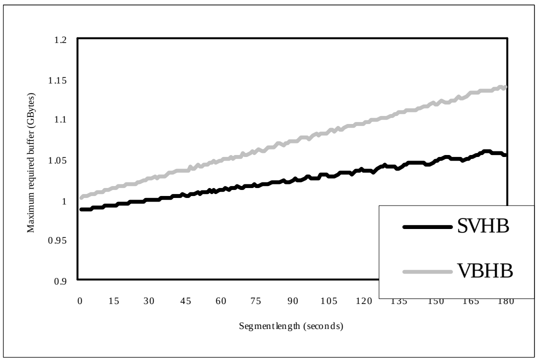


Figure 5: The maximum buffer requirements versus segment length in the movie, Jurassic Park III.

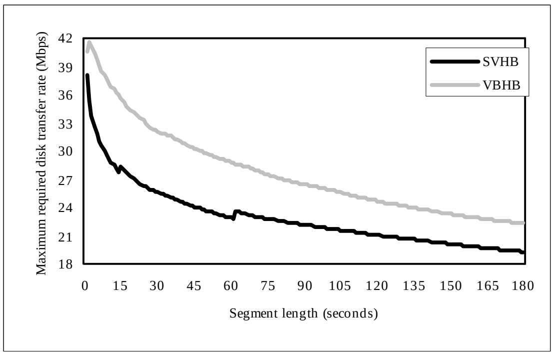


Figure 6: The maximum disk transfer rate versus segment length in the movie, Jurassic Park III.

$\Phi_i = W_i + R_i$, where $1 \le i \le N+1$. Figure 6 depicts the requirements for the movie, Jurassic Park III. The figure shows the SVHB scheme requires smaller disk transfer rate than the VBHB scheme.

4 Conclusions

The video broadcasting service is already popular on Internet. In this paper, we propose a HB-based broadcasting scheme for VBR video services. Unlike the HB scheme, the simple VBR harmonic broadcasting (SVHB) scheme ensures continuous playout. We further analyze the scheme by the viewers' waiting time, buffer requirements, and required disk transfer rate. Finally, we use a VBR video to evaluate the SVHB scheme and the VBHB scheme. The results indicate that the SVHB scheme outperforms the VBHB scheme on bandwidth consumption, maximum buffer requirements, and maximum required disk transfer rate. Future research could be directed toward finding new approaches to broadcasting live VBR videos.

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