Increasing multimedia system throughput with consumption-based buffer management

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Abstract. In a multimedia server, multiple media streams are generally serviced in a cyclic fashion. Due to non-uniform playback rates and asynchronous arrivals of queries, there tends to be spare disk bandwidth in each service cycle. In this paper, we study the issue of dynamically using spare disk bandwidth and buffer to maximize the system throughput of a multimedia server. We introduce the concept of minimizing buffer consumption as the criterion to select an appropriate media stream to utilize the spare system resources. Buffer consumption measures not only the amount of buffer but also the amount of time such buffer space is occupied (i.e., the space-time product). Different alternatives to utilizing spare disk bandwidth are examined, including different rate-adjustable retrievals of an already activated stream and prefetching the next waiting stream. For rate-adjustable retrievals, we study buffer consumption-based and remaining-time-based criteria for selecting an active stream to increase retrievals. Simulations are conducted to evaluate and compare different cases. The results show that (1) minimizing buffer consumption is the right criterion for maximizing the system throughput with spare disk bandwidth; (2) in general, prefetching a waiting stream incurs more buffer consumption, and thus is less effective than rate-adjustable retrieval of active streams in maximizing the system throughput; and (3) the advantage of rate-adjustable retrieval over prefetching is especially significant when service cycle time is small.

Key words: Multimedia retrieval – Buffer management – I/O – News on demand – Rate-adjustable retrieval

1 Introduction

Fast advances in computing technologies have make it possible and cost-effective to distribute in digital forms all kinds of multimedia information, such as video, audio, image, and text. For example, one can use a Web browser to easily access a vast amount of multimedia information around the globe through the ubiquitous World-Wide Web on the Internet. Many projects are currently being established to explore the potential of electronic commerce on the Internet, such as news on demand, electronic catalogs, electronic shopping, and video on demand. For an information/database provider in this environment, it is important to provide effective multimedia supports. In this paper, we study the issue of maximizing the system throughput of a multimedia server.

To provide multimedia data, especially video and audio, a server needs to deal with several difficult issues. Firstly, video and audio data are delay-sensitive. Namely, once the playback of a stream begins, the server must guarantee that enough resources are allocated so that it is played back continuously and it meets the real-time requirement. Secondly, video and audio data (even in a compressed form) requires large amounts of system resources, primarily storage and bandwidth both in disk retrieval and in network transmission. Thirdly, a multimedia object may contain multiple components with very different playback rates, such as video, audio and text. The server must ensure that these multiple components be synchronized during playback.

It is observed that to achieve good system performance, multiple multimedia streams should be serviced simultaneously in a cyclic fashion [2, 3, 5, 6, 8]. During each service cycle, data from each stream are retrieved from disk into the buffer for continuous playback. An admission control algorithm is used to ensure that, once a stream is admitted, there be enough data in the buffer for the continuous playbacks of all active streams. Due to non-uniform playback rates and stream lengths and asynchronous arrivals of queries, there tends to be some spare disk bandwidth and buffer space left unused in each service cycle. Such spare disk bandwidth can be used to increase media retrievals, making it possible to finish the retrievals of an active stream sooner. This early completion of retrievals for a stream makes disk bandwidth available to admit a new request, reducing the average wait time and improving the system throughput. This is especially useful for news-on-demand multimedia applications, where the lengths of queries are usually not very long (e.g., less than 5 minutes) and the arrival pattern tends to be bursty.

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In this paper, we study the problem of dynamically using spare disk bandwidth and buffer to maximize the system throughput of a multimedia server, given a fixed disk bandwidth and buffer. The critical issue here is what criterion should be used to select a candidate stream for which the additional disk bandwidth should be used. We examine different alternatives to the use of such spare system resources, including rate-adjustable retrievals of already active streams and prefetching a waiting stream. We observed that the best use of the spare disk bandwidth is to increase the retrievals of a media stream so that the buffer consumption caused by the additionally retrieved data is minimized. Here, buffer consumption \( [9, 10] \) is defined as the product of buffer space and the length of time this space is occupied. For example, if a media stream needs 500 KB of buffer for 100 s, then the buffer consumption is 50 MB-s. Namely, buffer consumption measures both space and time of buffer usage.

For rate-adjustable retrieval schemes, spare disk bandwidth is used to increase the retrievals of an active stream during a service cycle. Therefore, the retrieval rate of the chosen stream becomes non-uniform from cycle to cycle. It behaves as if the retrieval rate were adjustable, and thus we call it rate-adjustable retrieval. We compare different criteria for selecting such a candidate stream to increase retrievals: minimum remaining time and minimum buffer consumption. Simulations are conducted to compare these criteria under two different implementations. The first one is a simple rate-adjustable (SRA) implementation, where, once a candidate stream is selected, additional retrievals are performed until there is no more buffer available or no more media data left on disk for this stream. The second one is called checking-based rate-adjustable (CRA) implementation, where extra retrievals will be terminated if the additionally retrieved data will occupy the buffer space needed for the first waiting request to be admitted. The results show that (1) minimizing buffer consumption is indeed the right strategy to maximize the system throughput using spare disk bandwidth; (2) with sufficient buffer space or proper implementation, such as CRA, the system throughput is better improved with buffer consumption than with remaining time as the selection criterion; and (3) increased retrievals of an active stream is more effective than prefetching in minimizing buffer consumption and thus maximizing the system throughput.

There are many studies focused on the storage and retrieval aspects of video and audio data, such as those presented in [1–3, 5–8]. These studies generally were concerned with intelligent disk scheduling, or data allocation and placement of multimedia data. The issues of utilizing spare disk bandwidth to improve system throughput was first considered by Ng and Yang [4]. In [4], sharing buffer space among active streams and prefetching data for a waiting request were proposed to maximize both buffer and disk utilization of a multimedia server. Prefetching was shown to improve system throughput.

The rest of the paper is as follows. Section 2 provides the preliminary. Section 3 introduces the concept of minimizing buffer consumption and describes rate-adjustable retrieval schemes of multimedia streams. The different selection criteria and retrieval implementations, including SRA, CRA and prefetching, are presented. Section 4 describes our simulations and analyzes the results.

2 Preliminary

In this section, we provide an overview of the multimedia server environment discussed in this paper. We also describe a simple admission control algorithm that derives the service cycle time \( T \) from the resource requirements in disk bandwidth and buffer space for continuous playback. We assume that multiple multimedia streams are retrieved in a cyclic fashion. We first consider fixed-order disk scheduling and then generalize to the elevator-type sweeping scheme.

Assume that there are \( n \) multimedia streams that are currently active and being displayed. Let the playback rate of stream \( S_i \) be \( p_i \) and the amount of time retrieving \( S_i \) in each service cycle be \( t_i \). Assuming the seek time and rotational latency from \( S_i \) to \( S_j \) is \( s_{ij} \), then \( t_1 + t_2 + \cdots + t_n + s_{12} + s_{23} + \cdots + s_{n1} \leq T \), where \( T \) is the length of a service cycle. If we assume the total switching time is \( s \) (i.e., \( s = s_{12} + \cdots + s_{n1} \)), then the disk utilization \( \rho \) is given by

\[
\rho = \frac{t_1 + t_2 + \cdots + t_n + s}{T}.
\]

Within each service cycle, the total amount of data played back by \( S_i \) is \( T \times p_i \), and the amount of data retrieved for \( S_i \) is \( t_i \times R \), where \( R \) is the maximum disk-reading rate. Thus, in order to meet the continuity requirement of \( S_i \),

\[
t_i \times R \geq T \times p_i.
\]

From Eqs. 1 and 2, we can obtain a lower bound for \( T \) as follows:

\[
T \geq \frac{s \times R}{R \times p - P},
\]

where \( P = p_1 + \cdots + p_n \) is the total playback rate in a service cycle. Obviously, \( R \times p - P > 0 \) must be true in Eq. 3. In other words, the effective total retrieval rate must be greater than the total playback rate.

Now let us consider the buffer requirement \( B_i \) for stream \( S_i \) in a service cycle. Note that, for continuous playback of stream \( S_i \), enough data must be retrieved into the buffer in \( t_i \) time units and played back over a period of \( T \) time units. As a result, buffer space is needed for \( S_i \). In order to reduce the total disk seek time, an elevator-type of sweeping scheme is used for disk scheduling. Hence, the reading order in two different service cycles can be different [2, 8]. In this paper, we assume that double buffering is used to accommodate this kind of disk scheduling. Thus, for stream \( S_i \), the buffer requirement is as follows:

\[
B_i = 2 \times t_i \times R.
\]

If the maximum buffer is \( B_{max} \), it is necessary that the following equation must hold true.

\[
\sum B_i \leq B_{max}.
\]

With Eqs. 3 and 5, we have an admission control algorithm. Assume that \( S_1, \cdots, S_n \) are currently active and \( S_{n+1} \) is to be determined whether or not it can be admitted. Figure 1 shows a simple admission control algorithm based on Eqs. 3 and 5. In it, \( t_{sweep} \) is the disk arm sweeping time from the outmost cylinder to the innermost cylinder, or visa versa, and \( t_{latency} \) is the mean rotational latency for a stream. Table 1 summarizes the notation used in this section.