FLASH CACHE HYBRID STORAGE SYSTEM FOR VIDEO-ON-DEMAND SERVER

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UNIVERSITI SAINS MALAYSIA

2018

FLASH CACHE HYBRID STORAGE SYSTEM FOR VIDEO-ON-DEMAND SERVER

by

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Thesis submitted in fulfillment of the requirements

for the Degree of

Doctor of Philosophy

August 2018

DEDICATION

I am dedicating this entire work to the pure soul of my father who passed away two years ago but wished to be present at the time of my graduation, he is resting in peace under the mercy of ALLAH. I am also dedicating this PhD to my beloved mother Fatema, my beloved husband Nibras, my beloved son Dheya'a and all my loved ones.

ACKNOWLEDGEMENT

First of all, I would like to thank Allah the Almighty, the most beneficent for giving me the strength, health and patience to go through all obstacles in order to complete this research.

With a deep sense of gratitude, I would like to express my sincere thanks to my supervisor, Associate Professor Dr. Putra Sumari for his wisdom, advice, good-hearted nature, constructive criticism, endless support and patience in guiding me through the entire research and thesis-writing process.

My greatest appreciation goes to my beloved husband, Nibras for his encouragement, support, sacrifices and great patience at all times throughout the study. You were always around at times I thought that it is impossible to continue, you helped me to keep things in perspective, thank you so much. To my son, Dheya'a, for he has inspired me in his own ways to finish my thesis. I couldn’t imagine doing my PhD without him; you really gave me the reason to continue.

Most importantly, my sincere gratitude and deepest appreciation go to my beloved mother and pure soul of my father for their support and prayers that kept my spirit up. Thank you for your constant encouragement and support me to be the person I am today. The successful completion of this work is the fruit of their prayers, sacrifices and devotion. Thanks for everything.

And also, I would like to express my heartfelt gratitude and special regards to my dearest brothers and sisters, and all my friends for their support and encouragement and for putting spirit in my life, who supported me in every possible way to see the completion of this work.

Last but not the least, I wish to express my deepest appreciation and gratitude to all School of Computer Sciences members for their great contribution, responsiveness and valuable information. Thanks to all those who have one way or another helped me in making this study a success.

Ola Al-wesabi

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LIST OF ABBREVIATIONS

Astro	All Asia Television and Radio Company
ATA	Advanced Technology Attachment
BPIC	Block level Popularity aware Interval Caching
CCTV	China Central Television
DFS	Direct File System
DIC	Distributed Interval Caching
DMM	Data Migration Manager
DRAM	Dynamic Random Access Memory
DSC	Data Streaming Controller
EHSS	Enhanced Hybrid Storage System
FADM	Feedback-based Adaptive Data Migration
FC-DSC	Flash Cache-Data Streaming Controller
FCHSS	Flash Cache-based Hybrid Storage System
FC-MMS	Flash Cache- Media Management System
FIFO	First In First Out
FLARE	Flash for Replication
FTL	Flash Translation Layer
HBM	Hybrid Buffer Cache Management
HDDs	Hard Disk Drives
HU	Hybrid Unit
I/O	Input/ Output
IC	Interval Caching
ISC	Iteration Set Caching
LBA	Logical Block Addressing

LFU	Least Frequently Used
LRU	Least Recently Used
MDMT	Metadata Management Table
MFU	Most Frequently Used
MLC	Multi-Level Cell
MMS	Media Management System
MRU	Most Recently Used
N-VOD	Near-Video On Demand
OP-FCL	Optimal Partitioning of Flash Cache Layer
OPS	Over-Provisioned Space
PIC	Popularity Aware Interval Caching
PLFU	Pareto LFU
PLRU	Pareto LRU
PPV	Pay-Per-View
PRIC	Popularity and Streaming Rate Aware Interval Caching
PSIC	Pre-emptive but Safe Interval Caching
QoS	Quality of Service
RAM	Random Access Memory
RM	Replacement Manager
RMSE	Root-Mean-Square Error
RPM	Revolution Per Minute
SAS	Serial-Attached SCSI
SATA	Serial ATA
SCSI	Small Computer System Interface
SLC	Single-Level Cell

SSDs	Solid State Drives
TLC	Triple-Level Cell
TM	Threshold Manager
T-VOD	True-Video On Demand
VOD	Video-On-Demand

LIST OF SYMBOLS

F	The number of video files
HR_c	Cache hit ratio
IOPS	Input/output operation per second
L_{vi}	Length of video *i*
ms	Millisecond
n	The rank
$P(n,\alpha,F)$	Popularity of the video files
R_c	Reads served from the cache
R_{Total}	Aggregate number of reads served by the cache and disks
S_{seg}	The size of the segment
THR	Throughput
$Total\_seg\_no_{vi}$	Total number of segments for a video *i*
α	Zipf coefficient
λ	Poisson coefficient

SISTEM STORAN HIBRID CACHE KILAT UNTUK PELAYAN VIDEO IKUT PERMINTAAN

ABSTRAK

Sistem *video-on-demand* (VOD) membenarkan pengguna mengakses mana-mana video pada bila-bila masa. Sistem ini membolehkan pengguna untuk melihat video dalam mod penstriman masa nyata untuk tempoh lanjutan. Salah satu komponen penting dalam sistem VOD ialah pelayan storan hibrid. Komponen ini terdiri daripada HDD, SSD dan RAM, secara kolektifnya memenuhi keperluan mengakses data secara serentak dengan cepat dan pengagihan data yang besar kepada banyak pengguna. Walau bagaimanapun, sistem storan hibrid semasa masih menimbulkan banyak cabaran. (1) Integrasi dan peranan HDD, SSD, dan RAM adalah agak lemah dari segi mengoptimumkan pengaksesan pantas sebelum pengstriman ke sebilangan besar pengguna secara serentak. (2) HDD dan SSD mempamerkan susun atur data dan pengawal penstriman yang kurang baik dalam menyokong pengeluaran sejumlah aliran serentak yang tinggi. Tesis ini mencadangkan (1) sistem storan hibrid yang telah dipertingkatkan (EHSS) untuk pelayan-pelayan VOD. HDD, SSD, dan RAM telah diuruskan dan diintegrasikan dengan menggunakan mekanisme yang berkesan, di mana 10% teratas video yang paling popular telah digunakan untuk mencapai akses data dan perkhidmatan yang pantas kepada sebilangan besar pengguna secara serentak. (2) Sistem storan hibrid cache kilat (FCHSS) juga dicadangkan. Berbeza dengan seni bina EHSS, seni bina FCHSS tidak mempunyai RAM, di mana ia dikeluarkan dan digantikan oleh SSD berasaskan *flash*. SSD berasaskan *flash* telah digunakan dan bukannya RAM sebagai

cache untuk HDD untuk mencapai akses data dan perkhidmatan yang pantas kepada sebilangan besar pengguna secara serentak. (3) Susunan data baru menyimpan beribu-ribu segmen video dalam HDD dan SSD. Skim pengurusan penstriman, iaitu pengawal penstriman data (DSC) dan pengawal penstriman data cache kilat (FC-DSC) juga dicadangkan untuk menyokong EHSS dan FCHSS masing-masing. Keputusan seni bina storan hibrid yang dicadangkan dan skim pengurusan penstriman menunjukkan bahawa seni bina dan skim ini semuanya dapat menyediakan pengaksesan data yang cepat (masa menunggu yang pendek) dan meningkatkan penghantaran pelayan VOD. EHSS berasaskan pelayan VOD dengan DSC yang dicadangkan telah memberikan prestasi yang lebih baik daripada yang berasaskan pelayan VOD yang sedia ada kerana ia meningkatkan purata masa tindak balas dan pencapaian untuk pelbagai skala beban kerja yang intensif sebanyak 69.89% dan 194.11% masing-masing. Tambahan juga, FCHSS berasaskan pelayan VOD yang dicadangkan dengan FC-DSC menunjukkan peningkatan 73.53% dalam purata jumlah masa tindak balas purata dan peningkatan 298.91% dalam perputaran untuk semua saiz permintaan berbanding dengan purata jumlah masa tindak balas dan peralihan pelayan VOD- berdasarkan FADM.

FLASH CACHE HYBRID STORAGE SYSTEM FOR VIDEO-ON-DEMAND SERVER

ABSTRACT

A video-on-demand (VOD) system allows users to access any video at any time. This system enables users to view videos in the real-time streaming mode for extended durations. One of the important components of the VOD systems is the hybrid storage server. This component consists of HDD, SSD, and RAM, collectively fulfilling the requirement of simultaneous fast data access and large data distribution to numerous users. However, current hybrid storage systems still pose numerous challenges. (1) The integration and roles of the HDD, SSD, and RAM are relatively weak in terms of optimizing fast access prior to streaming to a large number of simultaneous users. (2) The HDD and SSD exhibit poor data layout and streaming controller in supporting the production of a high number of simultaneous streams. This thesis proposes (1) an enhanced hybrid storage system (EHSS) for the VOD servers. The HDD, SSD, and RAM are managed and integrated using an effective mechanism, in which the top 10% most popular videos are utilized to achieve fast data access and service to a large number of simultaneous users. (2) The flash cache hybrid storage system (FCHSS) is also proposed. Unlike the EHSS architecture, the FCHSS architecture has no RAM, which is removed and replaced by a flash-based SSD. The flash-based SSD is used instead of the RAM as a cache for the HDD to achieve fast data access and service to a large number of simultaneous users. (3) The new data layout stores thousands of video segments in the HDD and SSD. The streaming management schemes, namely, data streaming

controller (DSC) and flash cache-data streaming controller (FC-DSC), are also proposed to support the EHSS and FCHSS, respectively. Results of the proposed hybrid storage architectures and their respective streaming management schemes indicate that these architectures and schemes are all able to provide fast data access (low waiting time) and enhance the throughput of the VOD servers. The proposed VOD server-based EHSS with the proposed DSC provides better performance than the existing VOD server-based because it enhances the average response times and throughput for the various scales of intensive workload by 69.89% and 194.11%, respectively. Also, the proposed VOD server-based FCHSS with the FC-DSC shows a 73.53% enhancement in average total response time and a 298.91% enhancement in throughputs for all request sizes compared with the average of the total response time and throughputs of VOD server-based FADM.

CHAPTER ONE

INTRODUCTION

1.1 Background

Video-on-demand (VOD) is an interactive TV technology and referred to as on-demand video streaming service. This technology allows users to access a list of digital contents, such as movies, news, and education programs, from their homes at any time. There are several applications of VOD such as music-on-demand, news-on-demand (Chen et al., 2015; Mikki and Yim, 2015), Netflix (Huang et al., 2012), PowerInfo (Kamiyama et al., 2013), Hulu (Adhikari et al., 2012), YouTube (Pires and Simon, 2015), and Astro (all Asia television and radio company) (Kim, 2013). A few of these examples utilize a subscription model, in which providers require their customers to pay a monthly fee to access packaged contents (e.g., Netflix, Hulu, and Astro). Astro was introduced as the first satellite television in Malaysia. Astro allows customers to watch programs that they missed with additional cost. Other VOD services utilize an advertisement-based model, in which the access is free to internet users and platforms depend on advertising as their main revenue (e.g., YouTube).

VOD systems are popular nowadays and the rapid evolution of the Internet and the advancement of broadband network technology has led to the expansion of VOD services (Yu, H. F. et al., 2006; Yu et al., 2007; Ketmaneechairat, et al., 2009; Wu et al., 2011; Sumari and Kamarulhaili, 2005). The increasing of Internet speed at a lower cost, high-powered CPUs and processor speed, data compression algorithms, and high disk capacity contribute to achieve a common goal, which is to deploy VOD services (Yu et al., 2007; Ryu et al., 2011). Currently, the VOD services are commonly transmitted over the Internet to homes via personal computers, laptops, mobile phones, and other advanced digital media devices.

Eventually, VOD traffic will have accounted for more than 82% of all users Internet traffic by 2020 (Systems, 2016). Specifically, this percentage covers a huge number of users per month for the millions of videos streamed from the large digital libraries of video channels.

1.2 Hybrid Storage VOD Server

In a VOD system, the most important component is the server. The server stores a large number of video files and distributes these files from the disk storages to a large number of users. Data storage and distribution is a complicated task because of real-time requirements and large size of video data. These characteristics require servers to be able to quickly retrieve videos and distribute them to a large number of simultaneous users in real time (Little and Venkatesh, 1994; Rahiman and Sumari, 2008). With more users of VOD service systems, the demand for high-quality videos with a smooth display without distribution delay has become crucial (Ozfatura et al., 2014; Zeng et al., 2014).

In this context, the term “hybrid” refers to combining HDD, SSD, and RAM, making up the main component of a server to fulfill its role. The three components complement each other for the best service.

Conventional hard disk drives (HDDs) are spinning disks that use mechanical platters; magnetic platters cause delay and latency during data retrieval. The main advantage of an HDD is its high capacity and low cost per gigabyte (Siewert and Nelson, 2009; Kasavajhala, 2011). Although HDDs are cost effective, given that the disk capacity of HDDs increases by 60% yearly, its data access time and rotational latency improve by about 10% yearly, which degrades the performance of a VOD server (Manjunath and Xie, 2012).

Solid state drives (SSDs) are a new technology that does not use any moving parts when accessing data on the drive, and most SSDs are manufactured based on flash memory. Unlike HDDs, SSDs do not encounter access rotational latency because they have no mechanical parts. SSDs have semiconductor memory chips that use integrated circuits rather than magnetic media. The design of an SSD has more advantages in several aspects. First, transferring data to an SSD is faster than to a mechanical HDD. Second, random reading and writing processes are improved, which reduces the access latency of input/output (I/O) (Moon et al., 2014).

Studies on VOD systems use hybrid storage solutions that aim to achieve high speed access time and cost efficiency (Ryu et al., 2011; Manjunath and Xie, 2012; Ling et al., 2016) are focused on using SSD as a cache in VOD server and HDDs as permanent storage (Ryu et al., 2011). In this work, popular videos are copied from the HDD (permanent storage) to the SSD (buffer cache) for fast access. Another study named FLARE, which stands for flash for replication, proposed a replication scheme that uses a hybrid architecture (HDDs and SSDs) for the VOD storage servers. FLARE consists of at least one HDD and one SSD. HDDs are utilized as a permanent storage, whereas the SSDs are used as a buffer cache for only the first ten-minute of popular videos. FADM uses a combination of hybrid storages in the VOD servers (Ling et al., 2016). The hybrid storage in FADM consists of HDDs and cache devices (RAM and SSD). HDDs serve as the permanent storage, whereas SSDs are used as a cache for popular blocks, which are portions of videos.

1.3 Problem Statements

The desirability of the VOD system is based on the following features:

- Fast response service. A user should be able to view a video upon request with the shortest waiting time possible. An extensive waiting time makes the system undesirable and lacks commercial value.

- Support for a large number of users. The VOD system should allow the simultaneous video streaming of a large number of users at any particular time.

Generally, the efficiency of the aforementioned features relies on the storage server. The server component of the hybrid VOD system consists of the HDD, SSD, and RAM. The three components offer their own advantages and must be organized with a good collaboration mechanism.

The term good collaboration mechanism between the HDD, SSD, and RAM involves addressing the following problems:

1- The mechanism of smoothening the roles of the three components. HDD operation degrades drastically when the server needs to serve many simultaneous video streams. Disk bottlenecks result in limited scalability of a VOD server. Many factors should be considered to improve disk drive performance. Some of these factors are optimal bandwidth use, mechanical system optimization, and intelligent algorithms (to control disk caches to buffer data temporarily in RAM); considering these factors can facilitate the development of an ideal solution for optimizing disk drive performance (Paulsen, 2011). Several studies propose caching algorithms to enhance VOD system (Ozden et al., 1996; Sheu et al., 1997; Andrews and Munagala, 2000;

Fernández et al., 2003; Wujuan et al., 2006; Janardhan and Schulzrinne, 2007). However, caching algorithms use RAM as a buffer cache because RAM has a faster access speed. The HDD might have an increased disk capacity, but the improvement of disk access latency is limited because of delays in seek time and mechanical rotation time. In addition, incompatibility between the speed of disk access latency and the other components, such as RAM and CPU, result in long access delay when serving requests simultaneously (Ryu et al., 2011; Manjunath and Xie, 2012). SSDs are the media used to quickly deliver videos to users; a good video management scheme is required to allow SSDs to be the main buffer for accommodating the advantages of popular and unpopular videos, coping with real-time constraints and bandwidth requirements, and changing the system architecture. The use of SSDs instead of RAM involves crucial management issues, which should be addressed to ensure the full utilization of SSDs and thereby improve the VOD performance.

2- The mechanism of designing video data in a hybrid storage (HDD and SSD). The layout on the HDD or SSD affects the performance of video retrieval because a video is considered thousands of small bulks, and the number of simultaneous segments can be retrieved and consequently influence the number of simultaneous streams to users. In addition, the flow of the whole operation involves managing the requests of users, providing streaming instructions, communicating with HDD and SSD storages, and ending the streaming requested to manage and organize the storages according to the video data layout mechanism related to the hardware components. The streaming management scheme should address these issues within the video data layout mechanism to efficiently enhance the streaming management technology to serve numerous requests simultaneously and handle a large amount of data while reducing the server bandwidth.

This study aims to clarify an aspect of the hybrid storage for building a large-scale VOD, which leads to the research questions: What is the efficient structure to improve the performance of a hybrid storage VOD server in terms of average response time and throughput and how can the throughput of the storage devices be exploited to enhance the capability of the VOD server?

1.4 Research Objectives

This research aims to develop a hybrid storage server for VOD system that could minimize the response time and maximize the I/O throughput. The research goal can be achieved through the following objectives:

1. To enhance the architecture of the hybrid storage VOD system. The HDD, SSD, and RAM are the crucial architectural components of a hybrid VOD system. Therefore, enhancing these components in terms of their overall architecture and their collaboration is a crucial task because these components affect the overall performance of the system.

2. To propose a video streaming management scheme and a video layout scheme that could support the enhanced hybrid VOD server and thus improve the performance of the server. This scheme is capable of enhancing the use of throughput by allowing the sharing of more than one streaming without asking for plenty of throughputs at the server when users have multiple

requests. In addition, this scheme can help to improve the response time for the requests by directly linking the new request to the available streams.

3. To evaluate the performance of the proposed EHSS- and FCHSS-based VOD server architectures and to highlight the performance improvement of the proposed EHSS- and FCHSS-based VOD server with the streaming management schemes.

The performance related to these objectives is referred to increase the number of simultaneous users that can be served by the server and to reduce the waiting time of users in starting the playback upon request.

1.5 Significance of the Research

This research is very important because people now live in a world where the Internet is part of their daily routine. A large-scale VOD system is one of the modern technologies that distribute information from various fields online. It is considered a part of the e-learning system, which helps disseminate teaching and learning materials. Thus, changes in different types of disk storage capacities and architectures are considered to help reduce the performance bottleneck of a VOD system by using a high-capacity HDD to provide the required bandwidth in a VOD. In addition, using a flash-based SSD helps to achieve high I/O performance. Therefore, this research explores the benefits of the storage technology to enhance the performance of a VOD system in terms of serving multi-users within the same buffer and developing a hybrid storage system for the VOD server, in which SSD is used as a storage device instead of only as a cache.

1.6 Research Scope

This thesis is focused on enhancing the VOD server and its storage platforms in terms of reducing waiting time and serving many users simultaneously by using a hybrid storage system. This research proposes two types of architecture of hybrid storage system for VOD server (enhanced hybrid storage system [EHSS]/ flash cache hybrid storage system [FCHSS]). In addition, this research is conducted to propose a streaming management scheme for each type (DSC/FC-DSC). Each scheme has several procedures that can control and manage the streaming to serve requests. Both types utilize SSD as a storage device with HDDs and differ only in the type of cache for HDDs. In the EHSS architecture, RAM is used as a buffer cache, whereas another small-sized SSD is used as a buffer cache in FCHSS. This thesis used DiskSim 4.0 simulator to generate both architectures. Particularly, this thesis focuses on designing innovative streaming management scheme based on the hybrid storage system to enhance the performance of the VOD storage server.

1.7 Research Contributions

The contributions of this study are as follows:

1- An enhanced hybrid storage system (EHSS) architecture. This architecture enhances the management mechanism between the HDD, SSD, and RAM. The new mechanism improves the performance of the storage system in terms of providing higher input/output operation per second (IOPS) and fast random access read speed that helps to improve the throughput and response time of the storage system.

2- A flash cache mechanism for hybrid storage VOD servers called the FCHSS architecture. This storage system architecture also uses a small size of flash-based SSD as a cache instead of RAM. This architecture presents more improvement in the performance of the storage system in terms of throughput and response time of storage system because of the use of SSD in caching.

3- A new video layout scheme. This scheme arranges thousands of segments of video data to design the hybrid storage (HDD and SSD). This scheme plays an important role in organizing retrieved video segments upon request.

4- A new streaming management scheme, namely, data streaming controller/flash cache–data streaming controller (DSC/FC-DSC). These schemes enhance the throughput of the VOD storage server by exploiting the available streams for the multiple requests of different users. In addition, these schemes can help to improve the response time for the requests by directly linking the new request to the available streams. The components of these schemes [(DSC-SSD and DSC-HDD)/ (FC-DSC-HDD and FC-DSC-SSD)] work with the dynamic streaming table according to the video layout mechanism by continuously streaming to the users.

1.8 Research Justification

VOD systems store numerous videos and distribute these videos to users upon request. Most hybrid VOD servers use HDD as permanent storage because it provides higher capacity (terabytes) and costs less than SSD (Kim et al., 2016). Improving the performance of a VOD system by replacing HDD with SSD as the permanent storage is expensive. The cost of SSD per GB is approximately four times higher than that of HDD (O'Reilly, 2015; Mearian, 2016), thus making HDDs desirable to use as a permanent storage. Therefore, high I/O and better performance can be achieved by using an SSD-based storage device with existing permanent storage devices (HDDs). This thesis proposes two architectures to enhance the performance of the VOD storage system and considering the rapidly increasing capacity of SSDs. The first proposed architecture uses the SSD as a permanent storage that complements the HDD which can serve a large number of simultaneous requests by increasing the I/O bandwidth and implementing quick read operations of the SSD to reduce the waiting time in serving requests. The second architecture uses a small SSD as a cache device instead of RAM along with the SSD-based storage. Replacing RAM by small size of SSD is a good choice for storing segments since it does not lose its data each time it is powered down.

1.9 Research Framework

To accomplish the goals of this research, the research framework is presented and conducted in Figure 1.1.

i. Problem Identification

Problem assessment is an essential step in determining the solution to the problem. Based on the characteristics of a storage subsystem and streaming media data for a VOD server, it requires a storage subsystem that presents multiple service features, such as low startup latency for retrieving index data from the storage, high throughput to serve numerous simultaneous requests for large multimedia objects, and guarantee for real-time playback of continuous media data. To support various levels of services, a storage device has to guarantee satisfactory bandwidth utilization, which is the main requirement.

However, continuous media data demand much bandwidth, and the combination of hybrid storage devices exhibit a challenge when used in VOD servers. An efficient method to meet these demands is to manage the collaboration between hybrid storage devices and to schedule large segments of media data into hybrid storage devices according to a mechanism that can help to smooth the retrieval segments upon requests. SSD is presented and highlighted in this study for its characteristics, which demonstrate its practical benefits.

In consideration of the nature and attributes of streaming media applications, both HDD and SSD should be exploited for their desirable characteristics to enhance the performance of the hybrid storage VOD server. Therefore, the establishment of new enhanced storage server architectures and the development of streaming management system remain challenging but are necessary to improve the response time for serving requests while providing a high throughput.

ii. Knowledge Acquisition and Requirement Analysis for the VOD Storage Subsystem

Knowledge acquisition and requirement analysis are necessary to determine the efficient mode of meeting the storage subsystem requirements in a VOD server and define the requirements that need to be satisfied by the proposed architectures. Knowing how a VOD system is utilized enables to identify the requirements that it must meet. Overall, the entire VOD system has to meet the requirements of the client. This scenario, in turn, imposes requirements on the independent components of the VOD system.

This thesis concentrates on improvement for the server-side storage subsystem; thus, it is focused on the disk resources and the requirements the subsystem should meet.Given that the main function of a storage system is to store video data, a brief discussion about video data is given. Video data are continuous media data that change over time. In other words, the time at which the data are presented influences the validity of the information. Therefore, processing of such video data is time sensitive (Bulti and Raimond, 2015). In addition, a video contains a set of sequentially shown frames. Normally, video data involves three requirements: size, real time, and throughput. A VOD server contains a large number of large-sized videos. Thus, storing data in the main memory is impossible. For this reason, most video data are usually fetched and read from a secondary storage device. Therefore, the storage subsystem has to achieve the demands imposed by multimedia data. Given that video data are continuous media data presented as sequences of frames, failure to meet the real-time constraint causes a hiccup in video presentations.

On the server side, the storage subsystem should be able to satisfy real-time requirements. In general, playing back video data involves retrieving data from hybrid storage devices (HDDs and SSD); however, owing to the weak collaboration among HDD, SSD and RAM, storage devices (e.g., HDDs) still have high seek time and high rotational latency even if disk-scheduling algorithms and admission controllers are employed to reduce seek time and rotational latency (Ryu, 2014). The throughput demands of video data may increase depending on the resolution and coding format (Le and Bae, 2014). Furthermore, the majority of modern video-coding formats use variable bit rate (Seetharam et al., 2015; van der Schaar, 2015). Therefore, the practical bandwidth requirement may change frequently over time (Huang et al., 2015).

Playing back video data involves retrieving data from storage devices; however, the buffer size for variable-bit-rate videos is a poor index because it does not consider the amount of data required to proceed to the succeeding frames. Several service types should be provided to a VOD hybrid storage subsystem; these service types are high throughput, real time, large capacity, and low latency (low response time). In other words, a storage device for a VOD server should be capable of processing and serving requests immediately, providing high IOPS to serve many requests concurrently, rapidly accessing and retrieving data from various locations in the storage to respond to many requests simultaneously, and must have a huge capacity to store numerous video files. The requirements of the VOD storage subsystem is described to determine the appropriate solution within the available various storage devices to enhance the performance of the storage systems and overcome their weakness.

iii. Design of the Proposed Architectures

In this stage, the proposed innovative hybrid storage system architectures (EHSS/ FCHSS) as a base storage system for the VOD storage server are designed. The components of the proposed architectures and their specifications are described in detail in Chapter Four.

iv. Proposed Streaming Management System

In this step, the streaming management schemes (DSC/FC-DSC) is designed along with their component procedures to control and manage the streaming in the VOD server. The proposed streaming management can manage the request-serving process to achieve the research objectives.

v. Simulation

The hybrid storage architectures and their streaming management schemes for the VOD server are simulated and implemented in this stage.

iv. Evaluation Methods and Results

In this stage, the performance of the architectures of hybrid storage VOD server with the proposed schemes is evaluated to analyze their effect on the performance of the VOD server.

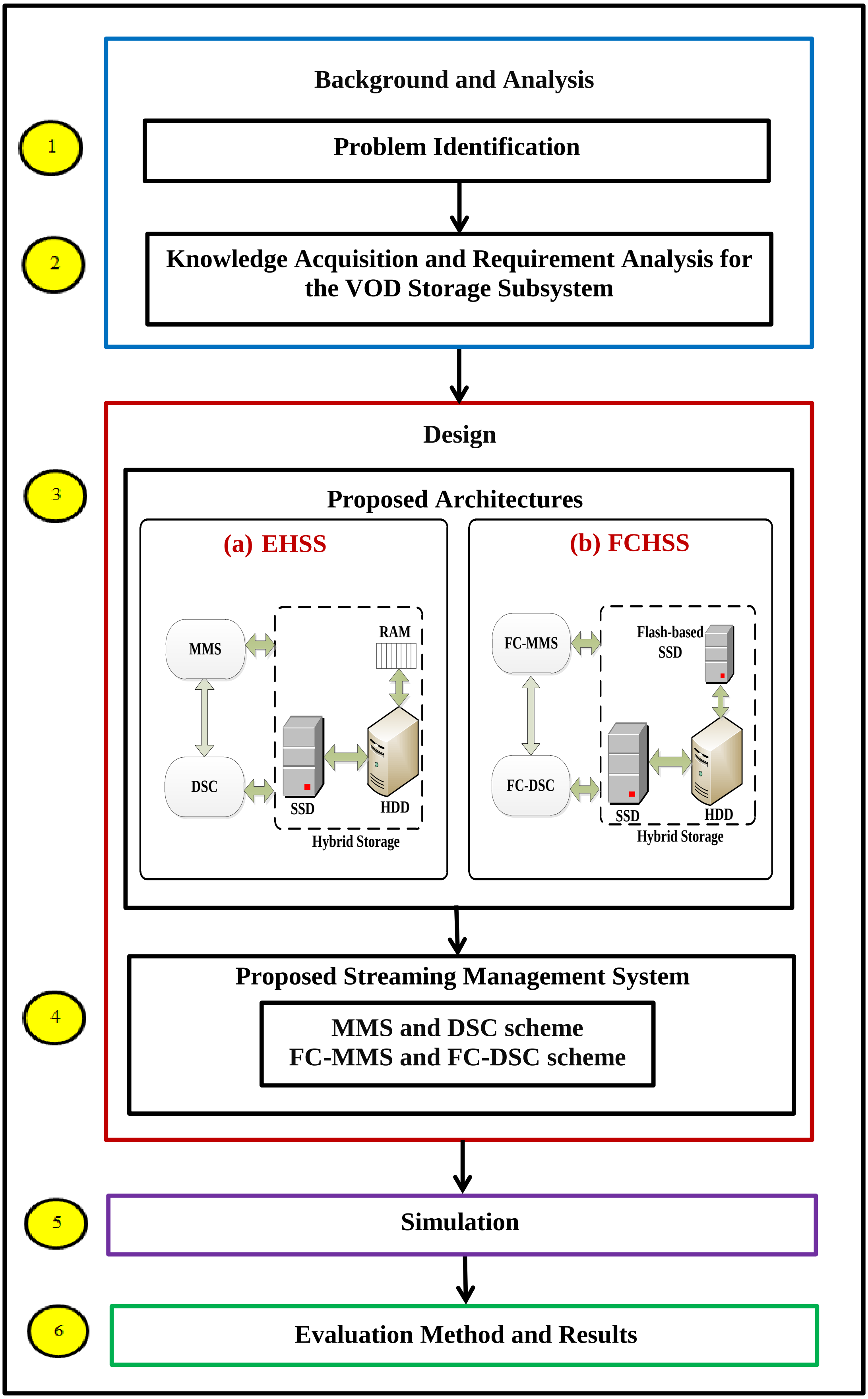

Figure 1.1: Research Framework

1.10 Organization of Thesis

The work of this thesis is organized into six chapters. This chapter (Chapter One) presents the objective of this thesis. It has briefly outlined the overview of the research on the background of a VOD, hybrid storage VOD server, problem statement, the objectives of this research, the significance of this study, and the contribution of the research. The rest of this thesis is organized as follows:

Chapter Two covers the literature review of the characteristics of streaming media storage server. This chapter also discusses the major bottleneck for different types of storage devices and clarifies the concept of VOD system. This is followed by the overview of the performance of the existing storage systems, which presents the current landscape of the hierarchy problem of the memory system. Then, the flash memory SSD and its NAND flash technology are described in detail. SSD is considered as an appropriate device because it provides fast random reading and high IOPS. Also, in this chapter, the various existing approaches to hybrid storage and the existing work of integration storage for the VOD server are presented.

Chapter Three covers the methodology discussion on how the proposed scheme is designed and presents the design procedure of the two proposed architectures, the proposed algorithms in both the two simulators, and the validation of such simulators. Also, this chapter presents the measures for evaluating the performance of the proposed architectures for the VOD hybrid storage server.

Chapter Four presents in detail the design and components of a developed hybrid storage system of the VOD EHSS server. Also, this chapter provides the media management system (MMS) that manages the transaction among the components of EHSS architecture. Then, the details of a new DSC scheme are presented, and the components of this scheme and its procedures are introduced. In addition, this chapter presents the second proposed hybrid storage system of VOD FCHSS server and its components. This part is followed by a detailed description of the components of FCHSS architecture, in which the management system FC-MMS of FCHSS server is illustrated. Moreover, the proposed FC-DSC scheme is presented in detail with its components.

Chapter Five presents the simulation setups of the EHSS architecture and the FCHSS architecture. The experimental results of the FCHSS architecture are provided and compared in various aspects with that of the EHSS VOD server architecture and the existing method of the VOD server.

Chapter Six concludes the research, highlights the major contributions, and gives suggestions for future work with regard to this research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Chapter Two presents an overview of the characteristics of the storage servers of streaming media, the major bottlenecks of different types of storage devices, and recent studies on hybrid storage architecture, which is commonly employed to solve major bottlenecks in most computer systems. Section 2.2 describes the characteristic of streaming media. Section 2.3 presents the concept of VOD systems. Section 2.4 examines the performance of storage systems and discusses the current landscape of the memory system hierarchy problem. Section 2.5 provides an overview of flash memory SSD and its NAND flash technology. Section 2.6 enumerates the attributes required for VOD storage systems. Section 2.7 presents optimization techniques to enhance the performance bottleneck in storage system. Section 2.8 explores several common hybrid storage approaches and existing work on integration storage for VOD servers. Section 2.9 presents the DiskSim 4.0 and its SSD extension model used to evaluate this work. Section 2.10 reviews the concept of caching and its features. Section 2.11 illustrates several caching algorithms. Section 2.12 provides a discussion of the presented studies and concepts, and Section 2.13 summarizes this chapter.

2.2 Streaming Media and Their Unique Features

Streaming media applications have become popular and ubiquitous in the digital lives in the last two decades. Users enjoy a wide variety of videos by using online services, such as Netflix (Huang et al., 2012), PowerInfo (Kamiyama et al., 2013), Hulu (Adhikari et al., 2012), and YouTube (Pires and Simon, 2015). Users can also create streaming media content on low-priced smartphones or cheap digital camcorders (Pegus et al., 2015).

Any streaming media system is generally assumed to be an input/output (I/O)-intensive application. In streaming media servers, large numbers of concurrent users demand video data from the servers every second. These simultaneous requests produce a mass of small-block random disk accesses that cause performance bottlenecks because of limited disk throughput. Streaming media services possess the following unique characteristics that are not present in traditional data-intensive applications.

- **Massive and Rapidly Growing Storage Demand**

  A large amount of new data, of which multimedia data account for the greatest portion, are annually generated worldwide. Videos accumulate very quickly; according to YouTube's statistics, 300 video hours are uploaded every minute (Smith, 2016). In 2015, Facebook hosted a total of 8 billion videos (Anderson, 2016), which generated 100 million hours of daily views (Constine, 2016).

  Such massive and rapidly growing storage demand indicates the need for streaming media management applications to utilize storage devices with a large capacity, such as SATA disks. Media libraries require a very large storage space to store media objects with high data rates and long playback durations.

- **High Quality of Service (QoS) Constraints**

QoS in streaming media systems is usually scaled by three metrics: response time, startup latency, and jitter. Response time refers to the duration between the time a user sends a request and the time the server sends a response. Startup latency is the waiting time spent by a user before the requested media content is initialized (Pan et al., 2016). Jitter indicates the variation in data transfer rates during playback.

Streaming media applications have stricter QoS constraints than the majority of online and all offline applications because a low QoS reflects an unsatisfactory service for streaming media clients. A high QoS, which ensures that many users can be served simultaneously, requires a large drive bandwidth with high I/O performance. Using modern storage devices and reducing bandwidth consumption help minimize access latencies and maximize the number of served users. Streaming media systems are generally hindered by QoS limitations caused by the performance bottlenecks of storage devices.

- **User Interaction**

Streamed contents generally have long playback durations, which result in various interactions between clients and servers. For example, nearly 65% of streaming media users view more than ¾ of a video (Insivia, 2017). In addition, users perform various unpredicted videocassette recorder (VCR) operations provided by streaming media systems, thereby generating varying access rates at different parts of a stream (Chen et al., 2004). Such operations may lead to a substantial waste of storage throughput and indicate the need for cache management.

In the next section, an overview of VOD systems is presented. VOD systems are a type of streaming media systems and are the focus of this work.

2.3 VOD Systems

VOD systems provide customers with high-quality performance at low prices (Zhao, Jiang, Zhou, Huang and Huang, 2014). These systems allow users to access media at any time without the need to leave their homes. One of the major obstacles in the development of VOD streaming servers is the cost of the server equipment and software. Another obstacle is the need to serve the maximum number of concurrent requests, which is an issue related to server capacity and available memory (Dan et al., 1995). True VOD (T-VOD) allows users to select their desired video at any time and streams the video content immediately. Figure 2.1 shows an overview of the T-VOD system, in which each user has an independent streaming channel.

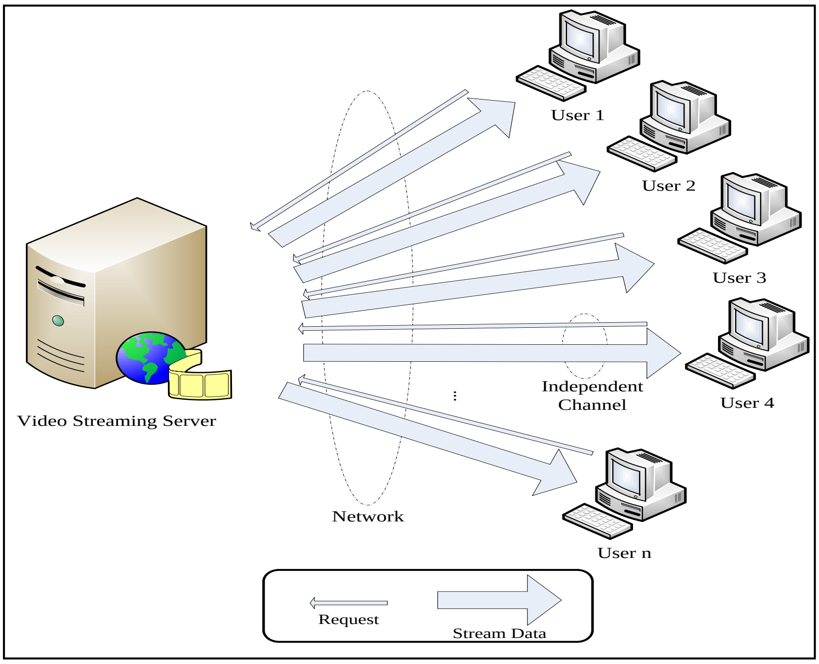

Figure 2.1: Overview of the (T-VOD) System

This work focuses on a VOD storage server to facilitate services, and VOD is synonymously used with T-VOD. In this technology, every requested video has an independent channel. Therefore, users are provided with full-function VCR controller as an interactive service. Interactive services can be classified into different categories depending on the level of interactivity. Table 2.1 shows five distinct types of interactive services (Little and Venkatesh, 1994; Ma and Shin, 2002; Dutta et al., 2015).

Table 2.1: Classification of Video Services (Ma and Shin, 2002)

Feature / Type	Video selection	Interactive	Number of spectators	Watching time
Live broadcast (No-VOD)	Yes, limited to displayed programs on a few channels	No	Unlimited	Undefined
Pay-per-view (PPV)	Yes, limited to prepaid specific programs	No or very limited	Unlimited	Pre-specified schedule times
Quasi VOD	Yes, limited to displayed programs on different groups	No	Unlimited	Pre-specified schedule times
Near VOD (N-VOD)	Yes, limited to provided programs in the same channel	Very limited	Unlimited	Pre-specified schedule times
True VOD (T-VOD)	Yes	VCR controller	Limited	Anytime

VOD systems consist of many essential components and predominantly utilize many proxy servers to cache videos that are frequently requested by local clients. One of the most critical components of VOD systems is the VOD proxy server or simply VOD server, which is primarily responsible for storing large video files and managing access to video content. The VOD server also enables continuous streaming of the requested video (Yu et al., 2007; Ryu et al., 2011).

Upon the arrival of user requests at the VOD server, they are accepted or rejected by the admission control depending on the ability of the server to avoid jitter on existing requests being served. The admission control serves the request from either the cache/buffer or the disk at the VOD server. The video content is then streamed at a rate compatible with the MPEG playback rate.

2.3.1 VOD Server

The VOD server is the main component of VOD system. It stores a huge number of large video files. The VOD server distributes the data from the storage drivers to users. One of the challenges is designing and implementing an effective and cost-effective VOD server. The main characteristics of the VOD server are as follows:

- **VOD server capacity:** VOD server capacity indicates the number of streams that can be served simultaneously. A large bandwidth is required to ensure that video streams are encoded during compression according to the type of video streams provided by the video server. For example, MPEG-1 encodes videos at 1.5 Mbps, whereas MPEG-2 encodes videos at 4 Mbps to 6 Mbps, which requires greater video server capacity (Ma and Shin, 2002).

- **I/O performance:** I/O workload is a key issue in a VOD server. A VOD server must accommodate numerous I/O requests per second to serve many concurrent video streams (Chen and Thapar, 1996). A random read I/O pattern, rather than a sequential read access, is preferred for data access to optimize the performance of an intensive VOD server (Ryu et al., 2011; Noyola, 2011).

- **Content management:** A VOD server should support a content management system, particularly when a single video file needs more streams than what can be handled by the device. Content management may involve copying or partitioning the content library (Agrawal et al., 2014). In dynamic content management, popular videos are handled and shared in centralized libraries in many edge servers on the network to ensure their proximity to the clients (Zhang et al., 2013).

- **Data storage:** Videos have very large file sizes, and VOD storage systems are responsible for storing large amounts of video data. The VOD storage system, whether it uses HDD or SSD, affects the overall performance of the VOD system (Wu and Zhang, 2015). Most solutions that use HDD as the main storage utilize RAM as a cache to reduce the latency access time. When multiple requests arrive and the RAM is already full, RAM can be freed up by removing unused video objects (Dan and Sitaram, 1993).

- **Fault tolerance:** Hardware or software failure is a major concern in VOD storage systems. This failure impedes the system because it prevents access to and delivery of services to all users. To avoid this problem and provide guaranteed services to all customers, fault tolerance should be supported by transferring to an alternative active server location without the knowledge of the customer and without affecting video playback (Ng and Xiong, 2001; Lu and Mori, 2009).

- **Open and scalable structure:** The VOD server structure should be able to simultaneously serve a large number of requests and adapt to extensions to increase the number of users and the amount of content. In addition, a VOD server should be able to adapt to diverse network distribution choices (Mineraud, 2013).

However, the design of a VOD server requires the consideration of various factors, such as storage subsystem, hierarchical storage scheme, scalable architecture, and performance cost of the server.

2.4 Storage System Performance

The data access time and performance of storage systems have not been at par with the steady advancement of processor performance and speed in recent decades. This gap causes the storage systems of most computer application systems to suffer from performance bottlenecks. Researchers have proposed different approaches, such as prefetching methods, intelligent scheduling, and caching policy, to address this problem and consequently optimize storage performance. Despite these efforts, the performance bottlenecks of storage systems still occur and limit the scalability of most computer systems even in high-performance computing (Zhao, Zhang, Zhou, Li, Wang, Kimpe and Raicu, 2014). Storage systems that depend on magnetic hard disk technology suffer from two main issues: latency gap and narrow interface between the storage and file system. These issues are illustrated in detail in the following section.