A Novel Computing-enhanced Cloud Storage Model Supporting Combined Service Aware

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***Abstract*—Cloud storage has been increasing in popularity recently due to its ability to deliver virtualized storage on demand over a network. As the amount of digital resources continues to grow at an astounding rate, more and more intelligent devices (such as GPU) are embedded as computing units to enhance the performance of storage system. How to seamlessly integrate these computing resources into cloud storage is an important problem that we should confront with. In this paper, a novel computing-enhanced cloud storage model is provided, which divides coarse-grained storage service into fine-grained service modules. By combining these sub-service modules with additional computing modules, a combined service can be constructed to satisfy user's complicated requests.**

Keywords-cloud storage; SOA; GPU; parallel; combined service; service aware

I. INTRODUCTION

Cloud storage has rapidly grown in popularity over the past few years [1]. Storage Networking Industry Association (SNIA) defines cloud storage as delivery of virtualized storage on demand. According to the definition, a cloud storage model consists of three common components. The first important part is the virtualized resource pool that can satisfy the complex requests. Compared with traditional resource management strategy, those resources that have been handled in cloud storage model are virtualized but not physical resources [2] [4]. Cloud storage model allows those resources to be shared among a vast number of users. Besides virtualization, a universal and friendly interface is another important component. Attracted by automatic scalability and extremely low cost, web services are increasingly opting for cloud storage over traditional storage system. In order to efficiently manage storage capacity and establish resource allocation strategy, Representational State Transfer (REST) interface is utilized as a common web service approach that allows users to easily access their services. The third one is the flexible service module that can be combined to construct scalable service to satisfy all kinds of user requests. Because Service-Oriented Architecture (SOA) [3] provides a service module that can adjust resources according to the demand, the integration of SOA and cloud storage helps to construct a service-oriented cloud storage model. It fulfills user's demands by combining sub-service modules to provide virtualized resources to users.

In order to deliver compound service to satisfy user's complicated requests, service aware plays an important role in constructing a cloud storage model for analyzing the speedup of performance. User's service requests, context information and provenance are extracted and stored as metadata to adjust storage strategy. Meanwhile, as a highly-parallel device, Graphics Processing Units (GPU) [5] is commonly used in most multimedia processing applications, while little attention has been paid to exploring these smart devices to support more generic functionality in storage system [6]. Because storage resources and computing resources can be linked together to provide a combined service to satisfy user's requirement, GPU is utilized to accelerate the computing speed [7] and becoming a largely under exploited resource in this paper. Besides dynamically scalable and virtualized architecture, the cloud storage model that has been constructed aims to seamlessly integrate computing resources into cloud storage system. Hence the decision of resource allocation between storage and computing appears to be a cost-benefit tradeoff [8] question, while additional metadata and provenance facilities is needed in order to balance these two kinds of resources.

The remainder of the paper is organized as follows. Section Ⅱ describes the architecture of cloud storage model. In section Ⅲ, storage service is divided into several fine-grained service modules and service processing workflow is described. Section Ⅳ introduces computing-enhanced service and section Ⅴ describes the combined storage service. Section Ⅵ presents the construction of prototype,

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while section Ⅶ indicates the experimental results. The final conclusion is induced in section Ⅷ.

II. ARCHITECTURE OF CLOUD STORAGE MODEL

Cloud offers a powerful abstraction that provides virtualized infrastructure, platform or software as a service where the complexity of fine-grained resource management is hidden from the upper user [9]. Currently used storage systems focus on how to efficiently utilize storage resources while seldom take the computing resources into account [10]. By combing storage service with computing service according to the awareness of user's service request, a novel cloud storage model that supporting combined service is generated.

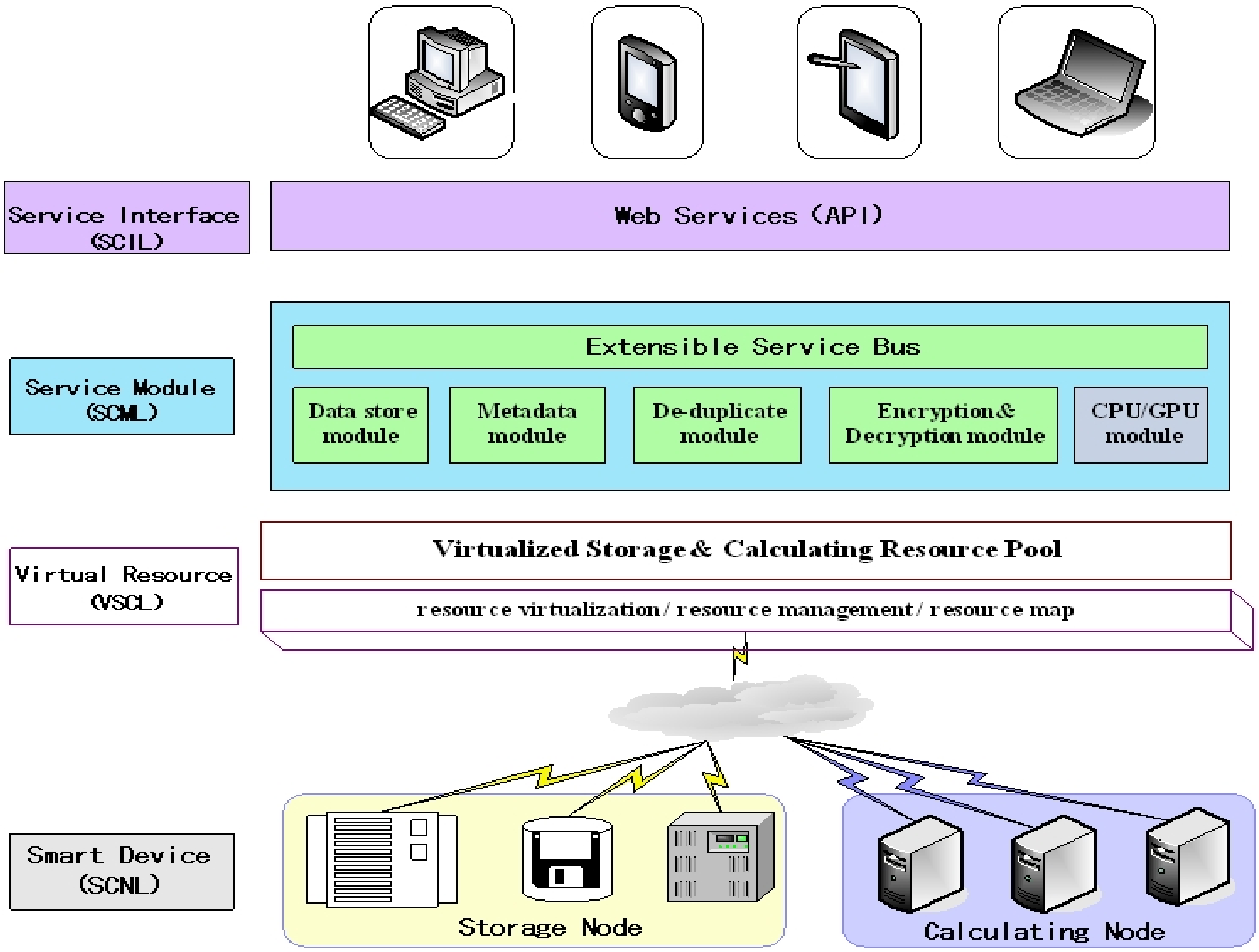

Figure 1. Architecture of cloud storage model

As shown in Figure 1, the architecture of cloud storage model is composed of four components: storage & computing node layer (SCNL), virtualized storage & computing layer (VSCL), storage & computing module layer (SCML), and storage & computing interface layer (SCIL). SCNL collects all kinds of storage and computing resources which can be dynamically joined or eliminated as intelligent nodes. The underlying resources are virtualized by VSCL, which integrates heterogeneous storage and computing power to generate a virtual resource pool. It also manages all kinds of resources and maps logical resources to physical resources. SCML divides coarse grained resources into several fine grained service modules, such as data store module, metadata module, de-duplicated module, encryption & decryption module and calculating module. Meanwhile, according to the design routing of SOA, new service can be flexibly plugged into the extendible service bus to construct a scalable storage system. In order to conveniently interact with user and aware those complex service requests, virtualized storage service is provided to the upper level through web service API, and all kinds of application can easily access cloud storage system through SCIL.

III. SERVICE PROCESSING WORKFLOW

When managing large amounts of data with different users' requirements, metadata service is a convenient mechanism to express those demands in such a way that underlying storage services can utilize different strategies to deal with those requirements [11]. System metadata and user metadata are two kinds of metadata that have been discussed in my former research paper [12]. Those metadata contain the underlying information of storage system and the upper semantic information of special application. Besides the above two metadata service, the cloud storage model also aware the context and provenance information to decide what kinds of sub-service module can be combined to satisfy user's complex requests. A metadata-based service processing workflow is as follows.

A. Service Aware and Metadata Generation

Firstly, as user's requests always maintain certain important information such as QoS, storage capacity and transmit rate, it plays an important role in various data management tasks such as backup and snapshot. Then SCIL aware this kind of service request to establish corresponding storage strategy. Secondly, when user delivers those data to the cloud storage system, SCIL analyses the context information of the data that have been stored, extract keywords from data elements, index the content and create associated metadata. The corresponding policies will be able to use the context to classify data elements according to their individual requirements. Finally, SCIL can also aware the environment in which the data is created and used. Hence all these characters are organized as metadata and provided as metadata module for later use.

B. Complex Service Combination

The role of metadata service can be regarded as a combined mechanism that integrates the data storage service with other service module. It regards metadata as a means to convey the user's requirements to the underlying storage system. In order to handle the complex requests for user data and metadata, fine grained service module is an essential portion in cloud storage system. Besides data storage service and metadata service, computing service and other extended service are regarded as optional modules to accelerate service processing. As shown in figure 1, SCML is composed of storage service and calculating service, which is divided into several sub-service to response complex request. Specially, GPU service module can dramatically reduce the CPU load in cloud storage system and enhance overall system performance by outsourcing those computing operations to the GPU. The combination of data storage service, metadata service, computing service can satisfy all kinds of requests. A detailed description of combined service will be discussed in section Ⅴ.

C. Virtualized Resource Management

Cloud systems often limit the size of an individual request to be tiny fraction of the total available capacity and focus on scaling to support large numbers of users. Hence those resources that have been handled in cloud storage model are virtualized resources. Relying on virtualized resources, users can easily shift their data from one storage space to another without considering the underlying physical devices. More importantly, virtualization isolates process units, whereby each application is able to utilize those shared resources, ensuring that the cloud storage platform could meet QoS requirements. Meanwhile, VSCL collects all kinds of virtualized resources and inspects the usability of underlying physical devices through block, file and object storage interfaces. But it is difficult to find the balance between computation and storage that maximizes the efficiency of cloud system, so optimization model is utilized to describe and distribute these resources. By analyzing the constrained condition (such as the power of storage and computing), we can maximize system performance under current environment.

IV. COMPUTING-ENHANCED SERVICE

By efficiently taking advantage of computing resources to accelerate storage processing, a seamlessly computing-enhanced service can be provided to user. These computing services can be utilized in following fields.

A. Computing-enhanced Hashing Service

Hash-based operations are commonly used in large scale storage system. How to utilize the computing power of GPU to enhance the hashing processing is a critical problem that we are confronting with. Some research group did lots of related work in this field, for example, StoreGPU [7] utilizes transparent GPU's computational power to support data-intensive application in distributed storage system.

B. Computing-enhanced Metadata Service

The efficiency of metadata management is critical for the overall performance of cloud storage systems. To achieve high data throughput, Bloom filter has been widely utilized to efficiently route metadata requests to desired metadata server [13]. As it uses several independent hash functions to generate a series of hash values into a bit array, the computational overheads of these implementations prevent their use in large-scale storage system. By utilizing multi-core CPU and parallelizable GPU processing units, we can rapidly enhance the performance of Bloom filter and provide a computing-enhanced metadata service.

C. Computing-enhanced Security Service

Encryption and decryption are computing-intensive operations in storage system. Traditionally the GPU has been used almost specially for floating-point operations and there hasn't been much development of cryptographic applications for GPU. Until recently, GPU start to support integer and bitwise operations, hence it began to be used in encryption and decryption fields. For example, Manavski [14] implements AES encryption using CUDA and report up to 20× speedups. Hence the GPU-enhanced security service can accelerate the security processing.

V. COMBINED SERVICE USE CASE AND STRATEGY

Besides the computing-enhance services that have been described in section Ⅳ, data store module and metadata module are two important components in constructing combined service. Data store module is used to actually transfer the data to and from the underlying storage devices without concerning anything other than the location of the data. Metadata module mainly concerns with the aspects on how to configure service and what quality of service the storage system should provide (such as backup, snapshot and content retrieval). The combined storage and computing service includes the following aspects:

A. *Combined Backup Service*

As far as the backup service is concerned, it consists of three kinds of processing: data store, metadata management and encryption & decryption. Therein, metadata service can classify data based on the awareness of file type and establish corresponding backup policies to provide combined service. Meanwhile, data storage service can be utilized to store user's files and deliver data through different storage interface. In order to ensure the security, GPU module is utilized to parallelize encryption & decryption processing as an additional service.

B. *Combined Snapshot Service*

The snapshot data service allows virtual copies of the data at a point in time to be taken and then exposed through a storage interface. Similar to backup service, in the snapshot's procedure, metadata service can aware the user's service request and analysis the time interval. Data store module applies differentiated storage interface to individual data type, such as block, volume, file and object. And computing-enhanced module is utilized to accelerate the de-duplicate operation.

C. *Combined Retrieval Service*

Because metadata information plays an important role in combining service, the combined retrieval service can be delivered to multi-users as follows: Firstly, content, context and provenance [15] information are extracted and stored in metadata module. Secondly, indexing is constructed and data store module is utilized to store those indexes. Thirdly, as the total indexing time can be significantly reduced by dividing data into independent nodes and distributing indexing to multiple machines for parallel processing [16], computing-enhanced module can be utilized to accelerate the indexing operation. Finally, data store module, metadata module and computing module are combined to satisfy user's complex query requests.

D. *Service Combination Strategy*

As we can see from the three use cases that have described above, the key challenge in balancing storage and computing service lies on what is to be stored directly and when computing is needed to accelerate storage processing (such as de-duplication, encryption). Moreover, computation time can be greatly effected by the amount of parallelism available in the cloud. And it is important to fully understand the parallelizability associated with a time sensitive computing to maximize the efficiency of combined service. If parallelizability is high, a strategy that utilizes the most powerful computing devices to lower access time will be the best choice. Hence, Service Level Agreement (SLA) can be utilized to construct a Cost Analysis Model [8] to balance the storage and computing service.

VI. PROTOTYPE CONSTRUCTION

In order to construct a platform to satisfy the above functions that we have described, three kinds of functional components are needed. The first one is service interface. As SNIA provides a Cloud Data Management Interface (CDMI) [17] to create, retrieve, update and delete data elements from the cloud, we can implement a functional interface according to CDMI. The second one is resource mapping and management in distributed environment. We utilize Google's MapReduce [18] and its open-source counterpart Hadoop [19] to express the allocation of virtualized resource while hiding the operational complexity of parallel execution across lots of smart nodes. The third one is an intelligent infrastructure that can seamlessly integrate storage nodes with computing nodes.

We take advantage of EUCALYPTUS [20] and content-aware network storage system [12] to construct a combined platform supporting service aware. As content-aware storage system is not suitable for cloud storage, we modified the architecture from following aspects. Firstly, the original platform only utilizes the content information that has been extracted from user data, while the service request information, context information and provenance information are ignored. So service aware processing is utilized to collect the above information in constructing a cloud storage model. Secondly, as the duplicate data in storage system consume numerous capacity and energy, content-aware storage system utilizes de-duplicate technology to lower energy consumption. But the hashing algorithms (MD5 or SHA-1) in detecting block boundaries need lots of computing resources and the original system only contain CPU resources. Hence, GPU computing resources are adopted to handle those data-parallel applications. Thirdly, content similarity retrieval is a key function in original system, which divides data into blocks, computes their identifiers (hashes of the block), and utilizes these identifiers to locate data. In cloud storage system, content indexing may consume lots of time to construct inverted index. So we distribute indexing to multiple machines for parallel processing. When users deliver query requests through service interface, content similarity retrieval is executed, meanwhile, those files that matching query requests and the related files that contain duplicate blocks (the same hashing value) are returned to users for browse.

VII. EXPERIMENTAL RESULTS

After the above modification, a computing-enhanced cloud storage prototype is constructed and experiments are implemented to measure the impact of computing-enhance service on cloud performance. The platform consists of 15 nodes in addition to one physical machine functioning as cloud controller to aware what kinds of service can be combined to satisfy user's request. Each node in the platform is composed of 4 cores 2.8 GHz CPUs and four 1T SATA disks, where 4 CentOS5.3 virtual machines can be started up in workstation running Xen 3.2.0. Meanwhile, Lucene [22] [23] is utilized as a retrieval facility to construct file's index and implement content similarity retrieval. As far as the GPU units are concerned, a GeForce 8600 GTS GPU was installed on one of the nodes along with CUDA 1.0 driver and runtime library [21].

TABLE I. SPEEDUP WITH DIFFERENT ACCELERATED METHOD

Computing-enhanced method	**Hashing (MD5) Speedup**	**Hashing (SHA-1) Speedup**	**Bloom Filter Speedup**
MapReduce	1.3	1.6	1.2
CPU+GPU	2.6	3.4	2.1
MapReduce+CPU+GPU	3.1	3.8	2.6

We use the performance that the original implementation running on content-aware storage system as the baseline to compute and compare the speedups achieved by computing-enhanced configurations. The speedup is defined as the ratio between original performance (such as implement time, storage capacity and throughput) and computing-enhanced performance. The final speedup is computed from the average results collected from 25 experiments. We confirm that this number of experiments is sufficient to reflect the performance in all sorts of experimental environment. Then two kinds of experiments are implemented to distinguish different application scenarios. The first one indicates the speedup with different accelerated method. As shown in table I, MapReduce is a method that distributes one workflow into multi-nodes to enhance processing efficiency. While GPU is a chip-level parallelization and its speedup is higher than MapReduce in current experiment. Hence the combination of MapReduce and GPU module can efficiently enhance the system performance.

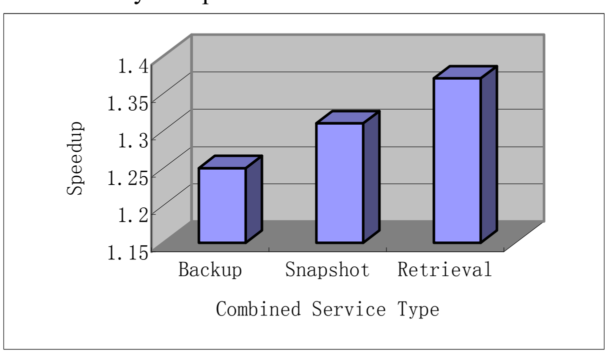

Figure 2. Speedup with different combined service

The second experiment scenario compares the speedup in different service combination strategy. As shown in Figure 2, the combined backup service needs encryption & decryption operation and consumes more time, its speedup is lower than others. As far as the combined snapshot service is concerned, de-duplicate is needed to decrease storage cost and the speedup is around 1.34. Because combined retrieval service can efficiently utilize MapReduce and GPU to accelerate the query performance, its speedup is the highest one among three combined service. The two experiments above indicate that the cloud storage model enhanced the performance of storage system by combining computing resources with storage resources.

VIII. CONCLUSION

In this paper, a novel cloud storage model is provided. It frees users from expensive storage management while also providing on-demand storage that can grow or shrink according to their requests. Besides the commonly used storage service, additional computing and retrieval service are extended to enhance the performance of system. As a highly-parallel device, GPU can support more generic functionality and is utilized as an important computing resource to enhance the storage performance in cloud storage model. While metadata plays an important role in managing resources and making storage strategy, a metadata-based service combination strategy is provided according to the service aware in this paper. The basic tests on prototype indicate that the novel computing-enhanced cloud storage model can efficiently satisfy user's complex request by delivering combined service.

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