Performance Evaluation of a Private Cloud Storage Infrastructure Service for Document Preservation

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Abstract — **Cloud computing platforms provide easy and transparent access to a company's storage infrastructure through services. Commonly known as Storage as a Service (STaaS), it allows users to store their data at remote disks and access them anytime from any place. On the other hand, with the deployment of Electronic Document Management (EDM) to manage the insertion, sharing, and retrieval of information assigned to a digital document it is necessary that the processes of searching, indexing and storage of digital documents are carried out efficiently. Besides the use of computational tools focused on archiving digital documents, the storage solution must provide reliability and authenticity on the availability of digital documents. In this scenario, this paper addresses the deployment project of a content-addressable storage infrastructure in a large company and conducts performance evaluation to measure the gains in availability, r/w access and scalability of the proposed solution.**

Keywords - cloud computing; cloud storage; content addressable storage; deduplication; electronic document management.

I. INTRODUCTION

The technological advancements in the last decade in different computational areas such as the Internet, programming languages, and on-demand services, have generated a need for storage systems for large amounts of digital data that support high performance, redundancy and scalability [1].

Currently it is possible to have access to information and digital documents regardless of their geographical location and they can be preserved for longer periods of time when compared to standard media. According to [2], "the issue of digital preservation presents itself as a real problem to be solved by the institutions, especially those that have a legal obligation to maintain long-term document".

The Directed Attached Storage (DAS) solution, widely used worldwide, has physical limitations due to a low capacity to support the expansion of storage drives, and presents fundamental flaws in terms of access security. Such technology should therefore not be used in production environments, especially those institutions that deal with classified documents.

The digital preservation must ensure that the content in digital format remain accessible over time and should provide reliability (reliability of a document as proof of what it is) and authenticity (trustworthiness over time) [3], factors that are related to digital document storage.

Cloud Computing portends a major change in how to store information and run applications. Instead of running programs and storing data on an individual desktop computer, everything is hosted in the cloud. Cloud computing lets you access all your applications and documents from anywhere in the world, freeing them from the edge of a physical computer a making it easier for group members in different locations to collaborate [4].

Cloud computing is a resource delivery and usage model to get resources (hardware, software, applications) through on-demand and at scale network as services in a shared, multi-tenant and elastic environment [5] and [6]. Computational capabilities in clouds rely in the concept of virtualization, which is based on several virtual machines providing services to consumers. Cloud computing aims to offer virtually unrestricted pay-per-use computational resources without the need to manage the underlying infrastructure.

This paper proposes the implementation of a system of content addressable storage (CAS) distributed with file-level deduplication, providing reliability and authenticity of stored digital documents, operating as a service in a private cloud, which is a cloud computing platform implemented within the corporate firewall, under the control of the organization.

The proposed solution is evaluated in a real-world scenario, the Court of Auditors of the State of Tocantins, Brazil (TCE-TO), and presents the gains related to the overall performance of the infrastructure, the expansion of the availability of the data and the scalability due to replication of objects to multiple CAS servers.

The results obtained at the end of this study demonstrate that the processes of searching, indexing and storing digital documents are realized with more effectiveness. For a benchmark, the results obtained are also compared with traditional block storage infrastructures.

II. CLOUD STORAGE

Cloud computing is typically defined as a specialized form of distributed computing that introduces utilization models for provisioning scalable and measured resources [7]. One of the primary uses of cloud computing is data storage. With cloud storage, data is stored on multiple third-party servers, rather than on the dedicated servers used in traditional networked data storage. STaaS (Storage as a Service) is a term used to describe a storage model where a business or organization (the client) rents or leases storage space from providers.

The deployment model refers to the location and management of the cloud infrastructure, which provides different levels of access and services. The four implementation models are categorized into public, private, hybrid, and community cloud. The private cloud model describes that a private cloud infrastructure is for the exclusive use of a company or person [8].

Storage as a Service has become popular because there is usually no start-up costs (e.g., servers, hard disks, IT staff and so on) involved. Businesses pay for the service based only on the amount of storage space used.

When storing data, the user sees a virtual server – that is, it appears as if the data is stored in a particular place with a specific name. But those place doesn't exist in reality. It's just a pseudonym used to reference virtual space carved out of the cloud. In reality, the user's data could be stored on any one or more of the computers used to create the cloud. Some key benefits of using cloud storage are [4]:

- Ease of management: the maintenance of the software, hardware and general infrastructure to support storage is drastically simplified by an application in the cloud.
- Cost effectiveness: for total cost of ownership, cloud storage is a clear winner. Elimination of the costly systems and the people required to maintain them typically provides organizations with significant cost saving that more than offset the fees for cloud storage
- Lower impact outages and upgrades: typically cloud computing provides cost effective redundancies in storage hardware. This translates into uninterrupted service during a planned or unplanned outage. This is also true for hardware upgrades which for the end user will no longer be visible.
- Disaster preparedness: off site storage isn't new. Cloud storage services not only keep your data off premise, but they also make their living at ensuring that they have redundancy and systems in place for disaster recovery.
- Simplified planning: cloud-based solutions are flexible and provide storage as needed. This eliminates the need to over provision for storage that may be needed to meet.

So, in general, cloud storage has both financial and security-associated advantages. Financially, virtual resources in the cloud are typically cheaper than dedicated physical resources connected to a personal computer or network. As for security, data stored in the cloud is secure from accidental erasure or hardware crashes, because it is duplicated across multiple physical machines; since multiple copies of the data are kept continually, the cloud continues to function as normal even if one or more machines go offline. If one machine crashes, the data is duplicated on other machines in the cloud.

A. *Content Addressable Storage*

In [9], CAS is defined as a storage device based in object, which has a unique address known as content address (CA - Content Address). Unlike location-based addresses, the addresses of content, once calculated, are not changed and always refer to the same content. In the event of a change in the contents of an object, a new CA is calculated and assigned to the new content. With this technology, it is straightforward to check if the data returned for a given document is exactly the same as the data that has been stored (authenticity) using the name or UUID (Universally Unique Identifier). The need for applications to know and manage the physical location of the information in the storage device is eliminated.

The integrity of a message (reliability) is guaranteed through an end-to-end communication process based on the content-MD5. The integrity of a message (reliability) is carried out through from a communication end-to-end that uses the MD5 to compute the content at 128-bit and the base64 to encode the data to transfer networked.

Even if an MD5 hash attack occurs and compromises the integrity of the content, there is also the procedure of content authenticity. For each reading procedure performed, the CAS device uses an hash algorithm to recalculate the address of the content of the object and compare the result with the address of the original content, that is, it has an implicit process of validation of the stored content.

The CAS technology is proposed as the storage infrastructure due to the fact that it allows direct access to the stored information and employs file-level deduplication, preserving the documents in an immutable way with reliability and authenticity.

III. RELATED WORK

The content-addressable storage (CAS) solution has been the target of a body of work that studies the problem of improving the performance of data traffic and preservation of digital data in storage devices. The paper [10] introduces a framework directed at storing objects to keep the digital data intact for long periods of time, based on the use of a content addressable storage system that is scalable and efficient. The article also discusses the preservation of data on storage devices by checking data integrity during archiving, location and recovery.

The use of cloud storage architecture for document archiving is recommended in [11], as well as the use of document replication mechanisms among CAS servers (to minimize service unavailability and the need for daily backups, and to improve scalability in a distributed storage environment). However, it becomes necessary to assess whether the structure of CAS provides real performance gains when compared to the direct-attached storage architecture.

As well as the studies presented by [10] and [12], aproach of this dissertation is directed to the digital preservation facing its management on the principles of authenticity and integrity in a storage structure of addressable content in which it will be applied a function hashing using an MD5 algorithm to identify similarity and eliminate redundancy when storing objects.

The authors [12] show that hashing functions, such as MD5 and SHA-1, are recommended for use in systems that need to uniquely identify a file, block, or byte and thus avoid storing identical data. A comparative analysis is also performed between these two hash functions, the results of which demonstrate that MD5 provides a better calculation speed to generate the content address of each data block input and thus detect possible duplications in the system compared to SHA- 1. Based on this context, the authors present a distributed deduplication storage system designed to provide gains with flow and scalability.

In [13], the authors develop a tool to assess the performance of services directed at object storage devices. It was stated that the following metrics should be considered in order to properly evaluate a solution: mean response time (elapsed time between the beginning and the completion of an operation), throughput (total number of transactions per second) and bandwidth (total amount of data transferred per second). The experimental setup consisted of 23 read transactions of 64 KB objects in 128 different containers (storage "directories") in a total time of 300 seconds in CAS servers. However, according to the authors, this tool is still in the development phase and is not available for analysis.

In [14], it is stated that the three major metrics that should be taken into account by organizations wanting to take advantage of cloud storage are: performance, availability, and scalability. It argues that an architecture aimed at cloud storage must offer "unlimited" storage capacity, as well as lay the foundation for the complete elimination of the need for daily backups through cloud data replication mechanisms

Both [13] and [14] point out that to analyze a storage structure in a private cloud, one should measure the response time, throughput and bandwidth using the following variables: concurrency (multiple concurrent connections), file size (from very small to very large) and the type of workload (reading, writing and mixed).

IV. EXPERIMENTAL ENVIRONMENT

In order to propose a storage solution that could be employed in TCE-TO, a test scenario with the same logical structure and considering the same type of devices was setup. This experimental environment consists of three data storage structures. In this environment there is one file server with block-level deduplication (block size of 4 KB), in which the “Opendedup” [15], software is used to provide a storage volume with inline deduplication (synchronous), which is responsible for the interaction between the application and the operating system through a one gigabit Ethernet interface.

As illustrated in Fig. 1, there will also be 1 file server per block with an operating system that has 1 Gigabit Ethernet interface, and 3 (IP: 192.1680.89; IP: 192.168.0.90 and IP: 192.168.0.91) CAS servers with 4 Gigabit Ethernet interfaces belonging to the server, which will be grouped for load balancing between network interfaces and fault tolerance.

All CAS servers will be associated in a cluster as "Tdinfocascluster" with the local replication procedure being handled by the network. The LAN interconnecting the web server and the benchmark computer is the same LAN that connects all the user desktops on TCE-TO, thus providing a realistic network traffic load scenario. All communication via the web is through a communication channel that uses a cryptographic function to protect the transferred data and metadata. The data storage servers are connected using the same subnet IP addresses and have direct communication with the web server, which is then connected to a computer with the benchmark software responsible for carrying out the evaluation process.

The goal of the experiment is to measure the performance, availability and scalability of the different storage structures. Table 1 presents the computational resources used in the testing environment.

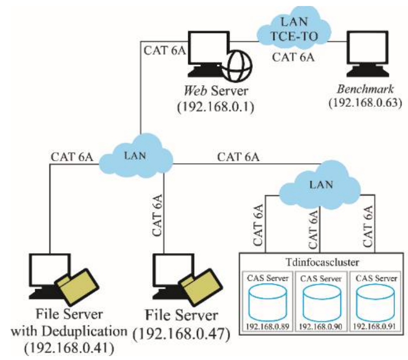

Figure 1. Evaluation Environment.

Finally, in the actual configuration, the storage service is provided by a private cloud as a web service. Moreover, each CAS server is allocated in separate buildings (within a radius of 500 meters). Moreover, the global distribution is present in the solution by configuration, thus, the administrator determines which servers are active and able to receive the files, and these servers can be in any network, local or global. Regarding allocation on demand, it is important to note that the servers can be used by other public service agencies when not in service to the TCE-TO. When storage space is required by enterprise (i.e. demand for the storage service increases), the servers will prioritize meeting the internal demand. Therefore, in the cloud, storage space is allocated and released on-demand.

Furthermore, there is no need to implement any pricing model because it is a private cloud belonging to the TCE-TO.

TABLE I. EQUIPMENT USED IN TESTS.

Hardware	Software / Tool
Server Dell PowerEdge R710 - Xeon(R) E5506 2.13GHz, RAM 24 GB	Apache 2.2.22 Debian 7.4
Server Dell PowerEdge R710 - Xeon(R) E5506 2.13GHz, RAM 24 GB	Opendedup 2.9.2
Server Dell PowerEdge R710 - Xeon(R) E5506 2.13GHz, RAM 24 GB	Siege 2.70
Itautec LX201 – Xeon 5000, 3.2 GHz, RAM 4 GB	Windows Server 2008 R2 Enterprise
HP ProLiant DL360e Gen8 Server	HP iLO Manag.

A. Methodology

Simulations are run in order to measure the performance, availability and scalability of all storage structures, through the software "Siege". This software is a benchmarking tool for carrying out HTTP load tests to determine the maximum traffic load that can be served by the storage system. The command line options used with Siege were [16]:

- -d: set the delay between user requests
- -c: define the number of simultaneous users (concurrent connections)
- -t: set the total simulation time

As described in Section 3, the metrics to be measured are the response time and bandwidth while varying the concurrency (multiple simultaneous connections), file size (varying from very small to very large files) and the type of workload (reads, writes, mixed) of the storage structures.

V. EVALUATION

In this section the performance, availability, and scalability of the proposed solution are assessed. The metrics used for the evaluation of these parameters are the throughput and response time. The tests conducted covered the reading and writing of multiple documents.

Throughout this section, the term "transaction" refers to the number of operations (read/write) concluded successfully between the benchmark computer and the data storage structure. A "fault transaction" is defined as an operation that could not be completed between the benchmark computer and one of the storage servers.

The number of connections established at a certain point in time is defined as the number of users connected between the benchmark and the respective storage structure, with respect to the beginning of a test cycle with Siege. Moreover, all the concurrent connections are initialized at the same time. Finally, the data traffic limit is set to one Gbps, which is the bandwidth limit of the deployed network (gigabit Ethernet).

A. Evaluation Environment

The performance test considers reading and writing over multiple concurrent connections, accessing multiple documents with varying sizes. In order to accurately simulate the real scenario, a document set was generated based on the real environment. The document format used was the PDF. This is the adopted standard by TCE-TO. Fig. 2 presents the histogram of frequency distribution of the size of the documents whose tests were performed.

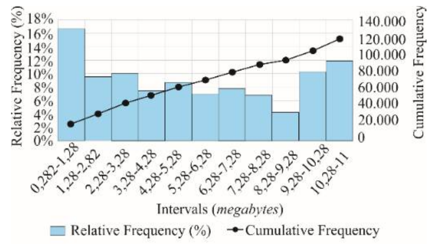

Figure 2. Histogram of Frequency Distribution of the Size of the Documents.

In total, 10 cycles of executions were carried out. The first cycle used a single connection, doubling with each subsequent cycle until 512 parallel connections were achieved. The independent replication method was used for each reading and writing test in order to obtain confidence intervals with 95% confidence level (reliability), in a total of 5 independent data collections.

The results presented were obtained in the environment discussed in Section 4. In order to ensure an evaluation with realistic background traffic, the measurements were made during work hours between 08:00 and 18:00, over a period of 60 days, with every measurement experiment for each of the different operation modes lasting 60 seconds.

One of the main advantages of cloud storage is the possibility of increasing its service capacity on demand. To test the scalability, an analysis was performed to determine how many objects could be added to the cloud (server cluster for object storage) and whether the performance remained constant as the number of CAS servers was increased. The availability of the cloud at different workloads was also assessed.

For the evaluation of the object storage solution (CAS), a single container (storage "directory") was created to receive all the saved documents. In addition, a comparison was made between block and object storage. Lastly, block-level deduplication with 4 KB block size was tested. The focus of this comparison was to obtain the number of read/write transactions per second supported by the storage solutions and their service availability.

As discussed in [17], the goal of this evaluation was to demonstrate through the results that the performance of object storage is comparable and in some cases better than block storage systems. All parameters used in the simulations are based on the literature [13] and [14].

B. Evaluation of the Reading Procedure in Multiple Documents

In the results in this section that show the average number of transactions in the process of reading/writing multiple documents, the horizontal axis is the number of concurrent connections and the vertical axis indicates the number of successful transactions (on the left) and the percentage of service availability (on the right).

In the results showing the average throughput and response time for reading/writing multiple documents, the horizontal axis is the number of concurrent connections and the vertical axis shows the average throughput (left) and response time (right).

As seen in Fig. 3, the results obtained indicate that for transaction volume and service availability while reading documents of varying sizes (kilobytes and megabytes) in a single container, storage per objects is recommended for up to 64 concurrent connections with 100% availability.

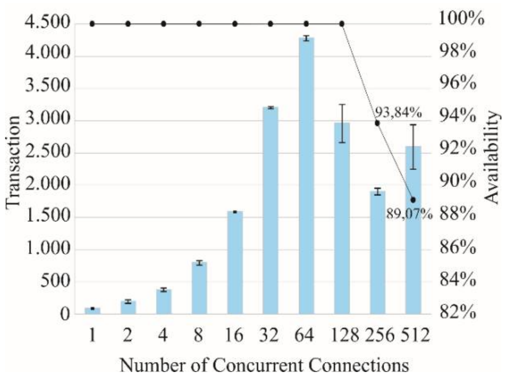

Figure 3. Average of Transactions in the Process of Reading Multiple Documents with Varying Sizes.

By analyzing Fig. 3, one can see that the average number of transactions was 4,278.40 for 64 concurrent connections and that the service availability and number of transactions decrease as the number of concurrent connections increases. This situation occurs because the number of transactions that can be performed on this storage structure has reached its data traffic limit.

Fig. 4 shows the average throughput and response time for reading multiple documents. In this environment the average response time is maintained below 6ms up to 128 concurrent connections, between 128 and 256 this time doubles.

Therefore, it is observed that the throughput grows up to a total of 128 concurrent connections and from this point on a sharp decrease in the number of transactions that can be performed takes place.

After this point, the response time doubles for 256 concurrent connections and with 512 concurrent connections the number of fault transactions grows. This occurs because there is a large amount of network traffic due to the number of read operations with documents of varying sizes, the limit supported between the web server and CAS server having already been reached which directly impacts the number of transactions that can be performed.

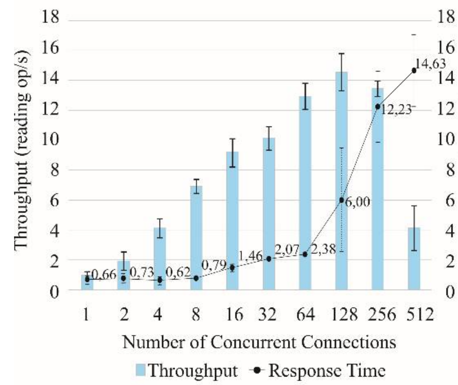

Figure 4. Throughput Average and Response Time for Reading Multiple Documents with Varying Sizes.

Fig. 5 illustrates that the storage per objects represented by "Average CAS Transactions" is similar to the other structures up to 16 concurrent connections. After this, the number of transactions with this structure increases up to 64 concurrent connections with an average of 100% service availability. This growth in the number of transactions occurs due to the distributed storage among the 3 CAS servers, namely scalability.

From Fig. 5 one can also conclude that both the structure per block represented by the "Average transactions per block" and the structure with deduplication represented by the "Average transactions deduplication" suffer from a reduction in the number of transactions when reading multiple documents with over 64 concurrent connections. This occurs because the response time for these servers when reading from multiple documents with varying sizes is higher than CAS server.

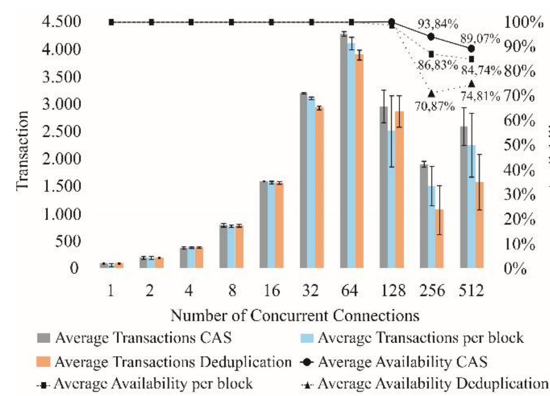

Figure 5. Average Transactions and Availability for Reading Multiple Documents with Varying Sizes in Distinct Scenarios.

For the file server with deduplication, as the number of concurrent connections increases it takes more time to process all of the transactions which negatively impacts the number of supported transactions and service availability. The average service availability is maintained at 100% up to 128 connections. By increasing the number of concurrent connections, the service availability reduces and, in the worst case, decreases 29,13%.

C. *Evaluation of the Writing Procedure in Multiple Documents*

Tests conducted for writing documents with distinct sizes through multiple concurrent connections also showed that storage per object is the most recommendable solution. Fig. 6 illustrates that as the number of concurrent connections increases, the number of transactions grows up to a threshold of 128 concurrent connections.

At that level one sees an average of 5,205.40 transactions and service availability of 100%. Above 128 concurrent connections, service availability decreases to 99.72% with 256 concurrent connections and 97.54% with 512 concurrent connections. Another negative point is that there was a considerable reduction in the number of transactions, yet the throughput was maintained as can be seen in Fig. 7. The reduction in the number of transactions occurs because the data traffic threshold has been reached.

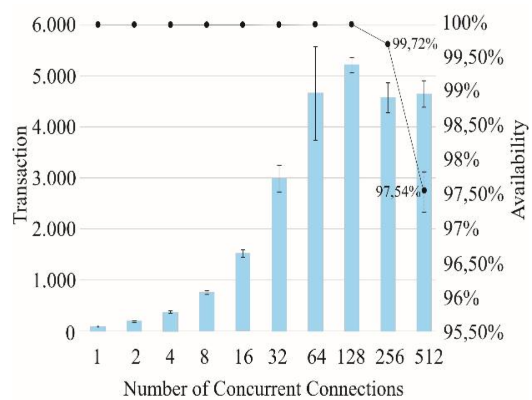

Figure 6. Average of Transactions in the Writing Process of Multiple Documents with Varying Sizes.

Fig. 6 shows that throughput increases up to 128 concurrent connections and the response time remains below 0,94 ms. Above this number of concurrent connections, the average throughput decays but remains near the limit and response time grows linearly. In this way it is possible to conclude that there will be no more performance gain after 128 concurrent connections.

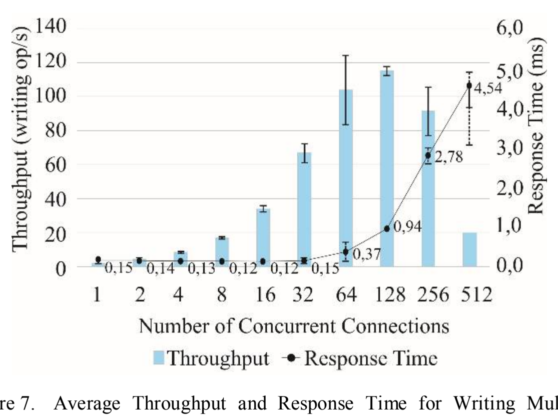

Figure 7. Average Throughput and Response Time for Writing Multiple Documents with Varying Sizes.

Fig. 8 shows the average number of transactions and availability of services across 3 structures, in which the storage by objects has maintained its average availability in all cases up to 128 concurrent connections. In this scenario the CAS server presented a very relevant feature compared to the other structures in that it kept the number of transactions performed close to its limit, or in other words, its scalability when running multiple connections with multiple documents.

Fig. 8 illustrates that the results obtained from the data storage with deduplication represented by the "Average Transactions Deduplication" compared to the other structures analyzed has a high confidence interval after 64 concurrent connections and low service availability as the number of concurrent connections exceeded the acceptable limit of transactions, which impacted the results obtained for each test cycle.

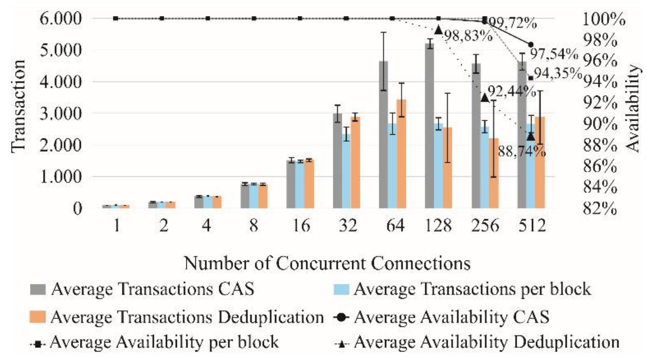

Figure 8. Average Transactions and Availability for Writing of Multiple Documents with Varying Sizes in Distinct Scenarios.

Finally, it is worth mentioning that in this environment, for each cycle after 64 concurrent connections, the web server locked up both with the block structure and the block structure with deduplication, the only solution being to reboot the server. No studies were performed to identify the reason for the web server freeze.

An important lesson is that the content-addressable storage architecture proved to be the most viable for read transactions with 64 concurrent connections and writing with 128 concurrent connections, with 100% service availability for each of the cases analyzed.

D. *Scalability and Replication*

Scalability is obtained by performing the reading and insertion of digital documents over an object structure with horizontally distributed container(s). In this way, search procedures, indexing and storage based on the ID of a digital document result in less network traffic than with hierarchical file systems.

A comparison was created to show off the capacity supported by each of the object storage servers when reading multiple documents. Based on the example in Fig. 9, it can be observed that by adding 2 more servers, the throughput grows until it reaches 128 concurrent connections, the limit reached in this test environment.

Above this value one can conclude that as more connections are made, the number of fault transactions increases once the throughput has reached its limit.

In the event of unavailability of a storage unit, the others devices belonging to the group continue to operate without impacting service availability.

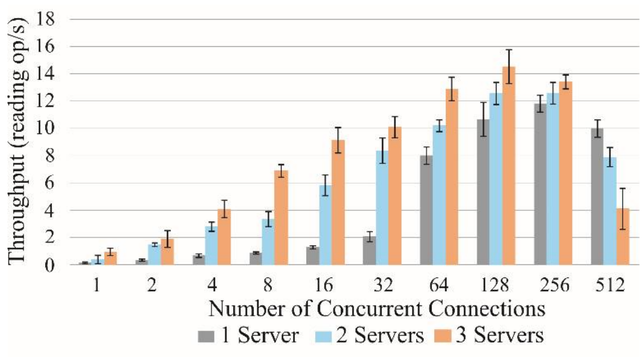

Figure 9. Average Throughput in a Distributed System.

If a total failure occurs and a CAS server requires replacement, a process of recovery begins which recovers the data from the other 2 online servers.

VI. CONCLUSION

With the object storage service becoming increasingly accepted as a substitute for traditional block storage systems, it is important to measure the performance of these services effectively. This paper proposes the deployment of content addressable storage (CAS) architecture with file-level deduplication for digital preservation in a private cloud platform and evaluates the resulting system.

The scenario presented in section 5.2 shows an increase of 15.36% in the percentage of read transactions and 48.67% in the percentage of write transactions compared to legacy (DAS) setups, with a storage per block structure and block-level deduplication with a size of 4 KB of fixed length.

We conclude that the object-based storage architecture enables real gains in the number of transactions carried out with marked improvement in both reading and writing until the flow rate threshold is reached. On the other hand, it was observed that when the number of connections is increased beyond the limit obtained for each test environment, the response time is prolonged and the data transfer rate is kept.

Similarly, the test for scalability also demonstrates that there is a growth in the number of transactions to the extent that more CAS servers must be added to reach the apex of data traffic supported by this infrastructure.

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