COMPARATIVE REVIEW OF WELL-KNOWN CLOUD SERVICE PROVIDERS (CSPS)

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ABSTRACT- *Cloud Computing gained massive interest during the last few years. It has recently become a hot topic in the IT revolution as it grows quickly and sharply. Yet, there are limited studies that focus on comparing Cloud Service Providers (CSPs). A technical review of well-known CSPs has been applied to underpin this research. This paper aims to technically review well-known CSPs based on the following criteria: a) infrastructure and computing services, b) storage technologies, c) developers' environments and support, d) security, and e) Price and payments plans. Beside contribution to the body of knowledge, this study delivers a review of well-known CSPs. The findings highlighted that there are some similarities among CSPs regarding concepts. However, they adopt different approaches of their services offered to their clients.*

Keywords- Cloud Computing, Technical Review, Cloud-based applications, Architectures; Models.

1. INTRODUCTION

Cloud Computing is a new emerging technology in BIM research and development [1]. The Cloud concept was introduced in 2004 [2]. However, awareness of Cloud had increased since 2007, when IBM and Google announced a Cloud collaboration project [3]. Cloud computing has recently become a phenomenon in the IT revolution as it grows quickly and sharply [4]. The use of Cloud is not restricted to a particular business domain. It has been implemented and used to underpin and support various software applications and platforms. It has the potential to transfer the IT industry making the software even more effective, attractive and cost less than traditional software [5]. Therefore, it is the most demanded advanced technology throughout the world. As a business paradigm and new technology, it became dominant and taken commercial computing to another level. Cloud offers easy access to a Cloud provider's high –performance and storage infrastructure over the Internet. One of the significant benefits of the Cloud is to hide the complexity of IT infrastructure management for Cloud users [6]. Lately, there is a remarkable development and use of Cloud services by general users and also by governments, Despite positive results, there is a challenge in both theory and practice to find a proper Cloud provider that meet individual requirements of an organization or a government [7].

Due to its status as a new concept in the latest years [8], there are many definitions of the term Cloud computing reported in [9, 10]. However, the majority of researchers have agreed upon the NIST definition [11] whereby "Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction". However, Cloud can be seen as a high virtualization for datacenters infrastructure that are distributed geographically and linked via high bandwidth network cables which provides variety of virtualized services ranging from providing whole infrastructures to small software applications as well as different types of services such as high-performance computing and massive scalable storage services based on a pay-per-use model.

2. RELATED STUDIES

This section provides an overview of related studies in this field. It first introduces Cloud Computing then it highlights existing research conducted in this area.

1.1. .Cloud Infrastructure

In general, Cloud infrastructure can be divided into four main layers: hardware layer, infrastructure layer, platform layer, and application layer.

- Hardware layer: the responsibility of the hardware layer is to manage the Cloud's physical resources. Those resources include physical servers, cooling systems and physical network equipment [12].
- Infrastructure layer: infrastructure layer is also called the virtualization layer that creates a pool of computing resources and storage solutions, achieved via the process of partitioning physical resources for the use of virtualization technology, e.g. Xen and VMware and is considered to be an essential part of the Cloud [12].
- Platform layer: the platform is built on top of the infrastructure layer, and consists of applications frameworks and operating systems. [12].
- Application layer: this layer exists at the top level of the Cloud hierarchy. It consists of different Cloud-based applications and traditional applications [12].

In general Cloud services delivery can be divided into three different models: Infrastructure-as-a-Service "IaaS", Platform-as-a-Service "PaaS" and Software-as-a-Service "SaaS" [13]:

- **IaaS:** is the delivery of complete computing infrastructure Over the Internet. Delivered services include machine instances that behave similarly to dedicated servers. These instances are completely controlled by developers who are fully responsible for its operation and manually handle Scalability process. IaaS is mainly for developers who want to develop their solutions on the top of the infrastructure and does not want to use any other of Cloud server providers tools or (Application Program Interface) APIs [14].
- **PaaS:** is higher level than IaaS as it provides a full/partial application development environment under an abstraction of machine instances. The developed application/solutions run on anonymous data centers. Moreover, developers must handle some of the constraints that the development environment enforces on their solution design [14].
- **SaaS:** are well-developed applications that offer to users customized and scalable software resources and storage. Thus, this differentiates SaaS from traditional web applications [14].

1.2. Common Cloud Service Providers (CSPs)

Due to the popularity of the Cloud Computing concept as a possible new business model, developed based on distributed processing, parallel processing, and grid computing, many giant IT companies, such as Amazon, Google, Microsoft, etc. have been seeking to develop Cloud computing technologies and products [8]. This section highlights several examples of famous CSPs, offering a general overview, and cross-comparative analysis between them.

- **Amazon Web Services (AWS): AWS** is a group of Cloud services that offers Cloud-based storage, Cloud-based computation, and other useful functionalities that enable Cloud users to set up applications and services based on on-demand protocols at service linked prices. AWS offers can be accessed over HTTP, using REST and SOAP protocols [12, 15].
- Microsoft Windows Azure platform: There are three principal components of Microsoft's Azure platform, and each one offers a precise set of services to Cloud users. These components are: (i) The Windows-based environment that is used to run applications and store data in data centers; (ii) SQL Azure offers Cloud-based data services based on the SQL Server; (iii) .NET Services that provide distributed services as infrastructure to both local applications and Cloud-based applications, which can be run on the Windows Azure platform [12, 16].
- **Google Cloud Platform (GCP**): GCP is Google's hosting service for web applications. It uses a pre-defined runtime environment to allow the development and deployment of Cloud-based applications. It offers different Cloud-based hosting services from other Cloud providers such as Amazon Web Services that operate on an IaaS level. GCP provides an application infrastructure based on PaaS level. In other words, GCP provides the deployed application with a set of application-oriented services due to the abstraction from the underneath hardware and operating system layers. This approach is appropriate for such a Cloud-based applications developers. The primary driver behind the GCP is its focus on three aspects: scalability, usage-based infrastructure, payment [13, 17].
- **Rackspace:** Rackspace has delivered enterprise-level hosting services to businesses of all sizes and types worldwide, since 1998. Rackspace is the global leader in hybrid cloud and the founder of OpenStack, the open-source operating system for the cloud. It operates across four continents and integrates the best technologies to meet specific customers' needs by delivering best-fit solutions and leveraging the public cloud portfolio, private cloud, dedicated servers, and a combination of platforms [18].
- **OpenStack:** In 2010, a collaboration between Rackspace Hosting and NASA resulted in the launch of an open-source environment to create OpenStack [19]. According to [20] OpenStack's mission is to offer a universal Open Source cloud computing platform to meet the requirements of public and private cloud providers, taking into account the simplicity of implementation and massive scalability. OpenStack operates on four core principles: open source, open design, open development, and open community. OpenStack is a Cloud operating system developed by datacenters. Furthermore, it is also seen as at the core of Cloud operations, enabling vendors to build various software to run in the Cloud. OpenStack consists of three main modules: Nova, for computing; Swift, for object storage; and Glance, an image service module [19].

1.3. Existing Comparative studies among Cloud Services Providers (CSPs)

Several comparative reports and white papers exist with which to assess Cloud providers. Authors of these are either interested in Clouds options used via blogs, company websites, or are professional academics in the field. Some comparisons have been provided. For example, [21] aimed to offer a starting point for those who were new to Cloud, or wanted to understand the options and services offered by Cloud providers. In order to facilitate the comparison among Cloud providers, he created dimensions to reflect important aspects of Cloud computing, including cost reduction; economic benefits of scaling; service levels for the customers; ease of use and flexibility when configuring servers; security; compliance; and technical support. He established fourteen criteria: (i) The price plan; (ii) The average monthly price; (iii) the Service Level Agreement (SLA); (iv) data center numbers; (v) certification and scale up (when paying more money was it possible to have extra storage and CPU etc.; (vi) scale out (if it was possible to deploy new server instances quickly); (vii) support and monitoring; (viii) APIs (was there an existing API which helped development); (ix) free trial (what did the customer get during a free trial); (x) operating systems support; (xi) instance type numbers; (xii) different server configurations available; (xiii) outbound data transfer costs; and (xiv) inbound data transfer cost. However, this study does not intend to undertake an in-depth technical comparison of different CSPs, and it will focus on reviewing existing studies and documentation provided by CSPs.

3. METHODOLOGY

Limited efforts are comparing different Cloud Service providers (CSP). However, to achieve the aim of this paper, a systematic review is conducted. This paper focuses on comparing well-known CSPs such as: Amazon, Microsoft Azure Google cloud platform. At this stage, this study does not intend to undertake an in-depth technical comparison of chosen CSPs; the following section compares CPSs from a documentation perspective. It considers the following parameters (infrastructure and computing services, networking technologies, storage technologies, developers' environment and support, and security).

4. RESULTS AND DISCUSSION

This section compares CPSs from a documentation perspective. It considers the following parameters; (4.1) infrastructure and computing services, (4.2) networking technologies, (4.3) storage technologies, (4.4) developers' environment and support, (4.5) security, and (4.6) price and payments plans:

4.1. Infrastructure and computing services

First, Amazon Elastic Compute Cloud [22] allows Cloud users to initiate and manage server instances at data centers, using APIs, tools, and utilities. EC2 uses a Xen virtualization engine, which runs on the top of this, and EC2 instances as a virtual machine. Users can upload and edit software after creating and initiating a new instance. When changes are complete, software is then packed to deliver a new machine image. Therefore, with this tool, it is possible to launch an identical copy at any time. Thus, almost all users have the feature of full control over the entire software stack on EC2 instances. EC2 supports place instances in multiple locations consisting of regions and availability zones. Regions are distributed geographically and comprise one or more availability zones, which are distinctive locations engineered to be immune from failure in other availability zones. They also provide network connectivity to other availability zones in the same region at a low cost. EC2 stores and retrieves machine images using Amazon S3 [12].

Nonetheless, Google Cloud Platform (GCP) in the Google App Engine (GAE) runtime environment presents areas in which deployed applications are executed. These applications do not run constantly if no invocation process has been made; they only run once an HTTP request is processed to the GCP through a web browser or other interface. When an HTTP request is made, the request handler forwards it to the GCP, which selects a server from the many servers running on the Google infrastructure; the application is then instantly deployed and executed during a limited time. The application Cloud then performs computing codes and returns results to the Request Handler, which forwards an HTTP response to the client [23]. It is crucial to highlight that the deployed application is embedded and runs entirely in a secured sandbox environment, assuming requests are still coming in and that the application is working on processing codes. Applications should only compute and run when there is a need, otherwise precious computing power and memory are being allocated unnecessarily. This paradigm shows the potential scalability of GCP. The ability to run multiple independent instances of a deployed application on different servers guarantees good levels of scalability [23].

Nevertheless, there are some limitations to this highly flexible application execution paradigm; e.g. requests are processed within a timeframe that is shorter than 30 seconds, after which the response has to be returned to the client before the application is again removed from the GCP. The application is deployed and started each time a request is processed; hence, additional time is needed to ensure the application is up and running in the GCP. However, the GCP aims to resolve this problem by caching the application in the server memory for as long as possible, adjusting to allow several subsequent requests in the same application [13]. Moreover, the GCP offers many services and links to all Google services APIs, e.g. Google Mail, Maps, and Google search engine, etc. The following are examples of services offered most directly to the developed prototype: Memcache, Url fetch, Mail, XMPP, Images, Users, OAuth, administration console [23].

Rackspace provides Cloud Servers that are flexible and scalable and allow users to spin up to hundreds of servers in minutes. It can be scaled up when users need power, and down when they do not. These Cloud servers were built entirely with RAID 10-protected, data-center-grade SSDs, Powerful Intel Xeon processors, and 40 Gigabits per second of highly available network throughput to every host machine. Users deliver Rackspace’s Cloud servers in minutes, to quickly scale capacity up and down [18]. OpenStack provides two computing modules: (a) Image Service model called (Glance): this provides a catalog and repository for virtual disk images. These disk images are most commonly used in OpenStack Compute. While this service is technically optional, any sizable cloud will require it; (b) Compute model called (Nova) provides virtual servers on demand [19].

4.2. Storage technologies

First, we consider Amazon Simple Storage Service [24], which stores data in the form of objects grouped in buckets. The size of each object ranges from 1byte to 5 GB of data. URI pathnames are essential to determining object names and must be explicitly created before using buckets. Buckets can be stored in one or several regions. The user should decide whether to choose these regions to enhance latency, reduce costs or address regulatory requirements [12]. Conversely, Windows Azure stores data in blobs, tables and queues. Data can be accessed over the internet via HTTP/HTTPS and the RESTful protocol. The Azure database uses the Microsoft SQL Server to provide a Database Management System (DBMS) inside the Cloud. This data can be accessed using ADO.NET and different data access interfaces compatible with Windows. It is also possible for users to use on-premises software to work with Cloud information. “Huron” Data Sync is used to synchronize relational data across different on-premise DBMSs [12].

Second, GCP Storage technologies. Google Cloud provide three types of storage solutions over its infrastructure: (a) Datastore: GCP uses a storage approach, called Bigtable [25], for data persistence. This storage approach differs from the Relational database approach. Data is stored in entities instead of the rows found in the relational database approach. Entities are always associated with a certain type. These entities have properties, that act in a manner similar to columns in the relational database scheme [13]. (b) Google Cloud SQL: This data storage solution was developed to form the MySQL database in the Google Cloud. It does not require an installation of software or maintenance; thus it is easy to use and ideal for small-medium applications. In addition to having full capabilities and functionalities, it has additional functionalities. The creation and management of these instances can be done via the Google Developer Console. The user can choose their hosting datacentres [23]. (c) Blobstore: The Blobstore storage API allows deployed application to assist large data objects that are much larger than the object size allows in the Datastore. These “Blobs” are valuable when serving large data files such as videos, images or in this case BIM models. They allow users to upload large files through an HTTP request [23].

Rackspace offers four storage technologies: (a) Cloud backup: this technology works on a file-level backup and restores capabilities to help safeguard customers' businesses. Users have the option to encrypt files using AES-256 encryption, and can automatically compress and de-duplicate files; (b) Cloud Block Storage: this technology provides a consistent and reliable storage performance. Customers can create and delete volumes in high-performance standards: (c) Cloud Files: offer unlimited, on-demand storage for users' files and media, serving customer content around the world at rapid speeds via the Akamai Content Delivery Network (CDN). Access to this technology is via Control Panel or API; (d) Cloud Databases: This technology delivers faster applications with Cloud databases, offering high-performance MySQL databases, with built-in redundancy and automated configurations included [18]. However, According to Ohlhorst [19], OpenStack storage implements two storage technologies: (a) Object Storage (Swift): allowing users to store or retrieve files, but not to mount directories like a file server; (b) Block Storage (Cinder): providing persistent block storage to guest Virtual Machines (VMs). This project was developed using code originally in Nova. It offers block storage or volumes, not file systems, like the Network File System (NFS).

4.3. Developers' environments and support

Most Cloud Providers offer on-demand access to a wide range of cloud infrastructure services, charging only for the resources used. By only providing resources throughout the duration of development phases or test runs, researchers can achieve important savings, as compared to investing upfront in traditional hardware. Developers primarily use local laptops or desktops to run development environments. This is typically the case where the Interactive Development Environment (IDE) is installed, where unit tests are run, and where source code is checked in, etc. However, there are several cases where on-demand development environments are hosted in the Cloud.

With Amazon Web Services (AWS), a developer can access a variety of different instance types, some with very specific hardware configurations. In the case of more complex working environments, AWS Cloud Formation makes it easy to arrange collections of AWS resources. The developer can code against and control IT infrastructure, whether the target platform for his/her project is AWS, or if the project involves orchestrating resources in AWS. In such cases, the developer can use various AWS SDKs to integrate their applications with AWS APIs easily, thereby removing the coding complexity relating to authentication, retries, error handling, etc. AWS SDK Tools are available for multiple languages: Java, .Net, PHP, Ruby, and for mobile platforms: Android and iOS. AWS also offers tools such as the AWS Toolkit for Visual Studio, and the AWS Toolkit for Eclipse, which makes it easier to interact with AWS from within the developer's IDEs [26]. For example, Windows Azure supports the following development environments: .NET framework built applications, Visual Basic, C++, C#, etc. and general purpose programs [12]. Alternatively, developers can use ASP.NET and the Windows Communication Foundation (WCF) to create Cloud applications and to manage independent background process applications as a companion for both applications.

The GAE environment was established over Google servers according to the programming language selected and used for developing and deploying Cloud applications. For instance, a Java Virtual Machine (JVM) was provided when using Java or other languages that support Java-based compliers (JRuby, Rhino and Groovy). A framework for rich web applications is also offered through Google Web Toolkit (GWT), and a Python-based environment is provided when using Python and related framework [13]. Nevertheless, Rackspace offers "Rackspace Templates" supporting developers who seek simplicity. The Rackspace Cloud Control Panel can be used to spin a pre-built, pre-validated stack in minutes. A developer simply clicks a few buttons and provides some basic information to get started. Rackspace builds standard stacks using industry best practices and has a growing catalog that includes WordPress, LAMP, Drupal, PHP, Ruby on Rails, MySQL, MongoDB, Cassandra, and more [18]. Finally, OpenStack provides a modular form called "Dashboard (Horizon)". This is a Web-based user interface for all OpenStack services. With this Web GUI, it is possible to perform most cloud operations; i.e. assigning IP addresses, launching an instance, and setting access controls [19].

4.4. Security

In terms of security aspects, the Amazon Virtual Private Cloud [27] provides a secure bridge between AWS Clouds, and an enterprise's IT infrastructure. It allows connection between an enterprises' infrastructure and a set of isolated AWS compute resources via a Virtual Private Network (VPN), as well as allowing an extension to management capabilities. These management capabilities can either be security services or firewalls. Amazon also has a management tool, known as "CloudWatch", which is very useful for collecting raw data from connected AWS services, e.g. Amazon EC2. After collecting raw data, it is processed into readable real-time metrics. These metrics refer to EC2, and contain CPU utilization and network in/out bytes disk read/write operations, etc. [12]. According to Arredondo [28], as recommended by the ISO 27001 standard, Rackspace adopts a security management model comprised of the following main stages: Plan, Do, Check, and Act. Their Customer Security Program is built on the foundation of this model and combines Rackspace expertise with technology and services. Whereas in OpenStack, "Keystone" is a security model providing authentication and authorization for all OpenStack services. It also delivers a catalog of services within a particular OpenStack Cloud [19]. Finally, security aspects associated with the majority of commercial CSPs must be complied with, as stated in the ISO 27001 standard [29].

4.5. Price and payment plans

Rodrigues T [21] determined some interesting points. First, that there was a considerable variation in Cloud providers' prices ranging from 40$ to 274$. The second point was that most Cloud providers claimed 100% uptime SLA, which might reduce fear when moving towards the Cloud. The third point was that many Cloud companies did not provide customers with a free trial to experiment with their Cloud platforms. However, it was possible to trial the platform for a small amount of money on a "pay-as-you-go" basis. The fourth point he made, was that certain tools were useful when comparing Cloud services providers, such as CloudSleuth [30].

Moreover, Li, et al. [31] conducted a piece of research named "CloudCmp", which aimed to compare different Cloud providers. CloudCmp sought to provide a systematic comparison of the cost and performance of selected Cloud Providers. These were interesting findings as outlined: (i) Regarding cost-effectiveness; Cloud instances were not cost effective. For instance, although it was only 30% more expensive, Rackspace's Cloud instances rose twice as fast as Amazon; (ii) Microsoft Azure was able to fully utilise the physical machine when there was no competition for local resources. Thus, at low cost, an instance could achieve high performance; (iii) there was a significant diversity across the Cloud providers in terms of storage services, e.g. Amazon's table query operations were faster than those of the others; and (iv) although the intra-data center traffic was free of charge, all the Cloud providers compared offered different intra-data center bandwidth, e.g. The bandwidth of Microsoft Azure was three times lower on average than Amazon's bandwidth. They argued that the time has now arrived for computing-as-a-utility and that CloudCmp could be extended to measure other Cloud providers. However, OpenStack provides open services that are free of charge [19].

Table 1 Summary of Technical Review Well-Known CSPs

	Amazon Web Services (AWS)	Microsoft Windows Azure	Google Cloud Platform (GCP)	Rackspace	OpenStack
a) infrastructure and computing services	EC2 (Xen virtualization engine)	Microsoft CLR VM	Google Cloud Platform (GCP)	RAID 10-protected, data-center-grade SSDs, Powerful Intel Xeon processors	Image Service model (Glance) & Computer model (Nova)
b) storage technologies	Amazon Simple Storage Service	blobs, tables and queues/	Datastore, Google Cloud SQL, Blobstore	Cloud backup, Cloud Block Storage, Cloud Files, Cloud Databases	Object Storage (Swift), Block Storage (Cinder),
c) developers' environments and support	Flexible	Flexible	Google APIs, Google App Engine (GAE)	Cloud Control Panel	Dashboard (Horizon)
d) security	Moderate	Moderate	Moderate	Moderate	Moderate
e) Price and payments plans	Free, commercial	Commercial	Free, commercial	Commercial	Free open-source

5. CONCLUSION

In conclusion, different approaches and technologies shape the underlying infrastructure of Cloud Service Providers (CSPs). Many new Cloud Service Providers emerges due to rapid innovation and development in Cloud technology. Cloud is seen as a good transformation medium to any new organization that have limited IT infrastructure, resources, and budgets. However, selecting suitable CSP must be undertaken based on several criteria afforded mentioned. There is a need to extend further the comparison among new CPSs based on extended criteria. Hence, future work will involve; (a) Further expand the criteria of comparison on afford-mentioned CSPs as well as adding more providers in the comparison process (b) develop a tool to technically and accurately measure differences among CSPs, and (c) prototype and validate the web-based end-users measurement tool.

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