Towards Comparative Evaluation of Cloud Services

Farrukh Nadeem

Department of Information Systems, Faculty of Computing and Information Technology,
King Abdulaziz University, Jeddah, Saudi Arabia.

Abstract: *In recent times Cloud technologies have seen a massive surge in terms of number of Cloud service providers and features available. Despite the developments there is still a lack of standards and comparison techniques for evaluating the Clouds. Each service provider has provided a distinct set of features differentiating it from other Clouds. This is due to lack of a comprehensive framework for comparison of Cloud services. This lack of framework leads to ambiguity and indecisiveness for the end user and most users eventually bear financial losses in terms of bad decisions. To address this issue, this paper presents a comprehensive list of parameters addressing major performance aspects of Cloud services. We further classify these parameters on the basis of their criticality, type and functionality. A brief survey of studies using these parameters is also presented.*

Keywords: Cloud computing, Cloud services comparison, performance comparison parameters.

1. Introduction

Cloud computing generally refers to using remote servers for storing and processing application and data rather than the local devices. There is no formal definition of Cloud computing available, although several authors have tried to describe it [26]. Among all these definitions some common features can be extracted. These main features are, namely; pay-as-you-go billing, on-demand provisioning, provisioning, self-servicing, elasticity and customization [2]. Pay-as-you-go billing means that users will pay for the resources or time duration for which the resources are used. Self-servicing makes use of autonomic computing to maintain itself without intervention by a human operator. Elasticity ensures that users can get as many resources as needed at runtime (scale up or down). Lastly, customization provides users with the flexibility of customizing services or resources based on their own needs. Cloud computing is mainly used for cost reduction and liberating users and enterprises from the technicalities of resources' maintenance. Enterprises and end users use Cloud services for dynamic allocation of resources.

Considering their deployment models, the Clouds can either be private, public or hybrid. In private model, an enterprise maintains a Cloud for its employees only, whereas in the public model a Cloud is available for open access against a price. The hybrid model is a combination of both public and private models. It is used in the case when an enterprise with a private model needs additional resources and hence it exploits those resources from a public Cloud. There are three main models of Clouds depending on the type of services they provide, namely, Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS). These models are called Cloud service models and are described in the following sections.

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In recent times, due to the rapid development in Cloud technology and increasing number of Cloud service providers (CSPs), it has become of significant importance to compare where each platform or service provider stands. Different CSPs have provided different features to distinguish them from others [15], but differences in the provided features restrict end users to draw an overall picture that can help them in comparative evaluation of the available CSPs to select the one that best suits their needs. Clouds are being used by a range of users. On one hand, there are giant enterprises and on the other hand, individual end users. In the presence of such diverse clients, the feature requirements change significantly. While enterprises might require more powerful computation and larger storage capacities, the end users might prefer more relaxed payments and lesser computational features. Therefore, it has become of primary importance to have a comprehensive framework to evaluate and compare CSPs across several performance parameters highlighting advantages and disadvantages of all Clouds for all kinds of users. To this end, in this paper, we present a comprehensive list of parameters that target at performance aspects of the Clouds. These parameters address needs of all major types of Cloud users. Later, we classify these parameters for three service delivery models of Cloud, i.e. IaaS, PaaS, and SaaS. We also evaluate these parameters for their criticality and functionality. We also present a brief survey of the existing studies that have used subsets of our list of parameters.

The rest of the paper is organized as follows. To highlight the differences among three service models of the Cloud, section 2 briefly describes the three service models. Section 3 presents our framework for evaluation and comparison of Cloud computing services. In section 4, we classify the presented parameters for their criticality, type and functionality. Related work is presented in section 5. Finally, we conclude in section 6.

2. Cloud Computing Service Models

Targeting at needs of different Cloud users, there are three major Cloud service models, namely, Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). Figure 1 shows these service models in Cloud architecture. In IaaS, users can request for core resources like computer servers, storage, network etc. alongwith the necessary virtualization capabilities. Users can use IaaS for computational tasks and storage purposes. IaaS can be accessed via a virtual infrastructure manager. In a layered structure, as shown in the Figure 1, IaaS is the lowest layer, which manages hardware resources. Common examples of IaaS providers include Amazon (EC2), Google (Google Compute Engine) and HP (HP Cloud) etc. PaaS provides operating system, Application Programming Interfaces (APIs) and other software packages to provide necessary environment for application deployment and execution. PaaS also includes basic utilities for integration of software systems. This layer is accessed via a Cloud development environment and is the second layer in Cloud architecture. PaaS providers include, Google App Engine, Windows Azure Cloud Service and Openshift etc. The final and the top most layer, SaaS, provides common off the shelf applications that users, instead of downloading on their own computers, run in the Cloud. This layer is accessed via a web browser. Famous SaaS providers include Apple's iCloud, iTunes and iWorks, Microsoft Office 365, and Google Apps etc.

3. Framework for Evaluation and Comparison of Cloud Computing Services

Cloud Computing Service Providers (also called Cloud Service Providers) can be compared based on the types of services they provide, their features, pricing, customer support, service availability and their compatibility with existing operating system platforms for desktops and mobiles, etc. Several articles and websites compare various CSPs. However, the lack of standardized architectural requirements makes it difficult to compare and evaluate CSPs -- because all CSPs do not provide all the features. In this section, we present a comprehensive framework of parameters for evaluation of several performance aspects of the services provided by CSPs. These parameters address needs of different Cloud customers and will help them select a CSP that will better fulfill their needs. To highlight the use of each parameter in different studies, we have also provided the references of those studies.

The following sections describe the performance evaluation parameters for IaaS, PaaS and SaaS respectively.

3.1 Performance Evaluation Parameters Common to IaaS, PaaS and SaaS

1. ***Pricing plans/ subscription type***: Different CSPs provide different billing models, for example, pay-as-you-go model, hourly or monthly packages, discounts, etc.
2. ***Base plan price***: Base plan price is used to compare the minimum hourly price of service usage. For IaaS, base plan price is mentioned for one virtual CPU core, memory per core and disk space.
3. ***Cost of data transfer/ bandwidth***: Cost of inbound and outbound data transfers becomes important when applications are dealing with large data sets. Some CSPs measure this cost in terms of network bandwidth allocated to Cloud user.
4. ***User/ control interface***: It is the method or tool used to access Cloud services. For example, GUI, web browsers, command line tools, APIs, etc. Availability of different tools extends users' flexibility and ease to use Cloud resources.

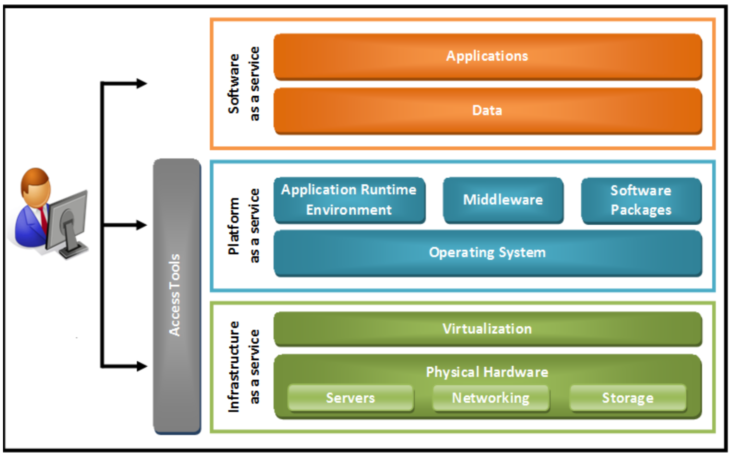

Fig. 1. Cloud architecture

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5. ***Security features***: Security is one of the most important factors to be considered while deciding to exploit services of public Clouds. Several dimensions of security in public Clouds include email/password security, firewall, backups, authorization, encryption, intrusion detection, persistence, data protection and fail over features etc. Cloud customers should also consider whether the offered security services are free of cost or not.

6. ***Service Level Agreement (SLA)***: SLA defines the types and level of services to be provided by the vendor and user's consent to these service specifications against a cost. The details of SLA cover different factors like SLA's methodology, performance guarantee and percentage and term, service outage credit, minimum outage duration, and professional support services such as migration assistance etc.

7. ***Guaranteed network availability***: The network performance plays a key role in overall performance of many applications. Such applications usually input/output large amount of data. In addition, guaranteed network availability is very critical for the applications whose instances are mapped to execute on distributed computer clusters and those instances need to communicate with each other. Guaranteed network availability is specified in the SLA.

8. ***Customer support services***: Customer support is essential especially for new customers as well as customers requiring advanced controls for their applications. Not all CSPs offer customer support. For those who provide customer support, the type of support provided should also be considered, for example, live chat, telephone, discussion forums, knowledge base, email, tutorials, etc.

9. ***Certifications***: A vendor's certification in a particular area shows strength of its services in that area. The security- and compliance-related certifications are of typical interest to Cloud customers. The examples of such certifications include PCI, SAS70, HIPAA, secure remote connect and secure site connect services, hardware appliance based IDS/IPS protection layer per customer, provision of MPLS network service, 2-factor authentication (RSA) integrated with Cloud stack, DDoS protection service, 3rd party Cloud security audit or trustee privacy program etc. [1, 7, 11, 21].

3.2 Performance Evaluation Parameters Typical for IaaS

1. ***Virtualization technology***: Virtualization [13] of resources refers to creation of virtual versions of resources to support their sharing and isolation, improve flexibility, ease management of complex systems, and reduce cost. Virtualization technology may be used for several resources including computational servers, storage, network, etc.

2. ***Storage framework***: The storage framework used by the service providers to store data (and the related support provided to the Cloud user for data access) is very critical for scientific applications, especially data-intensive applications. Examples of storage frameworks include block storage, cloud storage, etc.

3. ***Number of data centers***: The flexibility of choosing from a number of data centers available from various geographical regions attracts several Cloud customers, especially those with large volumes of data.

4. ***Auto scaling***: Also called rapid elasticity [2], it refers to the dynamic allocation and deallocation of resources based on user needs. Scaling can be done either automatically or on user demand.

5. ***Monitoring***: Several applications require resource and performance monitoring, especially, the applications with dependant tasks, like workflow applications [17]. The Cloud service providers are also compared on the basis of the types of monitoring services they provide and if these services are free of cost or not. Typical types of monitoring services include poor, average and extensive monitoring. In poor monitoring, vendors have no monitoring services. The customer either deploys a third party monitoring tool by himself or purchases vendors' extra services for monitoring. In average monitoring, vendors provide some simple monitoring tools. In extensive monitoring, vendors provide complete monitoring services integrated in the services offered.

6. ***Load balancing***: Some applications require more resources during their execution to balance the work load. Such load balancing is important for time critical applications or applications with deadlines. The Cloud customers need to know if automatic load balancing is provided by the CSPs.

7. ***Resource availability***: The availability of resources is considered in terms of factors like number of CPUs, number of virtual PCs and RAM available per virtual machine, persistent storage etc.

8. ***Availability of APIs***: Availability of APIs for accessing Cloud resources, and flexibility and the programming languages supported by these APIs are decisive measures for many application programmers in selecting a CSP. Even well known CSPs vary in their support and the flexibility of APIs.

9. ***Operating system compatibility***: CSPs can also be distinguished on the basis of their compatibility with different operating systems. Some of the operating systems supported by different CSPs include Linux, Cent OS, Open Solaris, Windows, etc.

10. ***Number of instances types***: Some CSPs allow users to select one of the available server configurations. Whereas, some others allow fully customizable servers to match users' needs.

11. ***Elastic IP address***: Some CSPs distinguish themselves by offering use of elastic IS addresses. The elastic IP addresses allow fine-grained control to Cloud programmers for mapping virtual machine instance to IP addresses.
12. ***Content delivery network***: The availability of Content Delivery Network (CDN) in a Cloud ensures serving contents to Cloud user with high availability and high performance.

3.3 Performance Evaluation Parameters Typical for PaaS

1. ***Target applications***: The type of applications targeted by a CSP is also an important parameter while selecting a CSP. Typical applications targeted by different CSPs are web-based applications, general purpose applications, and general applications for some particular operating system or storage services [27].
2. ***Programming frameworks***: Almost all the CSPs are restricted to different programming frameworks. The well know programming frameworks include Python (by Google), Microsoft .NET (Microsoft Azure), Java/C/C++/FORTRAN (by Sun), etc.
3. ***Root access***: Root access refers to administrative rights to access the hardware. Root access is required sometimes to meet applications' special requirements of hardware configurations.
4. ***Native database systems***: The database systems supported by the CSPs are of utmost importance for database applications. Several of the CSPs can be filtered out in the first step if they do not support the required database systems.
5. ***Resource pooling***: To run multiple instances of an application, pooling of multiple resources (like memory, database connections, libraries etc.) is required to provide consistency, space efficiency, support faster inter-process communication, reduce network traffic etc. This is a typical requirement for HPC applications and is of critical importance to HPC users.
6. ***Data backup***: CSPs can also be compared on the basis of the data backup services they offer. In some cases, the data-backup is performed on-demand and in others, it is performed automatically.
7. ***Integration capability***: Several of Cloud customers exploit public Cloud services in extension to their private Clouds. These customers require a seamless integration of their private and public infrastructures. However, CSPs vary largely in such integration support.
8. ***Fault tolerance***: Fault tolerance capabilities provided by the CSPs are of special interest for the applications that require large pool of resources, for example HPC applications and applications with long run times. Such capabilities include services for backup, replication, etc.

3.4 Performance Evaluation Parameters Typical for SaaS

1. ***Disaster management and recovery***: For the customers who deploy their business applications on public Clouds, vendor's capability to manage and recover from disasters is of critical importance. It includes procedures for disaster recovery, recovery time, and regular checking of systems.
2. ***Ownership of infrastructure***: Several vendors provide PaaS and IaaS services by exploiting third party IaaS, which is usually connected through public internet. In such cases, vendors can not guarantee high QoS, because the network access on public internet is the “best effort".
3. ***Global access***: Customers planning global access of the SaaS need to make sure that vendors’ services are available in all the concerned geographical areas, especially when there is requirement of fast response. In addition, there may be restrictions on data access in some countries.
4. ***Content support***: CSPs vary in their support for different types of contents, like email, calendar, photos, music, videos, etc.
5. ***Mobile access***: With the widespread of smart phones, people are getting increasingly interested in accessing Cloud services from mobile devices. This feature will soon become an important factor in selection of a CSP.
6. ***Up time***: Up time is the time duration since which the services are availability without any discontinuity. The high value of uptime indicates stability of the service.

4. Classification of Comparison Parameters

In this section, we classify comparison parameters for different Cloud service models on the basis of their criticality (low, medium, high), type of performance (static, dynamic), and its functionality. The criticality of a parameter is described as *high* if it is addressing performance of core resources or major user concerns (like security etc.), and *low* if it is addressing additional features which may not be of particular interest for a wide range of customers. A parameter is said to be static if it is describing static aspect of the Cloud performance, whereas a parameter describing dynamic aspect of the Cloud performance is said to be dynamic. In addition, a parameter is classified as functional if it is describing the core functions of the Cloud; otherwise it is classified as non-functional.

Table 1 describes classification of performance comparison parameters common to IaaS, PaaS and SaaS. Tables 2, 3, and 4 respectively describe classification of parameters for IaaS, and PaaS and SaaS. Table 5 describes a short survey of studies that used subsets of our parameters, and the number of Cloud platforms compared by these studies.

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Table 1: Comparison Parameters common to IaaS, PaaS and SaaS

Sr. #	Comparison Parameters	Criticality	Type	Functionality	References
1	Pricing plans	High	Static	Non-functional	[1, 24, 21]
2	Base plan price	Low	Static	Non-functional	[11]
3	Cost of data transfer/ bandwidth	Low	Static	Non-functional	[1, 11]
4	User/control interface	High	Static	Non-functional	[3, 11, 7, 21]
5	Security features	High	Static	Functional	[11, 9, 24]
6	Service level agreement	High	Static	Non-functional	[9, 24, 21]
7	Guaranteed network Availability	High	Static	Non-functional	[11, 21]
8	Customer Support Services	High	Static	Non-functional	[1, 11, 6, 21]
9	Certifications	High	Static	Functional	[1, 7, 11, 21]

Table 2: Comparison parameters typical for IaaS

Sr. #	Comparison Parameters	Criticality	Type	Functionality	References
1	Virtualization technique	High	Static	Functional	[27, 3, 11, 19, 21]
2	Storage framework	High	Static	Functional	[27, 24,21]
3	Number of data centers	High	Static	Functional	[1, 7, 21]
4	Auto scaling	High	Dynamic	Functional	[27, 1, 11, 9, 7, 24, 19, 21]
5	Monitoring	High	Dynamic	Functional	[1, 11, 9, 7]
6	Load balancing	High	Dynamic	Functional	[11, 7, 21]
7	Resource availability	High	Dynamic	Functional	[9]
8	Availability of APIs	Medium	Static	Functional	[3, 1, 19, 24
9	Operating system compatibility	Medium	Static	Functional	[11, 6, 9, 7, 19]
10	Number of instances	Medium	Static	Functional	[1]
11	Elastic IP address	Low	Static	Non-functional	[7]
12	Content delivery network	High	Static	Functional	[4, 21]

Table 3: Comparison Parameters typical for PaaS

Sr. #	Comparison Parameters	Criticality	Type	Functionality	References
1	Target applications	High	Static	Functional	[27, 3]
2	Programming frameworks	High	Static	Functional	[3, 11, 7, 19]
3	Root access	Medium	Static	Functional	[11]
4	Native database systems	High	Static	Functional	[11]
5	Resource pooling	High	Dynamic	Functional	[3, 19]
6	Data backup	Medium	Static	Functional	[7, 9]
7	Integration capability	Medium	Static	Functional	[3, 7]
8	Fault tolerance	Medium	Static	Functional	[3, 7]

Table 4: Comparison Parameters typical for SaaS

Sr. #	Comparison Parameters	Criticality	Type	Functionality	References
1	Disaster recovery	High	Static	Non-functional	[23]
2	Ownership of infrastructure	High	Static	Non-functional	[23, 25]
3	Global reach	Medium	Static	Functional	[23]
4	Content support	High	Static	Functional	[6, 25]
5	Mobile access	Medium	Static	Non-functional	[6]
6	Up time	Medium	Dynamic	Non-functional	[6, 25]

5. Related work

Several studies have been conducted in the past few years aiming at evaluating Cloud platforms. One such study was conducted by [22]. In his paper, the author proposed an experimental methodology for the performance evaluation of web services in the Cloud. The author hypothesized that replication configurations in Cloud computing could cause positive effects on non-functional parameter levels of web services. He presented an experimental evaluation of his methodology using Amazon's EC2 Cloud. His methodology consisted of five steps, namely, identifying benchmark, identifying configuration, running tests, analyzing results and recommendation. In his study, he used WSTest as a benchmark and a statistical tool for analysis. Another comparative study of Clouds was conducted by [19]. The authors compared the architectural details of four Cloud platforms. They presented both the similarities and differences among the compared Cloud platforms, and highlighted that despite the strengths of each Cloud there were still some issues present. Some of the issues raised in their paper are cluster failure in

Cloud, consistency guarantee, inter-operation and standardization, security, data transmission and synchronization in different clusters within the Cloud. Later on, [16] designed a comparator, “CloudComp", for evaluating the cost and performance of public Clouds. Their comparator published results of four Cloud services. The comparator used elastic computing, persistent storage and networking services offered by a Cloud for performance evaluation. The metrics, namely, benchmark finishing time, cost per benchmark, scaling latency, response time, throughput, and time to consistency and cost per operation, were chosen to evaluate Clouds across these four dimensions. The authors used Java based benchmarks that measured these metrics. However, their study was confined to only the common features of selected Cloud services.

Another performance evaluation study of the Amazon EC2 Cloud was conducted by Ostermann et al. [18]. The authors followed a two step procedure for their evaluation. In the first step named Cloud-specific evaluation, the authors tested the resource acquisition and release patterns of the Cloud over short and long periods of time. In the second step named, infrastructure-agnostic evaluation the authors tested the performance of Clouds using existing benchmarks suites, where jobs were run in isolation. In addition to these benchmarks, the authors also designed two sets of workloads namely, Single/Multi job run on single instance (SJSI/MJSI) and Single Job run on Multiple Instances (SJMI). These workloads in turn executed any one of the four open source benchmarks i.e. LMbench, Bonnie, CacheBench and HPC challenge benchmark. The authors then evaluated the results of these benchmarks on the basis of reliability, SJMI and SJSI workloads, memory performance, I/O performance and compute performance. The authors concluded that the performance and reliability of Amazon EC2 was low and for large-scale scientific computation. As a result of their observation the authors suggested improvements in the Cloud. Another similar performance evaluation study of four Clouds was conducted by [14]. In their paper, the authors conducted an empirical study using many-task computing (MTC) users. They defined MTC user as one with multiple jobs and multiple bags-of-tasks. The parameters used in this study were similar to those in [18]. The authors concluded that while Cloud computing is a good solution for temporary need of resources; it still lacks the computation power for large-scale computing applications. The authors also stated the computational power of the Clouds is low. The authors in [20] conducted a security analysis of three Cloud platforms. The authors compared the certificates won by each Cloud. In addition, the authors evaluated the strengths and security loopholes of each of the three Clouds. They also identified that the authentication and authorization are major issues present in all three Clouds. In light of their findings, the authors proposed the use of SHA-512 algorithm with a slight modification for securely saving user passwords.

Recently, Garg et al. [12] proposed a framework and mechanism, named SMICloud, to measure the quality of Cloud platforms and rank them based on user needs. Their proposed framework is a decision making tool that provides assessment based on Key Performance Indicators (KPI's). SMICloud also takes user's past experience into consideration for ranking the Clouds. Their proposed framework consisted of a two-step procedure. The first step consisted of gathering essential and non-essential requirements from the users and then comparing the Cloud platforms against those requirements. The Clouds that meet the most number of requirements are selected. Alongwith the selection of Clouds, SMICloud monitors their performance as well as past track of fulfilling SLAs with the customers. The second step ranks the Clouds according to the QoS requirements. This step is a multi-decision making process (MDMP) that is resolved with the help of analytical hierarchy process (AHP). The authors presented results of their framework for three Cloud platforms. Costa et al. [10] presented evaluation criteria for comparison of SaaS. The authors evaluated Google Aps and Microsoft Office 365 using their evaluation criteria.

In addition to the above mentioned studies, various online tools are also available for calculating the cost of acquiring Cloud services. One such website is [4], which has multiple configurations of available RAM, storage capacity and CPU power. The website also allows users to choose between different operating systems. Users can select from these available configurations and choose any of the 23 Cloud services to calculate their costs. Another website, [5] provides benchmark results of five Cloud services. The website reports the performance, availability and errors of reading and writing 10 KB and 10 MB files. In addition to these, a free Cloud performance monitoring service is provided by [8]. The website provides various applications (for example, global provider view, Cloud computing tweets and CDN performance analyzer etc.) for evaluation of Cloud performance. To compare performance of different Clouds, same application is hosted on all of the selected public Clouds for monitoring their networks, response time and availability.

In comparison to these studies, we present a comprehensive framework of performance parameters for comparison of three major Cloud service models, IaaS, PaaS, and SaaS. Our framework addresses needs of different Cloud customers (ranging from large enterprises to

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individual users). To ease selection of parameters for common Cloud users, we have further classified our parameters based on their criticality, type and functionality.

6. Conclusion

Common Cloud users many times bear financial losses by choosing inadequate CSPs that do not serve their needs. This is because of lack of a comprehensive framework for effective comparison of the CSPs. This paper presented a comprehensive list of parameters that evaluate performance of a CSP from several different aspects and address needs of different kinds of Cloud customers. On one hand, this study will serve as a guide for the end users for evaluating different CPSs and selecting a CSP that best suits their needs. On the other hand, the CSPs may use it to evaluate their services with respect to others'. On the basis of our study, we emphasize that there is a need of standardization of Cloud technologies and its features. Moreover, the highly critical factors, as marked in this study, must be adopted by all the CSPs to ensure high QoS for the end users.

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