A Break in the Clouds: Towards a Cloud Definition

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ABSTRACT

This paper discusses the concept of Cloud Computing to achieve a complete definition of what a Cloud is, using the main characteristics typically associated with this paradigm in the literature. More than 20 definitions have been studied allowing for the extraction of a consensus definition as well as a minimum definition containing the essential characteristics. This paper pays much attention to the Grid paradigm, as it is often confused with Cloud technologies. We also describe the relationships and distinctions between the Grid and Cloud approaches.

Categories and Subject Descriptors

H.3 [**Information Storage and Retrieval**]: Systems and Software—*Distributed Systems*; C.2 [**Computer Communication Networks**]: Distributed Systems—*Network Operating Systems*

General Terms

Computing theory

Keywords

Cloud Computing, Cloud Definition, Grid

1. INTRODUCTION

Cloud Computing is associated with a new paradigm for the provision of computing infrastructure. This paradigm shifts the location of this infrastructure to the network to reduce the costs associated with the management of hardware and software resources [16]. The Cloud is drawing the attention from the Information and Communication Technology (ICT) community, thanks to the appearance of a set of services with common characteristics, provided by important industry players. However, some of the existing technologies the Cloud concept draws on (such as virtualization, utility computing or distributed computing) are not new [29, 18, 23]

The variety of technologies in the Cloud makes the overall picture confusing [18]. Moreover, the hype around Cloud Computing further muddies the message [11, 23]. Of course, the Cloud is not the first technology that falls into hype. Gartner's Hype Cycle [12] characterizes how the hype about a technology evolves *"from overenthusiasm through a period of disillusionment to an eventual understanding of the technology relevance and role in a market or domain"*.

Arguably, Cloud Computing is now in the first stage of this hype cycle, labeled as 'Positive Hype' (see [12]). This reinforces the overall confusion about the paradigm and its capacities, turning the Cloud into an excessively general term that includes almost any solution that allows the outsourcing of all kinds of hosting and computing resources. Yet, the notions of transparent access to resources on a pay-per-use basis, relying on an infinitely and instantly scalable infrastructure managed by a third-party, is a recurrent idea.

The example of what has happened with the Grid illustrates the need of a crisp definition for Clouds: although there are well-known Grid definitions (probably Foster's [10] is the most widely accepted), none of them are widely accepted. A clear Grid definition may have helped to disseminate what the term 'Grid' actually means and what business benefits can be obtained from it. Thus, it is important to find a unified definition of what Cloud Computing is, delimiting the scope of research and emphasizing the potential business benefits.

There are many definitions of Cloud Computing, but they all seem to focus on just certain aspects of the technology [11, 14, 22, 5, 6, 24, 23, 18]. This paper tries to give a more comprehensive analysis of all the features of Cloud Computing, to reach a definition that encompasses them.

This paper proceeds as follows. First, in Section 2, we present an overview of the Cloud scenario. Section 3 analyzes present Cloud definitions, extracting relevant Cloud features and combining them to form both an integrative and a basic Cloud definition. In Section 4 we present the different approaches of grids and Clouds to clearly distinguish these two technologies. Finally, our conclusions are presented in Section 5.

2. TYPES OF CLOUD SYSTEMS AND ACTORS

This section tries to distinguish the kind of systems where Clouds are used and the actors involved in those deployments.

Actors.

Many activities use software services as their business basis. These *Service Providers* (SPs) make services accessible to the *Service Users* through Internet-based interfaces. Clouds aim to outsource the provision of the computing infrastructure required to host services. This infrastructure is offered 'as a service' by *Infrastructure Providers* (IPs), moving computing resources from the SPs to the IPs, so the SPs can gain in flexibility and reduce costs (see Fig 1).

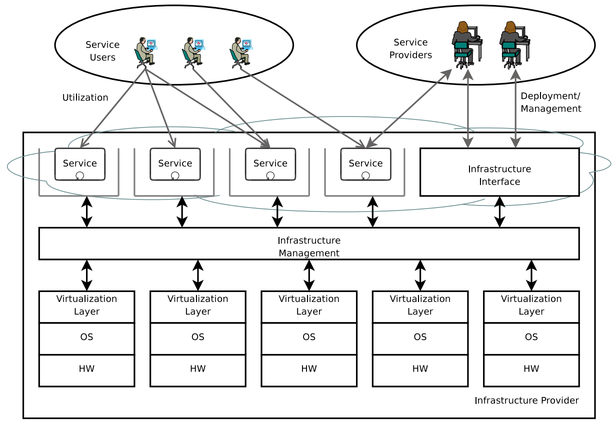

Figure 1: Cloud Actors

Depending on the type of provided capability, there are three scenarios where Clouds are used:

Infrastructure as a Service.

IPs manage a large set of computing resources, such as storing and processing capacity. Through virtualization, they are able to split, assign and dynamically resize these resources to build *ad-hoc* systems as demanded by customers, the SPs. They deploy the software stacks that run their services. This is the *Infrastructure as a Service* (IaaS) scenario.

Platform as a Service.

Cloud systems can offer an additional abstraction level: instead of supplying a virtualized infrastructure, they can provide the software platform where systems run on. The sizing of the hardware resources demanded by the execution of the services is made in a transparent manner. This is denoted as *Platform as a Service* (PaaS). A well-known example is the Google Apps Engine [1].

Software as a Service.

Finally, there are services of potential interest to a wide variety of users hosted in Cloud systems. This is an alternative to locally run applications. An example of this is the online alternatives of typical office applications such as word processors. This scenario is called *Software as a Service* (SaaS).

3. A CLOUD DEFINITION

In this section we will gather together most of the available Cloud definitions (see Table 1) to get an integrative definition as well as a minimum common denominator. Specially interesting is [11], as it gathers the definitions proposed by many experts. Although it lacks a global analysis of those proposals to reach a more comprehensive definition, it gives a clear idea of the different concepts that ICT experts have about Clouds.

Markus Klems [11] claims that *immediate scalability* and *resources usage optimization* are key elements for the Cloud. These are provided by increased *monitoring*, and *automation of resources management* [11, 14] in a *dynamic environment* [11, 6]. Other authors disagree that this is a requirement for an infrastructure to be considered as a Cloud [7].

Some authors focus on the *business model* (collaboration and pay-as-you-go) and the reduction in capital expenditure (Jeff Kaplan and Reuven Cohen in [11] and others in [28, 5, 14]) by the realization of *utility computing* (Jeff Kaplan and Reuven Cohen in [11] and others in [5, 14, 22, 6]). Until recently, it was often confused with the Cloud itself, but it seems now agreed that it is just an element of the Cloud related to the business model. Another major principle for the Cloud is *user-friendliness* [11, 28]. Buyya et al. [6] added that to reach commercial mainstream it is necessary to strengthen the role of Service-Level Agreements (SLAs) between the SP and the consumers of that service. We believe that SLAs should also be established between the SP and the IP to provide certain Quality of Service (QoS) guarantees.

Very recently, McFedries [22] described the data center (conceived as a huge collection of clusters) as the basic unit of the Cloud offering huge amounts of computing power and storage by using spare resources. This is related to the concept of *massive data scalability* proposed by Hand [15].

The role of virtualization in Clouds is also emphasized by identifying it as a key component [6]. Moreover, Clouds have been defined just as *virtualized hardware and software* plus the previous monitoring and provisioning technologies (see Douglas Gourlay and Kirill Sheynkman in [11]).

Yet some other experts (see Reuven Cohen, Praising Gaw, Damon Edwards, Ben Kepes definitions in [11], and the Bragg study in [5]) do not stress Cloud capabilities, but rather believe that Cloud Computing is a *"buzz word"* encompassing a wide variety of aspects such as *deployment*, *load balancing*, *provisioning*, and *data and processing outsourcing*. Table 2 shows the Cloud features identified from each of the definitions above.

Proposed Definition.

Taking these features into account we can provide an encompassing definition of the Cloud. Obviously, the Cloud concept is still changing and these definitions show how the Cloud is conceived today: **Clouds are a large pool of easily usable and accessible virtualized resources (such as hardware, development platforms and/or services). These resources can be dynamically reconfigured to adjust to a variable load (scale), allowing also for an optimum resource utilization. This pool of resources is typically exploited by a pay-per-use model in which guarantees are offered by the Infrastructure Provider by means of customized SLAs**. On the other hand, looking for the minimum common denominator would lead us to no definition as no single feature is proposed by all definitions. The set of features that most closely resemble this minimum definition would be **scalability**, **pay-per-use utility model** and **virtualization**.

4. CLOUDS AND GRIDS COMPARISON

A source of confusion around the Cloud concept is its relation with Grid Computing [24, 19]. The distinctions are not clear maybe because Clouds and grids share similar visions: reduce computing costs and increase flexibility and reliability by using third-party operated hardware. We will use well established definitions of the Grid and compare them to our global and essential definitions of the Cloud.

Author/Reference	Year	Definition/Excerpt
M. Klems [11]	2008	*you can scale your infrastructure on demand within minutes or even seconds, instead of days or weeks, thereby avoiding under-utilization (idle servers) and over-utilization (blue screen) of in-house resources...*
P. Gaw [11]	2008	*using the internet to allow people to access technology-enabled services. Those services must be 'massively scalable...*
R. Buyya [6]	2008	*A Cloud is a type of parallel and distributed system consisting of a collection of interconnected and virtualized computers that are dynamically provisioned and presented as one or more unified computing resources based on service-level agreements established through negotiation between the service provider and consumers*
R. Cohen [11]	2008	*Cloud computing is one of those catch all buzz words that tries to encompass a variety of aspects ranging from deployment, load balancing, provisioning, business model and architecture (like Web2.0). It's the next logical step in software (software 10.0). For me the simplest explanation for Cloud Computing is describing it as, "internet centric software...*
J. Kaplan [11]	2008	*a broad array of web-based services aimed at allowing users to obtain a wide range of functional capabilities on a 'pay-as-you-go' basis that previously required tremendous hardware/software investments and professional skills to acquire. Cloud computing is the realization of the earlier ideals of utility computing without the technical complexities or complicated deployment worries...*
D. Gourlay [11]	2008	*...the next hype-term...building off of the software models that virtualization enabled*
D. Edwards [11]	2008	*...what is possible when you leverage web-scale infrastructure (application and physical) in an on-demand way...*
B. de Haff [11]	2008	*...There really are only three types of services that are Cloud based: SaaS, PaaS, and Cloud Computing Platforms. I am not sure being massively scalable is a requirement to fit into any one category.*
B. Kepes [11]	2008	*...Put simply Cloud Computing is the infrastructural paradigm shift that enables the ascension of SaaS. ... It is a broad array of web-based services aimed at allowing users to obtain a wide range of functional capabilities on a pay-as-you-go basis that previously required tremendous hardware/software investments and professional skills to acquire*
K. Sheynkman [11]	2008	*Clouds focused on making the hardware layer consumable as on-demand compute and storage capacity. This is an important first step, but for companies to harness the power of the Cloud, complete application infrastructure needs to be easily configured, deployed, dynamically-scaled and managed in these virtualized hardware environments*
O. Sultan [11]	2008	*...In a fully implemented Data Center 3.0 environment, you can decide if an app is run locally (cook at home), in someone elses data center (take-out) and you can change your mind on the fly in case you are short on data center resources (pantry is empty) or you having environmental/facilities issues (too hot to cook). In fact, with automation, a lot of this can can be done with policy and real-time triggers...*
K. Hartig [11]	2008	*..really is accessing resources and services needed to perform functions with dynamically changing needs...is a virtualization of resources that maintains and manages itself.*
J. Pritzker [11]	2008	*Clouds are vast resource pools with on-demand resource allocation...virtualized ...and priced like utilities*
T. Doerksen [11]	2008	*Cloud computing is ... the user-friendly version of Grid computing*
T. von Eicken [11]	2008	*outsourced, pay-as-you-go, on-demand, somewhere in the Internet, etc*
M. Sheedan [11]	2008	*...'Cloud Pyramid' to help differentiate the various Cloud offerings out there...Top: SaaS; Middle: PaaS; Bottom: IaaS*
A. Ricadela [11]	2008	*...Cloud Computing projects are more powerful and crash-proof than Grid systems developed even in recent years*
I. Wladawsky Berger [11]	2008	*...the key thing we want to virtualize or hide from the user is complexity...all that software will be virtualized or hidden from us and taken care of by systems and/or professionals that are somewhere else - out there in The Cloud*
B. Martin [11]	2008	*Cloud computing encompasses any subscription-based or pay-per-use service that, in real time over the Internet, extends IT's existing capabilities*
R. Bragg [5]	2008	*The key concept behind the Cloud is Web application... a more developed and reliable Cloud. Many find it's now cheaper to migrate to the Web Cloud than invest in their own server farm ... it is a desktop for people without a computer*
G. Gruman and E. Knorr [14]	2008	*Cloud is all about: SaaS...utility computing...Web Services... PaaS...Internet integration...commerce platforms....*
P. McFedries [22, 15]	2008	*Cloud Computing, in which not just our data but even our software resides within the Cloud, and we access everything not only through our PCs but also Cloud-friendly devices, such as smart phones, PDAs... the megacomputer enabled by virtualization and software as a service...This is utility computing powered by massive utility data centers.*

Table 1: Cloud Definitions

Feature	Reference
User Friendliness	[11, 6, 24]
Virtualization	[11, 6, 24, 5]
Internet Centric	[11, 6, 24, 5]
Variety of Resources	[11, 24, 22]
Automatic Adaptation	[11, 14]
Scalability	[11, 6, 24, 22, 15]
Resource Optimization	[11, 24, 22]
Pay per Use	[11, 14, 6, 24, 5]
Service SLAs	[11, 6]
Infrastructure SLAs	[11]

Table 2: Cloud Characteristics

4.1 A Grid Definition

Although the essential principles of grids have not changed much in the last decade, there are still different conceptions about what a Grid really is. In 2002, Ian Foster [10] proposed a definition of the Grid as *"a system that coordinates resources which are not subject to centralized control, using standard, open, general-purpose protocols and interfaces to deliver nontrivial qualities of service"*. More recent definitions emphasize the ability to combine resources from different organizations for a common goal [4]). In [26, 20] the concern is not so much the coordination of resources from different domains, but how those resources must be managed and presented. In fact, is this divergence of conceptions about the Grid what this work aims to avoid for Clouds.

4.2 Feature Comparison

In this subsection we present the main features of a current Grid [4, 10, 26, 20] in order to compare them with Cloud main characteristics extracted from the definitions above [11, 6, 24], to differentiate both paradigms.

Table 3 compares different features of grids and Clouds. The remaining of this section highlights the similarities and differences between both paradigms.

Feature	Grid	Cloud
Resource Sharing	Collaboration (VOs, fair share).	Assigned resources are not shared.
Resource Heterogeneity	Aggregation of heterogeneous resources.	Aggregation of heterogeneous resources.
Virtualization	Virtualization of data and computing resources.	Virtualization of hardware and software platforms.
Security	Security through credential delegations.	Security through isolation.
High Level Services	Plenty of high level services.	No high level services defined yet.
Architecture	Service orientated.	User chosen architecture.
Software Dependencies	Application domain-dependent software.	Application domain-independent software.
Platform Awareness	The client software must be Grid-enabled.	The SP software works on a customized environment.
Software Workflow	Applications require a predefined workflow of services.	Workflow is not essential for most applications.
Scalability	Nodes and sites scalability.	Nodes, sites, and hardware scalability.
Self-Management	Reconfigurability.	Reconfigurability, self-healing.
Centralization Degree	Decentralized control.	Centralized control (until now).
Usability	Hard to manage.	User friendliness.
Standardization	Standardization and interoperability.	Lack of standards for Clouds interoperability.
User Access	Access transparency for the end user.	Access transparency for the end user.
Payment Model	Rigid.	Flexible.
QoS Guarantees	Limited support, often best-effort only.	Limited support, focused on availability and uptime.

Table 3: Grid vs. Cloud Characteristics

4.2.1 Resource Sharing

Grids enhance fair share of resources across organizations, whereas Clouds provide the resources that the SP requires on demand, giving the impression of a single dedicated resource. Hence, there is no actual sharing of resources due to the isolation provided through virtualization.

4.2.2 Heterogeneity

Both models support the aggregation of heterogeneous hardware and software resources.

4.2.3 Virtualization

Grid services are provided with interfaces that hide the heterogeneity of the underlying resources. Therefore, a Grid provides the ability to virtualize the sum of parts into a singular wide-area resource pool. Virtualization covers both, data (flat files, databases etc.) and computing resources [24]. Cloud Computing adds the virtualization of hardware resources too.

4.2.4 Security

Virtualization is related to security since it enables the isolation of environments. While in Clouds each user has unique access to its individual virtualized environment, Grids often do not deal with end user security. Thus, some authors argue that security has not been seriously explored [19]. Grids, nonetheless, offer security services and credential delegation to access all the resources available in a Virtual Organization [24].

4.2.5 High Level Services

Grids offer a handful of services such as metadata search, data transfer... [24, 26]. Unlike Grids, Clouds still suffer a certain lack of high level services, which is probably related to the lower level of maturity of the paradigm. Clouds let these issues to be treated at the application level [27], although federated Clouds will likely require several mechanisms to deal with these topics [25].

4.2.6 Architecture, Dependencies and Platform Awareness

Virtualization is a key enabler of architecture-agnostic Cloud applications. For example, SPs can deploy Enterprise Java Beans-based applications just as they can deploy a set of Grid services instead. The Cloud will treat them both equally. However, by definition grids accept only "gridified" applications [26], thus imposing hard requirements to the developers.

4.2.7 Software Workflow

Since grids are essentially service and job oriented, they imply the need to perform the coordination of the services workflow and location which is not necessary in on-demand deployments such as those in the Clouds.

4.2.8 Scalability and Self-Management

Both grids and Clouds free programmers of dealing with scalability issues [8]. Grid scalability is mainly enabled by increasing the number of working nodes; Clouds offer the automatic resizing of virtualized hardware resources. Scalability requires dynamic reconfiguration: as the system scales it needs to be reconfigured in an automated manner.

Scalability and self-management is simpler in a single administrative domain, but many problems can be found across organizational frontiers. In grids, many difficulties lay exactly in not having a single owner of the whole system [26]. Up-to-date Clouds are operated by single companies, but we envision federated Clouds facing similar problems as grids [25, 30, 28].

4.2.9 Usability

Clouds are easily usable, hiding the deployment details from the user [28, 6, 11]. This reduced entry point is a long-standing, yet unaccomplished, requirement of Grids [24]. Comparing a complex, invasive, and management-intensive vs. a simple and externally managed environment helps to explain the attention paid to Clouds.

4.2.10 Standardization

Grids have devoted huge efforts to reach standardization both in the user interface and in the inner interfaces (for accessing resources) (see [3]), and so reach seamless interoperability [21].

The user access interface to the Cloud is very often based on standard technologies such as those used in grids, however inner interfaces standardization is still a major issue. These internal interfaces are kept hidden by the enterprises, thus hampering the interoperability among different Clouds and the possibility of a worldwide federation of Clouds [24, 25, 30, 28]. Some of the challenges ahead for the Clouds, like monitoring, storage, QoS, federation of different organizations, etc. have been previously addressed by grids. Clouds present, however, specific elements that call for standardization too; e. g. virtual images format or instantiation/migration APIs [24]. So enhancing existing standards is granted to ensure the required interoperability. For instance, the OGF experience could be very important to accomplish this task [19].

4.2.11 Payment Model

Initial Grid efforts were mostly based on public funding while the Cloud has been driven by commercial offers. Typically, Grid services are billed using a fixed rate per service or different organizations sharing idle resources. On the other hand, Cloud users are usually billed using a pay-per-use model. More advanced payment models and SLA enforcement in a federated Cloud are just starting to be explored [25] that will tear down one of the barriers to moving traditional applications to the Cloud: the loss of cost control [17].

4.2.12 Quality of Service

In general, grids are not committed to a concrete QoS level beyond best-effort, likely due to its collaboration and resource sharing principles. Rather, it is the application built on top of the Grid who has to supply any service guarantees by itself. Mechanisms for SLA enactment between infrastructure providers in the Grid have been set [24].

On the contrary, QoS is an inherent features of many Clouds, e.g. Amazon has already included a rough attempt to provide a certain QoS by means of basic SLAs (99.9% infrastructure uptime) [27]. It is worth noting that the 'Amazon Web Service Customer Agreement' (Section 7.1) frees Amazon of any responsibility under '...power outages, system failures or other interruptions...'. Hopefully, more advanced/customizable SLAs are being supported [9] or implemented [25].

4.3 Convergence of Grids and Clouds

The Next Generation Grid expert group (NGG) [13] has developed a vision which *"underpins the evolution of Grid from a tool to solve compute- and data-intensive problems towards a general-purpose utility infrastructure"*. Grids need to accelerate the incorporation of virtualization technologies to gain some advantages that Clouds natively present (migrability, hardware level scalability). In addition, grids need to provide easier entry points so as to enable a wider adoption by end users, i.e., Grids are meant to be userfriendly, virtualized and automatically scalable utilities, which clearly shows a convergence with current Clouds.

Several approaches exist that combine Clouds and Grids together, which can also be seen as a combination of advanced networking with sophisticated virtualization. However, Clouds are also said to offer a limited set of features exposed (i.e. they present a higher abstraction level to the user). For instance, the Simple Storage Service by Amazon [2] can be regarded as a limited data Grid when compared to the CERN data Grid [19].

5. CONCLUSIONS

Clouds do not have a clear and complete definition in the literature yet, which is an important task that will help to determine the areas of research and explore new application domains for the usage of the Clouds. To tackle this problem, the main available definitions extracted from the literature have been analyzed to provide both an integrative and an essential Cloud definition.

Although our encompassing definition is overlapped with many grid concepts, our common denominator definition highlights the major features of Clouds, that make them different to Grids. Virtualization is the key enabler technology of Clouds, as it is the basis for features such as, on demand sharing of resources, security by isolation, etc. Usability is also an important property of Clouds. Also, security enhancements are needed so that enterprises could rely sensitive data on the Cloud infrastructure. Finally, QoS and SLA enforcement will also be essential before ICT companies reach high levels of confidence in the Cloud. Usability and virtualization could also be applied to grids to ease their usage, enhance their scalability, and allow on-demand services. NGG and OGF efforts are highly devoted to this task, enforcing standardization to enable a Cloud federation that can then deal with the required massive scalability.

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