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Cloud Computing: Taxonomy and Architecture

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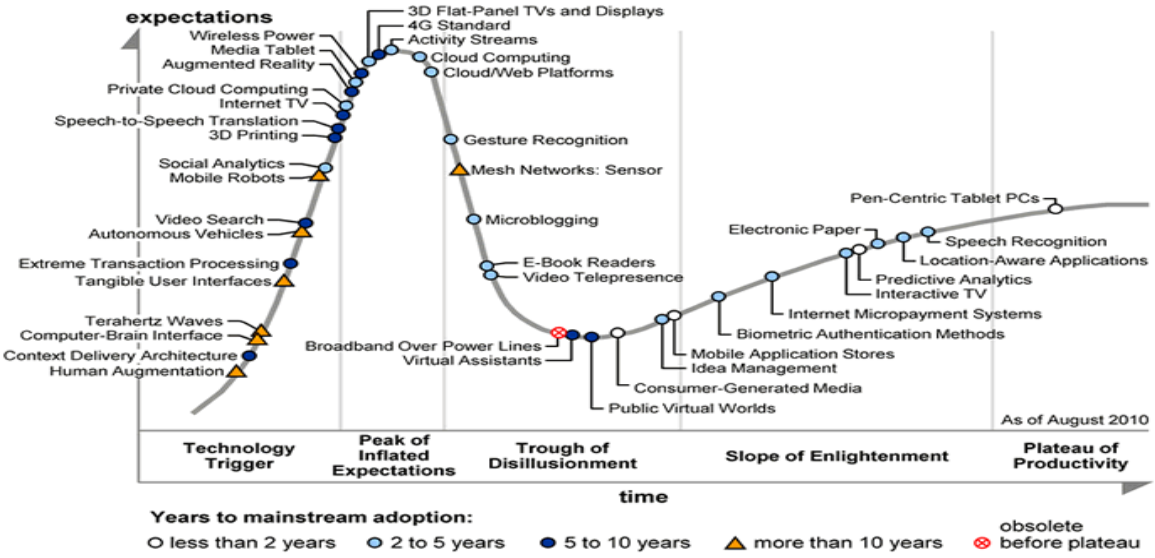
Abstract— Cloud computing, the long-held dream of computing as a utility, has finally came to realization. Cloud computing has the potential to transform a large part of the IT industry, making software even more attractive as a service and shaping the way IT hardware is designed and purchased. Developers with innovative ideas for new Internet services no longer require the large capital outlays in hardware to deploy their service or the human expense to operate it. These cloud applications use large data centres and powerful servers that host Web applications and Web services.This report gives an overview of what cloud computing means, its history along with the advantages and disadvantages. Finally the different types of Cloud computing services commonly referred to as Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS) are explained along with some examples to illustrate how they all work. This report also provides some guidance on situations where particular flavours of Cloud Computing are not the best option for an organization.

Keywords— Cloud Computing, Platform as a Service, Software as a Service, Infrastructure as a Service, Architecture.

I. Introduction

A major and generally accepted definition of Cloud Computing comes from the National Institute of Standards and Technology (NIST). The NIST definition [1] essentially says that:
"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. This paper is organized as follows: **Section 1** gives the introduction to cloud computing including the generally accepted definition of cloud computing along with a short history of cloud services. **Section 2** discusses important pros and cons of the cloud technology. **Section 3** gives some of the definitions involved. **Section 4** is the gist of the paper and discusses the cloud service architecture and supporting models; the SaaS, the PaaS and the IaaS along with examples where they can be used and not to be used. Finally, tables comparing some of the real cloud service providers were given based on which service model they are using for providing cloud services. Hype cycle is defined as a graphic representation of the maturity, adoption and social application of specific technologies. One can clearly see from the below Gartner's Hype cycle [2] that cloud computing as in 2009 is at its peak of expectation. Also many survey results shows that the cloud computing is going to be the next big thing after the web [3].



NIST also offers up several characteristics that it sees as essential for a service to be considered "Cloud". These characteristics include;

- On-demand self-service**:** By on – demand we mean that the end user has an ability to sign up instantaneously and receive services without the long delays that have characterized traditional IT.
- Broad network access**:** Ability to access the service via standard platforms (desktop, laptop, mobile etc).
- Resource pooling: Resources are pooled across multiple customers.
- Rapid elasticity**:** Capability can scale to cope with demand peaks.
- Measured Service: Billing is metered and delivered as a utility service.

So in general we may define cloud computing as:

"A style of computing in which dynamically scalable and often virtualized resources are provided as a service. Users need not have knowledge of, expertise in, or control over the technology infrastructure in the "cloud" that supports them. Furthermore, cloud computing employs a model for enabling available, convenient and on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, services) that can be rapidly provisioned and released with minimal management effort or service provider interaction."

A. Cloud Computing: Evolution over the Years [4]

- In 1999 Salesforce started delivering applications to users using a simple website. The applications were delivered to enterprises over the Internet, and this way the dream of computing sold as utility started being reality. Although the service was successful, some more time would pass until it would become widespread.
- In 2002 Amazon started Amazon Web Services, providing services like storage, computation and even human intelligence. However, only starting with the launch of the Elastic Compute Cloud in 2006 a truly commercial service open to everybody existed.
- 2009 marked a key turning point in the evolution of cloud computing, with the arrival of browser based cloud enterprise applications, with the best known being Google Apps.

Of course, all the big players are present in the cloud computing evolution, some earlier, some later. In 2009 Microsoft launched Windows Azure, and companies like Oracle and HP have all joined the game. This proves that today, cloud computing has become mainstream computing.

B. Advantages and disadvantages of cloud computing

a. Advantages

- ***Reduced Cost***: Cloud technology is paid incrementally, saving organizations money.
- ***Increased Storage***: Organizations can store more data than on private computer systems.
- ***Highly Automated***: No longer do IT personnel need to worry about keeping software up to date.
- ***Flexibility***: Cloud computing offers much more flexibility than past computing methods.
- ***More Mobility***: Employees can access information wherever they are, rather than having to remain at their desks.
- ***Allows IT to Shift Focus***: No longer having to worry about constant server updates and other computing issues, government organizations will be free to concentrate on innovation.
- ***Bonus advantage***: In a cloud computing environment resources can be shared across applications as well as customers resulting in greater use of the resources for a similar energy cost. For corporations spread over different time zones the computing power lying idle at one geographic location (during off-work hours) could be harnessed at a location in a different time zone. This reduces not only the power consumption but also the amount of physical hardware required. With cloud computing, virtual offices can be quickly set up and employees can easily work from home.

b. Disadvantages

- ***Security and privacy***: The biggest concerns about cloud computing are security and privacy. Users might not be comfortable handing over their data to a third party. This is an even greater concern when it comes to companies that wish to keep their sensitive information on cloud servers situated somewhere in the other part of the world. Privacy is another issue with cloud servers. After all, the success of a cloud service depends on its reputation, and any sign of a security breach would result in a loss of clients and business.
- ***Getting locked-in with a particular vendor***: With a company utilizing the services of a particular cloud vendor under the respective SLA (Service Level Agreement) it's not easy for the company to migrate to another cloud service provider.

II. Taxonomy Of Cloud Computing

A. Deployment Models [1]

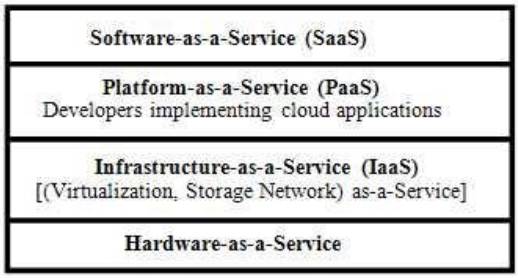
a) ***Private cloud***: The cloud infrastructure is operated solely for an organization. It may be managed by the organization or a third party and may exist on premise or off premise.

b) ***Community cloud***: The cloud infrastructure is shared by several organizations and supports a specific community that has shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be managed by the organizations or a third party and may exist on premise or off premise.
c) ***Public cloud***: The cloud infrastructure is made available to the general public or a large industry group and is owned by an organization selling cloud services.
d) ***Hybrid cloud***: The cloud infrastructure is a composition of two or more clouds (private, community, or public) that remain unique entities but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load-balancing between clouds).

B. Virtualization

Virtualization [6] is the technology that abstracts the coupling between the hardware and the operating system. It refers to the abstraction of logical resources away from their underlying physical resources in order to improve agility, flexibility, reduce costs and thus enhance business value. In a virtualized environment, computing environments, computing environments can be dynamically created, expanded, shrunk or moved as demand varies. Virtualization is therefore extremely well suited to a dynamic cloud infrastructure as it provides important advantages in sharing, manageability and isolation.

III. Cloud Computing Architecture [6]



Cloud architecture, the systems architecture of the software systems involved in the delivery of cloud computing, typically involves multiple cloud components communicating with each other over a loose coupling mechanism such as a messaging queue.

- SaaS applications are designed for end-users, delivered over the web.
- PaaS is the set of tools and services designed to make coding and deploying those applications quick and efficient.
- IaaS is the hardware and software that powers it all – servers, storage, networks, operating systems.

A. Software as a Service

Software as a Service (SaaS) is defined as software that is deployed over the internet. With SaaS, a provider licenses an application to customers either as a service on demand, through a subscription, in a "pay-as-you-go" model, or (increasingly) at no charge when there is opportunity to generate revenue from streams other than the user, such as from advertisement or user list sales. SaaS is a rapidly growing market as indicated in recent reports that predict ongoing double digit growth. This rapid growth indicates that SaaS will soon become commonplace within every organization and hence it is important that buyers and users of technology understand what SaaS is and where it is suitable.

a. Characteristics of SaaS

Like other forms of Cloud Computing, it is important to ensure that solutions sold as SaaS in fact comply with generally accepted definitions of Cloud Computing. Some defining characteristics of SaaS include;

- Web access to commercial software
- Software is managed from a central location
- Software delivered in a "one to many" model
- Users not required to handle software upgrades and patches
- Application Programming Interfaces (APIs) allow for integration between different pieces of software

b. Application area of SaaS

Organizations considering a move to the cloud will want to consider which applications they need from saas. As such there are particular solutions that are considered prime candidates for an initial move to SaaS;

- Applications where there is significant interplay between the organization and the outside world. For example, email newsletter campaign software.
- Applications that have a significant need for web or mobile access. An example would be mobile sales management software.
- Software that is only to be used for a short term need. An example would be collaboration software for a specific project.

- Software where demand spikes significantly, for example tax or billing software used once a month.

SaaS is widely accepted to have been introduced to the business world by the Salesforce Customer Relationship Management (CRM) product. As one of the earliest entrants it is not surprising that CRM is the most popular SaaS application area, however e-mail, financial management, customer service and expense management have also gotten good uptake via SaaS.

c. Situations where SaaS cannot be used

While SaaS is a very valuable tool, there are certain situations where it is not the best option for software delivery. Examples where SaaS may not be appropriate include;

- Applications where extremely fast processing of real time data is required.
- Applications where legislation or other regulation does not permit data being hosted externally.
- Applications where an existing on-premise solution fulfills all of the organization's needs.

Software as a Service may be the best known aspect of Cloud Computing, but developers and organizations all around the world are leveraging Platform as a Service, which mixes the simplicity of SaaS with the power of IaaS, to great effect.

B. Platform as a Service

Platform as a Service (PaaS) brings the benefits that SaaS bought for applications, but over to the software development world. PaaS can be defined as a computing platform that allows the creation of web applications quickly and easily and without the complexity of buying and maintaining the software and infrastructure underneath it. PaaS is analogous to SaaS except that, rather than being software delivered over the web, it is a platform for the creation of software, delivered over the web.

a. Characteristics of PaaS

There are a number of different takes on what constitutes PaaS but some basic characteristics include:

- Services to develop, test, deploy, host and maintain applications in the same integrated development environment. All the varying services needed to fulfill the application development process.
- Web based user interface creation tools help to create, modify, test and deploy different UI scenarios
- Multi-tenant architecture where multiple concurrent users utilize the same development application
- Built in scalability of deployed software including load balancing and failover
- Integration with web services and databases via common standards
- Support for development team collaboration – some PaaS solutions include project planning and communication tools
- Tools to handle billing and subscription management.

PaaS, which is similar in many ways to Infrastructure as a Service that will be discussed below, is differentiated from IaaS by the addition of value added services and comes in two distinct flavors;

- A collaborative platform for software development, focused on workflow management regardless of the data source being used for the application. An example of this approach would be Heroku, a PaaS that utilizes the Ruby on Rails development language.
- A platform that allows for the creation of software utilizing proprietary data from an application. This sort of PaaS can be seen as a method to create applications with a common data form or type. An example of this sort of platform would be the Force.com PaaS from Salesforce.com which is used almost exclusively to develop applications that work with the Salesforce.com CRM.

b. Applications of PaaS

PaaS is especially useful in any situation where multiple developers will be working on a development project or where other external parties need to interact with the development process. As the case study below illustrates, it is proving invaluable for those who have an existing data source – for example sales information from a customer relationship management tool, and want to create applications which leverage that data. Finally PaaS is useful where developers wish to automate testing and deployment services. The popularity of agile software development, a group of software development methodologies based on iterative and incremental development, will also increase the uptake of PaaS as it eases the difficulties around rapid development and iteration of software. Some examples of PaaS include Google App Engine, Microsoft Azure Services, and the Force.com platform.

c. Situations where PaaS cannot be used

We contend that PaaS will become the predominant approach towards software development. The ability to automate processes, use pre-defined components and building blocks and deploy automatically to production will provide

sufficient value to be highly persuasive. That said, there are certain situations where PaaS may not be ideal, examples include:

- Where the application needs to be highly portable in terms of where it is hosted.
- Where proprietary languages or approaches would impact on the development process.
- Where a proprietary language would hinder later moves to another provider – concerns are raised about vendor lock-in.
- Where application performance requires customization of the underlying hardware and software.

C. Infrastructure as a Service

Infrastructure as a Service (IaaS) is a way of delivering Cloud Computing infrastructure – servers, storage, network and operating systems – as an on-demand service. Rather than purchasing servers, software, datacenter space or network equipment, clients instead buy those resources as a fully outsourced service on demand.

. Generally IaaS can be obtained as public or private infrastructure or a combination of the two. "Public cloud" is considered infrastructure that consists of shared resources, deployed on a self-service basis over the Internet.

By contrast, "private cloud" is infrastructure that emulates some of Cloud Computing features, like virtualization, but does so on a private network. Additionally, some hosting providers are beginning to offer a combination of traditional dedicated hosting alongside public and/ or private cloud networks. This combination approach is generally called "Hybrid Cloud".

a. Characteristics of IaaS

As with the two previous sections, SaaS and PaaS, IaaS is a rapidly developing field. That said there are some core characteristics which describe what IaaS is. IaaS is generally accepted to comply with the following;

- Resources are distributed as a service
- Allows for dynamic scaling
- Has a variable cost, utility pricing model
- Generally includes multiple users on a single piece of hardware.

There are a plethora of IaaS providers out there from the largest Cloud players like Amazon Web Services and Rack space to more boutique regional players.

The line between PaaS and IaaS is becoming more blurred as vendors introduce tools as part of IaaS that help with deployment including the ability to deploy multiple types of clouds.

b. Applications of IaaS

IaaS makes sense in a number of situations and these are closely related to the benefits that Cloud Computing bring. Situations that are particularly suitable for Cloud infrastructure include:

- Where demand is very volatile – any time there are significant spikes and troughs in terms of demand on the infrastructure.
- For new organizations without the capital to invest in hardware.
- Where the organization is growing rapidly and scaling hardware would be problematic
- Where there is pressure on the organization to limit capital expenditure and to move to operating expenditure.
- For specific line of business, trial or temporary infrastructural needs.

c. Situations where IaaS cannot be used

While IaaS provides massive advantages for situations where scalability and quick provisioning are beneficial, there are situations where its limitations may be problematic. Example of a situation where we would advise caution with regards IaaS include:

- Where regulatory compliance makes the off shoring or outsourcing of data storage and processing difficult.
- Where the highest levels of performance are required, and on-premise or dedicated hosted infrastructure has the capacity to meet the organizations.

IV. COMPARISON OF SERVICES PROVIDED BY TWO DIFFERENT COMPANIES

A. Comparison of two SAAS providers

Force.com and Netsuite are two major SAAS providers. Their comparison on the basis of various parameters is given below:

TABLE I
Cloud Computing SAAS Providers

Features	Force.com[7]	Netsuite[8]

Computer architecture	Multitenant architecture with meta data driven development model which allow a single application to serve multiple customers.	Service oriented architecture
Load balancing	Load balancing among tenants.	Load balancers with "denial of service counter measures".
Fault tolerance	Self management and self tuning.	Hot Backups -All production data is stored to redundant locations. In the event of a system-level disaster, these backups give NetSuite the ability to restore data rapidly and reliably.
Storage	Force.com database deals in terms of relationship fields.	Stored in databases that implement N+1 system of redundancy and also in reliable tape media.
Security	SSL encryption and SysTrust SAS 70 type II -that ensures availability, security and integrity.	128 bit secure socket layer data encryption.

From the above comparison it is clear that Force.com is better in terms of architecture and security while Netsuite scores more when storage is considered.

B. Comparison of two PAAS providers

Google App Engine and Azure are the two leading PAAS providers. Their comparison on the basis of similar parameters is given below:

TABLE II
Cloud Computing PAAS Providers

Features	Google App Engine[9]	Azure[10]
Computer Architecture	Google Geo-distributed architecture	An internet-scale cloud services platform hosted in Microsoft Data centre, which provides an operating system and a set of developer services which can be used individually or together.
Load Balancing	Automatic scaling and load balancing	Built in hardware load balancing
Fault Tolerance	Automatic pushed to a number of fault tolerant servers -App Engine Cron Service	Containers are used for load balancing and availability: If a failure occurs, SQL data server will automatically begin using another replica of the container.
Storage	Proprietary Database(Big table distributed storage).	SQL server data services(SSDS) which allow storing binary large objects(BLOBS).
Security	Google Secure Data Connecter -SDC uses RSA/128 bit or higher AES CBS/SHA and TLS based server authentication.	Token Server (STS) create security, assertion, mark-up language token according to rule.

From table 2 it can be derived that in terms of Architecture, storage and security Google Apps Engine is better than Azure. SDC provides very high data security which is a major cloud computing issue.

C. Comparison of two IAAS providers:

Amazon Web Services and GoGrid are two major IAAS providers.Their comparison on basis of similar parameters is given below:

TABLE III
Cloud Computing IAAS Providers

Features	Amazon web services[11]	GoGrid[12]
Computing architecture	Elastic Compute Cloud EC2 allows uploading XEN virtual machine images to the infrastructure and gives client APIs to instantiate and manages them. -Public Cloud	Data center architecture which is designed to deliver a guaranteed QoS level for the exported services - automatically reconfiguring for infrastructure to cater for fluctuations in the demand
Load balancing	Service will allow user to balance incoming requests and traffic across multiple EC2 instances and Round Robin load balancing.	F5 load balancing, load balancing algorithm used as Round Robin, sticky session and source addresses.
Fault Tolerance	System should automatically alert, failover and re-sync back to the "last known consistent state".	Instantly scalable and reliable file-level backup source.
Storage	Simple Storage Service (S3) and simple database. It provides a semi-structure data store with querying capability.	Storage is a twostep process- 1) Connecting each server to private network. 2) Transfer protocols (FTP,SCP) to transfer data to and from cloud storage.
Security	Type II (SAS 70 type II) certification, firewall, X.509 certificate, SSL-protected API.	Don't provide a guarantee of security.

From Table 3 it can be deduced that in terms of security Amazon web services is better than GoGrid.

V. Conclusion

Cloud computing is a promising paradigm for delivering IT services as computing utilities and is regarded by some as the fifth generation of computing after Mainframe, Personal Computer, Client – Server computing and the Web. There are many open issues regarding the cloud computing, some of which are mentioned in the above tables where we have compared the cloud service providers on the basis of five points – computer architecture, fault tolerance, load balancing, storage and security. Evolution in computer architecture will definitely result in improvement of cloud services and new players may emerge with enhancement in cloud research. Load balancing and fault tolerance will definitely be a deciding factor for the reputation of the cloud vendors in the market. For example, Microsoft Azure had an outage that lasted 22 hours in March 13th – 14th, 2008. Cloud reliance can cause significant problems if the control of downtime and outages is removed from your control. Cloud storage enables client to put data into the cloud and without worrying about how it is stored or backed up. The main issues related to cloud storage are reliability and security.

The architecture and taxonomy discussed in this paper provide researcher and developer the ideas on the current cloud technologies and trends. This paper provides the information to evaluate and guidance on improvement of the existing cloud systems and to develop new cloud technologies.

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