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ABSTRACT

This paper outlines the key characteristics that cloud computing technologies possess and illustrates the cloud computing stack containing the three essential services (SaaS, PaaS and IaaS) that have come to define the technology and its delivery model. The underlying virtualization technologies that make cloud computing possible are also identified and explained. The various challenges that face cloud computing technologies today are investigated and discussed. The future of cloud computing technologies along with its various applications and trends are also explored, giving a brief outlook of where and how the technology will progress into the future.

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1. INTRODUCTION

Cloud computing has been a concept and a buzz word in the computing industry for many years now, the term has been widely used with many businesses not fully understanding what it actually is and how it will benefit them. The reason why the term was not fully understood was because it was still a concept and the underlying virtualization technology needed and our own networking infrastructure was still in its infancy which meant we could not unlock the full potential of cloud computing, until now. Microsoft has stated that for many businesses in the year 2012 it "stops being a buzzword, or a future goal and becomes a part of your plan, today" [1]. This technology has been steadily gathering momentum in many of today's industries, with many of IT's biggest corporations such as, Amazon, Google, Microsoft and Salesforce.com etc pushing the utilization of cloud technology this year. More and more businesses are starting to understand the cloud with some touting it to be "The fifth generation of computing"[2].

The National Institute of Standards and Technology (NIST) defines cloud computing as a model for enabling ubiquitous, 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 [3]. What NIST have outlined here is that cloud computing is not a new technology but rather a new delivery model for computing infrastructure, services and information using many existing technologies that have been harnessed and made available by the cloud service provider's (CSP's). Cloud service providers use the Internet infrastructure to allow communication between client side and server side services/applications [4] and offer the customer/user a pay-per-use model of the CSP's computing resources and infrastructure. Cloud computing can be described as a usage model in which resources are deliveries and, it means to provide resources, such as hardware, software and applications as scalable and "on-demand" services via public network in a multi-tenant environment [5]. From the description and definition of cloud computing outlined it's clear that cloud computing has many features, attributes and terminologies that have made the delivery model difficult to grasp for many. This article aims to explain the key concepts, terminologies and underlying technologies as

well as discussing the current challenges and future applications of cloud computing technologies which will deliver a much broader understanding, appreciation and adoption of cloud computing.

The rest of this paper is organised as follows. Section 2 discusses the characteristics of the cloud delivery model, section 3 provides an overview of the underlying virtualization technology, section 4 provides some predictions concerning the future of the cloud and section 5 concludes.

2. TECHNICAL ASPECT

The cloud delivery model has four essential characteristics that set it apart from any other computing model. Understanding these characteristics is essential and is the first step to grasping how important cloud computing technology will be for businesses and end users alike. The four essential characteristics of cloud computing are outlined below:

1. **Multi-tenancy (Resource Pooling) –** Cloud computing utilizes a multitenant model which allows multiple users/customers to share resources from a large resource pool. The resources are dynamically assigned and reassigned to facilitate each customers needs and includes processing, storage, memory, network bandwidth, and virtual machines
2. **Massive Scalability (*On-demand self-service*) -** Cloud computing offers the ability to dynamically scale from ten to thousands of systems and users can self-provision computing resources, such as servers and network storage, as needed without the need to notify the cloud service provider.
3. **Rapid Elasticity -** Users can rapidly increase and decrease their computing resources as needed, this is often achieved automatically, which gives the consumer impression that resources are infinite and that the application can always cope when in demand. When resources are no longer needed they are relinquished back into the resource pool.
4. **Measured Service (Pay-Per-Use) –** Any resources that are used are carefully monitored, controlled and recorded which allows the cloud service provider to be completely transparent with the consumer of the resources and facilities. The user only pays for the amount of resources they consume and are always made aware of any discrepancies, spikes or abnormal behavior regarding resources.

Cloud computing delivers the characteristics outlined above through three main services that have come to define cloud computing and how the end users can access their resources and services. Together these three services form the cloud computing stack shown in Figure 1. The services are known as Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS) and Infrastructure-as-a-Service (IaaS):

Software-as-a-Service (SaaS) – Offers users an easier way to access many of their standard business applications and services such as email and word processing packages etc, by allowing users to access these programs through the internet, there is no need to install and run the special software on your computer if you use the SaaS. Instead of buying the software at a relative higher price, you just follow the pay-per-use pattern, which can reduce you total cost [6]. This allows businesses to save money, as it removes licensing fees and they only pay for what they use and when they use. It also removes the need to upgrade software packages as the cloud service provider does this automatically so the end user will always be up-to-date. One of the greatest benefits of SaaS is that the user can access their work and services from anywhere in the world where they can connect to the Internet. Examples of SaaS today are Google's Gmail, Microsoft's Office Live and Cornerstone On Demand etc.

Platform-as-a-Service (PaaS) – Is a set of cloud-delivered services that provide an environment for application development, deployment, management and integration in the cloud [7]. This service is tailored towards software developers, it allows new software solutions to be developed and even existing solutions to be extended without the developer having the hassle of having all the software development kits (SDK's) and infrastructure. Many CSP's that offer PaaS have many web based tools to decrease development time and reduce costs for developers such as version control, agile and lifecycle planning etc. There are many examples of PaaS today such as Google's App Engine, Amazon's EC2 and Microsoft's Azure platform.

Infrastructure-as-a-Service (IaaS) – Is known for providing computational and storage infrastructure in a centralized, location-transparent service [8]. The infrastructure that is provided by the CSP includes storage, servers, bandwidth and network equipment, which includes software that monitors the use of the infrastructure and allows the user to only pay for what they use. Some of the most popular examples of IaaS today include Go Grid's ServePath and Amazon's Elastic Compute Cloud (EC2).

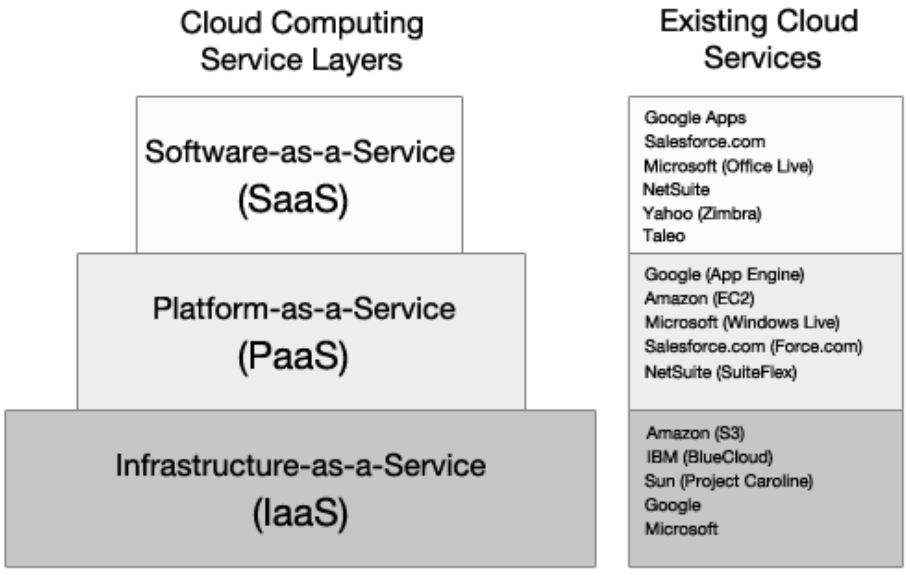

Figure 1: Showing the cloud computing stack and existing cloud services

3. The Underlying Technology (Virtualization)

Cloud computing technologies could never exist without the use of the underlying technology known as Virtualization. It allows abstraction and isolation of lower level functionalities and underlying hardware. This enables portability of higher level functions and sharing and/or aggregation of the physical resources [9]. Cloud computing heavily relies on virtualization as it virtualizes many aspects of the computer including software, memory, storage, data and networks. Virtualization is known to enables you to consolidate your servers and do more with less hardware. It also lets you support more users per piece of hardware, deliver applications, and run applications faster [10]. These attributes that virtualization hold are the core of cloud computing technologies and is what makes it possible for cloud computing's key characteristics of multi-tenancy, massive scalability, rapid elasticity and measured service to exist.

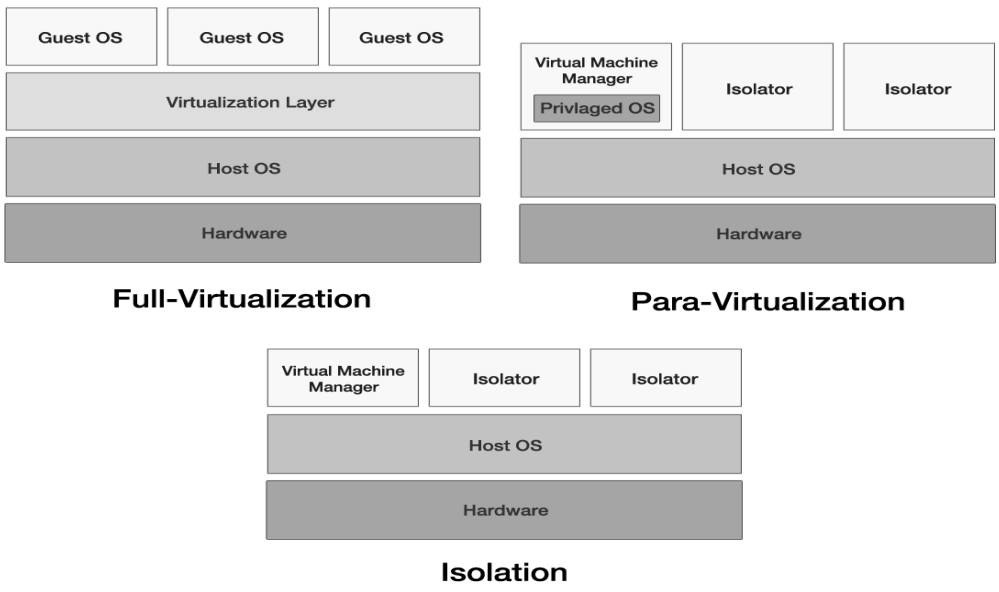

Figure 2: Three forms of virtualization

There are three types of Virtualization known as Full, Para and Isolation, each are explained below and are represented visually in figure 2.

Full Virtualization – This type of virtualization operates at the processor level, which supports unmodified guest operating systems that simulate the hardware and software of the host machine.

Para-virtualization – Utilizes the use of a virtual machine monitor, which is software that allows a single physical machine to support multiple virtual machines [11]. It allows multiple virtual machines to run on one host and each instance of a guest program is executed independently on their own virtual machine.

Isolation – Is similar to Para virtualization although it only allows virtualization of the same operating system as the host and only supports Linux systems but it is considered to perform the best and operate the most efficiently.

As more businesses are starting to move to the cloud, they should be aware of the many challenges that the technology is currently experiencing, its important that they are prepared to encounter some of these challenges during their migration towards cloud technologies. Cloud computing has been around for many years and has always been clouded in ambiguity as to what the technology was and many individuals would provide their own interpretations and opinions in defining various cloud delivery models. This is very much to do with lack of standards and a clear definition of each aspect of what cloud technology is and how it actually functions. Many cloud computing providers admitted they consider standards as the first step to commoditization, something they would rather not see this early in the emerging market [12]. So the lack of standards is partially to do with many cloud providers not wanting them defined yet, which is certainly going to cause more ambiguity and possibly slow down adoption of cloud technologies.

Cloud consumers do not have control over the underlying computing resources, they do need to ensure the quality, availability, reliability, and performance of these resources when consumers have migrated their core business functions onto their entrusted cloud [13]. Cloud service providers need to be transparent and responsible for the services they provide for their consumers to create consumer confidence in their services. Consumer confidence can be achieved through a mutual agreement commonly referred to as a Service Level Agreement (SLA). By migrating to the cloud service provider's infrastructure means that they have a large responsibility for the consumers data and services to be maintained and made available with the specification outlined in the SLA. A broker could lose $4 million in revenues per millisecond if their electronic trading platform is 5 milliseconds behind the competition [14], which is another reason why the consumer must be confident that their cloud provider can and will deliver a high-quality infrastructure.

Data governance is a large issue for consumers because when they migrate their systems to the CSP's infrastructure they lose control of their own data and they rely solely on the CSP's ability to make the data available and to make it secure in the process. Where the CSP's data centers are physically located can also make a large difference in terms of security and confidentiality as the US Patriot Act grants government and other agencies with virtually limitless powers to access information including that belonging to companies whereas in the EU this type of data would be much more secure [15], it is important consumers take this into account when selecting a cloud service provider. Security is the most important challenge for cloud technology, as CSP's have to protect the consumer's data from theft and ensure the consumer is not exploited. Consumers may be exploited from denial of service (DoS) attacks where the user or owner could actually end-up paying for the attack through their increased resource usage [16] as cloud computing is based on a pay-per-use billing model this would need to be taking into account by the CSP. They must also protect the data through the use of advanced encryption algorithms and ensure that their data centers are physically secure using advanced biometrics and many other authentication methods. Data must be kept private through the use of privileges, access controls and groups which can get very intricate with CSP's having a problem keeping track of dependencies between group rights and rights of group members [17]. The CSP's must ensure that no private data of any client is leaked or seen by someone is not authorized, this is a large concern due to the fact that cloud computing employs a multi-tenant model and many users share the same storage space and servers.

4. FUTURE OF THE TECHNOLOGY

As cloud computing is a relatively new delivery model it's future is not fully known but seeing as its popularity and excitement around the technology is constantly growing, it's safe to say that cloud computing is here to stay. Short-term forecasts predict that in 2012 80% of new commercial enterprise apps will be deployed on cloud platforms [18], which illustrates that cloud adoption is set to rise exponentially this year. In the long-term technology experts and stakeholders say they expect they will 'live mostly in the cloud' in 2020 and not on the desktop, working mostly through cyberspace- based applications accessed through networked devices [19]. The many stakeholders and enthusiasts of the technology see it as the next step in computing, with many businesses and individual users in the future using cloud technology in some shape of

form. Using cloud technologies will become even more popular as our network infrastructure is improved allowing less latency and quicker connections to the content on the cloud.

Cloud computing technologies are for everyone as it benefits the common user as much as it benefits stakeholders, business leaders and academics as cloud computing has the potential to reduce cost and risk, increase revenue, and enhance total customer experience [20] for everyone. There are a number of trends that have been projected such as that integrated public and private cloud infrastructure will become possible 2012, and many will take advantage of it [21]. This will be possible with emerging technologies such as vCloud Connector 1.5, which lets users running workloads on internal VMware infrastructure slide all or part of those workloads into a leased public cloud running the same infrastructure [22] allowing communication between private and public clouds. Businesses will want to share their information, services and infrastructure with other clouds that means that clouds are going to move towards a cloud network. This will facilitate collaboration for projects or engagements across enterprises and enabling conference calls including temporary, controlled access to internal information systems, knowledge bases or information distribution systems which usually are only accessible to employees [23]. All the common problems outlined in the previous section will have to be addressed with security being the largest challenge as it can influence the cloud market and also drive trends. There is a concern about cyber gangs hacking into commercial and military systems, which leads to a worldwide trend that temporarily reduces public cloud adoption [24] and in order to protect against these negative trends security and standards must not be ignored.

5. CONCLUSION

It is clear that cloud computing is here to stay for the foreseeable future, as the topic has had buzz around it for years now and it is finally being adopted by many with more to follow. The key concepts, terminologies and underlying technologies of cloud computing that were outlined should clarify and aid in the understanding of this complex topic. Through identifying the current challenges that cloud computing technologies are experiencing it allows cloud service providers to act upon them and also give consumers a better understanding of the problems which can affect them when migrating to cloud environments. In order for cloud technologies to be fully adopted by everyone the challenges in standards, consumer confidence, data governance and most importantly security must be addressed. The future of cloud computing is not definite but by analyzing the trends it seems that cloud technology will play a large part in our day to day lives. In the future business and consumers will benefit from higher interoperability between clouds and maybe even a cloud network which will improve sharing of resources and information. There are many uses for this technology and it is surely going to change the way in which we handle our data, services and access/store our digital content but for its full potential to be unlocked a broader understanding, appreciation and investment in cloud computing technologies is required.

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Kevin Curran BSc (Hons), PhD, SMIEEE, FBCS CITP, SMACM, FHEA is a Reader in Computer Science at the University of Ulster. His achievements include winning and managing UK & European Framework projects and Technology Transfer Schemes. He has published over 700 published works to date. He is the Editor in Chief of the International Journal of Ambient Computing and Intelligence (IJACI). Dr Curran is a Fellow of the Higher Education Academy, a Fellow of the British Computer Society and is listed by Marquis in their prestigious Who's Who in Science and Engineering. He is also listed in the Dictionary of International Biography and by Who's Who in the World.