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Cloud Computing: The New Paradigm of Computing for a Connected World

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Abstract - This paper is an attempt to study the emerging technological paradigm of Cloud Computing. The objective of the study is to research the extant literature to arrive at meaningful understandings of the concepts related to Cloud Computing. By deploying a qualitative research approach an attempt is made to conceptualize and clarify the terms related to Cloud Computing, its deployment models like Private Cloud, Public Cloud, Hybrid Cloud, etc. This paper also attempts to highlight the various cloud based services offered to customers at different levels of abstraction like IaaS, PaaS, SaaS, etc.

Keywords — Cloud Computing, IaaS, PaaS, SaaS, Public Cloud, Private Cloud, Hybrid Cloud

I. INTRODUCTION

The incumbent IT paradigm comprises of Pre-packaged software and hardware. In this paradigm, businesses usually acquire software and hardware which has a relatively expensive replacement cost and comes with pre-defined capacity in terms of software and hardware processing power. Hardware is often planned and purchased to meet long term operational goals such as increase in number of transactions; although in the immediate term, the technology remains underutilised. However, by the time the anticipated long term goal arrives, the hardware can be purchased for a fraction of the cost originally incurred. Thus, in the current IT paradigm, augmenting the software and hardware capacity usually requires high replacement costs (Capital Expenditure) for a fresh set of software and hardware.

The emerging IT paradigm of Cloud Computing gets rid of some these weaknesses of the incumbent paradigm as it enables high levels of efficiency, flexibility, and responsiveness while being less expensive. It also opens up new sets of opportunities as it enables new business models for the IT industry. In this paradigm, consumers mainly incur operational expenditure as they only need to pay subscription costs for using the shared infrastructure. The popularity of the emerging paradigm can be gauged from the fact that cloud infrastructure spending by users grew by 46% from $55 billion in 2017 to US$80 billion in 2018 [1]. So, what really is Cloud Computing? What are the various components of Cloud Computing? What are the emerging technological paradigms in Cloud Computing? We try to answer these questions in this paper.

II. METHODOLOGY

The qualitative research approach has been adopted for the study. Qualitative research is based on subjective assessment of phenomena and is determined by the researcher's insights and impressions [2]. Qualitative research may include research approaches such as phenomenology, ethnographies, narratives, grounded theory studies or case studies. The researcher collects qualitative information by employing various techniques including secondary sources for developing themes of study [[3]; [2]]. In this study, we have evaluated the secondary sources to review the emerging paradigm of Cloud Computing. From an analysis of the existing literature an attempt is made to conceptualize the concept of cloud computing and its various components.

III. CLOUD COMPUTING

Of late, the concept of Cloud Computing has gained currency but there is no agreement on its definition. Indeed, the term has managed to gain popularity even though without a commonly accepted definition in the academia. While the term 'Cloud Computing' may be new, the concepts encapsulated by it are by no means new. The ideas of time sharing, computing based on client-server architecture, data centres, etc have been in existing for decades.

According to the National Institute of Standards and Technology (NIST):

"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 [4]."

This is a good conceptual definition of cloud computing and it identifies "five essential characteristics":

1. **On-demand self-service:** Computing capabilities, such as server processing power and network storage can be provisioned by a consumer automatically, as and when required, without the need for human intervention with the service provider.

2. **Broad network access:** Capabilities are accessed over the internet through a variety of devices including handheld mobile devices, laptops, and Desktop computers by using standard mechanisms.

3. **Resource pooling:** A large amount of computing resources like processing power and storage are combined to serve many users with the provision for allocating such physical and virtual computing resources to meet consumer demand dynamically.

4. **Rapid elasticity:** The Computing capabilities are provided with the facility to meet the increase or decrease

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in consumer demand. This up-scaling and downscaling is often possible automatically and from the consumers' perspective, the computing resources appear to be extensible and can be accessed in the desired quantity as and when required.

5. **Measured service:** Cloud computing services provide the capability for measuring the storage, bandwidth, processing power, and the number of users. Thus Cloud systems provision a control mechanism which is transparent for both the service provider and the consumer and enables optimum utilisation of computing resources.

All of the cloud computing services are made possible by a technology called virtualisation. Therefore, before we discuss various types of cloud computing services, we will elaborate briefly on the related concept of virtualisation.

IV. VIRTUALISATION

In the words of Mike Adams, Director, VMware, a pioneer in virtualization and cloud software and services, "Virtualization is a foundational element of cloud computing and helps deliver on the value of cloud computing". It is the software that manipulates hardware, while cloud computing refers to a service that results from that manipulation [5].

Virtual machine monitor (VMM) or virtual manager is the core technology in virtualisation that separates software compute environments from the actual physical computer related infrastructure. Virtualization makes servers, workstations, storage and other systems independent of the physical hardware layer. This is done by installing a Hypervisor on top of the hardware layer, where the systems are then installed [5].

Virtualization involves creation of a virtual version of hardware, such as a computer server, storage device, network infrastructure or even an operating system so that it could be accessed by one or many machines at the same time [6]. It enables transformation of traditional computing to cloud computing that is more scalable, efficient and economical. Virtualisation is used in cloud computing in the following ways:

(a) Storage virtualization: Many storage devices in a network are combined into a virtual single storage unit and made available as shared resource to multiple clients.

(b) Server virtualization: One physical server may be divided into smaller virtual servers and made available to several clients.

(c) Operating system-level virtualization: This is a type of server virtualization technology which works at the operating system (kernel) layer.

(d) Network virtualization: One single physical network could be logically divided for use by multiple clients.

With reference to the various types of virtualisation discussed above, Gartner has outlined a set of technological concepts that Indian IT firms may monitor over the next few years [7]. Some of these concepts discussed below are still in their infancy and as the technology matures and firms work out their implementations the terms themselves are likely to change in meaning in the future. Some of the important IT trends in virtualisation are discussed below:

A. Software Defined Data Centres

Software-defined data centre (SDDC) involves virtualization of the entire data centre infrastructure and its delivery as a service. It is an approach in which involves virtualization concepts such as abstraction, pooling, and automation to the entire data centre's resources [8]. In a software-defined data centre, "compute, storage, networking, security, and availability services are pooled, aggregated, and delivered as software, and managed by intelligent, policy-driven software [9]." This is in contrast to traditional data centres where the infrastructure is typically defined by hardware and devices. Software-defined data centres are considered to be the next step in the evolution of virtualization and cloud computing as it provides a solution to support both legacy enterprise applications and new cloud computing services. Indeed, Software-defined data centres are the necessary foundational infrastructure for scalable, efficient cloud computing.

According to Torsten Volk, Enterprise Management Associates, there are three core components of the software-defined data centre: network virtualization sometimes referred to as software-defined networking, server or compute virtualization and storage virtualization or Software-defined storage. It also requires software for running the data centre services thus enabling an administrator to provision, control, and manage all the data centre components [10]. If hardware fails, software automatically redirects workloads to other servers in the data centre, minimizing service-level recovery time.

B. Software Defined Networks

Software-defined networking (SDN), or Network virtualization involves merger of hardware, software and network resources to create a software-based virtual network. This approach to computer networking evolved from work done at University of California, Berkeley and Stanford University around 2008 [11]. SDN allows network administrators to administer network services by abstraction of lower level functions. This is achieved by separating the network control plane (the system that determines where traffic is sent) from the data forwarding plane (the underlying system that forwards traffic to the intended destination). In the SDN approach, the control plane controls several devices. Software-Defined Networking is an emerging architecture that is dynamic, manageable, cost-effective, making it ideal for the high-bandwidth, elastic demands of today's applications [11].

SDN requires a mechanism for the 'control plane' to interact with the 'data plane'. One such method, OpenFlow, is an important component for building SDN solutions, but other techniques could also fit into the framework. The Open Networking Foundation was instituted to promote SDN and open standards for implementing software defined networks.

According to the International Data Corporation (IDC) software-defined networking market was expected to be about USD $3.7 billion by 2016, compared to USD $360 million in 2013 [12].

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C. *Software-defined storage*

Software-defined storage (SDS), or storage virtualization, refers to such storage infrastructure that is driven by intelligent software instead of hardware itself. It enables data centre administrators to manage multiple storage types and brands from a single software interface by decoupling the storage devices from the software that administers the storage infrastructure. SDS involves pooling and abstraction of the logical storage services and capabilities from the underlying physical storage infrastructure. It is unbundled from the actual storage hardware and it allows for provisioning of additional storage arrays as needed [13]. VMware has advocated that the term means that storage would have been abstracted, pooled, and automated. SDS enables enterprises to procure and deploy heterogeneous hardware without being concerned about issues of interoperability and under or over utilisation of any specific storage hardware resources. The main advantages of SDS over traditional storage devices include enhanced flexibility, automated management and provisioning, and cost efficiency.

According to IDC estimates, in the near future, the software-defined storage (SDS) market is expected to grow faster than any other segment of storage market [12]. SDS forms a part of a broader Software-defined data centre (SDDC) concept wherein all the virtualized resources like storage, server, security and networking resources necessary for running an application can be defined by software and provisioned dynamically.

There are mainly three types of Cloud computing services: **Infrastructure as a service (IaaS), Platform as a Service (PaaS) and Software as a service (SaaS).** Each of these may further have several sub categories under them as the industry evolves.

V. INFRASTRUCTURE AS A SERVICE (IAAS)

Infrastructure as a service (IaaS) [14] is a standardized, highly automated service, where infrastructure capabilities like compute resources, storage, networking capabilities and other critical computing resources are owned and hosted by a service provider and offered to customers 'on-demand' with the provision for the customers to deploy and run their software, which may include operating systems and applications. Infrastructure as a Service (IaaS) involves abstraction of hardware (server, storage, and network infrastructure) into a range of computing, storage, and connectivity capabilities that are offered as services for a usage-based cost.

IaaS service providers offer computers – physical or virtual machines – and other computing resources within the cloud computing operation that can support large numbers of virtual machines with the flexibility to scale services up and down according to customers' elastic demands. Services cover the levels of performance and the availability of virtualized infrastructure. Customers are able to self-provision this infrastructure, using a Web-based console provided by the service providers.

The raison d'etre of IaaS is to provide a flexible, standardized, and virtualized operating environment that can become the foundational layer for Platform as a Service (PaaS) and Software as a Service (SaaS).

Some examples of IaaS are: Amazon S3/EC2, Microsoft Windows Azure, and VMWare vCloud.

VI. PLATFORM AS A SERVICE (PAAS)

A **platform as a service (PaaS)** [15] includes a broad range of application infrastructure (middleware) services (including guest operating system; application execution runtime environment, storage, and integration of applications written for a pre-specified development framework; business process management, database services, and web server).

In the PaaS model, application developers develop and run their software solutions on a cloud based platform without having to buy or mange the underlying hardware and software layers as the same can be procured on usage based costing. Thus, PaaS provides an efficient and agile approach to operate scale-out applications in a predictable and cost-effective manner. Further, the underlying computing and storage resources scale automatically to meet the applications' demand. Thus, the customer does not have to allocate resources manually.

Service levels and operational risks are mutually dependent. The customer is expected to take responsibility for the stability and overall functioning of their application while the PaaS provider provides the platform capability (ensuring the infrastructure and operational functions) at the expected service level and cost [16].

Some examples of PaaS are: Google App Engine, Microsoft Azure Services Platform, and ORACLE/AWS.

VII. SOFTWARE AS A SERVICE (SAAS)

Software as a service (SaaS) [17] is a cloud services model in which the software is owned and managed remotely by one or more providers and generally delivered to a large number of users over the internet. This is the most sophisticated cloud computing model, hiding all the underlying details of operating system, database management systems, application servers, networking, storage, etc. from the end user. Therefore, the consumer is not involved in the management or control of the underpinnings of cloud infrastructure or even the capabilities of individual applications, except where the service provider has provided access to user-specific configuration settings for an application.

In the SaaS framework, the customer uses the service provider's applications running on a cloud infrastructure. These applications can be accessed from a variety of client devices through a client interface like a web browser or any other light weight client application. Unlike other applications, cloud applications are known to be scalable, i.e., they can handle large number of simultaneous users. This kind of scalability is achieved by replicating tasks onto multiple virtual machines as the application work load increases. As opposed to buying and installing packaged software in local machines, cloud based SaaS applications are typically offered on a monthly or yearly subscription fee per user, so price is dependent on the number of users enrolled for the service.

SaaS has the potential to reduce IT operational costs as all IT infrastructural hardware and software functions are abstracted away from the customer [18]. In this model, the operational risks related to maintenance of hardware and

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software shifts from the consumer to the SaaS provider. Further, the model can substantially reduce the customers' expenditure on IT hardware and software thus enable them to reallocate the savings towards meeting other organisational objectives. Additionally, since the applications are operated centrally, updates are available to users immediately without requiring them to install the updates to their local machines. One potential drawback of SaaS is that the users' data are stored on remotely located data centres hence there remains a risk of unauthorized access to the data. However, such risks are generally mitigated by provisioning adequate safeguards by the service provider as well as the consumer availing the service.

Software as a Service (SaaS) delivers enterprise applications, such as CRM, collaboration tools, and email. Some examples of SaaS are: Salesforce CRM, Oracle CRM On Demand, Microsoft Online Services, and Google Apps.

VIII. CLOUD COMPUTING DEPLOYMENT MODELS

There are several deployment models for the above mentioned cloud computing services. Some of them are discussed here.

A. Private cloud

Private cloud is cloud infrastructure which is available exclusively for one organization [16]. It may be run internally by the organization's in-house knowledge workers or externally by a third-party entity and may exist on the organisation's premises or elsewhere.

The private cloud is architected as per the specific requirements of a business. It involves pooling of computing resources for delivering a standardized set of services which is put under the control of a particular enterprise. Provisioning a private cloud involves virtualisation of the business environment and generally requires a significant level of engagement for determining the cloud computing needs of the organisation. Additionally, with the passage of time, the organisation may have to re-evaluate the existing resources and make decisions for provisioning additional resources.

The demand for a private cloud is often based on the organisation's need for controlling the entire hardware and software application stack under use of the organisation. Often this could be because of the regulatory framework of the government, applications high performance needs or because of the maturity of the application or for the purpose of differentiating the business. For example, data security concerns may prevent governments and banks from procuring public cloud services.

1) Private cloud options include:

Internally-hosted Private Cloud: An in-house Private Cloud enables a highly customised architecture and extensive operational control over the cloud infrastructure. It is usually built by employing the businesses existing human and computing resources. Internally-hosted private cloud comprises of a dedicated on-premises environment that is custom designed and administered internally.

Externally Hosted Private Cloud: An Externally Hosted Private Cloud comprises of a dedicated environment that is designed as per the internal needs of an enterprise but is hosted and managed externally. Businesses derive the cost benefits of outsourcing the data centre infrastructure while maintaining control over the service and architecture of the private cloud.

Private Cloud Appliance: A Private Cloud Appliance comprises of a dedicated environment that is hosted on-premise and it may be managed with in-house resources or externally. The design is provided by the vendor and may include market driven features and architecture. The predefined architecture lowers deployment risk for businesses and being internally hosted it provides additional benefits of internal control and security.

B. Public Cloud

Public Clouds are the original concept of cloud computing services delivered over the internet. It is offered by a vendor, who typically uses a "pay as you use" or "metered service" model [16]. This type of cloud enables users to pay only for the resources they consume; gain agility through quick deployment; and rapidly scale capacity. In addition, Public cloud enables services to be delivered with consistent availability, resiliency, and manageability. The major concern about this style of deployment is the fact that the data and the applications are located in remote locations which raises uneasy concerns about security, and that is the only reason why the other types of cloud deployment remain relevant.

1) Public Cloud options include:

Shared Public Cloud: The Shared Public Cloud enables rapid deployment, immense scalability, and low barrier to entry due to cost efficiency. It involves a shared physical infrastructure where the specifications for the architecture, level of customization, and magnitude of security are market-determined.

Dedicated Public Cloud: The Dedicated Public Cloud is functionally similar to a Shared Public Cloud except that it is provisioned on a dedicated hardware infrastructure which may enable better security and performance. Its architecture and services are defined by the vendor and it may be costlier than the Shared Public Cloud due to the dedicated hardware infrastructure.

C. Community Cloud

Community cloud infrastructure is one which hosts organizations from a specific community. It is exclusively shared between the organizations that have common concerns like (compliance, security, jurisdiction, etc.) and belong to a specific community. Community clouds may be managed in-house or by a third-party and hosted on-premise or externally. Unlike public cloud, the costs are spread over fewer users in Community cloud [16]. Therefore, cost savings are far less when compared to the public cloud but better than the private cloud.

D. Hybrid Cloud

Hybrid cloud infrastructure is a combination of two or more clouds (public, community, or private). The combination of these clouds is made possible by standardised technologies or proprietary software that binds the separate entities to enable portability of application and data. These intermediary technologies enable load

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balancing between different clouds [16]. Such composition increases the assortment of deployment possibilities for cloud services, with the possibility to use public cloud to meet temporary spikes in application workloads.

Cloud bursting is a deployment model in which an application runs in a private cloud, but when the workload increases beyond the capacity of the private cloud, it "bursts" to a public cloud to access the additional computing resources required by the application. The advantage of deploying a hybrid cloud is that an organization is only required to pay for the additional computing resources as and when they are needed.

The above mentioned Cloud Computing technologies have placed immense computing resources at the disposal of internet based service providers. This has enabled the rise of new breed of web based services in social networking, e-commerce, and even office productivity tools delivered over the internet to billions of users through connected devices. In the next section we would briefly discuss the recent advances made by various web based service providers globally and in India by harnessing the Cloud Computing technologies' infinite capacity for scale. We would also look at the various types connected devices and the ways in which they are being used for accessing various cloud based services.

IX. CONCLUSION

From the above discussion, it is evident that Cloud Computing is the new paradigm of computing in which computer system resources like storage and computing power are made available to the user over the internet from massive data centres situated in remote locations. Large cloud computing service providers operate from multiple data centres located across multiple regions in the world. Typically, the nearest data centre hosts the designated edge servers to cater to the cloud computing requirements of customers in the region. Cloud computing is founded on the principle of shared computing resources which can be made available on demand with the provision of scalability.

Cloud computing services include IaaS, PaaS, and SaaS. Infrastructure as a Service (IaaS) which involves abstraction of hardware (server, storage, and network infrastructure) and may include virtual machines, servers, storage, load balancers, network, etc. that are provided as services for a cost based on the extent of their usage. Platform as a Service (PaaS) is a collection of application infrastructure (middleware) which may include execution runtime, database, web server, development tools, etc. Software as a Service (SaaS) is a sophisticated cloud services model in which the software is owned and managed remotely by one or more providers and generally delivered to a large number of users over the internet. It includes software for Customer Relationship Management, Email, virtual desktop, communication, games, etc.

Cloud deployments models mainly comprise of Private, Public and Hybrid Clouds. If a cloud deployment is limited to a single organization it is referred as (private cloud or enterprise cloud). If the cloud computing resources are shared by many organisations it is referred as public cloud. If cloud service comprises of a mix of in-house private cloud and the public cloud it is referred as hybrid cloud.

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