Multi-Cloud: A Comprehensive Review

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***Abstract*—In the span of a decade, innovations in cloud computing have led to a new understanding of computing to be used as a utility. Majority of cloud service providers are making the service better and competitive for end-user. Aside from the number of services introduced by these providers, users are feeling uneasy and are unaware of consequences while switching from one service to another. Internal architecture of the cloud makes it difficult for end-users to understand. To overcome this issue a new concept of multi-cloud has been introduced. In multi-cloud technology, we can use multiple clouds from different vendors without platform complexity. Hence summarized, Multi-cloud is the usage of autonomous cloud platforms with one interface which may clue to different administrative and implementation domains. This paper reviews the literature of recently presented solutions and architectures for multi-cloud platforms.**

Keywords*—Cloud Computing, Multi-Cloud, Ubiquitous Computing, High Performance Computing, Anything as a Service

I. Introduction

Over the span of a decade in areas all around the world, a new term proliferated which has since come to be known as Cloud Computing. The increase in usage of Cloud Computing is directly related to the benefits expected from it. Cloud data centers are responsible for the deployment of thousands of computers and product hardware count directly amounts to the increase in their demand. Furthermore, this development in cloud computing has made a significant impact in the IT industry. In terms of energy and hardware, Relevant Processing time along with a limited cost is needed for scalability. Most development in the field is being done by IT tycoons such as IBM, Amazon and Google which are making great efforts to provide cost and performance effective cloud solutions.

A cloud user does not need to develop and maintain large infrastructure building or IT staff, instead the user is facilitated by only paying in real time for the resources they have utilized thanks to the clouds real time payment method. The services of cloud computing are scalable with the needs of the users [1], [2]. In the recent years, Evolution and Innovation in cloud computing has helped it to become one of the top rising fields. Research in the field has allowed it to offer operational services with less IT staff, lesser maintenance and quicker implementation. [3]. A significant impact has been seen in learning and teaching environments by the rise of Cloud Computing. Figure 1 below gives an abstract view of multi-cloud technology.

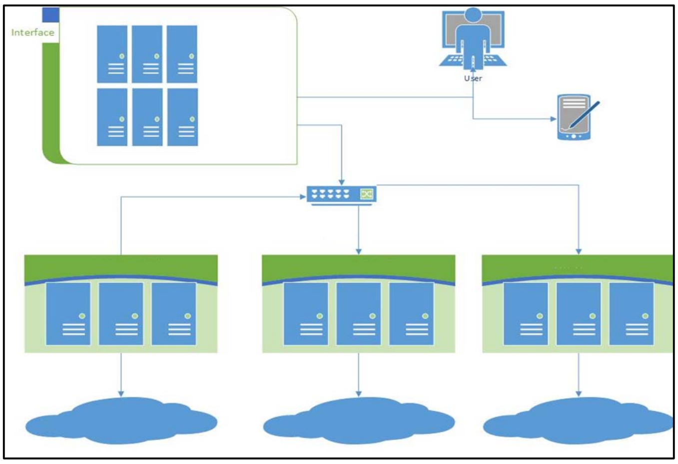

Fig 1: Multi-cloud technology abstract view

IT veterans are being forced by increasing business demands to provide better assistance to their corporate priorities by considering redirection of limited internal resources.

Graphic representation of generic infrastructure for cloud services is given in Figure 2 below which gives an abstract view of cloud service selection process including the following steps:

1. Cloud services provisioning/ cloud services
2. Cloud service providers
3. Deployment model

The terms like public/private/hybrid cloud computing and acronyms like: Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS) are frequently used, these terms are often understood in different ways.

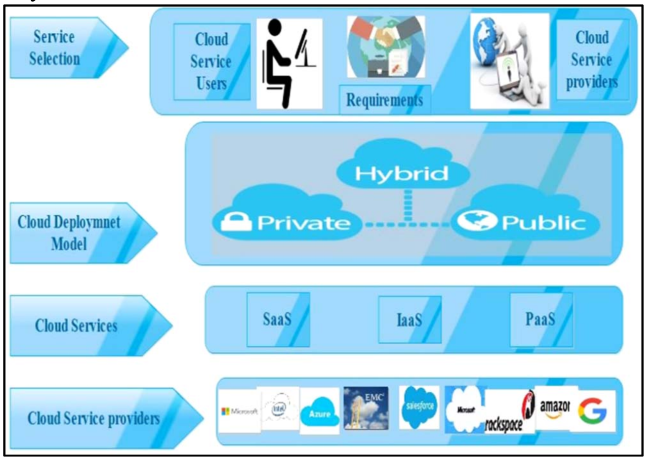

Fig 2: Cloud Infrastructure and services

The multi-cloud application interface hides the multi-cloud system complexities. Despite the facts, scattered architecture consists of multiple hardware, Virtual Machines, Operating systems, Private clouds, cluster etc. user access proposed multi-cloud services though single unified interface, which allows users to concentrate on the workflow (as shown in Figure 3 below). Interface that is user-friendly allows users to run workflows, avail cloud services (SaaS, PaaS, and IaaS). Testing and performance monitoring of scientific applications etc.

Cloud services are based on user requirements, a user may require Quality of Service (QoS), usability, data storage, the complexity of applications, middleware, scalability, programming language, etc. Single cloud cannot meet all the requirements. The term multi-cloud, introduced in [4] which states that just like cloudy sky has different colours and shapes, similarly cloud computing shouldn't be finalized with single cloud which leads to different implementations and administrative domains. Multi-cloud computing accumulates the usage of stand-alone, multiple cloud environments, which assume no prior agreement between cloud providers or third party owners.

Parameters such as performance, security, reliability and scalability are the preferred quality attributes of any system. Both in personal and professional software based systems, performance requirements have a large role in the collective quality. The development teams spent a lot of time and resources on functional testing and less or no attention to performing performance testing [5].

According to the authors of [6], ultimately a software based system worth is quantified by combining its functional and non-functional features, such as security, flexibility, interoperability, performance and usability. Performance is the method of measuring and assessing performance-related aspects of algorithm, design, architecture, module, configuration or overall software system. Performance-related aspects include time, throughput and resource utilization [7].

Emergence of cloud computing in business, impacts multiple fields of research including software testing. Clouds must be tested with the key parameters before deployment. Multi-tenant performance testing, Elastic load testing, high availability and testing which leads to failure are the key parameters to be considered while testing the performance of the applications and platform under tough and complex circumstances. Organizations decide about the deployment model, technologies or the techniques used, to handle the performance issues.

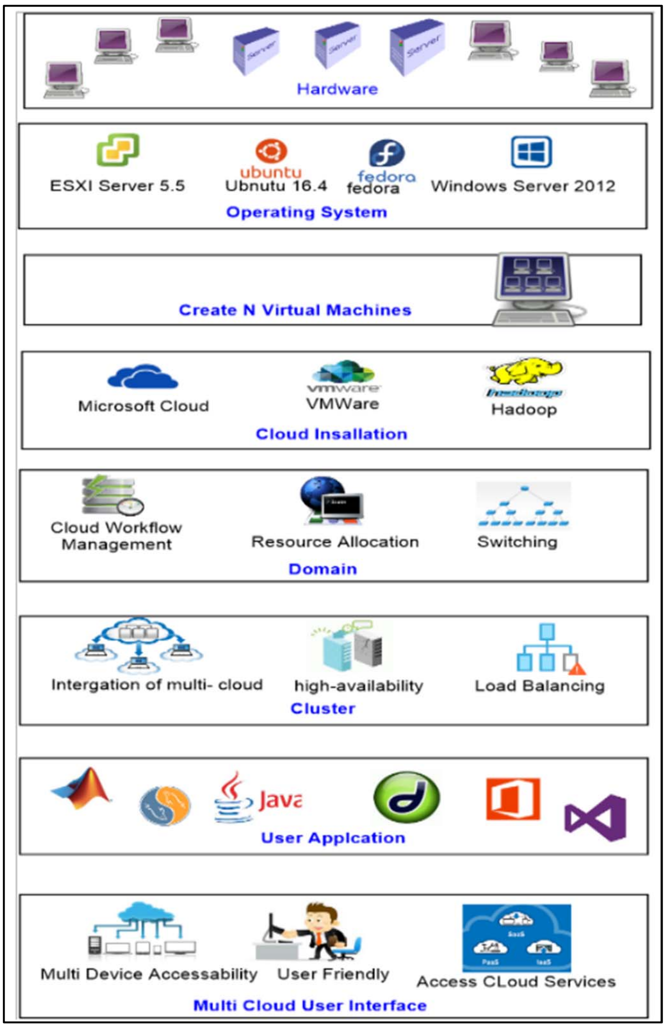

Fig 3: Multi-cloud User Interface encapsulates system complexities

Latency concerns (like network, processor and client-side potential) can disturb the performance [8]. Most of the cloud service providers offer multiple selections in pricing, performance, and functionality. Some provide Platform as a Service (PaaS), so consumers develop API based applications, others offer Infrastructure as a Service (IaaS) so customers run applications in Virtual Machines (VMs) provided. Certainly they also differ in features and pricing set models. Figure 4 does a comparison with individual and multi-cloud systems.

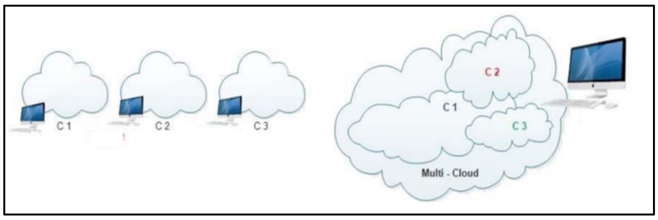

Figure 4: Individual Clouds vs. Multi-Cloud

II. Literature Review

Multi-cloud computing consists of many and autonomous cloud environments with no rational agreement with a third party or cloud providers. [9] soCloud is grounded upon the module-based platform, with a core focus on PaaS to address and improve the portability, elasticity, resource provisioning, and availability attributes of the multi-cloud system. soCloud is developed on standards of OASIS service components architecture. Ten cloud providers of different nature are used to deploy multi-cloud, including DELL KACE, CloudBees, dotCloud, Heroku, Eucalyptus, Windows Azure, Amazon EC2, OpenShift, Jelastic and Appfog private cloud. soCloud architecture is deployed based on the number of components including load balancer, service developer, node provisioning, constraints validator, monitoring, PaaS deployment, workload manager, controller components, SaaS deployment.

There has been a tremendous increase in data in some scientific domains. It is difficult to analyze this data with traditional computing facilities. Using traditional computing leads to wastage of time and other resources. In addition, organizations need to purchase and maintain local infrastructures. Solutions to overcome this issue includes parallel processing, High-Performance Computing (HPC), cloud computing.

A framework named BioCloud is proposed in [10]. The framework is developed for resource provisioning in bioinformatics application using multi-cloud environment. The framework is basically for the non-computer savvy bio-researchers to use multi-cloud as a gateway to informatics in their research. The basic purpose is to develop and deploy a decision-making system that helps to narrow down appropriate cloud provider and also the ability to change among multiple providers in a transparent and effective way. The framework uses scheduling algorithms to resolve resource management in multiple clouds. BioCloud is deployed based on loosely coupled architecture through Service Oriented Architecture (SOA). Architecture components include BioCloud Workflow Manager (BCWM) for SaaS and BioCloud portal.

The problem gets further complicated when applications demand different types of resources. Multi-cloud platforms have also been used to tackle these problems. The platforms target parameters such as resource utilization, adaptability, portability, elasticity etc. In this section, we discuss some related approaches proposed for multi-cloud environments. Articles [11], [12], [13] elaborate on cloud elasticity for further details on cloud elasticity. There exist frameworks for multi-cloud platforms as well as tools to select appropriate platforms for specific applications.

A multi-site virtual cluster cloud for High-Performance Computing (HPC) based infrastructure development is proposed in [14]. The approach uses a Virtual Private Network (VPN) on each site to provide a single domain. The authors introduced a smart virtualized machine scheduling mechanism to improve communication among clouds of different sites. The framework produced good results due to the use of virtual cloud cluster perform with highly parallel job and less communication among jobs.

Another multi-cloud platform that targets the security aspects of cloud computing is proposed in [15]. The approach targets access control on users' personal data and application deployment based on security requirements. The platform provides a private space to users' private data. State of the art techniques have been deployed for both security and access control.

An approach named ElasticDocker is proposed in [16]. The approach automatically empowers the elasticity to scale up and reduce the usage of the according to the demand of applications. The framework uses live migrations to effectively use the capacity of hosts. The framework is evaluated with the experimental results.

A multi-cloud environment for microservice applications is proposed in [17]. The approach targets the adaptability of the functionality of microservices applications. To handle issues similar to the allocation of resources to different services, the approach uses domain-specific language. The designed configuration is provided in a systematic and automated manner.

To handle commercial cloud-based simulations an approach named CloudSME is proposed in [18]. The framework targets to reduce the cost of commercial simulators. The proposed simulator works as a generic approach to handle applications to the capabilities of multi-cloud platform broker. The approach is evaluated with two different case studies from distinct areas.

[19] Conducted five-year longitudinal survey changes to identify potential benefits of cloud computing. Empirically tested the deduced research model and hypotheses derived from survey data collected in the last few years from over 200+ randomly chosen IT executives and businesses. Results obtained from the testing seconded the fact that the hypotheses explain approximately 50 percent of cloud computing performance data for both years.

In [20] a prototype for Complex Event Processing (CEP) has been created comprised of an end-to-end multi cloud-based solution for recognition of special situations in real time. Demo of the prototype included detection of fraudulent mobile activity in real time by using a robust engine for intra-cloud Complex Event Processing executed on a streaming cloud platform i.e. Apache Storm and CEP optimizer that selects the best execution plan from overviewing of data obtained from CEP engines in different clouds.

[21] is based on a model put forward for an effectual web service which mainly minimizes the total value of collected services and deals with the load balancing issues of replicated services placed on different cloud-based platforms by means of using a Composer Agent Algorithm. Thus, increasing the efficiency of work, decreasing latency and response time.

A prototype named KURMA is introduced in [22] which allows NAS based application programs to access the storage and File system. It's a cloud storage-based gateway system which helps to store data in the form of encrypted data blocks running on multiple clouds thus minimizing the possibility of a cloud outage and increasing cloud security. The response time of file data transfer is increased through replication of full file systems across multiple gateways. Testing the prototype in real time yielded a throughput of 52-91% for general purpose workloads but a solution having excellence in multiple domains is not cost efficient.

In order to move on from grids and clusters for processing of workflow-based applications, [23] suggests users to use a broker-based framework comprising of heterogeneous clouds which in turn helps to reduce the execution time of the work by keeping in view all related managing and scheduling policies. And also evaluates the existing workflows on top of the broker-based framework keeping in view the cost and performance gains. This helps to prove the importance and benefits of heterogeneous clouds with respect to single cloud based platforms.

[24] address the modern-day issues faced in the lifecycle management of replica applications based on services running on multi cloud. Resolution of such issues include using TOSCA to combine several heterogeneous clouds together to express capabilities and requirements using a logic-based approach by connecting to workflows, support faster matchmaking and cross-platform monitoring with lower latency.

Presence of many different types of multi-clouds causes hindrance in one's ability to choose what is best for his needs. In order to tackle this issue [25] introduces a multi-cloud selection tool that has not yet been introduced to literature and helps to choose the cloud based on traits such as deployment, quality, placement, security and cost effectiveness. Ibex engine was used as a background for another engine known as Choco which is a well-supported and developed constraint solving engine. Also being used as a composition tool, comparison showed performance better than Iaas composition work.

The following paper [26] suggest ways to successfully sustain a multi-cloud platform usage in different scenarios at high performance and also suggests that in order to move towards a more sustainable multi-cloud technology will require to complete currently partial solutions such as mOSAIC deployable PaaS or OPTIMIS toolkit.

[27] introduces a new Security modeling language named MUSA used for applications based on multi-cloud and on CAMEL abbreviated from Cloud Application Modelling and Execution Language. MUSA is the backbone for MUSA modeller which is being used as a web supporting tool in multi-cloud platforms and MUSA SecDevOps which is integrated with MUSA modeller. The following paper provides the solution for overcoming state of the art expensive modelling language and not only eases the computation of SLA including privacy but also takes into account risk analysis and security.

H. A. Imran et al presented a new naive model for providing a High-Performance Computing (HPC) cluster as a service. Their model is based on pre-existing HPC tools which include MPICH and MPI4py. A prototype has also been created making use of Raspberry Pi 3B and 3B+ boards. Presented model can majorly be used for educational purposes [28]. [29] Have done a comparison between use of MPI4py and MPICH for HPC. The paper empirical evaluated the performance loss that occurs because of the use of interpreted languages for HPC. [30] is a comprehensive survey of three main aspects: non-standard terms in existing literature, network-on-chip evaluation decisions as a means for exploring communication architecture, and latest classification virtualization methods.

Table 1 given below summarizes the techniques being discussed across the literature.

TABLE I. LITERATURE REVIEW SUMMARY

Ref.	Year	Prototype	Details	Multi-Cloud Based Platform	Parameters Discussed
28	2019	Signal Board Computer based	A new and naive model was presented which can make use of any type of computer resource.	MPICH and MPi4py	High Performance Compute Resource
22	2019	KURMA	Geo Distributed Multi-cloud Storage Gateways Creating Machines	Cloud Based Storage and File System	Data Storage Security Response Time Data Transfer Cost Flexibility
10	2018	BioCloud	Decision-Making System with scheduling Algorithm	BioCloud Workflow Manager and BioCloud portal	Resource Provisioning Resource Management
18	2018	CloudSME	Commercial Cloud-Based Simulations	HPC based Cloud Broker Platform	Cost Reduction Time Efficiency
15	2017	PaaSage	CAMEL based multi-cloud System	PaaSage Platform	Security Access Control
27	2017	MUSA Workflow	CAMEL based Web editor and maintenance tool	MUSA Modeller used in Multi-Cloud Platform	Security Cost Efficiency Time Efficiency Risk Analysis
9	2016	soCloud	OASIS based hardware architecture	soCloud SaaS Application	Portability Elasticity Resource Provisioning
20	2016	Ferari	Intra-Cloud Complex Event Processing Engine	Apache Storm	Response Time
21	2015	TOSCA	Composer Agent Algorithm	Multi-Cloud Traffic Management	Load Balancing Cost Minimization Processing Time Efficiency Latency

14	2013	OpenNebula	smart virtualized machine scheduling System	High-Performance Computing Infrastructure	Time Efficiency Better Performance
23	2013	Workflow	Workflow management System	Broker based Framework	Time Efficiency Cost Performance

III. CONCLUSION

This article provides a thorough review regarding multi-cloud technology and the prototypes that have been developed in order to minimize the gap between same services provided by cross vendor singular clouds. Moreover, it discusses different parameters i.e. time, cost, performance, security etc. which must be taken into account by cloud consumers when switching between different multi-cloud services. It is estimated that the next generation of multi-cloud will have improved latency, operation cost and will have better coordination between different single clouds interfaces.

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