Cloud Computing Architecture: A Critical Analysis

Isaac Odun-Ayo[1], Ananya M.[2], Frank Agono[1] and Rowland Goddy-Worlu[1]
[1]Department of Computer and information Sciences, Covenant University, Ota, Ogun, Nigeria
[2]Technical University of Munich, Munich, Germany

Abstract. Cloud computing has evolved to emerge the most topical IT paradigm in recent times. Cloud computing is rapidly transforming the IT landscape. On a pay-as-you-use basis, cloud consumers can access resources, applications and infrastructure provided by cloud providers. Such access could be in form of applications already deployed by cloud providers for use by the cloud users. It could be in form of the capability to develop and deploy user applications using services of a cloud provider. In addition, massive storage infrastructure is available for database and data supplied by the user. The cloud has several unique architectures and many more are still evolving. The primary ones are the SaaS, PaaS and the IaaS that can be deployed on private, public, community and hybrid clouds. This paper examines present developments in the cloud computing architecture and presents guidance for additional research. Papers published in journals, conferences, white papers were analyzed. The objective of this present work is to identify, examine and explain the current trends and development in cloud computing architecture. However, only 13% of the papers examined discussed Others-as-a-Service, while only 26% of the papers reviewed considered issues relating to the major actors involved in cloud computing. This will beneficial to cloud providers, users, and researchers alike

Index Terms **– Cloud Computing, architecture, PaaS, SaaS, IaaS.**

I. INTRODUCTION

"CLOUD computing is a model for enabling universal, on-demand and convenient 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" [1]. Cloud computing can be seen as network-enabled services that provide scalable, QoS guaranteed services on demand that can be accessed over the Internet [2]. Cloud computing allows for sharing of resources over the Internet. These resources are shared using infrastructure provided by a cloud service provider (CSP). The cloud consumer accesses the resources, which are scalable and ubiquitous, on-demand as–you–use and pay–as–you–go basis. Cloud computing also enables a level of abstraction between the required computing resource and the underlying architecture such as storage, network and services [2].

Cloud computing encompasses the client and server, and the three primary service delivery models. The cloud client comprise the software or hardware abstraction layer used for connection to the cloud services. Servers are used by the CSPs to provide the three primary services delivery types. There are several service delivery types, but the primary ones are Platform–as–a–Services (PaaS), Infrastructure–as–a–Service (IaaS), and Software–as–a–Service (SaaS). PaaS provides a computing platform for use by the consumer through the infrastructure provided by a cloud service provider [3]. The user can develop, test and deploy an application using a CSP's platform. The user does not have to install software required for this purpose. In IaaS, the CSP provides infrastructure in the form of servers, storage and computing resources for the consumer. The advantage of this is that the user does not have to invest in expensive IT infrastructure. Services are scalable and on–demand. In addition, the customer utilizes and pays for what is consumed. In SaaS, a CSP provides an application over the Internet for use by a customer [3]. In effect, the user does not have to purchase or install such applications. This provides a network–based access to software that is managed from a centralised location, and the customer has remote access [3]. There are four types of cloud development models: private, public, community and hybrid clouds. Private clouds are provided within an enterprise data centre. The organization has control over the cloud infrastructure and it is secure. Public clouds are services provided over the Internet by CSP using their own infrastructure. Scalable services are accessed on a pay-as-you-go (PAYG) payment model. Public clouds are considered less secured. Community cloud is cloud operated by several organizations possibly engaged in similar activities. The infrastructure could be hosted by a third party with an agreed policy in place for usage [3]. The purpose of this paper is to discuss cloud computing architecture. The paper takes a look at the primary abstraction layers on which services are offered. In addition, advances in the industry in terms of cloud computing architecture will be highlighted. The remaining part of the paper is organized as follows: Section 2 deals with related work. Section 3 will focus on the main cloud architecture. Section 4 discuss the industry trend in cloud architecture. Section 5 concludes the paper and suggests future work.

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II. RELATED WORK

In [4], private cloud computing and delegation of control is proposed. The aim was to examine issues in private clouds. The areas of pricing, regulations and data protection in terms of private cloud was discussed. This ensures an optimum benefit of such an investment in the long run. In [3], security in cloud computing: opportunities and challenges were presented. The approach examined several security issues. In addition, there was a brief discussion on cloud computing architectural framework. In [2], a review on cloud computing: design challenges in architecture and security is proposed. Various concepts relating to cloud computing architecture were examined in some details. Security concerns were also discussed with some solutions suggested. In [5], cloud computing - concepts, architecture and challenges were presented. The characteristics, benefits and issues in cloud computing were discussed. In [6], cloud computing: a study of Infrastructure–as–a–Service is postulated. The papers provide an understanding of IaaS in cloud computing. The roles of the provider and what is available to the consumer was also discussed. In [7], NIST cloud computing reference architecture provides a simple but detailed classification of most aspects of cloud computing. Almost everything about cloud computing is summarised in a crisp form. In [8], Cloud Computing Architecture is presented. The architecture is presented in terms of front end and back end. The front end involves the consumers, while the back end comprises the service providers. In [9], cloud architecture for the logistics business is proposed. The focus is on a cloud architecture to support logistics services. Various layers were proposed with the overall objective of cost reduction in logistics operations. In [10], cloud computing and inter-clouds - types, topologies and research issues is presented. The types of cloud services and deployment models were discussed. Thereafter, the need for inter-cloud and services that could be offered were examined. In [11], cloud computing security issues and challenges is presented. A survey of cloud services was carried out including deployment models. Thereafter, a taxonomy of cloud challenges was carried out. [12] proposed the use of Microsoft Azure hybrid cloud to implement an architecture for Software-as-a-Service (SaaS) model of content based image retrieval (CBIR). The focus is on digital images and CBIR in particular. The architecture allows a large set of images to be accessed and processed using the Microsoft Azure which is suitable for hybrid purposes. 1n [13], Cloud Services Architectures is proposed. The main focus is on the open cloud connect architecture. Various cloud interfaces were also described. In [14], Evaluation of mobile cloud architectures is proposed. The main focus of the work was to compare mobile architecture based on mobile cloud applications. In [15], multi-cloud Platform-as-a-Service model, functionalities and approaches is presented. The main focus is on multi-cloud architecture in terms of PaaS. Two models were proposed and discussed in the paper.

III. CLOUD COMPUTING ARCHITECTURE

A. Describing the NIST Model

According to NIST, five major actors have been identified in cloud computing [7]. The NIST Conceptual Reference Model diagram in [7] shows the actors which are discussed below.

a. Cloud Consumer: A person or organization that starts and keeps a business association with and requires services from suppliers of cloud services [22].
b. Cloud Provider: A person, organization engaged in supplying cloud computing services to interested persons or organizations.
c. Cloud Auditor: An organisation in charge of conducting independent evaluation of cloud computing, and determining the systems effectiveness and security.
d. Cloud Broker: A third-party organisation or individual that serves as an intermediary between cloud consumers and cloud providers. He/she is useful for negotiating terms and conditions of the contract for the purchase of cloud services.
e. Cloud Carrier: An intermediary person, organisation or entity that provides connectivity and transport of cloud services from cloud provider to cloud consumers.

The diagram showing interactions between the actors in cloud computing in [7] describes the relationship amongst actors in cloud computing. Highlighting the relevance of each party in actualising the delivery, use and maintenance of cloud services. In addition, NIST also provides five characteristics of the cloud [11]

a. On-demand self–service: Computing capabilities are allocated to users based on their predefined requirements. Capabilities such as server processing time and storage spaces are allocated automatically without human interference.
b. Broad Network Access: Thick or thin clients (ranging from tablets, laptops, workstations to mobile phones) enjoy access to the cloud by using standard mechanisms.
c. Resource pooling: Multi-tenant models pool together resources in order to provide services to multiple consumers. These services can be customised to satisfy the peculiarity of each consumers' requirements.
d. Rapid Elasticity: This describes the cloud providers' ability to rapidly deploy scalable resources at the request of consumers. The cloud architecture must be able to seamlessly scale up and down amongst each requests of users, ensuring that the capabilities appear unlimited to the consumer.
e. Measured Service: The cloud provider monitors and controls certain aspects of the cloud service to ensure effective resource usage and overall predictive planning. This is

achieved by the use of a metering capability embedded within the system.

B. Cloud Computing Services

A cloud architecture can be divided into the back end and front end. The front end is made visible to the user through connections to the Internet, allowing user interactions with the system [11]. The back end comprises the various cloud services models.

1) Software-as-a-Service (SaaS)

The user is offered a hosted set of software running on a platform and infrastructure owned by the cloud provider [2]. Applications are designed and developed to be simultaneously accessed by various cloud consumers over the Internet [11]. The hosted application is managed by the CSP, who maintains and ensures up-to-date running of the system. The hosted application supports multitenancy, it is available on demand and can be scaled up on down [11]. Some SaaS providers run on other cloud provider's PaaS or IaaS offerings [2].

Examples of SaaS [21]:

a. Email and Office Productivity: Email applications, word editors and processors, spreadsheets applications, presentations applications are typical examples in this category.
b. Billing: There are applications designed to monitor and manage customer billing. This is determined by users' system usage and subscriptions to products and services.
c. Customer Relationship Management (CRM): CRM are typical call-centre applications.
d. Financials: These are applications useful for tracking and reporting financial activities including processing of expenditure, generating invoices, payroll, and managing taxes.

2) Platform–as-a-Service (PaaS)

PaaS is a development service offered to the user through the Internet [2]. The user does not require any software installation or hardware requirements, thereby saving cost. It is a middleware upon which applications are built [11]. PaaS has built–in tools, built–in-security and web service interfaces for the deployed applications [11]. The deployed application can be integrated with other applications on the same platform and interfaced with other applications outside the platform [11]. PaaS has software comprising a database, middleware and development tools [2].

Examples of PaaS [21]:

a. Business Intelligence.
b. Database.
c. Development and Testing.
d. Integration.
e. Application Deployment.

3) Infrastructure–as-a–Service.

This is delivery of servers, storage, network and operating system, as a service [2]. IaaS provides an abstract machine with operating system already installed and configured [11]. IaaS enables data to be stored in different geographical locations. IaaS providers control activities in the cloud data centres while allowing users the flexibility to deploy and manage software services themselves [2]. The user has access to a virtual computer, storage, network infrastructure, computing resources for deploying and running software [6]. The cloud provider only manages the software and hardware, such as servers, storage devices, host OS and hypervisor for virtualization [5]. A typical cloud architecture diagram services available to cloud users is shown in [5].

Examples of IaaS [21]:

a. Content Delivery Networks (CDNs): CDNs record user content and files to improve the system performance such as speed and the cost associated with the delivery content for web-based systems. This is useful for handling diverse kinds of content for delivery to any website or mobile app.
b. Backup and Recovery: This provides ability for seamless backup and restoration of files.
c. Compute: This involves server requirements for maintaining cloud systems that can be configured and provisioned dynamically.
d. Storage: Highly scalable storage ability useful for recording activities of applications, file backups and recovery and storing files are also available.

C. Cloud Computing Deployment Types

a. Private Cloud. A private cloud is exclusively setup and run for a particular enterprise, but third party organizations are given access to manage them on the behalf of the cloud owner [11]. The private cloud can be operated on-premise or off-premise. Private cloud has privacy, security and control. The cost and energy efficiency is also good [11]. Private clouds have limited scalability and are restricted to an area.
b. Public Cloud. They are operated by a CSP, who owns the infrastructure and data centres. The infrastructure is on premise and enterprises can access services on-demand and pay-as-you-go basis [11]. Services are made available to an organizations and users over a public network through a browser [3] [6]. Public clouds are location independent, reliable and highly scalable, but less secure and not customizable [11].
c. Community Cloud. Community cloud is hosted by several organizations or institutions sharing common interest. Typical examples are universities using it for learning and research. Organisations may decide to manage the cloud system themselves on site or off site and may also decide to outsource the daily running of the system to a third party organization [11].
d. Hybrid Cloud. Hybrid Cloud represents a combination of either a selection or all cloud deployment types i.e. private, public or community cloud. Core activities are hosted on a private cloud, while less essential services are

outsourced to a public cloud. Each of the cloud remains a unique entity, but linked together by standardized technology [11]. Hybrid clouds are subjected to network and security issues.

D. Inter Cloud

Inter cloud can be simply referred to as an interconnection of clouds, like the network of networks [11]. This allows connection of multiple cloud infrastructure to make more computing resources available. There are two types of inter-cloud: the federated cloud and Multi cloud.

a. *Federation Cloud*: A federation cloud is an inter-cloud setup where a set of cloud providers wilfully combine their cloud infrastructure, this enables easy sharing of resources amongst the participating organizations. Every cloud provider voluntarily collaborates to exchange resources.
b. *Multi-Cloud:* Multi-cloud involves the use multiple independent cloud architecture acting as a single architecture. For example, organisations or enterprises could run a particular cloud activity that requires enormous resources on a private cloud and run other cloud activities requiring lower level of network resources or storage capability on a public cloud.

IV. INDUSTRY ARCHITECTURAL DEVELOPMENT

A. Hybrid Clouds

According to Spectrum Enterprise, an organisation's Information Technology structure is hybrid, except all of its structure is entirely based on physical infrastructure or entirely cloud based [16]. Research from Gartner predicts that by 2017, half of the main stream enterprises will have hybrid infrastructure. Hybrid cloud offers users easier access to and ability to manage private cloud solutions situated on premise. The hybrid cloud approach offers an organization the flexibility of evaluating resources for each job and then deciding the application that is most appropriate to execute the job [17]. An application with inconsistent rising and falling demand for network resources is best supported on the public cloud, while private clouds are most appropriate for applications requiring constant high levels of network resources. Hybrid cloud architectures could may involve varying levels of sophistication. For example, some organisations and enterprises employs SaaS expenditure tracking application to seamlessly connect to their billing systems, which makes it a hybrid cloud approach.

B. Private Clouds

An attempt was made to resolve the confusion between IaaS private cloud and server virtualisation environment in [18]. In cloud computing, virtualization is the foundation for all IaaS infrastructure and some tools can be used to manage the cloud just like a virtual data centre. On the other hand, the differences between an IaaS cloud environment and a virtual data centre are as follows [18]:

a. It is through standardization of environment that an enterprise can benefit from the cloud and lower cost.
b. Clouds are fully automated, hence all the standardized procedure will require the use of automated applications to enhance execution.
c. Clouds are self-service, hence every cloud consumer is provided access to particular workflow, which translates such approval into the permissions required by the user. Therefore, a provider must offer self-service.
d. There could be other cloud types apart from private cloud in an enterprise. However, multitenancy allows the private cloud to be properly isolated, while allowing high utilization of resources in a cost effective manner.
e. The cloud architecture can also be seen in terms of an IT portfolio with different deployment types and economics, degree of standardization and automation. An enterprise should expect only 15% of its application to be relevant for the present cloud and plan a gradually increase in percentage as events unfold.
f. It is better to start a private cloud on a small scale to allow for understanding. Moreover, it usually takes time before an organisation can appreciate the benefits of the cloud. It is also better to maximize utilization rate before expanding.
g. The cloud is a shared environment and it better for the customers to ask for expansion to justify further investment in a cloud infrastructure.

C. 2016 Cloud Computing Survey [19]

The review demonstrates that organizations have shown continued interest in migrating their IT activities and environment to the cloud utilizing a blend of public, private and hybrid cloud applications and solutions. The survey reported that the average company has migrated 45% of IT activities to the cloud, with 23% of this percentage of companies utilizing the private cloud, 15% in public cloud and 7% in hybrid cloud. The survey further highlighted that at the end of 2017, the average company is expected to have migrated 59% of the IT activities to the cloud with 28% in private cloud, 22% in public cloud and 10% estimated to use hybrid cloud. The average company will allocate 45% of its cloud budget to SaaS, 30% to IaaS, 19% to PaaS and 6% to other emerging cloud models, such as network-as-a-service, and database-as-a-service, generally known as anything-as-a-service. It is estimated that large organisations plan to invest 21% of their budget to acquiring PaaS cloud services as compared to 17% of small and medium scale businesses (SMBs). On the contrary, SMBs are most likely going to spend over 75% of their financial plan on acquiring SaaS cloud services.

D. 2017 Cloud Migration Report [20]

Statistics show expected rise of the use of public cloud among the companies surveyed by 28% year over year and

private cloud is also expected to grow, but by a smaller percentage of (15%).

Public and private cloud usage is expected to grow even more than 49% and 18% respectively year over year for companies that employs more than 1,000 people.

IV. ANALYSIS AND DISCUSSION

Table 1 shows several issues in cloud computing architecture and relevant work from several authors. Only one facet was used in this analysis, which are the core topics, discussed by these important authors. The authors are listed in no particular order.

TABLE I
COMPARATIVE ANALYSIS OF ARCHITECTURE ISSUES

AUTHOR and TITLE	Actors in cloud computing	Cloud Computing Characteristics	Cloud deployment methods	Cloud Computing Service Models	Others as a Service	Cloud Security Requirements
IDG Cloud Computing Survey			x	x	x	
CloudEndure, (2017)			x			
C. W. Buyer (2012).			x	x		
A. J. Ferrer; D. G. Pérez; and R. S. González (2016)			x	x		
J. Bou Abdo and J. Demerjian (2017).						
M. Toy (2015)	x			x		
A. Verma and S. Kaushal (2011)		x	x	x		x
M. Meena, A. R. Singh, and V. A. Bharadi (2016)				x		
F. Lui et al (2011)	x	x	x	x		x
B. K. Rani, B. P. Rani, and A. V. Babu (2015)		x	x	x		
G. Niharika and V. Ritu (2015)					x	
R. Dhakar, A. Gupta, and A. Vijay (2009)		x		x		
S. Bhardwaj, L. Jain, and S. Jain (2010)	x	x		x		
Y. Jadeja and K. Modi, (2012)			x	x		
V. Davidovic, D. Ilijevic, V. Luk, and I. Pogarcic (2015)			x	x		
M. Ali, S. U. Khan, and A. V Vasilakos (2015)		x	x	x		x
F. Hu et al. (2011)	x		x	x		x
P. Mell and T. Grance (2011)		x	x	x		
Cloud Taxonomy, http://cloudtaxonomy.opencrowd.com/				x		
R. B. Bohn, J. Messina, F. Liu, J. Tong, and J. Mao (2011)	x	x	x	x		
Marissa Comeau (2014)			x			
Y. Amanatullah, C. Lim, H. P. Ipung, and A. Juliandri (2013)	x			x	x	
C. Gong, J. Liu, Q. Zhang, H. Chen, and Z. Gong (2010)		x		x		
H. Takabi, J. B. D. Joshi, and G. J. Ahn (2010)		x	x	x		x
S. Ramgovind, M. M. Eloff, and E. Smith (2010)			x	x		x
M. Hogan, F. Liu, A. Sokol, and J. Tong (2011)	x	x	x	x		x
D. Chen and H. Zhao (2012)		x	x	x		x
S. Kächele, C. Spann, F. J. Hauck, and J. Domaschka (2013)				x	x	
N. Grovez, R. Buyya, (2012).		x	x	x		
T. Dillon, C. W. C. Wu, and E. Chang (2010)		x	x	x		
M. A. AlZain, E. Pardede, B. Soh, and J. A. Thom (2012).		x	x	x		x
B. P. Rimal, E. Choi, and I. Lumb (2009)				x	x	
Y. Singh, F. Kandah, and W. Zhang (2011)	x					
D. Wu, J. L. Thames, D. W. Rosen, and D. Schaefer, "DETC2012-70780," 2012, no. 1, pp. 1–14.	x	x		x		
L. M. Vaquero, L. Rodero-Merino, J. Caceres, and M. Lindner (2008)	x	x		x		
S. Subashini and V. Kavitha (2011)		x	x	x		x
Q. Zhang, L. Cheng, and R. Boutaba (2010).	x		x	x		x
R. Buyya, R. Ranjan, and R. N. Calheiros (2010)				x		

1) Major Actors Involved in Cloud Computing

[7] Identifies the significant actors involved in cloud computing as, cloud consumer, cloud provider, cloud broker, cloud auditor, and the carrier. [7] also describes a typical interaction between actors in the system; a cloud consumer could request for cloud services directly from a cloud provider or through a cloud broker. However, [23] claims that there are 6 major actors in cloud computing and that each has its own activities, requirements and responsibilities. [23] opined that a cloud developer is the additional actor missing in other works. From the analysis, only 26% of the papers reviewed considered issues relating to the major actors involved in cloud computing.

2) Characteristics of Cloud Computing

[11] wrote that the characteristics of cloud computing includes; on demand self-service, broad network access, resource pooling, rapid elasticity, and measured service, while about 50% of the papers examined focuses on this topic.

3) Cloud Deployment Methods

From the Table 1, it can be seen that 62%, which represents 22 of the 35 reviewed papers, discussed the various available cloud deployment methods. Some of them highlighted the merits and demerits of the various methods, and the majority concluding that the peculiarity of the demands of the cloud consumer would determine which is best to use.

4) Cloud Computing Service Models

Cloud computing service models was also discussed extensively in over 94% of the reviewed papers, revealing that knowledge about PaaS, IaaS and SaaS are in abundance.

5) Others-as-a-Service

Backup-as-a-service, storage-as-a-service, logistics-as-a-service, operating systems as a service(OSaaS), framework as a service(FaaS), database as a service(DaaS), network as a service(NaaS) and other models apart from the 3 primary ones were discussed in [19], [9], [23], [29] and [33]. However, only 13% of the papers examined discussed Others-as-a- Service.

V. CONCLUSION

From the review carried out, it has been possible to ascertain that cloud computing offers enterprises, SMEs and individuals access to scalable, on demand resources anywhere and at any time. Cloud users also do not have to worry about infrastructure cost involved in developing applicants in-house. The architecture of cloud provides three services and four deployment methods. Recent survey shows highest budget allocated to SaaS by enterprises, and utilization of public cloud is expected to continue to increase more than private clouds. Results from the analysis show that more research work is required in Others-as-a-Service models.

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