Context Based Cloud Service Architecture:

From Carrier Perspective

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Declaration

I, the undersigned, declare that the thesis comprises my own work in compliance with internationally accepted practices; I have fully acknowledged and referred all materials used in this thesis work.

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This is to certify that the thesis prepared by **Aschalew Gashaw**, entitled Context Based cloud Service Architecture: *From Carrier Perspective* and submitted in partial fulfillment of the requirements for the degree of Master of Science (Telecommunication Engineering) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

Cloud computing is one of the most discussed topics in recent years among distributed systems. Many Information System (IS) professionals now consider cloud technology as the best solution to improve the growth of business in every sector. Today, there are a plethora of cloud service architectures that are generated by prior studies. However, there is no de facto architecture that can satisfy context-based client requirements. The provider dependent architectures are designed in a way to suit the services and products of the respective cloud providers. While others are targeted for specific cloud service model and cloud deployment model.

These days, many organizations show interest to adopt cloud environment that is apt to their local settings. To this end, organizations require cloud service architecture tailored to their current context. On the other hand, carriers which adopt new technologies mostly with the recommendation of providers are challenged to satisfy client requirements. The study proposed a conceptual carrier-based cloud service architecture taking into consideration client's requirements and the capability of the carrier. The architecture was designed with three major components, namely Infrastructure as a Service (IaaS), Cloud Service Broker (CSB) and telecom capability services. The architecture has also incorporated the Service Oriented Architecture (SOA) based Enterprise Service Bus (ESB) architecture for dynamically configurable virtualised services.

A deployment environment is also constructed for the proposed architecture using the analysis result of the collected data from clients and carrier cloud provider. Industry best practice and standards have also been considered while generating the deployment environment. Finally, an evaluation of the proposed architecture has been conducted using experts review and it achieves a high degree of agreement among the participants.

Key words: Cloud computing, Cloud service, Cloud service architecture, Context

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Finally, the most important of all, my parents. Thanks for everything you gave me in the past, you give me in the present, and for what I know you will give me in the future. Thank you for always being by my side, for supporting me in everything that I do. Thanks for making me the person that I am today.

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Acronyms and Abbreviations

AHP	Analytic Hierarchy Process
API	Application Programming Interface
ARPU	Average Revenue Per User
BSS	Business Support System
CAPEX	Capital Expenditure
CCRA	Cloud Computing Reference Architecture
CET	Cloud Enabling Technologies
CPU	Central Processing Unit
CSB	Cloud Service Broker
CSP	Cloud Service Provider
DR	Disaster Recovery
DSRM	Design Science Research Methodology
ESB	Enterprise Service Bus
GSA	General Services Administration
GW	Gateway
IaaS	Infrastructure as s Service
IT	Information Technology
KPI	Key Performance Indicator
MMS	Multimedia Messaging Service
NIST	National Institute of Standards and Technology
OPEX	Operational Expenditure
OSS	Operations Support System
OTT	Over-The-Top
PaaS	Platform as a Service

R&D	Research and Development
REST	Representational State Transfer
SaaS	Software as a Service
SDK	Software Developer's Kit
SLA	Service Level Agreement
SME	Small and Medium Enterprise
SOA	Service Oriented Architecture
UPS	Uninterruptible Power Supply
USSD	Unstructured Supplementary Service Data
VAS	Value Added Service
VDI	Virtual Desktop Infrastructure
VM	Virtual Machine
VMM	Virtual Machine Manager
VPN	Virtual Private Network

Chapter 1

Introduction

This Chapter serves as an introduction for this research. It starts by providing a brief background and continues discussing the motivation. Next, statement of the problem and objective of the thesis is presented. Additionally, the delimitations and the scope of the thesis are established. Finally, it provides a quick glance on the structure of this thesis paper.

1.1 Background

Greater flexibility, scalability and cost benefits are the desires of modern enterprise Information Technology (IT) services [1] [2] [3]. To this end, as an emerging new computing paradigm for delivering on-demand and scalable computing services [4], cloud computing is likely to be an attractive and viable option for enterprises with different sizes. Its flexibility and pay as you go cost structure also make it more preferable [5].

Due to their network coverage, strong Support Level Agreement (SLA), and better customer experience carrier can deliver cloud services with guaranteed Quality of Service (QoS) for individual consumers and enterprise customers using centralized management system. This makes carriers to be preferable than other cloud solution providers (third party cloud service providers such as Google, Amazon and IBM). As reported in [6], cloud computing has reduced the cost of introducing new applications to market by 75%, and it was expected that 80% of the software will be offered to individuals and enterprises in the form of Software as a Service (SaaS), meanwhile over 90% of the companies or organizations were expected to provide mobile applications based on cloud computing. For carriers, cloud solution can help reduce Capital Expenditure (CAPEX) investment, reduce Operational Expenditure (OPEX) cost by deploying automation management system as well as adding new profitable services into service catalog, such as cloud storage, virtual machine lease and cloud application hosting services, etc.

In recent years, there has been a sharp rise in the number of cloud computing publications such as books, articles, white papers and technical reports. Many of these publications have discussed cloud service architectural methods, service selection, evaluation, deployment, implementation and challenges. Though, few studies have been publicized on cloud service architecture they are generated for specific cloud service model or vendor-based architectures. Currently, there is a lack of de facto standard or single architecture, which can meet the requirements of clients [7].

1.2 Motivation

Despite its rapid grow, cloud computing lacks well-defined architectural framework and operational model. As indicated in [8] current industry standardization activity is primarily focused on functional interoperability of deployment platforms and components supporting basic usage scenarios such as applications and Virtual Machine (VM) images creation, deployment, services request and execution management. National Institute of Standards and Technology (NIST) cloud computing reference architecture [8] [9] incorporates the initial cloud definition [10] and extends it with additional definitions to ensure interoperability of the future cloud implementations in the heterogeneous multi provider environment. However, with wider adoption of cloud computing services and integration into organizational computing resources, the demand for dynamically configurable and manageable composable services considering the context of the organizations will grow. Hence, client context-based cloud service architecture would play great role towards adopting this emerging technology on broader scale. Moreover, cloud computing has various challenges that needs to be addressed [11] and current solutions are far from satisfying the needs of stakeholders.

The emergence of cloud concept, its ongoing evolution, and the opportunities it provides have led many businesses to adopt. The telecom sector is one of the most active business areas to explore the opportunities offered by cloud. The slow operator’s subscriber growth in matured markets, price pressure on voice service from competing operators and traditional services such as Short Message Service (SMS) and voice being challenged by substitutes of social networks and Over the Top (OTT) services causes decline of telecom companies Average-Revenue-Per-User (ARPU) [12]. Besides, the requirements of high reliability, availability and complex management of the infrastructure and services is part of the challenges of telecom operators. To tackle these and other challenges carriers are being pushed to deploy emerging technologies like cloud solution. Cloud solution has brought the opportunity to minimize CAPEX and OPEX costs for carriers apart from being a new revenue stream. On the other hand, many carriers like ethio telecom does not yet deploy cloud solution due to their cloud business concerns. Among the concerns are data protection, privacy, cybercrime and lack of an appropriate context-based cloud architecture [13] [14]. Hence, the focus of this research is to generate a cloud service architecture for carriers considering the context of clients.

1.3 Problem Statement

Nowadays, due to its numerous advantages and benefits, several organizations are adopting and consuming cloud services. However, their adoption to cloud computing has concerns like QoS. Clients are facing challenges of finding a cloud service provider which can offer the services with guaranteed QoS [15]. On the other hand, carriers can offer an appropriate cloud service architecture to address the concerns. Though there are several cloud service architectures, carriers are being challenged to obtain a suitable cloud service architecture. Due to the diversity of cloud services and dynamic requirement of clients, obtaining an appropriate cloud service architecture for carrier-based cloud service providers is a challenge [16].

Carriers' cloud architecture is highly influenced by market promotion, experts experience and vendors recommendations without pre-analysis of their client's requirement. As a result, carrier cloud providers are muddled with satisfying customer requirements and lack of context-based cloud service architecture. Additionally, there is a challenge of lack of de facto standard or single architecture of cloud solution for carriers, which can meet the requirements of clients [17].

1.4 Research Objectives

1.4.1 General Objective

The objective of this research is to generate carrier-based cloud service architecture taking the client's profile and requirement as a context.

1.4.2 Specific Objectives

Specific objectives of the thesis include:

- Assessing related works.
- Identify artefacts and architectural components for the cloud service architecture.
- Organize and document applicable artefacts and architectural components for the architecture.
- Identify client contexts.
- Asses existing context-based cloud service architectures.
- Analyse and organize contexts, artefacts and architectural components.
- Propose a new architecture using the identified context and artefacts as well as architectural components.
- Evaluate the proposed cloud service architecture.
- Show and discuss significance of the proposed architecture.

1.5 Methodology

For this thesis Design Science Research Methodology (DSRM) has been applied with additional steps as seen in Figure 1.1. In DSRM the initial step is to identify the problems and motivation followed by defining the objective of the solution. The next step would be generating the design and building the development or implementation of the designed solution. Finally, the designed and deployed solution will be examined and evaluated using experts review and evaluation.

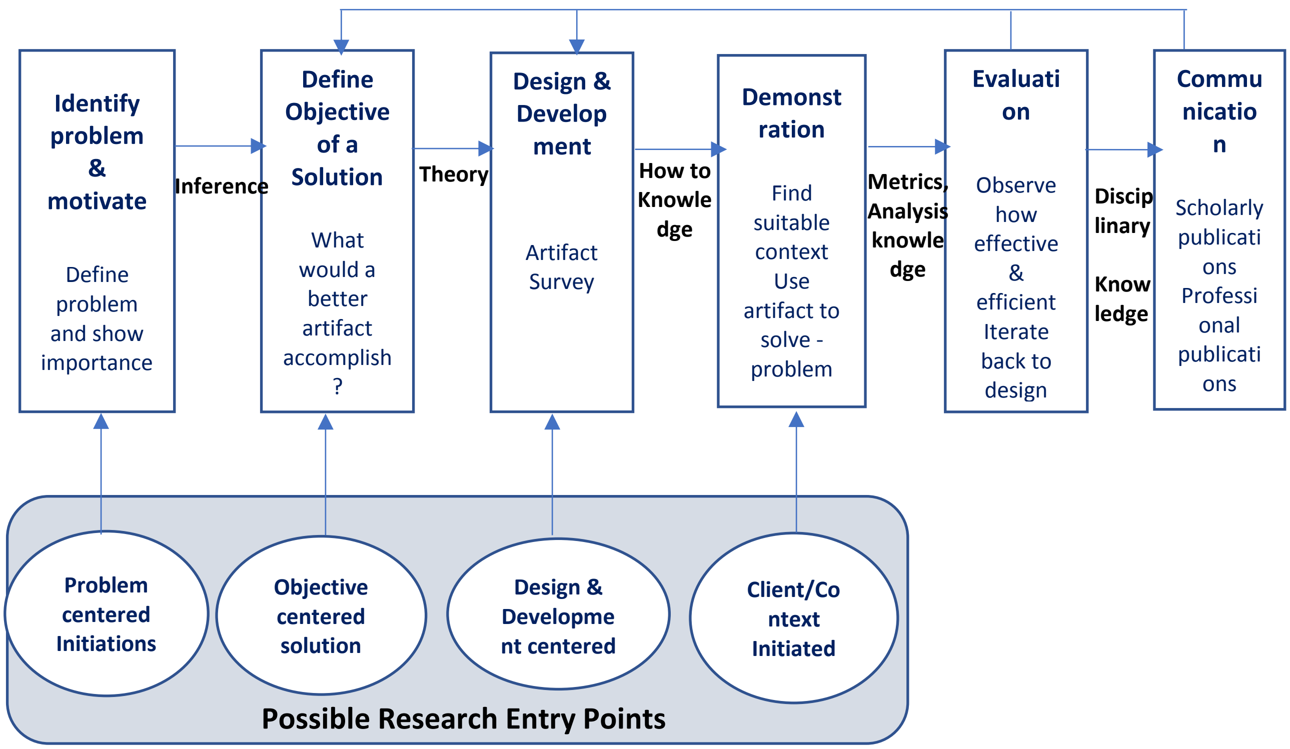

Figure 1.1 DSRM Process Model [6]

i. Inputs for Design and Development

For design and implementation of the architecture, the first step we applied is collecting client's requirement and context. This has been done in two steps. The first step is to identify which of the three services (i.e. Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS)) are required on the market using a survey. Analysis of the result of the survey is done using Pugh Decision Matrix. Basically, choice of cloud service selection requires a multi-criteria decision-making approach. Analytic Hierarchy Process (AHP) is not considered an appropriate tool in this context, given the limited number of factors involved in the selection of cloud service models and the fact that a hierarchical approach is not appropriate here, as the majority of factors are technical and are at the same level of decision making. Hence, Pugh Decision Matrix (PDM) is applied because there are only a small number of criteria used at this stage and there is only one level in the matrix. PDM is a Multiple Criteria Decision Making (MCDM) technique which compares alternatives based on criteria [18], thus PDM is better suited to the criteria and the decisions making for our case.

The next step is to collect the detail requirements of the chosen service using survey. The surveyed result is used as an input for design and development of the solution. However, for the design input the capability of the carrier provider and industry best practices and standards are also considered. The carrier provider taken is ethio telecom which is the sole telecom operator in the country. For the survey both questionnaire and interview has been conducted for selecting the cloud service type and gathering detail design input parameters respectively.

ii. Questionnaire and Interview Design and Validation

In this study both questionnaire and semi structured interview have been applied to gather information on the type of service requirement on the market and to collect design inputs respectively. Closed-ended questions are applied for the questionnaire that allows respondents to choose an answer that fits to their response. Such kind of question style is easy to answer and can be completed in short period of time. On the other hand, it makes the data analysis easier. Whereas, the interview contains both open-ended and closed ended questions. Cloud computing is somehow a new concept and experience, therefore, using these methods is best to explore the deign inputs in depth. Both the questionnaire and interview have two parts. The first part contains questions related to demographic information of each respondent. The second section contained items that is used to decide on the service type required on the market and to collect design inputs.

The content of the questionnaire and interview questions are constructed using literature review and from the required design input parameters. It has been reviewed by experts on the sector and M.Sc. students from Addis Ababa University and adjusted accordingly.

1.6 Scope of the Study

The target of this thesis is to generate a cloud service architecture considering the context of clients or users and seen from telecom carrier perspective only. The services of the cloud are delimited to the three popular cloud services, namely IaaS, PaaS and SaaS. On the other hand, the thesis is centered in Ethiopian context and survey is conducted using enterprises residing in Addis Ababa.

1.7 Research Significance

The study contributes for the knowledge of carrier-based cloud service architecture for the case of Ethiopian enterprise context. It plays a role towards achieving best user experience and satisfaction. The thesis also intends to support cloud providers to analyze and identify which cloud service architecture is preferable on the market to accommodate the firms need and requirements, and eventually to make them ready for those services in accordance with the proposed architecture.

1.8 Thesis Structure

The reminder of this thesis is structured as follows: chapter two provides literature review on background information of cloud computing concept and its characteristics and discusses some of the state of the art of cloud computing technology. In addition, it presents the reference architectures of cloud computing solution. The third chapter discusses related work on the subject.

Chapter four provides the proposed approach of the research followed by Chapter five which discusses analysis and results of the proposed architecture. The evaluation and validation of the proposed architecture is also presented in this chapter. At the end, Chapter six concludes the thesis and presents ideas for future work and improvements to the proposed architecture.

Chapter 2

Literature Review

This chapter provides our literature review and theoretical background of the research. We first start by describing cloud computing and discuss about its characteristics, architecture, service models and development models. In addition, we point out the prominent benefits of cloud computing and elaborate about cloud broker service. The technology background and technology enablers of cloud computing are also addressed in this chapter. Finally, we provide and discuss the various reference architecture of cloud and the concept of cloud broker service.

2.1 Cloud Computing

Cloud Computing is a new way of delivering and rating hosted services. Though there is no agreed definition of cloud computing, most scholars use the definition by NIST [3]. Which defines cloud computing as: A model for delivering on demand, ubiquitous and configurable IT resources (e.g., networks, servers, storage, applications, and services) from shared infrastructure. However, the concept of cloud computing is not enough to describe specialized roles and how they interact in extended business environments. For this reason, it is introduced the concept of Cloud Ecosystem. Cloud Ecosystem is a network of participating entities, where each entity has multiple roles in the evolution, provision and consumption of cloud services. This distributed ecosystem is subject to internal and external factors and the participants are not necessarily aware of all other entities in the Cloud Ecosystem (but they can affect or be affected by them) [18].

NIST definition of cloud computing consists of five essential characteristics, three service models, and four deployment models as described in the subsequent sections.

2.2 Essential Characteristics of Cloud Computing

NIST defines cloud computing with five essential characteristics as stated below.

i. **On-demand self-service:** Enables the users to access and consume computing capabilities automatically without any interaction between user and service provider.

ii. **Broad network access:** The computing capabilities are available through the Internet and can be used by heterogeneous users through standard mechanisms.

iii. **Resource pooling:** Heterogeneous computing resources can be combined and dynamically assigned to serve multiple users based on a multi-tenant model.

iv. **Rapid elasticity:** Based on the demand, every computing capability can be provisioned rapidly, elastically and/or automatically to scale out or in, to meet the fluctuations of the demand.

v. **Measured Service:** Automatically control and optimize resource usage as well as to provide monitoring, controlling and reporting for billing purpose and transparency between the service provider and the user.

2.3 Cloud Computing Service Models

In scientific literatures the most common service models are SaaS, PaaS and IaaS [3] [19]. However, academia attempted to extend the three main service models by adding other essential components such as security, coordination, management and quality as a service. According to [20] we can include database as additional service, while [21] suggests that storage, process and information can be included as well. Figure 2.1 provides an overview of cloud architecture and the corresponding service models for each architectural layer.

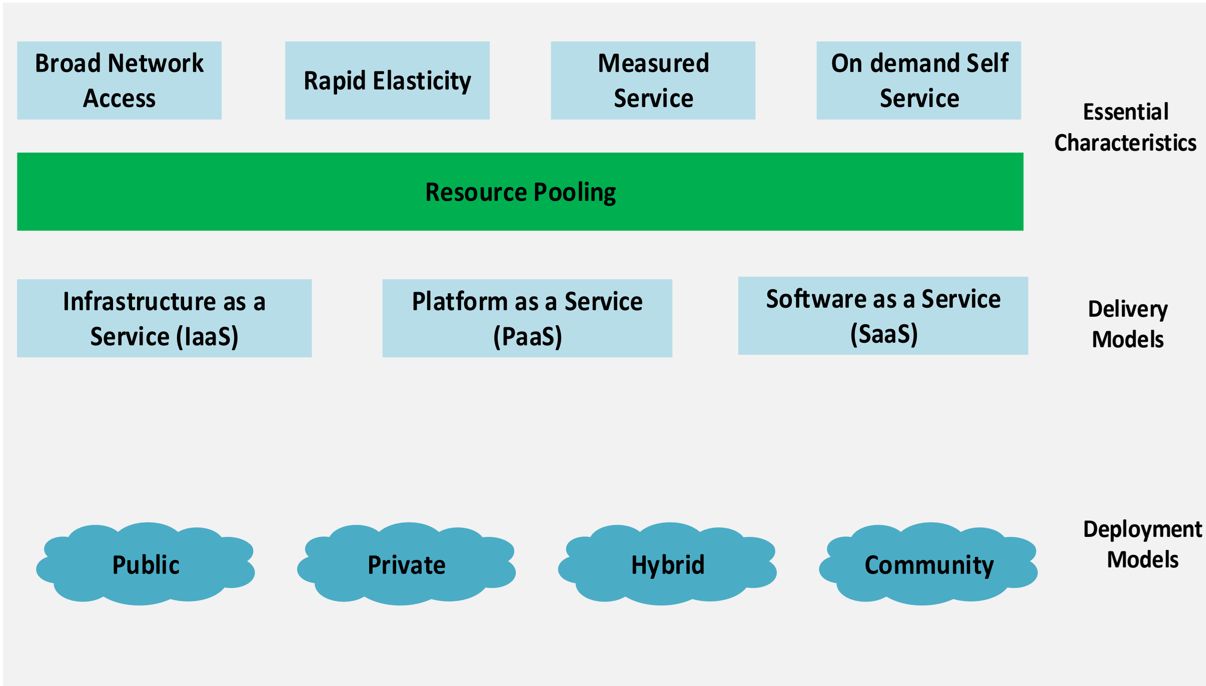

Figure 2.1 Cloud NIST definition, service and deployment models adopted from [3]

I. Cloud Software as a Service (SaaS): In this cloud service model the capability provided to the consumer is to use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through a thin client interface such as web browser (e.g., web-based email). The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings. Example: Google apps (Gmail, Google Docs, YouTube), Facebook, SalesForce.com [3].

II. Cloud Platform as a Service (PaaS): In this cloud service model the capability provided to the consumer is to deploy onto the cloud infrastructure using programming languages and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly application hosting environment configurations. Example: Google App Engine, AWS (Amazon Web Services), Elastic Beanstalk, Microsoft Azure.

III. Cloud Infrastructure as a Service (IaaS): In this cloud service model the capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer can deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, deployed applications, and possibly limited control of selected networking components (e.g., host firewalls). Example: Amazon's Elastic Compute cloud (EC2), Windows Azure Virtual Machines, Google Compute Engine [3].

2.4 Deployment Models

Four deployment models are described and listed in the NIST definition as shown below.

I. Private cloud: This type of cloud-based solution is provisioned and used by a single enterprise. The services in a private cloud are consumed by multiple users, and they are managed operated and owned by the enterprise itself, a third party or a combination between them [3]. The private cloud can be resembled with an on-premise infrastructure. However, this is not the case as private clouds inherit the characteristics of cloud computing (e.g., elastic service provisioning, virtualization, etcetera) and provide more benefits to the enterprise [22].

II. Community cloud: Community cloud is similar to private cloud; however, community cloud is shared among a group of organizations. In that way the risks and costs are shared among the members of the group. It is important that these organizations must share the same concerns such as policy, mission, compliance considerations and security requirements. The services in a community cloud are consumed by multiple users, and they are managed operated and owned by the enterprise itself, a third party or a combination between them [3].

III. Public cloud: Public cloud is when the provisioning of cloud-based solutions is publicly available for open use. The services are ubiquitous available through an internet connection. This deployment model is rising many security and privacy concerns. The services in a public cloud are consumed by multiple users, and they are managed operated and owned by enterprise, a governmental organization or a combination between them [3] [22].

IV. Hybrid cloud: The hybrid cloud is a combination of at least two distinct deployment models (e.g., public, private or community cloud) which are tailored to provide data and application portability. In that way some of the resources are residing on-premise while others are outsourced [23].

2.5 Benefits of Cloud Computing Solution

Some of the benefits of cloud computing solution for consumers is listed and described below.

Cost reduction: Cost reduction is achieved by avoiding big initial investments for software and hardware acquisition. The cost for maintenance and training can be also reduced. Therefore, organizations can allocate the reduced cost for other activities (e.g., integration of services, Research and Development (R&D)) [24] [23].

Business agility and scalability: Business agility and scalability of an organization can be achieved by adopting cloud-based solutions [23].

Access to new IT services: This will help small companies to acquire IT services easily that was impossible for them [23]. It will offer faster access to a variety computing services with no or minimum upfront cost [25].

Efficient IT system utilization: On-premise IT systems can be developed in a way to support peak capacity, implying that most of the computing resource sits idle. In numbers, 85% of the computing capacity stays idle with a utilization rates range between 12%-18% [20]. Cloud-based solutions provide efficient capacity utilization which results again to cost reduction [20]. As author [26] pointed out that only 10-30% of data centers computer power is used in off-peak, while features of cloud computing such as virtualization and pool resources could provide a better utilization of IT resources. This is because the cloud environment provides a shared pool in which resources are provisioned and released with respect to end users need.

Accessibility: Cloud computing is location independent [3], allowing users access anywhere, anytime, subject to an internet connection. In addition, in a cloud environment all computing operations will be performed in cloud, so users can access the environment from any device through web browser or other thin client interfaces [3] [26]. Thus, cloud computing offers more mobility to users, enabling them to access computing resources anytime, anywhere and on any devices.

Innovation: Cloud computing represents a change in the way computing services are provisioned. It has been argued that rather than focusing on the management of physical resources, IT staff will be freed up to focus on application and service development, encouraging greater innovation [27].

Green IT: Cloud environment can offer a greener environment because they enable multiple users to share common resources to satisfy users need. Hence, many data centers can be consolidated into one, reducing the energy required for computing power and cooling [26].

Economic benefits: One of the main reasons for enterprises to move to cloud is the associated economic benefits. The cost of getting reliable IT services was a barrier to many Small and Medium Enterprises (SMEs) in traditional IT environments [25], cloud may offer computing services at a reasonable cost.

Despite its all benefits of cloud computing, there are also many challenges while implementing cloud solution on one's environment. That is the reason why the decision makers must be very careful before deciding to migrate to the cloud. They must be careful which deployment model or combination of this models to choose. On the other hand, the selection of an appropriate cloud model depends on the business scenario and the business goals. For instance, applications that require significant computing capacity is preferable to deploy them on public cloud for cost efficiency [19]. It is also expected that certain deployment model would be more successful (e.g., hybrid clouds) than others [19]. Moreover, a detailed risk assessment is a must for a successful cloud migration.

2.6 Cloud Enabling Technologies

Cloud-Enabling Technologies (CET) encompass the vital support system for a cloud environment, which includes the automation and management stack. Cloud enabling technologies refers to the concrete realization of a cloud-based system and computing paradigms including abstract principles and certain concepts of an IT based architecture [28]. The authors in [28] state that although each of the cloud enabling technologies listed below existed before cloud computing gained momentum, some of them further evolved with the advent of cloud computing.

2.6.1 Broadband Networks and Internet

Cloud services are accessed via the network, usually the internet, from a broad range of client platforms, such as desktop computer, laptop, mobile phone, and thin client [3]. The existence of global networks, such as the Internet, enables remote provisioning of computing capabilities by cloud providers and permits ubiquitous access to these capabilities for cloud consumers [28]. This ubiquitous access of cloud service highly depends on the quality of performance of these networks. Therefore, enterprise consumers are faced with the decision whether to choose a private cloud deployment in their own data center and access its capabilities through the organization's own network or to choose a public internet-enabled cloud deployment model. In the private case, the network is usually completely managed and controlled by the respective organization. While in public case, the cloud provider assumes these responsibilities and can provide ubiquitous access to the computing capabilities through an internet connection. The private cloud deployment is less affected by connectivity, bandwidth, or latency issues when accessing the computing capabilities through a corporate network. However, public cloud deployments facing these issues usually applies superior internet connectivity at additional network usage charges [28].

2.6.2 Data Center Technology

Consolidating IT resources in close proximity with one another rather than having them geographically dispersed, allows power sharing, higher efficiency in shared IT resource usage, and improved accessibility for IT personnel [28]. IT resources in a data center comprise servers, storage, networking components, and software [7] [28], and can be physical or virtual in nature. The physical resources build the physical infrastructure of the data center, which serves as a hosting environment for virtual resources [28].

2.6.3 Virtualization Technology

Virtualization is the process of converting a physical IT resource into a virtual IT resource. Most types of IT resources can be virtualized, including server, storage (virtual disk), network, and power (Virtual Uninterruptible Power Supply (UPSs)).

Server virtualization is a technique of masking or abstracting the physical hardware from the operating system and enabling multiple operating systems to run concurrently on a single or clustered physical machine(s). This technique encapsulates an operating system and an application into a portable virtual machine (VM) [29] [30].

A virtual machine is a logical entity that looks and behaves like a physical machine. Each operating system runs on its own virtual machine. In server virtualization, a virtualization layer(hypervisor) resides between the hardware and virtual machine. The hypervisor provides standardized hardware resources to all the virtual machines [30]. The hypervisor interacts directly with the physical resources of the x86 based computer system and allows multiple operating systems and applications to reside on the same physical machine using its kernel and Virtual Machine Monitor (VMM).

The hypervisor kernel provides the same functionality as other operating systems, such as process creation, file system management, and process scheduling. It is designed to specifically support multiple virtual machines and to provide core functionalities, such as resource scheduling, Input/output (I/O) stacks [29] [30].

The VMM is responsible for the actual execution of commands on the Central Processing Units (CPUs) and performing Binary Translation (BT). A VMM abstracts hardware to appear as a physical machine with its own CPU, memory, and I/O devices. Each virtual machine is assigned with a VMM that has share of CPU, memory, and I/O devices to successfully run the virtual machine. When a virtual machine starts running, the control is transferred to the VMM, which subsequently begins executing instructions from the virtual machine [29] [30].

According to [31] [30] [32] [33] server virtualization offers the following benefits:

Server Consolidation: Compute virtualization enables running multiple virtual machines on a physical server. This reduces the number of physical server requirements [34].

Isolation: virtual machines can share the physical resources of a physical machine; but they remain completely isolated from each other as if they were separate physical machines.

Encapsulation: A virtual machine is a package that contains a complete set of virtual hardware resources, an operating system, and applications. Encapsulation makes virtual machines portable and easy to manage. For example, a virtual machine can be moved and copied from one location to another just like a file.

Hardware Independence: A virtual machine is configured with virtual components such as CPU, memory, etc. that are completely independent of the underlying physical hardware. This gives the freedom to move a virtual machine from one x86 machine to another without making any change to the device drivers, operating system, or applications.

Reduced Cost: Compute virtualization reduces direct costs like, space (leased or owned) for physical machines, power and cooling, hardware (including switches and fiber channel Host Bus Adapter (HBA)), and annual maintenance.

Virtual machines are implemented in various forms based on the hypervisor type applied namely: Full virtualization, Para virtualization and Hardware assisted virtualization [3]. x86 based operating systems (OS) are designed to run directly on the bare-metal hardware. So, they naturally assume that they fully own the server hardware. As shown in Figure 2.2, the x86 CPU architecture offers four levels of privileges namely: Ring 0, 1, 2, and 3 to operating systems and applications to manage access to the server hardware. The user-level applications typically run in Ring 3, whereas the operating system which needs to have direct access to the hardware must execute its privileged instructions in Ring 0.

Full virtualization: Each virtual machine is assigned a VMM, which performs BT and provides each virtual machine all the services like physical compute including a virtual BIOS and virtual devices.

Binary Translation provides 'Full Virtualization' because the hypervisor completely decouples the guest operating system from the underlying hardware. The guest operating system is not aware that it is being virtualized and requires no modification as seen in Figure 2.2.

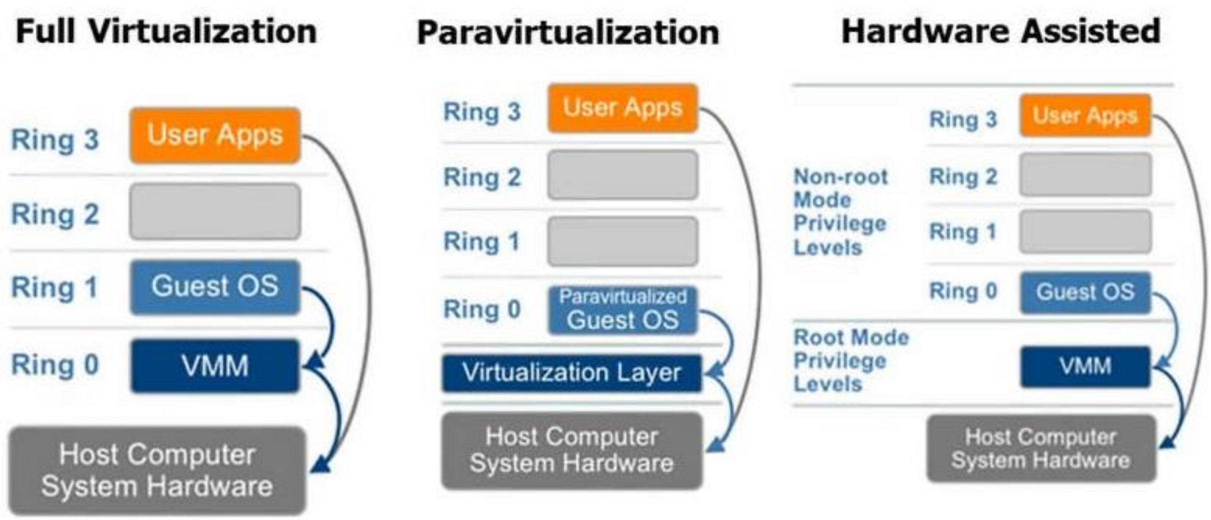

Figure 2.2. 1x86 CPU architecture adopted from [35]

Para virtualization: Guest operating systems (OSs) are aware of being virtualized. In this approach, the guest operating system kernel is modified to eliminate the need for Binary Translation as seen in Figure 2.2.

Hardware assisted virtualization: It is accomplished by making hypervisor-aware CPU to handle privileged instructions. Though virtualizing of x86 instruction set decreases the hypervisor overhead, it does increase the CPU overhead as seen in Figure 2.2.

2.6.4 Web Technology

Cloud computing is grounded on the presence of broadband networks, web technology is used for realizing and managing cloud services and their functionality, which is exposed to consumers through Web-based interfaces [36].

2.6.5 Multitenant Technology

Multi-tenancy is the key common attribute of both public and private clouds, and it applies to the three layers of cloud: Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS) and Software-as-a-Service (SaaS). A multi-tenant application enables a user to use the same application concurrently with multiple other users without interfering with the other users due to isolated operational environments. A dedicated instance is provided to each user with a customized user interface, individual application logic, and own data. Users share various artifacts such as middleware and databases, while adhering to certain security levels so that tenants are not able to access private data of other users. The isolation of the operational environments allows the implementation of metering capabilities that track each tenant's usage separately and supports the scalability when the number of tenants increase [28].

2.6.6 Service Technology

Cloud computing have adopted service technologies in order to provide a predefined Application Programming Interface (API) for using, configuring, and programming cloud services. These service technologies comprise Web services, Representational State Transfer (REST) and service agents [28] [37].

2.7 Cloud Broker Service

Cloud service brokering is a new service paradigm that provides interoperability and portability of application across multiple cloud providers [38]. These features ease the cloud service provider and customers concern and support new cloud service open market to increase cloud service profit. Cloud service broker entities and their interaction is shown in Figure 2.3.

Broker main architectural components (Gartner) [39]:

- Service aggregation
- Service arbitrage
- Service intermediation
- Cloud service management
- Cloud ecosystem orchestration

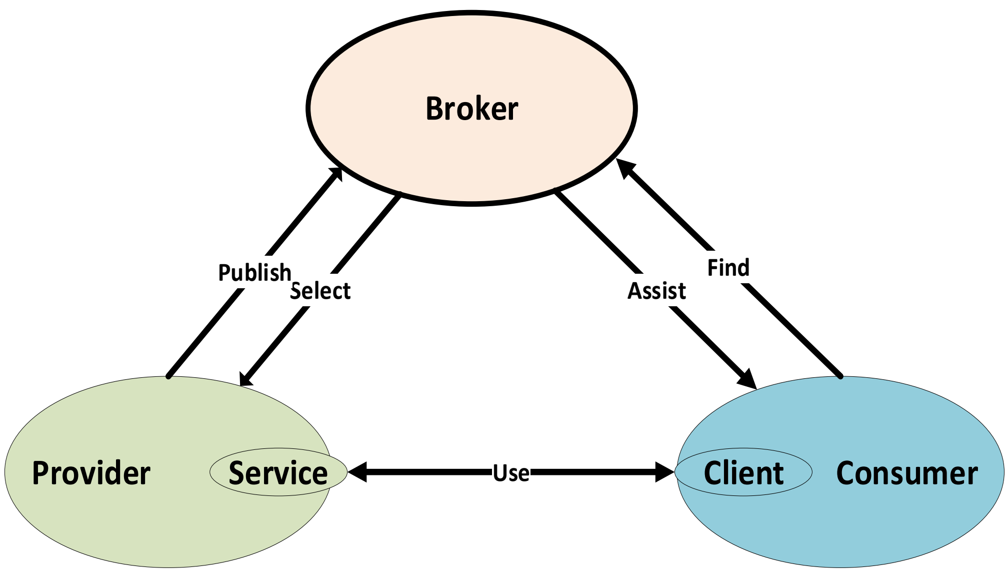

Figure 2.3 **Cloud service broker entities and their interaction**

In [40] open source service brokerage solutions are compared according to concerns like system category and type, core capabilities, core and advanced features, architecture and interoperability, service languages, programming model and service engineering, and quality interms of scalability, elasticity and SLA. In the research, the authors place emphasis on the emergence of cloud broker solutions on top of cloud management, the need for further separation of marketplaces and cloud broker solutions and service description mechanisms to commoditize the cloud.

A cloud service broker system provides a single and common interface through which consumers can provision and manage their services on multiple clouds [41]. The cloud broker and cloud provider will be also benefited from this solution.

2.8 Cloud Reference Architecture

In this section we have presented the most important reference architectures designed for the cloud computing environment. Specifically, we have introduced the proposed architectures of the worldwide cloud computing companies like Cisco and IBM and we also had a look at NIST reference architecture which is the starting point for all proposed architectures in the field. As one would expect, the provider dependent reference architectures are written is such a way to suit the services and products of the company, while NIST's architecture is a more general model with more comprehensive architectural details as highlighted in section 2.8.2. However, NIST offers a baseline high level generic architecture.

2.8.1 Overview

In existing literatures there are several different reference architectures, models and frameworks for cloud computing. A reference framework for cloud computing offers the baseline that stands on designing some interoperable cloud services and their integration in the existing infrastructures of the internet and private corporations. Additionally, a reference framework offers a draft or an architectural template that could be used by others that wish to adopt similar solutions. A reference model explains the concepts and relationships of the architectural components and the model, while the term reference framework refers to both architecture and model of reference [42]. A cloud computing architecture of a cloud like solution represents the structure of such a system. The term also refers to conceiving proper documentation of the architectural system of a cloud computing solution [43].

A reference model of cloud architecture represents the abstracting of the cloud computing concepts and relationships, which can be used to train organizations and to create standards and guidelines in the purpose of aiding these application concepts. Cloud Security Alliance or Open Security Architecture develops reference models for cloud which can be used by different companies in the purpose of adopting new cloud technologies. Also, companies being active in the field (Cisco, IBM, VMware and others), federal agencies (General Services Administrator (GSA) and others) work on some reference models of their own which have specific characteristics [44]. Next, we will present four of the most important reference architectures in the field:

2.8.2 NIST Cloud Reference Architecture

The national institute of standards and technology (NIST) "NIST cloud computing standards roadmap" [45] contain a reference architecture for the cloud. However. this reference architecture comes as a normal follow up of NIST's cloud computing definition. NIST's reference architecture is a high level conceptual generic model. This model defines a lot of actors, activities and functions which can be used in the process of cloud computing services development. It contains a series of opinions and descriptions which are the base of a talk regarding characteristics, usages and standards in the cloud computing field.

The NIST reference architecture focuses on the needs that the cloud services offer and not on a design that defines a solution and an implementation. This helps with understanding operational complications that can occur in the cloud computing. NIST reference architecture does not represent system architecture of a system specific to cloud computing, it is rather a tool for describing, analyzing and development of a specific architecture using a common reference framework.

The objective and target of this architecture includes:

- Understanding and illustration of various services of the cloud in the context of a generalized conceptual model for cloud computing.
- Providing technical references to governmental agencies and to other consumers for understanding, analyzing, categorizing and comparing cloud services.
- Security communication and analysis, possible standards for interoperability, portability and implementations.

In the document that NIST published there are five involved main actors which are involved in the development of a new taxonomy regarding cloud computing. In this direction NIST defines the actors as being cloud consumer, cloud provider, cloud auditor, cloud broker and cloud carrier as seen in Figure 2.4.

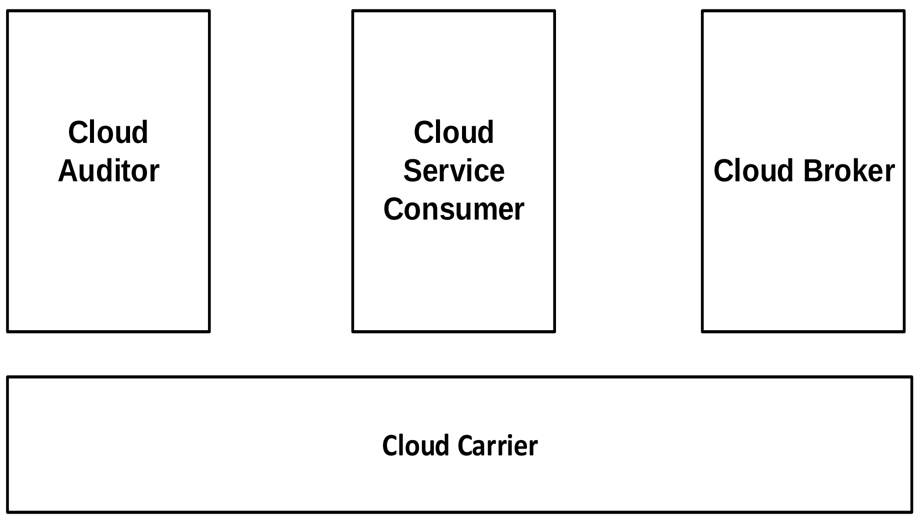

Figure 2.4 Actors involved in NIST cloud reference architecture

Cloud Auditor: A party that can conduct independent assessment of cloud services, information system operations, performance and security of the cloud implementation.

Cloud Consumer: Person, or organization that maintains a business relationship with, and uses service from cloud providers.

Cloud Provider: Person, organization or entity responsible for making a service available to cloud consumers.

Cloud Broker: An entity that manages the use, performance and delivery of cloud services, and negotiates relationships between cloud providers and cloud consumers.

Cloud Carrier: The intermediary that provides connectivity and transport of cloud services from cloud providers to cloud consumers.

2.8.3 IBM Reference Architecture

The proposed reference architecture from IBM is called IBM Cloud Computing Reference Architecture (CCRA) [46]. It was defined in 2009 and it is continuously being improved. This solution is based on client's experience in implementing cloud hosted solutions by IBM along the years, offering guidelines for building IaaS, PaaS, and SaaS for using IBM's products. IBM CCRA is reflected in the design of IBM's cloud, and developed for clients. IBM products focus on reducing costs and obtaining a high rate of security, reliability, scalability and control.

IBM CCRA consists of multiple documents, which presents the current state of knowledge in the field and it provides ideas for architecture and design for implementing cloud-based solutions. IBM CCRA saves time and money for clients by providing detailed documentation about the steps and the necessary components for building a cloud implementation for any type (public, private and hybrid). Clients can use IBM's experience with building public, private and hybrid cloud systems which are based on a common architecture with reusable entities and product recommendations.

Clients benefit with a faster start for building a cloud system which contains predefined cases and documentation that refers to architectural requirements or decisions that need to be made for security, service management, performance, scalability and virtualization.

The last version, IBM CCRA 3.0, offers a series of new benefits, these are:

- Prescriptive guidance for designing IaaS, PaaS, SaaS solutions by using IBM's products.

- Consists of various architectural products which represent the options in IT industry in regard of designing, implementing and administration roles and permissions in the cloud for consumers, service providers and builders of cloud services.
- Represents a modular framework which allows focusing on the most important field for cloud development (IaaS, PaaS and SaaS).
- It offers a comparative sketch with a scope of realizing an analysis of the clients of the cloud with the goal of identifying integration points.

2.8.4 CISCO Cloud Reference Architecture

As a reference framework Cisco follows the NIST model for the cloud, with different services (IaaS, PaaS and SaaS) and the four deployment models in the cloud: private, public, hybrid and community could. Cisco discusses about some of the benefits of a cloud-based solution, which include mainly an increased efficiency and agility in IT. It mentions some of the basic elements of developing in the cloud, which include the general steps of virtualization, integration, automation and finally cloud service offerings. After presenting these general steps Cisco shows the Cisco cloud strategy for enterprises which contain 3 essential points [47]:

- It offers products, services and solutions for enterprises to build a secure cloud;
- It allows enterprises to supply secure cloud solutions and services to internal clients;
- It contributes to the cloud marketplace by promoting innovative technologies, open source standards and ecosystems development.

CISCO reference architecture is built on top of a framework for providing services which can be used for hosting services outside IaaS on the basis of the same infrastructure: for example, virtual desktop infrastructure (VDI). The VDI solution from Cisco provides a complete infrastructure for an enterprise. However, it leads to an increase of control and security over data. Also, it offers an easy migration to other new desktop operating systems and it assures control over operational expenses and capital. Cisco's solutions for building a private cloud can be used also by service providers to build cloud infrastructures so they can provide public, private and hybrid solutions for their clients. In communication with service providers and companies Cisco is developing an ecosystem for cloud providers, developers and consumers. This ecosystem has the advantage of using common approaches to cloud technology, administration, interconnection and operation in the cloud.

Chapter 3

Related Works

In this chapter related works on the subject will be discussed and presented. The different cloud solution architectures will be assessed with respect to the work of this thesis. Cloud broker service is also discussed in relation to federating the different cloud service architectures.

3.1 Cloud Computing Architectures

Cloud computing architecture is composed of three layers: resource, platform and application. The resource layer is the infrastructure layer which includes physical and virtualized computing, storage and networking resources [48]. The platform layer includes components such as web server, application server, and enterprise service bus [48]. The application layer serves the user and it is mainly used for transaction processing and interaction [48]. On another study, cloud computing architecture consists of multiple different layers, as is the case with most distributed systems. [49] categorize cloud computing architecture, based on a comparison with Grid architecture, into four layers, which are fabric, unified resource, platform and application, as shown in Figure 3.1.

Fabric layer is the lower level layer of the architecture and includes the raw hardware resources, like storage resources. Whereas, unified resource layer contains abstract resources, through virtualization, that form integrated resources exposed to the upper layer and end users. Platform layer depends on the unified resources layer and includes an additional set of dedicated tools, middleware, and services to provide an environment for the applications development and deployment. And applications that run in the clouds are contained in the application layer [49].

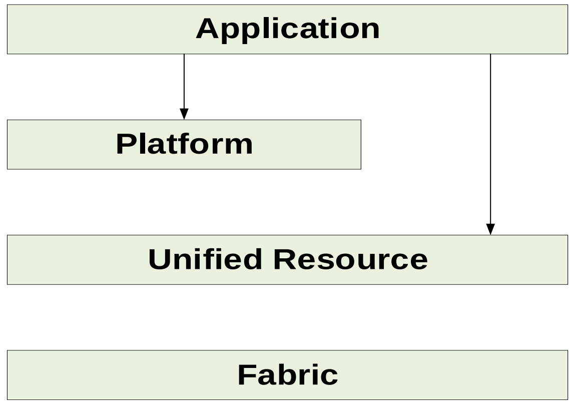

Figure 3.1 **Layers of cloud computing** [49]

On the other hand, another study shows that cloud architecture mainly consists of user-level middleware, core middleware, and system level [50]. Cloud application layers contain applications which can be accessed by end users directly. Alternatively, users' own applications can be deployed in this layer [50]. In addition, the user-level middleware layer contains software frameworks that assist the developer to create an environment for applications to be developed, deployed and executed in clouds. The platform level services that set the run time environment are performed in the core middleware layer to host and control services at user level application. Finally, the system level layer is where massive physical resources, like servers, exist, and these resources are managed by the virtualization services set above this layer [51].

Taking Aneka cloud Platform [52], which is a software platform and a framework for developing distributed applications on the cloud, harnesses the computing resources of a heterogeneous network of workstations and servers or data centers on demand. Aneka provides developers with a rich set of APIs for transparently exploiting these resources by expressing the application logic with a variety of programming abstractions. System administrators can leverage a collection of tools to monitor and control the deployed infrastructure. This can be a public cloud available to anyone through the internet, a private cloud constituted by a set of nodes with restricted access within an enterprise, or a hybrid cloud where external resources are integrated on demand, thus allowing applications to scale.

Aneka is essentially an implementation of PaaS model, and it provides a runtime environment for executing applications by leveraging the underlying infrastructure of the cloud. Developers can express distributed applications by using the API contained in the Software Development Kit (SDK) or by porting existing legacy applications to the cloud. Such applications are executed on the Aneka cloud, represented by a collection of nodes connected through the network hosting the Aneka container. The container is the building block of the middleware and represents the runtime environment for executing applications; it contains the core functionalities of the system and is built up from an extensible collection of services that allow administrators to customize the Aneka cloud.

Another proposed architecture is Hybrid cloud computing architecture in [53]. This system is based on local private cloud, combined with one or more type(s) of public cloud(s). The internal structures of private cloud and public cloud are the same, including infrastructure and virtualization layer, cloud platforms layer, cloud bus layer, cloud application layer, the management center and storage centers. The layer of infrastructure and virtualization is designed to incorporate the underlying hardware resources into a virtual cluster, providing a variety of virtual resources to the upper layer. The layer of cloud platform is used to run web applications or services and carry application specific development and application integration through its open interfaces. The cloud bus layer, consisting of a control bus, several node buses and adapters, is designed to manage and monitor the various services of the cloud platform layer.

In another study [54], the benefits of adopting cloud computing for telecom operators and the way it has to be constructed and deployed has been described. Distributed way of implementing the cloud datacenter has also been suggested for carriers. The distribution system consists of multiple cloud computing centers in different geographical locations. The system can provide carrier-grade cloud services such as video conferencing, and unified communications. It is connected to enterprise and other cloud computing platforms through standard interfaces. IT service providers and application developers can create more innovative cloud services and cloud applications with open APIs exposed by the system. Each distributed data center is made up by physical infrastructure, virtualized resource pool, resource management and maintenance platform. However, the study doesn't clearly show the details of the architecture and architectural methods apart from showing the benefits of applying distributed way of implementing cloud computing for carrier grade-based cloud service.

As discussed above several cloud service architectures are proposed by different scholars and industries so far. Some of the architectures developed is constructed to be used as a reference architecture. And others are designed to be applied for specific environment and for specific service type and deployment model. In addition, existing architectures doesn't incorporate telecom services in their proposed architecture. In this research a carrier cloud service architecture taking the context of clients is proposed. A telecom service component which offers VPN, Internet, VAS, and other telecom services is also included in the proposed architecture.

3.2 Cloud Broker Service

Due to the emergence of cloud solution the client's requirement goes beyond basic telecom services. Carriers need to provide customer centric services as to enhance their competitiveness in the market. Hence, they need to have an architecture that can integrate with other capable third-party providers. As noted in the previous section there are several architectures proposed for cloud computing. These architectures vary based on their intention towards serving some group, achieving some purpose and based on their market target [38]. However, the needs of a single client may not be achieved by any of the architectures. It may require combining one or more provider of cloud with a specific architecture. Two ways may be followed for achieving satisfactions of client's requirement. The first is to deploy a cloud architecture which considers the contexts of the clients in that market. The other is to have a platform which can integrate to heterogeneous cloud service providers and can offer a cloud service to clients based on their need by combining the service of one or more cloud service providers.

In this research, a cloud service broker is proposed to offer SaaS and PaaS capable services from third-party providers. Cloud service brokering is a new service paradigm that provides interoperability and portability of application across multiple cloud providers [39]. A cloud service broker system provides a single and common interface through which consumers can provision and manage their services on multiple clouds [41].

Chapter 4

Proposed Approach

This chapter outlines the proposed approach for the thesis including the research design, instrument development, data collection processes, and data analysis applied in this study.

4.1 Cloud Service Selection

The thesis was proposed with the scope of three services, namely IaaS, PaaS and SaaS, since these services are mostly popular among the various cloud service types mentioned in Chapter 2. Thus, the subsequent step was to undertake a survey to examine and analyze clients service interest and requirement among the aforementioned cloud services for the case of Ethiopia context. The choice of cloud service model requires a muti-criteria decision making approach, for our case we took PDM as stated in Section 1.5. Hence, the collected data is transformed and analyzed using PDM.

For the PDM, we have taken 9 variables as listed below [55].

- Control Over Resources
- Data Sensitivity
- Short time to market
- Cost
- Scalability
- Performance
- Availability
- Interoperability and Portability
- Capability to manage IT services

An example of a single client data analysis using PDM is shown in Table 4-2. Each criterion variable has been given an indicative decision weight for each service. Similarly, users will be able to set their own weightings for each variable, according to their business requirements. After weighting the variable, the weights for each variable are multiplied by each weight for each cloud service model. Then the highest score is taken as the cloud service choice of the client. For the example in Table 4-2, the client falls under SaaS.

Different symbols and values are used to measure the weights by different scholars. For instance, [57] uses symbols of negative (-) for worse, positive (+) for better and S for equal. Whereas, [56] applies values 1 to 3 to measure the weights as shown in Table 4-1. For our case we have adopted the later method.

Table 4-1 The critical variable and its weight measure of cloud service model selection [56]

Critical Factors	Description	Scale
Data sensitivity	To what extent is the data sensitive	3-1 (3 Very high 1 normal)
Control over resources	To what extent is the control over resources important	3-1 (3 Very important 1 Unimportant)
Capability to manage services	To what extent can the enterprise manage IT services	3-1 (3 Advance 1 Easy)
Short lead time	To what extent is short lead time important	3-1 (3 Very important 1 Unimportant)
Cost	To what extent is cost important	3-1 (3 Very important 1 Unimportant

Critical Factors	Description	Scale
Scalability	To what extent is scalability important	3-1 (3 Very high 1 normal)
Performance	To what extent is performance important	3-1 (3 Very high 1 normal)
Availability	To what extent is availability important	3-1 (3 very high 1 normal)
Interoperability and portability	To what extent are interoperability and portability important	3-1 (3 Very important 1 Unimportant)

Table 4-2 Analysis result of a client using Pugh Decision Matrix

	Control Over Resources	**Data Sensitivity**	**Short time to market**	**Cost**	**Scalability**	**Performance**	**Availability**	**Interoperability and Portability**	**Capability of IT to manage the services**	**Total**
IaaS	3	3	1	1	3	3	3	3	3	19
PaaS	2	2	2	2	2	2	2	2	2	18
SaaS	1	1	3	3	2	1	2	1	1	20
Weights	0	1	2	2	1	1	2	0	0	

4.2 Design Inputs

Three sources have been taken to organize and collect the design inputs; clients/users, operator(carrier) and desk review and industry best practices and standards.

Case I – Client/User side

Interview modality of assessment have been applied for the design input and a total of 62 companies have been interviewed. Note that surveyed companies have been chosen applying explanatory research with stratified sampling. When stratified sampling is applied the samples are grouped by sector. Ethio telecom enterprise company's categorization has been adopted for the grouping, which classifies enterprises based on their sectors as stated in Table 4-3.

Table 4-3 Category and quantity of enterprise customers

Category	**Quantity**
Financial Institutions	72
Government administration	591
International organizations NGO's and embassies	672
Production enterprises	493
Public service enterprises	469
Private service enterprises	812
Total	**3108**

Case II – Carrier/Operator side

Interview has been conducted with relevant ethio telecom departments and experts. Applying this method, the capability of the carrier interms of time, budget, human resources, organizational structure and process is identified.

Case III – Literature review and industry best practice and standards

Literatures, white papers and other relevant documents has been reviewed to gather the different architectural components, artefacts and parameters, to be applied on the proposed architecture.

4.3 Evaluation

To evaluate and validate the proposed architecture, six closed ended and three open ended questions were developed to examine the capability, comprehensiveness, usefulness and inclusiveness of the proposed cloud service architecture. The participants were given a brief description of the proposed architecture with examples before responding for questions.

Chapter 5

Results and Discussion

This chapter provides our proposed conceptual architecture with details of all the components and modules followed by the deployment section which constitutes the implementation of the architecture using inputs from clients, carrier provider and industry best practices and standards. Finally, expert's evaluation result has been presented to show that the architecture fits for its purpose. The clients cloud service selection has been also presented to show the needs of the market interms of the three common cloud service types, namely IaaS, PaaS and SaaS which is under the scope of the thesis research.

The first step towards identifying the context of clients was to see their preferred cloud service among the common service types IaaS, PaaS and SaaS. Next, detail contexts of the clients are identified using data collection method, which is directly used as a design input. However, for the design input the carrier provider environment has also been considered to make the architecture implementable. Additionally, industry best practices and standards are also applied to generate the design inputs for the conceptual architecture and its deployment.

5.1 Cloud Service Selection

Case I – Client/User side

For cloud service selection, we have disseminated questionnaires for 67 companies. From which 62 companies remain after data cleansing.

Among 62 surveyed companies; 41 falls under IaaS, 18 falls under SaaS and the remining 3 falls under PaaS. Hence, the result implies all the services are required on the market.

Case II – Carrier/Operator Side

The assessment conducted on the carrier environment shows that carrier is fit only for IaaS. Besides, the assessment shows that the carrier is not capable of implementing SaaS and PaaS at present due to the identified time and human resource constraints. Note that the assessed carrier in this thesis is ethio telecom.

The above result illustrated under Case I leads to the conclusion that all the service types under the scope of this thesis are required on the market and shall be incorporated on the proposed architecture. Whereas the assessment from the operator side (Case II) shows only IaaS can be deployed. Hence, we have proposed cloud broker service to align the needs of clients and the operator capability. Which implies full set of IaaS component is incorporated in the proposed architecture along with a cloud service broker component for handling PaaS and SaaS. Besides, implementing cloud broker service for SaaS and PaaS will support carriers to focus on their core business. Telcom service capability component for offering telecom services to cloud consumers is also incorporated in the proposed architecture. Telecom service capability services can be given in bundle with other cloud services or separately based on consumers demand. The logic will be set and managed using Business Support System (BSS) and Operation Support System (OSS) platforms of the carrier for rating and provisioning respectively.

5.2 Proposed Conceptual Cloud Service Architecture

The next step was to generate the conceptual architecture of the system taking into consideration outputs of Section 5.1.

As seen in Section 5.1 the carrier is capable for only IaaS whereas requirement of clients is to have all the three cloud services. Now to accommodate both scenarios, the study directly generate the IaaS architecture. However, for PaaS and SaaS a cloud broker service system is proposed.

Hence, the proposed cloud service conceptual architecture has IaaS and cloud broker components in addition to the telecom services capability component. The detail architectures of these components will be shown in sub Sections 5.2.1 and 5.2.2. Meanwhile, the overall architecture of the proposed cloud service architecture is presented in Figure 5.1.

External interfaces of the proposed cloud platform are listed and described below.

i. **Cloud broker:** The core cloud platform has direct connection to the cloud broker as one standalone cloud service provider.

ii. **Cloud Consumer:** This are clients and users of the service. Users and clients of the service can access the system with different access modes.

iii. **Cloud Service Creator:** Service creators can develop and design their services and launch or release on this cloud platform.

iv. **BSS:** This cloud platform is designed for carriers; hence the carrier BSS platform can be used directly for billing, provisioning and Customer Relation Management (CRM) services.

v. **OSS:** like the BSS system, this cloud platform will be under the supervision and provisioning functionalities of OSS platform of the operator.

vi. **Value Added Service (VAS) systems:** Telecom value added services like SMS, Unstructured Supplementary Service Data (USSD), payment Gate-Way (GW), and others will be integrated to this platform to give a seamless service for clients and users of the platform.

vii. **Other external systems:** This platform will also integrate to any other relevant external systems like external report system for fetching and analyzing the data from the platform.

Core component of the system includes IaaS and Telecom Operator Capabilities.

I. **IaaS:** this component basically constitutes the infrastructure as a service package described in Chapter 2.

II. **Telecom Operator Capabilities:** Telecom services that is offered by the carrier is incorporated in the design since the proposed cloud architecture is for carriers. However, to give this service along with cloud service as a bundle, there shall be internal provisioning and management component inside the cloud platform. This task is achieved using telecom operator capability component. Example of the services can be Virtual Private Network (VPN), Internet, SMS, USSD, and others.

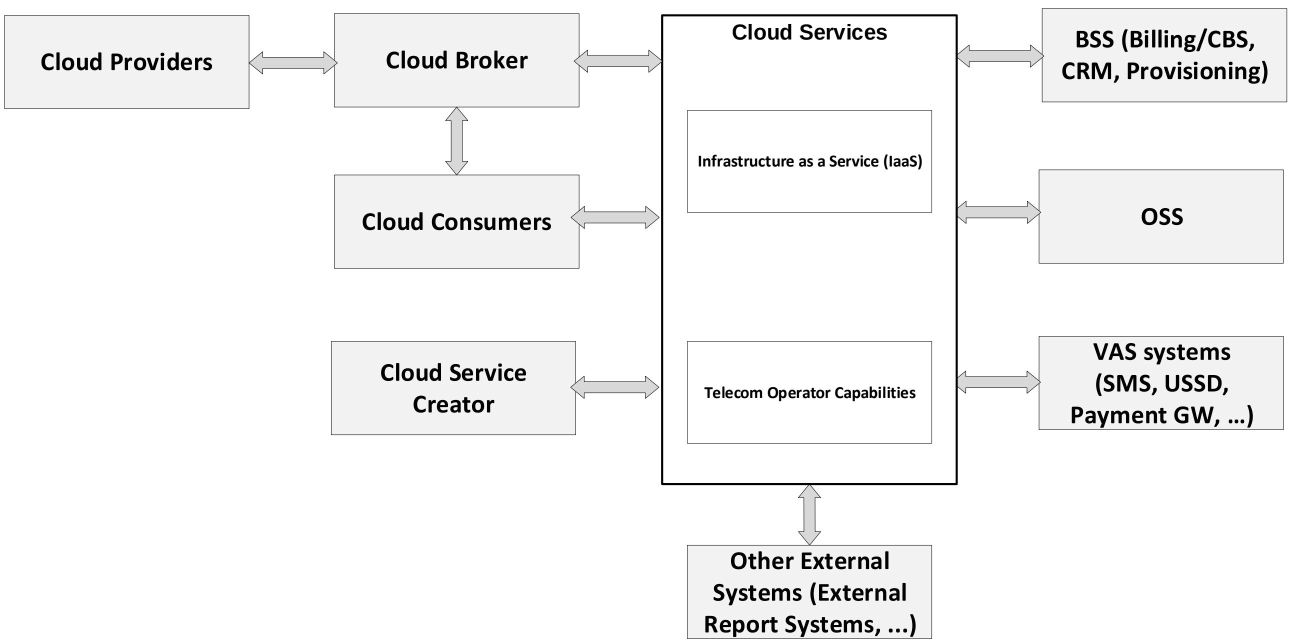

Figure 5.1 **Overall architecture**

5.2.1 Cloud Broker

Based on the above analysis, the proposed cloud service architecture will have two main components; cloud broker service and IaaS. In this section we will generate the detail architecture for the former component namely cloud broker service.

The following design concepts and principles are applied while generating the cloud broker service component.

- Exploring customer and service requirement based best-fit clouds in aspect of price, location, security, availability, etc. from the interfaced cloud service providers to the cloud broker platform.
- Easy query of data or reports by all stakeholders based on their privileges.
- Provisioning and management of cloud services given across the different cloud providers.
- Easy interfacing and sign up with the platform.
- Support Level Agreement (SLA) based service provisioning and lifecycle management.
- Flexible connection and interaction with the geographically dispersed and heterogenous clouds.

Taking those mentioned design principles and contexts of the clients the cloud broker service is generated as seen in Figure 5.2. Based on our proposed architecture, the broker platform consists of three main parts:

Access

This part is the frontend of the cloud service brokerage system for users and supports other functionalities too. Hence, mainly it supports three access portals for the provider, consumer and broker administrator as illustrated and discussed in subsequent subsections.

i. Cloud Service Provider (CSP) Portal

This component is used by the cloud service provider to sign up and login to the broker system to release their services. Before login to the system CSP need to have an agreement with the Cloud Service Broker (CSB). And for every subsequent access or login to the system afterwards, the CSP will be authenticated. Different CSP may have different privileges based on the deal with the CSB. The CSP portal component stores a list of available cloud service providers and their service types they can provision as well as the available SLA parameters. The services are defined by the cloud service providers. The service catalogue contains the required information to search and find services matching the user or service requirement. CSP register its cloud service using detailed information with resource quota. The primary information for CSP to register service or service package is listed and described below.

Attribute	**Description**
Name	Service/service package name
Detail description	Detail service description of the package or service
Provider profile	Information/description about the cloud service provider
Package profile	Service package details including each service specification
SLA profile	SLA specification of each service or service package
Support profile	Customer support information like refund, configuration, etc.
Billing profile	Tariff and its price policy information
Supported API	List of API for integration and their detail document

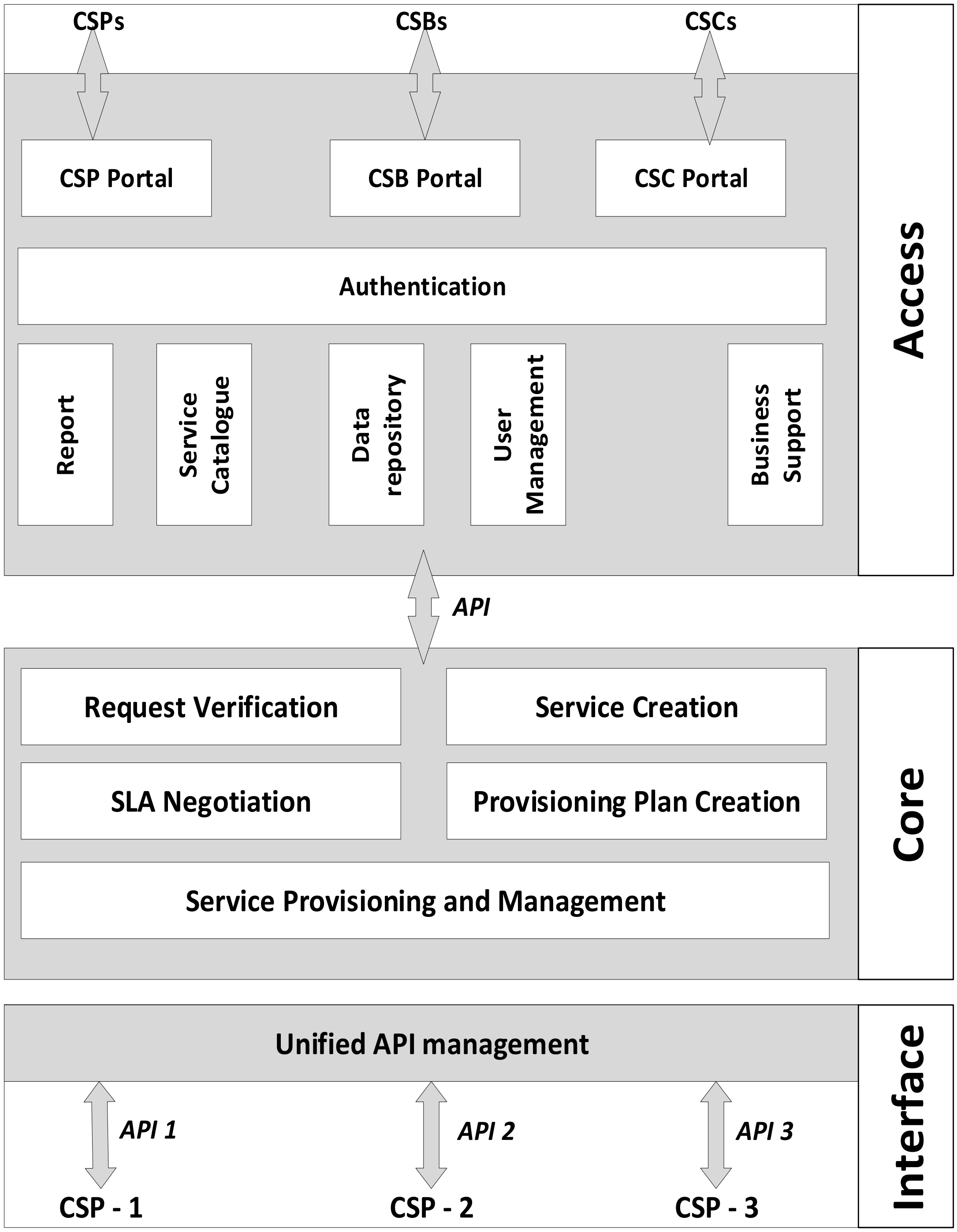

Figure 5.2 Proposed Cloud Broker Architecture

On the other hand, the above primary information will have the following metadata as illustrated in Table 5-1. There is also a report available for CSP to query and dump their services and products usage and statistics.

Main functionalities of CSP

- User management (all cloud service providers who wants to release a service shall register to the cloud service broker platform with a privilege assigned to them). It includes functionalities of password change, profile change, etc.
- Resource management (service quantity registration, update and monitoring).
- Service catalogue management (service registration, modify, delete).
- Accounting (audit and reconciliation).
- Billing (rating, charging and settlement).
- Report

Table 5-1 Proposed Conceptual Architecture Cloud Service Broker Metadata

CSP Profile	**SLA Profile**	**Billing Profile**
▪ Provider Name ▪ Description (provider profile) ▪ Address ▪ Contact information ▪ Other	▪ Service Name ▪ Service ID ▪ Service Description ▪ List of available services in the package ▪ Detail SLA parameters based on service type (Guarantee terms) like availability, usage, traffic, etc. ▪ Other	▪ Service Name ▪ Service ID ▪ Service Description ▪ Price modality ▪ Tariff ▪ Reward/Bonus ▪ Penalty ▪ Provisioning Policy (zone, price, location, etc) ▪ Other **Support Profile** ▪ Service Name ▪ Service ID ▪ Service Description ▪ List of available services in the package ▪ Refund support ▪ Help documents ▪ Contact information ▪ Support modes ▪ Support period (time range) ▪ Other

ii. Cloud Service Broker (CSB) Portal

This portal supports administrative functions to intermediate and deal with whole information about all CSP and CSC, such as management of users (CSP, CSB, CSC), registered and running services, monitoring, billing/invoice, reporting and others.

The service flow to release a new service is that CSP registers the service with all the necessary fields and then submit for confirmation. The CSB will be alerted that there is a new service to be confirmed. CSB review all the fields and confirm for launch, if it's a valid request, the service life cycle will change from draft state to commercial state. Then the service will be available and visible to CSCs for subscription. However, if CSB rejects the service release request, then CSP will be notified that service release has been rejected with justification. A single service will have Draft, Commercial, Idle and Delete state. Idle state refers to when the service is being suspended for specific time and it can be resumed anytime whenever required. Whereas, delete state refers to permanent removal of the service from the platform.

To provide SLA based service provisioning and management between CSP and CSC, it is necessary the CSB to receive service descriptions, guarantee terms, resource usage policy, pricing, and everything else related to service usage from CSP.

Hence, using the above information CSB can give the same level of SLA to CSC. For this purpose, the SLA specification described below is applied.

SLA Specification

Attribute	Description
Specification	CSP info and service (OS, SW, network) specification
Security	Level and policy
Account	User info
Service support	Interface and configuration

Property	Provisioning policy (zone, price, location, etc.)
Condition	Condition of property
Guarantee condition	Guaranteed property (availability, usage, traffic, etc.)
Reward (Bonus) /penalty	Type and action by type

Main functionalities of cloud broker portal include:

- User management (i.e. CSP, CSC, CSB users), including adding, modifying and deleting those user accounts.
- Cloud service management (monitoring, modify, start, stop).
- Accounting (audit and reconciliation).
- Billing (rating, charging, reward/bonus, penalty and settlement).
- Report

iii. Cloud Service Consumer (CSC) Portal

The cloud service consumer portal will be used by the cloud service clients that require a service on the cloud platform. Main functionalities of cloud service consumer portal include:

- User Management (password change, user profile change, etc.).
- Service Management (create, update, delete, monitoring of own services).
- Inquiry for accounting and report.

Core

Core component of CSB obtains various user requests from front end portal in defined form and returns processed result to user via each portal. On the other hand, it invokes and communicates with dispersed heterogeneous cloud using the unified API interface. Each of the components under Core component is illustrated in subsequent sub sections.

i. Request Verification

This component ensures that the service request issued by the user is valid or not. It verifies the service description syntax and semantics are correct and can be interpreted. The requested service types may not be known. Hence, it requires to be verified with the service provider registry information. Such verification is done by this component.

ii. Service Plan Creation

This component gets the verified user service request and creates a service plan using predefined template. Basically, this component will map the user request according to attributes defined and specified in a template.

iii. SLA Negotiation

SLA negotiations can be static or dynamic negotiations. Static negotiations compare or map user requests in accordance with the service provider registry information for the requested service. Whereas, dynamic negotiations require to interact with the service provider system to align the user requests and service provider offer. In this thesis static negotiation is applied. In the static negotiation of this component, the first step will be matching user requests with provider service policies using the pre-stored description and registry of the cloud services by the provider. Then aggregation of the proposed SLAs and ratings from the different heterogenous cloud providers with a list of possible combinations of services will take place. At the end, selection of the final provisioning solution according to the specified metric by proposing a list sorted by a consumer-defined metrics (cost, performance…) will be done.

iv. Provisioning Plan Creation

In this component the translated and selected provisioned request and the associated SLA terms in the SLA negotiation component will be transformed into a deployment plan. A provisioning plan will also be created according to a predefined metrics and attributes. Then the plan will be submitted to the service provisioning component.

v. Service Provisioning

The service provisioning component performs the sequence and arrangement of configuration and service provisioning tasks that is specific to a single service provider or generic across heterogeneous providers.

vi. Management

The management/monitoring component is responsible for measuring the Key Performance Indicators (KPIs) of the systems and services. In cloud systems, it provides data primarily for system monitoring, accounting/billing and SLA [41]. Monitoring helps to diagnose hardware and software problems, to enhance the resource utilization and to ensure the system's performance and security.

vii. Workflow Management Engine

In most of the tasks execution workflow logic is applied like tasks of scheduling, resource acquisition, per-execution of process, and others. Basically, Workflow Management Engine (WME) schedules jobs in workflow to remote resources based on user specified requirements with remote resources capable of meeting those demands.

Interface

This component of the cloud service broker provides a standard integration and interface API between the various heterogeneous cloud providers and the cloud service broker system. It translates and transforms the requests from cloud service broker provisioning component into understandable provider API calls. This component also manages the reverse transformation for the requests from the cloud provider to the cloud service broker system like monitoring, deployment and configuration calls return from CSP. The Unified API management will abstract the existing APIs heterogeneity through a common API in the proposed system. The API through which communication is performed will be the same for all broker services with its own specificities or configuration parameters. Additionally, authentication task takes place in this component using the attributes on this API designed for this purpose. This component also in charge of the service transaction between CSC and CSP. All the service transaction takes place only across this component. Additionally, the support document of detail API specification for CSP to integrate to the broker platform will be available on this component.

5.2.2 Infrastructure as a Service (IaaS)

The proposed architecture for IaaS extends the Service Oriented Architecture (SOA) [56] [57] based Enterprise Service Bus (ESB) architecture for dynamically configurable virtualized services. The Infrastructure as a Service provisioning involves dynamic creation of infrastructure consisting of different types of resources together with necessary control and management planes to be provisioned on demand. The proposed IaaS provides the design and operation of the composite or complex services provisioning on demand. It is based on the component services virtualization, which implies the logical abstraction of the (physical) component services and their dynamic composition. Which in turn allows easier services development and simple services integration environment [58]. The proposed IaaS architecture is depicted in Figure 5.3 which is designed following a layered architecture pattern, where each layer is described as below.

1 Presentation Layer

This part includes the user interface where users will view the released services and where they will request for subscription to different services.

2 Management Layer

Enables the coordination of the different composite services. It acts like a workflow management system.

3 Logical Adaptation Layer

Used to support the interaction of the virtualized services and resources with the physical interaction. Supporting major provisioning stages, in particular, service identification, service configuration and provisioning session management.

4 Component Services and Resources

The component resources and services include the computing resources (RAM and CPU), nodes, storages. In addition, co-location and power can be incorporated in this part.

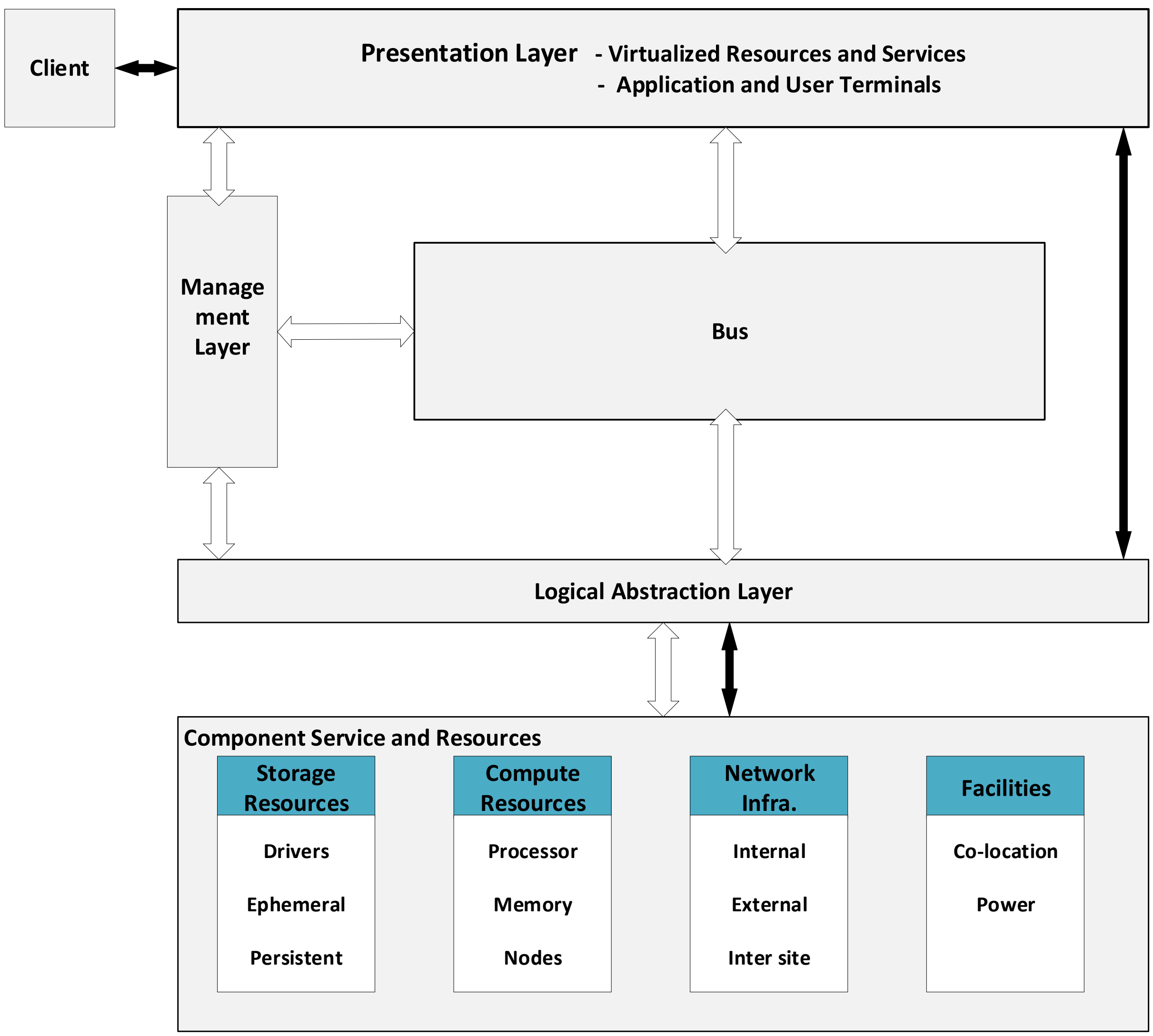

Figure 5.3 Proposed Infrastructure as a Service (IaaS) architecture

5.2.3 Telecom Operator Capabilities

Telecom operator capability service includes those services offered by the carrier which includes VPN service, VAS services (including SMS, Multimedia Messaging Service (MMS), USSD and others), internet services, etc. Clients can submit their preferred service request with the exposed interface. For instance, if the user request for SMS service, the request will be forwarded to the operator SMS service management. Hence, the operator can create SMS account based on the request.

Telecom operator capability service component functionality includes:

Provisioning: Authenticate and validate the user request and forward for the relevant telecom platform to provision the service for this consumer.

Telecom services storefront: It provides the different services catalogues of the operator with detail information to clients.

Telecom service bundled with cloud services: Handle cloud service requests which is in bundle with telecom services. For instance, to use infrastructure services the client needs to have an internet connection offered by the operator. Hence, internet service will be available and provisioned using this component dynamically upon the consent of the client.

5.3 Deployment

The deployment section is used as the implementation of the proposed architecture. In this section, the initial resource requirement for the proposed architecture will be developed and illustrated.

5.3.1 Design Input

Computing resources/VM requirement

i. **Clients Assessment Result**

The following parameters are collected on the assessment done for 62 companies consisting of VAS providers, NGO, manufacturing companies, financial institutions and governmental organizations as seen in Section 4.2. However, only 47 companies out of 62 gives complete feedback. And the below computation is done using the data from those 47 companies.

- Average number of machines used – 12
- Required specification – 2GB RAM with 4*2Ghz core processor
- Probability of customers to be at concurrent time - 40%.

ii. Carrier Requirement

The below inputs are collected from the carrier which is supposed to be implemented in the first phase of cloud solution deployment as a roadmap based on the discussion with experts and strategy of the organization.

Note: Those inputs from the carrier may vary to handle a greater number of clients depending on the market demand. However, it will not have an impact on the architecture as it is designed to be scalable horizontally and vertically.

- 19,000 vCPU
- 56,000 GB RAM
- 3,350,000GB storage
- Margin for redundancy and quality of service (SLA) is 30%.

iii. Industry Best Practice

The below parameters are collected from industry standard and best practices [59] [60] [61] [62] [63] [64]:

- A single physical core can accommodate on average 16 vCPU
- Average number of cores per physical CPU is 16
- Margin for redundancy and quality of service (SLA) varies between 15 to 40 percent.

The inputs for the design are summarized in Table 5-2.

Table 5-2 Summarized design inputs

Clients Assessment		Carrier Assessment		Industry Best Practice	
Parameter	Value	Parameter	Value	Parameter	Value
Average number of machines per client	12	Size of vCPU	19,000	Average number of vCPU per core	16
Specification requirement per server	2GB RAM & 4*2Ghz core processor	Size of RAM (GB)	56,000	Average number of cores per physical server	16
Probability of customers to be at concurrent time	40%	Size of storage (GB)	3,350,000	Margin for redundancy and quality of service (SLA)	15-40%
		Margin for redundancy and quality of service (SLA)	30%		

5.3.2 Computation

i. **Computing Resource**

Using the above input parameters:

One physical CPU can accommodate 16*16= 256 vCPU

Hence the number of servers required will be 19,000/256 = 75 physical servers (i.e taking the carrier requirement of 19,000vCPU from Table 5-2)

Taking 30% (carrier trend) redundancy for quality margin or SLA commitment. The industry also recommends between the range of 15 to 40 percent. (Refer Table 5-2)

The usable physical servers will be 75/1.3= **57 physical servers.**

However, client request is 12 machines with 4 core processor averagely, this implies 16*4*12= 768vCPU per client is required. (i.e. taking one core is equivalent to 16vCPU averagely from Table 5-2).

Transforming the above requirement of clients in vCPU to number of servers:

768/256= **3 servers** (i.e. taking one server is equivalent to 256vCPU as seen above)

Taking 40% value from Table 5-2 for the probability of customers to be at concurrent time.

It will accommodate 57/0.4*3= **48 clients on average.**

ii. Storage

To compute the requirement of storage resource, the clients are classified into three categories based on their contexts namely clients with high, moderate and low data intensive storage requirements as illustrated below:

i. High storage intensive

E.g. Content Providers like Yegha tube.

Average of size of a single content = 50MB

Average number of contents released per day is 10

Total size per day = 50 MB * 10= **500 MB**

ii. **Moderate storage intensive**

E.g. Highly transactional data like VAS SMS content providers

Average size of a single data = 1 KB

Average number of SMS transactions per day is 75,000

Total size per day = 1KB * 75,000= **75MB**

iii. **Low storage intensive**

E.g. simple website users

Average size of a single data = 1 MB

Total size per day = **1MB**

Assume the storage keeps the data for ten years, the respective requirements under each category will become:

i. Highly Storage Intensive Data Clients: 500MB * 365*10 = **1,825,000MB**

ii. Moderate Storage Intensive Data Clients: 75MB * 365*10 = **273,750MB**

iii. Lower Storage Intensive Data Clients: 1MB * 365*10 = **3,650MB**

The carrier requirement is **3, 350, 000 GB** as seen in Table 5-2

Taking 30 Percent redundancy for QoS as seen in Table 5-2, 2,577,000 GB usable storage will remain (3,350,000GB/1.3).

Hence it can accommodate (With the ratio of 8:17:22 for each requirement above becomes 14,600 GB: 4,653.75 GB:80.3 GB per ten years respectively),

611 clients (with the ratio of 104: 221: 286) or any combination of clients till the maximum amount of 2,577,000GB.

5.4 Evaluation and Validation

To validate the proposed architecture, six closed ended and three open ended questions were developed to examine the capability, comprehensiveness, usefulness and inclusiveness of the architecture. The participants were given a brief description of the proposed architecture with examples before responding for the questions. Figure 5.4 shows the results of the responses. The X-axis represents the number of respondents whereas the Y-axis represents the questions.

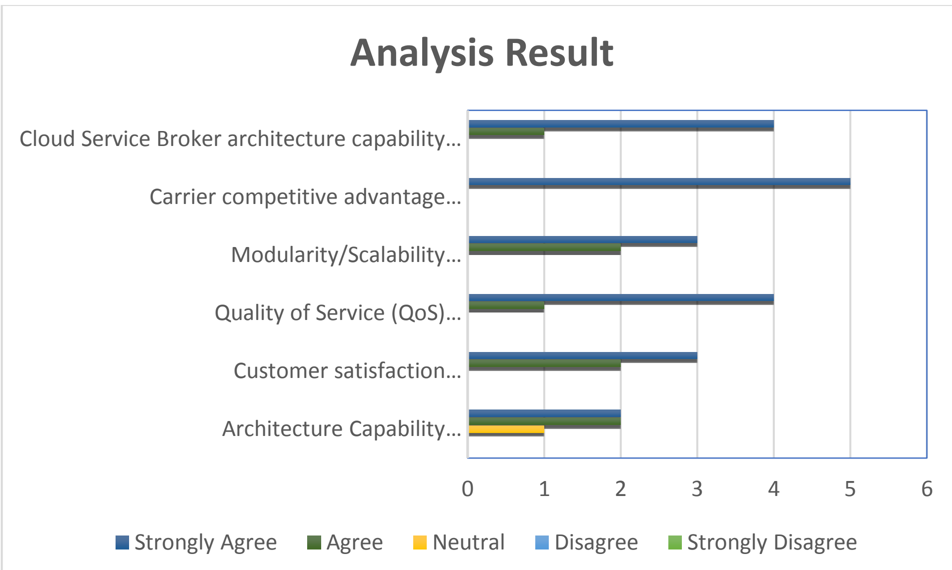

Figure 5.4 Summary of closed question responses for evaluation of the proposed cloud service architecture

The overall assessment of the proposed architecture achieved a high degree of agreement among the participants, as shown in Figure 5.4. All participants have agreed on the proposed architecture interms of its capability, competitive advantage for carriers, modularity and scalability, QoS, customer satisfaction. From the open questions, the respondents have suggested to include Disaster Recovery (DR) architecture. However, DR is not in the scope of the thesis.

5.5 Discussion

5.5.1 Cloud Service Selection

The first step towards generating the proposed architecture was to identify the type of service demand on the market using data collected from clients. The collected data was analyzed using Pugh Decision Matrix, which is a multi-criteria decision tool. The analysis shows that all the services are required on the market. However, the assessment from the carrier side shows that there is no capability to deploy PaaS and SaaS in recent period due to lack of human resource, time, and organizational structure. To align the needs of the clients with the carrier capability we proposed a cloud service broker platform. Using this platform, the carrier can offer both PaaS and SaaS to clients. Deploying cloud service broker platform will make the carrier a broker which intermediates the provider and consumer. The cloud service provider can be any cloud service provider which has an agreement with the cloud broker. The cloud consumers will have only a connection with the cloud broker and they assume the services are provided by the cloud broker. Any agreement and SLA will be provided by the cloud broker. Furthermore, implementing CSB will support the carrier to focus on core business.

The designed cloud service broker system supports integrated service provisioning and SLA based service lifecycle management. On the other hand, for IaaS, a detail full set of system architecture is generated. For all system design, we introduce the system concept, whole architecture and details of main components.

5.5.2 Proposed Conceptual Architecture

Based on the above result, the proposed conceptual architecture is constructed with a full set of IaaS and cloud service broker component as core components along with the telecom capability service component which is used to offer telecom services including VPN, internet, VAS services and others. In addition, the conceptual architecture has external interfaces including cloud consumer, cloud service developer, BSS and OSS, VAS services, and other relevant external entities. Compared to other existing architectures [1] [18] [43]

[52] [53] [54], the proposed architecture is equipped with integrated cloud service broker capability, offers telecom services and dimensioned only for the client context under Ethiopia case. For instance, taking Aneka [52] cloud architecture, it doesn't include IaaS and SaaS architecture whereas taking IBM cloud reference architecture [46], which provides all the services as a reference architecture is very generic. Besides, as one would expect, the provider dependent architectures are written in such a way to suit the services and products of the company. On the other hand, architectures like in [53] proposes an architecture suited for specific deployment model like Hybrid cloud.

A deployment environment is also constructed for the proposed architecture to be used as initial step towards adopting the architecture. For the deployment an interview is conducted to get the design inputs from both clients and the carrier side. Furthermore, industry best practices and standards are also taken into consideration as input while constructing the deployment environment.

5.5.3 Limitation of the thesis

The research has some limitations. The major limitation is lack of reference related work for comparison and validation. The research has also limitation in the approach to validate the proposed architecture. We have used review of experts to validate the proposed architecture. We believe an interesting result could be observed, if it was tested using real cloud environment; however, our limited budget and time as MSc student did not allow to perform this test. However, the authors believe that the architecture can be tested in real environment and could provide significant contribution for carrier-based cloud service architecture.

Chapter 6

Conclusion and Recommendations for Future Works

This Chapter presents the summary of conclusion of the study and recommendations for further works on this thesis research.

6.1 Conclusions and Contributions

In this thesis, a step by step methodology of developing a cloud service architecture considering the requirements and needs of clients as well as providers are presented. Design Science Research Methodology has been applied and Paugh Decision Matrix tool is used for data analysis purpose. 62 and 47 datasets are collected from enterprises in Addis Ababa using questionnaire and interview to deduce the type of service required on the market and to gather the design inputs respectively. Moreover, detail desk review and industry best practices and standards are applied to fulfill the artefacts and design parameters of the proposed architecture. A deployment environment has been also constructed for the proposed architecture using inputs from clients and the carrier. Industry best practices and standards has been also considered for building the deployment environment.

The proposed architecture constitutes of a full set of Infrastructure as a Service (IaaS), cloud service broker and telecom capability service components as core components. Implementing cloud broker service for SaaS and PaaS will support carriers to focus on their core business. Furthermore, external components like BSS, OSS, and others are interfaced to give comprehensive functionality of cloud service solution. The study can contribute for the knowledge of carrier-based cloud service architecture for the case of Ethiopian enterprise and cloud carrier context. The proposed architecture has been validated by experts in the industry. To this end, the overall assessment of the proposed architecture achieved a high degree of agreement among the participants. All participants have agreed on the proposed architecture interms of its capability, competitive advantage for carriers, modularity and scalability, QoS, customer satisfaction.

6.2 Recommendations for Future Works

In the future the work of this thesis can be extended to increase the accuracy of the cloud service architecture as to enhance satisfaction of clients. Here are lists of possible extensions to the works of this thesis.

- To enhance the inclusiveness of the proposed architecture by incorporating enterprises out of Addis Ababa.
- The study has not developed detail architecture of SaaS and PaaS, since carrier cloud provider doesn't have the capability to manage those services from resource and time perspective. However, the clients feedback shows there is a need on the market. Hence, the thesis proposed cloud service broker to align the clients and carrier cloud provider requirements. However, developing SaaS and PaaS detail architectures may be a possible extension to the work of this thesis considering the change in the capability of the carrier.
- The work of this study focuses to generate a cloud service architecture only from carrier cloud provider perspective. To generate an architecture considering other cloud providers can be also an extension to the work of this study.
- The service types under the scope of this thesis is IaaS, PaaS and SaaS. However, the thesis may be extended to include other service types of cloud.
- Security perspective of the architecture is not in the scope this thesis work. Hence, incorporating and looking the architecture from the security perspective is a possible extension to the work of this thesis.

References

[1] Kalogeras, Gialelis, and Alexakos, "Vertical integration of enterprise industrial systems utilizing web services," IEEE Transactions on Industrial Informatics, vol. 2, no. 2, pp. 120-128, 2006.

[2] L. Li, "Introduction: advances in e-business engineering," Information Technology and Management, pp. 49-50., 2011.

[3] G. Lin, J. Zhu, and Dasmalchi, "Cloud computing," IT professional, vol. 2, pp. 10-13, 2009.

[4] R. Buyya, C.S Yeo, and S. Venugopal, "Market-Oriented Cloud Computing : Vision, Hype, and Reality for Delivering IT Services as Computing Utilities," Proceedings of the 10th IEEE International Conference on High Performance Computing and Communication, pp. 5-13, 2008.

[5] J. Voas, and J. Zhang, "Cloud computing: New wine or just a new bottle?," IT professional, vol. 11, no. 2, pp. 15-17, 2009.

[6] Taleb, and Tarik, "Toward carrier cloud: Potential, challenges, and solutions," IEEE Wireless Communications, vol. 21, no. 3, pp. 80-91, 2014.

[7] B. Rimal, E. Choi, and I. Lumb, "A taxonomy and survey of cloud computing systems," in Fifth International Joint Conference on. Ieee, 2009.

[8] Y. Demchenko, and C. De Laat, "Defining generic architecture for cloud infrastructure as a Service model," *The International symposium on grids and clouds and the open grid forum Academia Sinica,* pp. 2-10, 2011.

[9] F. Liu, J. Tong, J. Mao, R. Bohn, J. Messina, L. Badger, and D. Leaf, NIST cloud computing reference architecture, vol. 500, NIST special publication, 2011, pp. 1-28.

[10] P. Mell, and T. Grance, The NIST definition of cloud computing, 2011.

[11] Y. Sami, M. Iain-James, L. Jean-Pierre, and T. Samir, "CompatibleOne: The Open Source Cloud Broker," Grid Computing, pp. 93-109, 2013.

[12] D. Bieler, "The future of telecom: strategies to move off the endangered species list," Future, 2011.

[13] B. Ian, "Cloud Services Survey 2017/18," Ovum, 29 Mar 2018. [Online]. Available: https://ovum.informa.com/resources/product-content/cloud-services-survey-201718. [Accessed 16 05 2018].

[14] R. Sapuram, MM. Modh, B. Narasimhan, and K. Grandhe, "A survey on security issues in service delivery models of cloud computing," Journal of Network and Computer Applications, vol. 34, pp. I - I I, 2011.

[15] S. Repschlaeger, R. Wind, and K. Zarnekow, Decision model for selecting a cloud provider: A study of service model decision priorities, Turowski, 2013.

[16] B. Ferguson, Kirsten, and C. Nicole, "Storing information in the cloud–A research project," *Journal of the Society of Archivists,* vol. 32, no. 2, pp. 221-239, 2011.

[17] Rimal, P. Bhaskar, C. Eunmi, and L. Ian, "A taxonomy and survey of cloud computing systems," in *Fifth International Joint Conference on. Ieee*, 2009.

[18] Cervone, and H. Frank, "Applied digital library project management: Using Pugh matrix analysis in complex decision-making situations," *OCLC Systems & Services: International digital library perspectives,* vol. 25, no. 4, pp. 228-232, 2009.

[19] Tritsiniotis, and D. Emmanouil, Get ready for the cloud: tailoring enterprise architecture for cloud ecosystems, University of Twente, 2013.

[20] Z. Qi, C. Lu, and B. Raouf, "Cloud Computing: State-of-the-Art and Research Challenges," *Internet Services and Applications,* vol. 1, no. 1, pp. 7-18, 2010.

[21] N. Motahari, R. Hamid, S. Bryan, and S. Sharad, "Outsourcing business to cloud computing services: Opportunities and challenges," *IEEE Internet Computing,* vol. 10, no. 4, pp. 1-17, 2009.

[22] Linthicum, and S. David, "Cloud computing and SOA convergence in your enterprise," in *a step-by-step guide*, Pearson Education, 2009.

[23] M. Armbrust, A. Fox, R. Griffith, AD. Joseph, R. Katz, A. Konwinski, G. Lee, D. Patterson, A. Rabkin, I. Stoica, and M. Zaharia, "A view of cloud computing," *Communications of the ACM,* vol. 53, no. 4, pp. 50-58, 2010.

[24] Mahmood, Zaigham, H. Richard, and EDS, Cloud Computing for enterprise architectures, Springer Science & Business Media, 2011.

[25] N. Motahari, S. Bryan, S. Sharad, and Hamid R., "Outsourcing business to cloud computing services: Opportunities and challenges," *IEEE Internet Computing,* vol. 10, no. 4, pp. 1-17, 2009.

[26] T. Dillon, C. Wu, and E. Chang, "Cloud Computing: Issues and challenges," *in Advanced Information Networking and Applications (AINA), 2010 24th IEEE International Conference on, Ieee,* p. 27–33, 2010.

[27] S. Marston, Z. Li, S. Bandyopadhayay, J. Zhang, and A. Ghalsasi, "Cloud Computing the business perspective," *Decision support systems,* vol. 51, no. 1, p. 176–189, 2011.

[28] M. Sajid, and Z. Raza, Cloud computing: Issues & challenges. In International Conference on Cloud, Big Data and Trust 2013 Nov 13 (Vol. 20, No. 13, pp. 13-15).

[29] E. Thomas, M. Zaigham, and P. Ricardo, "Cloud-Enabling Technology," in *Cloud Computing Concepts, Technology & Architecture*, Prentice Hall, 2013, p. 79–116.

[30] M. Sandeep, and S. Shashwat , "Pros and Cons of Cloud Computing Technology," *International Journal of Science and Research (IJSR),* 2013.

[31] Daniels, and Jeff, "Server virtualization architecture and implementation," *Crossroads,* vol. 16, no. 1, pp. 8-12, 2009.

[32] Jin, Yichao, W. Yonggang, and C. Qinghua, "Energy efficiency and server virtualization in data centers: An empirical investigation," in *Computer Communications Workshops (INFOCOM WKSHPS), 2012 IEEE Conference on. IEEE*, 2012.

[33] Erl, Thomas, P. Ricardo, and M. Zaigham, Cloud computing concepts, technology & architecture, 2013.

[34] V. Vijaya, R. Lakshmi, and P. Reddy, "Evaluation of different hypervisors performance in the private cloud with SIGAR framework," *International Journal of Advanced Computer Science and Applications,* vol. 5, no. 2, 2014.

[35] Sugerman, Jeremy, and L. Ganesh, "Virtualizing I/O Devices on VMware Workstation's Hosted Virtual Machine Monitor," in *USENIX Annual Technical Conference*, 2001.

[36] Zack, "Para Virtualization Full virtualization Differences," 13 06 2015. [Online]. Available: https://zhihuicao.wordpress.com/2015/06/13/para-virtualization-full-virtualization-differences/. [Accessed 27 6 2018].

[37] B. Elsevier, V. Christian, Selvi, and S. Thamarai, "Virtualization," in *Mastering Cloud Computing. Foundations and Applications Programming*, Elsevier, 2013, p. 71–109.

[38] F. Ian, Z. Yong, R. Ioan, and L. Shiyong , "Cloud Computing and Grid Computing 360-Degree Compared," *Workshop on Grid Computing Environments (GCE '08),* p. 1–10, 2008.

[39] S. Yangui, I. Marshall, J. Laisne, and S. Tata, "CompatibleOne: The open source cloud broker," *Journal of Grid Computing,* vol. 12, no. 1, pp. 93-109, 2014.

[40] L. Benoit, P. Daryl, B. Tiffani, W. Tim, C. Michele, C. Linda, and B. Robert, "The Role of CSB in the Cloud Services Value Chain," *Gartner,* vol. G00218960, 2011.

[41] Fowley, Frank, P. Claus, and Z. Li, "A comparison framework and review of service brokerage solutions for cloud architectures," in *International Conference on Service-Oriented Computing*, 2013.

[42] R. Sapuram, M. Modh, B. Narasimahan, and K. Grandhe, "Integrated cloud service brokerage (csb) platform functionality modules". United States Patent United States patent application US 14/096,004, 18 Sep 2014.

[43] Wilkes, and Lawrence, "Cloud computing reference architectures, models and frameworks," in *Everware CBDI*, 2011.

[44] R. ZOTA, and P. Alexandru, "An Overview of the Most Important Reference Architectures for Cloud Computing," *Informatica Economica,* vol. 18, no. 4, 2014.

[45] S. Marston, Z. Li, S. Bandayopadhayay, J. Zhang, and A. Ghalsasi, "Cloud computing The business perspective," *Decision support systems,* vol. 51, no. 1, pp. 176-189., 2011.

[46] Hogan, Michael, L. Fang, S. Annie, and T. Jin, NIST cloud computing standards roadmap, NIST Special Publication, 2011.

[47] R. Stifani, S. Pappe, G. Breiter, and M. Behrendt, *Ibm cloud computing reference architecture,* IBM Academy of Technology, 2012.

[48] Bakshi, and Kapil, "Cisco cloud computing-data center strategy, architecture, and solutions," *point of view white paper for us public sector 1st edition,* pp. 1-16, 2009.

[49] L. Qian, Z. Luo, Y. Du, and L. Guo, "Cloud computing: an overview," 2009.

[50] Foster, Ian, Z. Yong, R. Ioan, and L. Shiyong, "Cloud Computing and Grid Computing 360-Degree Compared," *Grid Computing Environment Workshop,* pp. 1-10, 2008.

[51] R. Calheiros, R. Ranjan, A. Beloglazov, C. DeRose, and A. Buyya, A Toolkit for Modelling and Simulation of Cloud Computing Environments and Evaluation of Resources Provisioning Algorithms. Software – Practice and Experience, John Wiley & Sons, Ltd, 2010.

[52] R. Buyya, R. Rajiv, Rodrigo, and N. Calheiros, "Modelling and Simulation of Scalable Cloud Computing Environment and the CloudSim Toolkit Challenges and Opportunities," *International Conference on High Performance Computing and Simulation,* vol. 21, no. 2, pp. 1-11, 2009.

[53] C. Vecchiola, C. Xingchen, and B. Rajkumar, "Aneka: a software platform for .NET-based cloud computing," *High Speed and Large Scale Scientific Computing,* vol. 18, pp. 267-295, 2009.

[54] Zou, Caifeng, D. Huifang, and Q. Qunye, "Design and implementation of hybrid cloud computing architecture based on cloud bus," in *Mobile Ad-hoc and Sensor Networks (MSN), 2013 IEEE Ninth International Conference on. IEEE*, 2013.

[55] D. Wang, J. Li , K. Xing, S. Jin, and K. Liu, "Carrier-grade distributed open cloud computing for telecom operators," *InNetwork Operations and Management Symposium (APNOMS),* pp. 1-8, 2012.

[56] A. Alhammadi, A knowledge management based Cloud Computing adoption decision making framework, Staffordshire University, 2016.

[57] Sarif, M. Siti, and S. Norshuhada, "Measuring helpfulness of personal decision aid design model," *Global Journal of Computer Science and Technology,* 2010.

[58] Shuen-Tai, Wang, Y. Lin, and H. Chang, "Developing a Web-Based Workflow Management System in Cloud Computing Platforms," *International Journal of*

Computer, Electrical, Automation, Control and Information Engineering, vol. 9, pp. 1370-1374, 2015.

[59] K. Laskey, J. Estefan, F. McCabe, and D. Thornton, Reference architecture foundation for service oriented architecture version 1.0., Oasis, Committee Draft., 2009.

[60] Chappell and David, Enterprise service bus, O'Reilly Media, 2004.

[61] H. Petritsch, Service-Oriented Architecture (SOA) vs. Component Based Architecture, Vienna: University of Technology, 2006.

[62] C. SLA, Cloud service level agreement standardisation guidelines, European Commission, Brussels, 2014.

[63] K. Surksum, "Best Practices for Oversubscription of CPU, Memory and Storage in vSphere Virtual Environments," 2012.

[64] V. Lee, C. Kim, J. Chhugani, M. Deisher, D. Kim, A. Nguyen, M. Satish, S. Chennupaty, P. Hammarlund, and R. Singhal, "An evaluation of throughput computing on CPU and GPU," *Debunking the 100X GPU vs. CPU myth,* pp. 451-60, 2010.

[65] G. Suo, and X. Yang, "Balancing parallel applications on multi-core processors based on cache partitioning," in *Parallel and Distributed Processing with Applications, 2009 IEEE International Symposium on. IEEE*, 2009.

[66] B. Heller, S. Seetharaman, P. Mahadevan, Y. Yiakoumis, P. Sharma, S. Banerjee, and N. McKeown, "Elastictree: Saving energy in data center networks," *In Nsdi,* vol. 10, pp. 249-264, 2010.

[67] Lowe, and D. Scott, Best practices for oversubscription of CPU, memory and storage in vSphere virtual environments, Technical Whitepaper, 2013.

Appendix A

Service Selection Questionnaires

Dear Participant, my name is Aschalew Gashaw, I am a postgraduate student at Addis Ababa University institute of Technology. Now I am doing a research as part of in partial Fulfillment of the Requirements for the Degree of Master of Science (Telecommunication Engineering) with a title **Context based Cloud Service Architecture: *From Carrier Perspective***. The objective of the research is to get clients preference on the type of cloud service.

Your response is only for academic purpose and all information will remain confidential and will be used for academic purpose only. The information is extremely important for the success of the research and to achieve its objectives. Hence, I would like to ask you to fill the questionnaire honestly and promptly.

If you need any clarification or there exist any unclear issue, please don't hesitate to contact me at the number and email below.

I would like to thank you in advance for your cooperation.

Regards,

Aschalew Gashaw

Email: aschu.hu@gmail.com

Phone: 0911516427

1. What is your Job Title?

   ☐ IT Manager ☐ IT Expert ☐ IT Architect ☐ Other, please specify_____

2. What is your level of knowledge about cloud computing

   ☐ I have expertise knowledge on cloud computing

   ☐ I have some knowledge about cloud computing

   ☐ I have no knowledge on cloud computing

3. Your company belongs to the sector:

   ☐ Financial Institutions

   ☐ Government administration

   ☐ International organizations NGO's and embassies

   ☐ Production enterprises

   ☐ Public service enterprises

   ☐ Private service enterprises

   ☐ Other, please specify_________________

4. Does your organization plan to migrate services and data to cloud computing?

   ☐ Yes ☐ No ☐ Already migrated to the cloud ☐ Don't know

5. What type of cloud computing does your organization use or plan to use? (You can select more than one.)

   ☐ Individual software packages (SaaS)

   ☐ Complete operating system and software package available via cloud services (PaaS)

☐ Just infrastructure services such as storage, network capacity etc (IaaS)

☐ Security services in the cloud

☐ Other (please specify)

6. On scale of 1 to 5 with the definitions for each scale under the variables, please rate the following for choosing an appropriate cloud service type.

Variables	1	2	3	4	5
Data sensitivity	☐	☐	☐	☐	☐
To what extent is the data of your company sensitive					
(5 Very high, 1 Very low)					
Control over resources	☐	☐	☐	☐	☐
To what extent is the control over resources important in your organization					
(5 Very important, 1 Unimportant)					
Capability to manage services	☐	☐	☐	☐	☐
To what extent is the capability of your company to manage IT services					
(5 advance, 1 easy)					
Short lead time	☐	☐	☐	☐	☐
To what extent is short lead time important for your company					
(5 Very important, 1 Unimportant)					
Cost	☐	☐	☐	☐	☐
To what extent is cost important for your company					
(5 Very important, 1 Unimportant)					
Scalability	☐	☐	☐	☐	☐
To what extent is service scalability important for your company					

(5 Very high, 1 Very low)	
	☐ ☐ ☐ ☐ ☐
Performance To what extent is service performance important for your company (5 Very high, 1 Very low)	
Availability To what extent is service availability important for your company (5 Very high, 1 Very low)	☐ ☐ ☐ ☐ ☐
Interoperability and portability To what extent are interoperability and portability important for your company (5 Very important, 1 Unimportant)	☐ ☐ ☐ ☐ ☐

Part II. Interview questioners for carriers on selecting cloud service type

You are invited to participate in this semi structured interview aimed at generating a cloud service architecture from carrier perspective. The general purpose of this study is to develop a cloud service architecture taking the clients context and carriers capability into consideration. The objective of this specific interview is to figure out the type of cloud service that can be released or deployed by the carrier. The interview consists of semi structured questions and the approximate time to answer all the 7 questions is about 15 minutes. Your participation in this study is completely voluntary and your response to the questions will be strictly confidential. Finally, I would like to deeply thank you for taking the time to answer these interview questions.

1. Which department are you working?
2. What is your job role?
3. Does your company have the plan or strategy to deploy cloud solution for external clients to launch their services?

   If yes?

   3.1. Which cloud service type will be included and deployed?

   3.2. Why others are not included?
4. Does the company have the financial capability to deploy the technology?
5. Does the company have the human resource to utilize the technology?
6. Does the company have organizational structure and on hand process to handle this technology?

   if not?

   6.1. From your experience, does the company has a trend to cope with such changes, structure and process with a short period of time?
7. Does your company have any preconditions to work with other cloud service providers?

   If yes? Specify the conditions?

Appendix B

Interview Questions for Design Inputs

I. Clients

You are invited to participate in this semi structured interview aimed at generating a cloud service architecture from carrier perspective. The general purpose of this study is to develop a cloud service architecture taking the clients context and carriers capability into consideration. The objective of this specific interview is to gather design inputs of cloud service architecture. The interview consists of semi structured questions and the approximate time to answer all the 11 questions is about 30 minutes. Your participation in this study is completely voluntary and your response to the questions will be strictly confidential. Finally, I would like to deeply thank you for taking the time to answer these interview questions.

1. Company name________
2. What is your job role?
3. What is your level of education?
4. How many boxes does your company own (i.e. existing and plan)?
5. What is the processor spec of the boxes (i.e. existing and plan)?
6. What is the RAM size of your machines (i.e. existing and plan)?
7. What is your storage requirement for every transaction you make (i.e. existing and plan)?
8. What is the maximum number of instructions generated by the boxes?
9. How many transactions do you make per day (i.e. existing and plan)?
10. How many users use the system concurrently?
11. Do you have any requirement on the availability and reliability of the system? If yes, please specify?

II. Carrier

You are invited to participate in this semi structured interview aimed at generating a cloud service architecture from carrier perspective. The general purpose of this study is to develop a cloud service architecture taking the clients context and carriers capability into consideration. The objective of this specific interview is to gather a design input for generating the cloud service architecture. The interview consists of semi structured questions and the approximate time to answer all the 5 questions is about 15 minutes. Your participation in this study is completely voluntary and your response to the questions will be strictly confidential. Finally, I would like to deeply thank you for taking the time to answer these interview questions.

1. Which department are you working?
2. What is your job role?
3. Does your company have the plan or strategy to deploy cloud solution for external clients to launch their services?

   If yes?

   7.1. Which cloud service type will be included and deployed?

   7.2.What is the size of processor to be deployed?

   7.3.What is the size of RAM to be deployed?

   7.4.What is the size of storage to be deployed?
4. What is the margin for quality of service or SLA applied on your company?
5. Do you have any requirement or strategy and roadmap on cloud solution that will be deployed in your organization?

Appendix C

Architecture validation questions

Please rate the extent to which you agree or disagree with the following statements based on the proposed architecture	1= Strongly disagree 2= Disagree 3= Neutral 4= Agree 5= Strongly agree				
	1	**2**	**3**	**4**	**5**
Architecture Capability The architecture provides a cloud service architecture tailored to a specific client's context.	☐	☐	☐	☐	☐
Customer satisfaction The architecture incorporates architectural components that can satisfy user needs.	☐	☐	☐	☐	☐
Quality of Service (QoS) The architecture offers cloud service to users with guaranteed QoS.	☐	☐	☐	☐	☐
Modularity/Scalability The architecture is modular for easy scalability and interoperability.	☐	☐	☐	☐	☐
Carrier competitive advantage The architecture provides one stop service for clients.	☐	☐	☐	☐	☐
Cloud Service Broker architecture capability					

The proposed cloud broker service architecture provides focus on core competency for carriers.	☐	☐	☐	☐	☐
Do the architecture support carriers to enhance user satisfaction and revenue?					
Are there any architectural components which are important to meet the needs and requirements of clients which have not been addressed in this architecture?					
Are there any changes you would suggest for improving the proposed cloud service architecture?					