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## Cloud Computing and Inter-Clouds - Types, Topologies and Research Issues.

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### Abstract

Cloud computing has become the buzzword in the computing world. From the time that Internet took over, computing technologies have developed to a great extent. Computers were connected and networking among computers has led to distributed computing which further led to cluster computing and grid computing and cloud computing. The cloud provides an environment where the requirements like computing power, data storage, memory, licensed and latest software and software development platforms are provided to the customer as utility computing. The cloud has deployment models and service models. In this paper we will discuss the service models, the different types of clouds, need of Inter-Cloud, Inter-Cloud and their architecture, types of Inter-Clouds, topologies in Inter-Cloud and research issues in Inter-Cloud.

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*Keywords:* computing; public cloud; private cloud; hybrid cloud; Inter-Cloud; federationcloud; multicloud.

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### 1. Introduction.

Cloud computing has emerged as a new computing paradigm in which there are two types of players. Cloud service providers and cloud end-users. The cloud aims to provide the consumer or end-user, computing environment with QOS (Quality of Service) and based on the dynamic requirements, and profits for the cloud service providers. The National Institute of Standards and Technology (NIST) defines cloud computing as “Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage application and services) that can be

rapidly provisioned and released with minimal management effort or service provider interaction”<sup>1</sup>. Cloud computing utilizes distributed resources by combining them to solve complex, large scale computation problems and to achieve higher throughput.

## 2. Characteristics of Cloud Computing

NIST specifies five characteristics<sup>1</sup> of cloud.

- On-demand self-service: Computing capabilities can be provided to a customer according to the requirement of the user. Capabilities like storage and server time are allocated without human interaction.
- Broad Network access: Using standard mechanisms, the cloud can be accessed through network using thick or thin clients. Examples of the clients are tablets, laptops, mobile phones and workstations.
- Resource pooling: In the multitenant model, the computing resources are pooled to provide service to multiple consumers. The computing resources can be present anywhere geographically and the exact location of resources is not known to the user.
- Rapid Elasticity: Depending on the user requirement, the capabilities and resources in the cloud can be released and provided automatically.
- Measured Service: The services provided to the user are measured by the cloud system and are reported to the user and the provider. Based on the type of service, the cloud system optimizes and controls the resource use by a metering capability.

## 3. Cloud Architecture

Front end and back end are two sections in a cloud system. What is seen by the user is the front end and the cloud is the back end and they are connected through the network which is usually the internet<sup>2</sup>. A runtime environment for applications is provided by the core middleware and another objective of core middleware is best utilization of the resources<sup>3</sup>. Figure 1 depicts the cloud architecture<sup>3</sup>.

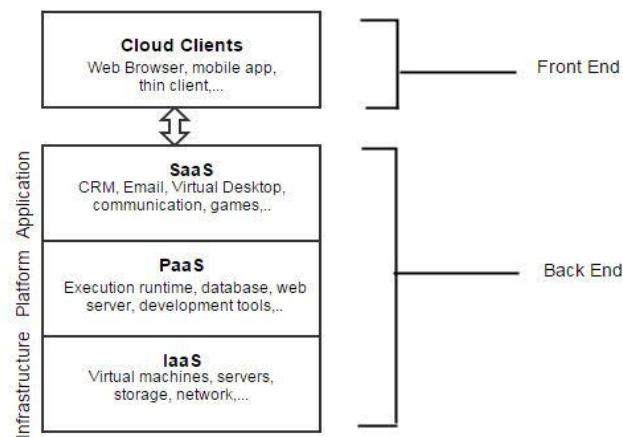


Figure1. Cloud-computing Architecture

### 3.1 Cloud Software as a Service (SaaS):

SaaS is a software delivery model providing access to applications through the internet as a web-based service<sup>3</sup>. Applications are built to be accessible to multiple users through a web browser.

Characteristics of SaaS<sup>4</sup>:

- The software is made available through the Internet.
- The Software is maintained by the service provider.
- The license to the software is based on subscription or usage and billed on a recurring basis.
- Zero maintenance is required at the end-user side and hence SaaS applications are very cost effective.
- Software is available on demand and can be scaled up and down according to the demand.
- Software is upgraded and updated automatically and also supports multitenancy.

GoogleApps, Oracle on Demand, SalesForce.com and SQL Azure<sup>5</sup> are some of the examples of SaaS.

### 3.2 *Cloud Platform as a Service (PaaS):*

PaaS solutions constitute the middleware on top of which applications are built and provide a development and deployment platform for running applications on the cloud<sup>3</sup>.

Characteristics of PaaS<sup>4</sup>:

- Built-in security, scalability, and web service interfaces are provided by PaaS.
- Built-in tools for defining business rules and defining workflow and approval processes are provided by PaaS.
- Integration of applications with other applications on the same platform is easy.
- PaaS provides web services interfaces which enable us to connect the applications outside the platform.

Force.com, Google AppEngine, Windows Azure Platform, GoGrid Cloudcenter are some of the examples of PaaS<sup>5</sup>.

### 3.3 *Cloud Infrastructure as a Service (IaaS):*

IaaS solutions are most popular and developed market segment of cloud computing. IaaS solutions bring all the benefits of hardware virtualization<sup>5</sup>.

Characteristics of IaaS<sup>4</sup>:

- IaaS provides virtual machines with pre-installed Operating Systems.
- Resources are available On-demand.
- IaaS allows storing copies of data in different locations.
- The computing resources in the cloud can be easily scaled up and down.

Examples of IaaS providers include Amazon ECC, Eucalyptus, GoGrid, Flexiscale, Linode, RackSpace Cloud, Terremark<sup>5</sup>.

## 4. Cloud Deployment Models

The four common deployment models are as follows:

### 4.1 *Public cloud*

The cloud infrastructure is owned by the cloud service provider. The cloud infrastructure exists in the premises of cloud provider. General public or a large industry group can access the cloud services for usage, on a pay according to usage method. The users are allocated the resources in the cloud on-demand. The resources are provided on a dynamic basis over the Internet. Small and medium enterprises (SMEs) benefit to great extent from using public clouds<sup>3</sup>. Advantages of Public clouds are location independence, cost-effectiveness, reliability, flexibility, utility style costing and high scalability<sup>4</sup>. Disadvantages are low security and less customizable.

### 4.2 *Private cloud*

The cloud infrastructure in a private cloud is operated solely for an organization. It can be managed by the organization itself or a third party. The private cloud can exist on premises or off premises<sup>6</sup>. Advantages of private clouds are higher security and more privacy, more control, cost and energy efficiency<sup>4</sup>. Disadvantages are limited scalability due to limited resources, inflexible pricing and Private cloud is limited to a particular area.

#### 4.3 Hybrid cloud:

The cloud infrastructure in a Hybrid cloud is a composition of two or more clouds (private, community, or public). Each of them remain as unique entities but are linked together by standardized or proprietary technology. This technology enables data and application portability<sup>1</sup>. Advantages of Hybrid clouds are scalability, flexibility, cost efficiency and security. Disadvantages are networking issues and security compliances.

#### 4.4 Community cloud:

The cloud infrastructure in a community cloud is shared by several organizations which have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It is generally managed by the organizations in the community or a third party and can be present either on-premises or off-premises<sup>1</sup>. Advantages of Community clouds are that they are secure than public clouds and sharing of resources among several organizations. Disadvantages are that it is less secure than private cloud and requires governing policies for administration.

### 5. Inter-Clouds.

The Inter-Cloud is an interconnected global "cloud of clouds" and an extension of the Internet "network of networks" on which it is based<sup>6</sup>. Inter-Cloud computing is interconnecting multiple cloud providers' infrastructures. The main focus is on direct interoperability between public cloud service providers<sup>7</sup>. To provide cloud services as utility successfully, interconnected clouds are required and interoperability and portability are important factors in Inter-Cloud<sup>9</sup>.

#### 5.1. Need of Inter-Cloud

The limitations of cloud are that they have limited physical resources. If a cloud has exhausted all the computational and storage resources, it cannot provide service to the clients. The Inter-Cloud addresses such situations where each cloud would use the computational, storage, or any kind of resource of the infrastructures of other clouds<sup>8</sup>. The Inter-Cloud environment provides benefits like diverse Geographical locations, better application resilience and avoiding vendor lock-in to the cloud client. Benefits for the cloud provider are expand-on-demand and better service level agreements (SLA) to the cloud client<sup>10</sup>.

#### 5.2. Types of Inter-Cloud:

- **Federation Clouds:** A Federation cloud is an Inter-Cloud where a set of cloud providers willingly interconnect their cloud infrastructures in order to share resources among each other<sup>10</sup>. The cloud providers in the federation voluntarily collaborate to exchange resources. This type of Inter-Cloud is suitable for collaboration of governmental clouds (Clouds owned and utilized by nonprofit institution or government) or private cloud portfolios (Cloud is a part of a portfolio of clouds where the clouds belong to the same organization). Types of federation clouds are Peer to Peer and Centralized clouds.
- **Multi-Cloud:** In a Multi-Cloud, a client or service uses multiple independent clouds. A multi-cloud environment has no volunteer interconnection and sharing of the cloud service providers' infrastructures. Managing resource provisioning and scheduling is the responsibility of client or their representatives<sup>9</sup>. This approach is used to utilize resources from both governmental clouds and private cloud portfolios. Types of Multi-cloud are Services and Libraries.

#### 5.3. Topologies of different Cloud Architectures.

- **Peer to peer Inter-Cloud federation:** Clouds collaborate directly with each other but may use distributed entities for directories or brokering. Clouds communicate with each other and negotiate directly without mediators. Peer to Peer Inter-Cloud federation is depicted in Figure 2(a). The Inter-Cloud projects that use Peer to Peer federation are RESERVOIR (Resources and Services Virtualization without Barriers Project), Open Cirrus, OPTIMIS, Arjuna Agility and Global Inter-Cloud by Bernstein et al<sup>9</sup>.

- Centralized Inter-Cloud federation: Clouds use a central entity to perform or facilitate resource sharing. The central entity acts as a storehouse where the available cloud resources are registered. Centralized Inter-Cloud federation is depicted in Figure 2(b). The Inter-Cloud projects that use Centralized Inter-Cloud federation are Inter-Cloud, Contrail, Dynmic Cloud Collaboration (DCC) and Federated Cloud Management.

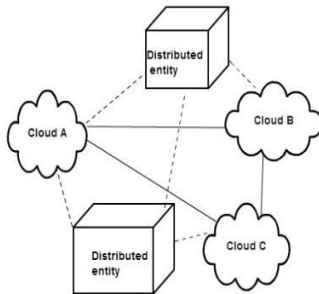


Figure 2(a). Peer to peer Inter-Cloud federation

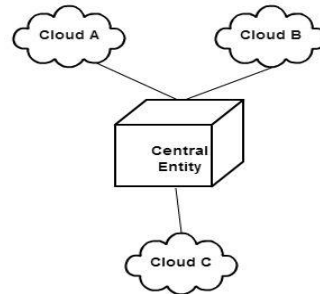


Figure 2(b). Centralized Inter-Cloud federation.

- Multicloud Service: Clients access multiple clouds through a service. A service is hosted by the cloud client either externally or in-house. The services contain broker components. The Multicloud Service is depicted in Figure 3(a). The Inter-Cloud projects that use Multicloud services are OPTIMIS, Contrail, mOSAIC, STRATOS and Commercial Cloud Manangement Systems<sup>9</sup>.
- Multicloud Libraries: Clients develop their own brokers by using a unified cloud API as a library. Inter-Clouds that use libraries facilitate the usage of clouds in a uniform way<sup>9</sup>. Multicloud Library is depicted in Figure 3(b). Examples of Several Multicloud Libraries are Java library JClouds, Python library Apache LibClouds, Ruby library Apache DeltaCloud, PHP library SimpleCloud, Apache Nuvem.

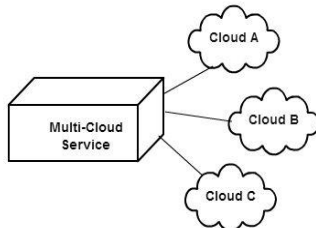


Figure 3(a). Multicloud service

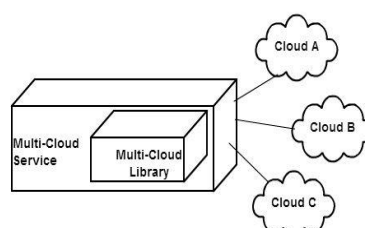


Figure 3(b). Multicloud Library

The classification of Inter-Clouds is summarized in the Figure 4 below<sup>9</sup>.

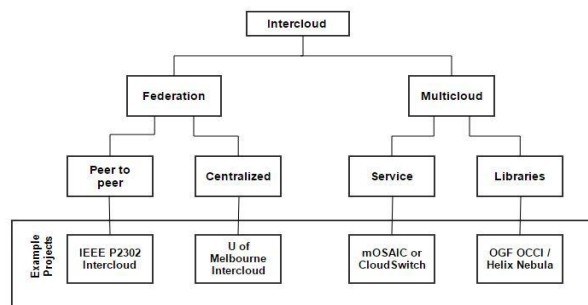


Figure 4. Classification of Inter-Clouds.

#### 5.4. Inter-Cloud –Research Issues<sup>10</sup>.

The requirements of cloud users often require different resources and the requirements are flexible and unpredictable most of the times. This aspect poses complex problems in provisioning of resources and delivery of application services. The following are the challenges faced in federation of cloud infrastructures:

- **Application Service Behaviour Prediction:** It is important that the system should be able to foresee the demands and the behavior of the services. Only when it can predict, it can take decisions intelligently to dynamically scale up and down. Prediction and forecasting models must be built. The challenge is to build such models that accurately learn and fit statistical functions suitable to different behaviors. It is more challenging to correlate between different behaviors of a service.
- **Flexible Mapping of Services to Resources:** It is important to maximize the efficiency, cost-effectiveness and utilization because of high operating costs and energy requirements. The system has to compute the best software and hardware configurations which result in a complex process of mapping services to cloud resources. Mapping of services must guarantee that QoS targets are satisfied along with maximum system efficiency and utilization.
- **Economic Models Driven Optimization Techniques:** Combinatorial optimization problem is a market driven decision making strategy which searches the optimal combinations of services and deployment plans. Optimization models must be developed which optimize both resource-centric and user-centric QoS targets.
- **Integration and Interoperability:** SMEs have a large amount of IT assets like business applications in their premises and may not be migrated to the cloud. Sensitive data in an enterprise also may not be migrated to the cloud for security reasons and privacy. A need related to integration and interoperability arises between assets on premises and the cloud services. Issues related to identity management, data management, and business process orchestration need to be resolved.
- **Scalable Monitoring of System Components:** The components in a federated system are distributed but the techniques employed for system monitoring and management use centralized approaches. Due to concerns of scalability, performance and reliability arising from the management of multiple service queues and large volume of service requests, centralized approaches are not suitable and architectures using service monitoring and management services based on decentralized messaging and indexing models are needed.

## 6. Conclusions

In this paper we have discussed the key concepts of cloud computing like architecture of Cloud Computing, service models and types of clouds. . We have also described the architecture of Inter-Cloud, need of Inter-Clouds, different topologies in Inter-Cloud and some of the research challenges in Inter-Cloud. The future cloud technologies are dependent on the Inter-Cloud and hence the research issues must be resolved.

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