# Intercloud: A Hype or Reality?

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The Intercloud, representing a logical evolution of the cloud paradigm, is fast gaining traction among industry players, cloud service providers and researchers. The idea of a global ecosystem of collaborating CSPs offering potentially infinite compute resources enabling seamless resource/service provisioning and consumption is alluring. This research paper examines the potential of the intercloud in enabling planetary scale services meeting both B2B and C2C use-case scenarios, while evaluating the technical and business challenges involved. We also present future perspectives and thoughts on evolution of the intercloud.

Keywords: intercloud system model, intercloud challenges, future trends in intercloud

## 1. INTRODUCTION

Compute resources/services provisioned and controlled by a single cloud service provider (CSP) are deemed essential to meet demands for guaranteed end-to-end quality, compliance and other reliability issues. It is envisaged that if a cloud system experiences an unexpected overload or a natural disaster, spare resources shall be required to cope with the situation. In order to guarantee the required service quality, such as service availability and performance it is intuitive to consider a mechanism for flexibly reassigning resources from other CSPs under an overarching intercloud system. In particular, private clouds built by small and medium enterprises (SMEs) are likely to collaborate with other clouds to effectively meet peak-load requirements, offer value-added services to their consumers or tap business opportunities in geographic areas where they do not have a presence. The intercloud appears a promising business model in this context.

According to Wikipedia [en.wikipedia.org ] "*The Intercloud scenario is based on the key concept that each single cloud does not have infinite physical resources or ubiquitous geographic footprint. If a cloud saturates the computational and storage resources of its infrastructure, or is requested to use resources in a geography where it has no footprint, it would still be able to satisfy such requests for service allocations sent from its clients*" .

Research in the intercloud domain has picked up pace with large industry players having a sizeable cloud presence embracing the intercloud concept. According to [Lawson ] "*Cisco's vision for intercloud is a "cloud of clouds" that encompasses both Cisco data centers and those of its partners*" . Ciscos vision is a perfect example of the federated intercloud (FI) [Villegas et al. 2012], which is a close-knit eco-system, built around a large CSP, a set of SMEs and a developer community with the standards driven by the large CSP. On the other hand is the concept of a non-federated intercloud or what we term the democratic intercloud (DI), which represents a more open-market approach to CSP-interactions built around a global standard. Both models shall be referred throughout the rest of the paper and a clear distinction made wherever required.

While the intercloud is an evolutionary business model, it does have its unique technical challenges. When actually considering cross-cloud interactions, it is challenging to satisfy demands for guaranteed end-to-end service quality (performance, availability, etc.) more so in flash crowd scenarios [Gupta et al. 2011]. Existing large CSPs like Amazon, Google etc. are also reportedly facing the problem of predicting geographic distribution of cloud users and providing QoS as per SLAs [Buyya et al. ]. According to [GICTF ] an intercloud must ensure following functions:

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(1) Guaranteed end-to-end quality for each service
(2) Guaranteed performance
(3) Guaranteed availability
(4) Convenience of service cooperation
(5) Service continuity
(6) Market transactions via brokers

These functions can be reliably achieved through adoption of common standards for cross-cloud communication, protocols for resource discovery and dynamic provisioning, resource/service orchestration, global trust and financial settlement mechanisms which are non-trivial to say the least. While technological solutions to the above issues do seem feasible in the near term, more complex business challenges need to be overcome before the intercloud can become a reality.

A number of surveys are available in the literature e.g. Grozev et al. [Grozev and Buyya 2014] provide taxonomies and classification in intercloud. They studied 20 projects in intercloud domain with focus on application brokering. Further Sotiriadis et al. [Sotiriadis et al. 2011a] review various techniques for scheduling in intercloud environment and evaluate current available meta-schedulers. Toosi et al. [Toosi et al. 2014] provide a survey of relevant aspects pertaining to cloud interoperability scenarios and architectures. The review papers available in literature have focused on evaluating specific aspects of the intercloud domain such as application brokering, meta-scheduling, interoperability etc. and survey existing state-of-the-art. This research paper provides a holistic overview of the domain and examines the issues involved from the perspective of individual stakeholders. It aims to explore the potential of the intercloud, while identifying the broad challenges that can stymie its adoption. It also examines current market trends and provides insights into its future evolution. The rest of the paper is organized as follows: Section 2 provides a detailed discussion of intercloud system model including use-cases and possible business models, while in Section 3 future trends are presented that could be significant in the evolution of intercloud. Section 4 provides conclusions of the paper and a concise summary of the intercloud domain.

## 2. SYSTEM MODEL

This section discusses the system models, organization and functionality of the intercloud as it exists in literature and practice, touching upon the business models it enables, summarizes the standardization efforts of various groups and the specialized services emerging for the intercloud. Before discussing the system models, it is useful to define the key actors in the intercloud:

(1) CSP: A CSP is the primary unit of the intercloud, providing the three classic cloud models IaaS, PaaS and SaaS, apart from implementing a standard interface for seamless integration with the intercloud. It is anticipated that the CSP will contribute a ratio of its resources to the intercloud; the ratio determined by the varying load from its traditional customers.
(2) SP: A Service Provider is a third-party utilizing the CSPs infrastructure to offer its own value-added services to potential consumers, creating a business model akin to the mobile application space. The SP is liable to pay a commission to the CSP for utilizing its resources and every time a user consumes its services.
(3) User: A user is the end-consumer of resources/services from the CSP/SP. Users can be potentially mobile and access services or consume resources from geographically diverse locations, expecting the same quality of service and a unified view of the intercloud via their primary CSP.
(4) Broker: The Broker is the glue that binds the intercloud and orchestrates in operations across CSPs, SPs and users. It works in conjunction with sub-modules to provide registration, authentication, cross-cloud orchestration, billing and settlement services. As per [DMTF ]'s The Open Cloud Standards Incubator a broker performs following functions:

- description of the cloud service in a template
- deployment of the cloud service into a cloud
- offering of the service to consumers
- consumer entrance into contracts for the offering
- provider operation and management of instances of the service
- removal of the service offering

Table 1: Benefits and Challenges for different stakeholder/actors in intercloud environment.

| | Benefits Foreseen | Challenges |
|---|---|---|
| For Users | Choice of CSPs | Highly abstracted, low control on data. |
| | Access to diverse services, choice of Service Providers | Authenticity of service providers and quality of services. |
| | Better service provisioning and response times based on geographical proximity. | Transparency in accounting |
| For Cloud Service Providers | Access to additional resources on demand. | Meeting intercloud resource commitments and performance guarantees along with those for traditional customers. |
| | Wide range of availability of datacenters with geographically reachability for users/customers request | Trust, security, workload migration issues with other CSPs |
| For Broker | Boosting intercloud revenues | Geographical-aware auto-scaling of services |
| | Self-sustaining eco-system of producers and consumers | Interfacing with large number of heterogeneous CSP brokers and tracking cross CSP transactions. |
| For Service Provider | Business benefits | SLA compliance across CSPs |
| | Greater access to a wide number of users | No governing body exists for legal cases |

We now introduce our definition of the intercloud as, "***An ecosystem of CSPs offering standardized mechanisms for resource discovery and consumption involving resource, data and service migration in a secure and seamless manner across different CSPs based on well-defined economic principles***".

A preliminary classification of the intercloud is presented in Figure 1.

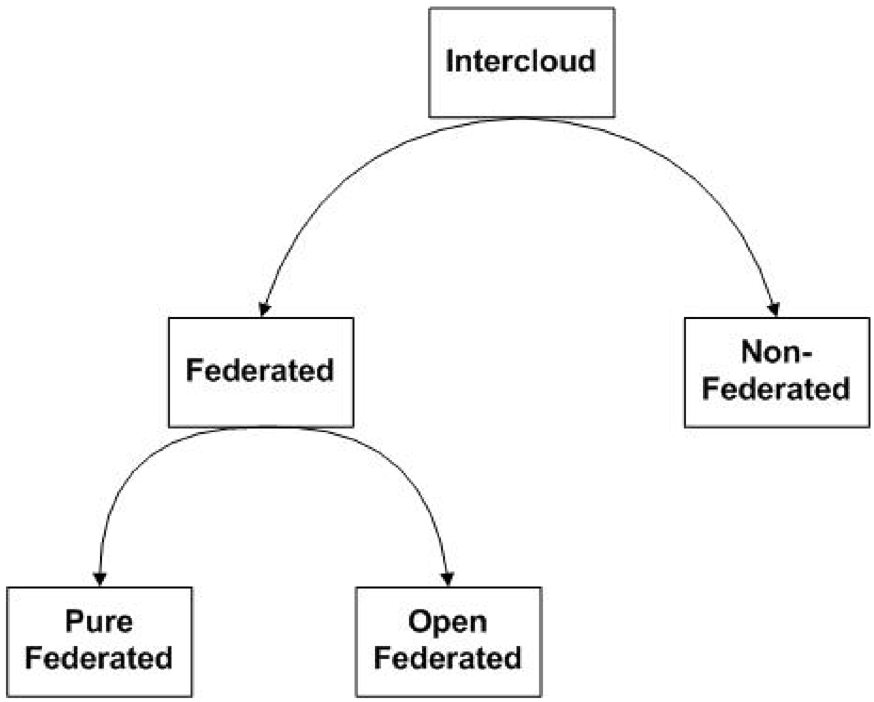


Figure1. Intercloud Classification

## 2.1 Federated Intercloud System

Authors in [Ferrer et al. 2012][Wetzel ][Sevcik and Wetzel ] describes an intercloud to be in a federation when few CSPs interconnect their services or infrastructures with common objective and predefined/dynamic policies. In [arjuna.com b] authors define a federation as "*an organizational structure where the parties concerned are autonomous but cooperate through agreement*". Being a part of a federation implies implementing common protocols and adopting a framework for:

(1) Resource Discovery
(2) Resource Requests
(3) Negotiation
(4) Resource Provisioning
(5) Resource Utilization
(6) Resource Release
(7) Accounting and Settlement

We provide a more comprehensive definition of the federated intercloud as "*An inter-connection of clouds following a set of common protocols, APIs and standards operating in a trusted environment with well established metering services*".
Trust is implicit within a federation and a central entity within the federation is expected to provide authentication services to all participants.
We provide a sub-classification of the federated intercloud as:

- Pure Federated: In this model, a large CSP acts as a resource/service reservoir and smaller players typically consume resources/services from the larger CSP with very little likelihood of offering any resources in return, in that sense it is akin to a client-server model for the

intercloud. Also, in such a system charges are typically pre-defined by the large CSP and when there is demand for resources, they are simply provisioned as per pre-defined agreements.
A common architecture for a pure federated model is a Hub and Spoke model as shown in Figure 2.

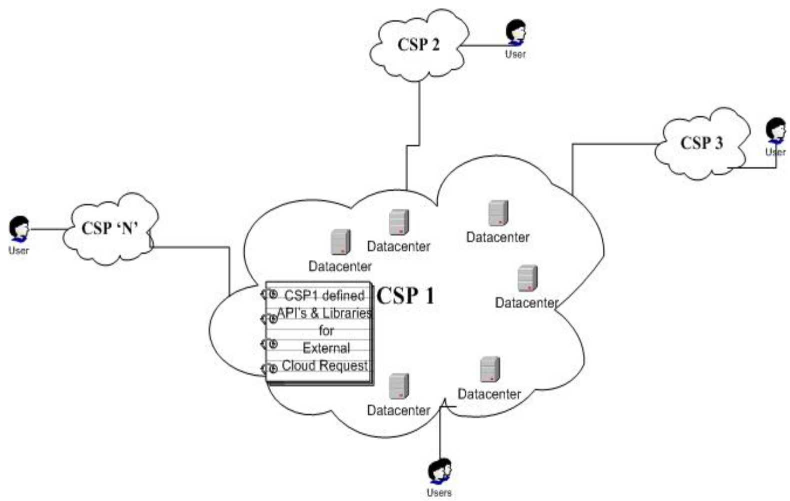


Figure. 2 The Hub and Spoke organization of a pure federated intercloud

- Open Federated: In this system, a resource discovery mechanism comes into play leading to determination of the best prospective CSP partner through negotiation. In this system every time resource sharing takes place, a new agreement is reached between participating CSPs. In that sense each CSP acts as both a resource provider and consumer. The model is depicted in Figure 3. The central entity facilitating negotiation and resource provisioning is not shown for brevity. Critics of the federated intercloud still count data lock-in as an area of concern as the data of the user circulates within a certain set of CSPs and user has a limited choice to provision resources from outside the community.

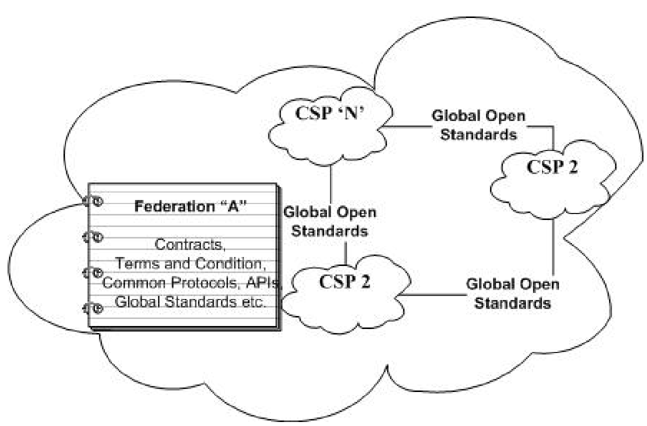


Figure 3. An example of an open federated intercloud.

## 2.2 Non-Federated or the Democratic Intercloud

In a democratic intercloud system all the CSPs interact with each other through peer-to-peer model [Gupta et al. 2011] or through a central hub/ exchange [Buyya et al. ] (Figure 4). The major difference between democratic intercloud and federated cloud is that, in a federation the CSPs are fixed, while in the democratic intercloud CSPs are free to join and leave as per requirement. A democratic intercloud is based on global open standards, setup. Moreover in democratic intercloud users have greater choice over service consumption and data migration due to performance, availability, cost issues etc.
This migration can be done in two ways:

- Automated transfer of data from one cloud to another (requires cross-CSP Migration) due to performance issues, resource constraints at the CSP (without user-intervention)
- Manual transfer initiated by the user due to deficient services.

We now define the democratic intercloud as "*An intercloud in which users can dynamically choose and consume services/resources from any participating SP or CSP and CSPs can interact with other based on a global open standard supporting dynamic negotiation*".
Intuitively, a democratic intercloud is more complex to envision with emphasis on trust management, authentication, non-repudiation, cross-cloud orchestration and metering services.

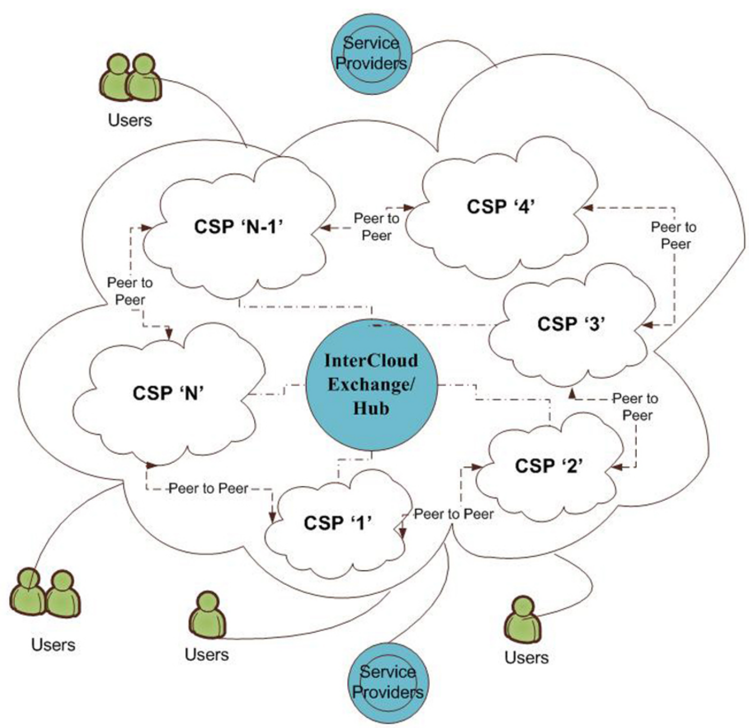


Figure 4. An example of a Democratic intercloud based on global open standards

While the democratic intercloud is in infancy stage, there are a broad spectrum of open source software like Eucalyptus [eucalyptus.com ], Openstack [openstack.org b] etc. which provide the interfaces, protocols, programming models, and deployment options of the proprietary clouds. These might provide a viable approach to create a democratic intercloud in future

Based on the above discussion we categorize intercloud operations based on the following parameters:

(1) Dynamic organization: The democratic intercloud supports both an *expansion process* to reflect new CSPs joining and the *contraction process* reflecting CSPs leaving [Brookbanks et al. 2011]. Some researchers also refer to expansion and contraction in terms of the resources availability after each CSP to CSP transaction within a federation. These processes happen under a set of procedures and standards agreed mutually by each of the participating CSP.

(2) Resource/Service Integration: Consider a case where CSPs or SPs can utilize services of other SPs or those deployed on other CSPs in order to offer value-added services to end users. Such kind of integration is termed as *vertical integration.* Example of vertical integration is present in [Stihler et al. 2012] where authors propose architecture to provide a platform for sharing services for mutual benefits residing in different CSPs. On the other hand different CSP-level resource collaborations fall under the purview of *horizontal integration.* Tusa and Celesti et al. [Celesti et al. 2010a]-[Tusa et al. 2011] presented a heterogeneous Cloud federation model, which they termed as "Horizontal Federation" for CLEVER [Tusa et al. 2010] (a virtualized cloud environment). They introduced a Cross-cloud federation manager component (CCFM) that is integrated into every Cloud provider while vertical service integrations are possible, they questions its practicality. Hassan et al. [Hassan et al. 2012] propose a game based distributed resource allocation scheme for a horizontal dynamic cloud federation.

(3) Architecture: [Grozev and Buyya 2014] provide the architectural classification for the intercloud, Other classifications such as those in [Toosi et al. 2014] classify the intercloud as *i) Centralized ii) Peer-to-Peer* and *iii) Hybrid:* In this type of system a central entity may perform the usual role while resource discovery/provisioning is done in a peer-to-peer manner.

Table 2, provides a summary of intercloud clasnifinatioc based on the discussios above.

Table 2: Classification of Intercloud

| Type of Intercloud | Dynamic Organization | Service Integration | Architecture |
|---|---|---|---|
| Pure Federated | None | None | Centralized |
| Open Federated | Contraction | Vertical and Horizontal | Centralized |
| Democratic | Expansion and Contraction | Vertical and Horizontal | Centralized, Peer-to-Peer and Hybrid |

## 2.3 Business Models

The intercloud enables several business models with the B2B model encompassing CSP to CSP transactions being the most obvious. To better understand the potential business models, stakeholder expectations from the intercloud are summarized in Table 3 below:

| Table 3: Stakeholder Expectations from Intercloud | |
|---|---|
| Intercloud Stakeholder | Expectations |
| Users/Consumers | (1) Optimization of cost, while achieving guaranteed performance<br>(2) Flexibility in service selection and consumption<br>(3) Service availability<br>(4) Service and performance analytics<br>(5) Hassle-free migration |
| Service Provider (SP) | (1) Maximization of revenue and profit<br>(2) Low cost of resources<br>(3) On-demand provisioning and scalability<br>(4) High-availability of resources<br>(5) Service visibility and access to geographically dispersed users<br>(6) CSP performance analytics<br>(7) Automated service management through service and user analytics |
| Cloud Service Provider (CSP) | (1) Guaranteed availability of other CSPs and access to additional resources as and when required<br>(2) Low cost of external resource-provisioning<br>(3) Fine-grained control over resource provisioning as per demand scenario.<br>(4) Clear accounting and settlement<br>(5) Performance guarantees for externally provisioned resources<br>(6) Maximize revenues through new business opportunities |
| Intercloud Broker | (1) Maximize revenues for CSPs and itself<br>(2) CSPs should fulfill their contractual obligations<br>(3) Large community of CSPs, SPs and users<br>(4) Geographic spread |

On the basis of above discussion the following business models emerge:

(1) Business to Business model (B2B): refers to commerce between two or moreCSPs or the intercloud broker and CSPs. The B2B model enables CSPs to:
- Cater to flash-crowd scenarios.
- Extend geographical reach through strategic provisioning
- Meet SLAs through dynamic provisioning of external resources

(2) Business to Consumer model (B2C or C2B): implies transactions between a user/SP and intercloud broker/CSP. The B2C or C2B model enables SPs to:
   - Provision resources from the intercloud to offer value-added services to end users
   - Offer planetary scale services by deploying cross-CSP services exploiting geographical distribution of the intercloud

(3) Consumer to Consumer model (C2C): covers transactions between users and SP (which is also a user from the intercloud perspective) fall under this category. Users can conceivably turn SPs and offer value-added services to other users. The C2C business model is the least explored in intercloud research, while we believe that the likelihood of the intercloud emerging as a global platform for deploying and consuming third-party services is high. The C2C model enables users to:
   - Access wide-range of services for better service selection
   - Optimize performance vs. cost
   - Access a vibrant marketplace
   - Easily deploy value-added services (cloud apps akin to mobile app)

Authors in [Kapoor et al. ] propose a global service-oriented ecosystem based on the intercloud supporting large-scale, geographically-aware and dynamic service deployment, optimization and consumption.

### 2.4 Economic Models

The intercloud is amenable to the implementation of the following economic models [Schonberg ][Saimi and Patel 2011]

- Commodity Market: CSPs and SPs price their resources dynamically on the basis of demand-supply ratio
- Posted Price Models: Advertisement of special offers to attract customers (spot pricing)
- Bargaining model: Negotiation to get best deal
- Tendering/ Contract-Net Model: participants (CSP, SP, users) agree upon a contract
- Auction Model: Auctioning of resources across CSPs
- Monopoly: when only one service provider/ cloud federation exist and price in non-negotiable.
- Bartering System Resources are provided in exchange of resources and no financial transaction takes place

These economic models are equally applicable to the traditional cloud or in fact any distributed economic system. In that sense, the intercloud does not give rise to any new economic models. The requirement in building a successful real world intercloud economic model includes:

- A globally accepted naming service for different elements of intercloud [Bernstein et al. 2009][Bernstein et al. 2011][Bernstein and Vij 2011]
- A credible system which tracks SLA compliance/violations and maintains accounts [arjuna.com a][29]
- A globally recognized Trust Authority [Bernstein and Vij ]
- A strong Auditing System [Bernstein and Vij ]
- Transparent and timely financial settlements [arjuna.com a]
- An arbitration mechanism [arjuna.com a][zimory.com ][spotcloud.com ]

### 2.5 Specialized Services

Recent Intercloud research and standardization efforts by several groups have led to the development of specialized services for facilitating intercloud functionality. This section details the work done on these specialized services for the intercloud.

(1) Security-as-a-Service
This entails an umbrella service providing services such as

- Trust management (between various intercloud entities)
Trust-as-a-Service (TaaS) is an intermediate service which maintains trust ratings for different CSPs, SPs and individual services and even users. Most of the work in Trust Management in intercloud system is based on establishing the credibility of users based on feedback analysis [T.Noor and Q.Sheng ]. This service plays a big role for selection of service or CSP based on its past behavior. Abawajy et al [Abawajy 2011] present a reputation management framework which aids a service consumer in assigning an appropriate weight to the feedback of different raters regarding a prospective service provider. Based on the framework a mechanism for controlling falsified feedback ratings from iteratively exerting trust level contamination is derived.
- Encryption services (secure communication)
Encryption-as-a-Service (EaaS), is based on a subscription model that allows cloud servicecustomers to take advantage of the security that encryption offers without having to install and use encryption on their own [Rouse b]. Marc et al [Mosch et al. 2014] present the $\pi$ -Cloud, a personal secure cloud that provides users with encryption services which can be used in an intercloud environment.
- Identity and access management (one user with fixed privileges can access whole intercloud)
Consider a case, when users registered with a particular CSP want to use or access another CSP, for reasons such as performance, availability of a particular service, or purely as backup, they would need to register or signup with the new CSP. A single sign-on system for the intercloud would solve this problem. Bernstein et al in [Bernstein and Vij ] present a trusted mediator model between elements in intercloud, providing identity and access management for users. Celesti et al [Celesti et al. 2010b] present identity and access management in federated cloud to manage the authentication needed among clouds for federation establishment.
- Secure workload migration (Porting workload/data from one cloud/service to other in a secure manner)
This service is useful in providing a secure connection between two different datacenters belonging to different CSPs. Ciscos Intercloud Fabric [cisco.com ] builds highly secure hybrid clouds by extending existing data centers to public clouds as needed, on demand, and with consistent network and security policies.This helps in creating highly secure connectivity across multiple clouds. They claim to provide secure workload migration by maintaining all network and security policies specific to that workload.

(2) Interoperability as a Service
Due to potential large-scale heterogeneity in intercloud environment, interoperability is a major issue to enable seamless cross-cloud interactions. Interoperability would enable two heterogeneous cloud environments to collaborate by sharing compute resources. The intercloud landscape consists of a diverse set of products and services that range from infrastructure services (IaaS), to specific software services (SaaS) to development and delivery platforms (PaaS), and many more. This variety of cloud services has led to proprietary architectures and technologies being used by vendors, increasing the risk of vendor lock-in for customers. In our view, the goal of cloud interoperability which is also to enable cloud users to avoid vendor lock-in allowing customers to make best use of multiple diverse cloud services is critical to the future success of the intercloud.
According to the Open Group [opengroup.org a] cloud computing system involves the porting of data, application, platform, and infrastructure components and the categories to consider are thus:

- Data Portability
- Application Portability

- Platform Portability
- Application Interoperability
- Platform Interoperability
- Management Interoperability
- Publication and Acquisition Interoperability
- Networking Support

A number of models have been developed or are under development by various working groups for interoperability. However the acceptability of these models varies widely. In table 4 we summarize various models in existence.

Table 4: Interoperability models in existence

| Model | IaaS | PaaS | SaaS | Data | Networking |
|---|---|---|---|---|---|
| Orchestration layer [Kostoska et al. ] | Yes | Yes | Yes | NA | NA |
| DMTF CIMI [dmtf.org b] | Yes | NA | NA | NA | NA |
| Adapters [Kostoska et al. ] | NA | NA | Yes | NA | NA |
| CMWG [dmtf.org b] | Yes | Yes | Yes | Yes | NA |
| Cisco Intercloud Fabric [cisco.com ] | NA | NA | NA | NA | Yes |

Table 5 below details the current work on standardization in intercloud interoperability.

Table 5: Interoperability Working Groups

| Standard/Protocol/Project Name | Aim | Defined/Developed |
|---|---|---|
| Open Virtualization Format (OVF) [dmtf.org c] | VM migration | Standard developed |
| Cloud Data Management Interface (CDMI) [snia.org ] | Create, retrieve, update and delete data elements from the cloud | Standard defined |
| Open Cloud Computing Interface (OCCI) [occi wg.org ] | API for all kinds of cloud computing management tasks | Protocol Defined |
| Topology and Orchestration Specification for Cloud Applications (TOSCA) [Lipton et al. ] | Enables the interoperable description of application and infrastructure cloud services, the relationships between parts of the service, and the operational behavior of these services (e.g., deploy, patch, shutdown) | Standard developed |
| Cloud Application Management for Platforms (CAMP) [Karmarkar and Pilz ] | defines an interoperable protocol that cloud implementers can use to package and deploy their applications | Standard developed |

| | | |
|---|---|---|
| Cloud Auditing Data Federation (CADF) [dmtf.org a] | Defines open standards for cloud auditing | Standard developed |
| LDAP [rackspace.com b], OpenID Connect [openid.net ] | Enable third party ID and Access Management functionality | Standard developed |
| US FIPS 140-2 [csrc.nist.gov ] | Specifies the security requirements to be satisfied by a cryptographic module utilized within a security system protecting sensitive information | Standard developed |

Cloud Foundry [cloudfoundry.org ] and Heroku [heroku.com ] are projects developed to provide interoperability in PaaS while OpenStack [openstack.org a] is operational on IaaS.

(3) Auditing as a Service
The goal of Cloud Audit is to provide a common interface and namespace that allows enterprises who are interested in streamlining theirauditprocesses (cloudor otherwise) as well ascloudcomputing providers to automate theAudit, Assertion, Assessment, and Assurance of their infrastructure, platform and services while allowing authorized consumers of their services to do likewise via an open, extensible and secure interface and methodology. Cloud Auditing [Rouse a] is a specification for the presentation of information about how a cloud computing service provider addresses control frameworks. The specification provides a standard way to present and share detailed, automated statistics about performance and security. Cloud Security Alliance (CSA) [cloudsecurityalliance.org ] and The Open Group (TOG) [opengroup.org b] are key players addressing this issue. CloudAudit [cloudaudit.org ] is a volunteer cross-industry effort from the best minds and talent in Cloud, networking, security, audit, assurance and architecture backgrounds.

(4) Meta-scheduling as a Service
Various classifications of schedulers are present which also includes in operating system, parallel and distributed computing etc. Among all these, the task of scheduling in meta-computing has proven to be the most complex [Sotiriadis et al. 2011b], mostly due to the involvement of a mixture of local resource management systems (LRMS) as an inter-cloud involves multiple LRMSs. Meta-Scheduling is an architectural strategy for managing and scheduling user services in virtualized dynamically inter-linked clouds. It handles message exchanging for the job distributions, the VM deployment in intercloud and the local resource management system details the management of the local cloud schedulers. It offers great flexibility by facilitating a lightweight resource management methodology while at the same time handling the heterogeneity of different clouds through advanced service level agreement coordination. The Inter-cloud Meta-scheduling (ICMS) Framework [Sotiriadis et al. 2013] uses meta-brokers that determine a middle-standing component for orchestrating the decision making process in order to select the most appropriate datacenter among collaborating clouds. The selection is based on heuristic performance criteria (e.g. the service execution time, latency, energy efficiency etc.). The key requirements for a meta-scheduler are identified in [Sotiriadis et al. 2011b] as:

- The management of unpredictability (dynamics)
- The heterogeneity of resources
- The geographically distribution of resources
- The variation of job requirements

- The compatibility on different SLAs
- The rescheduling support

## 3. FUTURE TRENDS IN INTERCLOUD

This section identifies the potential future directions in the intercloud domain

(1) Consolidation of the Federations
A question arises; do large CSPs really want the intercloud? Do they need to collaborate with other cloud vendors who are following different standards and protocols? Some of them might hesitate to adopt standards which would allow users to go elsewhere.
According to a Synergy research group survey [srgresearch.com ], the cloud market share in 2014 is shown in Fig. 4

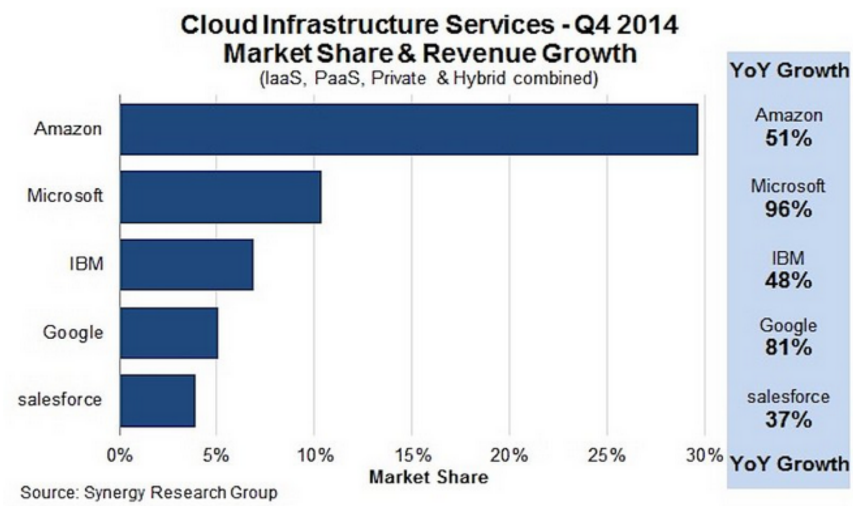


Fig. 4 Market share by Cloud Service Providers (Source: Synergy Research Group)

It is evident from the figure that the cloud landscape is dominated by a few big players. Dominant players seem to have very little motivation to engage with a broader eco-system when they already have a sustainable market-share. They might be inclined to grow their own partner eco-system leading to the emergence of a strong federal structure for the intercloud. A good example of this federalism is Ciscos approach to the intercloud. According to Cisco News Agency [newsroom.cisco.com ] Cisco recently added over 30 intercloud partners including Deutsche Telekom, BT, NTT DATA and Equinix, expanding its reach with 250 new data centers in 50 countries. Cisco is pushing for the use of open standards [rackspace.com a] to attract many players to its vision for the intercloud with itself at the center providing inter-cloud networking and value-added services. This trend continues in the work done in the interoperability and portability domains. Most of the standardization efforts have been directed at the IaaS layer although activity at the PaaS level is starting to accelerate. We expect a few standards and protocols shall survive and become pervasive. Openstack [openstack.org b] is following a different approach by providing an open governance model, being successful in attracting a broad supporting ecosystem. It might result in the creation of a de facto standard by building significant industry momentum. Similar is the case with hypervisors such as Hyper-V [technet.microsoft.com ] developed by Microsoft, ESXi [vmware.com ] created by VMware and XenServer [xenserver.org ] from Citrix are the biggest players in the market. ESX(i) is a component of VMware vSphereand according to a survey [starwind-software.com ] 76% of organizations choose VMware hypervisor. It is targeted mostly at the large enterprises.However Hyper-V is used extensively by SMB companies. This again shows only few hypervisor vendors are controlling the market. We foresee that the intercloud will thrive as "*Business Alliances*" centered around dominant players with deep pockets and not as a "*democratized model*" . Each business alliance or federation will attract small cloud vendors which will follow their standards and protocols. This scenario can be related to todays "Andriod" and "IOS" market share which according to [idc.com ]accounted for 96.3% of all smart phone shipments in 2014. Similarly in intercloud a pure democratic model is far from reality and we envisage that only two or three federations will survive and all the new vendors will align with these federations with a limited set of hypervisors in every cloud. For interaction between clouds a pre-defined common standard would be followed by each cloud within a federation. These standards would involve a set of APIs and protocols which would be proprietary of the federation only. The democratic intercloud based on open standards seems destined to be limited to academic research and some showcase projects.

(2) The rise of the intelligent brokers
As stated earlier, brokers are the glue which bind the intercloud. The broker links to multiple cloud services and understands the architecture of various hypervisors which is required to provide various benefits like performance management, optimal service deployment and geographically-aware auto-scaling, optimal service selection and consumption by the end-user in a seamless manner etc. Brokers mentioned in [Kapoor et al. ] monitor different services of same type and direct the users on the basis of its performance, location, past experience, reliability etc. A detail listing of brokers is displayed in [talkincloud.com ] performing multiple tasks towards intercloud.
Designing brokers which can maximize benefits for all stakeholders, which sometimes have conflicting interests, while operating across a huge geographic footprint is non-trivial to say the least. Such a broker may be required to:
(a) Interface with large number of heterogeneous CSPs and their corresponding hypervisors, SPs and end-users
(b) Implement a real-time performance management and analytics framework to make optimal decisions
(c) Track past performance of CSP resources and deployed services
(d) Maintain reputation ratings of all stakeholders and services
(e) Perform real-time load-balancing, dynamic deployments, service replication and migration in response to diverse geographical requests
(f) Ensure SLA-compliance and track violations across potentially billions of interactions /transactions
(g) Perform predictive analytics based on historical analysis to deliver high-performance
(h) Allow end-users a customized service selection and consumption mechanism
(i) Ensure transparency, fairness and prompt financial settlements among stakeholders
(j) Provide fool-proof security in a privacy preserving manner
The next-generation of intercloud cloud brokers may rewrite the way IT services are delivered provided the required standards are in place and the technical challenges in designing a planetary-scale broker addressed.

(3) P2P and the intercloud
We believe that the potential of P2P model remains underutilized in the intercloud. While Hybrid models have been proposed in literature combining elements of centralized and P2P models, not much work has been done in this domain. The P2P model is a natural fit to requirements of large scale distributed interactions between CSPs, SPs and users, where a purely central model might lead to issues such as performance bottlenecks and single-point-of-failure. Intercloud functionality such as resource/service discovery and negotiation can be easily accomplished via P2P interactions between participating stakeholders and then the centralized agency notified for tracking and financial settlement. Moreover, the centralized agency can expose APIs for stakeholders to access trust ratings of stakeholders enabling

decentralized interactions and making P2P interactions viable. Researchers in [Gupta et al. 2011] describe non-federated model of the intercloud based on P2P interactions without any central agency, while chord based resource mechanism based on P2P brokers is discussed in [Kapoor et al. 2013]. It is perceivable that P2P interactions shall play a central role in the realization of a truly global intercloud.

## 4. CONCLUSION

This research paper presents an overview of the intercloud domain in terms of future potential and adoption issues including technical and business challenges. It also proposes two categories of system models for the intercloud i.e. federated and democratic with a discussion around niche-services which have emerged to meet specific intercloud functional requirements. Finally, a forecast on the possible evolution of the intercloud is presented.

We envisage that going forward the intercloud market (specifically the federated cloud) shall consolidate and revolve around 2-3 big CSPs such as Google, Amazon and Microsoft with each creating partner ecosystems powered by developer communities, connectivity and bridge services, service deployment and management automation and of course well-defined economic models for monetization of services offered. In that sense the intercloud especially the democratic model enabling CSP to CSP collaboration may never take off except for niche application segments as existing large CSPs expand further to meet geographically dispersed customer requirements effectively.

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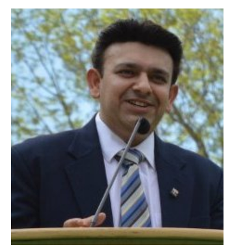

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