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Towards a Holistic Multi-Cloud Brokerage System: Taxonomy, Survey and Future Directions

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***Abstract*— The use of Cloud Computing can increase the service efficiency and Service Level Agreement for cloud users by linking them to the appropriate cloud service provider using cloud services brokerage paradigm. Cloud services brokerage represents a new promising layer to be added to cloud computing network, which manages the use, performance and delivery of cloud services; and negotiates relationships between cloud services providers and cloud services consumers. The work presented in this paper studies the research related to cloud service brokerage systems along with the weaknesses and drawbacks associated with each of these systems, with a particular focus on the multi-cloud-based services environment. In addition, the paper will end up with a proposed multi-cloud framework that overcomes the weaknesses of the other listed cloud brokers. The new framework aims at finding the appropriate data centre in terms of energy efficiency, QoS, and SLA. Moreover, it highlights the entire key features that must be available in the multi-cloud-based brokerage systems.**

Keywords— Cloud Computing, Broker, Service Provider, Aggregation, Energy Efficiency.

I. INTRODUCTION

Cloud Computing (CC) has recently emerged as a new computing paradigm for outsourcing scalable applications and virtual hardware infrastructure (i.e. computing units) that can be provisioned and released with minimal management from what so-called cloud data centres. The cloud data centres can be accessed at anytime from anywhere in the world via the users' heterogeneous machines that should be connected to the Internet [1]. Therefore, it represents a shift in the geography of computation, where the cloud resources' physical location is not a barrier whatsoever for the users and providers. In other words, the users do not need to worry about where the resources/services are based and/or how they can be accessed and used from one hand. From the other hand, the providers can offer their services/resources to anyone in the globe. In fact, the cloud providers manage, control and monitor the cloud data centres to ensure that the required services/resources conform and guarantee the Service Level Agreement (SLA) contract signed with their customers. The primary economic goal is to make these computational services available at users' needs anytime based on "pay-as-you-go" billing/pricing model.

Pay-per-use was the spark for the cloud users to start heavily using, and relying on, these kinds of services; which allowed them to easily and dynamically scale their services/resources up/down based on the available resources and SLA agreement with cloud providers. This enormous/rapid growth in cloud services/resources and cloud users have led to a significant increase in the cloud providers and the cloud data centres. Thus, this issue have led to significant increases in network traffic and the associated energy consumed by the huge infrastructure (e.g. extra servers, switches) required responding quickly and effectively to users requests. Consequently, the cloud users are now facing a very challenging and critical task in selecting the appropriate cloud offers and resources that fit their requirements. In addition, if the required recourses cannot be provided by one cloud data centre, the provider will not be able to guarantee the Quality of Services (QoS) and SLAs. One approach that can help to solve this situation is by enabling the users and their applications to be scaled out across multiple cloud data centres [2].

However, there are three main barriers hindered the implementation and success of the above solution: (i) the lack of the computing standards that must to be utilised and used by these heterogeneous data centres platforms obstructed the communication, cooperation and coordination among these providers, which resulted in "vendor lock-in" to one data centre; (ii) This has in turn made the customer dependent totally on using services and resources from one cloud provider, which is known as a "customer lock-in", or otherwise there will be a substantial switching cost to change the provider, which is against the cloud computing ambition; (iii) The increasing number of the used data centres in multi-cloud requires a significant portion of energy to send, receive, and process the users' jobs, taking into account that each data centre consumes as much energy as 25000 households [3].

Therefore, the only practical way to overcome the above issues/barriers is by using an intermediate cloud service broker [4]. According to NIST [5] cloud broker "*is an entity that manages the use, performance and delivery of cloud services and negotiates relationships between cloud providers and cloud consumers*". This definition is very broad and overlaps with the cloud service provider role itself. However, NIST was very specific in identifying the key tasks of the cloud broker as:

- Services Intermediation: improving specific services by creating value-added services to the consumers.
- Services Aggregation: integrating and combining services into one or more new services.
- Service Arbitrage: choosing the services from multiple providers.

However, the above three tasks have not been practically developed yet, nor showed any interest in the energy efficient multi-cloud environment. In addition, the Research and Markets in [6] highlighted the expected cloud brokerage market growth, at a Compound Annual Growth Rate (CAGR), of 45% between 2014-2018. By taking into consideration the expected growth and the problems shown above, Gartner and

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NIST in [7] and [5], respectively, have identified the cloud broker as a key concern for future cloud computing technology research and development. The following sections studies the literature in more details, and highlights the limitations and shortages with the existing cloud brokers systems.

II. LITERATURE REVIEW

A. *Multi-Cloud Broker Architecture*

InterCloud [8] is a resource management setting aiming to connect different data centres with each other in order to dynamically coordinate load distribution among various Clouds based on the topology shown in Fig. 1.

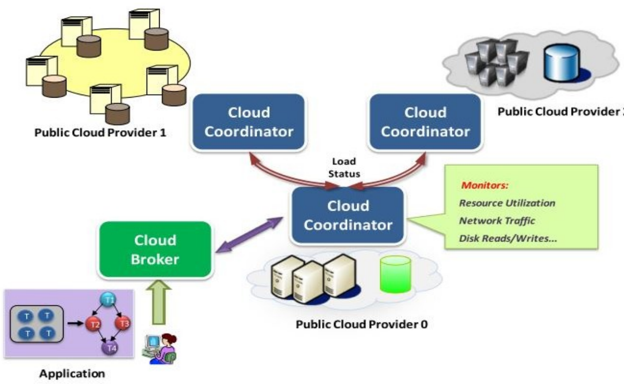

Fig. 1. Network Topology of Federated Data Centres.

In this approach, application can be scaled out among different data centres that geographically dispersed around the world. Mostly, the resources are close to the users in order to make the process more efficient. However, this study do not consider the energy efficiency, also as the application scales among different geographically areas, there is a need for an energy conception matrix.

Another broker system is proposed by Yang et al [9], the aim is to solve the problem of transferring bulk data in cloud computing, which cause the problem of reservation and resource utilization. In this system, the broker job is to reserve and select combined resources and assigns the best to the users. To select the best matched combined resources in a dynamic way they define a new algorithm within the broker. Moreover, based on user's requirement, the broker is responsible of submitting and accepting the request after checking the available data resource and network status. However, Scheduling can be the right way here; it can help to allocate the user's requests to the right available resources and can be built within the integration model. Fig. 2 shows the architecture of this broker.

Gatziu et al [10] designed a new cloud broker system which can manage and govern the clouds in business modules. The broker here can react to the changes in the business process by scaling up or down the configurations or choosing new provider.

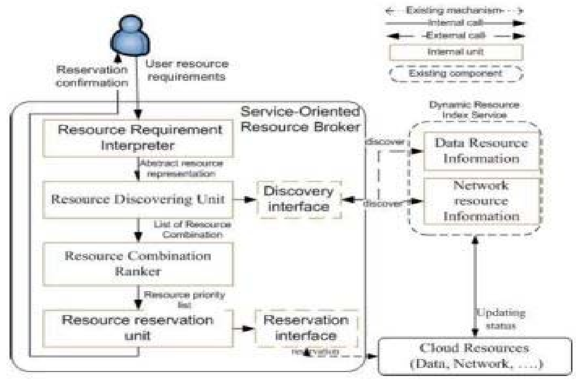

Fig. 2. Service-Oriented Resource Broker.

This system performs different roles such as service selecting and integrating, understanding business process and analysing and detecting non-explicit changes. However, an interface for such a system is needed to enable the consumers to select the suitable services. Fig. 3 explains how this broker handles changes.

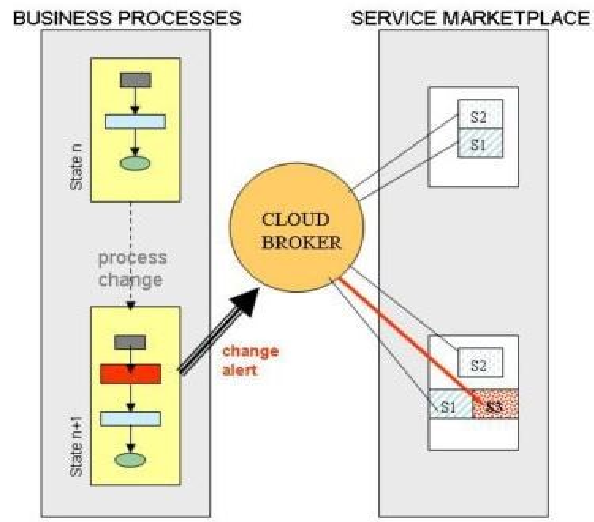

Fig. 3. How Changes Are Handled By Cloud Broker.

Usha et al [11] proposed a broker framework architecture that can chose and select the best services providers among many, based on the analyses of the QoS requirements. They use Pareto analysis to decide the suitable cloud provider based on two QoS parameters response time and throughput as shown in Fig. 4. In this system, an algorithm has been defined to obtain users QoS requirements along with the parameters that are suitable for them. They concluded that this system intended to select the appropriate cloud services providers with the given criteria to share its resources. The cost of the services should be considered here. Yet, they restricted their study only on two QoS parameters response time and throughput.

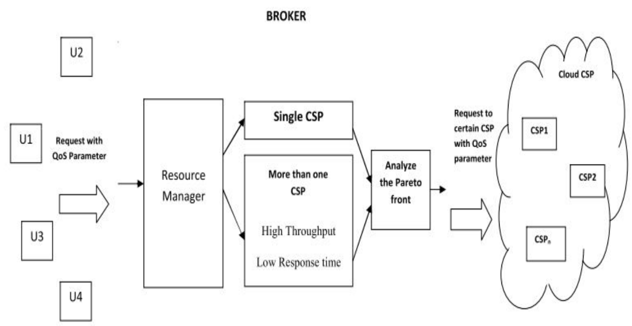

Fig. 4. QoS Parameters in the Broker.

Smart cloud broker [12] is a software tools, which allow consumers to choose from different Infrastructure as a Service (IaaS) clouds and buy the one that meets their business needs and technical requirements. Moreover, it allows the consumers to compare the performance of different (IaaS) offerings. In this study, the authors focused on benchmarking as a single way to measure and verify the performance of the computing resources. Specifically, they conducted an application stack benchmarking approach to measure the actual performance of the application. This Broker can enable the service interoperability by developing and using the services in multiple clouds through a unified interface. However, in this system there is no part that can take care of energy efficiency consumed by the datacentre. Moreover, this architecture cannot assure the best matching service provider to the user.

Hamze et al [13] introduced a framework for self-establishing an end-to-end service level agreement between multiple cloud service providers and Cloud User. They focused on quality of service QS for infrastructure as a service (IaaS) and network as a service (NaaS) services. This inter-cloud broker works as an intermediate layer between the cloud service users (CSU) and cloud service providers (CSP) to help establishing the service level required by users to secure the integration process [14, 15]. In addition, they included the network service providers (NSP)) in the architecture in order to provide bandwidth on demands. Hence, CSP job is to provide both IaaS and NaaS services as shown in Fig. 5. However, this study does not show the way in which the broker monitor SLAs at all levels in multiple clouds.

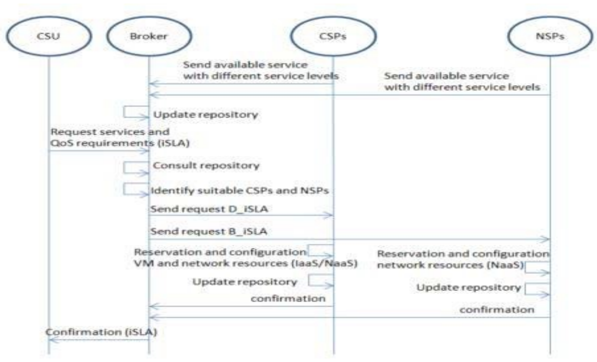

Fig. 5. Cloud Broker Scenario.

Another work was introduced by Han et al [16] to develop a Cloud service framework for the Cloud market using recommender system (RS) which can help consumers to choose the suitable services from multiple cloud providers to match their requirements. To assist user's decisions, they use network Quality of Services QoS and service rank analysis of resources provided by Cloud providers. QoS take account of execution time, average execution time, response time, average response time etc. while the Service-rank considers the quality of

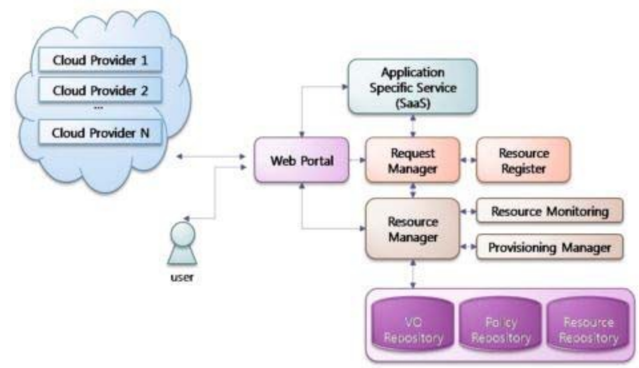

Fig. 6. Cloud Resource Recommendation System.

virtualization hypervisors used by many different platforms. However, their framework is limited to address only the issues related to IaaS. Moreover, the study does not consider the energy consumption in such a multi-cloud environment to minimise the energy. Fig. 6 shows the architecture of the cloud resource recommendation system.

B. *Cloud Energy Efficiency*

The authors in [17] presented a new routing strategy to reduce the cloud network CO_2 emissions by dynamically routing/transferring the on-demand energy-intensive data processing requests, via IP-over-WDM networks, to data centres that are powered primarily by renewable energy sources such as wind and solar. However, it can be clearly seen that this solution helps in reducing the CO_2 emissions at data centres level only.

Another complementary research shown in [18] studied the energy consumption in both: the data centre and in data transportation to data centres. They have used optical networks and virtualisation in IP-over-WDM architecture to save the power in the data centres and achieve green communication. Two models are proposed in that research:

- Delay-Minimized Provisioning (DeMiP), which aims to select the nearest data centre based on pre-computed distances between nodes in virtual topology, and then the virtual links from the virtual topology are mapped on physical topology by utilising Dijkstras algorithm for shortest path;
- The Power-Minimized Provisioning (PoMiP), which focuses on IP routers as power consumers in the transport network and aim to minimise the utilisation

of the IP router ports. It selects the virtual link with low-power.

An interesting study in [19] presents a cloud energy management system by using a sensor management function and a VM allocation tool. These sensors are deployed across multiple data centres and can be accessed and monitored via a unified interface for those multiple data centres. The collected data will be used and analysed via the sensor management function through four main phases: Monitoring, Calculation, Analysis, and Action. The study achieved 30% energy reduction at data centres level.

In [20] they found that the Cloud providers can reduce the total energy consumption by using Virtual Machines (VM) and server consolidation. This new way of virtualisation can assign tasks by multiple virtual machines (VMs) to a single physical server. The study focuses on the VM controller to determine the requirements of the VMs and to be placed on the servers. The framework uses a unique optimization procedure of the VM controller to minimize energy cost in active servers within the data centre. By enabling consolidation, some of the servers in the data centre will be turned off or put into sleep mode. The study shows that the current servers use 50% of the power in idle mode

III. Limitations Of Existing Cloud Brokers

As is mentioned above, the broker should act as a bridge between the customers and the providers in order to enable them to talk to each other and negotiate a certain service(s) using a standard language. The existing, and well known, cloud brokers suffer from the following issues:

- They are implemented as data center platform dependent systems, and thus they are not sufficient to work with the other heterogeneous platforms and infrastructure, which is an essential feature for the multi-cloud service broker.
- There is no standard multi-cloud service broker reference model and architecture that should have been utilized by the available brokers.
- There is no a standard multi-cloud services search and integration engine that could work both horizontally among available data centers in multi-cloud context, and vertically among the cloud services layers (i.e. IaaS, PaaS, and SaaS), to help the users in finding the best-fit services, according to their SLA, and integrate them to serve their needs.
- There is no standard multi-cloud based services/resources modelling and description language that can be exploited by the cloud services providers to describe their services and offers to the brokers; which can also be used by the brokers to introduce and offer the available services to their users.
- The lack of a quality assurance and services optimisation framework, to evaluate the SLAs, detect the failures and protect the system.
- Yet, there is no cloud broker model to consider the energy consumption in such a multi-cloud environment to minimise the energy that is consumed by cloud parties in sending and receiving data and services.
- The lack of service management and automation tool that enables customers to create their services portfolio based on legal, financial and operational criteria, and thus they can scale up/down/out.

Table 1: a comparison between the existing frameworks.

Models	Factors			
	Energy Efficient Data Centre	**Data transporting Energy Efficiency**	**Quality of Services (QoS)**	**Service level Agreement (SLA)**
Federated Inter-cloud**[8]**	✗	✗	✓	✗
Service-Oriented Broker**[9]**	✗	✗	✓	✗
Event-Based cloud broker**[10]**	✗	✗	✓	✓
Efficient QoS cloud broker**[11]**	✗	✗	✓	✓
Smart Broker**[12]**	✗	✗	✗	✓
Autonomic Brokerage Service**[13]**	✗	✗	✗	✗
Recommendation System**[16]**	✗	✗	✓	✗

IV. Proposed Model

The proposed model seeks to solve the energy consumption in the broker systems, and provide a high Quality of Services (QoS) based on the Service Level Agreement (SLA). It will be designed to find the appropriate data center in terms of energy efficiency and QoS in multi-cloud environments. Therefore, energy efficient routing solution for cloud computing is required to ensure the environmental sustainability. Since the data centres energy consumption has seen great deal of interest and work in the last years, however, cloud computing network energy consumption is still in its infancy and requires further research and development to be fully achieved. There are two main pillars for energy consumed at cloud computing that should be dealt with efficiently and equally to achieve the full green cloud computing network: (i) the amount of energy consumed at the data center and (ii) the amount of energy consumed on transporting the data between the user and the cloud data center. Since the current state-of-the-art solutions focus primarily on improving the energy consumed at the data centers. We seek of this work to propose and evaluate a high-end routing algorithm to fill in the gap. It should acts as an intermediary bridge for directing the user's requests to the green data centers based primarily on using the most energy efficient route to achieve the full green cloud computing network ambition while making sure the user's requirements, e.g. response time, are met. To accomplish this aim, we need to model the cloud computing network and its power consumption as a basis to compute the energy required by the cloud network before and after using the algorithm proposed in [21,22]. We will then formalize the interconnection between the cloud user and a green data center, by using a situation calculus model to define the logical state of the network. Once the interconnection is established and formalized, we then start calculating the time and energy required for both transportation and computation. Linear programming approach will be used thereafter to model the proposed algorithm, which will finally be evaluated against the well-known shortest path routing policy.

A. Basics and Rules

Since most of researches were focused on how to achieve green data centres, this has helped us using the following assumption with the proposed brokerage system:

There are n *green data centres to which a user machine i can be connected to through the Internet, to accomplish a certain task.*

So, one of these available data centres will be used, by which it must be accessible via the selected most energy efficient route. In other words, amongst multiple routes to a green data centre, the most energy efficient route will be chosen by the new framework. Modelling power consumption of the cloud network is an essential part of this work. One of the most widely accepted methods for modelling the power consumption of massively distributed network infrastructure, such as cloud network, is based on the telecommunications equipment inventory statistics and their historical sales figures (i.e. once the quantity and type of equipment in the network are known, the energy consumption of these equipment can be easily calculated). However, this approach alone can not predict/ show the actual network architecture and structure. Once the network architecture is known, then required components can be identified and energy consumption can be calculated accordingly. Telecommunications network-based model is an essential approach to be used side-to-side with the above one to fill in the gap. In this approach, the network is partitioned into a number of main parts: access network, metro/edge network, core network, data centre and IPTV web services network. The network model presented in Fig. 7, is a first-cut of such a massively distributed network, and as such it does not include much of the fine details of the network true structure and topology. However, it does show the main network architecture and the required components, which are needed for the energy consumption calculation purposes. The energy consumption of the network is calculated using with manufacturers data on equipment quantity and energy consumption for a range of typical types of equipment for each part of the network. Using a combination of the above two approaches help in calculating the power consumption of the entire network using real world network infrastructure components; and it also helps in predicting the growth in power consumption depends on the network architecture, and the equipment inventory statistics and their historical sales figures provided by the manufacturers. As shown in Table 2, the proposed model can achieve energy efficiency, QoS and SLA.

Table 2: the proposed broker Factors and Features

Models	**Factors**			
	Energy Efficient Data Centre	Data transporting Energy Efficiency	Quality of Services (QoS)	Service level Agreement (SLA)
Proposed model	✓	✓	✓	✓

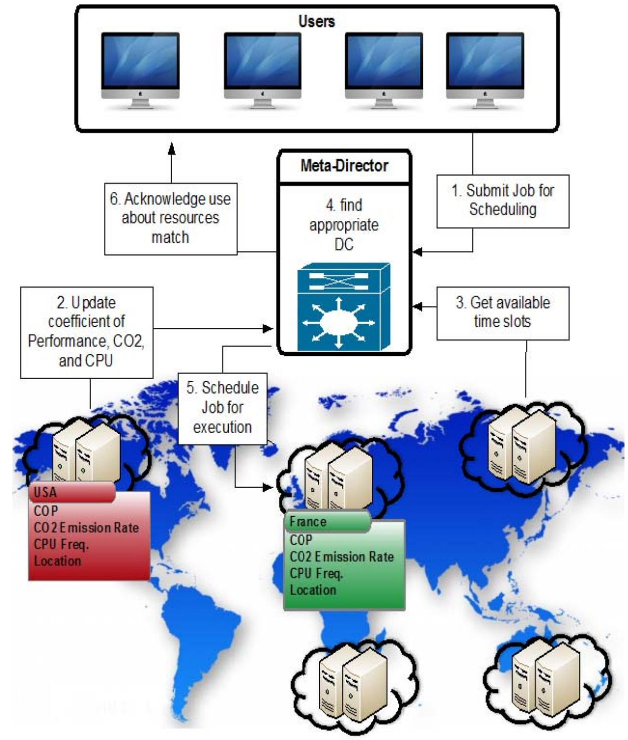

Fig. 7. Proposed Broker model

V. Conclusion and Future Work

The paper presents the research related to cloud service brokerage systems along with their weaknesses and drawbacks. It highlights the entire key features that must be available in the multi-cloud-based brokerage systems. Yet, most of the brokers are not sufficient to work with the other heterogeneous platforms and infrastructure, which is an essential feature for the multi-cloud service broker. Furthermore, since most of researches yet have not consider the energy consumption in such a multi-cloud environment in order to minimise the energy which is consumed by cloud parties in sending and receiving. We have proposed a model that seeks to solve the energy consumption in the broker systems, and provide a high Quality of Services (QoS) based on the Service Level Agreement (SLA). The future work should focus on designing and developing a novel software-defined broker framework for multi-cloud based services selection and delivery. This necessitates understanding how the cloud services are described and behaved on different data centers platforms and infrastructures to enable the broker to choose and priorities these services based on the users' needs.

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