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Highlights

- Discussed cloud broker and its need in interconnected cloud computing environments
- Existing architectures and frameworks of Cloud Brokering with respect to interconnected cloud computing environment are reviewed
- Presented taxonomy of cloud brokering techniques
- Analyzed strengths and weakness/limitations of cloud brokering techniques based on taxonomy and presented comparative analysis on performance metrics
- Discussed challenges and identified future research trends in cloud brokering

Brokering in Interconnected Cloud Computing Environments: A Survey

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Abstract

Cloud computing provides computing platforms and facilitates to optimize utilization of infrastructure resources, reduces deployment time and increases flexibility. The popularity of cloud computing led to development of interconnected cloud computing environments(ICCE) such as hybrid cloud, inter-cloud, multi-cloud, and federated cloud, enabling the possibilities to share resources among individual clouds. However, individual proprietary technologies and access interfaces employed by cloud service providers made it difficult to share resources. Interoperability and portability are two of the major challenges to be addressee to ensure seamless access and sharing of resources and services.

Many cloud service providers have similar service offerings but different access patterns. It is difficult and time consuming for a cloud user to select an appropriate cloud service as per the applications requirement. Cloud user has

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to gather information from various cloud service providers and analyze them. Cloud broker has been proposed to address the challenge of cloud users to get best out of cloud provider. Cloud broker is an entity which works as an independent third party between cloud users and cloud providers. Cloud broker negotiates with several cloud providers as per users requirements and tries to select the best services. Cloud broker coordinates the sharing of resources and provides interoperability and portability with other cloud providers.

In this paper, a comprehensive survey of cloud brokering in interconnected cloud computing environments has been provided. The need and importance of cloud broker has been discussed. The existing architectures and frameworks of Cloud Brokering are reviewed. A comprehensive literature survey of various Cloud Brokering techniques is presented. A taxonomy of Cloud Brokering techniques has been presented and analyzed on the basis of their strengths and weaknesses/limitations. The taxonomy includes pricing, multi-criteria, quality of services, optimization and trust techniques. The techniques are analyzed on various performance metrics. Research challenges and open problems are identified from reviewed techniques. A model for cloud broker is proposed to address identified challenges. We hope that our work will enable researchers to launch and dive deep into Cloud Brokering challenges in interconnected cloud computing environments.

Keywords: `Cloud Computing, Cloud Broker, Inter-cloud, Federated Cloud, Multi-Cloud, Hybrid Cloud`

1. Introduction

Cloud Computing [1, 2, 3, 4] exploits Internet and Virtualization technologies in order to provide computing resources in virtualized from which are available on demand, reconfigurable, rapidly provisioned and ubiquitously accessible [5] through minimum or zero management efforts. Computing resources such as computer networks, applications & storage servers, various applications are delivered as different services such as Infrastructure as a Service(IaaS), Platform as a Service(PaaS), Software as a Service(SaaS). The on demand availability of computing resources empowers cloud users to avoid unnecessary infrastructure investment and subsequently up-gradation & maintenance cost.

Service Oriented Architecture, Grid Computing [6], Cluster Computing [7] and Virtualization [8] technologies have preceded and enabled Cloud Computing. Container, a novel virtualization technique, provides improved utilization of cloud resources [9] by hiding low level hardware complexities. Docker packages applications and their dependencies in a single container [10]. Orchestration services are required to run multiple containers. Kubernetes [11], a container orchestrator, manages and deploys containers across cloud platforms and scales horizontally [9]. Cloud Computing can provide platform to run massively parallel applications using graphics processing unit(GPU) and tensor processing unit(TPU). It also provides storage as a service [12] using solid state drives(SSDs) for storing large databases. Various cloud providers such as Google, Azure and Amazon use TPUs, GPUs and SSDs for enhancing processing power for various applications such as machine learning.

In spite of tremendous development of Cloud Computing, it still suffers from the lack of standardization [13]. In the lack of standards, every Cloud Service Provider(CSP) offers his services to Cloud Service Users (CSUs) through his own proprietary access interfaces and methods. Involvement of various technologies as listed above and different access patterns of cloud services have created a huge heterogeneous environment for Cloud Computing. Every CSU has to tailor his applications as per CSPs requirements in order to utilize their services. If a CSU later decides to change CSP then it has to again change his applications as per new CSP's requirement. This becomes a time consuming and costly process which leads CSU to stuck with one CSP. It is called vendor lock-in [14] [15].

In order to provide computing facilities as utility, CSPs have to work in interconnect cloud computing environment (ICCE) [13]. Hybrid Cloud, Inter-Cloud, Federated Cloud, and Multi Cloud are various Interconnected cloud computing environments. These interconnected cloud computing environments are considered as independent and different cloud environment.

Hybrid cloud also known as cloud bursting is an infrastructure in which one private and one or more public clouds are incorporated. It is used when local private cloud cannot fulfill computing power for short duration or a sudden demand arises for additional computing power.

Inter-cloud was introduced by CISCO as "cloud of clouds" [16]. The Global Inter-cloud Technology Forum (GICTF), a Japanese organization defines Inter-Cloud as *a cloud model that, for the purpose of guaranteeing service quality, such as the performance and availability of each service, allows on-demand reassignment of resources and transfer of workload through a interworking of cloud systems of different cloud providers based on coordination of each consumers requirements for service quality with each providers SLA and use of standard interfaces.*

Federated Cloud or Cloud Federation is a cloud scenario in which group of CSPs participate and share their resources to improve services of federation. Federated Cloud is defined by [17] as *Cloud Federation comprises services from different providers aggregated in a single pool supporting three basic interoperability features - resource migration, resource redundancy, and combination of complementary resources resp. services.* EGI federated cloud [18] provides IaaS services. It is an initiative of European Intergovernmental Research Organizations, created by academic private clouds, to provide computing infrastructure.

Multi Cloud is created by more than one public or private clouds. Multi Cloud is defined by [19] as *Multi-cloud strategy is the concomitant use of two or more cloud services to minimize the risk of widespread data loss or downtime due to a localized component failure in a cloud computing environment.*

The offered services and infrastructure facilities in ICCE should be portable and inter-operable. Several solutions such as standard interfaces, protocols, formats, and architectural components that facilitate collaboration among cloud providers are proposed to address interoperability and portability issues. Cloud brokering is one of them. A cloud broker consolidates services from various CSPs and present them through a single interface to CSUs [20]. Cloud broker helps to mitigate vendor lock-in, because many cloud providers offer services that are not available in public or private clouds [13].

Some surveys [13],[21],[22],[23],[24] were previously published. These survey have discussed various ICCEs, architecture classifications, definitions, taxonomies and challenges. This paper presents survey on brokering techniques. It has been found to the best of our knowledge, this is the first paper which is going to provide detailed taxonomy of cloud brokering techniques. Our major contributions through this paper are as follows.

- A taxonomy of cloud brokering techniques on pricing, multi-criteria, optimization, quality of service and trust has been provided
- Rigorous works on pricing, multi-criteria, optimization, quality of service and trust are given
- Each taxonomy category is compared on different performance metrics with their strength and weaknesses/limitations
- The existing frameworks are reviewed and new cloud broker model is proposed
- Specific research gaps are identified and major challenges and open problems in Cloud Brokering are discussed

This paper is summarized as follows: Related surveys and cloud broker is discussed in Section 2. Section 3 describes existing cloud brokering frameworks and proposed model. Cloud brokering techniques are discussed in Section 4. Research challenges and open problems are discussed in Section 5. Conclusion and future directions are listed in Section 6.

2. Background

This section describes related surveys and cloud broker.

2.1. Related Survey

There exist some surveys, [13],[21],[22],[23],[24] in which interconnected cloud computing and their issues are discussed. A. N. Toosi et al.[13] have discussed interoperability and portability issues in interconnected cloud environments. Various factors such as vendor lock-in, geographical distribution of cloud resources, scalability, reliability, etc are discussed in interoperability adoption for interconnected cloud. They have discussed four approaches, cloud federation, hybrid cloud, multi cloud, and aggregated service by broker for achieving interoperability in interconnected clouds. Fowley et al. [21] have classified and compared various cloud service brokerage frameworks on the basis of attributes provided by Gartner and NIST. The frameworks are classified on the basis of capabilities, architecture, descriptive schemes for language, technical aspects. Mostajeran et al. have proposed a SLA-aware brokering for Inter-Cloud [22] for discussing role of SLA in inter-cloud environment. Grozev and Buyya have presented a survey which classify Inter-cloud architectures and brokering mechanisms employed by them [23]. They have classified 20 projects comprising both academic and industry. It has been found that all projects have implemented pricing technique as brokering characteristic. Liaqat et al. [24] have presented a survey on resource management in federated cloud. They have classified resource management functions into resource pricing, resource discovery, resource selection, resource monitoring, resource allocation and disaster management. They have characterized and compared techniques using various metrics.

2.2. Cloud Broker

The tremendous evolution of Cloud Computing has provided ample opportunities to new CSPs to enter into cloud environment with varied services. With the large number of similar services offered by many CSPs, it becomes a difficult task for CSUs to choose desired service as per their applications' requirements. CSPs face challenges such as understanding market, adapting to market conditions, and user expectations for services. Cloud broker can act as mediator in auction based service and resource purchases [25][26]. CSUs can also be benefited when long time reservation of resources is required [27]. Cloud broker can act as intermediary third party [28] to overcome above mentioned challenges. Cloud Broker can help CSUs in selection of best and most cost-effective cloud services. The National Institute of Standards and Technology(NIST) [5] defines a Cloud Broker as *an entity that manages the use, performance, and delivery of cloud service and negotiates relationships between Cloud Providers and Cloud Consumers*. The International Organization for Standardization [29] has defined cloud service broker as *"cloud service partner that negotiates relationship between cloud service customers and cloud service providers*.

Table 1: Summary of Related Surveys

Author(s)	**Area Covered**	**Issues Addressed**
Toosi et. al [13]	Interoperability and Portability	Requirement of Interoperability and Portability in ICCEs
Fowley et. al [21]	Classification of Cloud Brokerage Architectures	NIST and Gartner attributes are used in classification
Mostejeran et. al [22]	SLA-Aware Brokering	Authors have presented importance of SLA in brokering
Grozev and Buyya [23]	Brokering in Inter-cloud	Interoperability issue in inter-cloud is discussed
Liaqat et. al [24]	Resource Management in Federated Cloud	Resource Management functions are classified in various techniques

CSPs and CSUs are two main actors of cloud brokering. CSUs can get economical solutions using cloud broker while CSPs can get new opportunities for enhancing services and increasing profit. There are multi-fold motivations to adapt cloud brokering in ICCE. Interoperability [30] [16] for seamless transfer of services from one CSP to another. CSUs can execute and host their applications under legal boundaries or specific geographic locations [31] [32] using a cloud broker.

NIST [33] has categorized services provided by cloud broker in three categories namely: arbitration, aggregation and intermediation. Gartner [34] has categorized cloud borkerage services in three categories namely: aggregation, integration and customization. Arbitration enhances features of cloud services by providing flexibility in service selection. Aggregation aggregates more than one services in single service or new services to enhance the broker capabilities. Intermediation intermediates cloud broker to improve its functionality by adding values. Integration enhances service efficiency and agility. Customization customizes services from different CSPs by composition or decomposition. There are various cloud broker projects such as Appirio, AWS Marketplace, BlueWolf, Cloud Compare, CloudMore, Cloud Nation, Clouditalia, CompatibleOne, ComputeNext, DirectCloud, etc. which offers various cloud brokering services. Machine learning techniques enable cloud brokering an intelligent decision maker [35]. They are used in QoS aware cloud resource prediction, selection & allocation [36], user satisfaction, service ranking [37], security, etc. Gartner [38] forecasts that cloud access security broker market will reach from 10% to 60% large enterprises by 2020. Many approaches based on cloud access security broker are presented for authentication, authorization, encrypted searching & sharing [39][40].

3. Cloud Brokering Frameworks

This section describes Cloud Computing frameworks which consists of a broker as one of its components.

3.1. Federated Cloud Management

Marosi et al. have proposed an IaaS service centric Federated Cloud Management Architecture for Federated Cloud [41]. The services are provided through a container, Virtual Appliances(VA) [42]. VA consists of networking resources and software resources such as operating system, various libraries, etc. in metadata form. Architecture consists of Generic Meta-Broker, Cloud Broker and Virtual Machine Handler components. The generic meta broker service connects all cloud providers in federation cloud brokers help to manage them automatically. The generic meta broker service is consists of meta broker core, information system agent, collect information, match maker, and invoker components. Cloud broker manages service and virtual machine queue. Service queue is responsible to store request of individual VA. Cloud broker allocates VA as per service request. The virtual machine queues is responsible to manage virtual appliances. Virtual machine handler manages the service request for a VA.

3.2. Inter-Cloud Federation Framework

Inter-Cloud Federation Framework(ICFF) is a component of Intercloud Architecture Framework [43]. ICFF addresses interoperability and integration issues of Inter-cloud environments. ICFF consists of service brokers, service managers, trust managers and identity managers. Service broker's work is to negotiate for resources between CSP and CSU in federation. Every user interact with ICFF through these service brokers. They are responsible to allocate heterogeneous resources through the gateway. Service broker interacts with service registry, identity provider, trust manager and service discovery for smooth functioning of resource allocation.

3.3. STRATOS

STRATOS [44], a cloud broker service, is proposed for automated cloud resource and service management in inter-cloud environment. STRATOS is composed of Cloud Manager, Cloud Metadata Servicer, Broker, Topology Descriptor, Application Environment, Translation layer, Image database, Monitoring components. Broker, central part of STRATOS, is responsible to connect other framework components automatically. It searches CSP as per topology requirements. It also configures resources as per topology requirements. It uses monitoring information for making decision.

3.4. Federated Network of Clouds

A service centric framework [20] has been proposed for federated cloud which consists of Cloud Coordinator, Cloud Broker and Concentrator. Cloud users can access various services through cloud broker. Cloud broker is based on Service Oriented Architecture. It searches requested services and allocate them. It consists of four components, User Interface, Core Services, Execution Interface and Persistance. User interface, topmost layer acts as mediator between user application and cloud broker. It receives user requirements and translates them in technical forms such as execution requirements, QoS, number of resources etc. Core services, main functionality of broker is responsible for bargaining, determining appropriate services, new service discovery, service monitoring, migrating to specific cloud service in case of current services is not able to fulfill SLA. Execution interface provides execution support needed to execute applications. It interacts with the cloud coordinator for dispatching and monitoring execution of application. Persistance, last layer maintains database of cloud brokers. It is also responsible to update states of user interface, core services and execution interface, in database.

3.5. Proposed Cloud Broker Model

We are proposing a cloud broker model as shown in Figure 1. The model consists of cloud service user interface, cloud service provider manager, user feedback, trust management system, monitoring and service management components. CSU interact to cloud broker through cloud service user interface and provide their requirements. Service management component is responsible for discovering, ranking, selection and allocation of services. User feedback components collects QoS data as per usage of services. Monitoring components monitors SLA between CSU and CSP. Trust management system is responsible to calculate trust value of CSPs. CSP manager manages cloud services which are accessible through cloud broker.

4. Cloud Brokering Techniques

A state-of-art classification of brokering techniques in Pricing, Multi-Criteria, Optimization, QoS, and Trust has been provided in this section. All three com-

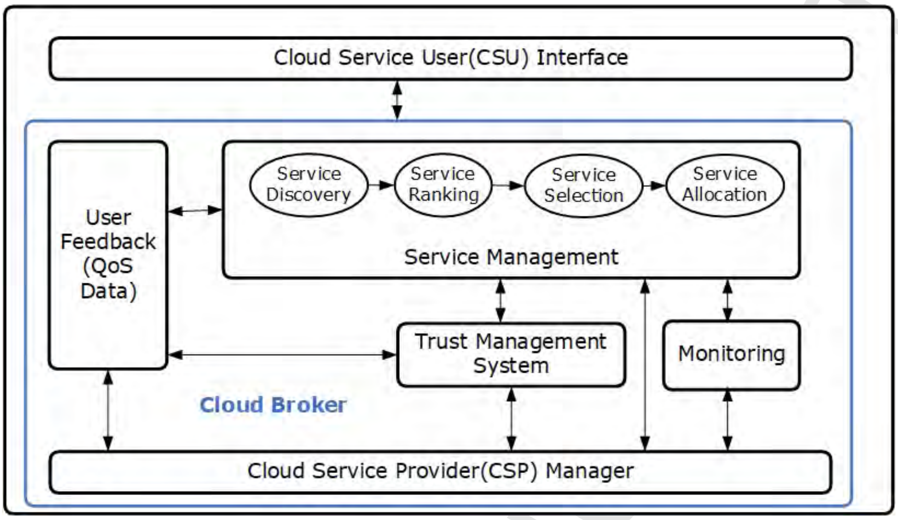

Figure 1: Proposed Cloud Broker Model

ponents, cloud broker, cloud user and cloud provider are considered in classification. Each category of technique is analyzed on two metrics. Strength and weaknesses/limitations of every technique is analyzed in first metric. Second analysis provides comparison on various performance metrics.

4.1. Pricing Techniques

Brokering techniques incorporating price as parameter are discussed below.

A model to minimize the cost in heterogeneous mobile cloud computing environment is presented with multiple brokers [45]. Here mobile cloud computing *is a rich mobile computing technology that leverages unified elastic resources of varied clouds and network technologies toward unrestricted functionality, storage, and mobility to serve a multitude of mobile devices anywhere, anytime through the channel of Ethernet or Internet regardless of heterogeneous environments and platforms based on the pay-as-you-use principle* [45]. Heterogeneity in mobile cloud computing refers to varied architectures, hardware and technologies of mobile devices along with technologies of cloud computing environments and wireless networks. Two different strategies have been used for service reservation to evaluate the model. First strategy is in which no cooperation among cloud brokers is considered and in second cooperation between cloud brokers in considered. In first strategy cloud brokers compete to reserve cloud resources from distant public clouds and local private clouds. In second strategy cooperating cloud brokers cooperate to share low cost resources. All the cloud brokers compete to provide low cost resources in order to minimize the total cost of all cloud brokers. Cloud brokers are bound with the competitive price above which no broker will pay. First strategy is evaluated theoretically using branch and bound techniques [46] by considering a disagreement point for equilibrium between brokers. Second strategy is evaluated on the basis of optimal algorithm in which non-convex cooperative problem is considered. Brokers optimize user cost without collision. Cooperative strategy is far better than competitive strategy if few brokers are in competition.

A trusted broker based framework [47] for mobile cloud has been proposed for resources allocation where mobile users share their idle resources. Resource sharing users lease their resources on a price and resource requesting users also put a request with a price to acquire a resource through a broker. A distributed algorithm is proposed to achieve desired competitive equilibrium in resource sharing. Here, competitive equilibrium is a point where two users maximizes their own payoff at a given price and no user can get better payoff by changing his decision. Similarly a distributed algorithm is proposed for resource requesting users to achieve Nash equilibrium. Proposed methods achieves better Nash equilibrium than optimal solutions.

A broker based model for reducing cost in resource allocation and reservation has been proposed for multi cloud [48]. Cost efficient methods are proposed for dynamic request redirection, grouping requests for cost reduction, and delayed allocation of resources for lazy updates. Real time experiments are carried out on supercomputers and real clouds. Results demonstrate cost reduction and guarantee of service level objectives compared to other methods.

A cloud broker is proposed in [49] for dynamic management of resource pricing and refunding. It considers relinquishing resource probability, profit earned, unique features of services SLA violation, service not functioning as per desire, another better service in given price is available and power issues are considered for refund. CSUs get refund on the basis of service utilization, acquired QoS and unutilized service.

IaaS providers offer their services and resources with varying pricing schemes such as pay as you go, pay less when use more for per unit, less payment for reserved resources, discounts in price. These schemes makes cloud resource and service purchase a complex task. Broker can help in this scenario by taking advantage of discounts and by purchasing resources in bulk. A randomized algorithm, online stack-centric scheduling (ROSA) has been proposed in [50] to minimize cost of user applications. Concave cost function [51] is used to model the pricing strategy and three different cost strategies are used to test algorithm on different types of jobs with varying deadlines. ROSA algorithm outperforms than conventional algorithms.

A broker based method [52] has been proposed for fulfilling dynamic requirement of user's applications which considers variable price. Dynamic needs of computing facilities of users are also considered. A genetic algorithm based solution is used to validate the proposed approach.

A framework for dynamic service allocation is proposed to satisfy availability & demand of computing resources for federated cloud [53]. Framework provides autonomic computing facility through feedback based control which uses decomposition-coordination method namely interaction balance. The framework provides monitoring of SLA, profit maximization and minimization of operating cost of both CSP and broker. Firstly, all computing resources are dynamically allocated among the services providers using interaction balance based approach which are observed to maintain the SLAs by service level controllers.

A centralized broker based model [54] is proposed to optimize the energy and cost of multiple mobile devices. Model studies effect of task offloading to cloud environment. The model has been tested in two different resource augmentation mobile clouds. Energy optimization and energy & cost optimization are tested through a task scheduling algorithm in first and second environment, respectively. It has been observed that when offloading of task has been performed with optimization then results are better than when it has been performed without optimization.

A brokerage service [55] to minimize the operating cost by exploiting different pricing offers of IaaS clouds has been proposed to get maximum benefits from various offers. These resources are served to CSU as per their demands with reduced price. Broker achieves minimum service cost by multiplexing long term instance reservations and spot offers. Dynamic programming and approximation algorithms are used to simulate proposed strategy and results show significant improvements.

A cloud broker for advance resource allocation [56] is proposed for federated cloud which considers user characteristics to allocate resources. The model predicts required resources and pricing on the basis of historical data of service utilization by CSUs. Users' historical records are used in deciding resources and pricing mechanism. It helps CSPs to attract more realistic users by offering incentives to them. Simulation results show that proposed broker outperforms when CUSs historical records are used in deciding price and resources.

A broker based approach based on dynamic pricing is proposed to automatic selection of cloud resources [57]. Three methods have been proposed. First method cloud-dominant strategy incentive compatible is based on auction strategy and uses VCG mechanism [58]. Second method cloud-bayesian incentive compatible is used for balancing budget & QoS satisfaction which is based on dAGVA mechanism [59]. The cloud vendor who bids lowest is selected. Third method, cloud optimal uses auction strategy to select appropriate CSP. Proposed broker implements all three methods for CSP selection. The simulation results show if number of cloud vendor increases then irrespective of any one from three method used, the cost of cloud resource selection is decreased.

Table 2 summarizes various pricing techniques on the basis of their strength and weaknesses/limitations. Table 3 provides comparison of performance metrics against pricing type, control orientation, centric orientation, platform, service and evaluation medium. Pricing type refers either static or dynamic price for use of resource or service, control orientation refers to how broker is placed in ICCE, centralized or decentralized, given technique is more towards either broker, user or provider is given in centric orientation, platform refers to IaaS, PaaS and SaaS, types of services provided by technique is referred in service and last evaluation medium gives details of implementation of given techniques.

Discussion: We observed that pricing techniques are biased as per their implementation in ICCE. Individual technique does not fit in every brokering scenarios because of their varied service access pattern. Pricing techniques behavior differ as per broker's implementation orientation. QoS based pricing method are not addressed well with respect to ICCE. It has been found from performance metrics that dynamic price is more considered. The broker's controlling is centralized.

4.2. Multi-Criteria Techniques

Multi-criteria techniques are used to solve multiple conflicting criteria problems. Techniques considering multi-criteria in cloud brokering are discussed.

A brokering approach based on multiobjective optimization has been proposed for resource allocation in hybrid cloud [60]. The approach based on genetic algorithm has to maximize user satisfaction, broker's revenue & resource usage and to minimize energy cost. Proposed approach has been tested through evolutionary based broker and obtained results are outstanding than other solutions.

A selection method considering multiple criteria such as cost, availability, reliability and performance has been proposed by [61]. It uses Pareto solutions [62] to consider multiple constraints. Authors have used multi objective genetic algorithm [63] to provide optimum solutions.

Toinard et al. have proposed broker based optimization method considering multiple criteria and imposed constraints for cloud service selection [64]. It uses Promethee method [65] in deciding trade-off between trust and QoS. The QoS parameters are assigned ranks based on Promethee method and these ranks are used to establish trust value. A prototype implementation is used to evaluate the given method. A three level scheduler is proposed for federated cloud environment [66].

Table 2: Summary of Pricing Techniques

Author(s)	**Environment**	**Objective**	**Strength**	**Weakness / Limitation**
[45]	Hybrid Cloud	To minimize user cost in multi-broker environment	Cooperative brokering is better compared to competitive	Single parameter user cost is considered to devise results
[47]	Multi Cloud	To design a double sided bidding mechanism to increase resource sharing and allocation	Double sided bidding mechanism achieves an equilibrium in resource sharing and allocation	Static price has been considered
[48]	Multi Cloud	To reduce cost in resource allocation and reservation	Proposed methods achieves cost reduction in resource allocation and reservation	Different cost efficient methods provide different results
[49]	Inter Cloud	To optimize resource usage price	Operating cost is minimized if historical data of customers' usage and providers are considered	Underutilization of cloud resources and their calculation is not mentioned
[50]	Multi-Cloud	To minimize user's cost	Proposed method achieves minimum cost in deadline based online scheduling	Loose deadlines for application are used
[52]	Mutli-Cloud	To dynamically allocate virtual machines	Proposed method is highly scalable in various conditions	Homogeneous environment is considered
[53]	Federated Cloud	To maximize profit and minimize operational cost	Dynamic allocation of resources maximizes broker's profit	Only homogeneous resources are considered
[54]	Hybrid Cloud	To optimize cost and energy	Proposed model reduces cost and energy	Task offloading constraints not considered

Table 2: Summary of Pricing Techniques

Author(s)	**Environment**	**Objective**	**Strength**	**Weakness / Limitation**
[55]	Multi Cloud	To minimize service cost	Instance reservation minimizes cost of operation	Not in all cases service cost can be reduced
[56]	Federated Cloud	To predict required resources	Proposed model predicts required resources with user's historical data	Very few parameters are considered
[57]	Multi Cloud	Automatic selection of cloud resources based on dynamic pricing	Proposed three different method outperforms in given situations	None method is giving best results in all situations

Table 3: Performance Metrics of Pricing Techniques

Author(s)	**Pricing Type**	**Control Orientation**	**Centric Orientation**	**Platform**	**Service(s)**	**Evaluation Through**
[45]	Static	Decentralized	Broker	IaaS	Resource Provisioning	Simulation
[47]	Static	Centralized	Broker	Iaas	Resource Allocation	Simulation
[48]	Dynamic	Centralized	Broker	IaaS	Resource Allocation and Reservation	Simulation
[49]	Dynamic	Centralized	Broker	IaaS	Resource Provisioning	Simulation
[50]	Dynamic	Centralized	Provider, Consumer, Broker	IaaS	Provisioning	Practical Implementation
[52]	Dynamic	Centralized	Broker	IaaS	Resource Allocation	Simulation
[53]	Dynamic	Distributed	Broker, Provider	IaaS	Allocation	Simulation

Table 3: Performance Metrics of Pricing Techniques

Author(s)	**Pricing Type**	**Control Orientation**	**Centric Orientation**	**Platform**	**Service(s)**	**Evaluation Through**
[54]	Static	Centralized	Broker	IaaS	Resource Provisioning	Simulation
[55]	Dynamic	Centralized	Broker	IaaS	Resource Provisioning	Simulation
[56]	Static	Centralized	Broker	IaaS	Resource Allocation	Simulation
[57]	Dynamic	Decentralized	Broker	IaaS, SaaS, PaaS	Resource Selection	Simulation

First level of scheduler is at broker level for selecting appropriate data center. Data centers are chosen based on their network latencies. They have used lowest latency time first, first latency time first, and latency time in round policies for network latencies. Second level of scheduler is at IaaS level for mapping VMs to chosen hosts in data centers. Ant Colony Optimization [67] and Particle Swarm Optimization algorithm [68] is used to perform scheduling. Third level of scheduler is at VM level for mapping jobs to selected VMs. All the schedulers are tested on the basis of response time metric.

A cloud brokerage service based on multi-criteria decision making [69] is proposed to provide cloud service recommendation. Proposed approach namely Preference-based cLoud Service Recommender(PuLSaR) provides preference based CSP recommendation. It uses Service Measurement Index(SMI) [70] which includes accountability, agility, assurance, financial, performance, security & privacy and usability as performance indicators. PuLSaR provides optimized cloud service selection and evaluation in heterogeneous cloud service model. It also provides service ranking mechanism and overcomes the problem associated with traditional ranking solutions.

Achar and Thilagam have proposed a broker for multi-cloud for CSP selection [71]. TOPSIS ranking method is used to rank services provided by CSPs. SMI is used to characterize CSP and prioritize them. Multi-criteria decision making problem is constructed by considering all parameters of CSUs. Each parameter is assigned a weight using AHP [72].

A cloud resource broker is proposed for multi-cloud [73] for providing effective and efficient management of cloud resources. Particle Swarm Optimization algorithm [68] is used for resource allocation considering jobs with deadline constraints. Minimization of execution time and cost are considered as objectives. Matlab based simulation and a cloud environment created with Eucalyptus is used to test it. Proposed method minimizes execution time, cost and reduces job rejection rate within given deadline.

A distributed cloud broker [74] is proposed for dynamically cloud resource selection. It addresses interoperability and heterogeneity of cloud platforms.

The centralized broker is decomposed in a group of distributed brokers to take advantage of cooperative and dynamic working between them to support unpredictable workload demands by CSUs.

An automated cloud resource trading model based on broker [75] is proposed which considers trading between consumer & provider and between brokers and sellers & providers. The contribution of proposed model is a complex negotiation method for trading cloud resources, Bargaining-Position-Estimation(BPE). The negotiation activities are based on regression namely Regression-Based-Coordination (RBC) are many-to-many between broker and cloud consumer and one-to-many between multiple cloud providers and broker. The broker using BPE gives better results in terms of utilities, very close to Market Driven Agents(MDA) [76] and higher than time dependent strategy. The broker using RBC gives better results in terms of higher utilities, success rate, and fast negotiations than utility-oriented coordination(UOC) [77] and patient coordination strategy(PCS) [78].

A scheduling and resource provisioning algorithm has been proposed to execute maximum number of bioinformatics based workflow applications within given budget and deadline constraints [79] for IaaS Clouds. They have proposed static and dynamic algorithm to achieve maximum number of workflow executions. Simulated results show that proposed algorithm outperforms.

Summary of multi-criteria techniques on the basis of their strength and weaknesses/limitations are given in Table 4. Table 5 lists comparison of above mentioned techniques on the basis of services provided, control orientation, criteria and evaluation medium. Criteria refers to parameters which are used to design and test given techniques. Other parameters are same as given in pricing techniques.

Discussion: We have observed that cost and execution time are mostly used as conflicting criteria for service discovery, selection, provisioning. Other criteria less addressed. Few frameworks are proposed for multi-criteria techniques. Centralized broker is mostly considered.

Table 4: Summary of Multi-Criteria Techniques

Author(s)	Environment	Objective	Strength	Weakness / Limitation
[60]	Hybrid Cloud	To optimize broker's cost and minimize energy cost	Multiobjective Evolutionary algorithm minimizes cost	Non-cloud platform used for testing
[61]	Multi Cloud	To provide multiobjective based optimum service selection	Multiobjective genetic algorithm provides optimum solutions	Implementation only considers to minimize cost
[64]	Multi Cloud	To select best cloud service provider based on multi-criteria	Method selects provider based on QoS and Trust	Weights to find trust of individual parameters is not given
[66]	Federated Cloud	To minimize response time	Method reduces response time as cloud machines increases	Proposed method only works in horizontal scalability
[69]	Multi Cloud	To provide preference based cloud service recommendation	Method considers multiple criteria to provide ranking of cloud services	Importance of individual criteria in evaluation is not given
[71]	Multi-Cloud	To select an appropriate CSP based on rank	Method efficiently assigns rank to individual CSP	Limited performance matrices are used
[73]	Multi Cloud	Efficient execution of scientific and deadline based jobs on multi cloud	Approach effectively minimizes cost and execution time	More constraints can be applied to test given approach
[74]	Multi Cloud	Automatic selection of cloud service provider based on SLA	Method selects CSP based on constraints, scalability, and SLA	Time complexity of proposed method is high
[75]	Multi Cloud	To investigate complex negotiations between multi-cloud entities	Proposed different strategies give better results in different conditions	No single strategy is best in all conditions

Table 4: Summary of Multi-Criteria Techniques

Author(s)	**Environment**	**Objective**	**Strength**	**Weakness / Limitation**
[79]	Multi Cloud	To maximize workflow execution within given budget and deadline	Static and dynamic methods achieves maximum workflow executions	Other parameters should be considered

Table 5: Performance Metrics of Multi-Criteria Techniques

Author(s)	**Services**	**Control Orientation**	**Criteria(s)**	**Evaluation Through**
[60]	Resource Allocation	Centralized	Cost	Simulation
[61]	Resource Provisioning	Centralized	Cost, Availability, Reliability, Performance	Simulation
[64]	Resource Selection	Centralized	RTT and Price	Prototype Implementation
[66]	Resource Scheduling	Hierarchical	Response Time	Simulation
[69]	Service Recommendation	Centralized	SMI Key Parameters	Simulation
[71]	Service Selection	Centralized	SMI Key Parameters	Simulation
[73]	Provisioning	Centralized	Execution Time & Cost	Simulation & Prototype Implementation
[74]	Resource Selection	Decentralized	SLA Defined	Simulation
[75]	Resource Allocation	Centralized	Cost and Time	Simulation
[79]	Resource Provisioning	Centralized	Budget and Deadline	Simulation

4.3. Optimization Techniques

Optimization problem refers to either maximize or minimize a function with given objective and conditions. Optimization is defined as *Finding the most suitable services for the clients or providers, which maximizes or minimizes one or several criteria and still adheres to the constraints [80].* We are going to discuss various parameters such as cost, time, energy, trust etc. either to minimize or maximize as per given criteria.

A broker based framework [81] has been proposed for connected Internet of Things(IoT) [82] to reduce response time and energy consumption as well as maximize broker's profit. IoT is a network of various uniquely identifiable such as computers, vehicles, physical devices, sensors, etc connected through Internet. Cloud of Things is an integration of cloud computing and IoT. Particle swarm optimization algorithm [68] has been studied for single objective and multiple objectives. It has been found that proposed optimization algorithm outperforms in terms of reduction of request response time and energy consumption and increases cloud broker profit than other state-of-art solutions.

A platform, namely BioNimbuZ has been proposed to improve computational time of bioinformatics applications on federated cloud [83]. The platform consists of four layers: application, integration, core and infrastructure. It has been tested by real bioinformatics workflow applications and results show improvement in computational time than single cloud.

A broker based method has been proposed to minimize cost of energy consumption in smart grid computation systems [84]. The smart grid is formed with the help of multiple private clouds. Various properties such as distributed computing within data center array, different time zones and geographical locations of private clouds are utilized. Simulation of proposed method was performed with Cloud Analyst [85] testbed. Results show significant cost reduction in energy consumption compared with other state-of-art solutions.

Simarro et al. have proposed a cost-optimization algorithm for placement of service considering data storage and transfer policies in order to optimize cost of infrastructure deployment in multi-cloud [86]. Algorithm considers storage location and time of on & off image as parameters for evaluation.

A brokering model is proposed for multi-cloud for automatically & dynamically evaluation of SLA [87]. The model applies multi-objective algorithm to address issues such as interoperability, execution cost variation, heterogeneity in cloud platforms. The model show that multi-objective based approaches are better to solve multi-cloud brokering problems. It reduces execution time and computational requirements but increases loss of optimality.

A broker based approach is proposed for dynamically cloud resource assignment [88]. Broker calculates user requirements in aggregated form using an aggregation algorithm and stores them in a template which is used to match CSPs' offers. A service scheduling algorithm is used to find an optimized match according to requirements and service offerings. Proposed algorithm is evaluated considering cost and performance constraints through simulation.

A broker based virtual machine mapping model is proposed for multi-cloud [89]. which considers VM execution time in mapping. VM execution time is modeled using truncated normal distribution. The results indicate that virtual machine mapping problem can be solve using optimization considering stochastic value of VM execution time.

A broker based resource allocation model is proposed for multi-cloud [90] to allocate resources from various CSPs dynamically and increase broker's profit. The method is based on Markov Decision Process(MDP) [91]. Optimize resource utilization is considered as another objective. The proposed approach exhibits better results in terms of revenue generation because static resources are better exploited.

An optimal broker based on Semi-Markov Decision Process [92] is proposed for mobile Inter-cloud [93] to address problem of mobile cloud market. Mobile users confront problem of better CSP in order to satisfy their needs within budget. It uses service cost as optimization criteria for CSP selection. It outperforms in VM utilization with less cost compared to other state-of-art solutions.

A distributed bio-workflow broker model has been proposed to optimize resource allocation in multi cloud [94]. The broker implements next generation sequencing algorithm to minimize makespan within given resource constraints. Results show that proposed method is outstanding for executing bioinformatics applications on cloud. Table 6 summarizes various optimization techniques on the basis of their strength and weaknesses/limitations. Table 7 gives comparison of above mentioned techniques on the basis of control orientation, objective, centric orientation, method used, service provided and evaluation medium. Objective refers to either minimize or maximize or both of given parameters, method used refers to type of method used to design technique, other parameters are same as discussed in pricing techniques.

Discussion: We have observed that single objective optimization techniques are more presented. The study shows that time and cost are considered optimization parameters by most of researchers. Aggregated optimization based techniques are less researched.

4.4. Quality of Services Techniques

Quality of Service (QoS) provides detailed description of a service performance in the given computing environment. In ICCE, biggest challenge to achieve desired QoS is allocation of resources such that they deliver expected output. QoS is more concerned with users' satisfaction in terms of assured QoS characteristics by CSPs.

A framework consists of distributed brokers has been proposed to monitor live VM migration [95] in non-sharable IaaS clouds. Brokers use MigrateFS, a special file system for performing synchronization of live VM migration. Efficient resource allocation methods are proposed to migrate a large number of VMs. These methods are implemented by migration scheduler and brokers. A priority level is assigned to individual migration task and VM migration took place according to priority level. Providing priority to migration tasks helps to minimize cost, reduction in SLA violations and reduces adverse effect on QoS. Prototype implementation of framework with different methods demonstrate reduction in cost and maintaining QoS during migration process.

A proxy broker based framework has been proposed for *management as a* *service* [96]. The broker works as a centralized controller to monitor QoS in distributed and multi-vendor public clouds. Proposed broker maximizes profits of CSP, increases degree of control and provides transparent management of QoS. The broker has been tested in Innovation Lab of a Global Telecommunication company. The results demonstrate better control on QoS than other state-of-art solutions.

Hamze et al. has proposed a framework to allocate network resources and virtual machines in inter-cloud and cloud federation [97]. The framework focuses on QoS parameters of Networking as a Service and Infrastructure as a Service. The research focuses on selection of best CSP in order to minimize cost. Framework was evaluated on cloud videoconferencing and compute intensive applications. Results demonstrate that broker architecture is more economical than federation one.

A brokering model for hybrid cloud has been proposed to achieve user satisfaction, maximize broker's revenue and minimize energy cost [98]. Three scheduling strategies are proposed and tested through simulation. Results show that they maximizes user satisfaction, broker's revenue and resource utilization while reduces energy consumption cost.

A cloud brokerage model is proposed to focuses on resource prediction, pricing, refunding and resource allocation [99]. Broker reserves cloud resources in advance for maintaining QoS. The model has to deal with the quality of degradation if refund of cost is to be given. The model decides pricing of services on the basis of user characteristics and accordingly QoS is maintained. The refund is provided on the basis of QoS acquired and service utilization.

A brokering framework has been proposed for context service selection in federated cloud [100] which uses CSUs Quality of Context requirements. It finds suitable personalized and adaptive context services to get high quality informative contents for mobile users. Framework consists of a selection algorithm which uses weighted utility function to rank individual context services. Quality of context attributes namely freshness and correctness probability are used for evaluation of proposed approach.

Table 6: Summary of Optimization Techniques

Author(s)	**Environment**	**Objective**	**Strength**	**Weakness / Limitation**
[81]	Multi-Cloud	To optimize energy consumption and request time	Pareto solutions reduces energy consumption and request time	No standard simulation tool or setup is used
[83]	Federated Cloud	To improve computational time	Bioinformatics workflow applications outperforms in computational time	Security and Container based solutions can be provided
[84]	Smart Grid based Cloud	To minimize cost of energy consumption	Method using functionalities of private clouds reduces energy cost	Average response time increases
[87]	Multi-Cloud	To automatically and dynamically evaluate SLA	Multi-objective are better to solve multi-cloud brokering	Approach given increases loss of optimality
[88]	Multi-Cloud	To optimize CSUs requirements with CSPs offers	MCDM Approach successfully optimizes cost and response time	All the users' requirements are treated as same level
[89]	Multi-Cloud	To test the effect of VM execution time in VMMP	Model successfully overcomes the stochastic effect of VM execution time	Only cost factor has been considered to verify the results
[93]	Hybrid Cloud	To propose optimal broker for cost reduction	SMDP Optimization method gives better CSP selection in reduced price	Only VM utilization is considered for optimization
[86]	Multi-cloud	To optimize infrastructure deployment cost	Total bill is drastically reduced considering the storage cost	Algorithm does not perform adequately in large number of VMs
[90]	Multi-Cloud	To optimize resource utilization and profit	Better results are obtained if static resources are more utilized	Homogeneous resources are considered
[94]	Multi Cloud	To optimize time	Algorithm optimizes total makespan	Few parameters considered

Table 7: Performance Metrics for Optimization Techniques

Author(s)	**Control Orientation**	**Objective(s)**	**Centric Orientation**	**Method Type**	**Service(s)**	**Evaluation Through**
[81]	Centralized	Energy, Profit, Response Time	Broker	PSO	Provisioning	Simulation
[83]	Centralized	Computational Time	Broker	N/A	Scheduling	Simulation
[84]	Distributed	Energy Consumption Cost	Broker	User Defined	Provisioning	Simulation
[87]	Centralized	Time, Cost, Availability	Broker	Genetic Algorithm	Provisioning	Simulation
[88]	Centralized	Cost	Broker	MCDM	Scheduling	Prototype
[89]	Decentralized	Cost	Broker	Meta Heuristic	Provisioning	Simulation
[93]	Centralized	Service Cost	Broker	Semi-Markov Decision Process	Selection	Simulation
[86]	Centralized	Cost, Response Time	Broker	Not Mentioned	Resource Allocation	Simulation
[90]	Centralized	Profit, Resource Utilization	Broker	Markov Decision Process	Resource Allocation	Simulation
[94]	Distributed	Makespan	Broker	Next Generation Sequencing	Resource Allocation	Simulation

A two broker based approach is proposed for CSP selection[101]. A service broker has been used at SaaS layer and another between CSP and CSU. An efficiency metric consists of availability, response time and reliability is used for CSP selection.

A broker for hybrid cloud to address specific QoS constraints has been proposed by[102]. The brokering algorithm satisfies high number of resource requests with given QoS constraints. It also maximizes CSP's revenue by applying various allocation policies.

A cloud storage broker is proposed[103] to find optimal placement strategy as per QoS demands. Two algorithms are proposed to achieve optimal placement. First algorithm is used to achieve user's QoS demands with minimum replication cost. Second algorithm is used to maximize object availability within given budget. Table 8 summarizes various QoS techniques on the basis of their strength and weaknesses/limitations. Table 9 gives comparison of QoS techniques on the basis of control orientation, centric orientation, platform, services provided, QoS parameters used and evaluation medium. QoS parameters refers to parameters used for designing and testing service. Other parameters are same as discussed in previous sections.

Discussion: We have observed that most of the surveyed techniques considers one or two QoS parameters for study. Conflicting QoS parameter based techniques are less focused. The above performance metrics show that mostly considered QoS parameters are price, response time, availability and reliability.

4.5. Trust Techniques

Trust in cloud computing is difficult to build because a cloud user hosts applications on a cloud which he does not have any further access or control. The cloud user has to trust the cloud provider for executing applications and hosting them. The control over data and processes depends on the cloud service model as well as confidentiality and integrity of user data [104]. Trust with respect to cloud broker is formally defined as *Trust is a quantified belief by a cloud broker with respect to the security, availability, and reliability of a resource* *within several specified time windows* [105].

A broker based approach has been proposed for scheduling workflow application in SaaS clouds [106] with given deadline and minimum cost. It has defined privacy constraints on multi-level for both data and task. No advance knowledge of workflow structure is required to define constraints. The proposed scheduling approach considers users requirements of task and data privacy at individual level and converts them in to a combinatorial optimization problem. It schedules tasks of individual users on available multiple cloud resources. Results show that it outperform in terms of cost reduction with given constraints than other state-of-the-art solutions.

A broker based framework has been proposed for encrypted data search [107] which is based on Cloud Access Security Broker(CASB) [108]. Broker provides encrypted data search and stores encrypted keys, metadata, and ciphertext ID pointers in cloud. Every search query is passed to local directory by broker.

Li et al. have proposed a broker based verification system for cloud service selection [109]. The system provides an efficient authenticated indexing structure which ensures authentic, complete and satisfiable cloud service selection. It is used to verify misbehavior of cloud broker in service selection. The system also provides a trusted collector which is responsible to gather various information from different CSPs. Trusted collector builds a problem free and authenticated database of CSPs. Trusted collector can also sell authenticated database to other brokers to earn profit. It outperforms in terms of verification of cloud service selection on parameters such as authenticity, user satisfaction and service completeness with other state-of-art solutions.

Barreto et al. have proposed a broker based framework for discovery and allocation of services in cloud federation [110] which provides authentication and authorization services. An auction based model is used for resource discovery. It helps in dynamic allocation of resources as compared to resource acquisition. The resources are acquired for a fixed time period and released after time period expires.

Table 8: Summary of Quality of Services Techniques

Author(s)	**Environment**	**Objective**	**Strength**	**Weakness / Limitation**
[95]	Share-nothing IaaS Clouds	To minimize live VM migration cost	Methods effectively reduces cost for migrating VMs	Only IaaS environment is considered
[96]	Multi Cloud	To propose a proxy broker to monitor QoS	Broker control QoS better than CSP tools	More number of parameters can be considered
[97]	Federated & Inter-cloud	To optimize cost ensuring QoS constraints of NaaS and IaaS	Optimization algorithm minimizes cost ensuring QoS constraints	Only single objective is considered
[98]	Hybrid Cloud	To achieve QoS constraints	Brokering approach maximize user satisfaction, broker's profit and minimize energy cost	Different scheduling strategy gives varying results
[99]	Federated Cloud	Method to address advance resource allocation & QoS	Method successfully monitors QoS levels and performs refunding	More heterogeneous resource based experiment required
[101]	Multi Cloud	To propose a method for achieving better QoS	Given method provides exchanges of QoS between brokers	More number of QoS parameters should be considered
[100]	Federated Cloud	To provide context aware cloud service selection	Given techniques select best CSP from federation	More number of QoC attributes should be used to verify results
[102]	Hybrid Cloud	To maximize CSP's profit and User Satisfaction	Method achieves user satisfaction and maximizes CSP's profit	Different Strategy gives different results under varying conditions
[103]	Multi-Cloud	To optimize storage cost	Algorithm optimizes storage cost	Single constraint is considered

Table 9: Performance Metrics for QoS Techniques

Author(s)	**Service(s)**	**Control Orientation**	**Centric Orientation**	**Platform**	**QoS Parameters**	**Evaluation Through**
[95]	Resource Allocation	Centralized	Broker	IaaS	Priority and Cost	Prototype
[97]	Resource Allocation and Selection	Centralized, Decentralized	Broker	IaaS	User Defined	Simulation
[98]	Resource Allocation	Centralized	Broker	IaaS	User Satisfaction & Cost	Simulation
[99]	Resource Allocation	Centralized	Broker	IaaS	User Defined	Simulation
[101]	Resource Selection	Centralized	Broker	SaaS, IaaS	Availability, Reliability, Response Time	Simulation
[100]	Service Selection	Decentralized	Broker	SaaS & IaaS	Freshness & Correctness Probability	Simulation
[102]	Resource Allocation	Centralized	Broker	IaaS	Cost and User Satisfaction	Simulation
[103]	Resource Selection	Centralized	Broker	IaaS	Cost & Availability	Simulation

A trusted broker model in proposed for multi-cloud [111] for trust collaboration among multiple IaaS CSPs. Three models, Cross Cloud Trust, Cross Domain Trust and Cross Project Trust for multi-cloud has been studied. Homogeneous cloud environment is considered to evaluate trust. Openstack [112] is used for prototyping.

A broker based approach based on service operator trust scheme(SOTS) has been proposed for resource matching for multi-cloud [105]. The trust value is calculated using multi-attributes such as reliability, availability, and security. Information entropy theory is used to evaluate trust value. For newly joining CSP, first service last audit scheme is used to provide penalty based trust value for initialization. The proposed adaptive method overcomes the traditional weighted or subjected trust schemes as per the results obtained through simulation.

A cloud brokering architecture has been proposed to assure trust among CSPs and CSUs [113]. The dependability property is chosen as a measurable metric because it can avoid unacceptable system failures. The architecture, DBA consists of fault detection, evaluation and decision making in case of failures either to recover or migrate. The simulated results considering reliability metric show that it successfully incorporates dependability property in CSP selection. Table 10 summarizes various trust techniques on the basis of their strength and weaknesses/limitations. A comparison of trust techniques on various performance metrics such as service provided, control orientation, centric orientation, platform and evaluation medium is given in Table 11. Here service refers to types of trusted services provided. Other parameters referred are same as discussed in previous sections.

Discussion: We have observed that authentication and authorization parameters are mostly considered for trust techniques. User feedback based techniques are more researched. Study shows that indirect trust is less researched.

Table 10: Summary of Trust Techniques

Author(s)	**Cloud Environment**	**Objective**	**Strength**	**Weakness/Limitation**
[106]	Hybrid Cloud	To minimize cost of workflow application within given deadline	Methods minimize cost of workflow application within given constraints	Different results obtained under different level of constraints
[107]	Multi Cloud	To provide encrypted search and secure data sharing	Method achieves encrypted data search	Method creates overhead in storing and searching data
[109]	Multi-Cloud	To propose a verifiable brokering approach for cloud service selection	Outperforms in authenticity, service completeness and user satisfaction	Returns a cloud service list in place of single cloud service
[110]	Federated Cloud	To securely search and allocate resources among federation members	Auction based model for resource discovery outperforms than centralized information services	External entity required to provide identity management
[111]	Multi Cloud	To propose trust model for multi-cloud	Trust applicable at different levels of multi-cloud environments is identified and tested	Model works only in homogeneous cloud environment
[105]	Multi Cloud	To propose a multi-attributes based trust scheme	SOTS successfully incorporates multiple attributes of resources to find trust value	User defined values are used for finding trust value
[113]	Multi Cloud	To implement dependability through trust	Model incorporates trust at different levels of given DBA architecture	Only reliability metric is considered to evaluate dependability

Table 11: Performance Metrics of Trust Techniques

Author(s)	Service(s)	Control Orientation	Centric Orientation	Platform	Evaluation Through
[106]	Privacy Preservation	Centralized	Broker	SaaS	Prototype Implementation
[107]	Encrypted data search	Centralized	Customer	SaaS	Prototype Implementation
[109]	Verification	Centralized	Broker	Iaas	Simulation
[110]	Authorization and Authentication	Centralized	Broker	SaaS	Simulation
[111]	Authorization	Centralized	Broker	IaaS	Prototype Implementation
[105]	Trust Management	Centralized	Broker	IaaS	Simulation
[113]	Provisioning	Centralized	Broker	IaaS	Simulation

5. Research Challenges and Open Problems

Some of major research challenges and open problems are identified from survey. They are listed below:

(i) *Cloud Brokering Framework*
ICCEs are gaining attention by both providers and consumers because of benefits such as reduced cost, more profit, efficient utilization of resources and services, and options to move from one CSP to another if not satisfied with present one. Cloud brokers in literature are proposed for either specific purpose or specific cloud environment. They do not fit in all ICCE as well as they do not consider every aspects of service requests and providers constraints. The cloud brokers are lacking in considering various aspects of ICCE in optimal selection of resources, efficient allocation of resources, optimal distribution of either application parts or service components among different collaborating CSPs. They are also lacking in providing migration of services and resources from one provider to another. New frameworks can be proposed to provide unified API or effective UI to CSU.

(ii) *Cloud Service Discovery Techniques and Publishing Market Place*
In ICCE, cloud providers do not have a registry or market place where they can publish their services. They are also lacking of standard format for publishing. CSUs are lacking by standardized discovery techniques. Efficient brokering techniques can be proposed for discovery services.

(iii) *Cloud Brokering Techniques for Service Selection*
Cloud users specify various criteria such as cost, time, data center location, QoS, etc. for a service to be allocated. Researchers have presented various techniques based on either cost or time. Many researchers have also focused on QoS and optimizing various parameters. Cloud service selection is a challenging task in ICCE because every cloud provider exposes its services and resources as per their proprietary models and interfaces. Efficient techniques are required which consider multiple objective for service selection.

(iv) *Cloud Brokering Techniques for Service Allocation*

Service allocation has to deal with various aspects of CSPs and CSUs. Cloud providers' exposes their resources as per their convenience. The demands from CSUs make difficulty for cloud broker to address them. Single provider may not be able to fulfill all the demands. Cloud broker has to consider SLA, cost, time, QoS demands, etc. in allocating services. Effective techniques are required to fulfill requirements of CSUs within constraints of CSPs.

(v) *Cloud Brokering Techniques for Service Provisioning*

Service provisioning refers to the process of reserving resources and utilizing as an when require. Researchers have proposed methods based on either single criteria or group of one or two criteria such as cost and time for service provisioning. Efficient techniques are required to take advantage of spot offers. Issues such as fulfilling requirement of cloud users from more than one cloud providers within given SLA is also a topic of research. Issues related to migrating a service from one CSP to another as assured SLA is not achieved is also a topic of research. One cloud broker has to contact with another cloud broker in order to satisfy user QoS constraints. This issue is not addressed well in literature. This leads to propose meta brokering framework to fulfill requirements of one broker from other brokers.

(vi) *Trust based Cloud Brokering Techniques*

The cloud resources in ICCE are virtualized, heterogeneous, and distributed at various geographically distributed. There must be trust between CSUs and CSPs in order to accomplish acceptance of cloud computing as a utility. This leads to design and develop trust aware techniques. CSUs are more concerned about trusted cloud resources so that they can execute their applications and store data in cloud data centers without worry. Efficient techniques are required to measure direct and indirect trust, based on usage patterns of cloud resources and based on users' feedback, respectively.

6. Conclusion and Future Directions

Brokering is an essential part for providing aggregated services to cloud users. Broker helps CSPs to provide aggregate services on three levels i.e. IaaS, SaaS and PaaS. It also helps CSUs to get all types of services under one roof. A comprehensive survey of cloud brokering in interconnected cloud computing environment (ICCE) has been presented. Existing frameworks of ICCE, having cloud broker as one of the components, are discussed. Cloud brokering techniques are classified in different categories such as pricing, multi-criteria, optimization, QoS and trust based on the attributes. The strength and weaknesses/limitations of all surveyed techniques have been analyzed. Specific research directions and the various issues, challenges and open problems are explained. A model for cloud broker has been proposed.

The cloud broker model proposed in section 2.2 will be designed and developed for our future work. The model will efficiently address research problems of cloud service management. Efficient techniques for service discovery in ICCE will be proposed. ICCE consists of similar types of service offered by various CSPs. Techniques to efficiently address QoS parameters in ranking of various services will be proposed. Techniques effectively addressing QoS parameters in service selection will be proposed. Service allocation on desired platform so that it can fulfill QoS requirement is one of important research issue. It will be addressed by competent techniques. Cloud brokering inherently a multi-criteria optimization problem. QoS parameters such as price, availability, reliability, response time, execution time, etc are important in designing optimization techniques for service management.

CSUs are interested in trusted CSPs and various security parameters such as authentication, authorization, data integrity & privacy, identity management, etc. Techniques based on multi-agent and machine learning algorithms to address above problems will be proposed. Machine-learning-as-service is getting attention in cloud platforms. Monitoring various SLA parameters is also challenging task in ICCE. The proposed cloud broker will include monitoring-as-a-service component to address monitoring issues.

References

[1] M. Armbrust, A. Fox, R. Griffith, A. D. Joseph, R. Katz, A. Konwinski, G. Lee, D. Patterson, A. Rabkin, I. Stoica, M. Zaharia, A view of cloud computing, Commun. ACM 53 (4) (2010) 50–58.

[2] R. Buyya, C. S. Yeo, S. Venugopal, Market-oriented cloud computing: Vision, hype, and reality for delivering it services as computing utilities, in: 10th IEEE International Conference on High Performance Computing and Communications, 2008, pp. 5–13.

[3] D. Nurmi, R. Wolski, C. Grzegorczyk, G. Obertelli, S. Soman, L. Youseff, D. Zagorodnov, The eucalyptus open-source cloud-computing system, in: 9th IEEE/ACM International Symposium on Cluster Computing and the Grid, 2009, pp. 124–131.

[4] L. M. Vaquero, L. Rodero-Merino, J. Caceres, M. Lindner, A break in the clouds: Towards a cloud definition, SIGCOMM Comput. Commun. Rev. 39 (1) (2008) 50–55.

[5] P. Mell, T. Grance, The nist definition of cloud computing, http://www.nist.org.

[6] R. Buyya, S. Venugopal, A gentle introduction to grid computing and technologies, database 2 (2005) 3.

[7] C. Yeo, R. Buyya, H. Pourreza, R. Eskicioglu, P. Graham, F. Sommers, Cluster computing: High-performance, high-availability, and high-throughput processing on a network of computers, Handbook of nature-inspired and innovative computing (2006) 521–551.

[8] D. A. Menascé, Virtualization: Concepts, applications, and performance modeling, in: Int. CMG Conference, 2005, pp. 407–414.

[9] P.-C. Quint, N. Kratzke, Overcome vendor lock-in by integrating already available container technologies towards transferability in cloud computing for smes, The Seventh International Conference on Cloud Computing, GRIDs, and Virtualization (2016) 38–41.

[10] P. E. N, F. J. P. Mulerickal, B. Paul, Y. Sastri, Evaluation of docker containers based on hardware utilization, in: International Conference on Control Communication Computing India (ICCC), 2015, pp. 697–700.

[11] D. Bernstein, Containers and cloud: From lxc to docker to kubernetes, IEEE Cloud Computing 1 (3) (2014) 81–84.

[12] M. I. Sukmana, K. A. Torkura, F. Cheng, C. Meinel, H. Graupner, Unified logging system for monitoring multiple cloud storage providers in cloud storage broker, in: International Conference on Information Networking (ICOIN), IEEE, 2018, pp. 44–49.

[13] A. N. Toosi, R. N. Calheiros, R. Buyya, Interconnected cloud computing environments: Challenges, taxonomy, and survey, ACM Comput. Surv. 47 (1) (2014) 7:1–7:47.

[14] B. Rochwerger, D. Breitgand, E. Levy, A. Galis, K. Nagin, I. M. Llorente, R. Montero, Y. Wolfsthal, E. Elmroth, J. Caceres, M. Ben-Yehuda, W. Emmerich, F. Galan, The reservoir model and architecture for open federated cloud computing, IBM Journal of Research and Development 53 (4) (2009) 4:1–4:11.

[15] D. Petcu, Portability and Interoperability between Clouds: Challenges and Case Study, Springer Berlin Heidelberg, 2011, pp. 62–74.

[16] D. Bernstein, E. Ludvigson, K. Sankar, S. Diamond, M. Morrow, Blueprint for the intercloud - protocols and formats for cloud computing interoperability, in: Fourth International Conference on Internet and Web Applications and Services, 2009, pp. 328–336.

[17] T. Kurze, M. Klems, D. Bermbach, A. Lenk, S. Tai, M. Kunze, Cloud federation, in: The Second International Conference on Cloud Computing, GRIDs, and Virtualization, 2011, pp. 32–38.

[18] Egi federated cloud (2018).
URL `https://www.egi.eu/federation/egi-federated-cloud/`

[19] M. Rouse, Multi-cloud strategy.
URL `http://searchcloudapplications.techtarget.com/definition/multi-cloud-strategy`

[20] R. Buyya, R. Ranjan, R. N. Calheiros, Intercloud: Utility-oriented federation of cloud computing environments for scaling of application services, in: International Conference on Algorithms and Architectures for Parallel Processing, 2010, pp. 13–31.

[21] F. Fowley, C. Pahl, P. Jamshidi, D. Fang, X. Liu, A classification and comparison framework for cloud service brokerage architectures, IEEE Transactions on Cloud Computing PP (99) (2017) 1–1.

[22] E. Mostajeran, B. I. Ismail, M. F. Khalid, H. Ong, A survey on sla-based brokering for inter-cloud computing, in: Second International Conference on Computing Technology and Information Management (ICCTIM), 2015, pp. 25–31.

[23] N. Grozev, R. Buyya, Inter-cloud architectures and application brokering: taxonomy and survey, Software: Practice and Experience 44 (3) (2014) 369–390.

[24] M. Liaqat, V. Chang, A. Gani, S. H. Ab Hamid, M. Toseef, U. Shoaib, R. L. Ali, Federated cloud resource management: Review and discussion, Journal of Network and Computer Applications 77 (2017) 87–105.

[25] S. A. Flor, F. L. Pires, B. Barn, Auction-based resource provisioning in cloud computing. a taxonomy, in: Latin American Computing Conference (CLEI), 2015, pp. 1–11.

[26] C. C. Chang, K. C. Lai, C. T. Yang, Auction-based resource provisioning with sla consideration on multi-cloud systems, in: IEEE 37th Annual Computer Software and Applications Conference Workshops, 2013, pp. 445–450.

[27] C. Gu, S. Chen, J. Zhang, H. Huang, X. Jia, Reservation schemes for iaas cloud broker: a time-multiplexing way for different rental time, Concurrency and Computation: Practice and Experience 29 (16).

[28] R. Buyya, C. S. Yeo, S. Venugopal, J. Broberg, I. Brandic, Cloud computing and emerging it platforms: Vision, hype, and reality for delivering computing as the 5th utility, Future Generation Computer Systems 25 (6) (2009) 599 – 616.

[29] I. S. Organization, Information technology - cloud computing - overview and vocabulary (2014).

[30] B. Rochwerger, D. Breitgand, E. Levy, A. Galis, K. Nagin, I. M. Llorente, R. Montero, Y. Wolfsthal, E. Elmroth, J. Caceres, et al., The reservoir model and architecture for open federated cloud computing, IBM Journal of Research and Development 53 (4) (2009) 4–1.

[31] L. Schubert, K. Jeffery, B. Neidecker-Lutz, The future for cloud computing: Opportunities for european cloud computing beyond 2010 (public version 1.0) (2010).

[32] R. N. Calheiros, A. N. Toosi, C. Vecchiola, R. Buyya, A coordinator for scaling elastic applications across multiple clouds, Future Generation Computer Systems 28 (8) (2012) 1350–1362.

[33] M. Hogan, F. Liu, A. Sokol, J. Tong, Nist cloud computing standards roadmap, NIST Special Publication 35.

[34] Gartner, Gartner - cloud services brokerage (2013).
URL `http://www.gartner.com/it-glossary/cloud-services-brokerage-csb`

[35] C.-H. Youn, M. Chen, P. Dazzi, Machine-Learning Based Approaches for Cloud Brokering, 2017, pp. 191–212.

[36] C. Reiss, A. Tumanov, G. R. Ganger, R. H. Katz, M. A. Kozuch, Heterogeneity and dynamicity of clouds at scale: Google trace analysis, in: Proceedings of the Third ACM Symposium on Cloud Computing, ACM, 2012, p. 7.

[37] G. F. Anastasi, E. Carlini, M. Coppola, P. Dazzi, Qbrokage: A genetic approach for qos cloud brokering, in: IEEE 7th International Conference on Cloud Computing, 2014, pp. 304–311.

[38] Gartner, Gartner - cloud access security brokers (2017). URL `https://www.gartner.com/doc/3834266/magic-quadrant-cloud-access-security`

[39] G. Wang, C. Liu, Y. Dong, H. Pan, P. Han, B. Fang, Safebox: A scheme for searching and sharing encrypted data in cloud applications, in: International Conference on Security, Pattern Analysis, and Cybernetics (SPAC), IEEE, 2017, pp. 648–653.

[40] C. Liu, G. Wang, P. Han, H. Pan, B. Fang, A cloud access security broker based approach for encrypted data search and sharing, in: International Conference on Computing, Networking and Communications (ICNC), IEEE, 2017, pp. 422–426.

[41] A. Marosi, G. Kecskemeti, A. Kertesz, P. Kacsuk, Fcm: An architecture for integrating iaas cloud systems, in: The Second International Conference on Cloud Computing, GRIDs, and Virtualization, 2011, pp. 7–12.

[42] C. Sapuntzakis, D. Brumley, R. Chandra, N. Zeldovich, J. Chow, M. S. Lam, M. Rosenblum, Virtual appliances for deploying and maintaining software, in: 17th USENIX Conference on System Administration, LISA '03, USENIX Association, 2003, pp. 181–194.

[43] M. X. Makkes, C. Ngo, Y. Demchenko, R. Strijkers, R. Meijer, C. de Laat, Defining intercloud federation framework for multi-provider cloud services integration, IARIA, 2013.

[44] P. Pawluk, B. Simmons, M. Smit, M. Litoiu, S. Mankovski, Introducing stratos: A cloud broker service, in: IEEE Fifth International Conference on Cloud Computing, 2012, pp. 891–898.

[45] Z. Guan, T. Melodia, The value of cooperation: Minimizing user costs in multi-broker mobile cloud computing networks, IEEE Transactions on Cloud Computing PP (99) (2017) 1–1.

[46] H. D. Sherali, W. P. Adams, A reformulation-linearization technique for solving discrete and continuous nonconvex problems, Vol. 31, Springer Science & Business Media, 2013.

[47] L. Tang, S. He, Q. Li, Double-sided bidding mechanism for resource sharing in mobile cloud, IEEE Transactions on Vehicular Technology 66 (2) (2017) 1798–1809.

[48] H. Shen, G. Liu, H. Wang, An economical and slo-guaranteed cloud storage service across multiple cloud service providers, IEEE Transactions on Parallel and Distributed Systems PP (99) (2017) 1–1.

[49] M. Aazam, E. N. Huh, M. St-Hilaire, C. H. Lung, I. Lambadaris, Cloud customer historical record based resource pricing, IEEE Transactions on Parallel and Distributed Systems 27 (7) (2016) 1929–1940.

[50] R. Zhang, K. Wu, M. Li, J. Wang, Online resource scheduling under concave pricing for cloud computing, IEEE Transactions on Parallel and Distributed Systems 27 (4) (2016) 1131–1145.

[51] S. S. Rao, S. S. Rao, Engineering Optimization: Theory and Practice, John Wiley and Sons, 2009.

[52] L. Chamorro, F. Lpez-Pires, B. Barn, A genetic algorithm for dynamic cloud application brokerage, in: IEEE International Conference on Cloud Engineering (IC2E), 2016, pp. 131–134.

[53] R. Mehrotra, S. Srivastava, I. Banicescu, S. Abdelwahed, Towards an autonomic performance management approach for a cloud broker environment using a decomposition-coordination based methodology, Future Gener. Comput. Syst. 54 (C) (2016) 195–205.

[54] M. Nir, A. Matrawy, M. St-Hilaire, Economic and energy considerations for resource augmentation in mobile cloud computing, IEEE Transactions on Cloud Computing 6 (1) (2018) 99–113.

[55] W. Wang, D. Niu, B. Liang, B. Li, Dynamic cloud instance acquisition via iaas cloud brokerage, IEEE Transactions on Parallel and Distributed Systems 26 (6) (2015) 1580–1593.

[56] M. Aazam, E.-N. Huh, Broker as a service (baas) pricing and resource estimation model, in: IEEE 6th International Conference on Cloud Computing Technology and Science (CloudCom), 2014, pp. 463–468.

[57] A. S. Prasad, S. Rao, A mechanism design approach to resource procurement in cloud computing, IEEE Transactions on Computers 63 (1) (2014) 17–30.

[58] A. Mas-Colell, M. D. Whinston, J. R. Green, et al., Microeconomic theory, Vol. 1, Oxford university press New York, 1995.

[59] Y. Shoham, K. Leyton-Brown, Multiagent systems: Algorithmic, game-theoretic, and logical foundations, Cambridge University Press, 2008.

[60] A. Quarati, D. D'Agostino, Moea-based brokering for hybrid clouds, in: International Conference on High Performance Computing Simulation (HPCS), 2017, pp. 611–618.

[61] S. S. Wagle, Cloud service optimization method for multi-cloud brokering, in: IEEE International Conference on Cloud Computing in Emerging Markets (CCEM), 2015, pp. 132–139.

[62] N. Barr, Economics of the welfare state, Oxford University Press, 2012.

[63] S. Das, B. K. Panigrahi, Multi-objective evolutionary algorithms, in: Encyclopedia of artificial intelligence, IGI Global, 2009, pp. 1145–1151.

[64] C. Toinard, T. Ravier, C. Crin, Y. Ngoko, The promethee method for cloud brokering with trust and assurance criteria, in: IEEE International Parallel and Distributed Processing Symposium Workshop, 2015, pp. 1109–1118.

[65] M. Behzadian, R. B. Kazemzadeh, A. Albadvi, M. Aghdasi, Promethee: A comprehensive literature review on methodologies and applications, European journal of Operational research 200 (1) (2010) 198–215.

[66] E. Pacini, C. Mateos, C. G. Garino, A three-level scheduler to execute scientific experiments on federated clouds, IEEE Latin America Transactions 13 (10) (2015) 3359–3369.

[67] M. Dorigo, M. Birattari, Ant colony optimization, in: Encyclopedia of machine learning, Springer, 2011, pp. 36–39.

[68] J. Kennedy, Particle swarm optimization, in: Encyclopedia of machine learning, Springer, 2011, pp. 760–766.

[69] I. Patiniotakis, Y. Verginadis, G. Mentzas, Preference-based cloud service recommendation as a brokerage service, in: 2nd International Workshop on CrossCloud Systems, 2014, pp. 1–6.

[70] J. Siegel, J. Perdue, Cloud services measures for global use: The service measurement index (smi), in: Annual SRII Global Conference, 2012, pp. 411–415.

[71] R. Achar, P. S. Thilagam, A broker based approach for cloud provider selection, in: International Conference on Advances in Computing, Communications and Informatics (ICACCI), 2014, pp. 1252–1257.

[72] T. L. Saaty, Decision making with the analytic hierarchy process, International journal of services sciences 1 (1) (2008) 83–98.

[73] T. S. Somasundaram, K. Govindarajan, Cloudrb: A framework for scheduling and managing high-performance computing (hpc) applications in science cloud, Future Generation Computer Systems 34 (2014) 47 – 65.

[74] A. Amato, B. D. Martino, S. Venticinque, Cloud brokering as a service, in: Eighth International Conference on P2P, Parallel, Grid, Cloud and Internet Computing, 2013, pp. 9–16.

[75] K. M. Sim, Complex and concurrent negotiations for multiple interrelated e-markets, IEEE Transactions on Cybernetics 43 (1) (2013) 230–245.

[76] K. M. Sim, A marketdriven model for designing negotiation agents, Computational Intelligence 18 (4) (2002) 618–637.

[77] K. M. Sim, B. Shi, Concurrent negotiation and coordination for grid resource coallocation, IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics) 40 (3) (2010) 753–766.

[78] I. Rahwan, R. Kowalczyk, H. H. Pham, Intelligent agents for automated one-to-many e-commerce negotiation, Aust. Comput. Sci. Commun. 24 (1) (2002) 197–204.

[79] M. Malawski, G. Juve, E. Deelman, J. Nabrzyski, Cost- and deadline-constrained provisioning for scientific workflow ensembles in iaas clouds, in: International Conference for High Performance Computing, Networking, Storage and Analysis (SC), 2012, pp. 1–11.

[80] A. V. Dastjerdi, R. Buyya, A taxonomy of qos management and service selection methodologies for cloud computing, Cloud computing: methodology, systems, and applications (2011) 109–131.

[81] T. Kumrai, K. Ota, M. Dong, J. Kishigami, D. K. Sung, Multiobjective optimization in cloud brokering systems for connected internet of things, IEEE Internet of Things Journal 4 (2) (2017) 404–413.

[82] J. Gubbi, R. Buyya, S. Marusic, M. Palaniswami, Internet of things (iot): A vision, architectural elements, and future directions, Future generation computer systems 29 (7) (2013) 1645–1660.

[83] M. Rosa, B. Moura, G. Vergara, L. Santos, E. Ribeiro, M. Holanda, M. E. Walter, A. Arajo, Bionimbuz: A federated cloud platform for bioinformatics applications, in: IEEE International Conference on Bioinformatics and Biomedicine (BIBM), 2016, pp. 548–555.

[84] S. Tayeb, M. Mirnabibaboli, L. Chato, S. Latifi, Minimizing energy consumption of smart grid data centers using cloud computing, in: IEEE 7th Annual Computing and Communication Workshop and Conference (CCWC), 2017, pp. 1–5.

[85] B. Wickremasinghe, R. N. Calheiros, R. Buyya, Cloudanalyst: A cloudsim-based visual modeller for analysing cloud computing environments and applications, in: IEEE International Conference on Advanced Information Networking and Applications, 2010, pp. 446–452.

[86] J. L. L. Simarro, R. M. Vozmediano, F. Desprez, J. R. Cornabas, Image transfer and storage cost aware brokering strategies for multiple clouds, in: IEEE 7th International Conference on Cloud Computing, 2014, pp. 737–744.

[87] A. Amato, S. Venticinque, Multiobjective optimization for brokering of multicloud service composition, ACM Trans. Internet Technol. 16 (2) (2016) 13:1–13:20.

[88] D. Rane, A. Srivastava, Cloud brokering architecture for dynamic placement of virtual machines, in: IEEE 8th International Conference on Cloud Computing, 2015, pp. 661–668.

[89] A. Q. Nguyen, P. Bouvry, E. G. Talbi, A new model for vmmp dealing with execution time uncertainty in a multi-clouds system, in: IEEE 4th International Conference on Cloud Networking (CloudNet), 2015, pp. 165–170.

[90] G. Oddi, M. Panfili, A. Pietrabissa, L. Zuccaro, V. Suraci, A resource allocation algorithm of multi-cloud resources based on markov decision process, in: IEEE 5th International Conference on Cloud Computing Technology and Science, Vol. 1, 2013, pp. 130–135.

[91] M. Puterman, Markov decision processes : discrete stochastic dynamic programming, John Wiley and Sons, 2014.

[92] D. J. White, Markov decision processes, Wiley Online Library, 1993.

[93] G. H. S. Carvalho, I. Woungang, A. Anpalagan, L. Barolli, M. Takizawa, Optimal cloud broker method for cloud selection in mobile inter-cloud computing, in: 9th International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing, 2015, pp. 239–244.

[94] B. Kim, C.-H. Youn, Y.-S. Park, Y. Lee, W. Choi, An adaptive workflow scheduling scheme based on an estimated data processing rate for next generation sequencing in cloud computing, Journal of Information Processing Systems 8 (4) (2012) 555–566.

[95] K. Tsakalozos, V. Verroios, M. Roussopoulos, A. Delis, Live vm migration under time-constraints in share-nothing iaas-clouds, IEEE Transactions on Parallel and Distributed Systems 28 (8) (2017) 2285–2298.

[96] N. Sfondrini, G. Motta, Slm-as-a-service - a conceptual framework, in: IEEE 2nd International Conference on Cloud Computing and Big Data Analysis (ICCCBDA), 2017, pp. 241–245.

[97] M. Hamze, N. Mbarek, O. Togni, Broker and federation based cloud networking architecture for iaas and naas qos guarantee, in: 13th IEEE An-

nual Consumer Communications Networking Conference (CCNC), 2016, pp. 705–710.

[98] A. Quarati, A. Clematis, D. DAgostino, Delivering cloud services with qos requirements: Business opportunities, architectural solutions and energy-saving aspects, Future Generation Computer Systems 55 (2016) 403–427.

[99] M. Aazam, E. N. Huh, Advance resource reservation and qos based refunding in cloud federation, in: IEEE Globecom Workshops (GC Wkshps), 2014, pp. 139–143.

[100] E. Badidi, A context broker federation for qoc-driven selection of cloud-based context services, in: The 9th International Conference for Internet Technology and Secured Transactions (ICITST-2014), 2014, pp. 185–190.

[101] E. Lim, P. Thiran, Communication of technical qos among cloud brokers, in: IEEE International Conference on Cloud Engineering, 2014, pp. 403–409.

[102] D. DAgostino, A. Galizia, A. Clematis, M. Mangini, I. Porro, A. Quarati, A qos-aware broker for hybrid clouds, Computing 95 (1) (2013) 89–109.

[103] Y. Mansouri, A. N. Toosi, R. Buyya, Brokering algorithms for optimizing the availability and cost of cloud storage services, in: IEEE 5th International Conference on Cloud Computing Technology and Science, Vol. 1, 2013, pp. 581–589.

[104] A. Ghosh, I. Arce, Guest editors' introduction: In cloud computing we trust - but should we?, IEEE Security Privacy 8 (6) (2010) 14–16.

[105] X. Li, H. Ma, F. Zhou, X. Gui, Service operator-aware trust scheme for resource matchmaking across multiple clouds, IEEE Transactions on Parallel and Distributed Systems 26 (5) (2015) 1419–1429.

[106] S. Sharif, P. Watson, J. Taheri, S. Nepal, A. Y. Zomaya, Privacy-aware scheduling saas in high performance computing environments, IEEE Trans. Parallel Distrib. Syst. 28 (4) (2017) 1176–1188.

[107] C. Liu, G. Wang, P. Han, H. Pan, B. Fang, A cloud access security broker based approach for encrypted data search and sharing, in: International Conference on Computing, Networking and Communications (ICNC), 2017, pp. 422–426.

[108] Gartner, How to evaluate and operate a cloud access security broker (2015).
URL `https://www.gartner.com/doc/3176323/evaluate-operate-cloud-access-security`

[109] J. Li, A. C. Squicciarini, D. Lin, S. Sundareswaran, C. Jia, Mmb^{cloud} -tree: Authenticated index for verifiable cloud service selection, IEEE Transactions on Dependable and Secure Computing 14 (2) (2017) 185–198.

[110] L. Barreto, J. Fraga, F. Siqueira, Conceptual model of brokering and authentication in cloud federations, in: 2015 IEEE 4th International Conference on Cloud Networking (CloudNet), 2015, pp. 303–308.

[111] N. Pustchi, R. Krishnan, R. Sandhu, Authorization federation in iaas multi cloud, in: 3rd International Workshop on Security in Cloud Computing, 2015, pp. 63–71.

[112] OpenStack, `http://www.openstack.org/` (2017).

[113] W. Abderrahim, Z. Choukair, Trust assurance in cloud services with the cloud broker architecture for dependability, in: IEEE 17th International Conference on High Performance Computing and Communications (HPCC), 2015, pp. 778–781.

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