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# Auction-based resource allocation mechanisms in the cloud environments: A review of the literature and reflection on future challenges

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## Summary

Cloud computing is an Internet-based computing and networking model, with elasticity and scalability capabilities where the services are delivered to its users in a non-demand style. In this computing paradigm, the request and response between users and providers must be managed using the resource allocation strategies. Therefore, allocating the provided resources to the users based on their needs is the important challenge in this environment. Also, an auction in the cloud is a process of buying and vending the cloud services by offering them up for bid and then selling the service to the highest bidder. However, to the best of our knowledge, there has not been any comprehensive and detailed paper about reviewing the state-of-the-art mechanisms on this important topic and providing open issues as well. Hence, this paper provides a comprehensive survey and review of the auction-based resource allocation mechanisms, which have been employed in the cloud environments up to now. Also, we classified the important cloud resource allocation mechanisms into four categories: one-sided, double-sided, combinatorial, and other types of auction-based mechanisms. Moreover, we reviewed the main progress in these four categories and defined the new issues. Finally, the paper offers the differences among reviewed mechanisms as well as guidelines for future investigation.

**KEYWORDS**
auction, cloud computing, resource allocation, review

## 1 | INTRODUCTION

Cloud computing is a new commercial model for the pervasive, convenient, and on-demand access to the virtualized and distributed resources that can be provisioned and released with low administration effort.[1-3] It is a kind of distributed system including a group of unified and virtualized resources based on service level agreements (SLAs) between the service providers and customers.[4,5] The Information Technology (IT) companies are offering many kinds of the cloud services, from the software and web application to storage and mail services.[6-8] The service models for the cloud includes many types such as Software as a Service (SaaS), which provides software applications as services using a web browser; Platform as a Service (PaaS), which provides the tools to create and host web application; Infrastructure as a Service (IaaS), which provides storage and computing clusters; and Expert as a Service (EaaS), which enables the users for requesting the skill and knowledge of people.[9-12]

Service-driven, self-healing, scalability, low costs, multi-faceted, and dependability are the main benefits of the cloud computing. However, there are numerous issues in the cloud environment, including a vulnerability, bandwidth costs, transparency access, trust, reliability, security, availability, resource management, task scheduling, and performance.[13,14] One of the most important parts of resource management component in the cloud is the resource provisioning.[15] It delivers suitable resource allocation to Virtual Machines (VMs) for matching the workloads. Resource provisioning also provides a virtual cluster with adequate instances and makes it ready for execution. Additionally, before the cloud providers provide a service to the consumers, the allocation mechanism needs to establish an SLA. Therefore, resource allocation has a significant impact in all types of provided services in the cloud environments for allocating the resources properly to the customers in order to perform their requests with low delay and infrastructure cost in a pay-per-use fashion.[16-19]

  

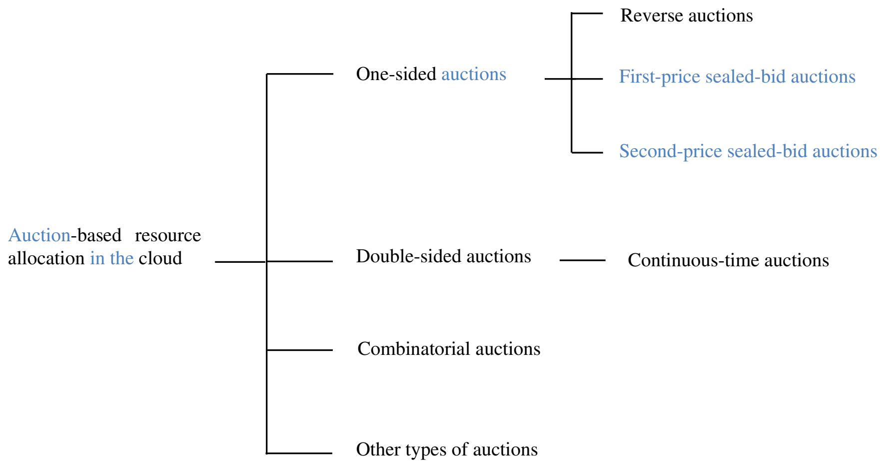


**FIGURE 1** A taxonomy of the cloud resource allocation mechanisms

However, in spite of the importance of the resource allocation approaches in the cloud environments, as far as we know, there has not been any complete and thorough paper reviewing the state-of-the-art mechanisms on this important topic and providing open issues as well.[20] Also, since resource allocation plays an important role in the cloud computing, the main aim of this paper is to review the current techniques and to outline some important challenges in this domain. For a better analysis of the resource allocation mechanisms in the cloud computing, in this paper, we divided them into four main categories, including one-sided, double-sided, combinatorial, and other types of auction-based mechanisms. Figure 1 presents the taxonomy of the cloud resource allocation mechanisms. As far as we know, this paper is the first effort to study the categorized resource allocation mechanisms with an exact emphasis on cloud computing and providing the future challenges. In a nutshell, the main contributions of the study are as follows:

- providing a review of the significant issues in a problem domain related to cloud resource allocation;
- overviewing the state-of-the-art methods for resource allocation and the technique they have been used in the cloud computing;
- exploring the open issues along with some suggestions to address them in the future.

The remainder of the paper is structured as follows. Section 2 summarizes some related works. Section 3 provides a discussion about resource allocation mechanisms in the cloud system and categorizes them. Section 4 offers the comparison of the reviewed mechanisms. Section 5 maps out some important open issues as future work. Finally, Section 6 concludes the paper.

## 2 | RELATED WORK

In this section, some review research works about resource allocation in the cloud environment have been carried out. This section will mention some review papers that discussed cloud resource allocation mechanisms and outline their main advantages and disadvantages to determine the difference between this paper and them.

One of the notable surveys about resource allocation in the cloud computing has been presented by Parikh.[21] The author has concluded that an efficient resource allocation method should meet following criteria such as cost reduction, power reduction, energy reduction, Quality of Service (QoS) enhancement, and utilization of resources. However, this study reviews few papers without any classification.

Furthermore, Anuradha and Sumathi[22] have reviewed resource allocation approaches in the cloud computing. They have classified few papers in four classes: an adaptive resource management, priority-based, dynamic, and utility functions resource allocation. They have concluded that genetic algorithm may give a better solution to recognize an efficient approach for resource allocation. However, in this paper, few articles are reviewed.

Also, Vinothina and Sridaran[23] have classified a few resource allocation methods into nine categories: SLA, policy, VM, application, gossip, utility, auction, hardware resource dependency, and execution time. Some of the methods mainly focus on processor and memory resources but are lacking in some factors. However, few articles have been reviewed and there is a gap for discussion of the open issue. Also, the recently published articles are not included in this paper.

Finally, Kumar et al[24] have discussed the double auction mechanisms in detail for cloud systems. They have calculated that a Truthful Multi-unit Double Auction mechanism (TMDA) can create high welfare for both the users and providers. However, they only have focused on double-sided auctions and other categories of the auction such as the combinatorial auction, and one-sided have not been studied.

Briefly, the previous review papers suffer from some weakness as follows:

1. The papers did not contain the novel proposed resource allocation mechanisms especially in 2016 and 2017.

2. Some papers did not consider the QoS parameters for analyzing the methods.
3. Many papers did not present any reasonable categorization of resources allocation mechanisms in the cloud.
4. Some papers did not provide the future challenges of resources allocation mechanisms in the cloud computing.
5. Some papers did not study entire categories of the auction in the cloud resource allocation mechanisms.
6. The mentioned reasons moved us to develop a survey paper on resources allocation mechanisms in the cloud computing to overcome all of these lacks.

## 3 | RESOURCE ALLOCATION MECHANISMS

Cloud computing as a popular type of distributed systems provides some mechanisms and infrastructures to share autonomous and geographically distributed resources efficiently.[25,26] In the cloud, there are various kinds of resources such as processors, a cluster of computing devices, storage space, online tools, data, information, and applications.[27] Therefore, allocating resources is a complex process involving multi-attribute and range queries dealing with the provision of the services according to the requirements of resource providers and users.[28] It is the procedure of allocating suitable resources to the requesters over the Internet. Resource allocation mechanisms should keep a record of each resource statuses in order to employ appropriate mechanisms to better allocate the resources to the requesters and consequently improve the operational cost. If the allocation process is not managed properly, some services may not be provided to the requesters.[29] Also, the auction is a primary market mechanism studied in various instances for selling commodities. An auction-based resource allocation is a market approach to expand and leverage the demand and supply resources in cloud computing. Both customers and providers do their effort to enhance their usefulness through an appropriate resource allocation mechanism in the market. Customers solicit their needs for resources with bids, and the winner will assign the resources by a specified auction mechanism.[30] In this section, some important resource allocation mechanisms are reviewed in four categories: one-sided, double-sided, combinatorial, and other types of auction-based mechanisms.

### 3.1 | One-sided auction-based mechanisms

In this section, we describe the one-sided auction-based mechanisms for resource allocation and their main features. Second, we discuss several significant mechanisms in this category. Finally, the reviewed auction-based mechanisms are compared and summarized in Section 3.1.3.

#### 3.1.1 | Overview of the one-sided auction-based mechanism

In a sealed-bid auction, bidders submit their bids at a given time and are not aware of each other's bids. In this type of auction mechanism, the highest bidder wins the resources. Vickrey[31] has proposed an auction method known as the second price sealed auction that is called Vickrey Auction. In this auction, bidders submit sealed bids, and the second highest bidder earns the product. It is clear that this method provides a benefit to the buyers than the sellers.[32] A reverse auction is another popular auction method employed by large organizations in which the buyer control the process.[33] Services are offered by a number of sellers, and they compete to get a deal. The lower the price, the higher is the chance of a sale. This method can be accessed online, through web browsers, unlike the traditional counterparts. The reverse auction's procedure starts with the posting a Request For Quote (RFQ) to a website from the buyer. After posting the RFQ, selected suppliers are invited to bid. Opposite to the aforementioned ones, this model benefits the buyers more than the sellers.[34] The next sub-section reviews several important one-sided auction-based mechanisms for resource allocation.

#### 3.1.2 | Popular one-sided auction-based mechanisms

In this section, the important one-sided auction-based mechanisms for resources allocation in the cloud environments are analyzed and discussed.

Lin et al[18] have offered a second-price sealed-bid auction mechanism for cloud resource allocation mechanisms. They have proposed a Vickrey auction based on a haring-out process for the cloud computing with the help of a rating approach. It guarantees privacy and security using some security of offered services features such as enforcing firewall policies.[35] When each period starts, customers show their bids to the provider. The offers are collected by the cloud provider, and the price is also determined. The resources are allocated to the first $k^{th}$ highest bidders. Cloud providers employ a truth-telling method since customers' payments are determined by their own bids. The revenue of the provider and the system efficiency has been enhanced. Another important characteristic of this process is its flexibility. However, it has some disadvantages such as the shortage of a suitable simulation and examination of the performance of the model. Also, the system could not clearly cope with SLA violation.

Wang et al[36] have introduced reverse auction to answer the resources allocation problem in the cloud environment that called Reverse Batch Matching Auction (RBMA). Three types of participants are supposed, Cloud Resource Consumer (CRC), Cloud Resource Provider (CRP), and Auction Intermediary (AI). The CRP is an entity owning the resources; the CRC is an entity that requests to lease resources and the AI control the whole process. The batch-matching mechanism lets the AI waits for the more CRC to send bids; thus, it develops the reverse auction mechanism from 1 CRC with *N* CRP to *N* CRC with *N* CRP. The twice-punishment mechanism is also employed to punish the CRC and the CRP once the fee is not reasonable. The resource allocation mechanism also employs an Immune Evolutionary Algorithm (IEA) to calculate the optimal allocation policy. The RBMA also uses the customer's feedback for representing the customer's satisfaction with the service offering of the resource. The model is effective and feasible and can progress the market effectiveness, service quality, and the resource utilization. However, the resources are not classified at any adequate level of details.

In the work of Hu et al,[37] the resource allocation based on first-price sealed-bid auction under a game theoretic framework has been proposed for the cloud systems. Each buyer can create its tasks with multiple levels of priorities. Thus, the same resource may be different for several buyers according to their prioritized requests. The resource allocation game proceeds in three stages. Firstly, each buyer tries to find non-malicious resource providers. Secondly, the information about providers' bidders is disclosed. Finally, a bid strategy adjustment will be done to bid for another resource when it finds that this resource can improve the value of its utility. The profit of the cloud providers and the users have been improved in this model. However, the system could not clearly indicate the execution time and the computational efficiency.

In the work of Li et al,[38] a dynamic pricing strategy based on reverse auction has been proposed that is called the Dynamic Pricing-Based Allocation Mechanism (DPAM). The cloud providers can change the resource price to boost the chances of selling and to improve competitiveness. The users select the best resource as the winner of the auction if it has a minimum value for the equation "*completion time* × *monetary cost*". The results have shown that the proposed strategy achieves the faster completion time, maximum resources utilization, and lower monetary cost. However, they did not consider any standard scientific datasets to run experiments for increasing the credibility of the results nor other QoS attributes such as response time, service providers' reputation, and reliability.

### 3.1.3 | Summary of the reviewed mechanisms

A one-sided auction technique assists cloud users to state their favorites from the number of existing resources in the clouds using their requirement through bids to reach resource. Table 1 summarizes the discussed one-sided auction-based mechanisms and presents their benefits and drawbacks.

## 3.2 | Double-sided auction-based mechanisms

In this section, we first describe the double-sided auction-based mechanisms for resource allocation and their basic features. Second, we discuss several most popular double-sided auctions for cloud resource allocation mechanisms. Finally, the discussed double-sided auction-based mechanisms are compared and summarized in Section 3.2.3.

**TABLE 1** Popular one-sided auction-based mechanisms and their properties

| Mechanism | Main idea | Advantages | Disadvantages |
|---|---|---|---|
| Lin et al[18] | They have proposed the deadline-constrained schema and distributed resource infrastructure for a virtual economy. | • High performance of the system<br>• High revenue for the cloud provides<br>• Low response time | • Lack of an appropriate simulation<br>• Low revenue for the user |
| Wang et al[36] | They have proposed a deadline-constrained resource allocation method based on reverse auction by adding the idea of batch matching. | • High efficiency<br>• High resource utilization<br>• High revenue for the cloud providers<br>• High service quality<br>• High user satisfaction | • Low revenue for the user<br>• Without classifying the resources at any sufficient level of detail |
| Hu et al[37] | They have proposed a deadline-constrained resource allocation based on a first-price sealed-bid auction by adding the idea of game theoretic. | • High revenue for the cloud provides<br>• High revenue for the users | • Without consideration of computational efficiency<br>• Without consideration of execution time |
| Li et al[38] | They have proposed a reverse auction by adding a dynamic pricing strategy. | • High resources utilization<br>• High revenue for the cloud provides provides<br>• High revenue for the user<br>• Low completion time<br>• Low execution time<br>• Low monetary cost | • Without consideration of reliability<br>• Without consideration of response time<br>• Without consideration of service providers' reputation |

#### 3.2.1 | Overview of the double-sided auction-based mechanism

In a double-sided auction, both the providers and the users rendered ask and bids. To patronize a neutral trade between the cloud users and providers, the model must use the double-sided auction model.[39] In a double-sided auction, the submitted tenders are requested by both the users and the providers, which are efficient than one-sided auctions. To encourage a reasonable interaction between the cloud providers and the users, the double-sided auction model is preferred over the conventional ones.[39] The Continuous Double Auction (CDA) is a mechanism for matching buyers and sellers of a service to define the prices at which trades are executed periodically. In this method, buyers' bid and sellers' offers may be submitted at any time during the trading period for which priority ranking is assigned, and they are listed based on the rank. If, at any given period, there are open requests and bids that match the prices and requirements, a trade is executed immediately.[40] The next sub-section reviews some important double-side auction-based mechanisms for resource allocation.

#### 3.2.2 | Popular double-sided auction-based mechanisms

In this section, some popular and applicable double-sided auction-based mechanisms for appropriate resources allocation in the cloud environments are discussed.

Wang et al[41] have proposed the Double Multi-Attribute Auction (DMAA) mechanism that allows multiple providers and consumers to trade in the market simultaneously. They also have considered multiple attributes, eg, price and non-price attributes. A Support Vector Machine (SVM) algorithm is also designed to predict the price and the Mean-Variance Optimization (MVO) algorithm is used for determining the auction winners. The simulation results have shown that proposed mechanism increases the total utilization of the resources. However, there are no optimal bidding prices for multiple users and optimal bidding strategies. The DMAA also achieves the higher execution time.

Jin et al[42] have proposed a double auction model called an Incentive-Compatible Auction Mechanism (ICAM) for the resource mapping between buyers and sellers. The ICAM proceeds in three stages. Firstly, the auctioneer determines a winning buyer for each seller. Secondly, the authors firmly couple winner determination and pricing to avoid possible untruthful actions of buyers. Finally, the auctioneer allows one buyer to acquire resources from one seller. However, this approach does not consider the resource demands of multiple users, and it does not encourage competition either between buyers or sellers.

Finally, Wu et al[43] have presented an automatic mechanism of resource allocation in the self-organizing cloud environment. They have presented two mechanisms, the Modified Vickrey auction (MVA) and the CDA, to implement dynamic pricing and resource allocation. They also supposed that the buyers are auctioneers and the sellers are bidders. Experiment results have shown that the CDA-based model is fit when the resource is inadequate and the MVA model is suitable when the resource is sufficient. Delivery of the appropriate resources with the minimal cost to the consumers is considered as a benefit of this mechanism. However, offering motivation for consumers to contribute their resources or to use others' resources and the QoS parameters have not been considered.

#### 3.2.3 | Summary of the reviewed mechanisms

Table 2 summarizes the discussed double-sided auction-based mechanisms and introduces their benefits and disadvantages.

### 3.3 | Combinatorial auction-based mechanisms

In this section, we represent the combinatorial auction-based methods for resource allocation and their basic properties. Then we deliberate several most popular combinatorial auction-based mechanisms for cloud resource allocation. Finally, the discussed combinatorial auction-based mechanisms are compared in Section 3.3.3.

**TABLE 2** Popular double-sided auction-based mechanisms and their properties

| Mechanism | Main idea | Advantages | Disadvantages |
|---|---|---|---|
| Wang et al[30] | They have proposed three methods MVO, SVM, and NNA for allocation, pricing, and QoS management, respectively. | • High resource utilization<br>• High user satisfaction | • High execution time |
| Jin et al[42] | They have offered an incentive auction for the resource mapping between cloud providers and users. | • High resource utilization<br>• High revenue for the cloud provides<br>• High revenue for the users<br>• High user satisfaction | • One-to-one matching manner |
| Wu et al[43] | They have offered an incentive for the providers to report the price based on their conditions. | • High execution efficiency<br>• High revenue for the cloud provides<br>• Low monetary cost | • Without considering of contributing resources of consumers<br>• Without ensuring the QoS proposed |

#### 3.3.1 | Overview of the combinatorial auction-based mechanism

A combinatorial auction is one the useful auction mechanisms in the cloud environment for resource allocation. It is an extended form of the auction for cloud where an auctioneer suggests a group of resources in form of bundles and bidders offer for these bundles. In other words, the combinatorial auction or the combination for a workflow property is considered as suggesting more than two resource types. As the auction is executed over the collection of items, it is helpful to both the buyer and the seller. It contributes greatly to progress the income and allocation efficiency.[44,45] The next sub-section offers a review and survey of several important combinatorial auction-based mechanisms of resource allocation.

#### 3.3.2 | Popular combinatorial auction-based mechanisms

In this section, many common and applicable combinatorial auction-based mechanisms of resources allocating in the cloud environments are discussed.

Auction-BasedResource co-Allocation (ABRA) model has been suggested by Ozer and Ozturan.[46] The model assigns the penalty costs to the unallocated resources after the auction. Decreasing the number of unallocated resources and increasing the total utilization of the resources provide an enhanced the resources allocation effectiveness. Integer linear programming is also employed in this model. For each resource instance, a penalty cost as a fixed price is considered. This model increases the full amount revenue of the service providers by improving the allocation rate.

Moreover, five new heuristics based on neighbor selection methods have been proposed by Ozer and Ozturan.[46] These methods are simulated annealing, threshold accepting, list-based threshold accepting, variable neighborhood search, and GA. The ABRA problem has been solved well using variable neighborhood search algorithm and GA. However, these methods have not considered the benefits of the users.

Also, Zaman and Grosu[47] have combined the auction-based and VM-based mechanisms and have created a new hybrid approach for resource allocation. They have suggested combinatorial auction which is called CA-Provision, which is handled with dynamic VM provisioning. In the cloud market, the dynamic VM provisioning is reflected using the demand and supply when an auction is executed. Customers must pay a reserve price, which is determined by the cloud providers. It has some benefits and disadvantages. Improving the utilization, the efficiency of allocation, and income for the cloud providers are the most important advantages of this mechanism. However, the benefit of users has not been considered in this mechanism.

Furthermore, Xing-Wei et al[48] have suggested a resource allocation method, which is based on the English combinatorial auction in the cloud environment. An enhanced auction model is employed at first, and then the ribbon capacity is considered to define the storage capacity of users. Next, the resource trading fee between resource buyers and providers is considered using the English combinatorial auction model. Finally, the best resource allocation solution is discovered based on a GA. The method is both effective and feasible, which increases the seller's profit and decreases the execution time of the process. However, the benefit of users is not considered.

Zaman and Grosu[49] have combined auction-based and VM-based mechanisms and have created a hybrid approach. They have proposed the enhanced mechanism based on the proposed method in their previous work,[47] which is called CA-Provision. CA-Provision collects offers from users, calculates the offer density for all offers, and sorts the offers based on their offer density. Then, it analyzes the reserve price and removes offers whose offer density fell below the reserve price. Afterward, it assigns computing resources to the users in the sorted order. Lastly, it computes the payment of each winning user to be paid to the cloud providers. This fee is the least value that a winning user must pay to get the requested resources. Other losing users pay nothing. The mechanism enhances the cloud resources utilization and yields higher revenue for the cloud providers. However, the benefit of users has not also been considered.

Moreover, Huu and Tham[50] have proposed a new allocation and cloud pricing model using combinatorial auction mechanisms. Three algorithms have been suggested to define the winners and to calculate the payment accordingly: green greedy algorithm, linear relaxation based randomized algorithm, and exhaustive search algorithm. Exhaustive search algorithm and linear relaxation based randomized algorithm utilize the objective function to calculate the total users' bid values, while the green greedy algorithm uses the energy consumption of users' resource bundles. Among these algorithms, the green greedy algorithm provides high revenue, whereas the entire consumed energy by winners' is less. However, the benefit of users has not been considered.

Wang et al[33] have proposed an intelligent combinatorial auction-based resource allocation method in the cloud computing that is called Multi-Attribute Auction Mechanism (MAAM). First, the frameworks of allocation mechanism are built, and afterward, tender descriptions are given. Second, a Support Vector Regression (SVR)–based method is assumed to convert a combination request into multiple single-resource requests. Third, the emotional parameter is sent for bidding approach and tender evaluation mechanism for determining an optimal tender of the CRP. Lastly, a reputation system is offered to deal with possible malicious activities in the auction market. The mechanism is fair and effective. Also, improving resource utilization on some conditions was an advantage of this mechanism. However, some metrics such as the energy consumption was not mentioned.

Furthermore, Samimi et al[39] have suggested a combinatorial double auction-based algorithm that is called Combinatorial Double Auction Resource Allocation (CDARA). Their model includes four entities: user, broker, cloud providers, and cloud marketplace. The broker is an entity that acts as a proxy between a buyer and seller. It is responsible for service and resource discovery,[51] possible service compositions, corresponding bid generating for each combination, and forwarding the user requests to the corresponding cloud providers. Cloud information service (CIS) also enables cloud providers to demonstrate their features and helps users to find their desired services.[39] When the offers of resources on the CIS are delivered, the brokers and the cloud providers send their bids to the auctioneer. In the next phase, the broker's requests and the cloud providers' offers are sorted based on their attributes (processor, memory, storage, and bandwidth). Afterward, the broker's/the cloud providers' lists are sorted in an descending/ascending order based on the bid density $\left(\frac{\text{user's bid}}{\sqrt{\text{total number of request items}}} \times t_i \text{ and } \frac{\text{The cloud provider's bid}}{\sqrt{\text{total number of offer items}}}\right)$. The request from the first broker is satisfied by the first cloud providers. In case the first cloud providers fail to answer to the request of the first broker, the next cloud providers are checked. Upon the completion of the first broker's request, it will proceed to the next sorted request of a broker. The algorithm is cost-effective, efficient, and rigorous for both the cloud providers and the user while producing higher revenues for the users and providers. The problem with this technique is that categorization of the bidders happens only based on the price. No penalty will be imposed by the provider when they fail to deliver service in question. Furthermore, there is no way to provide fairness among bidders.[52]

In the work of Nejad and Sabzevari,[53] the Imperialist Competitive Algorithm (ICA) has been used to define the winners of an auction after receiving the bid bundles. The objective function is performed by the sum of bided prices of auction winners, where bided price of users is a positive number and bided price of providers is a negative number. The high value of cost function shows the increase of winner users. The proposed algorithm is compared with GA, where the simulation results have confirmed that it has higher performance than GA in term of the speed of convergence and number of winner participants. It also increases the profits of users and providers. However, the mechanism can be affected by untruthful bidding.

Xu[54] has developed a combinatorial double auction mechanism for resource allocation in the cloud computing called CDA-CCRA that satisfies the demands of users and providers. The CDA-CCRA model is derived by a linear integer programming-based optimization method for determining the winner. The pricing model used in their study is the same as the model proposed by Li et al,[55] and their fitness function is to maximize the total profit. They compared the performance of the CDA-CCRA model against the performance of the Min-Max method and the DA-CCRA model.[56] Experiment results showed that it achieves maximum revenue of both users and providers and the utilization of the resources. However, the model does not avoid possible untruthful actions.

Nehru et al[57] have introduced a combinatorial auction-based dynamic model called the CA-Provision algorithm that avoids untruthful actions of users in cloud environments. The CA-Provision algorithm consists of three phases: 1) collecting the bids from the users; 2) determining the winner; 3) calculating the payment based on the usage of the resources. Simulation results showed that the provider's revenue is increased and truthfulness can be attained. However, some of the issues including efficient pricing mechanisms, VM migration techniques, security, privacy, and heterogeneity are not studied and discussed.

Finally, in the work of Sheikholeslami and Navimipour,[45] we have applied multi-objective Particle Swarm Optimization based on Crowding Distance (MOPSO-CD) to solve the auction-based resource allocation problem in the cloud environment. We have used six metrics, total utilization, total revenue of users, total revenue of providers, execution time, spacing metric, and the generational distance metric. In addition, the fuzzy set theory is employed to determine the best agreement solution. The experiments results proved that the proposed method can reduce computational complexity while creating higher incomes for both the users and providers. Also, it is evident that the proposed method can significantly enhance the resource utilization. However, studying the behavior of the proposed method in the case of various weighting parameters is not considered.

#### 3.3.3 | Summary of the reviewed mechanisms

Recently, combinatorial auctions have received notable regard. In the combinatorial auctions, the distributed resources, including the computing resource, storage resource, network bandwidth and so on, can cooperate with each other to perfect the tasks of the users.[45,55] Table 3 summarizes the discussed mechanisms and introduces their advantages and disadvantages.

### 3.4 | Other types of auction-based mechanisms

In this section, we first describe the other types of auction-based mechanisms for resource allocation and their basic properties. Second, we discuss several current hybrid mechanisms of resource allocation. Finally, the discussed hybrid mechanisms are summarized in Section 3.4.3.

#### 3.4.1 | Overview of the other types of auction-based mechanism

The truthful virtualized auction, proportional share auction, and multi-agent auction have also been applied to recognize different variants of auction-based cloud resource allocation mechanisms. The next sub-section provides a review and survey of many important other types of auction-based mechanisms of resource allocation.

#### 3.4.2 | Popular other types of auction-based mechanisms

In this section, some popular and appropriate other types of auction-based mechanisms of proper resources allocation in cloud environments are discussed.

**TABLE 3** Popular combinatorial auction-based resource allocation methods and their properties

| Mechanism | Main idea | Advantages | Disadvantages |
|---|---|---|---|
| Ozer and Ozturan[46] | They have proposed ABRA model with a heuristic algorithm. | • High resource utilization<br>• High revenue for the cloud provides | • Without considering the users' benefit |
| Zaman and Grosu[47] | They have proposed a deadline-constrained provisioning with using reserve price ensured for the resource. | • High resource utilization<br>• High revenue for the cloud provides<br>• Low monetary cost | • High execution time<br>• Without considering the users' benefit |
| Xing-Wei et al[48] | They have classified the resources using the GAs. | • High revenue for the cloud provides<br>• Low execution time | • High monetary cost<br>• Without considering the users' benefit |
| Zaman and Grosu[49] | They have proposed a deadline-constrained schema by consideration the users' demand when provisioning VM instances. | • High resource utilization<br>• High revenue for the cloud provides<br>• Low monetary cost<br>• Monotone allocation function | • High execution time<br>• Without considering the users' benefit |
| Huu and Tham[50] | They have considered the energy consumption as a parameter. | • High resource utilization<br>• High revenue for the cloud<br>• Low energy consumption<br>• Low execution time<br>• Low monetary cost<br>• Monotone allocation function | • Without considering the users' benefit |
| Wang et al[58] | They have considered the combinatorial demand and the malicious behavior issues. | • High effectively<br>• High feasibility<br>• High resource utilization<br>• High user satisfaction<br>• Low monetary cost<br>• Selecting cloud providers based on reputation | • High execution time<br>• Without Monotone the energy consumption |
| Samimi et al[39] | They have proposed a new market-based resource allocation model through appropriate practical evaluations | • High revenue for the cloud provides<br>• High revenue for the user<br>• Low monetary cost | • No proper load balancing<br>• Sorting of the bidders is based on the price only |
| Nejad and Sabzevari[53] | They have applied the ICA method to cloud resource allocation mechanisms for determining the winners. | • High revenue for the cloud provides<br>• High revenue for the user<br>• Low monetary cost | • Without Monotone the energy consumption |
| Xu[54] | They have determined the winner by a linear integer programming. | • High resource utilization<br>• High revenue for the user<br>• High user satisfaction<br>• Low execution time<br>• Low monetary cost | • Without consideration of cloud providers' benefit |
| Nehru et al.[57] | They have proposed a truth-telling scheme by using a dynamic combinatorial auction. | • High resource utilization<br>• High revenue for the cloud provides<br>• Low monetary cost | • Without consideration of users' benefit |
| Sheikholeslami and Navimipour[45] | We have applied the MOPSO-CD algorithm to cloud resource allocation mechanisms which achieve the lower generational distance and spacing metrics. | • High resource utilization<br>• High revenue for the cloud provides<br>• High revenue for the user<br>• Low execution time<br>• Low monetary cost | • Lack of different weighting parameters |

Tsai and Tsai[59] have employed a bid-comparable auction model to design a multi-customer multi-provider market mechanism, which adapts resource price. By using this model, the provider can adjust the existing capacity and submit a bid for a reserved resource to adjust its supply. This method finds the optimal offers for the requesters and the optimal reservation bids for providers using the gradient steepest approach. It improves the revenue of providers and resource utilization. However, the benefit of users has not been considered in this mechanism.

Since employing an efficient and reasonable resource allocation mechanism is the key to enhance the resources utilization in the virtualized systems, many strategies to optimize resource allocation have been proposed in this field.[60] They have combined auction-based and VM-based mechanisms and have created a new hybrid approach. They have proposed a virtualized resource auction and allocation model that is called VRAA based on incentive and penalty. In their approach, multiple VMs hosted on the same Physical Machine (PM) its resource. VMs and PM are considered as independent buyers and seller. During the auction and allocation processes, each VM presents an appropriate bidding price according to its own payoff ability in order to participate in the auction and compete for resources. The VM monitor allocates resources based on each VM's bidding price. They also have employed incentive and penalty strategies to encourage fair auction and prevent malicious competition so that the system can run with high effectiveness. It allocates the resources according to the VMs' demand and improves the system resource utilization. However, the benefits of users and the cloud providers are not considered well.

Finally, Wang et al[61] have introduced a distributed multi-agent-based resource allocation, which applies an auction-based VM allocation technology to select which VM should be assigned to which PM. Also, a negotiation-based VM consolidation technology is utilized to swap agents' allocated VMs. The multi-agent technology works by modeling agents as bidders and VMs as commodities. The technology is compared with benchmark bin packing, and genetic-based technology and experimental results showed the multi-agent approach can obtain excellent results both on energy cost and computation time. However, the multi-agent technology does not ensure higher revenue for the cloud providers.

### 3.4.3 | Summary of the reviewed mechanisms

In the previous section, we have investigated some selected other types of auction-based mechanisms and analyzed their merits and demerits. Table 4 shows the comparison of the most important benefits and faults of each studied article.

## 4 | RESULTS AND COMPARISON

In the previous section, some of the cloud resource allocation mechanisms methods have been investigated. The researchers concentrated on the most popular auction-based methods by considering four main categories including one-sided auction-based, double-sided auction-based, combinatorial, and other types of auction. Table 5 presents a side-by-side comparison of the resource allocation methods in cloud systems and the overview of the reviewed approaches in terms of response time, security, query types, budget balance, a combination for a workflow, computational efficiency, dynamic, economic efficiency, experimental platform, incentive compatible/truthful, SLA-Aware, and VM-based.

**Budget balance (BB):** This property means that the sum of the payment of all the buyers is equal to the sum of received payment of all the cloud providers. If the difference between the sums of all of these payments is higher than zero, it is named weakly budget-balance.[24]

**Combination for a workflow (CW):** This property means that both of the users and cloud providers produce or request more than two resource types. As the auction is done over the group of items, it is profitable to both of them.[45]

**Computational efficiency (CE):** The time complexity means that the auction result (allocation of resources, determining price and payment) be calculated in polynomial time.[42]

**Dynamic (D):** Since resource demand and supply can be dynamic and uncertain, numerous plans for resource allocation are suggested. By employing the dynamic availability of resource infrastructure and dynamic application demand, a virtual computing environment is able to be relocated across the infrastructure and scale its resources.

**Economic Efficiency (EE):** This property is determined by how well it improves the total revenue across all bidders.[62] Therefore, the resources must be allocated to those who value them most. An efficient market of cloud resources should maintain the balance between supply and demand whilst improving the benefits of both the buyers and the sellers.[30] In other words, an auction is efficient when the victorious bidder has best bid to offer.[45,63]

**TABLE 4** Popular other types of auction-based resource allocation mechanisms and their properties

| Mechanism | Main idea | Advantages | Disadvantages |
|---|---|---|---|
| Tsai and Tsai[59] | They have proposed a deadline-constrained schema for resource allocation using provider's capacity-constrained gradient steepest method. | • High revenue for the cloud provides<br>• High utilization of resources<br>• Low monetary cost | • High execution time<br>• Without consideration of users' benefit |
| Jiang et al[60] | They have allocated resources amongst multiple VMs based on Nash equilibrium of cooperative gaming. | • High utilization of resources<br>• Low monetary cost<br>• Low response time | • Without consideration of users' benefit<br>• Without consideration of cloud providers' benefit |
| Wang et al[61] | They have proposed a decentralized MA-based method by dispatching a cooperative agent to each PM. | • Low completion time<br>• Low energy consumption<br>• Low execution time | • Without consideration of users' benefit<br>• Without consideration of cloud providers' benefit |

**TABLE 5** Comparison among there viewed cloud resource allocation mechanisms methods

| | Paper | BB | CW | CE | D | EE | NRG | ET | EP | T | M | MC | P_REV | Util | SLA | U_REV | VM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| One-sided auctions | Lin et al[18] | N | N | NM | Y | N | NM | NM | Lack of an appropriate simulation | Y | NM | NM | H | NM | N | L | N |
| | Wang et al[36] | Y | N | NM | N | Y | NM | NM | Simjava 2.0 toolkit in the Eclipse platform | Y | NM | NM | H | H | N | L | N |
| | Hu et al[37] | N | Y | NM | Y | Y | NM | NM | C++ programming language and MATLAB 7.0 | Y | NM | NM | H | NM | N | H | N |
| | Li et al[38] | Y | Y | NM | Y | Y | NM | L | PC with 2 CPU cores, 4 GB RAM, and Microsoft Windows 7 OS | N | L | L | H | H | N | H | N |
| Double-sided auctions | Wang et al[41] | N | N | NM | N | N | NM | H | CloudSim | N | NM | NM | NM | H | N | NM | N |
| | Jin et al[42] | Y | Y | O(nm × (m + log n)) | N | Y | NM | NM | Windows PC with 3.16 GHz Intel CoreTM2 Duo processor and 4-GB memory | Y | NM | NM | H | H | N | H | N |
| | Wu et al[43] | Y | Y | MVA algorithm: o(m) CDA algorithm: o(n) | Y | Y | NM | NM | Generatedata[a] | Y | NM | L | H | NM | N | NM | Y |
| Combinatorial auctions | Ozer and Ozturan[46] | N | Y | O($B^2$) | N | Y | NM | NM | A dedicated AMD Athlon 2 GHz workstation with 1GB of memory | N | NM | NM | H | H | N | NM | N |
| | Zaman and Grosu[47] | N | Y | O(R + n log n) | Y | N | NM | H | The Parallel Workloads Archive[b] | Y | NM | L | H | H | N | NM | Y |
| | Xing-Wei et al[48] | Y | Y | NM | Y | N | NM | L | J2DSK1.4 based on Simjava2.0 | N | NM | H | H | NM | N | NM | N |
| | Zaman and Grosu[49] | N | Y | O(R + n log n) | Y | Y | NM | H | Real workload traces | Y | NM | L | H | H | N | NM | Y |
| | Huu and Tham[50] | N | Y | O($n^2$) | Y | Y | L | L | Java | Y | NM | L | H | H | N | NM | Y |
| | Wang et al[58] | N | Y | NM | Y | Y | NM | H | Simjava2.0 toolkit, using JDK1.6 | Y | NM | L | NM | H | N | NM | N |
| | Samimi et al[39] | Y | Y | NM | N | Y | NM | NM | CloudSim | Y | NM | L | H | NM | N | H | Y |
| | Nejad and Sabzevari[53] | N | Y | NM | N | Y | NM | NM | JAVA programming language | N | NM | L | H | NM | N | H | Y |
| | Xu[54] | N | Y | NM | N | Y | NM | L | CloudSim | N | NM | L | H | H | N | H | Y |
| | Nehru et al[57] | N | Y | NM | Y | | | | | Y | | | | | Y | | Y |
| | Sheikholeslami and Navimipour[45] | Y | Y | NM | N | Y | NM | L | MATLAB R2012b | N | NM | L | H | H | N | H | N |
| Other types of auctions | Tsai and Tsai[59] | N | N | NM | Y | N | NM | H | Amazon EC2 | N | NM | L | H | H | Y | NM | N |
| | Jiang et al[60] | N | N | NM | Y | Y | NM | NM | The virtualized test bed | Y | NM | L | NM | H | Y | NM | Y |
| | Wang et al[61] | N | Y | NM | Y | Y | L | L | Static and dynamic simulations | N | L | NM | NM | NM | N | NM | N |

[a]http://www.generatedata.com/
[b]huji.ac.il/labs/parallel/workload/logs.html
n: Total number of buyers; m: Total number of sellers; B: Total number of bids; R: Total number of resources; NM: Not Mentioned; Y: Yes; N: No; H: High; L: Low.

**Energy consumption (NRG):** This property means that data centers consume a large amount of energy to protect the large-scale Internet services, which is a significant proportion of the total cost. Accordingly, there is a need for task scheduling to minimize the energy consumption in the cloud systems.[64]

**Execution time (ET):** This property means that tasks are computing or running at the request of the users. There is a need for task scheduling to minimize the execution time in the cloud systems.[65]

**Experimental platform (EP):** Every cloud resource allocation mechanisms method uses some real test bed or cloud environment to validate their mechanism. For example, CloudSim is a simulated environment for validation.[66]

**Incentive compatible or truthful (T):** If the bidders reveal truly their preferences, they can win the auction, and if the bidders lie, they cannot better be off.[39]

**Makespan or completion time (M):** This property is the total time taken for a schedule to complete all the tasks. Therefore, we require decreasing the makespan value in our task scheduling algorithms.[67]

**Monetary cost (MC):** As mentioned, CPs in auction-based methods can request a price from users based on the amount of resource that requested by them. Scheduling algorithms in the auction-based methods should consider users' willingness to complete their applications in the most economical way possible. Therefore, there is a need for task scheduling to minimize the monetary cost in the cloud systems.[67,68]

**Providers' revenue (P_REV):** In an auction-based resource allocation method, the CPs compete with each other to increase their own revenue by selling their available resources.

**Resource utilization (Util):** Utilization is an important factor in determining the performance of the task scheduler from the CPs' perspective. The utilization-aware resource allocation has to ensure the increasing the total amount of resources actually consumed for CPs.

**SLA-Aware (SLA):** SLA is used as a protocol for costs and penalties determination based on performance level in the overall IT infrastructure. In cloud environments, it is a formal agreement between the cloud providers and its users, defining the functional and non-functional features of the offered services. An SLA includes some features of services such as availability, security, privacy, access fashion, problem resolution, performance, and authority change.[69]

**Users' revenue (U_REV):** In an auction-based resource allocation method, the users compete with each other to pay the lowest price possible to CPs for buying resources.

**VM-based (VM):** The significant term of cloud computing is virtualization. Virtualization divides the resources from the basic physical delivery environment. In the cloud management, it is significant to distinct resources from their physical implementations. Virtualization is very important in a cloud environment because it is possible to simplify many aspects of computing. One of the benefits of virtualization is the way that it abstracts hardware assets, basically allowing a single piece of hardware to be used for multiple tasks. In a cloud environment, the dynamic resources can be managed effectively using virtualization technology.[70]

## 5 | OPEN ISSUES

In this paper, we have surveyed a small but growing numbers of solutions for resource allocation in the cloud computing systems. While these approaches differ in their treatment of the clouds, we divide existing mechanisms into four main categories: one-sided auction-based, double-sided auction-based, combinatorial auction-based, and other types of auction-based. It is the basis that differentiates the resource allocation in the cloud computing from other forms of resource allocation. It has been observed that there is no single mechanism that addresses all issues involved in resource allocation. Therefore, there exist numerous challenges to be addressed or improved. In this section, we present some considerations about future perspectives of resource allocation in cloud computing. Many articles about cloud computing were explored ever since. In addition to what we discussed in Section 4, there are thousands of publications reporting of resource allocation mechanisms in the cloud. Due to the page limit, we only list the important ones. The core of the work on the cloud has focused on resource allocation aspects. We know that there is much more to do in this area, but we studied some papers that we think are helpful for academicians. We classified these mechanisms into four categories: one-sided auction-based, double-sided auction-based, combinatorial auction-based, and other types of auction-based, but there are much more categories to do in this area. Therefore, another area for future research is to study other categories of the resource allocation in cloud computing, for example, priority-based and heuristic-based resource allocation. Also, discussing different policies, utility functions in autonomic systems, hardware resource dependency, and heterogeneity-aware resource allocation in the cloud are very interesting lines for future research. Another area for future research is to adding two important research topics related to resource allocation in cloud environment including flow scheduling[71-73] and power/cost minimization.[74-76]

Furthermore, in the cloud computing, as the numbers of consumers are growing, clouds need for resources sharing with each other to optimize their QoS. Generally, cloud computing is prone to contention between the requests of users for resources accessing.[77] Contention happens when a user request cannot be accepted or cannot obtain enough resources because resources are involved by other requests. In spite of the fact that resource contention is not a new issue in cloud environments and various solutions have been proposed for it, addressing this problem is one of the major challenges in the allocation of cloud resources and more research is needed in the future.[78] Also, an adaptive cloud can self-adapt and its configurations and self-manage its resources according to different circumstances; therefore, the resource allocation in this type of network is a very challenging problem.[79] The question about energy management is another important aspect related to resource selection and optimization challenges. Due to the importance of current assumption about energy efficiency, the effort in this area will become increasingly concrete.

Analyzing the auction models in auction mechanisms is another challenging issue to measure their suitability for the dynamic and diverse resource market in the cloud computing. It is beneficial to introduce the game theory to auction-based resource allocation in the cloud computing. For auction-based resource allocation, the coordination of the cloud providers is important. Providers and customers can adopt uniform bidding strategies, uniform evaluation criteria, truth-telling schemes, etc. However, one way may be able to adopt auction-based resource allocation mechanisms between different cloud providers. In auction-based cloud resource allocation mechanisms, several optimization algorithms, eg, GA, simulated annealing algorithm, the immune algorithm has been utilized to optimize the resource allocation process. Other interesting lines for future research are the development of other optimization techniques for NP-hard problems, efficiently.

Another interesting point is that a buyer agent employs a smarter strategy to make his orders to reduce wasted resources and increase workflow completion rate and seller/buyer agents should adjust their order price based on the market price in competition with each other. Therefore, investigating the market behavior using more sophisticated strategies of seller/buyer agents is still very challenging.[80] However, the resource management is a complicated procedure because it deals with delivering software to millions of users to a service via a datacenter, while it is easy to distribute software for millions of users to run on their individual personal computers.[81] Therefore, there are several challenges involving the resource allocation based on SLA to discriminate and satisfy service requests based on the desired utility of users. While strict penalties can be avoided by manipulating several SLA parameters, developing the SLA parameters in number to increase efficiency is another challenging issue.[82]

As we know, the SLA management layer manages resource allocation. Scheduling and deploying service requests taking into account multiple SLA parameters such as the amount of processor required, network bandwidth, memory, and storage are still open research challenges for SLA-based resource allocation in cloud computing.[83,84] Eventually, optimizing cost/time, power consumption, the under-utilization of resources, balance load, request loss, and leasing cost are very interesting in the future. Many difficulties may arise for resource allocation in the cloud environments and many issues remain open for it; yet, researchers in many countries are working to address these challenges. We wish that our work provides a starting point for researchers interested in this subject and further orientation and information for those who are already working on its challenges.

## 6 | CONCLUSION

Currently, cloud computing has become a key IT buzzword due to its abilities to offer flexible dynamic and on-demand IT infrastructures, QoS guaranteed computing environments, and configurable software services. Resource allocation is a part of resource management, which assigns the existing resources in an economic way.[41] Therefore, the past and the state of the art mechanisms in the cloud resource allocation mechanisms and the taxonomy of them have been analyzed in this paper. The cloud resource allocation mechanisms are divided into four main categories: one-sided auction-based, double-sided auction-based, combinatorial auction-based, and other types of auction-based. For each of these classes, several proposed mechanisms were viewed and compared. In cloud computing, auctions are adopted gradually to solve resource allocation, and pricing problems and many cloud auction mechanisms are designed. In auction-based mechanisms, the combinatorial auction produces higher revenue generation with less computational time. Both the buyer and the seller prefer this model over others. In the cloud environment, the combinatorial auction is the most suitable auction methods for the resource allocation. Finally, the results indicated that many of the gains in the cloud model come from resource multiplexing using the virtualization technology.

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### REFERENCES

1. Chiregi M, Navimipour NJ. A new method for trust and reputation evaluation in the cloud environments using the recommendations of opinion leaders' entities and removing the effect of troll entities. *Comput Hum Behav*. 2016;60:280-292.
2. Hazratzadeh S, Navimipour NJ. Colleague recommender system in the expert cloud using the features matrix. *Kybernetes*. 2017;45(9):1342-1357.
3. Navimipour NJ, Hessami A, Masoud Rahmani A, Habibizad Navin A, Hosseinzadeh M. Job scheduling in the expert cloud based on genetic algorithms. *Kybernetes*. 2014;43(8):1262-1275.
4. Buyya R, Yeo CS, Venugopal S, Broberg J, Brandic I. Cloud computing and emerging IT platforms: vision, hype, and reality for delivering computing as the 5th utility. *Future Gener Comput Syst*. 2009;25(6):599-616.
5. Keshanchi B, Souri A, Navimipour NJ. An improved genetic algorithm for task scheduling in the cloud environments using the priority queues: formal verification, simulation, and statistical testing. *J Syst Softw*. 2017;124:1-21.
6. Aznoli F, Navimipour NJ. Cloud services recommendation: reviewing the recent advances and suggesting the future research directions. *J Netw Comput Appl*. 2016;77:73-86.

7. Cheng C-C, Cheng F-C, Lin P-H, Huang W-T, Huang S-C. A fastest Patchwise histogram construction algorithm based on cloud-computing architecture. *Int J Web Serv Res*. 2017;14(1):1-12. doi: https://doi.org/10.4018/IJWSR.2017010101
8. Gong C, Liu J, Zhang Q, Chen H, Gong Z. The characteristics of cloud computing. Paper presented at: 39th International Conference on Parallel Processing Workshops; 2010; San Diego, CA.
9. Navimipour NJ, Ashouraie M. Priority-based task scheduling on heterogeneous resources in the expert cloud. *Kybernetes*. 2015;44(10):1455-71.
10. Navimipour NJ, Rahmani AM, Navin AH, Hosseinzadeh M. Resource discovery mechanisms in grid systems: a survey. *J Netw Comput Appl*. 2014;41:389-410.
11. Navimipour NJ, Rahmani AM, Navin AH, Hosseinzadeh M. Behavioral modeling and automated verification of a cloud-based framework to share the knowledge and skills of human resources. *Comput Ind*. 2015;68:65-77.
12. Navimipour NJ, Rahmani AM, Navin AH, Hosseinzadeh M. Expert cloud: a cloud-based framework to share the knowledge and skills of human resources. *Comput Hum Behav*. 2015;46:57-74.
13. Gullhav AN, Nygreen B. A branch and price approach for deployment of multi-tier software services in clouds. *Comput Oper Res*. 2016;75:12-27.
14. Sebastio S, Gnecco G, Bemporad A. Optimal distributed task scheduling in volunteer clouds. *Comput Oper Res*. 2017;81:231-246.
15. Singh S, Chana I. Cloud resource provisioning: survey, status and future research directions. *Knowl Inf Syst*. 2016;49(3):1005-69.
16. Fouladi P, Navimipour JN. Human resources ranking in a cloud-based knowledge sharing framework using the quality control criteria. *Kybernetes*. 2017;46(5).
17. Liaqat M, Chang V, Gani A, et al. Federated cloud resource management: review and discussion. *J Netw Comput Appl*. 2017;77:87-105. https://doi.org/10.1016/j.jnca.2016.10.008
18. Lin W-Y, Lin G-Y, Wei, H-Y. Dynamic auction mechanism for cloud resource allocation. Paper presented at: 10th IEEE/ACM International Conference on Cluster, Cloud and Grid Computing; 2010; Melbourne, Australia.
19. Navimipour NJ, Charband Y. Knowledge sharing mechanisms and techniques in project teams: literature review, classification, and current trends. *Comput Hum Behav*. 2016;62:730-742.
20. Yousafzai A, Gani A, Noor RM, et al. Cloud resource allocation schemes: review, taxonomy, and opportunities. *Knowl Inf Syst*. 2017;50(2):347-381.
21. Parikh SM. A survey on cloud computing resource allocation techniques. Paper presented at: 2013 Nirma University International Conference on Engineering; 2013; Ahmedabad, India.
22. Anuradha VP, Sumathi D. A survey on resource allocation strategies in cloud computing. Paper presented at: International Conference on Information Communication and Embedded Systems; 2014; Chennai, India.
23. Vinothina V, Sridaran R. A survey on resource allocation strategies in cloud computing. *Int J Adv Comput Sci Appl*. 2012;1(3):97-104.
24. Kumar D, Baranwal G, Raza Z, Vidyarthi DP. A systematic study of double auction mechanisms in cloud computing. *J Syst Softw*. 2017;125:234-255.
25. Azad P, Navimipour NJ. An energy-aware task scheduling in cloud computing using a hybrid cultural and ant colony optimization algorithm. *Int J Cloud Appl Comput*. 2017;7(4). https://doi.org/10.4018/IJCAC.2017100102
26. Mohammadi SZ, Navimipour NJ. Invalid cloud providers' identification using the support vector machine. *Int J Next Gener Comput*. 2017;8(1):82-98.
27. Navimipour NJ, Navin AH, Rahmani AM, Hosseinzadeh M. Expert grid: new type of grid to manage the human resources and study the effectiveness of its task scheduler. *Arab J Sci Eng*. 2014;39(8):6175-6188.
28. Navimipour NJ, Souri A. Behavioral modeling and formal verification of a resource discovery approach in grid computing. *Expert Syst Appl*. 2014;41(8):3831-3849.
29. Vinothina V, Sridaran R, Ganapathi P. A survey on resource allocation strategies in cloud computing. *Int J Adv Comput Sci Appl*. 2012;3(6). https://doi.org/10.14569/IJACSA.2012.030616
30. Wang H, Tianfield H, Mair Q. Auction based resource allocation in cloud computing. *Multiagent Grid Syst*. 2014;10(1):51-66.
31. Vickrey W. Counterspeculation, auctions, and competitive sealed tenders. *J Financ*. 1961;16(1):8-37.
32. Lucking-Reiley D. Vickrey auctions predate Vickrey. *J Econ Perspect*. 2000.
33. Wang XW, Sun JJ, Li HX, Wu C, Huang M. A reverse auction based allocation mechanism in the cloud computing environment. *Appl Math*. 2013;7(1L):75-84.
34. Manoochehri G, Lindsy C. Reverse auctions: benefits, challenges, and best practices. *Calif J*. 2008;6(1):123-130.
35. Armbrust M, Fox A, Griffith R, et al. A view of cloud computing. *Commun ACM*. 2010;53(4):50-58.
36. Wang X, Sun J, Huang M, Wu C, Wang X. A resource auction based allocation mechanism in the cloud computing environment. Paper presented at: IEEE 26th International Parallel and Distributed Processing Symposium Workshops and PhD Forum; 2012; Shanghai, China.
37. Hu H, Li Z, Hu H. An anti-cheating bidding approach for resource allocation in cloud computing environments. *J Comput Inf Syst*. 2012;8(4):1641-1654.
38. Li X, Ding R, Liu X, Liu X, Zhu E, Zhong Y. A dynamic pricing reverse auction-based resource allocation mechanism in cloud workflow systems. *Sci Program*. 2016;2016:1-13.
39. Samimi P, Teimouri Y, Mukhtar M. A combinatorial double auction resource allocation model in cloud computing. *Inf Sci*. 2016;357:201-216.
40. Shi X, Xu K, Liu JC, Wang Y. Continuous double auction mechanism and bidding strategies in cloud computing markets. 2013. https://arxiv.org/abs/1307.6066
41. Wang X, Wang X, Wang C-L, Li, K, Huang, M. Resource allocation in cloud environment: a model based on double multi-attribute auction mechanism. Paper presented at: IEEE 6th International Conference on Cloud Computing Technology and Science; 2014; Singapore.
42. Jin A-L, Song W, Zhuang W. Auction-based resource allocation for sharing cloudlets in mobile cloud computing. *IEEE Trans Emerg Topic Comput*. 2015. https://doi.org/10.1109/TETC.2015.2487865
43. Wu X, Liu M, Dou WC, Gao L, Yu S. A scalable and automatic mechanism for resource allocation in self-organizing cloud. *Peer Peer Netw Appl*. 2016;9(1):28-41.

44. Cramton P, Shoham Y, Steinberg R. *Combinatorial Auctions*. Cambridge, MA: MIT Press; 2006.
45. Sheikholeslami F, Navimipour NJ. Service allocation in the cloud environments using multi-objective particle swarm optimization algorithm based on crowding distance. *Swarm Evol Comput*. 2017;35:53-64.
46. Ozer AH, Ozturan C. An auction based mathematical model and heuristics for resource co-allocation problem in grids and clouds. Paper presented at: 5th International Conference on Soft Computing, Computing with Words and Perceptions in System Analysis, Decision and Control; 2009; Famagusta, Cyprus.
47. Zaman S, Grosu D. Combinatorial auction-based dynamic VM provisioning and allocation in clouds. Paper presented at: IEEE 3rd International Conference on Cloud Computing Technology and Science; 2011; Athens, Greece.
48. Xing-Wei W, Xue-yi W, Min H. A resource allocation method based on the limited English combinatorial auction under cloud computing environment. Paper presented at: 9th International Conference on Fuzzy Systems and Knowledge Discovery; 2012; Chongqing, China.
49. Zaman S, Grosu D. A combinatorial auction-based mechanism for dynamic VM provisioning and allocation in clouds. *IEEE Trans Cloud Comput*. 2013;1(1):129-141.
50. Huu TT, Tham C-K. An auction-based resource allocation model for green cloud computing. Paper presented at: IEEE International Conference on Cloud Engineering; 2013; Santa Clara, CA.
51. Navimipour NJ, Milani FS. A comprehensive study of the resource discovery techniques in peer-to-peer networks. *Peer Peer Netw Appl*. 2015;8(3):474-492.
52. Baranwal G, Vidyarthi DP. A fair multi-attribute combinatorial double auction model for resource allocation in cloud computing. *J Syst Softw*. 2015;108:60-76.
53. Nejad EB, Sabzevari RA. A new method to winner determination for economic resource allocation in cloud computing systems. *J Adv Technol Eng Res*. 2016;1:51-6.
54. Xu J. A cloud computing resource allocation model based on combinatorial double auction. Paper presented at: 3rd International Conference on Information Science and Control Engineering; 2016; Beijing, China.
55. Li L, Liu Y-a, Liu K-m, Ming Y. Pricing in combinatorial double auction-based grid allocation model. *J China Univ Post Telecommun*. 2009;16(3):59-65.
56. Yifei Z, Bin Y. Service resource allocation based on service level protocol and double auction mechanism design. *Comput Meas Control*. 2014;4:99.
57. Nehru EI, Shyni JIS, Balakrishnan R. Auction based dynamic resource allocation in cloud. Paper presented at: International Conference on Circuit, Power and Computing Technologies; 2016; Nagercoil, India.
58. Wang X-Y, Wang X-W, Huang M. A multiple attribute decision and bidding based cloud resource dynamic allocation method. Paper presented at: 8th ChinaGrid Annual Conference; 2013; Changchun, China.
59. Tsai C-W, Tsai Z. Bid-proportional auction for resource allocation in capacity-constrained clouds. Paper presented at: 26th International Conference on Advanced Information Networking and Applications Workshops; 2012; Fukuoka, Japan.
60. Jiang C, Duan L, Liu C, Wan J, Zhou L. VRAA: virtualized resource auction and allocation based on incentive and penalty. *Clust Comput*. 2013;16(4):639-650.
61. Wang W, Jiang Y, Wu W. Multiagent-based resource allocation for energy minimization in cloud computing systems. *IEEE Trans Syst Man Cybern Syst*. 2017;47(2):205-220.
62. Morgan J. Efficiency in auctions: theory and practice updated copies of this paper can be found at www.wws.princeton.edu/~rjmorgan. *J Int Money Financ*. 2001;20(6):809-838.
63. Bellosta M-J, Kornman S, Vanderpooten D. Preference-based English reverse auctions. *Artif Intel*. 2011;175(7-8):1449-1467.
64. Huai W, Qian Z, Li X, Luo G, Lu S. Energy aware task scheduling in data centers. *J Wirel Mobe Netw Ubiq Comput Depend Appl*. 2013;4(2):18-38.
65. Madni SHH, Latiff MSA, Coulibaly Y. Recent advancements in resource allocation techniques for cloud computing environment: a systematic review. *Clust Comput*. 2016;20(3):2489-2533.
66. Singh S, Chana I. A survey on resource scheduling in cloud computing: issues and challenges. *J Grid Comput*. 2016;14(2):217-64.
67. Somasundaram TS, Govindarajan K. CLOUDRB: a framework for scheduling and managing high-performance computing (HPC) applications in science cloud. *Futur Gener Comput Syst*. 2014;34:47-65.
68. Salimi R, Motameni H, Omranpour H. Task scheduling with load balancing for computational grid using NSGA II with fuzzy mutation. Paper presented at: 2nd IEEE International Conference on Parallel Distributed and Grid Computing; 2012; Solan, India.
69. Jennings B, Stadler R. Resource management in clouds: survey and research challenges. *J Netw Syst Manag*. 2014;23(3):567-619.
70. Gaykar M, Deshmukh P, Tapkir N, Shende R, Badre RR. Dynamic resource allocation using virtual machines for cloud computing environment. *IEEE Trans Parallel Dist Sys*. 2015;24(6):1107-1117.
71. Al-Fares M, Radhakrishnan S, Raghavan B, Huang N, Vahdat A. Hedera: Dynamic flow scheduling for data center networks. Paper presented at: 7th USENIX. Symposium on Networked. Systems. Design and. Implementation; 2010; Boston, MA.
72. Curtis AR, Kim W, Yalagandula P. Mahout: Low-overhead datacenter traffic management using end-host-based elephant detection. Paper presented at: 30th IEEE International Conference on Computer Communications; 2011; Shanghai, China.
73. Guo Z, Hui S, Xu Y, Chao HJ. Dynamic flow scheduling for power-efficient data center networks. Paper presented at: IEEE/ACM 24th International Symposium on Quality of Service; 2016; Beijing, China.
74. Guo Z, Duan Z, Xu Y, Chao HJ. JET: electricity cost-aware dynamic workload management in geographically distributed datacenters. *Comput Commun*. 2014;50:162-74.
75. Qureshi A, Weber R, Balakrishnan H, Guttag J, Maggs B. Cutting the electric bill for internet-scale systems. Paper presented at: ACM SIGCOMM 2009 Conference on Data Communication; 2009; Barcelona, Spain.
76. Rao L, Liu X, Xie L, Liu W. Minimizing electricity cost: Optimization of distributed internet data centers in a multi-electricity-market environment. Paper presented at: 29th Conference on Computer Communications; 2010; San Diego, CA.

77. Salehi MA, Javadi B, Buyya R. QoS and preemption aware scheduling in federated and virtualized grid computing environments. *J Parallel Dist Comput*. 2012;72(2):231-245.

78. Toosi AN, Calheiros RN, Buyya R. Interconnected cloud computing environments: challenges, taxonomy, and survey. *ACM Comput Surv*. 2014;47(1). https://doi.org/10.1145/2593512

79. Das A, Grosu D. Combinatorial auction-based protocols for resource allocation in grids. Paper presented at: 19th IEEE International Parallel and Distributed Processing Symposium; 2005; Washington, DC.

80. Fujiwara I, Aida K, Ono I. Applying double-sided combinational auctions to resource allocation in cloud computing. Paper presented at: 10th IEEE/IPSJ International Symposium on Applications and the Internet; 2010; Seoul, Korea.

81. Nguyen NC, Wang P, Niyato D, Wen Y, Han Z. Resource management in cloud networking using economic analysis and pricing models: a survey. *IEEE Commun Surv Tutor*. 2017;19(2):954-1001.

82. Mohan NRR, Raj EB. Resource allocation techniques in cloud computing--research challenges for applications. Paper presented at: 4th International Conference on Computational Intelligence and Communication Networks; 2012; Mathura, India.

83. Emeakaroha VC, Brandic I, Maurer M, Breskovic I. SLA-aware application deployment and resource allocation in clouds. Paper presented at: IEEE 35th Annual Computer Software and Applications Conference Workshops; 2011; Munich, Germany.

84. Wu L, Buyya R. Service Level Agreement (SLA) in Utility Computing Systems. Melbourne, Australia: University of Melbourne; 2012. Technical Report.

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