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A truthful combinatorial double auction-based marketplace mechanism for cloud computing

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ABSTRACT

Designing market-based mechanism that benefits both the cloud customer and cloud provider in a cloud market is a fundamental but complex problem. Double auction is one such mechanism to allocate resources that prevents monopoly and is used to design an unbiased optimal market strategy for cloud market. This work proposes a truthful combinatorial double auction mechanism for allocation and pricing of computing resources in cloud. For resource allocation, utilitarian social welfare maximization problem is formulated using Integer Linear Programming (ILP) and a near optimal solution is obtained using Linear Programming based padded method. For payment, truthful and novel schemes are designed for both customers and providers. Moreover, the proposed mechanism is individual rational, computationally tractable, weakly budget-balance and asymptotic efficient. Performance evaluation and comparative study exhibit that the proposed mechanism is effective on various performance metrics such as utilitarian social welfare, total utility, customers' satisfaction, providers' revenue and hence is applicable in real cloud environments.

1. Introduction

Cloud computing is a new computing based business model where various resources such as CPU, Network, Storage, Memory etc. are offered as utility and are available on demand (Buyya, 2009). Cloud service providers such as Amazon, Google, Microsoft etc. use different pricing schemes to attract the customers i.e. they want to increase their revenue. Cloud users want to use cloud services to execute their jobs or applications but by paying optimal price with desired QoS. Economics based approach such as auction, bargaining, distributive justice etc. have been widely used in various computing environments such as grid computing (Buyya et al., 2002; Li et al., 2009), cloud computing etc. (Baranwal et al., 2017; Baranwal and Vidyarthi, 2014; Kumar et al., 2017; Xu et al., 2011) to achieve objectives of providers and customers both.

Auctions, where price is determined by the supply and demand of the resources (Klemperer, 2004), are applications of mechanism design if one wants to design an auction with some desirable auction properties such as truthfulness, individual rationality, budget-balance etc. An auction mechanism basically consists of two parts: Allocation function and Payment scheme which need to be designed carefully to achieve auction properties. Recently, auction has been used for selling the underutilized and spare cloud resources (AWS, 2016). Auctions are decentralized, easy to implement and well suited for distributed systems like grid computing, cloud computing etc.

In past, researchers have proposed resource allocation models in cloud computing based on double auction. Most of the models mainly focused on the allocation schemes and little attention has been given to payment aspect. Some of the mechanisms have designed pricing schemes which are either truthful for one-side of market or not truthful at all. Moreover, to the authors' best knowledge, there is not a single combinatorial double auction mechanism in cloud which is budget-balanced and truthful for all participants. Keeping these issues in mind, this work proposes a truthful double auction for a combinatorial/multi-unit multi-item cloud market being referred as **T**ruthful **C**ombinatorial/ **M**ulti unit multi item **D**ouble **A**uction for **C**loud Computing (TCMDAC). In TCMDAC, each cloud user demands multiple types of Virtual Machines (VMs) in form of bundle as cloud users generally demand the resources in the form of bundle (Baranwal and Vidyarthi, 2015; Samimi et al., 2016) and each provider offers multiple units of multiple types of VMs. TCMDAC uses LP based padding method for Cloud computing environment where a provider offers multiple

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types of VMs. A Virtual Padding User (VPU) is considered which increases the competition among users and eliminates the users with less credentials (i.e. users with less budget (less bid value) or more required resources or both). It is assumed that VPU is having unlimited budget. TCMDAC exhibits various interesting features such as it supports the combinatorial bidding and it enables simple decision making to produce a near-optimal allocation. Truthful payment for all users is designed using critical payments while marginal cost is used to calculate the truthful payment for cloud providers. The key contributions of this work are as follows:

- To the best of authors' knowledge, TCMDAC is the first truthful combinatorial double auction for cloud market which is truthful for all participants (cloud customers as well as cloud providers) and weakly budget-balanced.
- In TCMDAC, a LP (Linear programming) based padding method is used. The generated allocations are near optimal, asymptotic efficient and can be computed in polynomial time.
- Novel payment schemes are designed for both customer and provider in a way to achieve truthfulness and budget-balance.
- It is shown theoretically as well as practically that TCMDAC is individual rational, incentive compatible, weakly budget-balanced and asymptotic efficient.
- TCMDAC is compared with state of the art and the experimental results show that it is effective, efficient and applicable in real cloud environments.

The outline of the paper is as follows. Section 2 gives an overview of related work on double auction mechanisms in cloud computing. Section 3 describes the system model and problem formulation. Section 4 describes the proposed TCMDAC model. Section 5 presents the performance evaluation and comparative study through simulation. Section 6 concludes the work with some possible future directions.

2. Related work

Auction, a market design mechanism, is very helpful for designing and modeling the competitive market (Klemperer, 2004). Its various variants like single sided (Zaman and Grosu, 2013), double sided (Baranwal and Vidyarthi, 2015; Kumar et al., 2017; Samimi et al., 2016), forward auction (Mashayekhy et al., 2015), reverse auction (Baranwal and Vidyarthi, 2016), first price auction, second price auction (Zaman and Grosu, 2012) etc. are quite useful in different market situations and have been used in cloud computing for resource allocation.

Double auction mechanisms, where bidding is done from both the market players i.e. customer and provider, provide a concrete and suitable framework for modeling the both side completion in auction based cloud market. In addition, use of double auction instead of repeated single-sided auction reduces the computational burden and complexity on the provider side (Wise and Morrison, 2000). One-sided auctions also reduce the possible trades or transactions, especially in combinatorial auctions (de Vries and Vohra, 2003; Rothkopf et al., 1998). Double auction is a many-to-many auction that prevents monopoly and can be used to design an unbiased optimal market strategy for a cloud market. It is proven that in double auction, efficiency maximizing mechanism yields more revenue compared to the single sided auction in the long run (Wise and Morrison, 2000). Therefore, various benefits of double auction e.g. dynamic pricing, efficient resource allocation, supply and demand principle, less time consumption and consideration of both side competitions make it suitable for the cloud computing market (Bratton et al., 1982; Cason and Friedman, 1996; Kumar et al., 2017).

Double auction based resource allocation and pricing mechanisms have been applied in grid computing before cloud computing (Grosu and Das, 2004; Izakian et al., 2010; Li et al., 2009). Li et al. (2009) considered combinatorial bidding and proposed combinatorial double auction based resource allocation and pricing schemes for the grid market. Although the work claims the incentive compatible property through experimental studies, but the work does not satisfy incentive compatible property theoretically. Grosu and Das (2004) used three most popular double auctions for resource allocation in grid: McAfee Double Auction (PMDA), Threshold price Double Auction Protocol (TPDA) and Continuous Double Auction (CDA). Grosu and Das (2004) shows that CDA performs better than PMDA and TPDA in terms of resource utilization. Motivated by the work proposed by Grosu and Das (2004), Izakian et al. (2010) proposed a continuous double auction based resource allocation for grid computing where grid users request for the resources in an auction market for executing their jobs. In Izakian et al. (2010), a user's bid value increases with the decrease in the number of remaining resources or average mean remaining time as it tries to finish its running tasks as soon as possible by acquiring more resources which can be obtained by bidding higher values. The provider's bid value is determined by the total workload and fluctuates between its ask price and maximum price. After that, trading price is determined by taking an average of highest bid and lowest ask price. Economic efficiency and System performance were two criteria which were used in Izakian et al. (2010). Simulation results prove that the model performs better in terms of fairness deviation, resource utilization and mean trade price.

A Combinatorial Double Auction based resource Allocation model named CDARA in cloud computing environment has been proposed in Samimi et al. (2016). The resource allocation has been done using greedy schemes which approximate the solution by a factor of $\sqrt{M}$ where M is the total resource quantity offered in the market. Average pricing mechanisms have been used for users and providers, previously used in Li et al. (2009). Two evaluation criterion: economic efficiency and incentive compatibility have been used in experimental studies. Though the model claimed to be truthful as Li et al. (2009) through experimental studies, it is not truthful theoretically. The reason is that average pricing mechanism used in Li et al. (2009) and Samimi et al. (2016) would leave the scope for users and providers to manipulate the cloud market by bidding falsely (Baranwal and Vidyarthi, 2015).

A Fair, Multi-attribute Combinatorial Double Auction Model (FMCDAM) for cloud environment is proposed in Baranwal and Vidyarthi (2015). In FMCDAM, various QoS attributes were considered along with price for winner determination and resource allocation is done using greedy technique as used in Samimi et al. (2016). FMCDAM reduces the bidder drop problem by allocating resources in a fair manner. Moreover, if a provider offers false QoS assurance then a penalty is imposed on the provider and its reputation is decreased which lowers its winning chances in successive rounds. However, the mechanism does not maximize the social welfare and is not truthful either.

One way to handle the wrong market manipulation is designing a truthful auction mechanism which gives incentives to participants for revealing their true information. Another way, to stop the malicious behavior of market participants, is feedback rating based reputation system as proposed in Sun et al. (2013) and Wang et al. (2015). In Wang et al. (2015) the Winner Determination Problem (WDP) problem is solved using Paddy Field Algorithm (PFA) whereas Sun et al. (2013) solves the WDP problem using Group Search Optimization Algorithm. A family of greedy based combinatorial double auction allocation mechanisms has been proposed in Chichin et al. (2015b). In this, the authors only designed the allocation mechanism without proposing any pricing mechanisms. Two types of sorting criteria are considered for homogeneous and heterogeneous resources in cloud. Resource Relative Relation (RRR)