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An online sequential procurement mechanism under uncertain demands in multi-cloud environment ☆

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A B S T R A C T

The uncertainty of demands brings challenges for the private cloud providers, leading to low utilization of resources during periods of low-demand and low quality of service during periods of peak-demand, which has attracted much attention. In this paper, taking account into both uncertainty of demands and budget constraint, we design an online sequential procurement auctions of residual resources, which helps the busy cloud provider make an irrevocable decision about how to purchase resources during period of uncertain peak-demand. The crucial part of the mechanism is the seller accepting-rule based on a value-density threshold which is learned dynamically from the historical information. Given the condition that all the sellers are myopic, we prove that the mechanism is truthful, budget feasible and individual rational. Furthermore, we obtain the competitive ratio of the proposed mechanism when the demands of the BCP are δ-degree balance. Using real data from parallel computing centers, we construct 60 scenarios in six data settings, in which we compare our mechanism with average budget allocation and offline proportional sharing mechanism, the results show that in more than 85% scenarios the proposed mechanism has better performance than allocation with average budget, and it improves more than 20% valuation on average for the buyer, even if we use the estimate value of balance degree δ.

1. Introduction

The uncertainty of demands is one of the most critical problems faced by private cloud providers, which results in low resource utilization during periods of low-demand and low service quality during periods of peak-demand. It is an unsolved problem in a single cloud environment, but in a multi-cloud environment, cloud providers can improve the resource utilization or service quality by trading and sharing of residual resources.

Economic mechanisms have been applied widely in trading and sharing of residual resources among cloud networks, in which cloud providers either win more economic benefits or enlarge their resource capacity by sharing the resources dynamically [1]. As described in [2], economic mechanism is the key ingredient for effective resource utilization in cloud

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network which has received more attention [3–7]. Especially, due to data security and other reasons, many enterprises and universities would like to set up their private clouds instead of outsourcing their entire infrastructure to public clouds, which makes the trading and scheduling of resources among those private clouds more necessary [8].

Procurement mechanism is one of the major resource trading mechanisms, which has been applied to cloud networks [9–12]. In these works, the cloud providers (CPs) in the cloud network obtain the utility by sharing and scheduling the resources in the following ways: (i) when the cloud is in period of low-demand, the increased utility of the idle cloud provider (ICP) mainly comes from rented resources, i.e., its income from leasing VMs to other clouds subtracting its operational costs; (ii) when the CP is in period of peak-demand, the increased utility of the busy cloud provider (BCP) mainly comes from the improved service quality associated with the quantity of rented resources. For example, Hassan et al. [9] derived the procurement price based on Stackelberg Game for the busy cloud provider in peak-demand, in which the demand valuation function of resource buyer is concave. Prasad et al. [11] proposed three QoS-awared procurement mechanisms for the busy cloud provider, which adopted reverse auction to decide the allocation of sellers and the pricing.

The above-mentioned approaches only take into account static demands of the BCP, while resource buyers (BCPs) are always faced with more complex scenario – online uncertain resource demands in practice. For example, large scale promotion activities of a large online store, such as "double 11" in China, will attract a large number of customers to access the website, and during this period, it is necessary to increase the resource provisioning to release the pressure of the website. Since the uncertainty of workloads, the valuation of a resource for each provider varies with their workload status, and it represents the marginal price of the ICP or the marginal demand valuation of the BCP which is uncertain and unpredictable for each provider. In addition, similar to the usual purchase behavior, the resource expansion for a BCP is constrained by a limited budget. Obviously, the procurement mechanisms aforementioned cannot be applied to this scenario directly. Zhao et al. [13] investigate online procurement of storage resources but without considering the budget constraint. To the best of our knowledge, there are few works addressing the online procurement with uncertain demands and budget constraint in multi-cloud environment.

Therefore, in this paper we aim to design a truthful, budget feasible, individual rational mechanism for above online procurement under uncertain demands, the objective of which is to improve the total valuation of purchased resources of the BCP. Among these properties of the mechanism, truthfulness can incentivize ICPs to report their truthful costs, which is the basic condition for decreasing purchasing cost of resources, budget feasibility can guarantee that the total payment does not exceed the limited budget, and individual rationality insures that each ICP participating the mechanism obtains non-negative utility, which can incentivize ICPs to share their residual resources. However, there are two main difficulties in our work: (1) given a limited budget, how to allocate the budget to each time step of peak-demand period; (2) with non-increasing marginal demand valuations at each time, how to incentivize the ICPs to share their idle resources with truthful costs at each time step. To address those problems, we novelly combine a truthful static auction with a learning-accept rule, and form an online sequential procurement mechanism with budget (OSPB). The contributions of this work are summarized as follows:

Firstly, we address the budget allocation problem during peak-demand period when the demand valuation functions of the BCP and the bids of ICPs are uncertain in the next time. By dividing the demand period into L stages: $g_1, g_2, ...g_L$, we design an accepting rule for the ICPs according to value-density threshold instead of a direct budget allocation, where value-density is the valuation brought by unit cost.

Secondly, to incentivize the ICPs to share their idle resources with truthful costs at each time step, we design truthful reverse auctions both in stage g_1 with fixed budget and stage g_l, $l > 1$ with value-density, which constitute our online sequential procurement mechanism.

Thirdly, we obtain the competitive ratio of OSPB mechanism which is closely related with the distribution of the workloads of the BCP and the bids of ICPs, and the results of simulations show that it is a more efficient mechanism compared with average budget allocation under the random environment.

The rest of this paper is organized as follows. We discuss the related work in Section 2. After describing the system model in Section 3, we propose an online sequential resource procurement mechanism in cloud market in Section 4. In Section 5 we analyze the properties of our mechanism and the competitive ratio. Section 6 reports the performance evaluation of our mechanism with real data from parallel computing centers. Section 7 finally concludes this paper.

2. Related work

Economic models are used to analyse sharing and scheduling resources among cloud networks which have attracted more interests. There are mainly three concerns in those economic models: one is how to improve the revenue of CPs by selling the residual resources, which has been investigated in many literatures [4,14–16]; the other is how to improve the valuation or profit in peak-demand state by renting resources from CPs, which also has received more attention [11,9,17]; the third is how to improve the utility of whole cloud network, in which cloud federation is introduced in the cloud networks [18,19]. In our work, we mainly focus on the second concern which is related to both cloud computing and online procurement mechanism design with budget constraint, and we only review the most related ones in this part.

Based on Stackelberg leadship model and cooperation game model, Hassan et al. [9] studied two resource purchase models in a horizontal cloud federation environment, in which the valuation function of resources is concave, and the objective of buyer is to maximize the utility. Prasad et al. [11,17] presented a cloud resource procurement approach which