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Market-based Service Allocation for Distributed Computing

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Abstract Market-based resource allocation is expected to be an effective mechanism to allocate resources in a cloud computing environment, where the resources are virtualized and delivered to users as services. In this paper we propose a market mechanism to efficiently allocate multiple computation/storage services among multiple participants, or the Cloud Service Exchange. The proposed mechanism enables users (1) to order a combination of arbitrary services in a co-allocation or a workflow manner, and (2) to receive future/current services at the forward/spot market.

Keyword Cloud computing, Grid computing, Scheduling, Market-based resource allocation, Combinational auctions

1. Introduction

Cloud computing is an emerging service paradigm for distributed computing environment. The computing resources, either software or hardware, are virtualized and allocated as services from providers to users. QoS is an important issue for industrial users to utilize cloud computing environment in their business. Advanced features related to QoS include performance guarantee of a service, co-allocation of multiple services and supporting a workflow organized by different services.

In the near future, we can expect that hundreds of providers compete to offer resource services and thousands of users also compete to receive the services to run their complex tasks on cloud computing environment with guaranteed QoS and limited budgets. However, an efficient recourse allocation mechanism among resource providers and users has not been well discussed.

In this paper, we propose a market-based resource allocation mechanism, which allows participants to trade their services effectively by means of the double-sided combinational auction. A market mechanism is one of the promising solutions to cope with the situation where a large number of participants, e.g. providers and users, trade the multiple kinds of resource services. The proposed mechanism enables the participants to trade future and current services in the forward market and the spot market, respectively.

2. The Design Goal

This section briefly discusses the requirements for the proposed mechanism.

- **Economic efficiency**: When the allocation is economically efficient, it is impossible to increase a participant's welfare without decreasing another participant's welfare; i.e. there is no wasted resource. Maximizing the total welfare is a sufficient condition for economic efficiency. We employ the mixed integer programming method to strictly maximize the total welfare.
- **Predictability and flexibility**: Since the supply and demand in cloud computing environment change dynamically over time, the users may desire predictable allocation in advance as well as flexible adjustment in runtime. The proposed mechanism employs dual market mechanisms, the forward market for advance reservations of resources and the spot market for immediate reservations.
- **Combinational biddings**: The users may want to run complex tasks with advanced features, e.g. co-allocation. The proposed mechanism accepts combinational bids, with which the user can express complemental requirements for resource allocation.
- **Double-sided auctions**: In the proposed mechanism, both resource providers and users compete to offer/receive resources. Prices of resources are reflected by supply and demand of resources. The conventional commodities market mechanism [1] does not satisfy the requirement for the proposed mechanism. The proposed mechanism employs the double-sided auction model.

3. Related Work

Market-based resource allocation has been a hot topic in the grid literature for a decade. Schnizler et al. [2]

introduced the double-sided combinational auction into grid service/resource allocation. In [2], resources are bundled by the resource providers and the users cannot select combination of resources. Tan et al. [3] proposed the Stable Continuous Double Auction (SCDA). It is not truly combinational, i.e. the users need to bid on multiple auctions in order to receive multiple resources. Amar et al. [4] illustrated a comprehensive grid market model including the futures market and the centralized/decentralized spot market. However, a detailed model of the futures market is not discussed.

While the computing resource market is not yet realized at the industrial level, the electricity market has been in practical operation for several years. For instance, Japan Electric Power Exchange (JPEX) started the operation in 2005. According to [5], it provides three markets: (1) the spot market for trading the electricity on the next day, (2) the forward market for trading the electricity delivered in some weeks or months, and (3) the forward bulletin board market for free transactions. Since the electricity and the computing service have similar nature (i.e. they cannot be stored), we regard the electricity market as a preceding model to the computing service market. However, the electricity market model cannot be directly applied to cloud computing because the electricity is almost uniform whereas the computing services vary in types and quality.

The stock market deals with a variety of stocks which can be stored and resold unlike the computing service. In this area, studies on the dealing strategy and the mechanism design are carried out recently by means of multi-agent simulation. U-Mart [6] is a test bed for multi-agent simulation of the stock market, especially focused on futures trading. It allows machine agents and human agents to trade future stocks at the same time. We are developing our evaluation framework to be compatible with U-Mart's agents so that human agents can participate in experiments.

4. The Market Model

Figure 1 shows cloud computing environment with the proposed mechanism, the Cloud Service Exchange. There is a centralized exchange including the forward market and the spot market, where resource provider/user agents participate to sell/buy the computing/storage resources abstracted as services. The participants interact with the spot market and the forward market independently using the bidding language described below.

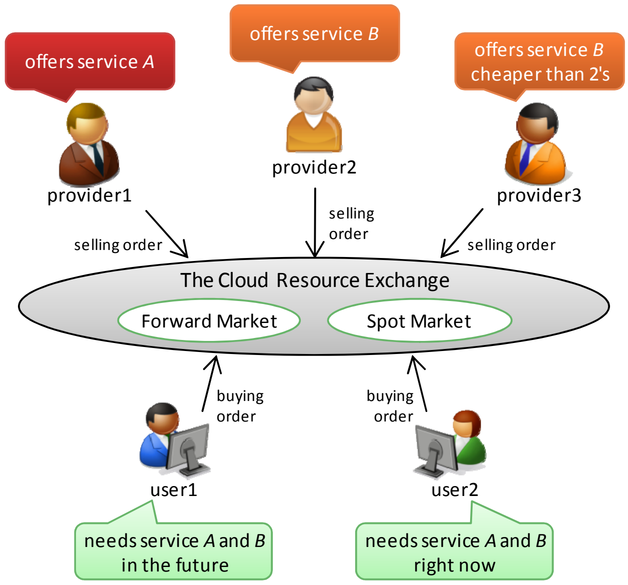

Fig.1 Overview of the Cloud Service Exchange.

Regarding the service we assume following conditions:

- The amount of a service can be measured in a throughput (e.g. 60GB/h of service *A*).
- From the provider's point of view, a resource can be divided into arbitrary fraction (e.g. a resource of 60GB/h is divided into 20GB/h for *user1* and 40GB/h for *user2*).
- From the user's point of view, a task can be divided into sub-tasks and executed on multiple resources (e.g. a task of 40GB/h is allocated a resource of 10GB/h from *provider1* and that of 30GB/h from *provider2*).
- Also, a task can be migrated during the runtime (e.g. a task running on a resource from *provider1* is suspended and resumed on that from *provider2*).

The proposed mechanism is characterized by three properties: (1) the bidding language defines the protocol between participants and markets, (2) the allocation scheme determines assignment of services, and (3) the pricing scheme fixes prices at which the participants trade their services. Below we formulate each property for each market.

4.1. The Forward Market

The forward market deals with long-term advance reservations by means of the clearinghouse auction. It makes contracts periodically. A service is divided into timeslots, e.g. 1pm-2pm, and the timeslot is traded in the market. The market accepts orders from users any time but makes contracts every certain period, e.g. 3 hours.

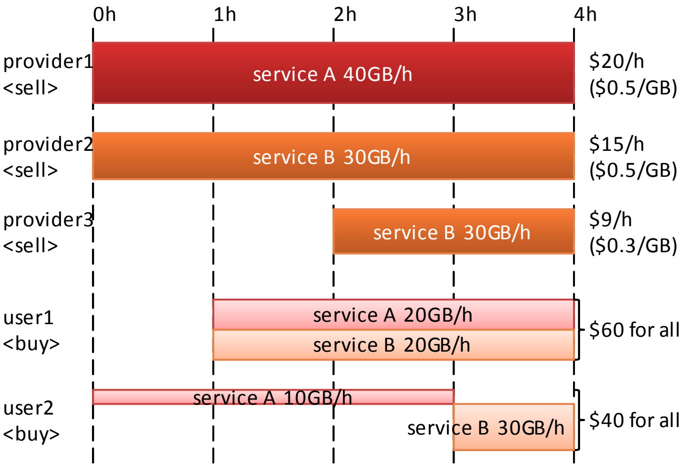

Fig.2 Example orders in the forward market.

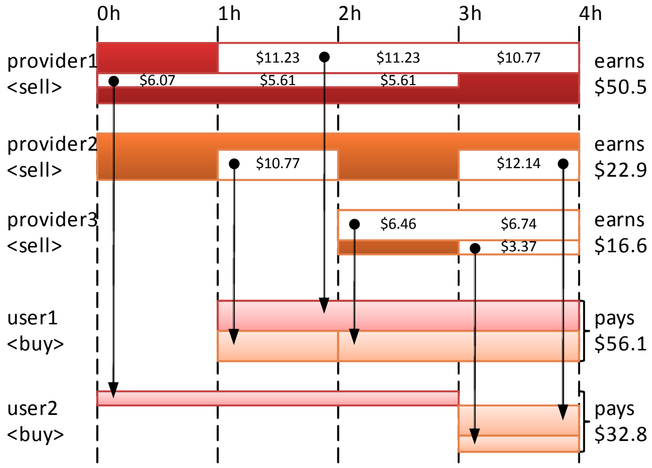

Fig.3 Example allocation in the forward market.

4.1.1. Bidding Language

The bidding language describes the information in orders from participants to a market.

A buying order from a user includes the following information:

- Valuation: The maximum price at which the user wish to buy the bundle of services.
- A bundle of arbitrarily services, each of which include:
  - Name: the kind of service
  - Quantity: the amount (throughput) of the service
  - Arrival: the earliest timeslot to start the task
  - Deadline: the latest timeslot to finish the task
  - Length: the total number of timeslots required to run the task

Note that valuation is given to a bundle, not to each particular service. In this way the user can express requirements for receiving multiple services, e.g. co-allocation or workflow. A contract is made if all services in the order are reserved for the user.

A selling order from a provider includes the following information:

- Valuation: the minimum price per timeslot at which the provider wish to sell the service
- Name: the kind of service
- Quantity: the amount (throughput) of the service
- Timeslot: the timeslot to provide the service

Note that a selling order includes only one service at one timeslot. The provider makes multiple orders for each service and each timeslot.

Formulation

Let $M=\{m_1,\dots,m_{|M|}\}$, $m_i=\{v_i,S_i\}$ be selling orders; $N=\{n_1,\dots,n_{|N|}\}$, $n_j=\{v_j,S_j\}$ be buying orders; $G=\{g_1,\dots,g_{|G|}\}$ be services; $1\le t\le T$ be timeslots; and v_i and v_j be valuation. A buying order is formulated as

$$S_j=\{(g_k,q_{j,k},a_{j,k},d_{j,k},l_{j,k})\mid 1\le k\le |G|\}$$

where $q_{j,k}$ is the quantity of service g_k, $a_{j,k}$ is the arrival time, $d_{j,k}$ is the deadline and $l_{j,k}$ is the length. Similarly, a selling order is formulated as

$$S_i=(g_k,q_{i,k},e_{i,k})\ ;\ 1\le k\le |G|$$

where $e_{i,k}$ is the timeslot.

4.1.2. Allocation Scheme

The allocation scheme determines a winner of an auction. We formulate the winner determination problem into a linear mixed integer program (MIP). Here we introduce four series of decision variables: $u_j\in\{0,1\}$ denotes whether the buyer n_j gets all services in the bundle; $x_{j,k}\in\{0,1\}$ denotes whether the service g_k is allocated to the buyer n_j; $z_{j,k,t}\in\{0,1\}$ denotes whether the service g_k is allocated to the buyer n_j in the timeslot t; $0\le y_{i,j,k,t}\le 1$ denotes the percentage of the service allocated to the buyer n_j in the timeslot t, where the service g_k is owned by the seller m_i. The solver then maximizes the total welfare w by solving the MIP:

Maximize

$$w=\sum_{j=1}^{|N|}v_ju_j-\sum_{i=1}^{|N|}\sum_{j=1}^{|M|}\sum_{k=1}^{|G|}\sum_{t=1}^{T}v_iy_{i,j,k,t} \quad (1)$$

s.t.

$$\sum_{k=1}^{|G|}x_{j,k}-|G|\,u_j=0; \quad 1\le j\le |N| \quad (2)$$

$$\sum_{t=1}^{T}z_{j,k,t}-l_{j,k}\,x_{j,k}=0; \quad 1\le j\le |N|,1\le k\le |G| \quad (3)$$

$$\sum_{j=1}^{|N|}y_{i,j,k,t}\le 1; \quad 1\le i\le |M|,1\le k\le |G|,1\le t\le T \quad (4)$$

$$q_{j,k}z_{j,k,t}-\sum_{i=1}^{|M|}q_{i,k}y_{i,j,k,t}=0; \quad 1\le j\le |N|,1\le k\le |G|,1\le t\le T \quad (5)$$

$$(a_{j,k}-t)z_{j,k,t}\le 0; \quad 1\le j\le |N|,1\le k\le |G|,1\le t\le T \quad (6)$$

$$(t-d_{j,k})z_{j,k,t}\le 0; \quad 1\le j\le |N|,1\le k\le |G|,1\le t\le T \quad (7)$$

$$(a_{i,k} - t)\sum_{j=1}^{|N|} y_{i,j,k,t} \le 0; \quad 1 \le i \le |M|, 1 \le k \le |G|, 1 \le t \le T \tag{8}$$

$$(t - d_{i,k})\sum_{j=1}^{|N|} y_{i,j,k,t} \le 0; \quad 1 \le i \le |M|, 1 \le k \le |G|, 1 \le t \le T \tag{9}$$

$$u_j \in \{0,1\}; \quad 1 \le j \le |N| \tag{10}$$

$$x_{j,k} \in \{0,1\}; \quad 1 \le j \le |N|, 1 \le k \le |G| \tag{11}$$

$$z_{j,k,t} \in \{0,1\}; \quad 1 \le j \le |N|, 1 \le k \le |G|, 1 \le t \le T \tag{13}$$

$$0 \le y_{i,j,k,t} \le 1; \quad 1 \le i \le |M|, 1 \le j \le |N|, 1 \le k \le |G|, 1 \le t \le T \tag{14}$$

4.1.3. Pricing Scheme

The pricing scheme calculates a price, which a provider/user actually earns/pays. The proposed mechanism employs the K-pricing scheme for pricing. This scheme intends to distribute the welfare generated by trading between the provider and the user. Let $0 \le K \le 1$ be an arbitrary fraction. The price p is then calculated as $p_{i,j,k,t} = K(v_j z_{j,k,t}) + (1-K)(v_i y_{i,j,k,t})$ for each resource and timeslot.

4.2. The Spot Market

The spot market deals with short-term allocation by means of the continuous auction. It makes contracts continuously. The market matches orders whenever they come. The contracted service is allocated to the user within the current timeslot. The bidding language, the allocation scheme and the pricing scheme are almost same as those of the forward market except that they have only one timeslot.

5. Simulator

We implemented the core auction mechanism in our simulator. Our simulator is based on MACE [2] and utilizes CPLEX or lp_solve as the backend solver.

Figure 2 and 3 illustrate examples of forward trading among five participants: *provider1* offers service *A*; both *provider2* and *provider3* offers service *B* with different prices; *user1* needs service *A* and *B* simultaneously; *user2* needs service *A* followed by *B*. As a result, all the users' needs are fulfilled. Note that *provider3* wins the competition for service *B* because the lower selling price makes more total welfare.

Figure 4 and 5 illustrate spot trading among participants. In this case *user4* loses the competition for service *B* because *user3* pays higher price. *Provider1* still has enough capacity for service *A*, but it is not allocated to *user4* since the order is combinational.

6. Conclusions and Future Work

In this paper we proposed the market-based resource allocation mechanism on cloud computing environment. It allows users to order an arbitrary combination of services to different providers. The proposed mechanism runs the forward market and the spot market independently to make predictable and flexible allocation at the same time. The preliminary experiments show that the auction mechanism works properly.

We are interested in the behavior of the exchange, particularly the interaction between the spot market and the forward market. We anticipate that a forward price shows a forecast of a spot price in the future. We are going to investigate the market behavior including such an interaction.

Our goal is to establish an efficient market-based resource allocation mechanism suitable for cloud computing. We are now extending our simulator to evaluate the proposed mechanism.

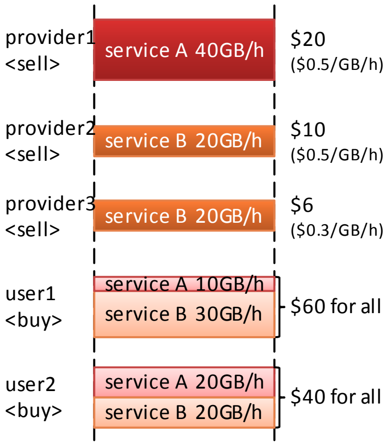

Fig.4 Example orders in the spot market.

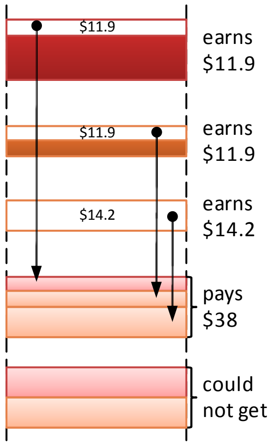

Fig.5 Example allocation in the spot market.

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