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Combinatorial Double Auction-Based Scheme for Resource Allocations in Grids

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Abstract. Offering Grid services in an open market determines an optimization case for finding the best suitable resource allocation for a given number of requests and existing resources. Thus, appropriate resource allocation schemes, supporting accounting, are required in addition to a pricing scheme, which supports financial fairness criteria. The newly developed Resource Allocation Model Developed for the Combinatorial Double Auction (RAMDCoDA) achieves these requirements, while being incentive compatible. Therefore, this paper introduces the mechanism, the pricing scheme, and their evaluation.

Keywords: Grid Services; Resource Allocation; Accounting and Pricing; Auctions; Combinatorial Double Auction

1 Introduction

Grid services offered in an open market do have to show a scheme for resource allocations, which should follow a path of fairness. Since a commercial approach on fairness includes price settings with right incentives, grid services offered should be supported by a suitable resource allocation, accounting, and pricing (often termed billing) scheme. As economic theory tells, auctions do have the potential, if applied in a sensible manner, to achieve these fairness criteria.

Therefore, especially Combinatorial Auctions (CA) can represent satisfying characteristics in the Grid services market. Within CAs the

user can bid for combinations of resources on which tasks can be executed. Instead of bidding for single-item resources for several times, within a single round the user can bid for multiple resources. This can improve the economic efficiency, while maximizing the revenue of the Grid. However, existing CA-based resource allocations [1], [8] usually focus on the users' side and they do not take accounting and price requirements of providers into consideration. Additionally, there is no specific definition with which providers will provide resources for winning bidders. Moreover, due to the computational complexity of pricing the CA, the final price paid by the agent is often regarded as its bid or the simple division of the auctioneer's total income, which cannot ensure incentive compatibility.

Thus, a novel resource allocation model is proposed, suitable for accounting purposes and a corresponding pricing scheme (sometimes termed billing), which is based on Combinatorial Double Auctions (CoDA) and which offers a better performance. Analytical experiments of the Resource Allocation Model Developed for the Combinatorial Double Auction (RAMDCoDA) show that the new scheme is effective. Moreover, RAMDCoDA is incentive compatible, which encourages participants to bid for resources according to their true valuation.

The remainder of the paper is organized as follows. Section 2 surveys related work on existing schemes. While Section 3 does introduce the underlying resource allocation model RAMDCoDA in grids, Section 4 defines the corresponding pricing algorithm. This model and pricing algorithm are simulated (cf. Section 5) and conclusions are drawn afterwards in Section 6.

2 Related Work

Existing pricing schemes can be classified into three main categories of economic models: Bargaining Models, Commodity Market Models, and Auction Models.

For a bargaining model a game theoretic pricing strategy was proposed by [2], addressing an efficient job allocation in mobile grids.

In this scheme, the two players, namely the Wireless Access Point (WAP) Server (acting on behalf of the Grid community) and the mobile device, play an incomplete information alternating-offer, non-cooperative bargaining game to decide upon the price per unit resource charged by that mobile device.

The Commodity Market Model determines a common model used for pricing; key sources on this topic include [7], [9], [10], and [17]. The market optimizes the price to achieve a market equilibrium, in which demand equals supply. When the market is brought to an equilibrium, it reaches a Pareto-optimal allocation. This means that a change in price cannot increase the utility of one participant in the market without worsening the utility of at least one of the other market participants. Selected relevant research, such as demand prediction, is introduced for pricing in commodity market [10], [17].

The original Auction Models include either one-to-many or many-to-many interactions. In one-to-many auctions one agent initiates an auction and a number of agents can propose a bid. The English auction, the Dutch auction, first-price auctions, and the Vickrey auction belong to this category. The basic philosophy behind these auctions is that the highest bidder always gets the resource and the current price for a resource is determined by bid prices in different ways. In many-to-many auctions, several agents initiate an auction and several other agents can bid in the auction. The double auction is the most widely used auction for many-to-many auctions. In these auctions, buyers and sellers are treated symmetrically with buyers submitting bids and sellers submitting offers. There are two types of double auctions, Continuous Double Auction (CDA) and periodic double auction. A CDA matches buyers and sellers immediately on detection of compatible bids. In contrast, a periodic version of the double auction collects bids over a specified interval of time and clears the market at the expiration of the bidding interval. Besides, a double auction can be classified into Single-unit Double Auction (SDA) and Multi-unit Double Auction (MDA). SDAs focus on the single-unit trade in one auction. In an MDA market sellers and buyers submit “asks” and “bids”, respectively. A trade is made if a buyer’s bid exceeds a seller’s

ask. Typically, a seller has multiple units for sale and a buyer wants to purchase more than one unit. Therefore, a seller's ask may match several buyers' bid and a buyer's bid may satisfy several sellers' asks. CAs are a newer category; instead of selling items or resources individually, the seller allows bids on bundles of items, enabling bidders to deal with entities of direct interest and avoiding the risk of obtaining incomplete bundles. Given a set of combinatorial bids, the seller decides on how to allocate individual goods to those bundles for which bids were placed. This aims at maximizing the revenue.

Pricing schemes based on the auction model include an autonomous pricing mechanism proposed by [15], in which prices are decided by Grid traders within their trading process. The mechanism uses a bidding strategy to come to an agreement of resource prices between consumers and producers. The consumer uses priority analysis to choose one producer from the supply table. Secondly, [6] also proposes a type of autonomous pricing mechanism, in which consumers and producers are autonomous agents that make their own decisions according to their capabilities and their local knowledge. The CDA model is used in this scheme. Sellers or buyers start with a fixed price and update it over time. The updated value is defined based on past resource or task utilization of this particular seller/buyer. Furthermore, [4] designs an MDA e-market mechanism that is strategy-proof with respect to the reservation price, weakly budget-balanced, and individually rational, and also makes sellers unlikely to under-report the supply volume to drive up the market price. The similar MDA mechanism is discussed in [12] for resource allocation on computational Grids, while discussing the efficiency of the mechanism as well. Finally, [8] introduces the pricing strategy in combinatorial grid. In this scheme, resource agents administrate available memory, CPU, network bandwidth, and disk capacities on their particular host computers systems on the supply side. On the demand side, task agents collect required resource combinations including CPU, network bandwidth, and disk capacity needed to accomplish their production tasks. Between resource and task agents there is a market mediator allocating resources employing a CA. In order to accelerate the price-finding process; the

auctioneer provides a feedback on the resource availability to bidders to adjust their bid for not accepted bids in consecutive rounds.

The distinguishing characteristic of the work proposed is determined by the use of CoDA onto resource allocation and pricing. The CoDA combines both advantages of a double auction and the CA. Moreover, the model designed can obtain the complete allocation information and trade price as described in the following sections.

3 CoDA-based Resource Allocation Model

Distributed resources within a Grid, including the computing resource, storage resource, or network bandwidth, have to cooperate with each other to complete tasks requested for by users. Therefore, the idea of the CA is suitable for resource allocation in Grids. In the CA, the winner determination algorithm finds an optimal allocation of resources for all current tasks, increasing the economic efficiency and maximizing the revenue [11]. It is well known that double auctions in which both sides submit demand or supply bids are much more efficient than several one-sided auctions combined. Moreover, comparing with the one-side auction, the double auction can prevent a monopoly. CoDAs [14] can not only represent advantages of the CA, but also consider requirements of both buyers and sellers. Therefore, it does – from a modelling perspective – represent good characteristics for Grid resource allocations.

The novel CoDA-based resource allocation model is shown in Fig. 1. It is composed out of four entities: User Broker (UB), Grid Service Provider (GSP), Grid Market Auctioneer (GMA), and Grid Information Service (GIS). Each grid user operates a UB. There are four components of the UB. The Resource Discovery component is responsible for finding resources according to users' requirements; it contacts the GIS to obtain the list of resources that matches these requirements. The Auction Agent is responsible for generating resource combinations based on the list of resources returned by the GIS. For each combination of resources, it generates a bid within the user's

budget and submits the bid and the corresponding combination to the GMA. The Price Depository component is responsible for storing price information related to the task, at a later stage, this information can be used for accounting. The Job Management Agent is responsible for sending the user job to resources and collecting the results.

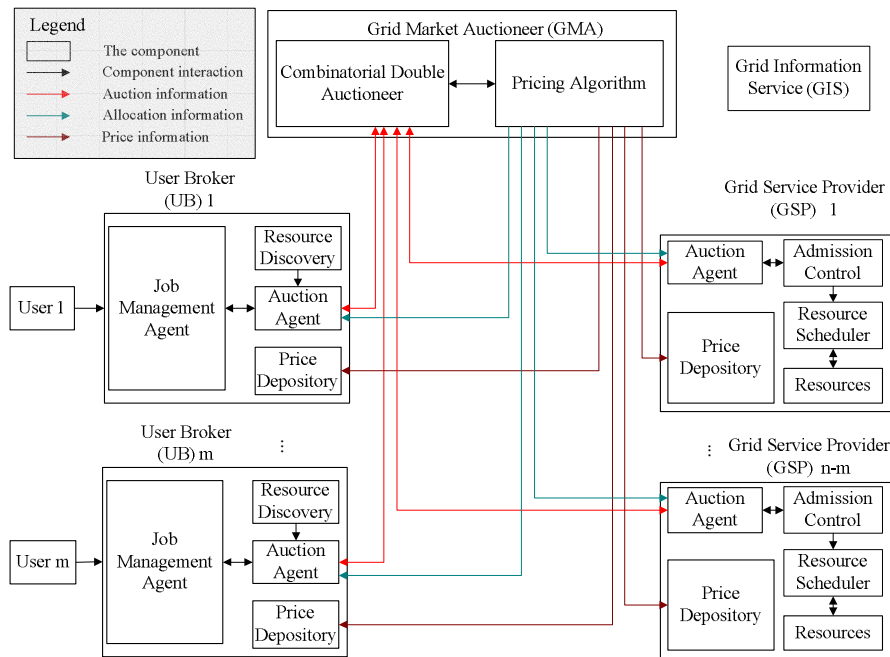


Fig. 1.Resource Allocation Model Developed for the Combinatorial Double Auction (RAMDCoDA)

The GIS provides resource registration services and maintains a list of resources available in the Grid. Each GSP will register all the resources it can provide at the GIS. The UB can contact the GIS to discover the required resources as shown above.

A GSP is the Grid node, which contributes its resources to the Grid and profits from this offer. Here, the Auction Agent is responsible for generating the resource combination it would sell. For each resource combination, it generates a bid (ask price) and submits the bid and the corresponding combination to GMA. The Admission Control component receives the auction result from the Auction Agent and

decides, whether the tasks sent from the UB will be managed or not. The Resource Scheduler is responsible for allocating all tasks to the corresponding resources. The Resources Component denotes the set of all resources the node owns.

Within the Grid Market Auctioneer, the Combinatorial Double Auctioneer is responsible for collecting the combination of resources and corresponding bids sent by the UBs and GSPs. Based on the corresponding bid information it runs the CoDA algorithm to determine the winner UBs and GSPs. Additionally, it sends the result obtained to the UBs and GSPs, who have won the auction. Finally, the Pricing Algorithm is responsible for generating particular allocation results and corresponding price information. The price calculated will be sent to all UBs and GSPs, who did participate in the trade.

4 The Pricing Algorithm

The model determined above shows that the pricing algorithm is the key part of the double auction approach. Thus, for the resource allocation the algorithm proposed follows five steps to determine the best suited resource price.

1. Assuming that there are n participants in the CoDA system, including m users and $n-m$ GSPs, UBs and GSPs submit resource combinations (bundles) and bids, in form of B_j , to the GMA. B_j can be specified as (a_j, p_j) , where $a = (a_{1j}, \dots, a_{ij}, \dots, a_{kj})$, a_{ij} is the unit of item i requested (when $a_{ij} > 0$) or supplied (when $a_{ij} < 0$) in the bundle j . The symbol k denotes that there are k items of resource to be considered jointly in the auction. p_j is the amount the bidder is willing to pay for the bundle j , if $p_j > 0$ and it is regarded as a buy bid; otherwise it is regarded as a sell bid. Afterwards, the combinatorial double auctioneer runs the CoDA algorithm represented in Eqn. (1) and receives the result x_j [14].

The objective of the CoDA is to maximize total trade surplus, while satisfying the constraint that the number of units selected by buy bundles does not exceed the number provided by the selected sell

bundles for each item. It can be seen that the model can be solved as the 0-1 programming problem. All solutions proposed for the winner determination problem in CA [3], [16] can also be used for reference.

$$\max \sum_{j=1}^n p_j x_j , \quad (1)$$

$$s.t. \sum_{j=1}^n a_{ij} x_j \leq 0 \quad \forall i \in K ,$$

$$x_j \in \{0,1\} \quad \forall j \in \{1,\dots,n\} .$$

Afterwards, the GMA informs UBs and GSPs about the bid's acceptance and rejection and requests the winner GSPs to reserve the resources awarded. Loser participants can renew their bids in the next round. The winner participant is denoted as the trader in the following.

2. For each trader, the average price ap_j is calculated (cf. Eqn. (2)).

$$ap_j = \frac{p_j}{\sum_{i=1}^k a_{ij}} . \quad (2)$$

All traders can be divided into buyers and sellers. Buyers are ranked in the decreasing order of the average price; the result is denoted as the buyer list bl . While sellers are ranked in the increasing order of the average price, the result is the seller list sl . All sellers will be classified by the resource item, and the algorithm achieves $sl_i, i \in \{1,\dots,k\}$ for each item of the resource, where q_i represents the resource quantity list corresponding to the sl_i .

3. Generating the average trade price matrix atp , in which $atp(s,t)$ represents the average trade price, when the sth buyer in the bl

trades with the t th seller in the list sl , the value is calculated as follows in Eqn. (3):

$$atp(s,t) = \frac{ap_{bl(s)} + ap_{sl(t)}}{2}. \quad (3)$$

4. The resource allocation and pricing is done in order from the first buyer in bl to the last one. $allocation_i$ and tp_i , which are both $g \times h$ matrices, represent the particular allocation and pricing results of the resource i , respectively. Here g denotes the number of buyers in bl , h denotes the number of sellers in sl . The allocation and pricing algorithm is defines as follows:

Input: B, bl, sl, sl_i, q_i

Output: $tp_i, allocation_i; i \in \{1, \dots, k\}$

(1) Initialization:

$s = 1, i = 1, tp_i = [0]_{g \times h}, allocation_i = [0]_{g \times h}$,

(2) Inquire the average trade price matrix atp ; compare the buyer's requirement $a_{ibl(s)}$ with $q_i(m)$

$m \leftarrow$ the location of the first non-zero quantity in the list q_i

$t \leftarrow$ the location of seller $sl_i(m)$ in the list sl

If $q_i(m) \geq a_{ibl(s)}$

$tp_i(s,t) = tp_i(s,t) + a_{ibl(s)} \cdot atp(s,t)$;

$allocation_i(s,t) = allocation_i(s,t) + a_{ibl(s)}$;

$q_i(m) = q_i(m) - a_{ibl(s)}$;

$a_{ibl(s)} = 0$;

Go to step (3);

else

$tp_i(s,t) = tp_i(s,t) + q_i(m) \cdot atp(s,t)$;

$allocation_i(s,t) = allocation_i(s,t) + q_i(m)$;

$a_{ibl(s)} = a_{ibl(s)} - q_i(m)$;

$q_i(m) = 0$;

Repeat step (2);

(3) Store the temporary allocation result $allocation_i$ and pricing information tp_i , determine whether all the resource requirements of the s th buyer are satisfied, If all requirements are satisfied
 Go to Step (4);
 else
 $i = i + 1$;
 Go to Step (2);

(4) Determine whether all buyers' requirements are satisfied, i.e., whether get to the end of the bl ,
 If end of the bl
 EXIT;
 else
 $s = s + 1$;
 $i = 1$;
 Update $tp_i, allocation_i, q_i$;
 Go to Step (1);

Finally, each trader will receive a trade price represented by the vector tpb or tps , which is given by Eqn (4).

$$tpb = \left(\sum_{i=1}^h \sum_{i=1}^k [tp_i]_{g \times h} \right)^T, \quad tps = \sum_{s=1}^g \sum_{i=1}^k [tp_i]_{g \times h}, \quad (4)$$

T denotes the transposition of the matrix.

5. Finally, the GMA sends the related information in those vectors tpb, tps , and $allocation_i$ to each trader.

5 Simulation Results and Discussion

Based on the model and pricing algorithm presented above a functional and performance investigation has been undertaken. While the functionality of the RAMDCoDA shows the interactions needed to obtain the result of a corresponding price, the performance needs an analytical approach. Thus, a simulation has been performed. Experiments were run in Matlab on a Pentium (R) D CPU with 2.80

GHz each and 1 GB memory. Key rules for the parameter selection are as follows: for buyers, the value of each item of resource is within the range $[bvl_i, bvu_i]$, for sellers, the value of each item of resource is with the range $[svl_i, svu_i]$, with the constraint $svl_i \leq bvl_i, svu_i \leq bvu_i$ to lower the possibility that the too many bids of sellers are higher than bids of buyers. The demand and supply quantity of resource i from each participant, i.e. $|a_{ij}|$, is uniformly distributed over the interval $[0, d_i]$ and $[0, s_i]$ respectively. Based on the assumption above, each buyer can give its valuation of his resource combination within the range $\left[\sum_{i=1}^k a_{ij} bvl_i, \sum_{i=1}^k a_{ij} bvu_i \right]$, while each seller can give its valuation within $\left[\sum_{i=1}^k a_{ij} svu_i, \sum_{i=1}^k a_{ij} svl_i \right]$. In the following simulation, all participants will bid for resource combinations according to their true valuation, which means bids are equal to those valuations. For each item of the resource, a reference resource can be chosen as the unit, take the storage resource for example, a unit could be 1 GByte storage space; thus, the demand of 3 of the storage resource represents a participant's need of 3 GByte space for its task.

The particular simulation undertaken considers 3 items of resources in the Grid, denoted as A, B, and C. These resources may include in a real-world scenario storage, access bandwidth, and a certain software library needed to run the Grid's task of a weather simulation. In the case considered, 16 participants are involved in the CoDA, including 6 UBs and 10 GSPs. For UBs, the value ranges of 3 items of resources are $[5, 10]$, $[10, 15]$, $[15, 20]$ respectively, while for GSPs, the ranges are $[4, 8]$, $[8, 12]$, $[12, 16]$ respectively. Moreover, $d_1 = d_2 = d_3 = 5$, $s_1 = s_2 = s_3 = 3$ has been selected. All detailed units of demand or supply of each participants and the bid for the resource combination can be found in Table 1. Due to the fact that parameters are selected randomly according to the rules above, the results will be different for the various selected parameter settings. However, the proposed method can get always the complete allocation information and price results, as described in the following based on those parameter settings in Table 1.

Through solving the CoDA represented in Eqn. (1), participants 1, 2, 3, 5, 6 and 7, 8, 10, 11, 12, 13, 15, 16 are the winning bidders. The bids of 4, 9 and 14 are rejected in this round.

Table 1. Parameter Settings for each Participant (Simulation)

No.	A	B	C	p	No.	A	B	C	p
1	0	3	3	104	9	-2	-3	-1	-80
2	4	3	3	136	10	-1	-3	0	-36
3	3	3	4	144	11	-2	-2	0	-38
4	2	0	1	33	12	0	-1	-3	-70
5	4	3	2	125	13	-3	-3	-1	-93
6	1	5	1	93	14	-2	0	-3	-71
7	0	-2	-2	-59	15	0	-3	-3	-76
8	-3	-2	-3	-110	16	-3	-1	-1	-54

The allocation and pricing results using the input values of Table 1 and the pricing algorithm are shown in Fig. 2. bl determines the buyer list as discussed above. Its order is the same as the row order of $allocation_i$ and tp_i , while the seller list sl has the same order as the column order of these matrices. It can be seen that Fig. 2 gives the complete information of the allocation and all trade prices. Take buyer 1 for example: his demand is (0 3 3) - determining the request for 0 units of resource A and 3 units for resource B and C, respectively - and the bid is 104. His trade information can be obtained from the corresponding row based on his position in bl , i.e. the first row, in the $allocation_i$ and tp_i matrices. As marked in $allocation_i$ in Fig. 2, all requirements of buyer 1 are satisfied by 3 sellers jointly, thus, here the first seller in sl , i.e. 10, provides 3 units of resource B; the third seller in sl , i.e.16, provides 1 unit of resource C; and the fourth seller in sl , i.e. 15, provides 2 units of resource C. They will charge this buyer 39.5, 14.1, and 30 monetary units, respectively, as marked on tp_i in Fig. 2. Similarly, the trade information of each seller can be gained from the corresponding column in the matrices. The total payment of each buyer and the total income of each seller are shown in tpb and tps , corresponding to the buyers and sellers in bl and sl respectively.

The result of the $allocation_i$ will be sent to the Auction Agent component of the respective GSP and UB from the Pricing Algorithm component in the GMA. For UB, the information is forward to the Job Management Agent, which will send the jobs to the corresponding GSPs. For the GSP, the information will be inquired by the Admission Control component, to decide whether the task sent by the UB can be managed or not. The trade price information in tp_i will be sent to the

Price Depository component in the UB and GSP considered. As mentioned already, this information can be used for a later accounting.

$$\begin{aligned}
 \text{allocation}_1 &= \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 3 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2 & 2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} & \text{tp}_1 &= \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 11.7 & 23.9 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 37.0 & 0 & 13.6 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 26.9 & 27.4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 13.5 & 0 & 0 \end{bmatrix} \\
 \text{allocation}_2 &= \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 2 & 2 & 1 \end{bmatrix} & \text{tp}_2 &= \begin{bmatrix} 39.5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 23.9 & 12.6 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 39.8 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 40.3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 27.0 & 28.0 & 15.4 \end{bmatrix} \\
 \text{allocation}_3 &= \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} & \text{tp}_3 &= \begin{bmatrix} 0 & 0 & 14.1 & 30.0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 13.5 & 13.8 & 28.2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 13.8 & 14.3 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 14.2 & 31.1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 15.4 \end{bmatrix} \\
 \text{bl} &= [1 \ 3 \ 5 \ 2 \ 6] & \text{tpb} &= [83.6 \ 127.6 \ 118.6 \ 139.8 \ 99.4] \\
 \text{sl} &= [10 \ 11 \ 16 \ 15 \ 13 \ 8 \ 7 \ 12] & \text{tps} &= [51.2 \ 47.8 \ 63.7 \ 83.4 \ 94.6 \ 109.8 \ 56.5 \ 61.9]
 \end{aligned}$$

Fig. 2. Selected Results of the Allocation and Pricing Simulation

Utilities of these traders involved are illustrated in Fig. 3. Due to the assumption that all participants will bid for resource combinations according to their true valuation, for buyers it holds that $utility = bid - trade\ price$, while for sellers it holds that $utility = trade\ price - bid$ [13]. The average prices of the traders are calculated as indicated in Eqn. (2). The trade prices can be obtained from the results in Fig. 2, as shown by tpb and tps . Then, utilities can be calculated according to the definition above. Fig. 3 shows that buyers with a larger average price and sellers with a smaller average price can obtain more utilities after the pricing process, *i.e.*, these traders will receive the compensation through the pricing algorithm.

It can be seen that the pricing algorithm defined can determine the resource allocation and pricing of 13 traders in a single round. These results include the complete resource allocation status and trade price information for each UB and GSP involved. Comparing with the single-item auction, which needs multiple rounds of auctions for a single item of resource to be auctioned off, RAMDCoDA performs more efficiently. Moreover, comparing with the existing allocation schemes based on the CA, RAMDCoDA can consider all requirements of both users and GSPs. It can adjust the final payment based on the

trade information. Therefore it is very suitable for resource allocation in Grid. This is due to the following reasons: (a) the efficiency, (b) the combination of both advantages of the double auction and the CA, including the prevention of a monopoly, while considering requirements of both sides and permitting bidding for the resource combination requested by the task, and (c) it can achieve the explicit allocation and trade price information as well as the incentive compatibility characteristic, which are missing in a pure CA-based approach.

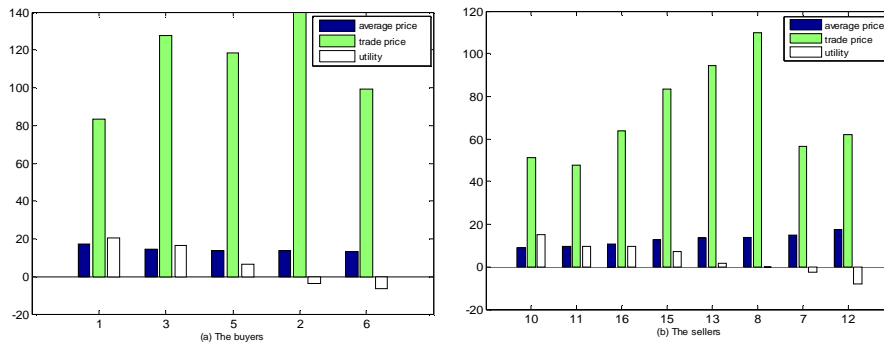


Fig. 3. Utilities of Traders Involved

The achieved incentive compatibility characteristic is explained with the following settings. For example, in order to obtain a better utility through misrepresenting the true valuation, *i.e.*, a try to lower the trade price, buyer 5 bids for the combination at price 110 instead of 125. Other participants still hold their original bid as shown in Table 1. The proposed pricing algorithm can achieve results, in which the final trade prices of buyers 1, 2, 3, 5, and 6 are 83.6, 131.5, 127.6, 123.3, and 95.6, respectively. Comparing these numbers with the *tpb* list in Fig. 2, it can be seen that the misrepresenting of buyer 5 does lead to a higher trade price for himself, while the trade prices of buyer 2 and 6 will remain lower. The reason for this effect is that the bid change of buyer 5 will lead to the change of its location within list *bl*, which causes the buyer to trade with the higher bid sellers. The same effect will happen to sellers who intend to misrepresent their true valuation. Therefore, RAMDCoDA encourages participants to bid according to their true valuations of resources needed.

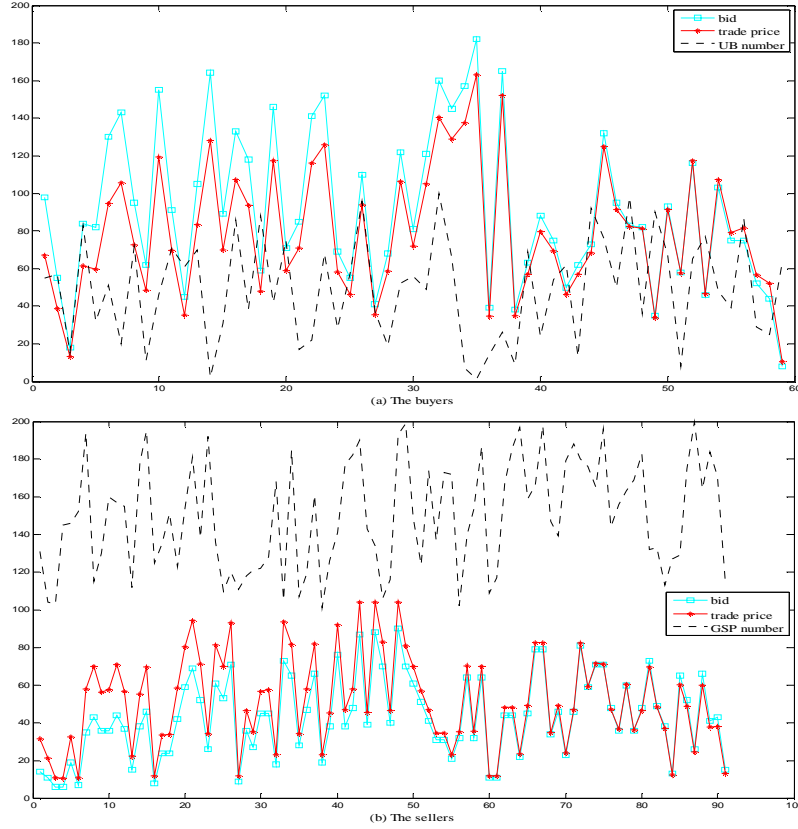


Fig. 4. Results of the Pricing Algorithm ($n=200$)

In order to demonstrate the performance of the pricing algorithm developed for RAMDCoDA, a resource allocation on a larger scale has been simulated. It is assumed that 200 participants are involved in the CoDA, including 100 UBs and 100 GSPs. The rules of these parameter value selection is the same as in the previous experiment, i.e. $k = 3$, $d_1 = d_2 = d_3 = 5$, $s_1 = s_2 = s_3 = 3$, for UBs, value ranges of 3 items of resources are $[5, 10]$, $[10, 15]$, and $[15, 20]$, respectively, while for GSPs, ranges are $[4, 8]$, $[8, 12]$, and $[12, 16]$, respectively. Since this selection has been done randomly and through solving the CoDA, 59 UBs and 91 GSPs are the winning bidders. In any other case of randomly selected parameter values, different UBs and GSPs would be winning, however, the algorithm proposed would work the same way. Therefore, these results of the algorithm are illustrated in Fig. 4, representing a demonstration case. It presents the comparison between

the original bid and the trade price. All buyers (sellers) are ranked in a decreasing (increasing) order of the average price first, the horizontal axes in Fig. 4 (a), (b) represent the corresponding position in bl and sl respectively. Dotted lines in the figure do not relate to the price, they determine the original UB or GSP number corresponding to the number on the horizontal axis, i.e., the position in bl or sl . For example, buyer 35 in Fig.4 (a) denotes the 35th buyer in bl , from the dotted line, it can be seen that buyer 35 represents the first (no. 1) UB in the simulation. The original bid and trade price of this UB are 181 and 162.7 monetary units, respectively. It can be seen that the algorithm proposed can complete the resource pricing efficiently, the trend of the trade price obtained is similar to that of the original bid. Moreover, the buyer (sellers) in the front of the list bl (sl) can receive a compensation, while the last set of buyers (sellers) will pay (get) the higher (lower) price for the service than their original valuations, i.e., they will get negative utilities. This means that the trader will pay (get) the higher (lower) price for the service than their original valuations, while the rational trader often would not like to act in this way. If the trader only enters into a transaction under a positive utility, the trader with the negative utility can quit the current resource allocation, and shall renew its bid in the next round. When all participants' utilities are not negative, the designed mechanism exhibits individual rationality [5]. Most traders shall act as a rational individual except those are urgent to request or sell the resources.

6 Summary and Conclusions

The newly developed Resource Allocation Model Developed for the Combinatorial Double Auction (RAMDCoDA) determines an effective means in support of Grid services resource allocation, accounting, and pricing. Moreover, RAMDCoDA's architecture and pricing algorithm are incentive compatible, which encourages participants to bid for their resource requests and supplies according to their true valuation. As analytical investigations have presented, the allocation and pricing results needs a single round of auctions only, in contrast to single-item auction. Furthermore, all requirements of both users and

GSPs are taken into account. Finally, the algorithm achieves the explicit allocation and trade price information.

Therefore, RAMDCoDA offers a valuable approach for Grid service providers within a commercial situation to market their services. The scheme's simplicity and effectiveness determine reasonable arguments for a practical approach. In addition, the resource usage obtained is fair and can be applied for accounting purposes, thus, GSPs and users will benefit from the proposed approach.

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