

# Auction Protocols for Resource Allocations in Ad-Hoc Grids

Behnaz Pourebrahimi and Koen Bertels

Computer Engineering Laboratory, Delft University of Technology, The Netherlands  
{b.pourebrahimi,k.l.m.bertels}@tudelft.nl

**Abstract.** Different auction-based approaches have been used to allocate resources in Grids, but none of them provide the design choice for a specific economic model while considering the interest of all participants in the market. In this paper, we implement an auction-based framework for producer and consumer matchmaking in an ad-hoc Grid. In ad-hoc Grids, where the availability of resources and tasks is highly dynamic, the producers and consumers have to compete for providing and employing the resources. The framework is used to assess the usefulness of a particular mechanism using a set of criteria in different network conditions. We present the performance analysis of different auction mechanisms namely First-Price, Vickrey and Double Auctions in a many-to-many manner. The evaluation is performed in terms of throughput, consumer and producer surplus, and uncertainty measure for obtaining required resources in different network conditions.

## 1 Introduction

Economic-based approaches have been widely studied for resource allocation in Grid [1,2,3]. These approaches mainly focus on efficiency of a particular economic model in the condition where the resources have predefined use and access policy. None of these researches attempts to provide a design choice for a specific economic model while considering the interest of all participants in the market. We propose a meta research on economic-based resource allocation in ad-hoc Grids where resources have different access, use, and cost models and show high variations in their availability patterns. We developed a framework to simulate the Grid components such as Grid users, resource providers and resource allocator(matchmaker) in an ad-hoc Grid. This framework helps to study the impact of different auction models for resource allocation while considering different parameters from Grid owners and Grid users perspectives.

In our implementation of an ad-hoc Grid, every node in the network can act as a consumer or a producer of resources at any time when there is a need for resource or there is a resource available. In such dynamic condition, there is no global information available and decision-making process is distributed across all users and resource owners. We consider many-to-many auctions for match-making between these competitive and selfish consumers and producers as these

type of auctions support simultaneous participation of producer/consumer, observes resource/request deadlines and can accommodate the variations in resource availability. In our framework, matchmaking model uses three auction protocols (Continuous Double Auction, First Price and Vickrey Auction) in a many-to-many market approach. This paper is not intended to merely compare the efficiency of different auction protocols but intends to provide a design choice in ad hoc Grid by comparing them based on throughput, consumer surplus, producer surplus and uncertainty measure in getting required resources in different conditions of the network.

The paper is structured as follows: we discuss related work in Section 2, Section 3 studies different auction mechanisms and describes the reason for our choice of three specific auction protocols. System implementation is discussed in Section 4. In this section, we present system architecture and pricing algorithm. Experimental setup and results are presented in section 5. In Section 6, we discuss the results and finally we conclude in Section 7.

## 2 Related Work

In the literature, we can find several computational markets that use auctions for resource allocation such as [4,5,6]. Most of the previous works consider only one type of the auction and compare it with other economic and conventional models. Gomoluch et al [7] investigate that under which circumstances market-based resource allocation by Continuous Double Auction (CDA) and by the proportional share protocol, outperforms a conventional round-robin approach. It is concluded for a cluster of homogeneous resources the Continuous Double Auction will perform best. However, if the load is low, the differences between three protocols are small, and using the computationally less expensive Round-Robin protocol might be sufficient. For a situation where there is a choice of resources with different quality of load - as it is the case in a computational Grid - the results of Round-Robin will be worse than for two market-based protocols [7]. The CDA will perform best in most cases[7]. [8] presents a periodic double auction mechanism with uniform price for resource allocation on Grid. In this work, auction takes place in rounds and all exchanges are performed with the same price. There are few researches that compare different auction models. [9] compares three different variations of Double-Auction protocols from both resource's and user's perspectives. Comparison parameters in [9] are resource utilization, resource profit and consumed budget. It concludes that CDA protocol outperforms the other two variations of DA from both user's and resource's perspectives. In [10], three types of auction protocols are investigated; First-Price Auction, Vickrey Auction and Double Auction. Resource utilization, resource profit and user payment is measured as the parameters for comparing these protocols. Simulation environment consists of limited number of resources with predefined capabilities, reservation price and Risk Averse/Risk Neutral users. Their results show the First-Price Auction is better from resource's perspective while Vickrey Auction is better from user's perspective. Double Auction favors

both resources and users [10]. The work in [11] analyzes the different auction models in terms of communication demand for resource allocation in Grid computing environments. The investigation is done on First-Price sealed, English, Dutch and Continuous Double Auctions. Their experiments show that English auction present higher communication requirements while CDA presents least demand of communications.

In above mentioned researches, economic based resource allocation has been done in the context of conventional Grids. In conventional Grid, resources are assumed to be dedicated with a fixed number of nodes which provide services. The main contribution of this paper is to provide a design choice for resource allocation in ad-hoc Grids considering Grid objectives and network conditions. We provide a framework for auction-based resource allocation in ad-hoc Grids, in which every node can be a consumer or a producer of resource at any time according to its current workload and its available resources. The experiments are performed in different network conditions with varying number of resources and tasks available in the network. Three auction protocols are compared based on throughput, consumer surplus, producer surplus and budget and transaction price variation in different network conditions.

### 3 Economic Price-Based Mechanisms

Microeconomic based resource allocation approaches can be identified in two, *price-directed* and *resource-directed* (non-price based) approaches. Non-price approaches are either selfish or cooperative and they are based on Game theory or cooperative mechanisms[12][13]. In the price directed approaches, consumers and producers interact via market mechanisms for allocating resources. Two main broad of mechanisms for setting prices are: **commodities markets** and **auctions**. In both the mechanisms, the main components are *consumers*, *producers* and a third party that acts as a *mediator* between consumers and producers. The third party in auction models is auctioneer that determines the sale of an individual resource (or a resource bundle) based on the bids. The basic philosophy behind auctions is that the highest bidder always gets the resources, and the current price for a resource is determined by the bid prices. The third party in commodity market, sets a price for a resource (or a bundle of resources) based on demand and supply. The price is calculated based on tatonnement process [14]. The tatonnement process varies the price of the individual or bundle of resources until an equilibrium is reached. Commodity markets rely on polling aggregate supply and demand repeatedly to calculate the equilibrium price and all allocations are performed in this price. As in ad hoc Grids the resources are not dedicated and supply/demand of resources is very dynamic, the complexity of implementing such centralized market which rely on the aggregate supply/demand of resources becomes infeasible. Therefore, we have selected auction models as the platform for matchmaking of consumer and producer of resources in ad-hoc Grids. In the following section, we study different auction models.

### 3.1 Auction Mechanisms

Auctions can be classified into *open* or *close* auctions. In open auctions, bidders know the bid value of other bidders. In closed or sealed auctions, the participants' bids are not disclosed to others. Within auction based economic models, pricing is driven by how much value resource owner places on the goods (services) and access to services is won by that consumer whose valuation comes closest to that of the resource owner [15]. In these models, there is no global information available about the supply and demand and buyers and sellers usually are not aware of the other's bids or asks and they decide on their local knowledge. An overview of the most popular auction mechanisms is provided below.

- **English Auction:** In English auction the seller openly announces a minimal price for the good to be sold. It follows a sequential bidding in which buyers take turns publicly to submit increasing bids. Buyers decide a private value depending on their requirements. A bidder stops bidding when its private value is reached. The auction continues until only one potential buyer remains, so that the highest bidder wins the item at the price of its bid.
- **Dutch Auction:** Dutch auction is a sequential auction in which the auctioneer starts with a high price and continuously lowers the price until a sale is confirmed by the first bidder to indicate acceptance of a price. The rate of price reduction is up to auctioneer and it has a reservation price below which not to go. Dutch auction may terminate when the auctioneer reduces the price to reservation price and still there is no buyer.
- **First-price Auction:** The First-price auction is a simultaneous bidding auction in which bidders submit sealed bids. In this auction, each bidder submits only one bid without knowing the others' bids. The highest bidder wins and pays his or her own bid price.
- **Second-price Auction (Vickrey):** In the Vickrey Auction, bidders privately submit sealed-bids simultaneously. It is a single round bidding auction. The winner in Vickrey Auction is the highest bidder but it pays the price of the second-highest bid. If there is no second-highest bidder, then the price of the commodity is the average of the commodity's minimum selling price and the consumer's bid price.
- **Double Auction:** It is a two sided auction in which buyers and sellers are treated symmetrically with buyers submitting requests and sellers submitting offers. There are two types of double auctions, **continuous double auction (CDA)** and **periodic double auction**. Continuous Double Auction matches buyers and sellers immediately on detection of compatible bids. In this type, buy orders(bids) and sell orders(offers) may be submitted at anytime during the trading period. A periodic version of the double auction instead collects bids over a specified interval of time, then clears the market at the expiration of the bidding interval [16]. Pricing policy adopted by auctioneer can be classified into **uniform-price policy** and **discriminatory policy**. In uniform policy, all exchanges occur at the same price determined in auction clearing stage. Whereas in discriminatory policy, the prices are set individually for each matched buyer-seller pair.

For resource allocation in ad-hoc Grids, we need an auction mechanism that supports simultaneous participation of producer/consumer, observes resource/request deadlines and can accommodate the variations in resource availability. English and Dutch auctions are sequential and are based on open-cry where each bid has to be broadcasted to all participants. This becomes a considerable communication overhead in the context of ad-hoc Grids. Moreover their inability to observe time deadlines and no support for the simultaneous participation of producer/consumer are the reasons that make them unsuitable for ad-hoc Grid resource allocation.

First-price auction, Vickrey auction and Double auction are simultaneous and close bid auctions. We implement these three auctions in a many-to-many manner where both consumer and producers can submit their asks or bids at any time. To fulfill the deadline constraints for requests and offers more efficiently, we consider an auctioneer that continuously collects requests and offers from participants, instead of collecting them in a specified time intervals.

## 4 System Implementation

Design challenge is to develop a test bed that can help one in making the design choices for resource allocation in ad-hoc Grids considering Grid objectives and network conditions. Here we describe system components and pricing algorithms for the developed test bed.

### 4.1 System Architecture

The model is composed of three agents (see figure-1): **Consumer (buyer)**, **Producer (seller)** and **Auctioneer**. There is one consumer/producer agent per node. This agent controls the process of buying/selling resources by estimating the execution time of the job or availability of the resource. This agent also calculates the price and submits a request/offer for corresponding job/resource to the auctioneer. The consumer/producer agent is also responsible for accepting the offer/request for a matched resource/job from the auctioneer. The auctioneer agent controls the market using either First price or Vickrey Auction or

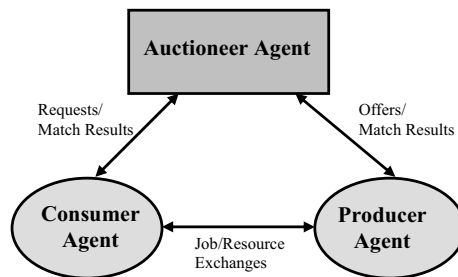


Fig. 1. System Components

Continuous Double Auction Protocol. Auctioneer receives requests and offers continuously and keeps them in its repositories till the time to live (TTL) for them is expired or a match is found. The matching between requests and offers is performed through one of the following protocols:

- **First-price Auction:** In this model, The producers submit their offers for a resource along with a reservation price, the minimum price below which they don't sell. Consumers submit their requests together with a bid price. The consumer agents use a learning mechanism (discussed in section 4.2) to calculate the bid prices. The auctioneer sets up a first price auction for each received offer. The highest bid wins the auction if the bid price is bigger than the offer reservation price and the offered resource satisfies the task's constraints (resource quantity, budget and time frame). In this protocol, transaction price is the bid price.
- **Vickrey Auction:** This model is similar to first price auction, except that the transaction price is the second highest bid price. In fact the winner pays bid price of the first loser. If there is no second highest bidder then the transaction price will be the average of bid and ask prices.
- **Continuous Double Auction:** CDA with discriminatory pricing policy is used as the third protocol for resource allocation in an ad hoc Grid. The buyers and sellers announce their desire to buy or sell computational services to the market. The auctioneer finds the matches between buyers and sellers by matching offers (starting with lowest price and moving up) with requests (starting with highest price and moving down). When a task query arrives at the market place, the protocol searches all available resource offers and returns the best match which satisfies the task's constraints which are resource quantity, time frame and price. When a resource becomes available and several tasks are waiting, the one with the highest price bid is processed first. In this model, consumer and producer agents use the pricing mechanism described in section 4.2 for calculating the bid and ask prices. The transaction price is calculated as the average of ask price and bid price.

## 4.2 Consumer/Producer Pricing Algorithm

The pricing strategy presented here, defines a logical price by local analysis of the previous trade cases. This bidding mechanism has been introduced in [17]. In the three auction protocols (First Price, Vickrey and CDA), consumer agents calculate their bid prices using this history-based pricing mechanism. Producer agents define their ask prices with this bidding mechanism if CDA is used as the auction mechanism, otherwise their ask price is their minimum price.

The price indicates the price of each unit of resource that consumer and producer agents are willing to buy or sell. Let denote by  $p_b(t)$  the bid price of a consumer agent at time  $t$  and  $p_a(t)$  the ask price for a producer agent at time  $t$ . We assume that each consumer agent has a maximum bid price, denoted  $max_b$ .

This maximum price is determined by the node's budget. Each producer agent has a minimum ask price. More formally, we have that:

$$\forall t, p_a(t) \geq \min_a \text{ and } p_b(t) \leq \max_b \quad (1)$$

In our bidding algorithm, agents update their ask (respectively bid) prices using the experience they gained from their previous utilization of the Grid. Informally, the idea is as follows. If an agent has not been successful in buying resources, at current time the agent updates its bid price in a way that tends to increase its chance to buy resources in the future. If an agent has been successful, it conservatively continues to bid in a way that ensures its chance of buying resources in the future. A seller agent behaves in a similar manner. If it has not been successful in selling resources, at current time it updates its ask price in a way that increases its chance of selling its resources in the future. Otherwise, it behaves in a conservative manner. Formally, the ask price of a producer agent at time  $t$  is computed according to the assignment in (2), while the bid price for a consumer agent is given by assignment (3).

$$p_a(t) \leftarrow \max\{\min_a, p_a(t-1) + \alpha \cdot p_a(t-1)\} \quad (2)$$

$$p_b(t) \leftarrow \min\{\max_b, p_b(t-1) + \beta \cdot p_b(t-1)\} \quad (3)$$

where  $\alpha$  and  $\beta$  are coefficients which determine the rate at which the price is increasing or decreasing. These parameters are set according to variations in task or resource utilization at each individual node over time periods.

For a given node, we define the *task utilization* as the ratio of allocated tasks to all submitted requests and the *resource utilization* as the ratio of allocated resources to all submitted offers. Formally, let  $T = [s, e]$  be a time period (length of the history). We shall call  $s$  the start of  $T$  and  $e$  will be called the end of  $T$ . Let  $ru(T)$  and  $tu(T)$  be the resource and task utilization, respectively, over the time period  $T$ . For a given time period  $T$ , the resource utilization ( $ru(t)$ ) and the task utilization ( $tu(t)$ ) are formally given by Equation (4).

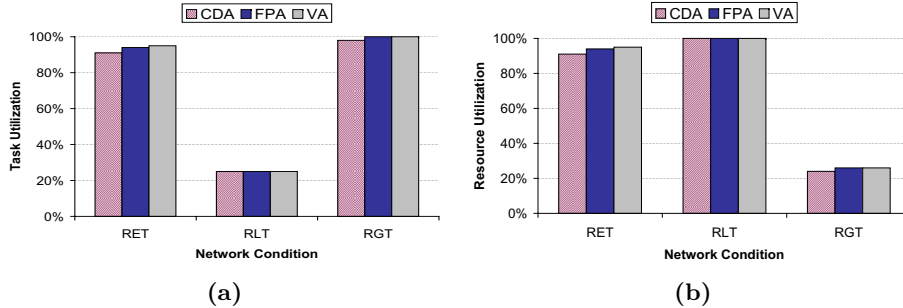
$$ru(T) = \frac{S(T)}{N_o(T)} \quad , \quad tu(T) = \frac{P(T)}{N_r(T)} \quad (4)$$

where  $S(T)$  and  $P(T)$  are respectively the total numbers of sold and purchased resources in the time period  $T$ .  $N_o(T)$  and  $N_r(T)$  are respectively the total numbers of offered and requested resources in the time period  $T$ . We now define variations in resource and task utilization. To this end, let  $T_1 = [s_1, e_1]$  and  $T_2 = [s_2, e_2]$  be two consecutive time periods such that  $e_1 = s_2$  and  $e_2$  is the current time. We capture variations in resource (respectively task) utilization from period  $T_1$  to  $T_2$  by the following equations:

$$\Delta ru_{(T_1 \rightarrow T_2)} = ru(T_2) - ru(T_1) \quad , \quad \Delta tu_{(T_1 \rightarrow T_2)} = tu(T_2) - tu(T_1) \quad (5)$$

We now define the parameters  $\alpha$  and  $\beta$  as follows:

$$\alpha = \begin{cases} -(K - (ru(T_2))^2)^2 & \text{if } \Delta ru_{(T_1 \rightarrow T_2)} \leq 0 \\ L * (ru(T_2))^2 & \text{if } \Delta ru_{(T_1 \rightarrow T_2)} > 0 \end{cases} \quad (6)$$



**Fig. 2.** Task Utilization and Resource utilization for three protocols in different network condition

$$\beta = \begin{cases} (K - (tu(T_2))^2)^2 & \text{if } \Delta tu_{(T_1 \rightarrow T_2)} \leq 0 \\ -L * (tu(T_2))^2 & \text{if } \Delta tu_{(T_1 \rightarrow T_2)} > 0 \end{cases} \quad (7)$$

where  $K$  and  $L$  respectively define the maximum rate of aggressive and conservative bidding (refer to [17]). In our experiments, we have considered  $K = 1$  and  $L = 0.1$ .

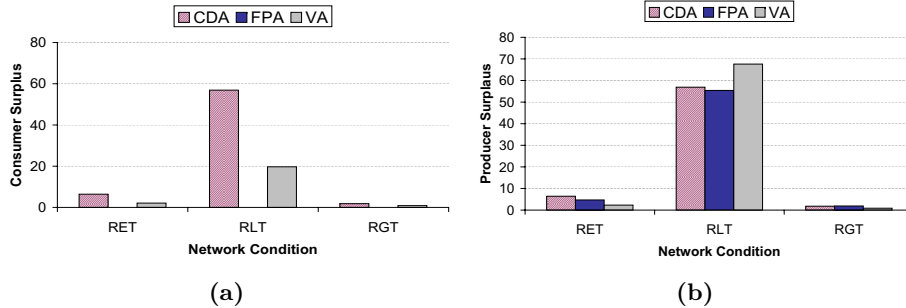
## 5 Performance Evaluation

Throughput, consumer surplus, producer surplus and uncertainty level in obtaining the resources are the criteria to compare the three auction protocols in different network conditions considering availability of tasks and resources. Overall throughput of the system is measured and economic benefit of individual nodes is studied in term of consumer and producer surplus for three auction protocols at different network conditions. The variation in available budget is measured among consumers participating in grid to assess the level of uncertainty for getting the required resources in different auction protocols and in different network conditions.

### 5.1 Experimental Setup

Our application test-bed is developed using J2EE and Enterprise Java Beans. Auctioneer is deployed on JBoss application server. Consumer and producer of resources are buyers and sellers in the market. There is one consumer and one producer agent per each node. Whenever a node needs computational service for running its tasks, it sends a request to the auctioneer through the consumer agent and whenever a node has some computational service available, it sends an offer through the producer agent. All nodes are assigned equal budget when joining the grid. The limited budget defined for each node can be used to trade for required resources. The nodes earn credits by devoting the idle computational resources





**Fig. 3.** (a) Consumer Surplus, (b) Producer Surplus for three protocols in different network condition

for demanding consumers. Each request or offer submitted by consumers or producers has the following specifications:

- Request={ resource type, resource quantity, ttl (time to live for request validity), bid price , budget }
- Offer={ resource type, resource quantity, ttl (time to live for offer validity), ask price }

Cpu time is considered as the resources. Resource request is expressed in the term of cpu time, a ttl (time to live) to determine the time during which the task has to be executed, a price that consumer is able to pay for each unit of resource, and the total amount of the budget that consumer has. An offer includes: a ttl which is the time during which the cpu is available, the type of cpu and a price below which the producer does not sell the resource. In matchmaking between consumers and producers, auctioneer considers not only the price but also the quantity of the resource and ttl constraints. TTLs and task execution times are generated randomly for each request and offer.

The experiments are performed in a local ad hoc Grid with 60 nodes in three different network conditions: **the balanced network** which is the type of the network where there is more or less an equal number of tasks and resources, **the task intensive network** where there are more tasks than resources and **the resource intensive network** where there are more resources than tasks. We provide these different network conditions by creating unbalanced number of tasks and resources in the network. Tasks and resources are generated respectively with probability of 50%-50% in balanced network, 80%-20% in task intensive network and 20%-80% in resource intensive network in a random order. In following section, we study the results obtained from running our simulation using three auction protocols. In all protocols, the starting price for consumers and minimum price for producers has been considered in the same range.

## 5.2 Experimental Results

The experimental results within different network conditions are presented in following sections. In the figures, balanced network condition is referred to as

*RET*, resource intensive network condition as *RGT*, and task intensive network condition as *RLT*. We also use the abbreviation terms *CDA* and *FPA* and *VA* respectively for Continuous Double Auction, First Price Auction and Vickrey Auction.

### 5.3 Throughput

Throughput of the system is measured in the terms of task and resource utilization. **Task Utilization** is defined as the ratio of allocated tasks to all submitted requests. **Resource Utilization** is defined as the ratio of allocated resources to all submitted offers in the system. We run the simulation for each model at different conditions and measure the task and resource utilization. As can be seen from the results in Figure 2(a) and 2(b), three mechanisms show more or less the same task/resource utilization in different conditions. In the balanced condition(*RET*), the Vickrey and First Price auctions auction show around 3% to 4% more throughput over the Continuous Double Auction which can be also the side effect of simulation. We conclude that three auction models are interchangeable concerning the overall throughput of the system in any network condition.

### 5.4 Consumer Surplus

Consumer surplus is the difference between the price that consumers are willing to pay (bid price) and the actual price (transaction price). The average consumer surplus is calculated for the matched consumers in three protocols within different network conditions. Matched consumers are the consumers which have found matches for their requests. As expected, the consumer surplus for First-Price is equal to zero. As in this auction, the transaction price is equal to consumer price (bid price). In *CDA* and Vickrey auctions the consumers usually pay less than what they bid, so these auctions favor the consumers. We can see from the figure 3(a) that consumer surplus is higher in *CDA* than in Vickrey. Higher consumer surplus in *CDA* is because of the higher difference between the bid prices and transaction prices in *CDA* compared with the other two auction protocols. In all protocols, consumer surplus has its highest value in task intensive network (*RLT*) and lowest value in resource intensive network (*RGT*). As in task intensive networks(*RLT*), consumers increase the price to outbid their competitors and consequently the difference between transaction and bid price increases. On the other hand, due to abundance of resources in a resource intensive network (*RGT*) the consumers bid the low prices which are close to ask price. Considering the consumer surplus, *CDA* provides the highest surplus for consumers in task intensive network (*RLT*). However, *CDA* is interchangeable with *VA* in the balanced (*RET*) and resource intensive (*RGT*) networks at this concern.

### 5.5 Producer Surplus

Producer surplus is the amount that producers benefit by selling a resource at market price that is higher than the price the producer is willing to sell. In

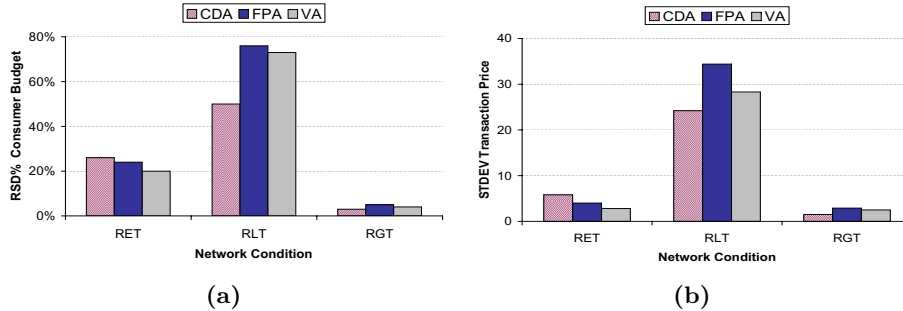


Fig. 4. (a) Variation in Consumers' Budget, (b) Variation in Transaction Prices

fact, the producer surplus is difference between transaction price and ask price. We compute the average producer surplus for the matched producers in three protocols within different network conditions. Matched producers are the producers which have found matches for their offers. The results in figure 3(b) show that the Vickrey auction provides the higher producer surplus as compared to other two auction protocols in task intensive network. Producer surplus is approximately equal for three auction protocols in resource intensive and balanced network conditions. The higher producer surpluses in case of task intensive network and lower producer surplus values in other two network conditions can be explained with the same reasoning as already discussed in section 5.4.

As consumers pay first highest price in First price auction and pay the second highest price in Vickrey auction. So it may be expected that producer surplus will be more in first price auction in comparison with Vickrey auction. This illusion can be clarified with the following explanation in a task intensive network. Consumer pay higher prices in First price auction so they run out of budget more quickly compared with Vickrey auction. We studied the available budget to every node in both protocols at end of simulation and found that some nodes in First price auction got zero budget. As a conclusion where the producer surplus is the selection criterion, the three auction models are interchangeable in the balanced and resource intensive networks. In a task intensive network, VA is the best option.

## 5.6 Uncertainty Measure

The level of uncertainty for consumers in getting the required resources is indicated by measuring the variation in the available budget among consumer agents. Higher variation in consumers' budget shows lower reliability and higher uncertainty in obtaining the required resources. We measure the budget variation during the trading time for the three auction protocols in different network conditions (see figure 4(a)). The budget variation is presented using relative standard deviation (RSD). RSD% is defined as  $RSD = (stdev/mean) * 100\%$ , where *mean* is the average and *stdev* is standard deviation of consumers' budget. As no

**Table 1.** Design Choices

Network Condition/Criterion	Throughput	Consumer Surplus	Producer Surplus	Uncertainty Measure
Balanced Network	Interchangeable	CDA, VA	Interchangeable	Interchangeable
Task Intensive Network	Interchangeable	CDA	VA	CDA
Resource Intensive Network	Interchangeable	CDA, VA	Interchangeable	interchangeable

budget is injected to the network, the mean of consumers' budget is the initial budget given to the nodes. From the figure 4(a), we can see that task intensive condition has the highest budget variation and resource intensive condition has the lowest. So, uncertainty level is higher in task intensive network than in the two other networks. Whereas, in resource intensive network condition where resources are abundantly available and the transaction prices are low, so probability of getting the required resources is high for consumers. Comparing different protocols, we can see that in the balanced and resource intensive conditions, the budget variation is more or less in the same range in the three protocols. In a task intensive network, CDA shows the lowest variation in budget among three protocols. The budget variation in CDA is around 26% lower than in the FPA and 23% lower than in the VA. It means when resource are scarce, consumer have lower level of uncertainty for getting resources in CDA than the two other protocols. The variations in consumers' budget are consistent with the variation in transaction prices. In our system, the prices are limited by budget(see section 4.2). Higher variation in transaction prices shows higher instability and higher uncertainty. Figure 4(b) shows the standard deviation of transaction prices in different network conditions. We can conclude that considering the uncertainty measure, CDA in the task intensive networks and any protocol can be selected in balanced and resource intensive networks.

## 6 Results Discussion

This meta-research targets to answer the question: for Grid user/owner, under which network condition, which economic model is suitable? We consider four factors to present Grid and user objectives namely throughput, consumer surplus, producer surplus and the uncertainty measure.

The results show the system throughput in terms of task and resource utilization is approximately the same in the three auction protocols. Therefore, in this regard the protocols are interchangeable. When resources are scarce (task intensive condition) and many resource consumers are waiting for the resources then CDA is an appropriate approach. Because, it increases the economic benefit of the Grid consumers while it gives a promised throughput. However, Vickrey auction favors producers in task intensive condition as it gives higher producer surplus. CDA and Vickrey auction are interchangeable in balanced and in resource intensive conditions regarding consumer surplus. Producer surplus is approximately the same for the three protocols in balanced or resource intensive network.

We observe that any auction protocol can be chosen in a balanced condition and a resource intensive condition while considering the uncertainty level for obtaining resources. In a task intensive network, CDA presents lowest variation in consumers' budget and transaction prices as compared to other two protocols. So, the level of uncertainty is lower for CDA protocol in the task intensive networks. By looking at the results summery presented in table 1, it is observed that CDA can be a design choice in different network conditions regarding the most criteria.

## 7 Conclusion

In this paper, we provide a framework for auction-based resource allocation in an ad-hoc Grid. We study the impact of choosing a particular economic model in an ad-hoc Grid. The framework enables us to analyze different auction protocols (First Price Auction, Vickrey Auction, Continuous Double Auction) while observing Grid user/owner objectives. The assessment criteria in the framework consider system as well as user preferences. These criteria are throughput, consumer surplus, producer surplus, and uncertainty measure. These parameters are measured in three different network conditions regarding availability of tasks and resources. Based on our experimental results, different design choices are discussed in section 6.

## Acknowledgement

We would like to thank Tariq Abdullah from Delft University of Technology, Computer Engineering Laboratory, for his helpful comments on the draft manuscript.

## References

1. Wolski, R., Brevik, J., Plank, J.S., Bryan, T.: Grid resource allocation and control using computational economies. In: *Grid Computing: Making The Global Infrastructure a Reality*. John Wiley & Sons, Chichester (2003)
2. Buyya, R., Abramson, D., Giddy, J., Stockinger, H.: Economic models for resource management and scheduling in grid computing. *Concurrency and Computation: Practice and Experience* 14(13-15), 1507–1542 (2002)
3. Kurose, J.F., Simha, R.: A microeconomic approach to optimal resource allocation in distributed computer systems. *IEEE Transactions on computers*, 705–717 (May 1989)
4. Waldspurger, C.A., Hogg, T., Huberman, B.A., Kephart, J.O., Stornetta, W.S.: *Spawn: A distributed computational economy*. *Software Engineering* 18(2), 103–117 (1992)
5. Nisan, N., London, S., Regev, O., Camiel, N.: Globally distributed computation over the internet - the popcorn project. In: *ICDCS 1998: Proceedings of the The 18th International Conference on Distributed Computing Systems*, p. 592. IEEE Computer Society, Los Alamitos (1998)

6. Lalis, S., Karipidis, A.: Jaws: An open market-based framework for distributed computing over the internet. In: GRID, pp. 36–46 (2000)
7. Gomoluch, J., Schroeder, M.: Market-based resource allocation for grid computing: A model and simulation (2003)
8. Weng, C., Lu, X., Xue, G., Deng, Q., Li, M.: A double auction mechanism for resource allocation on grid computing systems. In: Jin, H., Pan, Y., Xiao, N., Sun, J. (eds.) GCC 2004. LNCS, vol. 3252, p. 269. Springer, Heidelberg (2004)
9. Kant, U., Grosu, D.: Double auction protocols for resource allocation in grids. In: Proceedings of the International Conference on Information Technology: Coding and Computing (ITCC 2005), pp. 366–371 (2005)
10. Grosu, D., Das, A.: Auction-based resource allocation protocols in grids. In: Proceedings of the 16th IASTED International Conference on Parallel and Distributed Computing and Systems, pp. 20–27 (November 2004)
11. de Assuncao, M.D., Buyya, R.: An evaluation of communication demand of auction protocols in grid environments. Technical report, Computing and Distributed Systems Laboratory, The University of Melbourne, Australia (2006)
12. Hurwicz, L.: The design of mechanisms for resource allocation. *American Economic Review* 63(2), 1–30 (1973), <http://ideas.repec.org/a/aea/aecrev/v63y1973i2p1-30.html>
13. Ferguson, D.F., Sairamesh, J., Yemini, Y., Nikolaou, C.: Economic models for allocating resources in computer systems. In: Clearwater, S.H. (ed.) *Market-Based Control*, pp. 156–183. World Scientific Publishing Co. Pte. Ltd., Singapore (1996)
14. Walras, L.: *Elements of pure economics; or, the theory of social wealth*. Allen and Unwin (1954)
15. Buyya, R., Abramson, D., Venugopal, S.: *The grid economy* (2004)
16. Wurman, P., Walsh, W., Wellman, M.: Flexible double auctions for electronic commerce: Theory and implementation. *Decision Support Systems* 24, 17–27 (1998)
17. Pourebrahimi, B., Bertels, K.: Adaptation to dynamic resource availability in ad-hoc grids through a learning mechanism. In: The 2008 IEEE 11th International Conference on Computational Science and Engineering (July 2008)