An Evaluation of Communication Demand of Auction Protocols in Grid Environments

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Dynamic pricing and good level of Pareto optimality make auctions more attractive for resource allocation over other economic models. However, some auction models present drawbacks regarding the high demand of communication when applied to large-scale scenarios. In a complex Grid environment, the communication demand can become a bottleneck; that is, a number of messages need to be exchanged for matching suitable service providers and consumers. In this context, it is worthwhile to investigate the communication demand or complexity of auction protocols in Grid environments. This work presents an analysis on the communication requirements of four auction protocols in Grid environments, namely First-Price Sealed, English, Dutch, and Continuous double auctions. In addition, we provide a framework for developing auction protocols in a Grid simulator called the GridSim.

1. Introduction

Grid computing [1] came along from the need to utilize globally distributed computing and storage resources in a networked environment for solving large-scale problems in science, engineering and commerce [3]. This technology is also considered a key enabler for creation of virtual organizations (VOs) [2] and cyberinfrastructure required for e-Science [4] and e-Business [5] applications.

However, one of the key challenges with grid computing technology is the efficient and sustained sharing and management of resources. To that end, the area of microeconomics provides a source of ideas. This is done on the notion that: (i) Grid resources are priced and charging for their use can provide incentives for resource providers to share their resources. (ii) The economic behavior of consumers and providers defines how to allocate resources. (iii) Markets can offer a decentralized approach for scheduling in which each participant acts in order to maximize her own utility. In applying economic methods to this problem, one must take into account factors such as pricing of resources and its relationship with supply and demand.

In an auction, an auctioneer wants to allocate a good, whereas bidders or market participants bid reflecting their desire in taking the good. The auctioneer decides to whom allocate the item when the auction clears by using an auction policy to find the best bid. Auctions provide a method for determining prices based on bidders' bids, which reflect demand, and owners' reserve prices, which reflect supply abundance or scarcity [6][7]. This way, auctions simplify the allocation problem by summarizing the bidder's wishes and owners' offers in terms of price.

Auctioning models are a source of solutions to the challenge of resource allocation in Grid because they provide a decentralized structure, are easier to implement than other economic models and respect the autonomy of resource owners. Resource owners provide shares of resources to the Grid, while maintain committed to users within their administrative domains. The dynamic nature of the Grid requires mechanisms where resource users and owners can agree upon the amount of resources they will use and the price paid for them. Auctions allow owners and users to establish prices to resources in the Grid and guarantee social efficiency in resource allocations.

However, auctions present some drawbacks regarding the demand they place on communication i.e., interactions involved in negotiation of service price. In a complex Grid environment, the communication requirements of some auction models may become a bottleneck. Hence, it is important to analyze such economic models from a communication complexity perspective in order to identify the requirements of different auction protocols when applied to Grid environments.

In this work we investigate the communication requirements of four auction protocols in Grid environments, namely First-Price sealed, English, Dutch and Continuous double auctions. Since the amount of information carried by messages in auctions varies with different scenarios, we measure the number of messages exchanged and then identify the suitability of each strategy to Grid computing in terms of communication complexity. In addition, we contribute towards the development of a framework for realizing auction protocols in the GridSim simulator [8], which simplifies the task of development and evaluation of auction models in simulated Grid environments.

The rest of this paper is organized as follows. Firstly, we present the motivations as well as background ideas in Section 2. Section 3 presents a description of the framework for the simulation of auction protocols in GridSim. Section 4 contains a brief discussion of the auction protocols analyzed in this paper. Simulation environment and experimental results are presented in Section 5. Finally, Section 6 concludes the paper along with thoughts on future work.

2. Motivations and Background

In the literature, we find several works applying auction models for resource management for distributed computing systems. Though such models have provided good outcomes, there is a need for investigating their suitability for Grid computing. Such analysis can take into account several criterions such as social efficiency, equilibrium and complexity of auction protocols. Another important study is on their requirements of communication when applied to Grid environments. When using auction protocols in Grid environments, one must concern on the number of messages required to clear an auction, which imposes restrictions to configurations with a large number of users and resources.

Grosu and Das [9] present an analysis of First-Price auction, Vickrey auction and Double auction. The work in [14] presents an analysis of three different Double auction protocols. The aim of these works is to analyze the suitability of auction protocols to resource allocation in Grids; the analysis is performed from the perspective of both users and providers. Experimental results support that First-Price auctions favor providers, Vickrey auctions favor users, and Double auctions favor both. The analysis takes into account user payments, resource profits, and resource utilization. However, they do not consider communication complexity in this evaluation.

The work in [7] presents a series of factors to consider when choosing an auction model to use. The auction mechanisms taken into account comprise the receiving of bids, the manner in which information is revealed and its quantity, and how the auction is cleared. However, communication demand and complexity is not among the factors considered in this work.

Mathias *et al.* [10] use an approach similar to the one present in this work, in which a broker is the auctioneer and resources are the bidders that bid for the execution of jobs. The performance of a First-Price sealed auction is measured considering queue time, runtime, and makespan. However, the demand of communication may be a problem in a large-scale scenario and it is not taken into account.

Shen *et al.* [11] propose an adaptive negotiation approach for Grid computing. By following this approach, the system can adapt to computation needs by changing the models currently in use. In this regard, communication could be one of the factors used to alternate from a model to another. In this context, it will be interesting to investigate the communication requirements of different auction models, which agents can take into account when choosing a suitable protocol.

3. Design of the Auction Framework

This section provides an illustrative scenario for an auction in Grid computing and discusses the design of the auction framework. The example considers a descending Dutch auction that follows the standards provided by FIPA [12]. FIPA is a non-profit organization that defines standards for multi-agent systems and for communication among agents in multi-agent systems.

The main participants in an ordinary auction are the seller, the auctioneer and the buyers or bidders. Figure 1 presents an example of reverse auction for Grid computing in which users are buyers, brokers are auctioneers and resource providers are sellers. In reverse auctions, the buyer starts the auction and the sellers bid to sell a service to the buyer. In such a case, a Dutch auction becomes ascending. Hereafter, we use the terms users to buyers, auctioneer to refer to the broker and bidders to resource providers.

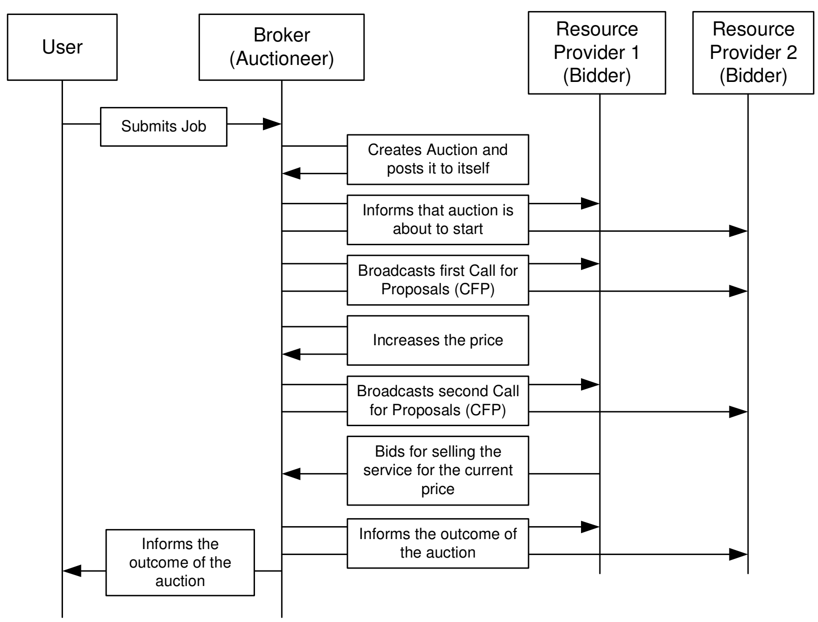

Figure 1. General view of our auction model.

Initially, the user submits jobs to her broker. In the Grid, a broker is responsible for submitting and monitoring jobs on the user's behalf. The broker creates an auction and sets additional parameters of the auction such as job length, the quantity of auction rounds, the reserve price and the policy to be used (e.g. English or Dutch auction policy). As the broker also plays the role of auctioneer, it posts the auction to itself; otherwise, the auction would be posted to an external auctioneer. The auctioneer informs the bidders that a Dutch auction is about to start. Then, the auctioneer creates a call for proposals (CFP), sets its initial price, and broadcasts the CFP to all the bidders. Resource providers formulate bids for selling a service to the user to execute her job. At the first time that bidders evaluate the CFP, they decide not to bid because the price offered is below what they are willing to charge for the service. This makes the auctioneer to increase the price and send a new CFP with this increase in the price. Meanwhile, the auctioneer keeps updating the information about the auction. In the second round, a bidder decides to bid. The auctioneer clears the auction according to the policy specified beforehand. Once the auction clears, it informs the outcome to the user and the bidders.

Based on this general model of auctions, we have designed and implemented a generalized auction framework that allows users to develop and evaluate auction protocols for resource management in Grids by using GridSim Grid simulator. Some of the features offered by the current release of GridSim include advance reservation, networking with differentiated services and resources with different allocation policies. However, the simulator does not offer a framework for auctions that minimizes the effort in evaluating auction protocols, leading users interested in the topic to develop their own methodology for auctions from scratch.

The main classes that compose the auction framework are (Figure 2):

- **Auctioneer:** This class extends GridSim entity and implements the basic behavior of an auctioneer. An auctioneer may involve in multiple auctions. The auctioneer sends call for proposals, receives bids, maintains a list of the auctions, and removes them when they are cleared.
- **Auction:** An auction contains basic attributes that are common to every auction.
- **OneSidedAuction:** This class extends Auction and defines methods for auctions that accepts only bids, unlike double auctions. Users may implement different auctions by extending this class and implementing the following methods: onStart(), onClose(), onStop(), onReceiveBid() and onReceiveRejectCallForBid(). These methods have to be implemented to define the behavior of the auction for when it starts a round, when it closes a round, when the auction finishes, when it receives a bid and when the auction receives a rejection respectively.
- **DoubleAuction:** It defines the basic behavior for a double auction. A double auction accepts asks and bids, and tries to match them. Extensions of

this class need to implement the methods: onStart(), onStop(), onReceiveAsk() and onReceiveBid().

- **Message:** The class Message provides the basic functionality for messages exchanged by auctioneers and bidders. The framework provides specializations of this class for call for proposals, bids, reject proposal messages, and so on.

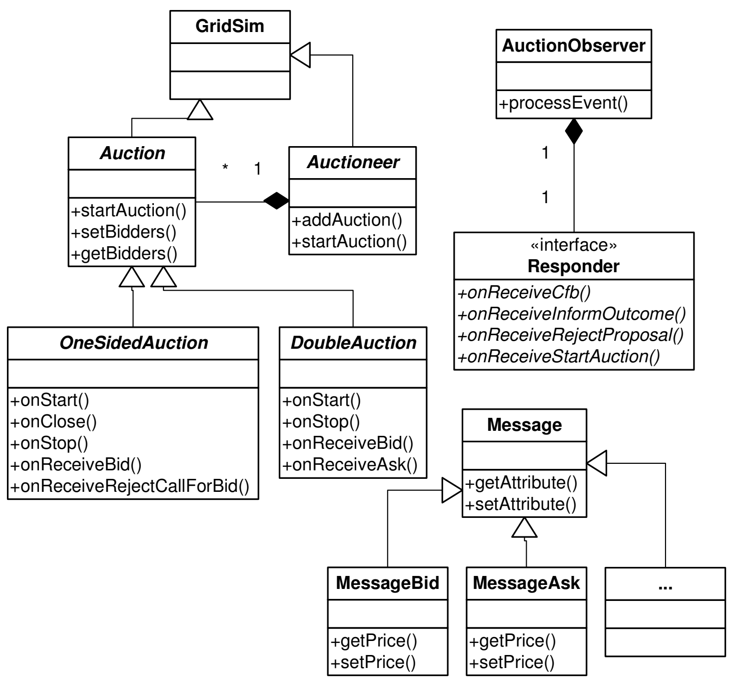

Figure 2. A class diagram of the auction framework.

- **AuctionObserver:** To participate in auctions, a bidder uses an observer. The bidder could extend the GridSim class and forward messages regarding auctions to the observer, and then the AuctionObserver treats the message and returns the corresponding message to the auctioneer. An observer has a responder, which is responsible for implementing the bidder's side of the auction policy.
- **Responder:** A class that implements this interface is responsible for defining the bidder's policy. That is, when a bidder receives a call for proposal message, for example, the method onReceiveCfp() of the

responder class will be called. The user has to implement the behavior of the responder upon the receiving of different messages.

4. Auction Protocols

This section presents a brief overview of the auction protocols examined in this work. FIPA standards were followed for the implementation of English and Dutch auctions policies [13] [12].

4.1. *English Auction (EA)*

The English auction [15] is an ascending auction in which the auctioneer tries to find the price of a good by proposing a price below the supposed market value and slowly raising the price. Initially, the auctioneer issues a call for proposals, then waits to see whether a bidder is interested in taking the good for that price. As soon as a bidder makes a proposal, the auctioneer will issue a new call for proposals with an increase in the price. The auction stops when no bidder is interested in paying the current price for the good. Thus, the auctioneer allocates the good to the bidder who has made the past highest bid.

4.2. *Dutch Auction (DA)*

The Dutch auction [15] is a descending auction and differs from the English auction in the sense that the auctioneer starts by issuing a call for proposals with a price much higher than the expected market value. The auctioneer then gradually decreases the price until some bidder shows interest in taking the good for the price announced.

4.3. *First-Price Sealed Auction (FPSA)*

In our implementation of the First-Price sealed auction, bidders are not aware of each other's offers. In addition, it is a single round auction, which makes it very similar to an e-procurement. In our policy, the minimum price is the reserve price of the good. When bidders receive a call for proposals, they can verify the minimum price and either decide to bid or not to bid for the good. The auctioneer waits a given time for the bids and then allocates the good to the bidder who has valued the good the most. The auctioneer then informs bidders about the final price and is the winner when it clears the auction.

4.4. *Continuous Double Auction (CDA)*

The Continuous double auction [16] works with a system of bids and asks. The price is found by matching asks and bids. After the auction is started, the auctioneer accepts asks and bids and tries to match asks and bids. The auctioneer informs the bidder and the seller about the price when it matches a match is done.

5. Simulation Environment and Experimental Results

In order to evaluate the suitability of the auction protocols discussed in Section 4 for resource allocation in Grids, we developed a simulation environment and performed several experiments. The first experiment considers a worst-case scenario in which auctions are all-to-all; that is, all auctioneers send messages to all possible bidders in the Grid.

In our first simulation, a user submits experiments (jobs) to her broker, which in turn initiates an auction for each job, similar to the example presented in the Section 3. We use reverse auctions here. Therefore, resource providers are the bidders and they bid for executing jobs. We have implemented policies and responders for First-Price sealed, English, Dutch, and Continuous auctions. We simulated configurations of 1, 5, 10, 20, 30, 40 and 50 resources, each with 1000 MIPS (million instructions per second) processing capacity. The configurations have 2, 10, 20, 40, 60, 80 and 100 users respectively. The cost per second of CPU is uniformly distributed from 5 to 10. The limit of auction rounds for English and Dutch is set to 10 and each round with timeout of 1 minute. The First-Price sealed auction has only one round. Each user generates 10 jobs uniformly distributed in an interval of 5 hours. The job length follows a uniform distribution from 2000 to 5000 MIs (Millions of Instructions). A user receives a budget uniformly distributed between 300 and 900 to spend with the execution of jobs. We consider that a user wishes may spend from a minimum of 10% to a maximum of 100% of this budget to have her jobs executed. To choose the price paid to execute a job, the user utilizes her budged proportionally to the length of the jobs. As we use reverse auctions, the auctioneer tries to find the lowest bid. This way, an English auction starts with the auctioneer sending call for proposals with the price set to the maximum amount of budget allocated to the task. The auctioneer continues to decrease the price until the number of rounds reaches its limit or no bidder is interested in executing the job for the price announced. Dutch auction starts with an initial price set to the minimum amount of budget that the user wants to pay, which increases until a bidder shows interest in executing the job for announced price. The First-Price sealed auction starts with the announced price set to the maximum budget used for the job. After the auctioneer gathers all the bids, she allocates the job to the provider that has made the lowest bid.

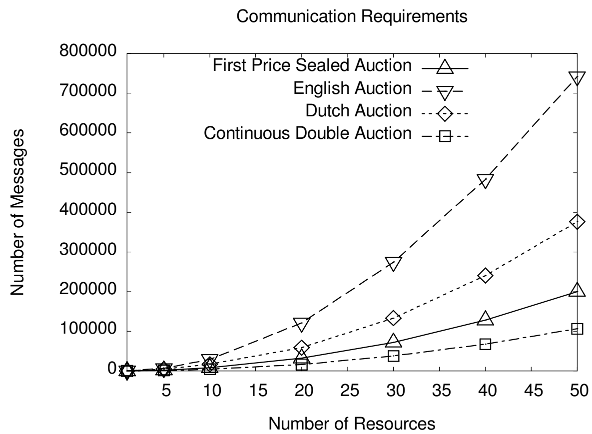

Figure 3. The communication demand of different protocols.

A bidder (resource provider) bids depending on the job length and auction scenario. The bidder evaluates the cost to execute the job and applies an expected marginal profit that follows a uniform distribution from 1% to 50%. The bidder sends a bid if the price announced by the auctioneer is greater than the sum of her cost and marginal profit. In English and Dutch auctions, the price set in the bid is the price announced whereas in First-Price sealed and Continuous double auctions, the price inserted into the bid is the price initially estimated by the bidder.

In Continuous double auctions, the auctioneers match asks and bids. The auctioneer maintains a list of asks ordered in a decreasing order and a list of bids ordered in an increasing order. When the auctioneer receives an ask she proceeds as follows:

1. She compares it with the first bid of the list. If the price in the ask is greater than or equal to the bid's value, it informs that seller and bidder can trade at the price (`price ask + price bid) / 2`)
2. Otherwise, the auctioneer adds the ask in the list.

If the auctioneer receives a bid, she does the following:

1. She compares it with the first ask of the list. If the price in the ask is greater than or equal to the bid's value, it informs that seller and bidder can trade at the price (`price ask + price bid) / 2`).
2. Otherwise, the auctioneer adds the bid in the list.

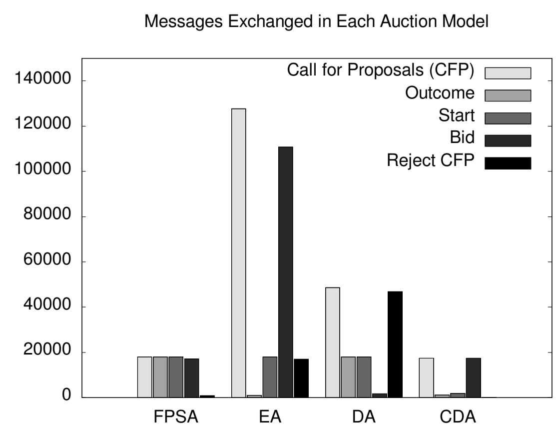

Figure 4. Number of messages exchanged in each auction model.

Figure 3 shows the number of messages exchanged for the different configurations of resources in each kind of auction. Figure 4 presents the number of messages grouped by category when the environment has 30 resources. We recall that the number of users is the double of the number of resources in each configuration. The English auction is the model that presents the greatest number of messages, followed by the Dutch auction. The First-Price Sealed auction model presents less requirements of communication mainly because it has just one round. The protocol that performs better and has less communication demand is the Continuous double auction. The English auction model presents a higher number of messages because multiple bidders can bid in a single round, even though it considers only the first bid in each round and discards the others. The Dutch auction differently, presents fewer messages because bidders do not bid while they are not interested in the price. The performance of the English auction is also related to the starting price and the price setting mechanism because it may start at a price very distant from the final one and can take several rounds to achieve it. We notice that the First-Price Sealed auction presents a good performance because the auctioneer may start the auction signaling a maximum price and expecting whatever price below the suggested price.

However, it may compromise the social welfare of the system by excessively benefiting users.

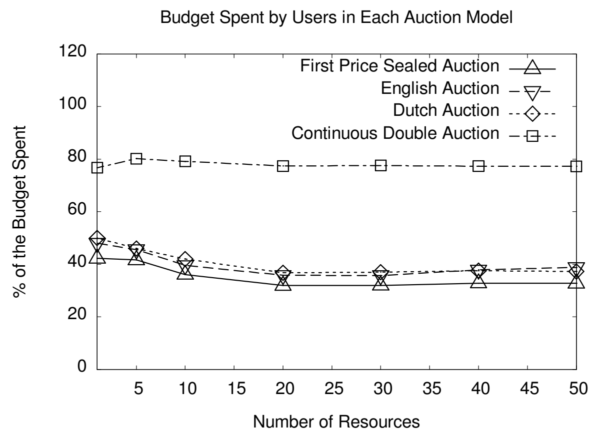

Figure 5. Percentage of budget spent by users in each auction model.

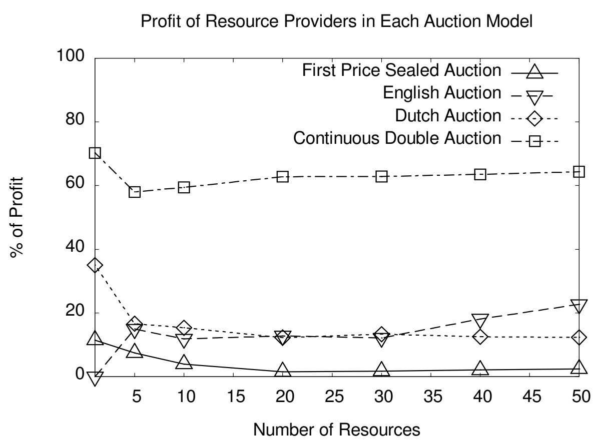

Figure 6. Percentage of profit made by resource providers.

We have also measured the percentage of the user spent in each auction model. Figure 5 presents the amount of budget used in the different auctions. Both English and Dutch auctions presented similar performance, while the First-Price sealed allows a user to spend less of her budget. This is due to the bidders being able to choose any price below the one announced. The Continuous double auction generally encourages users to set higher prices as it leads to quick clearance. It is argued that this protocol compensates both bidders and sellers [9]. Therefore, to evaluate whether the Continuous double auction provides better profits to bidders we measure the percentage of profit made by resource providers. The results shown in Figure 6 demonstrate that Continuous double auction provides higher profit to providers. In addition, we conclude that First-Price sealed benefits whereas offers the lower profit to providers.

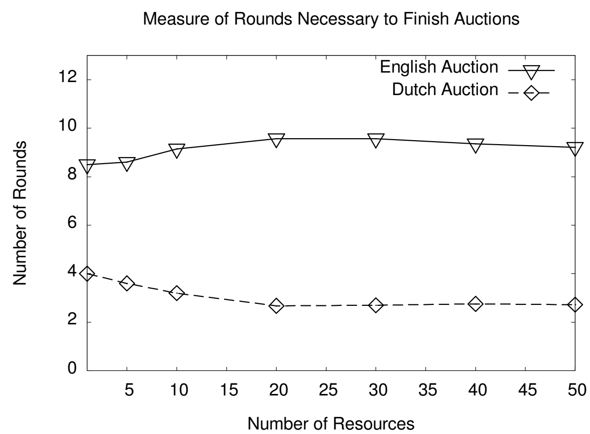

Figure 7. Rounds necessary for each model to close the auction.

As English and Dutch auctions offered similar performance regarding profit earned and budget spent, we also measure the number of rounds necessary by each auction to close the auction. First-Price sealed and Continuous double auctions have one round. The results presented in Figure 7 show that Dutch auction requires fewer rounds to reach the final price.

6. Summary and Conclusion

We presented an investigation on the communication requirements of First-Price sealed, English, Dutch, and Continuous double auctions for resource allocation in Grid computing environments. We have carried out experiments that demonstrate that English auctions present higher communication requirements while Continuous double auctions present least demand of communication. In addition, we demonstrated that English and Dutch auctions lead to the same final prices, even though the number of rounds required might differ.

In addition, we have developed an auction framework that simplifies setting up of performance evaluation experiments in a Grid simulator called GridSim. An example of the use of such framework was presented as well as how auction policies can be developed in order to extend the framework.

In the future, we plan to improve our experiments by considering the social welfare in the system. And also analyze which auction models are better in this regard, which ones benefit providers and which ones benefit consumers and in what scenarios. In addition, we would like to investigate whether it is possible to develop agents that automatically choose one out of a set of auction protocols according to the peculiarities of the Grid environment.

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