Internet Based Auctions : A Survey on Models and Applications

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Web based auctions and negotiations have become quite popular due to their implementation and integration in electronic commerce applications. Online auctions have become an effective approach in the buying and selling process, employed in the rapidly emerging Internet-based electronic commerce platforms. The goal of this paper is to outline research efforts in relation to online Internet-based auctions modeling and applications. The key research topics in the area are identified and the paper focus on the issues of auction modeling, use of agents in Web-based auction implementations, auctions computational and combinatorial analysis as well as on security issues involved in online auctioning. The most popular implementations, applications and servers are also referenced and discussed.

Additional Key Words and Phrases: online Auctions, Internet-based auctions, e-auctions survey, e-commerce modeling and applications.

1. INTRODUCTION

The major increase of business and commerce activities over Internet-based systems has resulted in a rapid involvement of auction models and techniques into widely used e-commerce applications and frameworks. Since negotiations are involved in most current applications that demand settling product or service prices, the Internet provides an ideal environment for trading applications. Negotiating over Internet facilitates the opening of businesses and organizations to a vast number of customers, aiming to improve economic measures (such as lowering both the business costs and the customer accessing times).

Auctions are exemplary negotiation mechanisms, particularly well suited to automation. A variety of auctions, models and techniques exist due to the differences in the trading products, in the rules for users as well as in the pricing policies. A recent paper [Wurman et al. 2001] presents a general parametrization of auction rules capturing the similarities and differences of several auction types. This parametrization is particularly useful for the classification of research efforts in the

field of auction analysis and for revealing novel auction mechanisms. More specifically, a broad categorization of auctions (see [Harkavy et al. 1998], [Wurman et al. 2001]) can be based on auctions pricing policies and will identify the increasing price (or *English*), the sealed-bid and decreasing price (or *Dutch*), the first(second)-price sealed bid, the call markets and the continuous double (or *CDA*) auctions. Web based implementations of different auction types involve the specification of an auction model as well as appropriate design of methodologies and techniques which will support the overall auction process.

The goal of this paper is to outline the most important research issues in the field of online Internet-based auction technology. The paper focuses in surveying on the following key research topics :

—*Internet-based auctions modeling*: A Web based auction should be governed by a model which will define the deal making and the automated trading schemes. As an example, an approach to such modeling is to consider multi-attribute auctions to automate negotiations accompanied by several techniques and mechanisms for products and services procurement. In most cases, multi-attribute auctions serve as an extension to the set of current market mechanisms.

—*Combinatorial auctions and computational analysis*: Mechanisms governing certain types of auctions and negotiations are quite complicated, especially when there is a large number of buyers who are allowed to bid for subsets of all the goods for sale. The optimal allocation problems arising from such auctions are quite hard combinatorial problems requiring efficient algorithms.

—*Security issues in Internet auctions*: Users of online auctions and negotiations have to be assured of their security and privacy. Efforts to avoid fraud in negotiations have focused in designing and implementing appropriate protocols to protect all parties involved in an Internet-based auction.

—*Applications and Agent-based Implementations*: Various auction platforms and prototype models have been proposed in earlier research or commercial efforts. Several (mainly academic) Internet-based auctions platforms have introduced agent-based implementations in the negotiation process.

Since a vast amount of economic transactions is conducted through auctions, there is a lot of work in economics related to auction theory. In [Klemperer 1999] an elementary survey of auction economic theory is provided along with an extensive literature references list. An example of a recent paper on auction theory presenting new protocols for the problem of decentralized scheduling is [Wellman et al. 2001]. However, it has to be emphasised that the purpose of this paper is to focus on the contributions to auctions in e-commerce settings, from the computer science perspective.

The remainder of the paper is organized as follows : Section 2 introduces the most indicative modeling approaches for online Internet-based auctions environments and frameworks. In Section 3 the combinatorial and computational analysis of auctions is discussed, whereas security issues in auctions are outlined in Section 4. Examples of recent Internet based auction servers and applications are presented in Section 5. Finally, conclusions and further research topics are discussed in Section 6.

2. ONLINE AUCTIONS : MODELS AND FRAMEWORKS

Auctioning over Internet facilitates business and customer interactions by both accelerating the trading process and lowering the cost of access. Issues related to Web-based auction's quality of interaction, design approach and information accessibility arise as challenging research areas. These design issues arise due to the diversity of different auctions platforms and applications with respect to their information, interaction and design quality. The evolution of e-commerce technologies has contributed to the development of various dedicated auctions and negotiation servers. An effort to assess Internet-based auctions is presented in [Barnes and Vidgen 2001] where an evaluation tool is experimented over some commercial Internet-based auction examples. Here, we discuss some of the most indicative research efforts in relation to modeling of Internet-based auctions frameworks and servers.

Online auctions modeling involves the specification and the configuration of the auction process in terms of the following main features and characteristics:

—*specify whether the auction process refers to a single-attribute or a multi-attribute mechanism.* Multi-attribute auctions enable automated negotiations on several attributes of a deal, such as price, quality, delivery time or terms of payment. There are several unsolved practical and theoretical problems related to multi-attribute auctions due to the complexity of the bidding rules. This is discussed extensively in [Bichler 2000] where the web-based implementation and the results of an experiment are described, in an attempt to investigate the economic behavior of multi-attribute auctions compared to single attribute auctions. The statistical analysis of the experimental data showed that the overall utility achieved in multi-attribute auction formats was significantly higher than that in single attribute auctions, while the efficiency was similar. A clear conclusion of the study is that in situations of many negotiable attributes, it is necessary to provide bidders with advanced decision support tools, since the determination of the attributes which achieve the highest utility (i.e. the best bid) is a rather difficult task.

—*specify whether the model will deal with a single or a multiple item auction.* Multi-item auctions are discussed in a recent work [Bansal 2001], where the theory of multi-item ascending auctions is extended towards a multi-unit demand scenario. A simple greedy bidding strategy which results in efficient allocation and price discovery, is proposed. Furthermore, an adaptive model is proposed in [Morris et al. 2000] where the dynamic bidding over an online auction system is studied. This model supports multiple item bids since buyers (or consumers) can bid for a finite number of goods during a finite number of bidding periods. This model is parameterized in terms of fixed market, dynamic market and seller control scenarios. These parameters guide the auction model under specified assumptions that refer to the different case status of both the customer and the seller. These dynamic adaptive pricing strategies are evaluated under a developed market simulator.

—*define whether the auction sessions will be completed in one or more stages.* A multi-stage negotiation framework is proposed in [Lim 1999] where a four-stage model is used for bilatelar negotiation. At a first stage, issues identification

is performed, followed by range specification and the definition of self utility functions and estimation of opponent's utility functions. The last stage is related to the outcome and strategic analysis. This proposed conceptual framework is proved to facilitate negotiations to express preferences in a quantitative and systematic manner.

Furthermore, in [Beam et al 1999] four representative Internet-based automated trading modeling scenarios are presented based on a three separate layers approach: The *architecture layer* which defines the technology space and determines the technologies available for use in negotiations, the *rules layer* which defines the auction's rules and allowed actions and the *the strategy layer* which defines how to proceed towards the best deal, given the technical capabilities of the architecture and the general agreement about the rules.

3. COMBINATORIAL AND COMPUTATIONAL ANALYSIS

Rules controlling the biddings in auctions and the possible restrictions on the amount of goods for which a customer is allowed to bid, can make the whole auction procedure extremely complicated. Recently, there is a growing interest in "combinatorial auctions". Combinatorial auctions are mechanisms in which a number of goods are for sale and the buyers are allowed to bid on combinations (subsets) of goods. Furthermore, it can be assumed either that all the goods for sale are different or that certain items are identical. In the later case, the auction is called "Multi-unit combinatorial auction". One of the problems arising in combinatorial auctions is an optimization problem, i.e. our purpose is to find the optimal allocation of the goods to the bidders in order to maximize the auctioneer's profit or some other objective function. These problems are very hard due to the enormous number of possible combinations when the numbers of buyers and goods are large. Optimal solutions or approximations can be found by appropriate search algorithms from operations research along with heuristic rules for efficient search.

As examples of the ongoing research on the above topics we refer to the recent papers [Nisan 2000], [Gonen and Lehmann 2000] and [Wurman and Wellman 2000] which consider problems in combinatorial auctions. More specifically, in [Nisan 2000] combinatorial auctions with multiple non-identical items are considered with respect to two aspects: the bidding language and the allocation problem. By the notion of bidding language we mean the syntax and the semantics for bids. After examining a number of languages in order to compare their expressibility versus their simplicity, it is shown that one language ("OR-bids with phantom items") can polynomially simulate the others. The allocation problem refers to the stage of the auction where all bidders have bid and the items must be allocated among the bidders in such a way that a target function (auctioneer's revenue or total economic efficiency) is optimised. For determining the best allocation, an approach based on linear programming is suggested for auctions where prices can be attached to individual items, a case where the linear programming finds an optimal allocation (see also [Bikhchandani and Mamer 1997]). Additionally, greedy and branch-and-bound heuristics based on linear programming are suggested for other cases.

In [Gonen and Lehmann 2000], the authors consider the case of a multi-unit combinatorial auction and they investigate the use of branch-and-bound search

techniques. They also provide mathematical formulation for the allocation problem and they describe it as a generalization of the weighted-set packing problem (see also [Rothkopf et al. 1998]) in order to prove that the problem is not only NP-hard but also hard to approximate.

In [Wurman and Wellman 2000] a progressive combinatorial auction with an anonymous, non-linear pricing scheme is presented. Such an auction is characterized by an iterative procedure where each iteration's bids present an improvement over the previous. There are a number of benefits of such a model such as the saving of effort for the agents, the avoidance of strategies based on identity and fairness of the payment scheme.

While research work in operations research and artificial intelligence has dealt with computational aspects of multi-objects auctions, a recent work [Penn and Tennenholtz 2000] presents a complementary approach where simple constraints are imposed on possible allocation of goods. This paper deals with the complexity of constrained multi-object auctions and exposes a connection of the related computational problem with the optimal b-matching problem. The basic variant of this constrained multi-object auction is proven to be polynomially solvable and two extensions of this problem are also investigated.

4. SECURITY ISSUES

One of the most critical issues in auctions and negotiation systems is security. Security is related to many different aspects which are relevant to the protection of the involved parties against fraud, the authorization of the participants, the verification of the bids, the auctioneer's integrity and the customer's privacy. Even in auctions which follow a simple non-interference policy and leave the consumers to handle the auctions in a person-to-person manner, there is a risk of fraud. For instance, eBay [Gengler 1999] was forced by public opinion to take special measures in order to reduce fraud. eBay's auction environment supports a security control program which performs user identity verification, bans sellers from buying their own items, enforces a policy against dead-beat bidders, and provides a feedback forum.

The key security issues in relation to the online auctions involve several research topics such as architectures for protocols, cryptography, etc. In [Franklin and Reiter 1996] the design and implementation of a secure distributed auction service is presented. This service guarantees the secrecy of sealed bids, the declaration of the proper winning bidder and the collection of digital cash payment from only the winning bidder.The design of the service is based on several cryptographic primitives, such as multicast secret sharing, digital cash and verifiable signature sharing and ensures tolerance against malicious collaboration by any number of bidders and fewer than one-third of the auction servers.

In [Subramanian 1998] a protocol is presented for fully automated electronic auctions between anonymous customers and a merchant whose identity is public. The protocol is modelled and analysed taking into account an intruder capable of passive or active attacks, and the authors prove that it ensures security, atomicity, anonymity, privacy and low overhead cost. A set of protocols for sealed-bid electronic auctions is described in [Harkavy et al. 1998], where a bidder's privacy is preserved by using a form of secure distributed computation. The proposed scal-

able secret-bid, second-price auction is based on a two-phase bid resolution towards determining the winning bidder. Open problems are discussed and a list of further work directions is provided in this area.

Another architecture is proposed in [Naor et al. 1999] by preserving the privacy of the participants while maintaining communication and computational efficiency. The novelty of the architecture is based on a new entity, the "Auction Issuer" (a financial institution or a large company) which is responsible for generating the programs computing the auctions without taking an active part in the protocol. In the same paper, extensive references and comments are also given from previous related work on security.

An example of a more technical paper on cryptography is [Catalano and Gennaro 2000] which presents new protocols for verifiable signature sharing that can be applied to ensure security in distributed auctions. An interesting application is an electronic auction in which all the bids must be done by verifiably sharing a check drawn from the same bank. This way the winner of the auction cannot default the final price since the proxies can reconstruct his check, while their bids will never come out.

Furthermore, a recent paper [Watanabe and Imai 2000] presents a protocol for sealed-bid actions which allows the auctioneer to determine the winning bid in a universally verifiable way and also prevents both the bidders and the auctioneer from getting useful information regarding the bids of losers. The protocol is based on the existence of a trusted third party invoked only when a bidder cheats or simply crashes. In any case, there is a deviation from the rules, for example loss of registration information or sending of irregular messages. Overall, this proposed protocol achieves all of the desirable security properties.

5. APPLICATIONS - AGENT BASED IMPLEMENTATIONS

Internet-based auction applications and implementation approaches are quite recent and relate to a number of the issues raised in earlier sections. For example, [Kumar and Feldman 1998] present an application where a variety of commonly used auction mechanisms such as security requirements and pre-auctions and post-auction interactions are supported. Requirements for an Internet auction application are identified, the activities of a complete auction-based trading process are described and the differences between Internet and conventional auctioning are emphasized. This application is based on an object model which supports various auction types and supports a detailed process flow between buyers, sellers and settlement system.

Several auction servers have been developed for supporting various features of the electronic negotiation process. The *eMediator* is a highly enhanced server which supports combinatorial bidding, bidding via price-quantity graphs, and mobile agents [Sandholm 1999; Sandholm 2000]. The *eMediator* components determine the winners of the combinatorial auction by identifying profitable contracts for the participating agents. Since optimal winner determination is computationally complex, a highly optimized search-based matching algorithm has been introduced. In this method, each agent willingly takes on a task from another agent (as long as it is paid more by the other agent).

One of the most important components of the *eMediator* is its Internet auction prototype called *eAuctionHouse*, which serves as a site allowing users over the Inter-

net to buy and sell goods as well as setting up markets [Sandholm and Huai 2000; Sandholm 2000]. *eAuctionHouse* is enhanced to include a mobile agent system, called *Nomad* [Sandholm and Huai 2000] towards a next generation system for the electronic auctions. The additional features in this system mainly refer to the use of two mechanisms (either a TCP/IP connection or the *Nomad* agents) for creating or closing auctions. Furthermore, the *Nomad* architecture has interfaces for agent specification and agent management whereas mobile agents travel to the *eAuction-House* site and actively participate in auctions on the user's behalf, even when the user is disconnected from the network. Additionally, this system supports the creation of mobile agents by allowing users to program their own agents or launch parameterizable agents that have been designed and programmed in advance.

The configurable auction server developed in University of Michigan is a scalable and flexible auction server for both human and software agents. This server is described in [Wurman and Wellman 1998] where the proposed scalable auction server (called *AuctionBot*) is overviewed. The proposed model involves the specification of some parameters which are categorized with respect to bid's definition, information availability as well as price setting. *AuctionBot* manages many simultaneous auctions under a design that separates the interface from the core auction procedures and supports the widest range of auction types. The *AuctionBot* architecture is based on a design that supports an effective Web interface and a separate TCP/IP interface such that the interaction with the auctions database can be made by both users and software agents. The usefulenes of the AuctionBot modeling is based on its large parameter space and its open agent API which is suitable for employing research experimentations and computations.

Agents are a recent tool for nowdays emerging and demanding applications that require complex workflow processes and have been applied in e-negotiations and e-auctions due to their flexibility and adaptiveness. Since designing agents for bidding in simultaneous electronic auctions is a rather challenging and complex problem, a number of specialized and focused agent-based applications have been proposed for employing specific tasks. For example, in [Greenwald and Stone 2001] the task-specific details and strategies of agents are described, for the first trading agent competition held in Boston, Massachusetts on July 2000. Another example is the trading agents in electronic auction markets test-bed as implemented under the *Fishmarket* auction house [Rodriguez et al. 2001].

Auction name	URL address
eBay	http://www.ebay.com
AuctionNet	http://www.auction.net
Priceline.com	http://www.priceline.com
Egghead.com	http://www.egghead.com/aa/auctions.htm
Auction Hunter	http://www.auctionhunter.com
Internet Auction List	http://www.internetauctionlist.com

Table 1. Internet-based Auctions: implementation examples.

The Internet has facilitated and contributed to an extensive development of online consumer auctions. Many Internet-based auction implementations are available

to the Web users community. Some indicative examples of Web available auction sites are given in Table 1. The wide spread of e-commerce has resulted in a number of firms working on the sector of electronic negotiations. For example, *eBay, Priceline.com, Hagglezone* and *Makeusanoffer.com* are referred as a case study for their e-negotiations frameworks. More specifically, [Hobson 1999] summarizes each of these companies' frameworks, focusing on how they design the "rules of the game" in the e-negotiation field. An overview of some negotiation models is presented in relation to auctions, e-negotiation models, consumers characteristics, state-your-price buying as well as person-to-person haggling.

Furthermore, a commerce middleware component, called "Auction Manager" is presented in [Mullen and Wellman 1998]. This middleware framework is designed to simplify and automate both the creation of new markets and the matching of users to existing markets. The Auction Manager uses market-oriented inference rules in order to automatically compose and decompose marker offers and to determine starting and running auction charges.

6. CONCLUSIONS - FUTURE WORK

Online auctions have become a vital and emerging component to most consumer and business electronic commerce applications. This paper provides an overview of current research efforts in relation to Internet-based auctions modeling and applications. As presented here, most research efforts are related to auctions parameterization and their frameworks modeling, design and use of agents for auctions impementation, combinatorial and computational auctions analysis as well as security issues. Since e-auctions and e-negotiations processes are crucial to the overall performance of related electronic commerce applications, various directions for future work can be proposed. Further research topics could focus on modeling and evaluation of the costs involved in an electronic auction process in relation to network traffic or bandwith resourses. Furthermore, such costs can be interpreted in terms of either timing (for example, response time in real-time implementations) or monetary perspective (prices of tools providing decision and security support).

ACKNOWLEDGMENTS

The authors would like to thank the referees for their valuable comments which have considerably improved this papers structure and readability.

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