OICAS: An Online Iterative Combinatorial Auction System

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Abstract – *An online iterative combinatorial auction system called OICAS is designed and developed. The system can be used to auction multiple items each with a single unit simultaneously and a bidder can bid any bundle of items. A new auction mechanism, called the Ascending Revenue Mechanism, and a novel winner determination algorithm are proposed. Unified Modeling Language (UML) models are developed for describing the system. A prototype of OICAS is implemented using Visual Basic and Microsoft Access. Computational testing shows that this system is fast enough to be used online.*

Keywords: Ascending revenue mechanism, combinatorial auction, online auction, iterative auction, winner determination algorithm, UML diagram, OICAS.

1 Introduction

Auction is a market form in which the price of an item is based on the competition of participants. Usually, the auctioneer sells one item at a time, and bidders can bid for it at any time when the auction is in progress. Auction has become more popular in recent years because of online auction. Online auction overcomes the restriction that people have to attend an auction in a specific physical location at an appointed time. Some of well-known online auction sites are eBay.com, Amazon.com, and Yahoo.com.

In the auction realm, there are many situations in which sellers sell multiple goods while it is very important to buyers that they can bid for a combination of items. The value of a bundle of items is not just simply the sum of the separate value of each item in the bundle. Some examples of this type of auction include the FCC (U.S. Federal Communications Commission) spectrum allocation [3], [4], [5], [6], airport time slot allocation [11], and railroad segment allocations [2]. This type of auction is called combinatorial auction or bundle auction.

Depending on mechanisms used, auctions can be classified into many categories. Bidding and winner determination rules are the core of a mechanism. The simultaneous ascending mechanism is one of mechanisms utilized to auction multiple items each with a single unit. In this type of auction, sellers auction items simultaneously with multi-round sealed bids. In each round, buyers can bid as many items as they are interested. But they have to bid each of them separately and cannot put a bundle of items in one bid. The temporary winning bids in each round are the combinations of the highest bid for each item. The auction ends at the round with no new bid submitted. Each item's highest bid wins that item and pays the price of that bid [6]. Since this mechanism dose not allow bidders to bid on bundles of items, it cannot be utilized in combinatorial auctions. Bidders may not get the entire collection of items that they are interested.

The adaptive user selection mechanism (AUSM) is used in multi-round auctions to sell multiple non-identical items. In each round, bidders can bid on any bundle of items at any time before this round ends. The usual stop condition in a round is that there is no new bid submitted in a certain period of time after the last bid. Then the auctioneer finds the winning bids with the maximum revenue in this round and announces the result. Bidders have an opportunity to win by adjusting their bids in the next round. If no new bid is submitted in the new round, or the total revenue does not increase, the auction ends. The last round winners win the auction and pay their bids [7].

The Vickrey-Clarke-Groves mechanism (VCG) is used to sell multiple items to many bidders. A bidder submits sealed bids for each possible package simultaneously. The auctioneer then determines the winners with the maximum total revenue based on all bids. A winner pays the amount of his/her winning bid(s), and receives a refund (also called Vickrey payment) that equals to the increment of the total revenue caused by his/her bid(s). This mechanism is impractical because (1) the Vickrey payment can make revenue deficient and (2) there is a problem of cheating [10].

Online auctions have many advantages, such as reducing transaction cost, getting more bidders, allowing bidders to join an auction easily, and describing complex products easier. Because of the computational complexity, combinatorial auctions for multiple different items are difficult to implement online.

The major objective of this paper is to design and develop an online iterative combinatorial auction system called OICAS. The system can be used to auction multiple items each with a single unit simultaneously and a buyer can bid any bundle of items. The system can be utilized in Business-to-Business (B2B) or Government-to-Business (G2B) transactions. A new auction mechanism, called the Ascending Revenue Mechanism, and a novel winner determination algorithm are proposed. The system is developed using Unified Modeling

Language (UML) models. A prototype of OICAS is implemented using Visual Basic and Microsoft Access. Computational testing is carried to demonstrate that this system is fast enough to be used online.

2 Ascending Revenue Mechanism

For auctioning multiple items each with a single unit simultaneously, the following auction mechanism, called *Ascending Revenue Mechanism,* is proposed [12].

Ascending Revenue Mechanism: this mechanism is used to auction multiple items simultaneously. Bidders can bid any bundle of items at any time during the auction. But for any new bid, it must bring additional total revenue for the auctioneer with at least the minimum increment. The temporary winning bids are the new bid and other bids that can bring the auctioneer the maximum revenue with no overlap items among them. The final winners whose bids are part of the winning bid combination after the auction ends win the items they bid and pay the amount of their bids.

Bidding rule: based on the *Ascending Revenue Mechanism*, any new bid should increase the total revenue to the auctioneer with at least the minimum increment. In other words, a *new bid must win* at the time of submission.

Termination condition (ending rule): the auction stops at the pre-announced ending time and no more bids are accepted after the ending time.

Based on the *Ascending Revenue Mechanism* and bitwise representation of items and bundles of items, a new winner determination algorithm is developed [12].

3 An Online Iterative Combinatorial Auction System

3.1 Overview of the System

The system designed in this paper can be used to auction multiple items each with a single unit simultaneously. If a bidder wants to get some items together while he/she does not want to obtain only part of them, he/she can bundle the desired items in one bid. The *Ascending Revenue Mechanism* is used. That is, in order for a bid to be accepted during the bidding process, the bid must bring more revenue to the auctioneer. The online iterative combinatorial auction system has following characteristics:

(1) The auctioneer can determine who can participate in an auction.
(2) Only legitimate users (bidders) can participate in an auction.
(3) Bidders can bid for any bundle of items with acceptable price.
(4) The system shows bidders the required minimum winning prices of their bids automatically.
(5) The system displays the winning bids in real time.
(6) Bidders can trace the history of the auction any time.
(7) Bidders can see the information about an item any time.

3.2 Unified Modeling Language (UML) Models

Unified Modeling Language (UML) is a standard visual graphical modeling language to describe models for software systems and engineering projects [9]. Unlike Visual Basic, C, and other programming languages, UML cannot be used to implement executable software by itself. It is used to develop software models (structure and framework) that provide clear descriptions to programmers about what the software systems should do and how the systems work. Programmers can implement the systems by developing executable software.

In an online iterative combinatorial auction system, the auction process is divided into three parts: auction preparation, bidding process, and auction clearing process. Since computing the minimum winning price is a time consuming process and bidders may often inquire the minimum winning prices for some bundles of items, calculation of the minimum winning prices is carried out by a bidder's computer. When a bidder submits a bid, the web sever checks the minimum winning price, computes the current total value, and determines the winning bid combination (WBC).

The auction preparation use case diagram is provided in Figure 1, which shows the activities that have to be completed before an auction. An auctioneer or agent has to announce the auction by giving out information such as what items will be auctioned, when it will begin and end, and what are conditions to participate in the auction. The companies who are interested in the auction must apply for participation by providing required materials. After required materials are verified, the companies who meet the conditions are accepted to participate in the auction and are provided with a unique account (user name and password). Before starting the auction, bidders should download and install the client software from the web server. The applicants who are not approved get the materials back from the auctioneer.

The use case diagram for the bidding process is shown in Figure 2. To participate in the auction, a user must sign into the auction system using the account provided by the auctioneer. Once the user signs into the auction system, he/she can bid for any items. The web site shows the current winning bid combination, the auction items, and the minimum price required for his/her bid to become part of the winning bid combination at this time. After selecting the items he/she is interested, the bidder's computer calculates the minimum price he/she can win. The auction web page is a dynamic one. It shows the minimum winning prices as the selections are made. After a bidder inputs his/her price (cannot be less than the minimum winning price) and confirms the bid, the auction web server verifies the minimum winning price. If the bid is still a winning bid, the web server accepts this bid, computes the total revenue in this auction, shows the current winning bid combination, and updates the related data and database. Otherwise, the web server re-computes the minimum winning price and returns the bid.

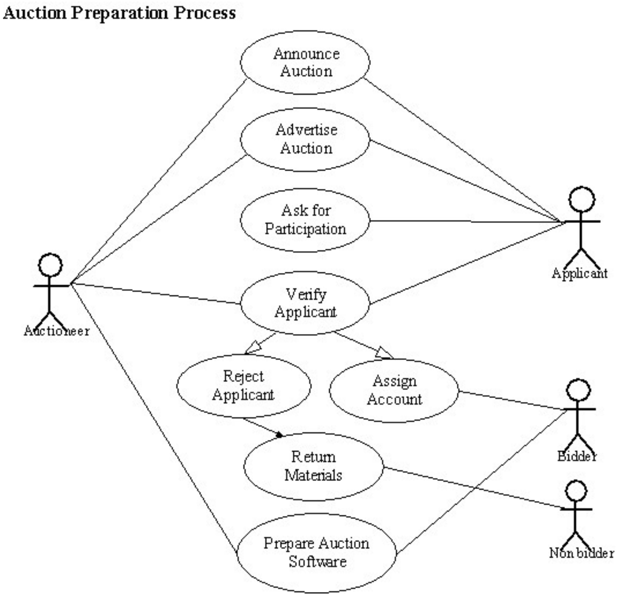

Figure 1. Use case diagram for the auction preparation process

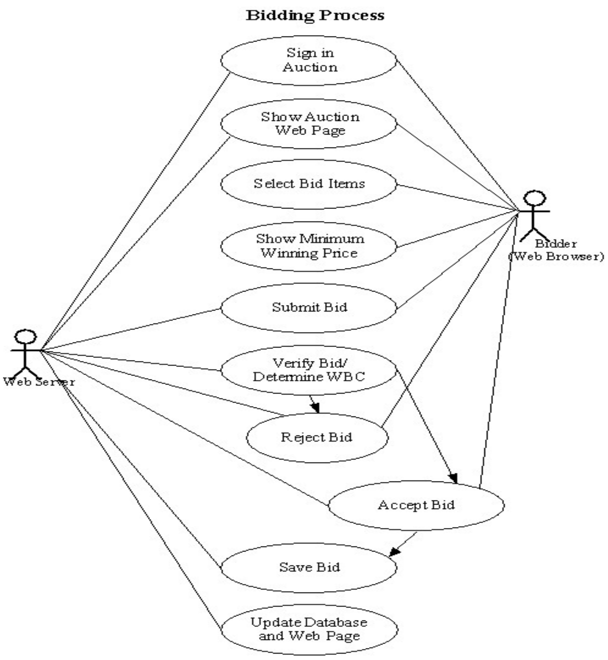

Figure 2. Use case diagram for the bidding process

The use case diagram for the auction clearing process is shown in Figure 3. When the auction ends, the final winners have to pay for their winning items, and the losers get back the materials they provided to the auctioneer. These activities are completed by the web server or auctioneer. After a payment is verified by a bank, the auctioneer sends the items to the bidder. The delivery can be traced by the bidder and auctioneer. When all winners receive their items, the entire process is completed.

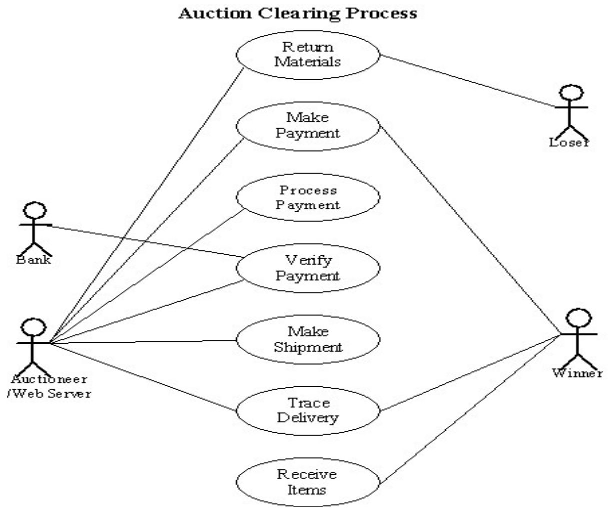

Figure 3. Use case diagram for the auction clearing process

Activity diagrams are used to describe workflow. They are derived from use case diagrams. The activity diagram for the bidding process is shown in Figure 4.

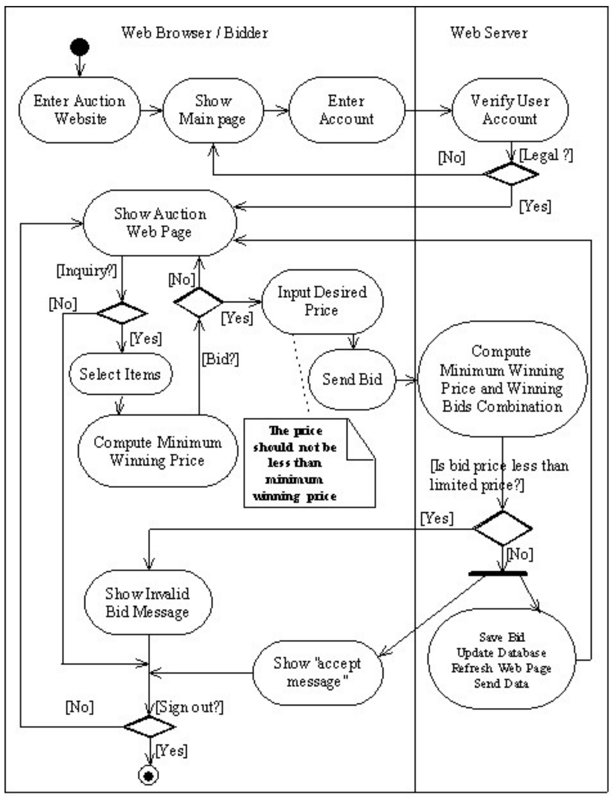

Figure 4. Activity diagram for the bidding process

UML class diagrams are used to describe the system's static structure, such as classes and the relationships among them. Figure 5 shows the class diagram for the bidding process. Deployment diagrams show the deployment and configuration of the components on physical nodes of the networked computer system. In this auction system, bidders communicate with the web server by using the Internet HTTP protocol (TCP/IP) through web browsers. The operating system of a bidder's computer (client) can be Microsoft Windows, Linux, or Unix. The auctioneer communicates with a bank also using the Internet HTTP (TCP/IP) protocol, as shown in Figure 6.

The aforementioned are some UML diagrams used to show conceptual models and structures of this system. It can be implemented by using Java.Net, C#, VB.Net or other Internet programming language.

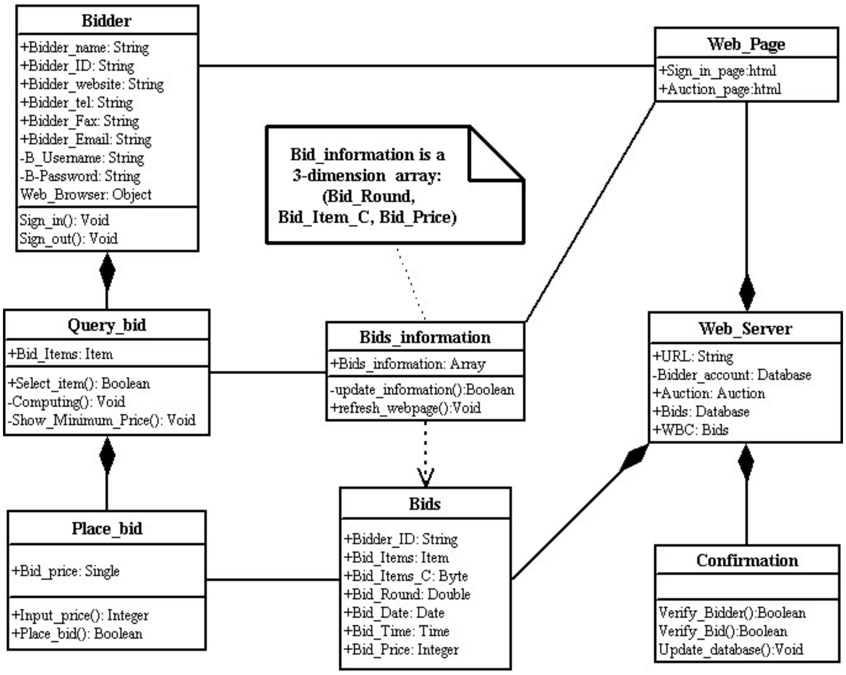

Figure 5. Class diagram for the bidding process

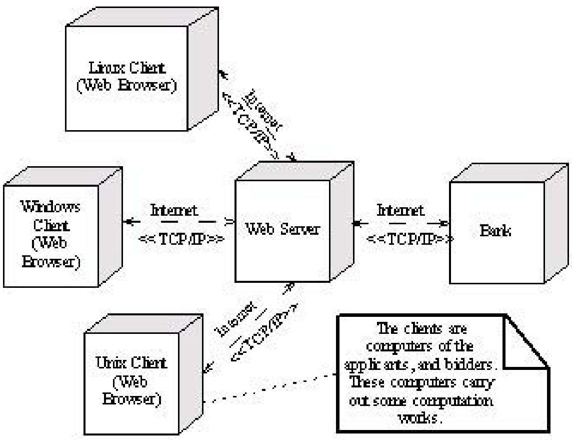

Figure 6. Deployment diagram

4 A Prototype of the Online Iterative Combinatorial Auction System

A prototype of the online iterative combinatorial auction system is implemented using Visual Basic 6.0 programming language and Microsoft Access database. This prototype includes two parts: Online Iterative Combinatorial Auction Maintenance System (OICAMS) and Online Iterative Combinatorial Auction System (OICAS).

4.1 Online Iterative Combinatorial Auction Maintenance System (OICAMS)

In order to develop and maintain an online iterative combinatorial auction system, the auctioneer needs to develop and implement a system to maintain the auction database. This system is called the Online Iterative Combinatorial Auction Maintenance System (OICAMS). The main purposes of OICAMS are:

- to assign user names and passwords to candidates who meet the conditions of an auction;
- to exhibit items for auction, such as to input information about items and their starting prices; and
- to delete items from auction.

In OICAMS, the auctioneer also can monitor all bids and the winning bids at any time when the auction is in progress or after the auction ends. The "View Bids" window is used to show all bids, as given in Figure 7. The auctioneer can trace bid history at any time. The bid history includes the bid number, bidder's identification, bid items, bid price, bid time and total revenue after that bid.

All winning bids can be seen in the "View Winning Bids" window shown in Figure 8. The auctioneer can monitor the current winning bid combination at any time. When the auction ends, the bidders whose bids are among the winning bid combination are final winners.

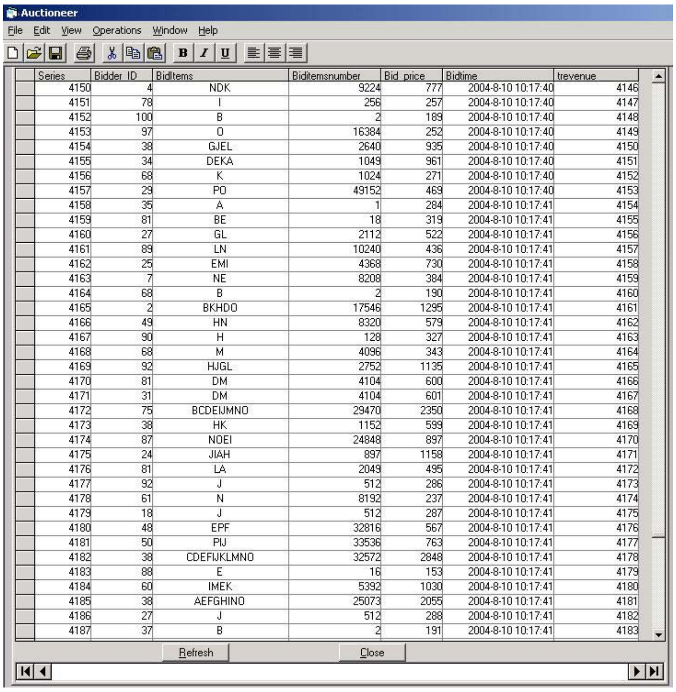

Figure 7. The "View Bids" interface of OICAMS

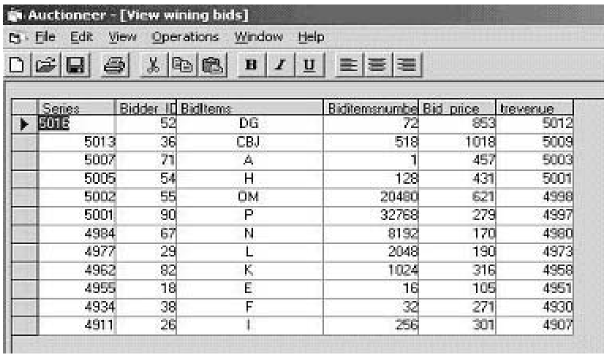

Figure 8. The "View Winning Bids" interface of OICAMS

4.2 Online Iterative Combinatorial Auction System (OICAS)

OICAS is an auction conducting system used by the auctioneer and bidders. It allows bidders carrying out the following tasks:

- seeing the detailed information of each auction item,
- tracing the auction history,
- checking the winning bid combination,
- inquiring the minimum winning price for any bundle of items in which he/she is interested, and
- placing a bid for any bundle of items.

In OICAS, a user can submit the bid(s) either manually or automatically. The interface for manual bid method is shown in Figure 9. A bidder can check the minimum winning price for any bundle of items he/she is interested by validating the items' check boxes and pressing the "Confirm Selection" button. If the price is suitable, the bidder can input his/her desired price in the "Input desired price" box (the price must not be less than the minimum winning price shown in "Minimum price" box), and then press the "Place Bid" button. Alternatively he/she can just click the "Place Bid" button after pressing "Confirm Selection" button. The system accepts the bid with the minimum winning price.

The automatic bid approach is used to simulate various scenarios of combinatorial auctions, such as eight items with five thousand bids, 16 items with ten thousand bids, and 30 items with thirty thousand bids. Through the automatic bid approach, the system can automatically submit thousands of bids in a few minutes with the minimum winning price (automatically calculated) as the price for each bid. These bids come from the "Bid Generator" software.

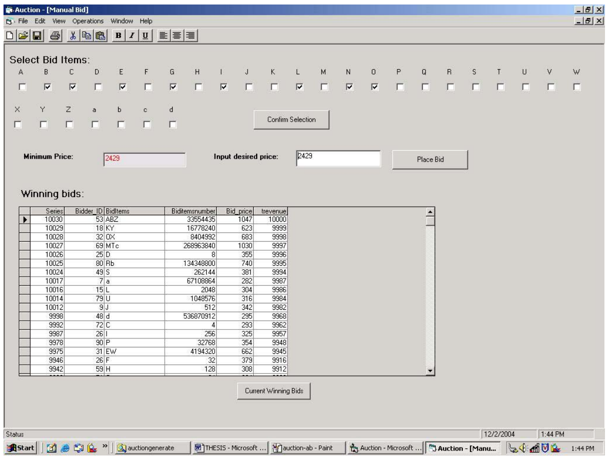

Figure 9. The "Manual Bid" interface of OICAS

5 Computational Testing

Bid processing time is the core of an online combinatorial auction system. Since real combinatorial auction data are not available, the alternative bids have to be generated by computer. A bid generation program, called "Bid Generator", is developed. In this bid generator, a user can select the auction size by inputting the number of items. How many bids to generate and the number of participants can also be chosen. Moreover, a user can select a bid generation scheme from "Random Bids", "ρ = 1/2", and "ρ=1/3" [1], [8]. "ρ = 1/2" scheme generates bids according to ρ = 1/2 probability which means: 1/2 bids have one item, 1/4 bids have two items, …, 1/32 bids have five items, and so on.

By using the automatic bid and manual bid approaches, many scenarios are tested to determine the bid processing time. Some of the results are shown in Tables 1 to 3, where the time unit is millisecond. All tests are carried out using a 1.7 GHz Pentium IV compatible computer with 256 M RAM under the Microsoft Windows 2000 environment.

As shown in Tables 2 and 3, the longest bid processing time in the ρ = 1/2 bid scheme and ρ = 1/3 bid scheme is 280 and 460 milliseconds, respectively, when the auction size is 30 and the total number of bids is 30,000 bids. These data show that OICAS is fast enough to be used online. Even at the extremely case – in random bid scheme, the bid processing is fast enough when the number of total bids is under 10,000. In the real world, the number of total bids can rarely reach a few thousands.

Table 1. Bid processing time (milliseconds) for the random bid scheme

Total Number of Bids	Auction Size					
	8	12	16	20	24	30
1,000	10	40	40	40	40	40
5,000	20	110	170	180	180	190
10,000	20	160	350	370	370	380
15,000	30	170	520	540	540	560
20,000	40	170	630	690	700	740
25,000	40	180	800	850	910	920
30,000	40	190	890	1130	1130	1140

Table 2. Bid processing time (milliseconds) for the ρ= 1/2 bid scheme

Total Number of Bids	Auction Size					
	8	12	16	20	24	30
1,000	10	20	20	20	20	20
5,000	20	35	40	50	60	60
10,000	30	60	80	90	100	110
15,000	30	70	100	120	140	155
20,000	40	85	120	150	170	200
25,000	40	95	150	190	205	235
30,000	40	105	170	210	230	280

Table 3. Bid processing time (milliseconds) for the ρ= 1/3 bid scheme

Total Number of Bids	Auction Size					
	8	12	16	20	24	30
1,000	10	20	20	25	30	30
5,000	20	60	80	90	95	110
10,000	20	110	140	160	170	190
15,000	30	110	190	210	230	245
20,000	35	120	210	280	300	330
25,000	40	140	260	320	360	390
30,000	40	150	300	360	440	460

6 Conclusions

An online iterative combinatorial auction system, called OICAS, has been designed and developed. OICAS incorporates the *Ascending Revenue Mechanism* and a new winner determination algorithm. Computational tests show that OICAS is fast enough to be used online for moderate size combinatorial auctions. OICAS can not only be used to sell multiple items simultaneously, but it can also be used to buy multiple items by representing the bidders' prices in negative. Since the procurement activities are common in B2B and G2B transactions, this system can be used by businesses and governments.

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