# Efficient Combinatorial Auction Mechanisms in Electronic Commerce

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Keywords: Resource Allocation, Combinatorial Auction, New_FixedPrice, New Combinatorial Auction using LinearProgramming (New_CA_LP), Combinatorial Auction using Greedy, New Combinatorial Auction using Greedy Approach ( CAGREEDY-MODIFIED).

Abstract: Electronic commerce or e-commerce is the trading of products or services via internet. The product with little demand is generally sold in fixed price. However, when the demand of a product is huge, auction mechanism can be used to maximize the profit. Selling price of some inevitable products like medicine does not depend on the demand. Auction is the best method for selling products which provide maximum possible profit to the sellers and the buyers get the product in reasonable price. Today, a large part of e-commerce uses online auction for selling their products or to provide any service to the worldwide buyers. Winner determination and payment value calculation of combinatorial auction is a very complex task. The solution to this problem demands optimal result to the auctioneer within manageable time and the satisfaction of both the buyers and sellers in terms of profit. Most simple combinatorial auction already used by many websites for e-procurement is fixed price auction. Fixed price auction is not truthful and gives more profit to the seller. In this paper we study different auction mechanisms for item procurement in e-commerce and proposed a new truthful auction strategy that outperforms the existing approaches in the context of time and truthfulness.



## 1 INTRODUCTION

Auction is the most important mechanism for dynamic pricing in e-commerce (Muller, 2001). The seller offers a variety of items or service for sale with the aim of obtaining more profit. Online Auction is useful to maximize the seller revenue and provides an opportunity to a buyer to buy the products or services at fair market value based on selling price and not asking price. A seller can meet maximum numbers of customer from different geographic area because of the location independence of e-commerce. Combinatorial auctions have been gaining significant interest as an automated mechanism for selling multiple products or services to a single buyer (Narahari and Dayama, 2005). Combinatorial auction is extremely useful in numerous e-business applications such as e-selling, e-procurement, e-logistic etc. Combinatorial auctions are those those in which participants place bids on combination of products or services, called packages, rather than individual product (Cramton et al., 2005). In this case, participants or buyers either win all the products or services of the package they have requested to buy or lose. Combinatorial auctions are useful to a buyer to buy all the related products or services altogether at one bid at fair market value and seller also able to sell bundle of products or services at a time at maximum profit. Auctions have gained much greater prominence as the means of determining prices at which goods are bought and sold as a result of improved communication and information processing capabilities of the personal computers and the Internet (Morgan, 2002). At a consumer level, the auction site eBay and Amazon have transformed the market for buying and selling collectibles as well as a host of other products and their sales revenue continue to grow rapidly by more than 90 percent in last five years (http://www.marketwatch.com/investing/stock/ebay/financials).

### 1.1 Some Applications of Combinatorial Auctions

Numerous applications have been reported in various



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research papers for combinatorial auction. We have only discussed few of the applications areas of combinatorial auction.

Spectrum Allocation: Wireless and mobile technologies are growing very rapidly in recent times. Service providers need to provide emerging wireless service and new wireless architecture to fulfill the requirement of huge number of wireless/mobile devices and applications. In static resource management system spectrum is allocated for long term basis. Some radio spectrum may leave idly where some wireless systems are unable to work due to spectrum crisis. Static resource management in wireless system is inefficient in modern era since demand and supply may not always match. Auction is widely used to dynamic allocation of spectrum to improve the channel/spectrum utilization(Zheng et al., 2014). Government or authorities use auction mechanism to sell the spectrum license among telecommunication companies.

Electricity Distribution: In (Zhongjing and Yingying, 2014)(Sarlati et al., 2013) hierarchical electricity distribution retailers distribute electricity using auction mechanism. The electricity market consists of one generation provider (owner of whole electricity), several retailers (different companies) and many consumers. Combinatorial auction mechanisms are used by electric generation provider to assign electricity to the retailers.

E-Procurement: Auctions are widely used in E-procurement (Narahari and Dayama, 2007)(Shikui et al., 2014)(Gregory and Molson, 2013). Procurement is purchase of goods and services. Buyers look for sellers who would sell the items and services. Sellers with similar goods and services submit their bids; Sellers also obtain the information regarding goods and interest of other sellers which help them to price negotiation. Buyers continue the bid until one seller is ready to offer lower price than the one offered in the last bid or the end of time. More than one round is required to finalize the winner.

Resource allocation: In cloud computing, cloud provider rent their various resources to the user for their use over internet. Users from various location of the world may hire resource from cloud. Combinatorial auction mechanism is used by cloud providers to rent their resources to the users (Zaman and Grosu, 2013a)(Iosifidis and Koutsopoulos, 2010) on pay per use basis.

### 1.2 Literature Review and Research Motivation

There are three basic techniques of combinatorial auction; i.e. Fixed Price Auction, Combinatorial Auction Linear Programming (CA-LP) and Combinatorial Auction with Greedy approach (CA-GREEDY).

Shikui (Shikui et al., 2014) has proposed the Fixed Price Auction mechanism which is the simplest combinatorial auction and is used by many cloud providers. It has been proved that it is not incentive compatible (Zheng et al., 2014).

Archer (Archer et al., 2005) has proposed one mechanism CA-LP of combinatorial auction using linear programming problem and (Shikui et al., 2014)has given extended version of CA-LP. Though CA-LP is incentive compatible but it has been solved by linear programming problem and results non linear time complexity.

CA-GREEDY is another combinatorial auction mechanism proposed by Archer (Archer et al., 2005), Zaman (Zaman and Grosu, 2013b). This mechanism takes less time to determine the winner and calculating payment value and it is incentive compatible but not like CA-LP.

CA-Provision is another approach using greedy mechanism proposed by (Zaman and Grosu, 2013a).

A plethora of research has been done on combinatorial auctions. None of the existing literature compares the performance parameter of the existing popular multi-item auction used in e-commerce. The objective of this paper is to compare the three auction techniques and proposed a new mechanism design approach to improve the performance.

Rest of the paper is organized as follows: section 2 present the comparison of popular auction mechanisms in e-commerce. The multiple products selling is represented as mechanism design problem in section 3, the new proposed Fixed Price, CA-LP and CA-GREEDY-MODIFIED mechanism is discussed in section 4. The simulation of proposed mechanisms is detailed in section 5; finally we conclude the paper and discuss future research direction in section 6.

## 2 COMPARISON OF COMBINATORIAL AUCTION MECHANISMS

Basic parameters for measuring performance of any auction mechanism are truthfulness, execution time and the value of utility function. Utility of each user is the difference between the bid values she has asked for her requested resources at the bidding time and the original price she has been charged for using resources. Execution time means total time taken to execute the algorithm to determine the winner and for calculating the payment value. Truthfulness means that each bidder bids their true value of the resources. We have implemented all the existing combinatorial auction mechanisms in MATLAB environment and tested for various numbers of inputs. For all simulations, inputs are randomly generated within the given range and the following values of performance parameter found.

Table 1: Performance comparison of combinatorial auction mechanisms.

| | Truth fullness | Value of the utility function | Time Complexity |
|---|---|---|---|
| Fixed Price | No | Zero | Low |
| CA-LP | Yes | High | High |
| CA-GREEDY | Yes | Average | Average |

The above table shows that Fixed Price auction is not at all truthful and the value of the utility function is zero so the seller's revenue is very high but its execution time is low. The seller revenue is very high in this case but not maximum. We have proposed New_FixedPrice combinatorial auction where the seller may earn maximum possible profit. But CA-LP ensures that truthfulness is the dominant strategy of each user and the value of utility function is too high compared to other combinatorial auction. But execution time of CA-LP is very high. So CA-LP is the best combinatorial auction mechanism for all performance parameters for small input values. CA-LP takes longer time to execute a large number of inputs. But payment method of CA-LP mechanism is designed in such a way that the user pay zero for the product with a little demand. But the product with a little demand is generally sold at the fixed price. In this paper, we have proposed New_CA_LP where we extended the payment part of CA-LP so that seller's revenue will not be zero for any product, the buyer has to pay minimum fixed price of the product. CA-GREEDY mechanism also ensures truthfulness, execution time and value of the utility function at average. CA-GREEDY is very useful for large number of inputs but value of the utility function is not quite bright. In a research paper Zaman (Zaman and Grosu, 2013a) has given one new method; i.e. CA-PROVISION based on CA-GREEDY where the value of utility function is better than CA-GREEDY but not like CA-LP. In this paper we have modified the CA-GREEDY mechanism (CA-GREEDY-MODIFIED) to improve the value of the utility function so that CA-GREEDY-MODIFIED will be the best choice for combinatorial auction for a large number of inputs and provides best value for all performance parameters.

# 3 MULTIPLE PRODUCT DISTRIBUTION AS A MECHANISM DESIGN PROBLEM

For formulating the multiple product or service selling process we consider the following notations and assumptions:

1)Let

$$I = (u_1, u_2, ..., u_n)$$

be the set of n buyers,

$$K = (r_1, r_2, ..., r_m)$$

be the set of m available products or services and $r_i$ is the total number of available products or resource of type i and

$$W = (w_1, w_2, ...w_m)$$

be the set of weights where $w_i$ is the weight or minimum value per unit of ith product.

2) A set of winners WIN contains list of winners.

3) Each user or buyer precisely knows the value that he bids but does not know the bid value of the others. The bidder i submits the bid

$$(a_{i1}, a_{i2}, ..., a_{im}, v_i)$$

Where $a_{ij}$ denote the number of $j^{th}$ resource request by user i and $v_i$ is the valuation of total items requested by her. User i can put $a_{ij}$ as zero, if she does not want any number of resource j.

4) Bidders are not aware of the type and number of requested products and total valuation submitted by other bidder.

5) Let

$$P = (p_1, p_2, ...p_n)$$

be the set of payment value paid by the buyer to the seller.

6) The agents always try to maximize a utility function. Utility function defines as the difference between bid value submitted by user and the value actually paid.

The below mentioned matrix represents the bid profiles of all the bidders.

$$bid = \begin{pmatrix} a_{11} & a_{12} & ... & a_{1m} & v_1 \\ a_{21} & a_{22} & ... & a_{2m} & v_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & ... & a_{nm} & v_n \end{pmatrix}$$

After collecting all the individual bids, combinatorial auction mechanism determines the winners and it also fixes the charge paid by every winning bidder.

# 4 NEW PROPOSED MECHANISM

In this section, three mechanisms have been presented to solve the problem of multiple product sale to a single buyer in a single bid. The first New_FixedPrice auction, is the extended version of Fixed Price Auction by Archer (Archer et al., 2005). The next two mechanisms are the proposed New-CA-LP and CA-GREEDY-MODIFIED based on linear programming problem and Greedy mechanism.

## 4.1 New Fixed Price Auction (New_FixedPrice_Auction)

Fixed Price Auction mechanism is the simplest combinatorial auction and is used by many cloud providers (Zaman and Grosu, 2013b). The Fixed-Price auction mechanism defines a fixed price vector ($q_1$ ,$q_2$,...$q_m$) where $q_i$ is the price a buyer has to pay to buy one instance of $i^{th}$ product. Archer (Archer et al., 2005) explains this mechanism as first come first serve basis until the products are exhausted. In this case during the opening of the market there will be a huge traffic to submit the request first. The fixed price auction mechanism has been extended by re-ordering the users in descending order of the respective bid value. The bidder with the highest bid value will get the first chance to win the products. Bidders win the products depending on their bid values, no need to compete for submitting the bid first and the auctioneer profits more. It also makes sure that in order to get the requested bundle of products, the valuation vi of buyer $u_i$ is at least $F_i$ , where $F_i$ is the sum of the fixed prices of each products in her bundle. In this case the bid value reflects necessity and urgency of the products. The algorithm for implementing the fixed price auction is given below(Algorithm-1).

In the our algorithm (Algorithm-1), reordering of the bids is included and time complexity increases from O(n) to O(nlogn). But using this method an auctioneer can avoid one time rush and the resource providers have a chance to earn more revenue because resource providers distribute resources from high to low bid value. Fixed price method is not incentive compatible (Zheng et al., 2014) resource allocation. The Winners have to pay the value what they have declared during bid submission. To encourage users to participate in auction we need to charge less than the value declared by them.

Algorithm 1. New_FixedPrice_Auction.

$Step\,1: Collect\,the\,bid\,from\,the\,users.$
$Step\,2: Arrange\,the\,users\,in\,order\,(u_1,u_2,...,u_n)$
$\quad so\,that\,v_1 >= v_2 >= ...v_n$
$Step\,3: Initialize\,WIN = \phi$
$Step\,4: for\,i = 1\,to\,n$
$\quad if\,v_i >= \sum_{j=1}^{m} a_{ij} * q_j\,then$
$\quad\quad if\,A_i <= R$
$\quad\quad\quad then\,WIN = WIN\,UNION\,\{i\}$
$\quad\quad\quad and\,R = R - A_i$
$\quad\quad\quad where A_i = (a_{i1}, a_{i2}, ..., a_{im})$
$\quad\quad\quad and\,R = (r_1, r_2, ..., r_m)$
$\quad\quad [End\,If]$
$\quad [End\,If]$
$[End\,for]$
$Step\,5: for\,i = 1\,to\,n$
$\quad If\,i \in WIN\,then\,p_i = v_i$
$\quad Else\,p_i = 0$
$\quad [EndIf]$
$[EndFor]$

It is assumed that two types of products are offered by the buyer. Relative weight of the products is W=[2 ,1] and fixed prices are 10 and 15 respectively. Total ten users participate in the bidding process. Numbers of products of each type are 10 and 15 respectively.

Table 2: Examples of Submitted bids.

| No of Products (r1) | No of Products (r2) | Bid Value |
|---|---|---|
| 2 | 1 | 40 |
| 1 | 2 | 30 |
| 2 | 5 | 60 |
| 3 | 3 | 35 |
| 2 | 4 | 50 |
| 3 | 1 | 33 |
| 2 | 0 | 20 |
| 0 | 5 | 60 |
| 1 | 3 | 55 |
| 4 | 2 | 85 |

Each users(i) bid is 3-tuple ($r_{i1}$,$r_{i2}$,$v_{i3}$) where $r_{i1}$ is the number of requested instances of item 1, $r_{i2}$ is the number of requested instances of item 2 and $v_{i3}$ is the bid value that user i wants to pay for the requested items.

Result: Existing Fixed Price auction and proposed New_Fixed_Price auction have been implemented on the above data set and the result is given below (Table-3):

## 4.2 New_CA_LP

Combinatorial Auction-Linear Programming (CA-

Table 3: Result of New_FixedPrice Auction.

| | Winner set | Payment set | Seller revenue |
|---|---|---|---|
| Existing Fixed Price auction | 1, 2, 3, 5, 6 | 40, 30, 60, 50, 33 | 213 |
| New_ Fixed Price Auction | 10, 8, 3, 9, 1 | 85, 60, 60, 55, 40 | 300 |

LP) represents as standard linear programming problem. Archer (Archer et al., 2005) explained the combinatorial auction just like the virtual machine allocation problem in (Zaman and Grosu, 2013b), the bidder can request maximum one ($a_{ij}$ ε {0,1}) resource of each type Where as in (Shikui et al., 2014) user can request any number of resources ($a_{ij}$ ε {0,1,2,3,....}). Archer (Archer et al., 2005) reduced the number of resources to prohibit oversell of the products. In our case the total number of products is not reduced because we consider oversell is impossible. Winners are selected if the requested products are available. The payment calculation part of the algorithm (Zaman and Grosu, 2013a) is modified and as a result of that the price of the less demand product will be the fixed value. According to (Zaman and Grosu, 2013b) payment of each winner is the minimum value to win the bid. In the situation while demand is less than supplies, one buyer becomes the winner irrespective of her bid value. The buyer may become the winner even when the bid value is zero; then that user pays zero for using resources. Every seller asks at least fixed price for low demand products. For example, one seller has two types of products (r1, r2). Total numbers of available products are (2, 2). Four buyers submit their bids

$$bid = \begin{pmatrix} 2 & 3 & 60 \\ 1 & 3 & 70 \\ 3 & 2 & 90 \\ 2 & 0 & 80 \end{pmatrix}$$

In this situation only the requirements of $4^{th}$ user matche with the availability. Existing CA-LP calculates the payment value as the critical value to win and the payment value of user $u_4$ is 0.

The existing CA-LP mechanism provides the buyer with maximum value of utility function but the sellers may become looser. So in our algorithm an auctioneer calculates payment value as the minimum price to win the product but it should not be less than the fixed price of the product. The algorithm is given below

Algorithm 2. New_CA_LP.

$Step\,1 : Fixed\ prices\ of\ the\ products\ are\ (y_1, y_2, ..., y_m)$
$Step\,2 : Collect\ the\ bid\ from\ the\ users.$
$(a) Solve\ the\ following\ linear\ programming\ problem$
$Maximize\ \sum_{i=1}^{n} v_i * x_i$
$Subject\ to\ \sum_{i=1}^{n} a_{ij} * x_i <= r_j$
$for\ j = 1, 2, ..., m\ where\ x_i >= 0$
$and\ the\ value\ of\ x_i\ is\ the\ winning$
$probability\ of\ user\ u_i$
$Step\,3 : Winner Determination$
$(a) Initialize\ WIN = \phi$
$(b) For\ each\ user\ u_i\ taken\ in\ descending\ order\ of\ x_i$
$If\ A_i <= R$
$then\ WIN = WIN\ UNION\ \{i\}$
$and\ R = R - A_i$
$where\ A_i = (a_{i1}, a_{i2}, ..., a_{im})$
$and\ R_i = (r_1, r_2, ..., r_m)$
$[EndIf]$
$[Endfor]$
$Step\,4 : Payment\ Calculation$
$(a) For\ each\ user\ u_i \in WIN$
$Perform\ binary\ search\ for\ v_{i'}\ in\ [0, v_i]$
$where\ v_{i'}\ is\ the\ critical\ value\ to\ win$
$If\ v_{i'} >= \sum_{j=1}^{m} a_{ij} * y_j\ then$
$set\ p_i = v_{i'}$
$Else$
$set\ p_i = \sum_{j=1}^{m} a_{ij} * y_j$
$[EndIf]$
$[Endfor]$
$(b) Set\ p_i = 0\ for\ i\ does\ not\ belong\ to\ WIN$

Result:Existing CA-LP auction and our proposed New_CA_LP auction mechanisms have been executed on the above data set where minimum service charges for the resources are [3,3] and the result is given below(Table-4):

Table 4: Result of New_CA_LP.

| | Winner set | Payment set | Value of the utility function |
|---|---|---|---|
| CA-LP | 9, 10, 8, 1, 7, 2 | 35, 52, 0, 26, 15, 27 | 130 |
| New_CA_LP | 9, 10, 8,1,7,2 | 35, 52, 15, 26, 15, 27 | 120 |

## 4.3 CA-GREEDY-MODIFIED

The winner determination and payment mechanism of CA-GREEDY and CA-PROVISION in (Zaman and Grosu, 2013b)are extended in CA-GREEDY-MODIFIED. In strategy-proof auction each user would maximize her utility . CA-GREEDY and CA-PROVISION provide the seller with more benefit as their users utility is less in comparison to CA-LP. For maximizing the value of the utility function, we have changed the payment mechanism of greedy method. We use Vickery-Clark-Groves (VCG) mechanism for payment value calculation. The algorithm is given below.

Algorithm 3. CA-GREEDY-MODIFIED.

$Step\,1: Collect\, the\, bid\, from\, the\, users.$
$Step\,2: Winner\, determination$
$(a) WIN = \phi$
$[Find\, out\, approax\, valuation\, based\, on$
$the\, number\, items\, requested\, and\, weight$
$of\, the\, items]$
$(b) for\, i = 1\, to\, n$
$$S_i = \sum_{j=1}^{m} a_{ij} * W_j$$
$[End\, for]$
$(c) Reorder\, the\, users\, such\, that$
$v_1/s_1 >= v_2/s_2 >= \ldots >= v_n/s_n$
$(d) for\, i = 1\, to\, n$
$if\, A_i <= R$
$then\, WIN = WIN\, UNION\, \{i\}$
$and\, R = R - A_i$
$where\, A_i = (a_{i1}, a_{i2}, \ldots, a_{im})$
$and\, R = (r_1, r_2, \ldots, r_m)$
$[EndIf]$
$[End\, for]$
$Step\,3: Payment\, Calculation$
$(a) For\, each\, user\, i \in WIN$
$Perform\, binary\, search\, in\, 0\, to\, v_i,\, such$
$that\, we\, find\, a\, critical\, value\, v_{i'},$
$which\, is\, the\, least\, value\, to\, win.$
$$If\, v_{i'} >= \sum_{j=1}^{m} a_{ij} * W_j$$
$then\, set\, p_i = v_{i'}$
$Else$
$$set\, p_i = \sum_{j=1}^{m} a_{ij} * W_j$$
$[EndIf]$
$[End\, for]$
$(b) Set\, p_i = 0\, for\, i\, does\, not\, belong\, to\, WIN$

The CA-GREEDY-MODIFIED mechanism determines the winners in accordance with ranking the buyers in descending order of their unit price ($v_i/s_i$) (Lehmann et al., 2002) and then they are greedily selected as winners from the list. Before selecting the winner the mechanism verifies that the new combination of products does not exceed the number of available items of each type of products. The payment $p_i$ a winner $u_i$ pays is calculated as the minimum price to win the bid but it should not be less than the fixed price of the products i.e. the winners pays the critical value.

Result: We have implemented existing CA-GREEDY (Narahari and Dayama, 2007), CA-PROVISION(Zaman and Grosu, 2013a) auctions and our proposed CA-GREEDY-MODIFIED auction on the above data set where fixed price for the products is [3,3] and the result is given below:

Table 5: Result of CA-GREEDY-MODIFIED.

| | Winner set | Payment set | Value of the utility function |
|---|---|---|---|
| CA-GREEDY | 10, 9, 8, 1, 5 | 67, 54, 52, 39, 42 | 36 |
| CA-PROVISION | 10, 9, 1, 8, 7, 2 | 83, 53, 36, 50, 20, 0 | 48 |
| CA-GREEDY-MODIFIED | 10, 9, 1,8,7 | 51, 12, 9, 15, 6,9 | 188 |

## 5 RESULTS AND DISCUSSION

We have implemented all the combinatorial auction mechanisms in MATLAB environment. MATLAB environment is convenient for matrix operation and it exhibits the execution time of the entire program or portion of the program. Input data sets are randomly generated within a specified range for a given number of users. Once the data sets are generated, all the strategies are tested on the same data sets. Execution time, profit and the values of the utility functions of all the simulations are collected, to generate comparative graph for the specified algorithms. We compare the performance of existing Fixed Price auction with the New_Fixed Price auction, existing CA-GREEDY with CA-GREEDY-MODIFIED and also the performance of CA-GREEDY-MODIFIED with the performance of other combinatorial auction based mechanisms in respect of execution time and the value of the utility function.

Fixed price auction that is the most simple auction mechanism has already been used by many e-commerce web sites. In this case the users pay the actual value that she has submitted at the bidding time. So the value of the utility function is zero. We compare our New_FixedPrice auction mechanism with the existing fixed price auction in respect of execution time (Figure-1) and seller revenue(Figure-2). In comparison with the existing Fixed Price Auction, New Fixed price Auction mechanism provides the service provider with more profit. The execution time of New Fixed price Auction is higher than the existing one but it is better as it is a polynomial time problem.

The same types of winner determination and payment method have been used in New_CA_LP mech-

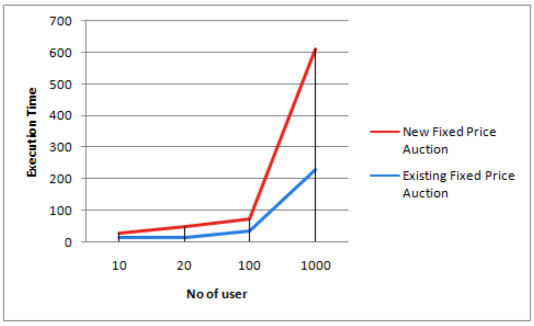


Figure 1: Execution time of New_FixedPrice Auction vs Existing Fixed Price Auction.


Figure 2: Seller Revenue of New_FixedPrice Auction and existing Fixed Price Auction.

anism as in the existing CA-LP. Only difference between New_CA_LP and existing CA-LP is that New_CA_LP charge fixed price for low demand products whereas CA-LP may charge very low price even if it may be zero. So we are not conferring any comparative results of New_CA_LP and CALP because of equal execution time and utility functions value.

Figure-(3) and Figure-(4) represent the value of the utility function and require time of CA-GREEDY, CA-PROVISION and CA-GREEDY-MODIFIED for different number of users and resources. Figure-(3) shows that our CA-GREEDY-MODIFIED takes maximum time to execute in comparing to other two auc-

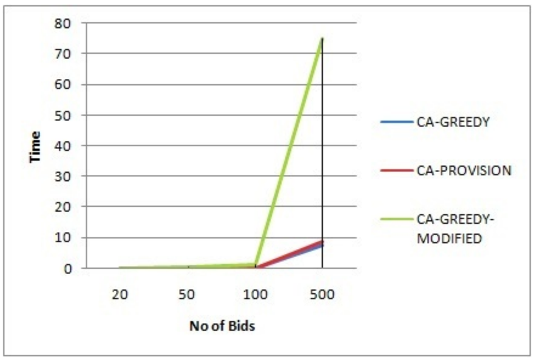


Figure 3: Execution time of CA-GREEDY-MODIFIED, CA-GREEDY and CA-PROVISION.

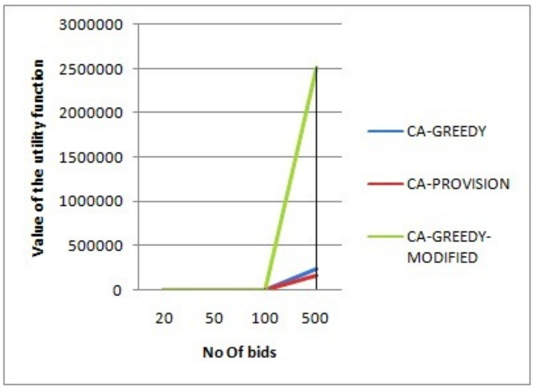


Figure 4: Utility function's value of CA-GREEDY-MODIFIED, CA-GREEDY and CA-PROVISION.

tion mechanisms but its utility functions value, another performance parameter is also very high in comparison with other two. For small input values three mechanisms perform the same approximately. But for large inputs the value of the utility function of CA-GREEDY-MODIFIED is 50 percent more than CA-GREEDY and CA-PROVISION mechanisms but its required 60 to 80 percent more execution time.

Figure-(5) and Figure-(6) shows the evaluation results of all the combinatorial auction mechanisms when there are different number of bids and different number of products. We can see that CA-GREEDY-MODIFIED always outperforms the other three auction mechanism. Figures-(5) and (6) demonstrates the value of the utility function and execution time of CA-LP, CA-GREEDY, CA-PROVISION and CA-GREEDY-MODIFIED mechanisms. It shows the value of the utility function of CA-LP is much better than CA-GREEDY and CA-PROVISION but more or less the same as CA-GREEDY-MODIFIED. But the execution time is too high comparable to other auction mechanisms. CA-LP auction mechanism takes more than one hour for 500 users bidding for 50 different items. CA-GREEDY-MODIFIED auction takes

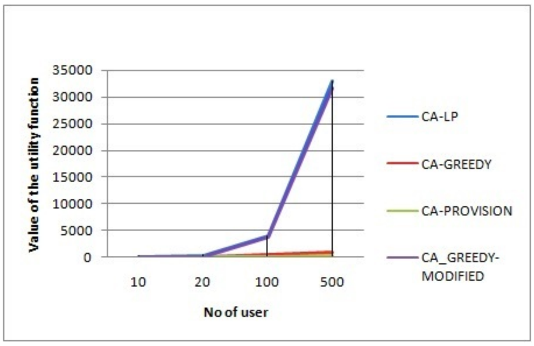


Figure 5: Utility function's value of CA-GREEDY-MODIFIED, CA-GREEDY and CA-PROVISION and CA-LP.

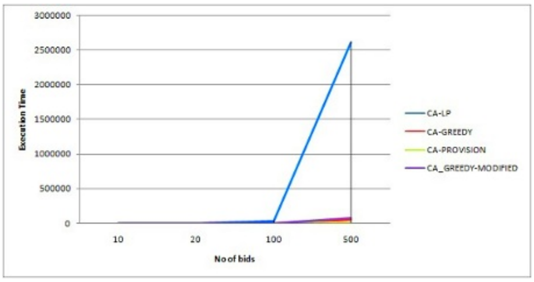


Figure 6: Execution time of CA-GREEDY-MODIFIED, CA-GREEDY and CA-PROVISION and CA-LP.

less time and utility functions value is also high. In CA-GREEDY-MODIFIED auction mechanism users pay minimum value to win the resources. So truth telling is the dominant strategy of the CA-GREEDY-MODIFIED auction.

## 6 CONCLUSION

The indispensability of combinatorial auction for selling a group of products has been look over for any e-commerce application. Extensive simulation experiments have been carried out to concluded that CA-GREEDY-MODIFIED is clearly a better choice for selling products or service over Internet. The value of the utility function of New_CA_LP is better than the other auction mechanisms. In CA-GREEDY approach execution time is less than the other truthful auction mechanisms but the utility function value is not so good as CA-LP. Moreover, CA-LP is solved by linear programming problem which is a NP complete problem. So execution time of CA-LP auction mechanism is infinite for large number of inputs. The utility value of the proposed CA-GREEDY-MODIFIED is better than CA-GREEDY and is closer to CA-LP and takes less time than New_CA_LP. So CA-GREEDY-MODIFIED is the best auction mechanism to sell multiple products via electronic devices. Further work includes the deployment of the proposed mechanisms on an experimental e-commerce testbed and tries to reduce execution time of CA-GREEDY-MODIFIED.

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