Decision Support Systems 48 (2010) 323–330

Contents lists available at ScienceDirect

Decision Support Systems

journal homepage: www.elsevier.com/locate/dss

Combinatorial reverse auction based on revelation of Lagrangian multipliers

Fu-Shiung Hsieh

Department of Computer Science and Information Engineering, Chaoyang University of Technology, Taiwan

ARTICLE INFO

Article history:
Received 8 January 2009
Received in revised form 3 August 2009
Accepted 30 August 2009
Available online 13 September 2009

Keywords:
Auction
e-Commerce
Integer programming
Optimization
Bid

ABSTRACT

Recently, researchers have proposed decision support tool for generating suggestions for bids in combinatorial reverse auction based on disclosure of bids. An interesting issue is to design an effective mechanism to guide the bidders to collectively minimize the overall cost without explicitly disclosing the bids. We consider a winner determination problem for combinatorial reverse auction and study how to support the bidders' decisions without explicitly disclosing the bids of others. We propose an information revelation scheme for a buyer to guide the sellers to generate potential winning bids to minimize the overall cost. The main results include: (1) a problem formulation for the combinatorial reverse auction problem; (2) a solution methodology based on Lagrangian relaxation; (3) a scheme to guide the sellers to generate potential winning bids for the bidders in multi-round combinatorial reverse auctions based on revelation of Lagrangian multipliers; (4) a heuristic algorithm for finding a near-optimal feasible solution and (5) results and analysis of our solution algorithms.

1. Introduction

Auctions are popular, distributed and autonomy preserving ways of allocating items or tasks among multiple agents to maximize revenue or minimize cost. In economics, different types of auctions have been proposed and extensively studied, including English Auction (open ascending price auction), Dutch auction (open descending price auction), sealed first-price auction, etc. Single item auctions are by far the most common auction format, but they are not always efficient. Combinatorial auctions [4,16,22,26] enable several bidders to bid on different combination of goods according to personal preferences. Allowing bids for bundles of items is the foundation of combinatorial auctions. Bidders can select multiple items at one time and offer those items a price. It enables bidders to decide combinations of auction according to personal preferences of bidders. Combinatorial auctions are beneficial if complementarities exist between the items to be auctioned. Well-known examples are the auctioning of Federal Communications Commission's radio spectrum licenses, the sales of airport time slots, and allocation of delivery routes. Applying combinatorial auctions in corporations' procurement processes can lead to significant savings [17,18]. Reverse auction is a business auction model that can be applied to corporations' procurement. Combinatorial reverse auction enables buyers to simultaneously purchase multiple goods with the lowest prices from the sellers.

Combinatorial auctions have attracted considerable attention in the existing literature. An excellent survey on combinatorial auctions can be found in [3,19]. Combinatorial auctions have been notoriously difficult to solve from a computational point of view [21] due to the exponential growth of the number of combinations [25]. The combinatorial auction problem can be modeled as a set packing problems (SPP) [2,5,10,24] Sandholm et al. mentioned that determining the winners so as to maximize revenue in combinatorial auction is NP-complete [22,23]. Many algorithms have been developed for combinatorial auction problems. Exact algorithms have been developed for the SPP problem, including iterative deepening A* search [23] and the direct application of available CPLEX IP solver [2]. Gonen and Lehmann proposed branch and bound heuristics for finding optimal solutions for multi-unit combinatorial auctions [7]. Jones and Koehler studied combinatorial auctions using rule-based bids [13]. In [8]; [11,12] the authors proposed a Lagrangian heuristic and a Lagrangian relaxation approach for combinatorial reverse auction problems, respectively. Although combinatorial reverse auctions have been extensively studied, most studies focus on the development of efficient solution algorithms to determine winners. From the viewpoint of a bidder, how to find a potential winning bid that maximizes the profit is a key issue. In practice, each seller has no idea about the bids placed by other sellers at the beginning of a combinatorial reverse auction. Therefore, each seller is "blind" in creating his bids. The bid placed by a seller is usually a profit maximizing bid that does not take into account the bids placed by other sellers. However, a profit maximizing bid may not be a winning bid. An interesting question is to design an information revelation mechanism to assist a seller to find profit maximizing winning bids while minimizing the cost of the buyer.

Recently, decision support in auctions and combinatorial auctions has received significant attention. Adomavicius and Gupta presented

E-mail address: fshsieh@cyut.edu.tw.

0167-9236/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.dss.2009.08.009

several metrics that bidders can use to evaluate the current auction situation and the potential of each bid being among the winners [1]. The weakness of solving the winner determination problem (WDP) of combinatorial auctions in one shot is the black box nature of integer programming. Another stream of literature in combinatorial auctions is on ascending auctions, in which bidders, instead of bidding one price for the bundles, engage in multiple rounds of auctions of different bundles. Adomavicius and Gupta [1], among other proponents of the approach, argued that one advantage over the seal-bid one-shot format is that bidders can get pricing feedback from the process. Our approach may open up the black box slightly to the bidders by offering the values of Lagrangian multipliers to them.

Kwasnica et al. provided the bidders with a vector of prices (one for each commodity) that new bids must beat in order to be accepted [14]. Gallien and Wein presented a system and the underlying theory for an optimization-based multi-item auction mechanism that relies on the solution of a linear program for minimizing the buyer's cost under the suppliers' known capacity constraints [6]. They assist suppliers in finding a winning bid price. The underlying assumption is that the suppliers are willing to disclose their cost functions to a supposedly neutral third party auction organizer. Hohner et al. provided feedback to nonwinning bidders regarding clearing prices, at which supply for each item equals demand [9]. Leskelä et al. [15] proposed a decision support tool for generating suggestions for bids that would be among the current winners of the auction. Their results indicate that the quantity support tool is useful as it decreases the total cost to the buyer and improves the efficiency of the auction. The support tool of Leskelä et al. requires the information of the bids placed by other bidders. To apply the support tool of Leskelä et al. requires disclosing the bids of other bidders. An interesting question is how to develop an effective method to support bidders' decision without disclosing the bids while minimizing buyer's total cost. The goal of this paper is to design an effective mechanism to guide the bidders to collectively minimize the overall cost in combinatorial reverse auction. We consider a winner determination problem for combinatorial reverse auction in which a buyer wants to acquire items from a set of sellers and each seller can provide a set of items. We propose an information revelation scheme for a buyer to guide the bidders to generate potential winning bids to minimize the overall cost without disclosing the bids to all the bidders.

One way to reduce the computational complexity in solving the winner determination problem (WDP) for combinatorial reverse auction is to set up a fictitious market to determine an allocation and prices in a decentralized way to adapt to dynamic environments where bidders and items may change from time to time. In this paper, we apply Lagrangian relaxation technique to develop a solution algorithm for WDP. We propose a multi-round combinatorial reverse auction algorithm to efficiently find a solution based on revelation of Lagrangian multipliers for each type of item at the end of each round. In our multi-round combinatorial reverse auction algorithm, Lagrangian relaxation is applied to obtain a solution at the end of each round. To take advantage of Lagrangian multipliers to efficiently guide the bidders in the bidding processes, the Lagrangian multipliers are revealed to all the bidders. We propose a combinatorial reverse auction information revelation scheme based on Lagrangian multipliers. A seller may generate a new bid according to the most recently revealed Lagrangian multipliers.

Lagrangian relaxation provides a systematic approach to determine an allocation and prices based on the introduction of Lagrangian multipliers, which set prices for each item to be purchased by the buyer. If two or more sellers compete for the same item, the price will be adjusted. This saves bidders from specifying their bids for every possible combination and the buyer from having to process each bid function. Based on the price for the individual items, bidders submit bids. The bundle associated with a bid is tentatively assigned to that bidder only if the price of the bid is the lowest. Based on the iterative price adjustment mechanism, a solution will be obtained. It should be emphasized that Lagrangian relaxation is not guaranteed to find the optimal solution to the underlying problem. Furthermore, it is not guaranteed to produce a feasible solution by applying Lagrangian relaxation technique. In case the resulting solution is not feasible, a heuristic algorithm must be applied to adjust the infeasible solution to a feasible one. We develop a heuristic algorithm for finding a near-optimal, feasible solution based on the solution of the relaxed problem. We also demonstrate the advantage of multi-round combinatorial reverse auction algorithm (with revelation of Lagrangian multipliers) by comparing it with the single-round combinatorial reverse auction algorithm (without information revelation). Our results indicate that significant improvement in costs can be achieved by applying our method at the price of more but acceptable CPU time.

In summary, the main results presented in this paper include: (1) a problem formulation for the combinatorial reverse auction problem; (2) a solution methodology based on Lagrangian relaxation; (3) a price information revelation scheme to facilitate auction based on an economic interpretation of Lagrangian multipliers and (4) results and analysis of our solution algorithms.

The remainder of this paper is organized as follows. In Section 2, we present the problem formulation. In Section 3, we propose the solution algorithms for the dual problem and give an economic interpretation for our solution approach. In Section 4, we propose a combinatorial reverse auction information revelation scheme based on Lagrangian multipliers. In Section 5, we concentrate on the heuristic algorithm for finding a feasible solution. Finally, we demonstrate the effectiveness of the proposed algorithms by analyzing the results of many numerical examples. We conclude this paper in Section 7.

2. Combinatorial reverse auction problem formulation

In this paper, we first formulate the combinatorial reverse auction problem as an integer programming problem. We then develop solution algorithms based on Lagrangian relaxation. Fig. 1 illustrates an application scenario in which Buyer requests to purchase at least a bundle of items 2A, 3B, 2C and 1D from the market. There are three bidders, Seller 1, Seller 2 and Seller 3 who place bids in the system. Suppose Seller 1 places two bids: (1A, 2B, p11) and (1C, 1D, p12), where p11 and p12 denote the prices of the bids. Seller 2 places two

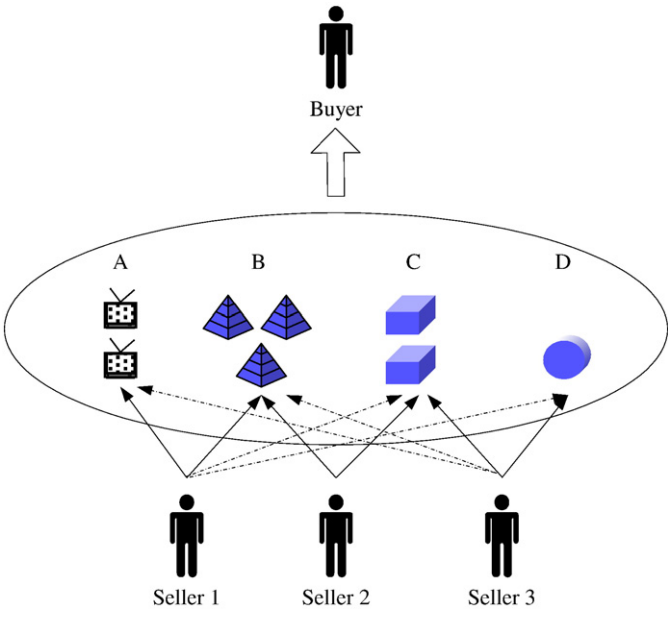

Fig. 1. Combinatorial reverse auction.