Expert Systems with Applications 42 (2015) 8014–8026

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Regulation of the buyers' distribution in management systems based on simultaneous auctions and intelligent agents

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ARTICLE INFO

Article history:
Available online 2 July 2015

Keywords:
Simultaneous auctions
Intelligent systems
Distributed management
Software agents
Electronic markets

ABSTRACT

In solutions based on simultaneous auctions, participants are enabled to conduct and clear their own auctions, so that many auctions can be running at the same time. This configuration is increasingly being proposed for the installation of distributed management systems based on economic criteria in contexts such as the Smart Grid, computational grids and the cloud. In particular, these solutions are commonly complemented by the presence of software agents which automate the users' participation in an intelligent manner. This work focuses on the effect that the distribution of the bidders' participation actually has on the effectiveness of parallel auctions as management system. Firstly, the problem is introduced, showing that, in practice, bidders have incentives to prefer some auctions over others, thus tending to concentrate their participation in a limited subset of auctions. Also, as part of the theoretical formulation, with the aim of preserving the essence of markets and keeping competition active, it establishes a set of players' essential rights that any solution to the problem should preserve. The text then continues with the design and implementation of a regulatory mechanism that uniformly distributes buyers' participation among the available auctions. Realistic experiments are provided in order to demonstrate both the negative effects that buyers' concentration actually causes, and the effectiveness of the new regulatory mechanism, which manages to strengthen parallel auctions as a distributed management system. Likewise, it is proven that the solution is scalable, reactive and suitable for large distributed environments.

1. Introduction

The study and implementation of applications based on electronic auctions is increasingly common in the industrial and technological fields, for which they are proposed as an effective management mechanism whose principal strengths are the use of economic criteria and the active participation of the interested parties in the solution. When auctions are used as management system, factors such as the size of the context and the acceptance of combinatorial bids may make a centralized approach unfeasible, as this easily results in a NP-complete problem (Sandholm, 2002). In these cases, simultaneous auctions (or *parallel auctions*) arise as an appealing mechanism that simplifies the complexity of the problem and offers participants a high level of autonomy. Specifically, simultaneous auctions is the configuration by which each player can hold and clear its own auction, so that many auctions can be running at the same time. When using parallel auctions the role of central auctioneer, who is traditionally in charge of evaluating all offers and determining the solution, is replaced by the action of all the participants, who acting as bidders and sellers shape a completely distributed management system. In many settings parallel auctions are easier to solve because the clearing algorithm only have to determine the winning bids for the corresponding auctioneer.

The emergence of new technologies allows the implementation of distributed management solutions based on simultaneous auctions in application contexts common to artificial intelligence and expert systems in which users increasingly demand more participation, such as grid computing (Buyya, Abramson, & Venugopal, 2005), cloud computing (Buyya, Yeo, Venugopal, Broberg, & Brandic, 2009), power networks (Penya & Jennings, 2005), e-commerce sites (Fasli, 2007), networking (Preist, Bartolini, & Byde, 2003; Haque, Jennings, & Moreau, 2004), and transportation logistics (Robu, Noot, PoutrT, & van Schijndel, 2011; Satunin & Babkin, 2014). All of these are in a position to enjoy solutions based on large and highly participatory markets. In particular, when it comes to auctions, users are commonly represented by

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http://dx.doi.org/10.1016/j.eswa.2015.06.019
0957-4174/

autonomous software agents which represent their preferences and particular goals by using decision-making methods and machine learning techniques.

However, building management systems on parallel auctions introduces new risks. In particular, if the volume of negotiations is not high enough, the system may fail in its purpose, or cause significant losses. In this regard, a fact that affects to the performance of parallel auctions is that objective and particular factors can actually lead the bidders to prefer some auctions over others, with the result that the overall participation may end up concentrated in a limited subset of auctions. In practice, this condition means that most of the sellers and buyers fail to seal deals. Because of this, a mechanism that regulates the distribution of buyers among the available auctions, thus ensuring a minimal level of activity, could be needed to achieve effective management systems. However, the introduction of such a distribution control mechanism poses new challenges, among which are: respecting the distributed nature of parallel auctions, managing thousands of agents simultaneously, and preserving the essence of markets so that the motivation for bidding remains. To this end, this article is devoted to the design, implementation and evaluation of a novel control mechanism that uniformly distributes buyers' participation in parallel auctions markets. Specifically, this work serves to:

- Explain how, in practice, objective and particular factors motivate buyers to prefer some auctions over others, and how this behavior can affect to the overall performance of parallel auctions as a management system.
- Define the set of rules which would insure that the introduction of any mechanism intended to redistribute buyers' participation would maintain the players' motivation.
- Design and implement a scalable, reactive and non-blocking control mechanism that uniformly distributes buyers across the whole spectrum of available auctions. Furthermore, the mechanism is designed to deal with usual characteristics of auctions, such as the presence of starting prices and bids expressed in form of linear piece-wise functions.
- Evaluate through realistic experiments both the effect that the agglomeration of buyers actually has on the performance of management systems based on parallel auctions, and the effectiveness of the proposed control method to counteract it.

The remainder of this article is organized as follows. Section 2 defines the type of auction and context at which the proposal is targeted. Section 3 describes the factors that may lead to an over-concentration of buyers. Section 4 designs the architecture of the proposed solution, and defines the features required for the implementation and essential rights of the players to be maintained. Section 5 details the algorithms used to implement the solution. Section 6 shows the outcome of experimental tests and explains factors that affect the performance. Section 7 discusses important features of the solution and describes its main advantages and limitations. Section 8 is the conclusion.

2. An overview of auctions

Auctions (Krishna, 2009) are a powerful market mechanism for allocating resources so that users can express their interests and preferences. The solution therefore is not guided by the pursuit of efficiency, but finding equilibrium taking into account the valuation of the resources by users. In the simplest case, a seller offers a product to a set of buyers who make bids according to both their private valuation of the product and a bidding strategy.

In determining the winner, the following three dimensions are commonly used to characterize auctions: (a) the method for determining the final price of the product, which is usually set as *first-price* or *second-price*; (b) the visibility of other players' bids, which can be *open-cry* or *sealed*; and (c) the sense in which the price varies, which can be in ascending or descending order.

- In a first-price auction, the resource is allocated according to the price of the winner bid; while in a second-price auction, the resource is paid at the price corresponding to the second-winner bid.
- In an open-cry auction, all agents can see what all other agents are bidding; while in a sealed auction, bids are private.
- In an ascending auction, the price rises every time a buyer outbids the standing bid (the current winning bid); while in a descending auction, the price is decreased continuously by the auctioneer until a bidder accepts it.

Another common parameter of auctions is the so-called *starting price*, which represents the minimum price at which the auctioneer is willing to sell the product. So, when a starting price is defined, bidders are not allowed to place bids lower than it. Auctioneers can also define a *reserve price*, which represents the minimum price that the winner must bid; if this price is not placed, the seller is free to not allocate the resource. The reserve price is commonly kept secret by the auctioneer.

The following four formats are the most common ways to carry out auctions (Sandholm, 1999):

- *English auction*: This is a first-price, open-cry, ascending auction. The dominant strategy is to bid the current price plus some small amount. Under this format, auctioneer usually sets a reserve price. The English auction is perhaps the most common form, having long been used in art auction houses.
- *Dutch auction*: This is an open-cry descending auction in which the auctioneer continuously lowers the price until a buyer (traditionally through a gesture, verbal signal, and nowadays via electronic communication) agrees to buy at the announced price. Dutch auction is used in flowers markets, and its most outstanding characteristic is that it can be concluded quickly because: (i) only one bid can be placed; and (ii) the auctioneer controls the rate at which the price is decreased.
- *First-price sealed-bid*: In this format each buyer places a bid that is secret from the other participants. The winner is the buyer who places the higher bid. The product is purchased at this price. This type of auction encourages participants to spy on each other, which makes it very inefficient.
- *Second-price sealed-bid*: This is also known as *Vickrey* (Vickrey, 1961). Bids are secret. The buyer with the highest bid wins the auction but the price he/she pays is the price of the second highest bid. The Vickrey auction is well known because the best strategy for buyers is to bid according to their valuation of the product, which leads to a more efficient system.

A more advanced approach is the so called *double auction* (Friedman & Rust, 1993), which is also known as *two-sided* auction. In this case, sellers and buyers submit their corresponding asks and bids to a central auctioneer, who is in charge of processing them and determining the price that clears the market. Double auctions are widely used in stock markets and have also shown to be a valid mechanism for allocating scarce resources in industrial and technological processes. However, several factors may make the clearing process hard to manage. Its complexity especially increases when: (a) multiple units of the product can be asked and bidden;