Robust Combinatorial Auction Protocol against False-name Bids

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Abstract

This paper presents a new combinatorial auction protocol (LDS protocol) that is robust against false-name bids. Internet auctions have become an integral part of Electronic Commerce (EC) and a promising field for applying agent and Artificial Intelligence technologies. Although the Internet provides an excellent infrastructure for combinatorial auctions, we must consider the possibility of a new type of cheating, i.e., an agent tries to profit from submitting several bids under fictitious names (false-name bids). If there exists no false-name bid, the generalized Vickrey auction (GVA) satisfies individual rationality, Pareto efficiency, and incentive compatibility. On the other hand, when false-name bids are possible, it is theoretically impossible for a combinatorial auction protocol to simultaneously satisfy these three properties.

The Leveled Division Set (LDS) protocol, which is a modification of the GVA, utilizes reservation prices of auctioned goods for making decisions on whether to sell goods in a bundle or separately. The LDS protocol satisfies individual rationality and incentive compatibility, although it is not guaranteed to achieve a Pareto efficient social surplus. Simulation results show that the LDS protocol can achieve a better social surplus than that for a protocol that always sells goods in a bundle.

Introduction

Internet auctions have become an especially popular part of Electronic Commerce (EC). Various theoretical and practical studies on Internet auctions have already been conducted (Monderer & Tennenholtz 1998; Wurman, Wellman, & Walsh 1998; Sandholm 1996). The Internet provides an excellent infrastructure for executing much cheaper auctions with many more sellers and buyers from all over the world. However, we must consider the possibility of new types of cheating. For example, an agent may try to profit from submitting false bids made under fictitious names. Such a dishonest action is very difficult to detect since identifying each participant on the Internet is virtually impossible. We call a bid under a fictitious name a *false-name bid*. The problems resulting from collusion have been discussed by many researchers (Rasmusen 1994; Varian 1995; Sandholm 1996). Compared with collusion, a false-name bid is easier to execute since it can be done alone, while a bidder has to seek out and persuade other bidders to join in collusion.

In (Sakurai, Yokoo, & Matsubara 1999; Yokoo, Sakurai, & Matsubara 2000), the effects of false-name bids on auction protocols were analyzed. The obtained results can be summarized as follows.

- The generalized Vickrey auction protocol (GVA) (Varian 1995), which has been proven to satisfy individual rationality, Pareto efficiency, and incentive compatibility if there exists no false-name bid, fails to satisfy incentive compatibility when false-name bids are possible.
- There exists no combinatorial auction protocol that simultaneously satisfies incentive compatibility, Pareto efficiency, and individual rationality for all cases if agents can submit false-name bids.
- The revelation principle (Mas-Colell, Whinston, & Green 1995) still holds even if the agents can submit false-name bids.

In this paper, we concentrate on private value auctions (Mas-Colell, Whinston, & Green 1995). In private value auctions, each agent knows its own preference, and its evaluation value of goods is independent of the other agents' valuations. We define an agent's utility as the difference between the true evaluation value of the allocated goods and the payment for the allocated goods. Such a utility is called a *quasi-linear* utility (Mas-Colell, Whinston, & Green 1995). These assumptions are commonly used for making theoretical analyses tractable.

An auction protocol is incentive compatible, if bidding the true private values of goods is the dominant strategy, i.e., the best way to maximize the utility for each agent. The revelation principle states that in the design of an auction protocol we can restrict our attention only to incentive compatible protocols without losing generality (Mas-Colell, Whinston, & Green 1995). In other words, if a certain property (e.g., Pareto efficiency, individual rationality) can be satisfied using some auction protocol, the property can also be satisfied using an incentive compatible auction protocol. We say that auction protocols are robust against false-name bids if each agent cannot obtain additional profit by submitting false-name bids. If such robustness is not satisfied, the auction protocol lacks incentive compatibility.

A Pareto efficient allocation means that the goods are allocated to bidders whose evaluation values are the highest, and that the sum of all participants' utilities (including that of the seller), i.e., the social surplus, is maximized[1].

An auction protocol is individually rational if each participant does not suffer any loss, in other words, the participant's payment never exceeds its evaluation value of the obtained goods. In a private value auction, individual rationality is indispensable: no agent wants to participate in an auction where it might be charged more money than it is willing to pay.

Since these three properties cannot be satisfied simultaneously when agents can submit false-name bids, we must give up Pareto efficiency and consider an auction protocol that satisfies incentive compatibility and individual rationality, and that can achieve a relatively good social surplus.

In the rest of the paper, we first describe the GVA and show an example where the GVA is not robust against false-name bids. Then, we describe our newly developed protocol, called *Leveled Division Set (LDS) protocol*, and provide the proof that the LDS protocol satisfies incentive compatibility. Furthermore, we show simulation results that demonstrate that this protocol can achieve a better social surplus than a protocol that always sells goods in a bundle. Finally, we discuss the merits/demerits of the LDS protocol.

Generalized Vickrey Auction Protocol (GVA)

An overview of the GVA is as follows. Let G denote one possible allocation of goods.

1. Each agent declares evaluation values for possible allocations[2]. Let $v_x(G)$ denote agent x's declared evaluation value for the allocation G.
2. The GVA chooses the optimal allocation G^* that maximizes the sum of all the agents' declared evaluation values.
3. The payment of agent x (represented as p_x) is calculated as follows:

$$p_x = \sum_{y \neq x} v_y(G^*_{\sim x}) - \sum_{y \neq x} v_y(G^*).$$

Here, $G^*_{\sim x}$ is the allocation that maximizes the sum of all agents' evaluation values except agent x. In the GVA, agent x pays the decreased amount of social surplus of the other agents caused by its participation. The GVA has been proven to be incentive compatible if there exists no false-name bid (Varian 1995; Mas-Colell, Whinston, & Green 1995).

Next, we show an example where the GVA is not robust against false-name bids.

Example 1 *Let us assume two agents are participating in an auction of two different goods, A and B, and declare the following evaluation values. The evaluation values of an agent are denoted by a tuple: (the value for A alone, the value for B alone, and the value for A and B together).*

- *agent 1: (6, 6, 12)*
- *agent 2: (0, 0, 8)*

The evaluation values of agent 2 are all-or-nothing, i.e., having only one good is useless. In this case, both goods are allocated to agent 1. Its payment is calculated as 8, since if agent 1 does not participate, agent 2 obtains both goods and the social surplus is 8; when agent 1 does participate, agent 1 obtains all goods and the social surplus except for agent 1 is 0. The obtained utility of agent 1 is $12 - 8 = 4$.

Now, let us assume that agent 1 submits a false-name bid using the identifier of agent 3.

- *agent 1: (6, 0, 6)*
- *agent 2: (0, 0, 8)*
- *agent 3: (0, 6, 6)*

In this case, A is allocated to agent 1 and B is allocated to agent 3. The payment of agent 1 (or agent 3) is calculated as $8 - 6 = 2$, *since when agent 1 does participate, agent 3 obtains B and the social surplus except for agent 1 is 6. In reality, agent 1 obtains both goods by paying 4. Therefore, its utility is* $12 - 4 = 8$, *which means that agent 1 can make a profit by submitting a false-name bid.*

Robust Protocol against False-name Bids

Basic Ideas

A trivial protocol can satisfy incentive compatibility even if agents can submit false-name bids, i.e., selling all goods in a bundle and use the second-price (Vickrey) auction protocol (Rasmusen 1994) to determine the winner and its payment. We call this simple protocol the *set protocol*. Selling goods in a bundle makes sense if goods are complementary for all agents, that is, the utility of a set of goods is larger than the sum of the utilities of having each good separately. However, if goods are substitutional for some agents, the set protocol is wasteful; the social surplus and the revenue of the seller can be significantly worse than that for the GVA

Let us consider a simple case where there are two goods A and B. To increase the social surplus, we must design a protocol where goods can be sold separately in some cases. To guarantee that the protocol is robust against false-name bids, the following condition must be satisfied.

Proposition 1 *If A and B are sold separately to different agents, the sum of the payments must be larger than the highest declared evaluation value for the set of A and B.*

If this condition is not satisfied, there is a chance that a single agent uses two false-names to obtain these goods. However, designing an incentive compatible protocol satisfying this condition is very difficult because we usually need to utilize the second highest evaluation values of goods to calculate the payment, and manipulating the second highest evaluation values is rather easy if an agent can submit false-name bids. We must solve the difficult dilemma of satisfying the above condition on payments without using the second highest evaluation values, which are essential to calculating the payments.

[1] In a more general setting, Pareto efficiency does not necessarily mean maximizing the social surplus. In an auction setting, however, agents can transfer money among themselves; thus the sum of the utilities is always maximized in a Pareto efficient allocation.

[2] The reported evaluation values may or may not be true.

	case 1	case 2	case 3
level 1	[{(A,B)}]	[{(A,B,C)}]	[{(A,B,C,D)}]
level 2	[{(A),(B)}]	[{(A,B)}, {(B,C)}, {(A,C)}]	[{(A,B,C)}, {(B,C,D)}, {(A,D)}]
level 3		[{(A),(B),(C)}]	[{(A),(D),(B,C)}]

Figure 1: Example of Leveled Division Sets

Our newly developed protocol solves this dilemma by utilizing *reservation prices* of goods (Rasmusen 1994). The seller does not sell a good if the payment of the good is smaller than the reservation price. Let us assume the reservation prices of A and B are r_A and r_B, respectively. If we sell goods separately only when the highest declared evaluation value for the set is smaller than $r_A + r_B$, we can satisfy the condition of Proposition 1. In the following, we are going to show how this idea can be introduced to the GVA.

Leveled Division Set Protocol

In the following, we are going to define several terms and notations. To help readability, we use three different types of parentheses to represent sets: (), {}, and [].

- a set of agents $N = \{1, 2, \ldots, n\}$
- a set of all auctioned goods $M = (1, 2, \ldots, m)$
- a division of goods $D = \{S \subseteq M \mid S \cap S' = \emptyset \text{ for every } S, S' \in D\}$[3]
- For each good j, the reservation price r_j is defined.
- For a set of goods S, we define $R(S)$ as $\sum_{j \in S} r_j$.

A *leveled division set* is defined as follows:

- Levels are defined as $1, 2, \ldots, max\_level$.
- For each level i, a division set $SD_i = [D_{i1}, D_{i2}, \ldots]$ is defined.

A leveled division set must satisfy the following three conditions.

- $SD_1 = [\{M\}]$ — the division set of level 1 contains only one division, which consists of a set of all goods.
- For each level and its division set, a union of multiple sets of goods in a division is always included in a division of a smaller level, i.e., $\forall i \geq 2, \forall D_{ik} \in SD_i, \forall D' \subseteq D_{ik}$, where $|D'| \geq 2, S_u = \bigcup_{S \in D'} S$, then there exists a level $j < i$, with a division set SD_j, where $D_{jl} \in SD_j$ and $S_u \in D_{jl}$.
- For each level and its division set, each set of goods in a division is not included in a division of a different level, i.e., $\forall i, \forall D_{ik} \in SD_i, \forall S \in D_{ik}, \forall j \neq i, \forall D_{jl} \in SD_j, S \notin D_{jl}$.

Figure 1 shows examples of leveled division sets. Case 1 shows one instance where there are two goods (A and B), and case 2 and case 3 show instances where there are three and four goods, respectively.

[3] Note that we don't require that $\bigcup_{S \in D} S = M$ holds, i.e., satisfying $\bigcup_{S \in D} S \subseteq M$ is sufficient.

For a division $D = \{S_1, S_2, \ldots\}$ and one possible allocation of goods G, we say G is allowed under D if G allocates each set of goods in D to different agents. Also, we allow that some set of goods is not allocated to any agent. In that case, we assume that the set of goods is allocated to a dummy agent d, whose evaluation value for each good j is equal to the reservation price r_j. For each level i and its division set $SD_i = [D_{i1}, D_{i2}, \ldots]$, we represent a union of all allowed allocations for each element of SD_i as SG_i.

To execute the leveled division set protocol (LDS protocol), the auctioneer must pre-define the leveled division set and the reservation prices of goods. Each agent x declares its evaluation value $B(x, S)$ for each subset of goods S, which may or may not be true. The declared evaluation value of agent x for an allocation G (represented as $v_x(G)$) is defined as $B(x, S)$ if S is allocated to agent x in G, otherwise $v_x(G) = 0$. Also, we define the evaluation value of a dummy agent d for an allocation G as the sum of the reservation prices of goods that are not allocated to real agents in G. The winners and payments are determined by calling the procedure LDS(1), which is defined as follows.

Procedure LDS(i)

Step 1: If there exists only one agent $x \in N$ whose evaluation values satisfy the following condition: $\exists D_{ik} \in SD_i, \exists S_x \in D_{ik}$, where $B(x, S_x) \geq R(S_x)$, then compare the results obtained by the procedure GVA(i) and LDS$(i+1)$, and choose the one[4] that gives the larger utility for agent x. In this case, we say agent x is a *pivotal* agent. When choosing the result of LDS$(i+1)$, we don't assign any good, nor transfer money, to agents other than x, although the assigned goods for agent x and its payment are calculated as if goods were allocated to the other agents.

Step 2: If there exist at least two agents $x_1, x_2 \in N, x_1 \neq x_2$ whose evaluation values satisfy the following condition: $\exists D_{ik} \in SD_i, \exists D_{il} \in SD_i, \exists S_{x_1} \in D_{ik}, \exists S_{x_2} \in D_{il}$, where $B(x_1, S_{x_1}) \geq R(S_{x_1})$, $B(x_2, S_{x_2}) \geq R(S_{x_2})$, then apply the procedure GVA(i).

Step 3: Otherwise: call LDS$(i+1)$, or terminate if $i = max\_level$.

Procedure GVA(i)**:** Choose an allocation $G^* \in SG_i$ such that it maximizes $\sum_{y \in N \cup \{d\}} v_y(G)$. The payment of agent x (represented as p_x) is calculated as $\sum_{y \neq x} v_y(G^*_{\sim x}) - \sum_{y \neq x} v_y(G^*)$, where $G^*_{\sim x} \in SG_i$ is the allocation that maximizes the sum of all agents' (in-

[4] If the condition of Step 1 is also satisfied for LDS$(i+1)$, then compare with the results of GVA$(i+1)$ and LDS$(i+2)$ also, and so on.

cluding the dummy agent d) evaluation values except that of agent x.

Note that the procedures in GVA(i) are equivalent to those in the GVA, except that the possible allocations are restricted to SG_i. We say that the *applied level* of the LDS protocol is i if the result of GVA(i) is used.

Examples of Protocol Application

Example 2 *Let us assume there are two goods A and B, the reservation price of each good is 50, the leveled division set is defined as case 1 in Figure 1, and the evaluation values of agents are defined as follows.*

	A	B	AB
agent 1	80	0	110
agent 2	0	80	105
agent 3	60	0	60

Since there exist two agents whose evaluation values for the set are larger than the sum of the reservation prices (i.e., 100), the condition in Step 2 of LDS(1) is satisfied; agent 1 obtains both goods by paying 105. Note that this allocation is not Pareto efficient. In the Pareto efficient allocation, agent 1 obtains A and agent 2 obtains B.

Example 3 *The problem setting is basically equivalent to Example 2, but the evaluation values are defined as follows.*

	A	B	AB
agent 1	80	0	80
agent 2	0	80	80
agent 3	60	0	60

There exists no agent whose evaluation value of the set is larger than 100. In this case, the condition in Step 3 of LDS(1) is satisfied, and then the condition in Step 2 of LDS(2) is satisfied. As a result, agent 1 obtains A and agent 2 obtains B. Agent 1 pays 60, and agent 2 pays the reservation price 50.

Example 4 *The problem setting is basically equivalent to Example 2, but the evaluation values are defined as follows.*

	A	B	AB
agent 1	80	0	110
agent 2	0	80	80
agent 3	60	0	60

There exists only one agent whose evaluation value of the set is larger than 100. The condition in Step 1 of LDS(1) is satisfied; agent 1 is the pivotal agent. Agent 1 prefers obtaining only A (with the payment 60) to obtaining both A and B (with the payment 100). Therefore, agent 1 obtains A and pays 60.

Note that in Example 4, B is not allocated to any agent. This might seem wasteful, but it is necessary to guarantee incentive compatibility. In Example 2, if agent 2 declares its evaluation value for the set as 80, the situation becomes identical to Example 4. If we allocate the remaining good B to agent 2, under-bidding becomes profitable for agent 2.

Example 5 *There are three goods A, B, and C. The reservation price for each is 50, and the leveled division set is defined as case 2 in Figure 1. The evaluation values of agents are defined as follows.*

	A	B	C	AB	BC	AC	ABC
agent 1	60	30	30	90	60	90	120
agent 2	30	60	30	90	90	60	120
agent 3	30	30	60	60	90	90	120

The condition in Step 2 of LDS(3) is satisfied. Agents 1, 2, 3 obtain A, B, C, respectively, and each pays the reservation price 50.

Proof of Incentive Compatibility

It is obvious that the LDS protocol satisfies individual rationality. Here, we prove that it also satisfies incentive compatibility.

Theorem 1 *The LDS protocol satisfies incentive compatibility even if agents can submit false-name bids.*

To prove Theorem 1, we use the following lemmas.

Lemma 1 *In the LDS protocol, the payment of agent x who obtains a set of goods S is larger than (or equal to) the sum of the reservation prices $R(S)$.*

The proof is as follows. Let us assume that the applied level is i. The payment of agent x (represented as p_x) is defined as follows: $p_x = \sum_{y \neq x} v_y(G^*_{\sim x}) - \sum_{y \neq x} v_y(G^*)$. The set of allocations SG_i considered at level i contains an allocation G', where G' is basically the same as G^* except that all goods in S are allocated to the dummy agent d rather than x. The following formula holds.

$$\sum_{y \neq x} v_y(G') = \sum_{y \neq x} v_y(G^*) + R(S)$$

Since $G^*_{\sim x}$ is the allocation that maximizes the sum of all agents' evaluation values (including the dummy agent) except x in SG_i, $\sum_{y \neq x} v_y(G') \leq \sum_{y \neq x} v_y(G^*_{\sim x})$ holds. Thus, the following formula holds.

$$\begin{aligned} p_x &= \sum_{y \neq x} v_y(G^*_{\sim x}) - \sum_{y \neq x} v_y(G^*) \\ &\geq \sum_{y \neq x} v_y(G') - \sum_{y \neq x} v_y(G^*) = R(S) \end{aligned}$$

Lemma 2 *In the LDS protocol, an agent cannot increase its utility by submitting false-name bids.*

The proof is as follows. Let us assume that agent x uses two false names x' and x'' to obtain two sets of goods $S_{x'}$ and $S_{x''}$, respectively. Also, let us assume that the applied level is i. From Lemma 1, the payments $p_{x'}$ and $p_{x''}$ satisfy $p_{x'} \geq R(S_{x'})$ and $p_{x''} \geq R(S_{x''})$. Now, let us assume that agent x declares the evaluation value $R(S)$ for the set $S = S_{x'} \cup S_{x''}$ by using a single identifier. From the condition of a leveled division set, there exists a level $j < i$, where $S \in D_{jl}, D_{jl} \in SD_j$ holds. In this case, the condition in Step 1 of LDS(j) is satisfied, i.e., only agent x declares evaluation values that are larger than or equal to the sum of reservation prices. Thus,

$\sum_{y \neq x} v_y(G^*_{\sim x}) = R(M)$, and $\sum_{y \neq x} v_y(G^*) = R(M) - R(S)$ hold. As a result, the payment becomes $R(S) \leq p_{x'} + p_{x''}$, i.e., the payment of agent x becomes smaller than (or equal to) the payment when agent x uses two false names. Similarly, we can show that when an agent uses more than two identifiers, the payment of the agent becomes smaller (or equal to) the payment when the agent uses only one identifier.

Lemma 2 states that false-name bids are not effective in the LDS protocol. Now, we are going to show that truth-telling is the dominant strategy for each agent under the assumption that each agent uses a single identifier.

The following lemma holds.

Lemma 3 *When there exists no false-name bid, and the applied level of the LDS protocol remains the same, an agent can maximize its utility by declaring its true evaluation values.*

The proof is as follows. As long as the applied level is not changed, the possible allocation set SG_i is not changed. The payment of agent x is defined as $\sum_{y \neq x} v_y(G^*_{\sim x}) - \sum_{y \neq x} v_y(G^*)$. We represent the true evaluation value of agent x of an allocation G as $u_x(G)$. The utility of agent x is represented as $u_x(G^*) + \sum_{y \neq x} v_y(G^*) - \sum_{y \neq x} v_y(G^*_{\sim x})$, i.e., the difference between the evaluation value and the payment. The third item of this formula is determined independently from agent x's declaration if there exists no false-name bid. Therefore, agent x can maximize its utility by maximizing the sum of the first two items. On the other hand, the allocation G^* is chosen so that $\sum_{y \in N \cup \{d\}} v_y(G) = v_x(G) + \sum_{y \neq x} v_y(G)$ is maximized. Therefore, agent x can maximize its utility by declaring $v_x(G) = u_x(G)$, i.e., declaring its true utility.

Next, we show that an agent cannot increase its utility by changing the applied level.

Lemma 4 *An agent cannot increase its utility by over-bidding so that the applied level decreases.*

The proof is as follows. Let us assume that when agent x truthfully declares its utility, the applied level is i, and by over-bidding, the applied level is changed to $j < i$. In that case, for every set of goods S included in the divisions of level j, agent x's evaluation value of S must be smaller than the sum of the reservation prices $R(S)$; otherwise, level j is applied when agent x tells the truth. On the other hand, by Lemma 1, the payment for a set S is always larger than the sum of the reservation prices $R(S)$, which means that agent x cannot obtain a positive utility by over-bidding.

Lemma 5 *An agent cannot increase its utility by under-bidding so that the applied level increases.*

The proof is as follows. Agent x can increase the applied level only in the following two cases.

1. Agent x is the pivotal agent when agent x truthfully declares its evaluation values.
2. By under-bidding, another agent y becomes the pivotal agent.

In the first case, when agent x tells the truth, agent x is the pivotal agent and the larger level is applied if agent x prefers the result of that level; thus under-bidding is useless. In the second case, agents other than y cannot obtain any goods; the utility of agent x becomes 0. In both cases, agent x cannot increase its utility by under-bidding.

From these lemmas, we can derive Theorem 1. □

Evaluation

In the LDS protocol, we can expect that the social surplus and the revenue of the seller can vary significantly according to the leveled division set and reservation prices. In this section, we show how the social surplus changes according to the reservation prices using a simulation in a simple setting where there are only two goods A and B.

We determine the evaluation values of agent x by the following method.

- Determine whether the goods are substitutional or complementary for agent x, i.e., with probability p, the goods are substitutional, and with probability $1 - p$, the goods are complementary.
  - When the goods are substitutional: for each good, randomly choose its evaluation value from within the range of $[0, 1]$. The evaluation value of the set is the maximum of the evaluation value of A and that of B (having only one good is enough).
  - When the goods are complementary: the evaluation values of A and B are 0. Randomly choose the evaluation value of the set from within the range of $[0, 2]$ (all-or-nothing).

Figure 2 shows the result where $p = 0.5$ and the number of agents $|N|$ is 10. We created 100 different problem instances and show the average of the social surplus by varying the reservation price. Both A and B have the same reservation price. For comparison, we show the social surplus of the GVA (assuming there exists no false-name bid) and the set protocol. Figure 3 shows the result where $p = 0.7$.

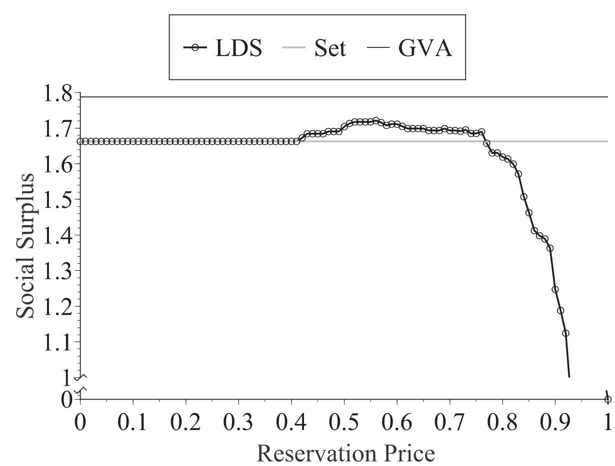

Figure 2: Comparison of Social Surplus ($p = 0.5$)

When the reservation price is small, the results of the LDS protocol are identical to the set protocol. We can see that

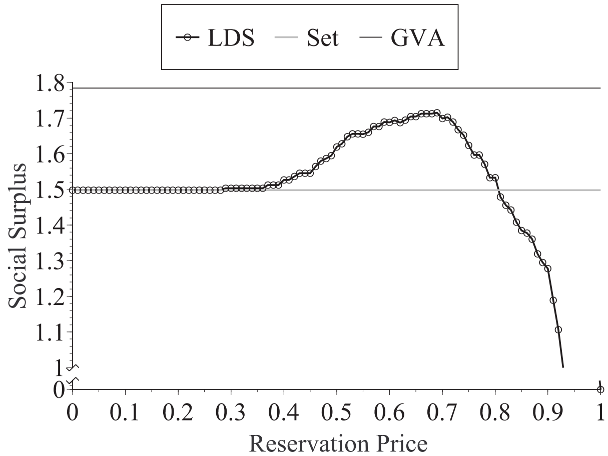

Figure 3: Comparison of Social Surplus ($p = 0.7$)

by setting an appropriate reservation price, the obtained social surplus becomes larger than that for the set protocol. When the probability that the goods are substitutional becomes large, the difference between the set protocol and the GVA, as well as the difference between the set protocol and the LDS protocol, becomes large.

Discussion

As far as the authors know, the LDS protocol is the first non-trivial protocol that is robust against false-name bids. One shortcoming of this protocol is that when the leveled division set and reservation prices are not determined appropriately, there is a chance that some goods cannot be sold. In that case, the social surplus and the revenue of the seller might be smaller than that for the set protocol.

One advantage of the LDS protocol over the GVA is that it requires less communication/computation costs. To execute the GVA, the bidder must declare its evaluation values for all possible subsets of the goods. Also, the seller must solve a complicated optimization problem to determine the winners and their payments (Sandholm 1999; Fujishima, Leyton-Brown, & Shoham 1999; Rothkopf, Pekeč, & Harstad 1998). In the LDS protocol, the allowed divisions are pre-determined, and bidders need to submit bids only for these subsets. Furthermore, the search space of the possible allocations is much smaller than the search space that must be considered in the GVA.

Conclusions

In this paper, we presented a new combinatorial auction protocol (LDS protocol) that is robust against false-name bids. This protocol satisfies individual rationality and incentive compatibility and can achieve a relatively good, though not Pareto efficient, social surplus. The main idea of the LDS protocol is to utilize the reservation prices of goods to make decisions on whether to sell goods in a bundle or separately. Simulation results showed that this protocol can achieve a better social surplus than that for the set protocol.

One remaining research issue is how to find the leveled division set and reservation prices that maximize the social surplus or the revenue of the seller. We are working on a method to find the appropriate leveled division set and reservation prices based on certain expectations of bidders' evaluation values.

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