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An Efficient Double Auction Mechanism for Job Allocation

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***Abstract*—Job allocation is a common application of human resource competition in the market. The third-party platform plays a vital role in coordinating the supply relationship between job suppliers and job seekers in order to help the talent market to allocate resources reasonably. For maximal social welfare, this paper proposes and implements a greedy double auction mechanism (GDA) based on the descending order of bid differentials. In the process of auction, virtual positions are regarded as heterogeneous commodities, and greedy algorithm is used to solve the optimal solution which maximizes social welfare and satisfies constraints. GDA has the economic attributes of individual rationality, budget balance as well as authenticity by the theoretical proof. At the same time, the feasibility and effectiveness of the mechanism are verified by simulation experiments. The experimental results show that the GDA mechanism has higher social welfare and average utility of job seekers, which can make job providers and excellent job seekers have a stable foothold in the increasingly fierce human resources competition market.**

***Index Terms*—Double auction, Task allocation, Mechanism design, greedy algorithm**

I. Introduction

Nowadays, the Internet has become the largest distribution center of information, and there is massive information interaction at all times. With the development of the Internet, the scale of Internet users is growing, and the economic value of the Internet is growing. More and more industries choose to embrace the Internet [1]. For a company, the traditional way of advertisement in the newspaper has been a kind of low efficiency and low utility behavior. On the contrary, it is a wise means to publish job-hunting information on the Internet, attract a large number of potential candidates, and select the most suitable talents. Therefore, the position competition can be regarded as a special task allocation in human resource market [2].

In the job supply and demand market, job suppliers are diverse, and job seekers' own attributes are also different. In addition to the position provider, the platform generally participates in the market as a third party. The third party platform knows the cost and price of suppliers and buyers comprehensively. Therefore, in the allocation of job resources, we should consider the effectiveness of all the candidates from a third-party perspective, allocate an optimal seeker for each position, and maximize the total social welfare [3]. That is, in numerous matching schemes, we need to find a scheme to maximize the overall utility and raise the position mapping rate as high as possible. However, the decentralization and uncertainty of resources in the talent market make it a challenging task to optimize the allocation of resources [4], [5].

For the job allocation problem, it can be considered as the resource allocation problem in the talent market. Many scholars solve the resource allocation problem through the market mechanism, such as literature [6], [7]. However, these methods mostly use a single matching algorithm, which can not adapt to the dynamic market changes. For example, when the participants exceed a certain range, these methods appear the issues like poor matching efficiency and low utility [8], [9]. In view of the above problems, this paper intends to use the auction mechanism to solve the job allocation problem in the talent market. Auction is one of the effective means to solve the resource competition in multi-agent system. Because the position is a scarce resource, there must be a great number of job seekers participating in the competition for one position. In order to get this position, job seekers may reduce their bids, making the company that offers the position profitable, but the utility of his own is not satisfactory. If the existing

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auction mechanism is directly applied to solve the problem, it may not achieve expected results. For example, in a unilateral auction, only one job can be traded at a time. If we adopt the mode of multilateral auction, it will undoubtedly increase the cost of communication and calculation.

Therefore, this paper proposes a greedy double auction method to solve the job allocation problem. Double auction [10] refers to a "many-to-many" trading state, which consists of multiple buyers and sellers. The auction involves not only the competition between buyers, but also the competition among sellers. Double auction can be applied to dynamic markets such as securities trading and computing network resource allocation [11]. For example, papers [12]–[14] use double auction to solve the resource allocation in cloud computing. Document [15] applies auction to transparent computing. Under the ideal transparent computing model, the resource allocation mechanism based on double auction can analyze the demand boundary of communication bandwidth, thus realizing the optimization configuration of bandwidth resources. Tian [16] proposed grid resource reservation algorithm based on periodical double auction, in which true bid is the only optimal strategy for both buyers and sellers. Double auction has gradually become a hot topic in resource allocation. The platform based on double auction mechanism is used to make the job seekers and the supplier submit their own job information and bids. For the position, the provider's salary ceiling exists, so winning at a low price is a basic bidding strategy for most competitors. However, winning the bid at a low price also means that he loses other competitive opportunities. For a particular position, the larger the difference between the offer of the provider and bid of the seeker, the higher the social welfare created.

In this paper, we regard the position allocation problem as the resource competition in multi-agent system. The third-party platform adopt the greedy double auction mechanism in order to solve this issue. In the following sections, we will give some important symbols and definitions underlying the mechanism and explain how to solve position allocation with GDA mechanism. The theoretical proof and experimental results show that the GDA mechanism has a better performance than others. Finally, we conclude our results.

II. Overview of System Model

Position auction is a new application on the internet for job seekers and providers. For a popular position, the company that provides jobs can choose the most suitable employees to be qualified for the position; for a general position, it can also increase the company's benefits by choosing a lower-priced employee.

Normally, in the process of position auction, job seekers are often more than the number of positions. The title of the position can be the same, it can be provided by different companies, but each position is unique and distinguishable. This paper excludes the possibility of concurrent employment in the model. We believe that the job information already contains the description of all the work obligations. That is to say, concurrent employment may be one of the positions. In addition, it is not allowed to hold several jobs in different companies.

TABLE I
Symbols and their implications underlying GDA

Symbols	Implications
c_i	the company i provides the job
s_k	the job seeker k
job_{ij}	the job j which provided by company i
p_{ij}	the value of job j which evaluated by company i (i.e. salary paid to job seekers)
b_{ij}^k	the bid of seeker k for job_{ij}
S_w	the winner set of job seekers
J_w	the set of allocated jobs
p_{ij}^S	the utility of winner job seeker S after job_{ij} is allocated
p_{ij}^J	the utility of company i after job_{ij} is allocated to seeker
U_{ij}^k	the utility of job seeker s_k after job_{ij} is allocated to her
U_{ij}^J	the utility of job j after job_{ij} is allocated to her
U^S	the total utility of all winner job seekers
U^J	the total utility of companies . where provided jobs are allocated successfully
W	the social welfare

In this model, the set of companies that provide positions is denoted by $Company = \{c_1, c_2, \dots\}$, and $c_i \in Company$ represents the company i; the set of job seekers is denoted by $Seeker = \{s_1, s_2, \dots\}$, and $s_k \in Seeker$ represents the job seeker k. Each company provides a certain number of positions job_{ij} to the third-party platform, the set of all positions is denoted by J. For each position, it has its own value p_{ij} which is evaluated by the company. Job seeker s_k gives a series of bids $B_k = \{b_{i1}^k, b_{i2}^k, \dots\}$ to the platform according to their ability and job demand (b_{ij}^k means the bid of seeker k for job_{ij}). Then $Bid = \{B_1, ..., B_{|Seeker|}\}$ indicates the set of all seekers' bids. We assume that the bid of s_k is -1 when the job seeker is not competent for a particular position.

Obviously, different positions in different companies have different attractions to job seekers. For job seekers, he will not quote for positions that he is not competent or interested in. For the positions they are interested in and competent for, they will combine their own preferences and make a strategic offer. For example, if a bidder graduates from the computer department and wants to work in the software development industry, he will quote for a software development position according to his actual ability and ideas.

The third party platform which determines the final allocation of positions plays a fair and intelligent role in the system, it can be informed of the bids from both sides, but it will not be disclosed to any one of the two sides. There is a one-to-one mapping relationship between the winner set of job seekers $S_w \subseteq Seeker$ and the winner set of positions $J_w \subseteq J$. The mapping function is marked as $\sigma : \{k : s_k \in S_w\} \rightarrow \{i, j : job_{ij} \in J_w\}$.

The utility of the position. If a company's position is distributed to a suitable candidate, the company gains utility by subtracting the actual salary paid to the seeker p_{ij} from the position's utility to the company p_{ij}^S, or the company's utility is 0.

$$U_{ij}^{J}=\begin{cases}p_{ij}^{S}-p_{ij}, & if job_{ij}\in J_w\\ 0, & otherwise\end{cases} \tag{1}$$

The utility of the job seeker. If the job seeker s_k succeeds in obtaining a position, then the utility of the job seeker is that the salary that company actually pays p_{ij} minus his job bid b_{ij}^{k}. Otherwise, his utility is 0.

$$U_{ij}^{k}=\begin{cases}p_{ij}-b_{ij}^{k}, & if job_{ij}\in J_w, s_k\in S_w\\ 0, & otherwise\end{cases} \tag{2}$$

Then utility of all positions is $U^J=\sum_{job_{ij}\in J_w}U_{ij}^{J}$, the utility of all job seekers is $U^S=\sum_{s_k\in S_w}U_{ij}^{k}$. In other words, the utility of whole position is the total utility of all companies. The social welfare in this paper is defined as the sum of the utility of both companies and seekers after the position distribution. That is, $W=U^J+U^S$.

III. Greedy Double Auction Mechanism

In the general double auction model, the auction goods are homogeneous, which is sorted by the bid. The order of bidding often follows the following rules:

- Time First: When the buyer and the seller have the same bid price, the buyer who bids earlier will prioritize transactions;
- Price First: The buyer who bids higher will prioritize transactions. In contrast, the seller who asks lower price will prioritize transactions;
- Transaction Price: The transaction price is generally the average of bidding and asking price. The premise of the transaction is that the seller's asking price is lower than the buyer's bid.

The double auction model used in this paper is different from the general one, mainly reflected in the following three aspects:

- The auctioned goods come from various positions offered by different companies are heterogeneous;
- There is a one-to-one correspondence between the bidder and the auction goods;
- Third-party platforms have access to all product (or position) as well as bid information, however, this information is private to both parties.

A. Linear Programming Problem

Based on the above assumptions, this paper solves the optimal solution by linear programming method. Firstly, we assume that all positions job_{ij} are consist of a matrix which marked as i and j. If $job_{ij}=0$, the bidder does not participate in the competition. On the contrary, if job_{ij}=1, the bidder will compete for the job. Therefore, the feasible solution we get is a set of three-dimensional space coordinates based on i, j, k.

In this three-dimensional space, each point (x, y, z) represents the final job distribution solution. The abscissa x of the point indicates the company offering the position, the ordinate y of a point indicates the position offered by the company, and the vertical coordinate z of the point indicates the applicant for the job distribution.

In this paper, we use X_{ij}^{k} to represent the job allocation, $X_{ij}^{k}\in\{0,1\}$. $X_{ij}^{k}=1$ means job_{ij} is assigned to the job seeker s_k. Instead, the job is not assigned to the job seeker s_k. In order to facilitate the understanding of the following paper, we introduce some symbols to help represent some situations in the auction. X^k is a binary variable with a range of {0,1}. If and only if the job seeker s_k gets a position, $X^k=1$ and the position is allocated to a seeker, $X_{ij}=1$. Finally, the set of X_{ij}^{k} is the ultimate solution. This winner set should meet the following constraints:

1. Each job seeker s_k in solution will only appear once at most:

$$X^k=\sum_{X_{ij}}X_{ij}^{k}(\forall i,j) \tag{3}$$

2. Each job job_{ij} in solution will only appear once at most:

$$X_{ij}=\sum_{k}X_{ij}^{k}(\forall k) \tag{4}$$

3. There is no empty set in solution:

$$X^k\geq X^{k+1}(\forall k) \tag{5}$$

Therefore, the Winner Decision Problem that needs to be solved in this paper is a linear programming problem as follows:

$$Max\sum_{1}^{|X_{win}|}X_{ij}^{k}\{[p_{ij}-\frac{p_{ij}-b_{ij}^{k}}{2}]+[\frac{p_{ij}-b_{ij}^{k}}{2}-b_{ij}^{k}]\} \tag{6}$$

where, $Xwin$ represents the solution which maximizes the social welfare in auction and meets the constrains.

B. Greedy Double Auction Algorithm

Since the positions involved in the auction are heterogeneous , their respective attributes are not identical. So, we can also regard job auctions as a combination of multiple consecutive unit auctions. Since the goods participating in the auction are distinguishable, the ordering of goods in traditional auctions needs to be changed. In previous double auctions of homogeneous goods (e.g. stocks), we can sort them according to bids and submission time. In the position auction, company provides job_{ij} and p_{ij}, while job seeker s_k applies for job_{ij} and gives b_{ij}^{k}. Therefore, we previously statistic the jobs we are competing, exclude jobs that are not competed, and put them into the set $J_{potential}$.

When the job seeker k submits the bid b_{ij}^{k} for the specific job job_{ij}, the platform will compare the bid of company p_{ij}. If $p_{ij}\geq b_{ij}^{k}$, the transaction can be completed. If the candidate is selected, the final actual transaction price is $\frac{p_{ij}+b_{ij}^{k}}{2}$. Therefore, we need to count the valid jobs in $J_{potential}$ and put them into the set J_{value}. Meanwhile, put the valid bid for each job in

J_{value} into set bid_m. bid_{mn} represents the nth valid bid for job m in J_{value}. The set of valid bid sets for all jobs in all J_{value} is Bid, $Bid = \{bid_1, bid_2, ..., bid_{|J_{value}|}\}$.

In algorithm 1, we want to find the valid bid.

Algorithm 1: Valid Bids

Input: J, S, B
Output: $J_{potential}, J_{value}$
for $t = 1 \rightarrow |B|$ **do**
  if *B_t is marked with i, j* **then**
    Put job_{ij} into $J_{potential}$
  end
end
for $t = 1 \rightarrow |J_{potential}|$ **do**
  Read J_t get i, j
end
$index \leftarrow 0; count \leftarrow 0;$
for $s = 1 \rightarrow |B|$ **do**
  Search b marked with i, j
  if $b_{ij}^x \leq p_{ij}$ **then**
    count=count+1;
    Put b_{ij}^x into bid_{index}
  end
end
if $count > 0$ **then**
  Put job_{ij} into J_{value}
end

Since the job seeker and the position are one-to-one correspondence, the situation that a job seeker who has multiple jobs or a job correspond to multiple people does not exist. Therefore, even if the bid is valid, the final job distribution needs to be considered. After the J_{value} is found, we choose the effective bid set for each job. For J_m, there are $|bid_m|+1$ possible choices. In all combinations, there must be a solution that maximizes social welfare. From a holistic perspective, if positions are fully distributed and assigned to seekers who give the lowest asking price, it must maximize the social welfare.

The job seeker will not arbitrarily bid for additional utility because the requirements of the job are often very clear. In each bidder's information, you can find out the job applicant's willingness by comparing quotes and bids. If the difference between the bid and the asking price is large, it means his willingness to apply for this position tends to be strong. We rank all the differences in the effective bids for each occupation in descending order and priority to deal the highest. In algorithm 2, we sort valid bids according to their difference between the value of position. Based on the greedy mechanism, we give priority to the transaction where quotation and the bidding with large price difference, and then remove all the winners' biddings until all the bidding is deleted or positions are distributed.

IV. Proof of Economic Attribute

Theorem 1: The time complexity of the greedy double auction (GDA) mechanism is $O(m*n+2n^2)$.

Algorithm 2: Greedy Allocation

Input: J_{value}, Bid, S, J
Output: $Solution$
for $s = 0 \rightarrow (|Bid| - 1)$ **do**
  Read bid[s]'s index i, j, k ;
  $D_{ij}^k = p_{ij} - b_{ij}^k$
end
Sort all D_{ij}^k in Bid while maximum put forward;
Put result into $NewBids$
$J_w = \emptyset, S_w = \emptyset$
for $s = 1 \rightarrow |NeewBids|$ **do**
  if $|NewBids| > 0$ **then**
    Read $NewBids$ and get marked i, j, k;
    Put s_k into S_w, put job_{ij} into J_w;
    Remove all bids in $NewBids$ marked with i or j and k;
  end
end

Proof 4.1: First, we judge whether the bidding is effective, put the difference between the asking and bidding price in the effective bidding sequence, and record the target position as well as the bidder. The process involves a double loop with time complexity $O(m*n)$. After that, we sort all the differences in descending order by bubble sort and take the bidding with large differences into consideration firstly, the corresponding time complexity was $O(n^2)$. Finally, since a position can only correspond to one candidate, the remaining biddings of selected bidders should be ranked when calculating social welfare. This process involves a nested two-lever iteration whose time complexity is $O(n^2)$. Therefore, the time complexity of GDA is $O(m*n+2n^2)$.

Theorem 2: The greedy double auction (GDA) mechanism is individual rational.

Proof 4.2: In algorithmic design, if a candidate lies about his true desire to apply for a job, he is unable to compete for a position. At this point, $p_{ij}^S = 0, U^S = 0$. When the position job_{ij} has only one valid bidder, if and only if $p_{ij} \geq b_{ij}^k$, then $U^S = \frac{p_{ij}+b_{ij}^k}{2} - b_{ij}^k$. Therefore there must be $U^S \geq 0$. When the position job_{ij} has more than one effective bidder, there must be a lowest bidder. If the applicant s_k has lowest bid, then $U^S \geq 0$. If the bid is not the lowest, then $U^S = 0$. To sum up, the greedy double auction mechanism is individual rational.

Theorem 3: Greedy double auction (GDA) mechanism is budget-balanced.

Proof 4.3: In a double auction, the transaction price between the buyer and the seller is the average of the buyer's bid and the seller's asking price. As a result, $p_{ij}^S = p_{ij}^J$. In other words:

$$\sum_{job_{ij} \in J_w} p_{ij} - \sum_{s_j \in S_w} p_{ij}^S = \sum_{s_j \in S_w} p_{ij} - p_{\sigma(ij)}^s = 0 \quad (7)$$

Thus, greedy double auction is budget-balanced.

TABLE II
SIMULATED EXPERIMENTAL PARAMETERS

Parameters	Descriptions	Range
m	the number of positions	50
n	the number of job seekers	$[20, 100]$
A	the value of positions	$[4500, 7500]$
B	the bid of seekers for positions	$[4000, 8000]$
d	step length	10

Theorem 4: Greedy double auction (GDA) mechanism is truthful.

Proof 4.4: For any job seeker $s_k \in Seeker$, we assume the job seeker s_k can get the position in true bid b_{ij}^k. There are two situations when he misreports his bid:

(1) the bid ${b'}_{ij}^k$ lower than true bid: Job seeker wins bid, his new utility is $U^{S'}$. Because the applicant's utility is the deal price of the position minus his asking price, and the deal price is the average of the bidding and asking price. So $U = \frac{b+p}{2} - b$. Due to ${b'}_{ij}^k \leq b_{ij}^k$, so $U^{S'} \leq U^S$. In this case, the false bid leads to a lower utility.

(2) the bid ${b'}_{ij}^k$ higher than true bid:
1). job seekers fails the competition, $U^{S'} = 0$.
2). job seeker wins the bid, due to the utility function: $U = \frac{b+q}{2} - b = \frac{p-b}{2}$. The price of the position remains unchanged with the raise of bid b provided by the seeker. As a result, job seekers' utility declines.

To sum up, when a job seeker lies about his bid, he will not get a higher utility. Therefore, the GDA mechanism is truthful.

V. Experimental Results and Analysis

In order to verify the feasibility and effectiveness of the GDA mechanism, we design a simulation experiment to compare the performance of GDA, mainly from two aspects:

- the social welfare of the mechanism;
- the position matching rate;
- the average utility of 'buyers'.

A. Experimental Design

We assume that only one company is responsible for providing 50 positions with salary between 4500 and 7500. The number of job seekers is range from 20 to 100, and the bid price for each position is between 4000-8000. We will increase 10 people at a time, comparing the results of two mechanisms under different job seekers. It should be noted that we use the average of multiple results, and the bidding and asking price are random numbers with limited intervals. Table 2 shows simulated experimental parameters.

B. Experimental Results and Analysis

In this section, we mainly compare the social welfare and average utility of job seekers between the common sequential double auction mechanism (DA) and the greedy double auction mechanism (GDA).

DA mechanism which follows the rule of time priority and price priority determines the bidders of each position, and makes correspondence between bidding and the position. After that, DA mechanism ranks the corresponding of bidding. Firstly, sort by time, and then sort according to the asking price. If the first bid is lower than the company's asking price, the position is temporarily assigned to this bidder. Finally, when the time window closes, the winners of each bidder will be sorted out and the final task allocation will be completed by those who have the maximal social welfare.

As shown in Figure 1, with the increasing number of job seekers, the social benefits of DA and GDA also increase. Apparently social welfare increased rapidly as the number increased at first. When the number of people gradually increases to no more than 120, the growth of social welfare tends to be smooth. Then we can draw the conclusion that when the number of positions remain unchanged, the increase in the number of job seekers is conducive to the increase of social welfare. However, the welfare will be reduced after reaching a certain value. At the same time, it is not difficult to conclude that GDA has higher social welfare than DA under the same conditions. This is because when designing a GDA mechanism, the difference between the asking and the bidding price is first calculated. After that, they are arranged in descending order. In this paper, the bidder with the largest difference is selected according to the descending order, then we delete the current largest bid and other bids proposed by this bidder as well as other bids for this position. The price of the transaction will be recorded in the current social welfare set, and all valid bids will be found through multiply iteration. Therefore, we have found out the optimal combination with maximal social welfare among all bids theoretically. In the DA mechanism, the number of bids is small because of the small number of job seekers. Secondly, due to the time sequence of bids, in the same time window, the bids of job seekers follows the principle of time priority.

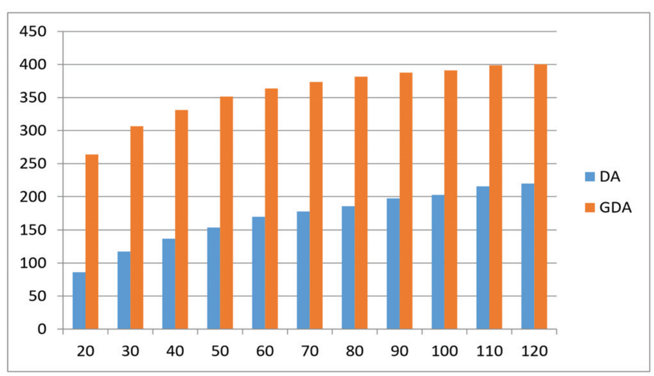

Fig. 1. Social welfare between DA and GDA

As shown in Figure 2, the blue curve describes the growth trend of position matching rate of DA while the yellow curve represents the GDA matching rate. With the increase of job seekers, the matching rate of DA and GDA has both increased. GDA has a great advantage in the early stage. When the number of job seekers is mores than 40, the matching rate of DA is higher than that of GDA. And we find that the rate of position matching gradually slowed down as the number of job seekers increased. This is due to the particularity of the job. DA mechanism needs two rounds when it used to be allocate position. For the first time, it finds the highest bid of each position and reassigns the specific position for the second time. In the case of two distribution rounds and less competitive bidding, the allocation rate of DA is less than GDA. Later, after the rapid growth of bidding types, more types of bidding can be chosen. Therefore, more competitive bidding is available for each position. In order to pursue higher social welfare, we find out the best matching solution that maximize the utility of job seekers and providers. Therefore, the matching rate of GDA is higher when there are fewer people in the early stage, but the matching rate of DA is higher than that of GDA when there are more people in the later stage.

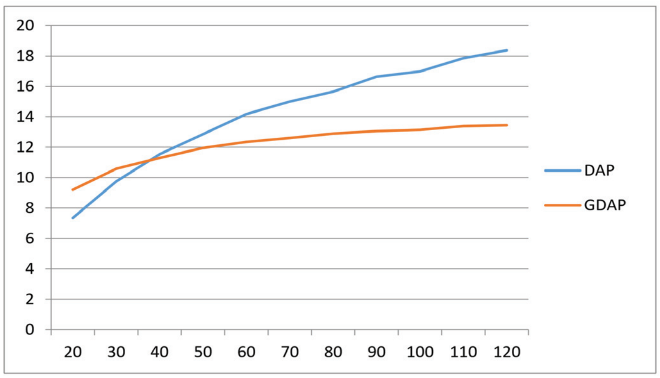

Fig. 2. Position matching rate between DA and GDA

From Figure 3, we can find that the average utility of GDA is higher than that of DA. With the increasing number of job seekers, the average seeker's utility of DA and GDA are basically stable and occasionally fluctuate. First of all, with the same number of job seekers, the social welfare of GDA is higher. When the number of people is more than 50, GDA has a lower matching rate. Therefore, when not less than 50 people, GDA will undoubtedly have a higher average job seeker utility. When the number of job seekers is less than 50, the matching number itself does not differ greatly, and the social welfare of GDA is higher. Therefore, under the same circumstances, the average utility of job seekers of GDA is higher.

VI. Conclusion

In this paper, we design a special task assignment–position allocation model based on double auction model. A greedy double auction mechanism (GDA) based on descending order of difference between asking and bidding price is proposed for the model. The purpose of the GDA mechanism is to maximize the overall social welfare in the auction. The theory proves that GDA mechanism has such economic attributes as authenticity, individual rationality and budget balance. The mechanism has effectively improved social welfare and the average utility of job seekers.

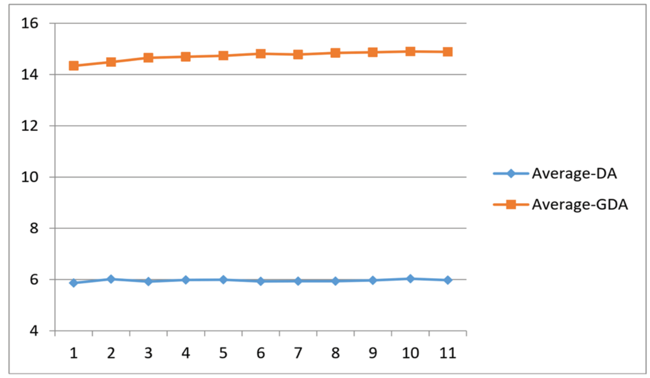

Fig. 3. Average utility of seeker between DA and GDA

References

[1] YongQin Fan, Research on Internet recruitment strategy of enterprises[D], Jilin University, 2014.
[2] Lai, Kevin, Huberman, Bernardo A, Fine, Leslie R. Tycoon: A Market-Based Resource Allocation System[J]. Ssrn Electronic Journal, 2004, 1(3): 813-820.
[3] Yu-E, Huang, Xiang-Yang, et al. Privacy-Preserving Strategy Proof Auction Mechanisms for Resource Allocation[J]. Tsinghua Science and Technology, 2017, 22(2): 119-134.
[4] Sean Marston, Zhi Li, Subnajyoti Bandyopadhyay, Cloud computing-the business perspective[J]. Decision Support Systems, 2011, 51(1): 176-189.
[5] Felix Brandt, Felix Fischer, Markus Holzer. Symmertries and the complexity of pure nash equilibrium[J]. Journal of Computer and System Science, 2009, 75(3): 163-177.
[6] Chen Shi-wei, Pan Yu. Credibility-based dynamic resource distribution strategy under cloud computing environment[J]. Computer Engineering, 2011, 37(11): 45-48.
[7] XueSeng SHI, Ge XU. Utility maximization model of resource allocation for cloud virtual machine, Chinese Journal of Computers, 2013, 36(2):252-262.
[8] Rodrigo N, Rajiv Ranjan, Anton Beloglazov. CloudSim: A toolkit for modeling and simulation of cloud computing environments and evaluation of resource provisioning algorithms[J], Software-Practice and Experience, 2011, 41(1): 23-50.
[9] Fawcett L , Broadbent M H , Race N J P . Combinatorial Auction-Based Resource Allocation in the Fog[C]// Proceedings of Fifth European Workshop on Software-defined Networks. IEEE, 2017.
[10] Kant U, Grosu D. Double Auction Protocols for Resource Allocation in Grids[C]// Proceedings of International Conference on Information Technology: Coding and Computing. IEEE Computer Society, 2005: 366-371.
[11] YaJuan Wang, XianJia Wang. Incentive compatible mechanism for multiunit online double auction[J]. Journal of Management Sciences in China, 2015, 18(8):1-11.
[12] Fujiwara I, Aida K, Ono I. Applying Double-Sided Combinational Auctions to Resource Allocation in Cloud Computing[C]// IProceedings of International Symposium on Applications and the Internet. IEEE Computer Society, 2010:7-14.
[13] Samimi P, Teimouri Y, Mukhtar M. A combinatorial double auction resource allocation model in cloud computing[J]. Information Sciences, 2016, 357:201-216.
[14] Baranwal G, Vidyarthi D P. A fair multi-attribute combinatorial double auction model for resource allocation in cloud computing[J]. Journal of Systems and Software, 2015, 108:60-76.
[15] Wang J, Liu A, Yan T, et al. A resource allocation model based on double-sided combinational auctions for transparent computing[J]. Peer-to-Peer Networking and Applications, 2017(10): 1-18.
[16] TIAN Dong, CHEN Sh.u-yu, WU Chang-ze. Grid resource reservation algorithm based on periodical double auction[J]. Journal of Computer Applications, 2007, 27(1):15-18.
[17] McAfee R P. A dominant strategy double auction[J]. Journal of economic Theory, 1992, 56(2): 434-450.