Title:

A Mechanism for Fair Distribution of Resources with Application to Sponsored Search

Authors:

Evgenia Christoforou, IMDEA Networks Institute, Madrid, Spain and Universidad Carlos III, Madrid, Spain
Antonio Fernández Anta, IMDEA Networks Institute, Madrid, Spain
Agustín Santos, IMDEA Networks Institute, Madrid, Spain

Contact author:

Evgenia Christoforou
IMDEA Networks Institute
Avda. del Mar Mediterraneo, 22
28918 Leganes, Madrid, Spain
Telephone: +34 914816964
FAX: +34 914816964
E-mail: evgenia.christoforou@imdea.org

Abstract:

As advertisement is shifting from the traditional media to the Internet, advertising in web search engines has emerged in the form of *sponsored search.* Advertisers pay the search engine to show their content, usually in order to get traffic to their own websites. A large amount of the search engine's income derives from sponsored search. In sponsored search, a number of advertisers are competing for a limited number of slots in each specific keyword search in the search engine. In order to distribute the available slots among the advertisers, search engines are starting to hold keyword auctions. The questions that appear in this setup from a mechanism design point of view are two, how to assign advertisers to slots (or vice versa), and how to price each slot. This work proposes a novel approach were distributing the slots among the advertisers is based on how much each advertiser values appearing in a keyword search slot at a specific time. The proposed approach makes this value independent of her true payment to the search engine, which can take the form of a flat fee. For this purpose we have designed a new auction mechanism that fairly distributes resources (or goods, e.g., slots) in online fashion, based on the users' declared preferences, while being socially efficient. While the main motivation for this work was sponsored search, the proposed mechanism can be used in general for the fair distribution of resources in an online fashion among a set of users. Hence, we refer to this mechanism as Fair and Efficient Distribution of Resources (FEDoR). FEDoR can be used even when the auction is done in a distributed fashion (i.e., without central authority), and it provides fairness, social efficiency and incentive compatibility.

Type of submission:

3.Trabajos publicados recientemente, o pendientes de publicacin, en conferencias o revistas.

Appearing in:

ArXiv, http://arxiv.org/abs/1502.03337.

A Mechanism for Fair Distribution of Resources with Application to Sponsored Search

Evgenia Christoforou[1,2], Antonio Fernández Anta[1], and Agustín Santos[1]

[1] IMDEA Networks Institute, Madrid, Spain
[2] Universidad Carlos III, Madrid, Spain

1 Introduction

Sponsored search [6] is a vital source of income for search engines (i.e. Google, Yahoo!, Bing, etc.). By the term *sponsored search* we are referring to the commercialization of the content that is displayed on demand each time a user performs a keyword search in a search engine. Due to the limited space in a search result, and in order not to affect the user experience, the space for advertisements is restricted. Hence, sponsored search often takes the form of auctions for the advertisement space available in a keyword search.

In the framework of sponsored search auctions we have two agents. On the one hand, we have the advertisers (bidders), that have to carefully select the search engine, keywords, time frame, and geographical location of the ads to be placed. The goal of the advertisers is to have as much quality traffic to their websites as possible, while staying on budget. On the other hand, we have the search engine (seller), that wants to maximize her revenue without compromising the user experience with too many or irrelevant ads. Thus, the search engine wants to have a mechanism to auction ad spaces (slots) that is easy to understand by the advertisers, and that provides her high revenues. A desirable property of this mechanism is to be incentive compatible (i.e., the best strategy for the advertisers is to bid their true values). Advertisers may value a slot based on different metrics, like the cost per mille impressions (CPM, the cost for the advertisement appearing a thousand time in a specific keyword search), the cost per click (CPC, how much she values a click of a user), or the cost per action (CPA, how much she values a user actually making a transaction on her website). Hence, depending on the goal of the advertiser, an auction mechanism may be more or less appealing to her.

In general terms, an online auction mechanism addresses two questions in its design: (1) how to allocate bidders to auctioned goods (e.g., slots) and (2) what price each bidder pays for the good. The most straightforward type of auction is the generalized fist price auction (GFP), were the ith highest bidder gets the ith ''best good'', and pays the amount of her bid to the seller. In the generalized second price auction (GSP) [4] the ith highest bidder gets the ith best good, but pays to the seller the bid of the $(i+1)$st highest bidder. In the Vickrey-Clark-Groves (VCG) [3] auction the ith highest bidder gets the ith best good, but pays the *externality* that she imposes on the other bidders by winning that slot. The auction mechanism of Google [1] is a GSP auction that also takes into account a “quality score” [2]. Part of that quality score is the click through rate (CTR) that a specific advertiser will obtain if it gets a specific slot. In this case, the payment of the bidder that wins a slot is obtained by multiplying her bid by the CTR of that slot. In this work we have modeled the CTR as a weight of the importance of each slot or good.

Related Work This work has been inspired, and forms an extension of, the work of Santos et al. [8]. In that work a fair collaborative system was designed and analyzed. More precisely, in that work a set of players has a common interest in the execution of a set of tasks. Executing a task comes with a different cost for each player. Every time a task has to be executed, players declare their cost for computing the task. The mechanism provides a fair way of optimal allocation (total cost is minimized), without using any payment. When a new task appears, it is assigned to the most suitable player . The authors assume that selfish players may exist, that try to avoid executing tasks in order to increase their benefit. The proposed mechanism is called QPQ. It uses the concept of *linking mechanisms* [5], where instead of offering incentives or payments to the players to declare their true values, it limits the players responses to a probability distribution known to the mechanism designer. However, unlike the linking mechanisms, QPQ does not assume that the probability distribution of the players costs is known. In addition the presence of non-rational players is assumed.

In our work, instead of tasks, we have a set of goods (i.e. slots) that we want to be fairly allocated among the players. The difference here is that players wish to receive the good. In addition, in this work we assume that instead of one, k non-identical goods are assigned to the n players each time. But, as the work of Santos et al. [8], we do use a linking mechanism and a GoF (Goodness of Fit) test that decides whether the declared values of a players follow a uniform distribution.

Our work focuses on fair allocation of goods to players (i.e., even distribution of slots) while maximizing the social utility (i.e., achieving efficiency). Rahman et al. [7] focus on P2P systems, and propose an alternative approach to resource allocation that achieves fairness and efficiency on effort-based incentives, as opposed to contribution or output-based incentives. This work is somehow related to ours by the fact that we also consider that fairness is not proportional to the bids that players bid, but in our work no incentives are necessary to achieve efficiency. In addition, we give analytical proofs of the properties of our mechanism, unlike the work of Rahman et al. [7].

2 Contributions

The FEDoR Mechanism As we mentioned before, this work was motivated by the framework of sponsored search. However, its contributions are applicable to the general area of fair resource allocation. We assume a general model of an infinite sequence of auctions, each of a set of k non-identical goods. There are n players that value the event of receiving anyone of the goods of the set. We assume that the ith best good has a weight w_i, for every $i \in [1, k]$, so that if the value player j assigns to a set of goods is v_j, the utility for the player of receiving the ith best good is $v_j \cdot w_i$. We assume that these weights do not change from one auction to another. We have designed a distributed online auction mechanism that we refer as Fair and Efficient Distribution of Resources (FEDoR). Unlike classical auctions (GFP, GSP, VCG), with FEDoR players do not pay a price when they gain a slot/good. Instead, they pay a flat fee for entering the sequence of auctions. Our mechanism works under the assumption that the distribution of valuations of each player over all the sets follows an independent uniform distribution in the interval $[0, 1]$. (If this is not the case, the values can be normalized using a PIT transform to such a distribution, as shown in [8]), and that it is possible to detect, from a theoretical aspect without error, whether the bids issued by the players follow this distribution (i.e., we have a perfect *goodness of fit* –GoF– test).

The FEDoR mechanism in a sponsored search environment works as follows. Players declare their desire to participate in r rounds (where r is large) and pay the flat fee in advance. In this way, in each round we have the same set of players. When a set of k goods is issued, each player j can estimate its valuation v_j on the set. This value v_j is sent as the player's bid to the seller (the search engine). When all players' bids arrive (communication is assumed to be reliable and synchronous), the seller checks whether any player publishes a dishonest value by applying a GoF test (which we assumed is perfect). If a value v_j does not pass the test, it is replaced by a random value picked uniformly in $[0, 1]$. With these reviewed bids, the search engine proceeds assigning the slots to the k highest bidders. The slots are assigned giving the most valuable slot to the highest bidder, the second most valuable to the second highest, etc.

When the FEDoR mechanism is used in a distributed system without a central entity, it follows the lines described in [8]. The behavior is the same as described before, but the bids are sent to all the players. Then, the GoF test is done by all the players over the same values (and hence results in the same outcome). If a value v_j does not pass the test, it is regenerated by using a pseudorandom generator of uniformly distributed values in $[0, 1]$, using the bids of the other players. Hence, all players will have the same regenerated value.

Analytical Results We analytically show that the FEDoR mechanism guarantees *fairness*, which means that every player will receive the ith best good, for every i, the same number of times in expectation. Additionally, we have shown analytically that the mechanism is *socially efficient*, in the sense that the social utility (the total valuation of the goods assigned) is maximized, subject to the fairness property. We show that being honest and announcing the real valuation of the goods at every round maximizes the expected utility (value of goods received) of a player. This means that the mechanism is *truthful*.

Experimental Results We have conducted experiments that compare the utility of the seller and the players produced by the FEDoR mechanism with the classical mechanisms GSP, and VCG with externality. To do so, we have simulated the three mechanisms. The results obtained are presented in Figure 1. From Figure 1(a) we can notice that the utility of the seller and every player are the same for VCG and GSP in the case of one slot. When the number of slots increases, the utility of the seller is greater with GSP than with VCG, while on the other hand the utility of the player is greater in VCG than in GSP. The advantage of FEDoR, as it is shown in Figure 1, is that the flat fee that the players pay to participate provides a tradeoff between seller and player utilities, and allows to chose any point in the lines shown in the figure. From Figure 1(b) we derive the same conclusions. In addition we notice that while the number of players increases the utility decreases in all three mechanism. On the contrary the utility of the seller increases in all three mechanism when the number of player increases.

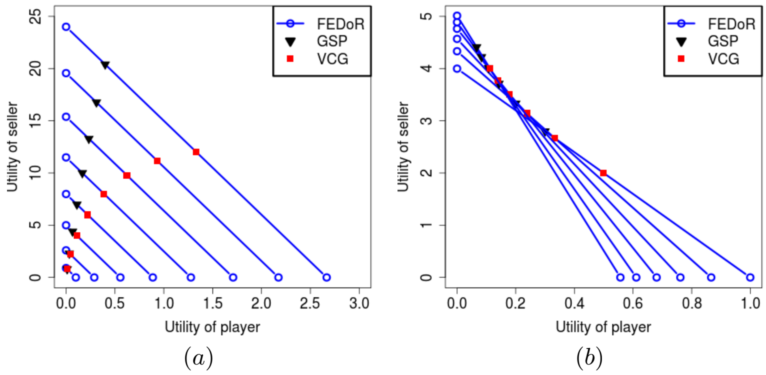

Fig. 1. Comparing FEDoR with VCG and GSP. The values for FEDoR form a line in each experiment, since the utilities of seller and players can be tuned with the flat fee. The values for VCG and GSP always lie on top of the corresponding FEDoR line. Plots represent the mean utility of the seller and one player over 1000 rounds of execution and 200 experiments. (a) Scenarios with 9 player and the number of slots/goods increasing from 1 (leftmost line) to 8 (rightmost line). (b) Scenarios with 3 slots/goods and the players decreasing from 9 (line with largest slope) to 4 (line with smallest slope).

Additional features of FEDoR for sponsored search In addition to the properties presented, we believe our mechanism specific benefits when applied to sponsored search. For instance, it addresses the issue of ranking and payment schemes by using a flat fee and the PIT transform, which makes it independent of which approach is used (CPM, CPC, CPA, etc.). Another advantage of the FEDoR mechanism from the advertiser's side is that it can be easily understood (e.g., compared to VCG). Additionally, it provides a sense of fairness to the bidders, and allows them to know from the start the amount to be paid (the flat fee) making them more prone to participate in the sponsored auction. From the sellers side, FEDoR is also good since it allows to adjust its revenue (by choosing the flat fee), while providing a friendly mechanism to the bidder, giving them incentives to advertise in the specific search engine. Our experimental results have shown that the FEDoR mechanism is more easily adjustable compared to GSP and VCG, and it can provide any tradeoff between seller and bidder utility, subject to the desires of the mechanism designer.

3 Conclusions and Future Work

We have seen that FEDoR provides an alternative to the traditional auction mechanisms (VCG and GSP) by giving the flexibility to the mechanism designer to set the desired tradeoff between seller utility and player utility. In addition the mechanism can be used in a distributed setting and it is independent of goods valuations and payment measures.

Throughout this work we have assumed that the CTR of the slots (i.e., the weight of the goods) are the same for all players, but there exist cases when this is not the case. As a future direction we would like to extend our mechanism to include this particular case.

Acknowledgments: This work has been partially funded from research funds by the Regional Government of Madrid (CM) grant Cloud4BigData (S2013/ICE-2894) cofunded by FSE & FEDER, the Spanish Ministry of Economy and Competitiveness grant HyperAdapt (TEC2014- 55713- R), the Spanish Ministry of Education grant FPU2013-03792, the NSF of China grant 61520106005 and partially funded by Real Colegio Complutense (RCC).

References

1. Google."google adwords". www.adwords.google.com/.
2. Google."how are ads ranked". https://support.google.com/adwords/answer/1722122?topic=115, 2005.
3. L. M. Ausubel and P. Milgrom. The lovely but lonely vickrey auction. *Combinatorial auctions*, pages 17–40, 2006.
4. B. Edelman, M. Ostrovsky, and M. Schwarz. Internet advertising and the generalized second price auction: Selling billions of dollars worth of keywords. Technical report, National Bureau of Economic Research, 2005.
5. M. O. Jackson and H. F. Sonnenschein. The linking of collective decisions and efficiency. *manuscript, California Institute of Technology*, 2003.
6. B. J. Jansen and T. Mullen. Sponsored search: an overview of the concept, history, and technology. *International Journal of Electronic Business*, 6(2):114–131.

7. R. Rahman, M. Meulpolder, D. Hales, J. Pouwelse, D. Epema, and H. Sips. Improving efficiency and fairness in p2p systems with effort-based incentives. In *Communications (ICC), 2010 IEEE International Conference on*, pages 1–5. IEEE, 2010.
8. A. Santos, A. Fernández Anta, and L. López Fernández. Quid Pro Quo: a mechanism for fair collaboration in networked systems. *PloS one*, 8(9):e66575, 2013.