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Auction-Based Participation Promotion in Decentralized Networks

Noriko Matsumoto[1], Koki Taguchi[2] and Norihiko Yoshida[1]

Abstract

In a volunteer-based self-organizing network, such as a peer-to-peer (P2P) network, a wireless ad-hoc network, and a device-to-device (D2D) network, participation and cooperation of volunteer nodes are crucial for the network to sustain. We call this kind of network a "decentralized" network in this paper as we cannot assume any centralized global management nor control.
Rewarding by auction has been thought to be effective to keep or promote incentives to participation and cooperation in many studies. This short paper proposes a simple and light-weight mechanism for decentralized networks based on the concept of Vickrey auction. This paper focuses on two problems of fair execution and participation incentives in particular. Results of the simulation-based experiments and evaluations confirm that the proposed mechanism is effective in promoting participation incentives.

Keywords: Participation incentives, Free-rider problem, Auction, Decentralized networks.

[1] Rissho University, Japan
[2] NS Solutions Corp., Japan

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1. Introduction

In a volunteer-based self-organizing network, such as a peer-to-peer (P2P) network, a wireless ad-hoc network, and a device-to-device (D2D) network, participation and cooperation of the volunteer nodes are crucial for the network to sustain. We call this kind of network a "decentralized" network in this paper as we cannot assume any centralized global management nor control.

In a decentralized network, nodes are not always willing to participate or cooperate. Some node may be non-cooperative on purpose, by accident, or by breakdown, doing nothing good or doing something bad. Such node may not provide any resources but only consumes other nodes' resources (i.e. the Free-Rider problem), or may spread malicious contents. It may not transfer messages properly but only discard them, or may transfer messages wrongly, or even worse, may cause flooding of waste messages. Such node should be forced to participate and cooperate, or otherwise, should be eliminated from the network.

Matsumoto, et al. [1] discussed how to evaluate trustworthiness (or coopera-tiveness) of new-comer nodes so as to eliminate nodes with low trustworthiness when the network grows. However, it was left untouched how to make nodes participate and be (more) cooperative, or how to keep cooperative nodes from losing incentives and falling into free riders.

Rewarding by auction has been thought to be effective to keep or promote incentives to participate and cooperate in many studies: Obreiter, et al. [2] on research perspective; Liu, et al. [3], Yang, et al. [4], and Ayad, et al. [5] on mobile ad hoc networks; Lee, et al. [6] on heterogeneous networks; Wu, et al. [7] on P2P streaming networks, Liu, et al. [8] on wireless sensor networks. Such promotion for participation and cooperation by auction has recently been applied to crowd-sourcing [9, 10] and mining for Blockchain [11] as well.

Devices in a decentralized network, for IoT in particular, are generally of low performance and sensitive to power consumption. A sophisticated algorithm and mechanism might not be suitable for a network of such devices if it caused much computation and much communication traffic, and a simple and light-weight mechanism would be preferable.

This short paper tries to integrate the concepts of two preceding studies, and proposes simple and light-weight mechanism based on the concept of Vickrey auction [12] for decentralized networks. Vickrey auction is widely used for incentive promotion for participation and cooperation. The rest of the paper is organized as follows: Section 2 describes our proposed mechanism. Section 3 presents simulation-based experiments to evaluate the proposal. Section 4 contains some concluding remarks and future work.

2. Proposed Mechanism

An auction consists of an auctioneer and potential bidders. In a computer network, the auctioneer is a service provider, and the bidders are service customers. Vickrey Auction is a sealed auction and executed in one round. The highest bidder is the winner, however pays a price that is equal to the second-highest bid. The dominant strategy for every bidder is to bid her/his true valuation. Consequently, Vickrey auction rewards the item to the bidder who values it most, and realizes Social Choice Function which maps the utility functions of the participants to a particular outcome. The scheme of rewards or remuneration is mostly digital currency, or sometimes reputation.
Implementation of Vickrey Auction on a decentralized network has two issues.

1. Fair execution, i.e. the fear of dishonest auctioneers, and privacy, i.e. reluctance of bidders to reveal their true valuation. To address these, Liu, et al. [3] adopted an approach to introduce a jury of trust, whose members are chosen out of the network participants.
2. Participation incentives, i.e. promoting the least wealthy bidders so as not to quit recurring auctions. To address these, Lee, et al. [6] introduced Participation Incentive Generalized Vickrey Auction (PI-GVA), in which frequent losers obtain some priorities in auctions according to the number of auctions they have lost thus far.

To address both the two issues, our idea is to integrate the above two mechanisms to achieve cooperation promotion by fair execution. Those mechanisms are actually old ones, however simple and light-weight, and considered to be suitable for low performance decentralized networks.

(1) Following Liu, et al. [3], our mechanism is composed of the below steps:

1. The auctioneer announces an auction to network participants including potential bidders and jury members.
2. Bidders send their bids to the jury members.
3. The jury determines a winner, and notifies to the winner and the auctioneer.
4. The auctioneer contacts the winner.

It was proved that the auction protocol tolerates up to one third of the jury members to be missing or faulty [3]. In other words, two thirds at least of the jury members should be trustworthy.

(2) Lee, et al. [6] pointed out that auction on a network is recurring as services are requested and provided repeatedly. Since the wealth of bidders is distributed unevenly, Vickrey Auction rewards only the bidders with the highest wealth. Less wealthy bidders who do not win for several rounds loses incentive to participate,

and may drop out of the auction after they conclude that they cannot win in the auction. Such a drop in the number of bidders decreases the price competition in the auction and may ultimately result in revenue collapse.

In order to resolve the bidder drop problem, PI-GVA was introduced. This mechanism used the below winning score, instead of a bid, for selecting a winner.

$$S_r(b_i) = \frac{b_i}{\mu} \cdot p_{ir} - w_{ir}$$

for bidder *i* in round *r*, where b_i is the average bid of bidder *i* until round r, p_{ir} is the cumulative number of rounds in which the bidder participated until round r, w_{ir} is the cumulative number of wins until round *r*, and μ is a constant that controls the effect of bid values on the winning score.

Since $b_i/\mu \cdot p_{ir}$ represents the expected number of wins, the winning score $S_r(b_i)$ measures the difference between the expected and real numbers of wins for bidder *i* in round *r*. The higher the winning score is, the lower the bidder's expectations for winnings are, and therefore the higher the probability of her/him quitting out of the auction is.

The participation of a loser in the last auction round is rewarded directly by increasing her/his winning score for the current and future auction rounds. The increased winning score improves the bidder's chances to win in the future auction rounds. In this manner, the PI-GVA mechanism controls the bidder drop problem by encouraging bidders' participation in future auction rounds.

Consequently, we adopt this concept of (2) in our mechanism outlined in (1). PI-GVA assumed that all the participants were trustworthy and cooperative. Therefore, if we think of participation incentive under "the fear of dishonest participants", integration of (1) and (2) is considered effective.

3. Experiments

It is worth mentioning that Liu, et al. [3] presented idea only, without any implementation design or evaluation whether theoretical or simulation-based. Lee, et al. [6] presented some simulation-based evaluation regarding percentage of dropped users.

We implemented two simulators, one for our proposed mechanism and the other for the original Vickrey auction (VA) for comparison. Using them, we conducted some simulation-based experiments for evaluation. Each result presented here is an average of ten trials.

The experiment setup is: the number of rounds is 10,000; there is one auctioneer node; there are 10 bidder nodes, and 50 jury member nodes, where more than two thirds of them are trustworthy. Each bidder has its own wealth in ascending order, where the bidder node 1 has the minimum, and the bidder node 10 has the maximum. The wealth of each bidder limits her/his willingness to pay and impacts her/his true valuation. Each bidder bids her/his true valuation to maxi-mize her/his expected utility in the recurring auction.

To model the bidder drop behavior, we introduce Tolerance to Consecutive Losses (TCL) [6] and RET. TCL denotes the maximum number of consecutive losses that a bidder can tolerate before quitting an auction. If the number of consecutive losses exceeds the bidder's TCL, the bidder considers that its true valuation prevents it from ever becoming a winner, and quits the auction. RET denotes the number of rounds after which a bidder having quitted reconsiders and comes back to the auction.

Figure 1 shows the number of each bidder's wins after 10,000 rounds where both TCL and RET are 100. In VA, the richer a bidder is, the more it wins. In the proposed mechanism, The number of wins of the richest bidders are restrained, while the numbers of wins of moderate bidders increase. Its consequence is presented in Figure 2, which shows the number of recurring quits. In the proposed mechanism compared to VA, the numbers of quits decrease, even drop to almost zero except for the poorest bidders in particular. This implies that the proposed mechanism is effective in promoting participation incentive.

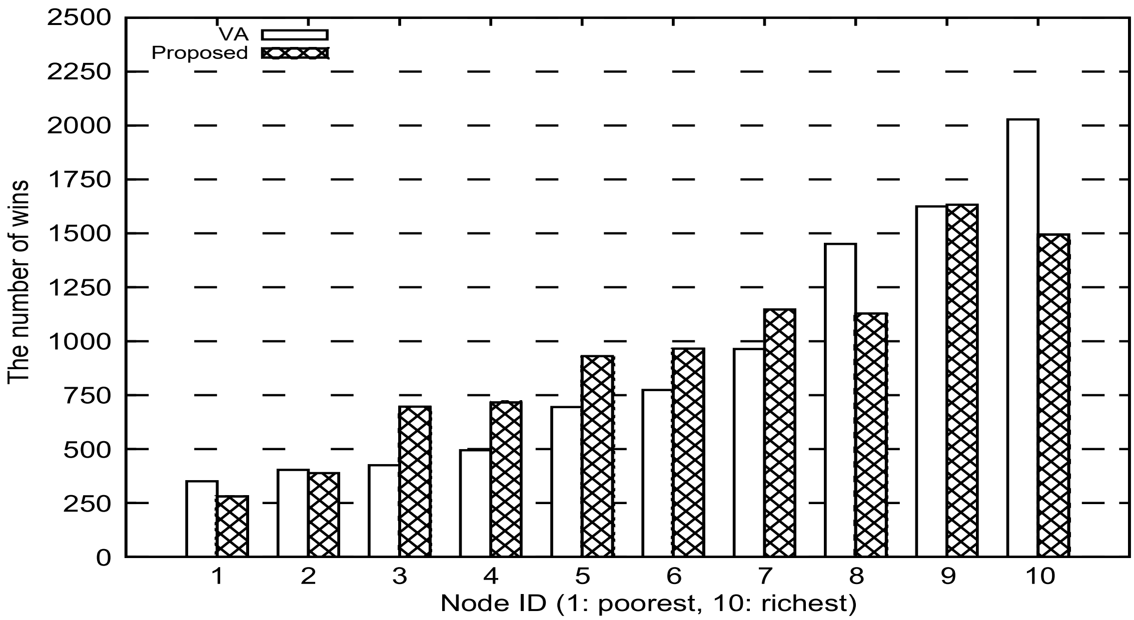

Figure 1: The number of wins

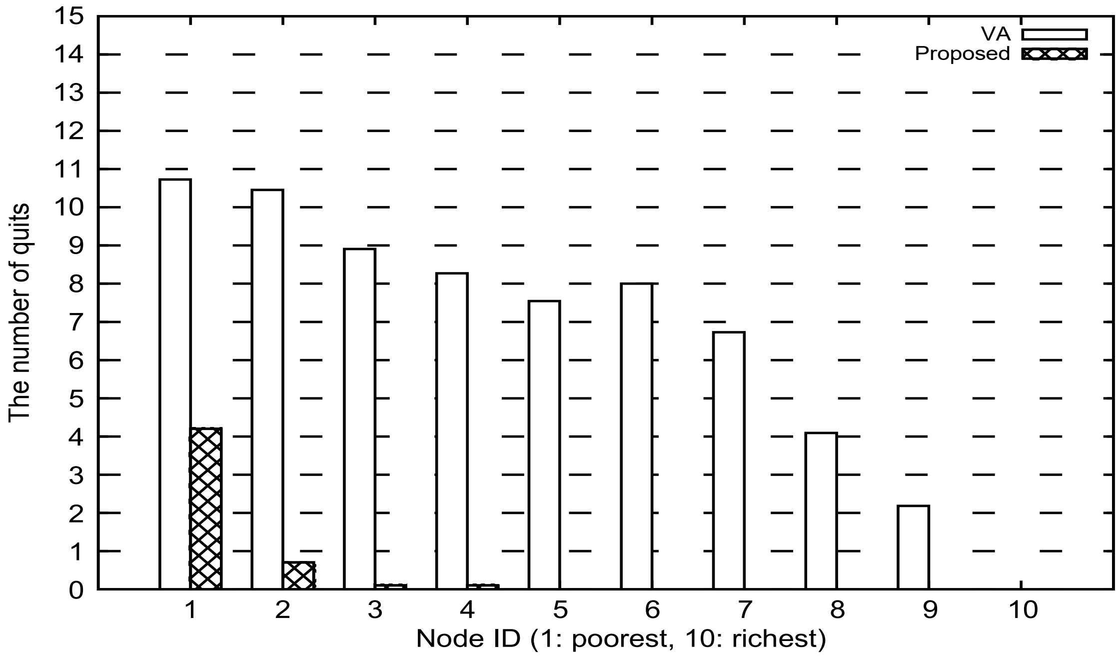

Figure 2: The number of quits

4. Concluding Remarks

This paper proposed a simple and light-weight mechanism for auction-based incentive promotion to participation and cooperation of participants. To address both the problems of fair execution and participation incentives, the mechanism integrated the concepts of two preceding studies. The results of the simulation-based experiments and evaluations confirmed that the proposed mechanism was effective in promoting participation incentives. We suppose that our approach is also applicable to newer and more sophisticated mechanisms, possibly more complex and heavy-weight, as well.

We have obtained some preliminary, yet promising results, however we are still at the beginning of this research, and there are still many issues which must be addressed. One of the next directions is to introduce trust management. If we apply trust management presented in Matsumoto, et al. [1], the jury members may be chosen out of already-trustworthy participants. Another interesting challenge is to apply this kind of incentive mechanisms to distributed ledger technologies [11] and volunteer-based federated machine learning [13].

References

[1] N. Matsumoto, M. Hiraide, and N. Yoshida, Trust Management in Growing Decentralized Networks, *Journal of Computations & Modelling*, **12** (3), (2022), 1-12.

[2] P. Obreiter, B. König-Ries, and M. Klei, Stimulating Cooperative Behavior of Autonomous Devices: An Analysis of Requirements and Existing Approaches, *Proc. Socond International Workshop on Wireless Information Systems*, (2003), 12 pages.

[3] J. Liu and V. Issarny, Service Allocation in Selfish Mobile Ad Hoc Networks Using Vickrey Auction, *Proc. 9th International Conference on Extending Database Technology*, (2004), 385-394.

[4] B. Yang and H. Sun, Packet Forwarding Based on Cooperative Game and Auction Theory in Wireless Ad Hoc Network, *Proc. International Conference on Multimedia Information Networking and Security*, (2010), 149-153.

[5] H. K.-B. Ayed, F. Jaïdi, and I. Doghri, Fairness and Access Control for Mobile P2P Auctions over MANETs, *Journal of Theoretical and Applied Electronic Commerce Research*, **7** (3), (2012), 11-27.

[6] J.-S. Lee and B. K. Szymanski, A Participation Incentive Market Mechanism for Allocating Heterogeneous Network Services, *Proc. Global Communications Conference*, (2009), 1-6.

[7] C. Wu, Z. Li, X. Qiu, and F. C. M. Lau, Auction-based P2P VoD Streaming: Incentives and Optimal Scheduling, *Transactions on Multimedia Computing, Communications, and Applications*, **2** (3), (2010), 20 pages.

[8] Q. Liu, X. Xian, and T. Wu, Game Theoretic Approach in Routing Protocol for Cooperative Wireless Sensor Networks, *Proc. International Conference in Swarm Intelligence*, (2011), 207-217.

[9] X. Zhang, Z. Yang, Z. Zhou, H. Cai, L. Chen, and X. Li, Free Market of Crowdsourcing: Incentive Mechanism Design for Mobile Sensing, *Transactions on Parallel and Distributed Systems*, **25** (12), (2014), 3190-3200.

[10] J. Li, Y. Zhu, Y. Hua, and J. Yu, Crowdsourcing Sensing to Smartphones: A Randomized Auction Approach, *Transactions on Mobile Computing*, **16** (10), (2017), 2764-2777.

[11] N. C. Luong, Z. Xiong, P. Wang, and D. Niyato, Optimal Auction for Edge Computing Resource Management in Mobile Blockchain Networks: A Deep Learning Approach, *Proc. International Conference on Communications*, (2018), 1-6.

[12] W. Vickrey, Counter Speculation, Auctions, and Competitive Sealed Tenders, Journal of Finance, **16** (1), (1961), 8-37.

[13] M. Qi, Z. Wang, S. Chen, and Y. Xiang, A Hybrid Incentive Mechanism for Decentralized Federated Learning, *Distributed Ledger Technologies: Research and Practice*, **1** (1), (2022), 15 pages.