Limiting the Deviation Incentives in Resource Sharing Networks*

Extended Abstract

Yukun Cheng
Suzhou Key Laboratory for Big Data and Information Service, School of Business,
Suzhou University of Science and Technology
ykcheng@amss.ac.cn

Xiaotie Deng, Yuhao Li
Center of Frontier of Computer Studies,
Department of Computer Science and Technology,
Peking University
xiaotie,yuhaoli.cs@pku.edu.cn

KEYWORDS

Resource Sharing; P2P Network; Incentive Ratio; Market Equilibrium

ACM Reference Format:
Yukun Cheng and Xiaotie Deng, Yuhao Li. 2020. Limiting the Deviation Incentives in Resource Sharing Networks. In *Proc. of the 19th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2020), Auckland, New Zealand, May 9–13, 2020,* IFAAMAS, 3 pages.

1 INTRODUCTION

Crowdsourcing, Peer-to-Peer (P2P) resource networks and sharing economies have created a sequence of new waves [11, 13, 16], to explore the power to match the needs of users and supplies from providers through the Internet and mobile networks [7, 10, 15]. To motivate sharing, [12] pioneered the use of incentive techniques to drive cooperation and to promote voluntary contributions by participating agents. Arbiguably, the BitTorrent protocol, created by Cohen [9], has been well recoganized, and then the BitTorrent network becomes one of few Internet wide successful P2P systems [17].

Pioneered by the idea of BitTorrent, Wu and Zhang [19] proposed the proportional response protocol (PRP) to allocate the bandwidth resource on P2P networks, under which each peer contributes its bandwidth to its neighbors in proportion to the amount received from them. The PRP not only is local information based, but also converges to a fixed point solution, which is exactly the same with a market equilibrium [19]. Those classic works developed a theory on the economic property of PRP except its incentive compatibility open. However, how to provide agent incentives to follow the designed protocols stands out the most important factor dictating the success of the designed protocols. The work in [19] left an open problem whether an agent would gain more utility if it cheats to report false information about its private information.

Recent effort has been made to show the PRP protocol promotes voluntary participations of network agents. [5, 6] have demonstrated that no agent can gain more utility by manipulative actions, such as cutting communication links or misreporting the amount of resource it owns. Obviously, the more manipulation a protocol can withstand, the better the protocol will perform in the realistic environment.

Unfortunately, in further analysis, it was shown that an agent can make such deviations to change the resource allocation for its benefit [1, 14, 18]. Past progress in this direction has been slow. Recently, several studies [2–4, 8] have been conducted on the incentives from Sybil attack, a grave threat in P2P system, for the resource sharing on some special networks such as trees, cliques and cycles, and characterize how much one can improve its utility at most and formalize the improvement formally by the cocept of *incentive ratio*.

The contribution in this paper is to establish the first result with a constant upper bound of incentive ratio on general networks. Our work settles a standing open problem along the line of research for bounding the incentive ratio for Sybil attack to the BitTorrent system.

2 PRELIMINARIES

The resource sharing problem on P2P network is modeled on an undirected graph $G = (V, E; w)$, on which each vertex represents an agent with an upload resource amount w_v. Denote the neighborhood of v by $\Gamma(v)$. Let $X = \{x_{vu}\}$ be an allocation of resource in the system, where x_{vu} is the amount of resource agent v allocates to its neighbor u. The utility of agent v from allocation X is $U_v(X) = \sum_{u\in\Gamma(v)} x_{uv}$.

Naturally, the resource sharing on P2P network can be understood as a *pure exchange market*, in which agent brings divisible resource to the market and exchanges its resource with neighbors to derive utility. As *market equilibrium* is well known as a standard economic notion for characterizing efficient allocations, we would like to pursue an allocation from a *market equilibrium* for resource sharing on P2P networks. Many works focused on the computation of market equilibrium. Specially for the resource sharing problem on P2P network, Zhang and Wu [19] proposed a *proportional response dynamics* to fairly allocate resource, which converges to a market equilibrium, and the corresponding equilibrium allocation can be obtained by a combinatorial mechanism.

Bottleneck Decomposition and BD Allocation Mechanism. For a subset $S \subseteq V$, let us define $w(S) = \sum_{v\in S} w_v$, and $\Gamma(S) = \cup_{v\in S}\Gamma(v)$. Note that $\Gamma(S) \cap S = \emptyset$ if and only if S is independent. Define $\alpha(S) = w(\Gamma(S))/w(S)$, named as the α ratio of S. A set B is

*This work was supported in part by National Natural Science Foundation of China (No. 11871366, 61761146005, 61632017). The authors contribute this work equally and the corresponding author is Xiaotie Deng.

Proc. of the 19th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2020), B. An, N. Yorke-Smith, A. El Fallah Seghrouchni, G. Sukthankar (eds.), May 9–13, 2020, Auckland, New Zealand.

called a *bottleneck*, if $\alpha(B) = \min_{S\subseteq V} \alpha(S)$. In addition, the bottleneck with the maximal size, is called the *maximal bottleneck*.

The *bottleneck decomposition* of a graph is obtained as follows. Given $G = (V, E; w)$, start with $V_1 = V$, $G_1 = G$, and $i = 1$. Find the maximal bottleneck B_i of G_i and let G_{i+1} be the induced subgraph on $V_{i+1} = V_i - (B_i \cup C_i)$, where $C_i = \Gamma(B_i) \cap V_i$. Repeat the process until $V_{k+1} = \emptyset$ for some $k \geq 1$. $\mathcal{B} = \{(B_1, C_1), \cdots, (B_k, C_k)\}$ is the bottleneck decomposition of G, in which (B_i, C_i) is the i-th bottleneck pair and $\alpha_i = w(C_i)/w(B_i)$ is the α-ratio of (B_i, C_i). Based on the bottleneck decomposition, we call vertex v a *B class* (or a *C class*) vertex if $v \in B_i$ (or $v \in C_i$), $i \leq k$, respectively.

From a bottleneck decomposition, an allocation (named as *BD allocation*) can be exlored from *BD Allocation Mechanism* as follows. For a pair (B_i, C_i), construct network $N = (V_N, E_N)$, with $V_N = \{s, t\} \cup B_i \cup C_i$ and directed edges (s, u) with capacity w_u for $u \in B_i$, (v, t) with capacity w_v/α_i for $v \in C_i$ and (u, v) with capacity $+\infty$ for $(u, v) \in (B_i \times C_i) \cap E$. The max-flow min-cut theorem ensures a maximal flow $\{f_{uv}\}$, $u \in B_i$ and $v \in C_i$, such that $\sum_{v\in\Gamma(u)\cap C_i} f_{uv} = w_u$ and $\sum_{u\in\Gamma(v)\cap B_i} f_{uv} = w_v/\alpha_i$. Let $x_{uv} = f_{uv}$ and $x_{vu} = \alpha_i f_{uv}$. For any other edge $(u, v) \notin (B_i \times C_i) \cap E$, let $x_{uv} = 0$.

Wu and Zhang [19] proposed some important results showing that, if set $p_v = \alpha_i w_v$, when $v \in B_i$; and $p_v = w_v$ when $v \in C_i$, then the price vector $p = (p_v)$ together with BD allocation X is a market equilibrium. Morever, $U_v(X) = \alpha_i w_v$ if $v \in B_i$ and $U_v = w_v/\alpha_i$ if $v \in C_i$.

Resource Sharing Game. Some works are interested in the *resource sharing game*, in which an agent may manipulate BD allocation mechanism by different strategies to change the resulting allocation. We mainly study the impact of Sybil attack for the resource sharing on general networks, and compute the incentive ratio of BD allocation mehcanism to characterize the extent to which utilities can be increased. Sybil attack is modeled as: agent v splits itself into m nodes $v^1, \cdots, v^m$, $1 \leq m \leq d_v$ (d_v is the degree of v) and assigns amount w_{v^i} of resource to each node v^i, satisfying $0 \leq w_{v^i} \leq w_v$ and $\sum_{i=1}^m w_{v^i} = w_v$.

We **observed** that the maximum utility from Sybil attack can be achieved by splitting into d_v nodes and each node is connected to one neighbor. Such an observation simplifies the discussion and make the strategic agent only focus on the weight assignment among d_v nodes to obtain the optimum. In the resulting network G', v's new utility U'_v is the sum of utilities from all copied nodes, denoted by U'_v. Then the incentive ratio of v is informally defined as $\zeta_v = \max\{U'_v/U_v\}$ and the incetive ratio of BD allocation mechanism is $\zeta = \max \zeta_v$. The main contribution in this paper is the following.

Theorem 2.1. *The incentive ratio of BD allocation mechanism against Sybil attack on general network is no more than three, i.e., $\zeta \leq 3$.*

3 INCENTIVE RATIO ON GENERAL NETWORKS

From the observation in Section 2, we only need to study the strategy that v splits into d nodes, $\{v^1, \cdots, v^d\}$, each node being adjacent to one neighbor, and assigns weight $(w_{v^1}, \ldots, w_{v^{d_v}})$ to each node. To obtain the result in Theorem 2.1, we shall prove for any $(w_{v^1}, \cdots, w_{v^{d_v}})$, v can not get more than three times of its original utility, i.e., $U'_v \leq 3 \cdot U_v$. Our main technique is to decompose the whole process from the initial network G to the ultimate one G' into $d-1$ step. In each step, v plays once *Resource Reserved Binary (RRB)* split. Given allocation X on current network, we say an agent plays RRB split to split one node out, if it partitions its neighborhood into two disjoint subsets: N_1 and N_2; and then splits itself into two nodes v^1 and v^2, along with weights $w_{v^l} = \sum_{u\in N_l} x_{vu}$, such that v^l is adjacent to all neighbors in N_l, $l = 1, 2$. In addition, between two adjacent steps, we shall adjust the weights of nodes properly. Therefore, we develop a successive process to help us to compute the incentive ratio.

Transform Process. Given the initial network G with weight profile $\mathbf{w}$, BD allocation X of G and a weight assignment $\{w_{v^1}, \cdots, w_{v^d}\}$, transform process includes:

- Pre-Processing: For each neighbor u^i, if $x_{vu^i} = w_{v^i}$, let v split node v^i out and connect v^i to u^i with weight $w_{v^i} = x_{vu^i}$. At the end of pre-processing, some neighbors of v are adjacent to nodes one-to-one, and others are connected to one node $\widetilde{v}$. Set the the resulting network to be G and $v := \widetilde{v}$.
- RRB Split: Partition $\Gamma(v)$ into two disjoint subsets: $\hat{N} = \{u^i | x_{vu^i} < w_{v^i}\}$ and $\check{N} = \{u^i | x_{vu^i} > w_{v^i}\}$. Let v play RRB split to split itself into two nodes $\hat{v}$ and $\check{v}$, such that all neighbors in $\hat{N}$ or $\check{N}$ are connected to $\hat{v}$ or $\check{v}$, respectively.
- Increasing process: Increase $w_{\hat{v}}$ continuously. During the increasing process, BD allocation X changes and at least one neighbor $u^i \in \hat{N}$ obtains more resource. Once the updated allocation $x_{vu^i} = w_{v^i}$, then let $\hat{v}$ split v^i out and connect u^i to v^i. Denote $\widetilde{v}$ to be the node that the rest neighbors in $\hat{N}$ are connected to. Set $\hat{v} := \widetilde{v}$ and continue to increase $w_{\hat{v}}$ until each split out node is a leaf and has a weight of w_{v^i}.
- Decreasing process: Decrease $w_{\check{v}}$ continuously. During the decreasing process, BD allocation X changes and at least one neighbor $u^i \in \check{N}$ obtains less resource. Once the updated allocation $x_{vu^i} = w_{v^i}$, then let $\check{v}$ split v^i out and connect u^i to v^i. Denote $\widetilde{v}$ to be the node that the rest neighbors in $\check{N}$ are connected to. Set $\check{v} := \widetilde{v}$ and continue to decrease $w_{\hat{v}}$ until each split out node is a leaf and has a weight of w_{v^i}.

In our constructive proof, we first execute the increasing process to increase $w_{\hat{v}}$ and split some node out iteratively, and then execute the decreasing process to decrease $w_{\check{v}}$ and split some node out iteratively. Note that there is a interim network $\widetilde{G}$, at which the increasing process has finished and then the decreasing process is about to begin. Conveniently, we denote U_v, $\widetilde{U}_v$ and U'_v to be the initial utility on G, the interim utility on $\widetilde{G}$ and the ultimate utility on G'.

Our proof for Theorem 2.1 includes two parts. The first is to prove $\widetilde{U}_v \leq 2 \cdot U_v$ if v is in B class; and $\widetilde{U}_v \leq 3 \cdot U_v$ if v is in C class, at the end of the increasing process. The second it to prove $U'_v \leq \widetilde{U}_v$ at the end of the whole process.

Proof for Theorem 2.1. In summary, if v is a C-class vertex, then $U'_v \leq \widetilde{U}_v \leq 3 \cdot U_v$; if v is a B-class vertex, then $U'_v \leq \widetilde{U}_v \leq 2 \cdot U_v$. □

REFERENCES

[1] Ning Chen, Xiaotie Deng, and Jie Zhang. 2011. How profitable are strategic behaviors in a market?. In *European Symposium on Algorithms*. Springer, 106–118.

[2] Zhou Chen, Yukun Cheng, Xiaotie Deng, Qi Qi, and Xiang Yan. 2017. Limiting users Sybil attack in resource sharing. In *International Conference on Web and Internet Economics*. Springer, 103–119.

[3] Zhou Chen, Yukun Cheng, Xiaotie Deng, Qi Qi, and Xiang Yan. 2019. Agent incentives of strategic behavior in resource exchange. *Discrete Applied Mathematics* 264 (2019), 15–25.

[4] Zhou Chen, Yukun Cheng, Qi Qi, and Xiang Yan. 2017. Incentive ratios of a proportional sharing mechanism in resource sharing. In *International Computing and Combinatorics Conference*. Springer, 137–149.

[5] Yukun Cheng, Xiaotie Deng, Yifan Pi, and Xiang Yan. 2015. Can Bandwidth Sharing Be Truthful?. In *International Symposium on Algorithmic Game Theory*. Springer, 190–202.

[6] Yukun Cheng, Xiaotie Deng, Qi Qi, and Xiang Yan. 2016. Truthfulness of a Proportional Sharing Mechanism in Resource Exchange. In *Proceedings of the Twenty-Fifth International Joint Conference on Artificial Intelligence, IJCAI 2016, New York, NY, USA, 9-15 July 2016*, Subbarao Kambhampati (Ed.). IJCAI/AAAI Press, 187–193. http://www.ijcai.org/Abstract/16/034

[7] Yukun Cheng, Xiaotie Deng, and Mengqian Zhang. 2019. A Novel Business Model for Electric Car Sharing. In *International Workshop on Frontiers in Algorithmics*. Springer, 76–87.

[8] Yu-Kun Cheng and Zi-Xin Zhou. 2019. An Improved Incentive Ratio of the Resource Sharing on Cycles. *Journal of the Operations Research Society of China* 7, 3 (2019), 409–427.

[9] Bram Cohen. 2003. Incentives build robustness in BitTorrent. In *Workshop on Economics of Peer-to-Peer systems*, Vol. 6. 68–72.

[10] Judd Cramer and Alan B Krueger. 2016. Disruptive change in the taxi business: The case of Uber. *American Economic Review* 106, 5 (2016), 177–82.

[11] Xiaotie Deng, Jianping Wang, and Juntao Wang. 2017. How to design a common telecom infrastructure for competitors to be individually rational and collectively optimal. *IEEE Journal on Selected Areas in Communications* 35, 3 (2017), 736–750.

[12] Michal Feldman, Kevin Lai, Ion Stoica, and John Chuang. 2004. Robust incentive techniques for peer-to-peer networks. In *Proceedings of the 5th ACM conference on Electronic commerce*. ACM, 102–111.

[13] Juho Hamari, Mimmi Sjöklint, and Antti Ukkonen. 2016. The sharing economy: Why people participate in collaborative consumption. *Journal of the association for information science and technology* 67, 9 (2016), 2047–2059.

[14] Leonid Hurwicz. 1972. On informationally decentralized systems,Decision and Organization(CB McGuire and R. Radner, Eds.), Chap. 14. (1972).

[15] Jing Lan, Yuge Ma, Dajian Zhu, Diana Mangalagiu, and Thomas Thornton. 2017. Enabling value co-creation in the sharing economy: The case of mobike. *Sustainability* 9, 9 (2017), 1504.

[16] Liang Ma, Xin Zhang, and Gao Shan Wang. 2017. Identifying the reasons why users in China recommend bike apps. *International Journal of Market Research* 59, 6 (2017), 767–786.

[17] Johan Pouwelse, Paweł Garbacki, Dick Epema, and Henk Sips. 2005. The bittorrent p2p file-sharing system: Measurements and analysis. In *International Workshop on Peer-to-Peer Systems*. Springer, 205–216.

[18] Donald John Roberts and Andrew Postlewaite. 1976. The incentives for price-taking behavior in large exchange economies. *Econometrica: Journal of the Econometric Society* (1976), 115–127.

[19] Fang Wu and Li Zhang. 2007. Proportional response dynamics leads to market equilibrium. In *Proceedings of the thirty-ninth annual ACM symposium on Theory of computing*. ACM, 354–363.