Synergistic based Social Incentive Mechanism in Mobile Crowdsensing

Can Liu[1], Feng Zeng[1,*], and Wenjia Li[2,*]

[1] School of Software, Central South University, Changsha, China,
{liucan512, fengzeng}@csu.edu.cn

[2] Department of Computer Science, New York Institute of Technology,
New York, USA ,
wli20@nyit.edu

Abstract. Most Mobile Crowdsensing(MCS) applications are large-scale and the quality of sensing for sensing tasks is interdependent. Previous incentive mechanisms have focused on quantifying participants' contribution to the quality of sensing and provide incentives directly to them, which are not applicable to the above scenario. To tackle this problem, in this article, we introduce a novel approach for MCS, called the synergistic based social incentive mechanism. The basic idea is to leverage the social ties among participants to promote cooperation. To maximize the utility of service provider, a moral hazard model is used to analyze the optimal contract between service providers and mobile users in the case of asymmetric information. Experiments show that the synergistic based social incentive mechanism can give users continuous encouragement while maximizing the utility of the principal.

Keywords: MCS; incentive mechanism; synergy; social relationship

1 Introduction

Under the circumstance that smartphones integrate many sensors, the research on MCS are becoming important and popular in recent years. Compared to traditional sensor networks, there are many advantages of data collection by MCS [1, 2]. Crowdsensing with smart devices can be used for large scale sensing of the physical world at low cost by leveraging the available sensors on the devices.

When performing sensing tasks, resource consumption like power consumption and traffic consumption will reduce the enthusiasm of users to participate in the sensing tasks. Therefore, the study of incentive mechanism is of great significance in the mobile crowdsensing system. The three most dominant incentive mechanisms in MCS are the game based incentive mechanism[3], auction based incentive mechanism and contract based incentive mechanism.

The reverse auction is the most frequently used auction method in the auction-based incentive mechanism[4–6]. Considering that users have the risk of exposing their privacy when participating in sensing tasks, [7, 8] proposed a two-stage auction algorithm for privacy-preserving issues separately. The contract is a popular approach in platform-leading approaches [9–11]. Li et al. in [10] believed that the agreement on the qualities and payments in crowdsensing systems can be best modeled as a contract. Inspired by the effort-based reward from the labor market, several works [12, 13] studied this problem by providing users with the amount of reward that is consistent with their performances.

The works above have provide necessary incentives for users to participate in the crowdsensing activity with independent tasks. In practice, most sensing applications are large-scale and the quality of sensing for sensing tasks are interdependent (e.g., data aggregation applications). Since the quality of sensing is interdependent among a collection of sensing tasks performed by independent participants, it is desired to stimulate cooperation among participants.

In this article, we propose a novel contract-based incentive mechanism by using the moral hazard problem from game theory, called the synergistic based social incentive mechanism. The social relationship between mobile users was applied to MCS, stimulating the cooperation between users. Then, we present detailed analysis of the conditions of cooperation and equilibrium status. Simulations are provided to demonstrate that the performance of the proposed incentive mechanism is better than traditional incentive mechanisms.

2 System Model

We consider large-scale sensing applications where the quality of sensing for sensing tasks is interdependent, and there is a synergy effects among users. Tasks in the MCS system are connected to each other due to interdependence, while participants are connected to each other by social relationships. In order to perform the task, participants need to cooperate with their social friends. It is shown in [14] that with the social relationship, participants can exert pressure on their social friends so that their behaviors will become better. We exploit this principle to promote cooperation between a participant and his/her social friends in this article. In the case of asymmetric information, we analyze the optimal contract between service providers and mobile users in order to maximize the utility of service providers.

2.1 0peration Cost

According to the commonly used method of simplifying the agent's effort cost function in the principal-agent problem, assume that the operation cost of the mobile user i is

$$C_i = \frac{1}{2}ka_i^2 + \frac{1}{2}k\sum_{j=1,j\neq i}^{n} a_{ij}^2 \tag{1}$$

The output of mobile user i is

$$x_i = a_i + \sum_{j=1,j\neq i}^{n} a_{ji} + \varepsilon_i, i = 1, 2, ..., n \tag{2}$$

$\varepsilon_i \sim N(0, \sigma^2)$, the sensing performance of tasks is given by Equation 3.

$$X = \omega\sum_{i=1}^{n} x_i \tag{3}$$

2.2 Reward Package

Inspired by the effort-based reward from the labor market [15], we define the user's reward package R_i in crowdsensing as a linear combination of several rewards: 1)fixed salary, 2)performance-related reward, 3)task sharing reward, 4)spiritual motivation. The reward package of user i is written as Equation 4.

$$R_i = R_0 + \beta x_i + \lambda X + R_p \tag{4}$$

2.3 Utility of Mobile User

All mobile users are rational and selfish. They are interested in accepting the mechanism provided by the principal only if the utility obtained under this mechanism is positive, the utility function of user i is shown in Equation 5.

$$U_i = R_i - C_i \tag{5}$$

2.4 Utility of Principal

Assuming that the service provider is risk-neutral, the utility function of principal is expressed as Equation 6.

$$U = E(X - \sum_{i=1}^{n} R_i) \tag{6}$$

3 Problem Formulation

With the system model, we can formulate the principal's utility maximization problem, which can be written as Equation 7.

$$\begin{aligned} &\max_{a_i, a_{ij}, \beta, \lambda} U \\ &s.t(IR) U_i \geq \overline{U_i} \\ &(IC)(a_i, a_{ij}) \in \arg\max(U_i) \end{aligned} \tag{7}$$

Proposition 1. *The basic condition for achieving cooperate is $k > bn$. In this case, $a_{ij} > 0$, the mutual influence of social members is positive.*

Proof. The definition of a_{ij} shows that a_{ij} reflects the mutual relationship among users. Thus, the condition for achieving cooperation is $\mathrm{a_{ij}} > 0$.

$$a_{ij}^* = \frac{b\beta + \lambda\omega k}{k(k - bn)} > 0 \Leftrightarrow k - bn > 0 \Leftrightarrow k > bn \tag{8}$$

Therefore, when $\mathrm{k} > bn, \mathrm{a_{ij}} > 0$, cooperation can be achieved. And there is the best strategy for users.

$$\begin{aligned} \mathrm{a}_i^* &= \frac{(k - bn - b)\beta + \lambda\omega k}{k(k - bn)} \\ \mathrm{a}_{ij}^* &= \frac{b\beta + \lambda\omega k}{k(k - bn)}, \forall j \neq i \end{aligned} \tag{9}$$

For the service provider, take the participation constraint into the objective function, the optimization strategy of principal is

$$\beta^* = \frac{kn^2\omega^2 (k - bn)^3 \rho\sigma^2}{-k^3 + n^2\omega \left[k + \rho(k - bn)^2\right] + \left[b(2k - bn) + (k - bn)^2 + \rho\sigma^2 k\right]}$$

$$\lambda^* = \frac{\left[b(2k - bn) + (k - bn)^2 + \rho\sigma^2 k\right]}{k + \rho\sigma^2 (k - bn)^2} \left(1 - \frac{k^2\rho\sigma^2 k - bn^2}{-k^3 + n^2\omega}\right) (k - bn) \left(k + \rho k - bn^2\right)$$

4 Simulation

In the experiments, we conduct a comparison of the principal's utility among different incentive mechanisms: 1)Incentive mechanism proposed in this paper, we name it by General, 2)When mobile users's reward is only composed of material rewards, and thus we name it by Single Bonus, 3)The third one called Independent, in this case, mobile users' rewards are only related to the performance of tasks that they perform.

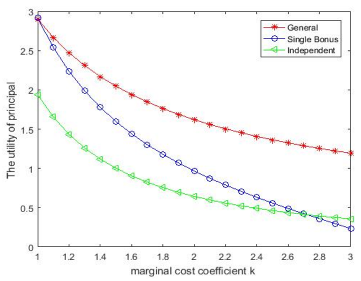

Fig. 1. The principal' s utility as the marginal cost coefficient k varies

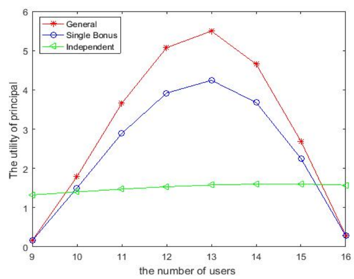

Fig. 2. The principal' s utility as the number of users varie

From the the curves in Fig. 1, we see that as the cost coefficient k increases, the principal' s utility is decreasing as well. In addition, we see that the principal obtains the largest utility in the General case. Followed by the Single Bonus, while the Independent gives the least utility. From the simulation results in Fig. 2, we see that as the number of users increases, the utility of the principal in the General case and the Single Bonus case increases, and then decreases after reaching the maximum value. In the Independent case, the utility of principal increases gradually with the increase of the number of users.

5 Conclusions

In this article, we have proposed a novel incentive mechanism for MCS, which leverages the power of social relationships to promote cooperation. Different from other works, we then focus on the scenario where the quality of sensing tasks are interdependent. The results show that the synergistic based social incentive mechanism is more cost-effective to promote cooperation.

References

1. He S, Shin D H, Zhang J, et al. Near-Optimal Allocation Algorithms for Location-Dependent Tasks in Crowdsensing[J]. IEEE Transactions on Vehicular Technology, 2017, PP(99):1-1.
2. Yang G, He S, Shi Z. Leveraging Crowdsourcing for Efficient Malicious Users Detection in Large-Scale Social Networks[J]. IEEE Internet of Things Journal, 2017, 4(2):330-339.
3. Nie J, Xiong Z, Niyato D, et al. A Socially-Aware Incentive Mechanism for Mobile Crowdsensing Service Market[J]. 2017.
4. Zhu X, Yang M, Jian A N, et al. Crowdsourcing incentive method based on reverse auction model in crowd sensing[J]. Journal of Computer Applications, 2016.
5. Zhu X, An J, Yang M, et al. A Fair Incentive Mechanism for Crowdsourcing in Crowd Sensing[J]. IEEE Internet of Things Journal, 2017, 3(6):1364-1372.
6. Duan Z, Li W, Cai Z. Distributed Auctions for Task Assignment and Scheduling in Mobile Crowdsensing Systems[C]// IEEE, International Conference on Distributed Computing Systems. IEEE, 2017:635-644.
7. Wang Y, Cai Z, Tong X, et al. Truthful incentive mechanism with location privacy-preserving for mobile crowdsourcing systems ☆[J]. Computer Networks, 2018, 135:32-43.
8. Wang Y, Cai Z, Yin G, et al. An incentive mechanism with privacy protection in mobile crowdsourcing systems ☆[J]. Computer Networks, 2016, 102:157-171.
9. Duan L, Kubo T, Sugiyama K, et al. Motivating Smartphone Collaboration in Data Acquisition and Distributed Computing[J]. IEEE Transactions on Mobile Computing, 2014, 13(10):2320-2333.
10. Li M, Lin J, Yang D, et al. QUAC: Quality-Aware Contract-Based Incentive Mechanisms for Crowdsensing[C]// IEEE, International Conference on Mobile Ad Hoc and Sensor Systems. IEEE Computer Society, 2017:72-80.
11. Zhao N, Fan M, Tian C, et al. Contract-Based Incentive Mechanism for Mobile Crowdsourcing Networks[J]. Algorithms, 2017, 10(3):104.
12. Luo T, Tan H P, Xia L. Profit-maximizing incentive for participatory sensing[C]// INFOCOM, 2014 Proceedings IEEE. IEEE, 2014:127-135.
13. Duan L, Kubo T, Sugiyama K, et al. Incentive mechanisms for smartphone collaboration in data acquisition and distributed computing[J]. Proceedings - IEEE INFOCOM, 2012, 131(5):1701-1709.
14. Mani A, Rahwan I, Pentland A. Inducing peer pressure to promote cooperation.[J]. Scientific Reports, 2013, 3(3):1735.
15. Bebchuk L A, Fried J M, Walker D I. Managerial Power and Rent Extraction in the Design of Executive Compensation[J]. University of Chicago Law Review, 2002, 69(3):751-846.