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Quality-aware incentive mechanism based on payoff maximization for mobile crowdsensing

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A B S T R A C T

Recent years, we have witnessed the explosion of smart devices. These smart devices are more and more powerful with a set of built in sensor devices, such as GPS, accelerometer, gyroscope, camera, etc. The large scale and powerful smart devices make the mobile crowdsensing applications which leverage public crowd equipped with various mobile devices for large scale sensing tasks be possible. In this paper, we study a critical problem of payoff maximization in mobile crowdsensing system with incentive mechanism. Due to the influence of various factors (e.g. sensor quality, noise, etc.), the quality of the sensed data contributed by individual users varies significantly. Obtaining the high quality sensed data with less expense is the ideal of sensing platforms. Therefore, we take the quality of individuals which is determined by the sensing platforms into incentive mechanism design. We propose to maximize the social welfare of the whole system, due to that the private parameters of the mobile users are unknown to the sensing platforms. It is impossible to solve the problem in a central manner. Then a dual decomposition method is employed to divide the social welfare maximization problem into sensing platforms' local optimization problems and mobile users' local optimization problems. Finally, distributed algorithms based on an iterative gradient descent method are designed to achieve the close-to-optimal solution. Extensive simulations demonstrate the effectiveness of the proposed incentive mechanism.

1. Introduction

Mobile crowdsensing [1,2] is a new paradigm which takes advantage of pervasive mobile users to collect and analyze data beyond the scale of what has previously possible and has drawn extensive research attention recently. Recent years, we have witnessed the number of smart devices (i.e. smartphones (iPhone, Huawei, etc.), wearable devices (Google Glasses, Apple watch, etc.), vehicle electronic devices (GPS, OBD-II, etc.)) is proliferating rapidly. Meanwhile, the capabilities of these smart devices' computation and communication are more and more powerful. These smart devices are equipped with various powerful built-in sensors, such as GPS, microphone, camera, gyroscope, accelerometer, etc. These make the smart devices become an important information interface between users and sensing environments. All the developments in micro electronics make the design of mobile crowdsensing be possible.

To make the crowdsensing systems be possible, two factors are very important: Large amount of pervasive smart devices and the technology and communications improvement of there smart devices. According to the International Data Corporation's report, the shipment of smartphones reached 1 billion in 2013 [3]. It has been estimated that the amount of smartphone users worldwide reached 2.5 billion in 2015 [4]. At the same time, wearable devices are more and more general in our life. These imply a large crowd of potential pervasive participants for mobile crowdsensing applications. On the other hand, nowadays, the computation capability of smart devices has been greatly strengthened. Besides, the development of 3G, 4G, 5G and Wi-Fi makes the smart devices could easily upload the sensing data to the crowdsensing application servers. Let us image that if all the smart devices in the world construct a crowdsensing network, it will be the largest sensing network that can be used to accomplish various sensing tasks without deploying large scale of static sensor networks.

Due to the great potential of mobile crowdsensing, lots of works have been designed for various crowdsensing applications, such as Sensorly [5] for making cellular/Wi-Fi coverage maps, Noise-Tube [6] for noise monitoring, SignalFuru [7] and VTrack [8] for monitoring the traffic. Micro-Blog [9] for facilitating real-time recoring and sharing of multimedia contents. LiFs [10] and TrMCD [11] for indoor localization. TruCentive [12] for crowdsourced parking, and DietSensing [13] for sharing pictures with a community to com-

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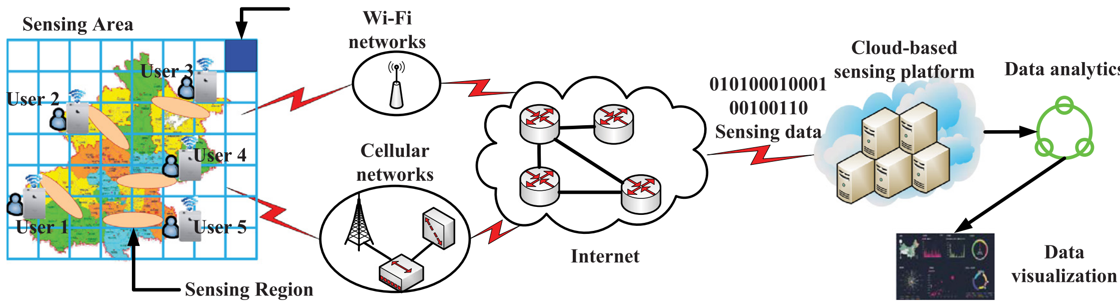

Fig. 1. System model of mobile crowdsensing.

pare eating habits. Moreover, riding the recent wave of social networks such as Facebook and MySpace, CenseMe is presented in [14], which is a novel applications that exploits the capabilities of mobile phones to automatically infer people's sensing presence and sharing this information with their social graph.

In the crowdsensing systems, as shown in Fig. 1, the sensing platforms which issue the sensing tasks reside in the cloud. A large group of smart devices distributed in the particular area which can be employed to do the sensing tasks connected with the sensing platforms via the cellular networks or Wi-Fi networks. The application servers then combine data from multiple participants, extracts the community summary, and use them to build a spatial and temporal view of the phenomenon of interest.

Lots of existing applications and systems, such as [5,8,15–17] are based on the voluntary participation of mobile users. However, in mobile crowdsensing, participators need to consume resources such as battery power, storages, computing power, etc. Furthermore, the mobile users may also reluctant to participate in the mobile crowdsensing due to the potential privacy threats when sensing data is submitted with their sensitive information (i.e. location tags, etc.). Therefore, the mobile users will refuse to participate in the mobile crowdsening without sufficient incentives. Without mobile users participation, the crowdsourcers could not achieve the good service quality. Many existing works [18–22] study how to use auction mechanism to provide incentive to users. These works usually assume that the mobile users are all rational and completely strategic. Then, Nash equilibria is computed at which each player would not change its strategy unilaterally if others do not change their strategies. The Nash equilibria always leads to sub-optimal system performance. Moreover, existing studies [21,23,24] model the interactions between platforms and mobile users as a two-stage game, then Stackelberg game theory is used to solve the interactions. This will also lead to sub-optimal system performance. None of these works based on game theory can maximize a system-wide objective which takes all the participants in the mobile crowdsensing systems into account.

Our work in this paper considers an area where lots of mobile users with smart devices randomly distribute in it, and the task initiators reside in the sensing platforms could issue various sensing tasks. We focus on maximizing the system-wide performance or social welfare for this mobile crowdsensing system. The social welfare is defined as the sum of all the participants' payoff, these participants include sensing platforms and mobile users. To accomplish this goal, we are facing two great challenges. First, the social welfare maximization problem can not be realized on the sensing platforms side. Due to the history sensing information, the sensing platforms only know the sensing quality of the mobile users, but do not know the private information of the mobile users. Consider the characteristics of the smart devices, for example if the mobile users are inside, it is easy to charge the smart devices at any time, in this case, the cost functions of the smart devices are very low. However, if the mobile users are outside, it is difficult for the mobile users to charge the smart devices, in this case, the cost functions of the smart devices are very high. This leads to another challenge. The crowdsensing is a large real-time system and we need to solve the social welfare maximization problem instantly.

To overcome these challenges, the dual decomposition method is employed to divide the social welfare maximization problem into a set of local optimization problems which can be solved by the sensing platforms and the mobile users. The sensing platforms issue task requests and provide unit prices for the tasks, the mobile user will respond an optimal sensing time that she/he will provide for the corresponding sensing platform, at the same time maximize her/his own payoff. It is worth pointing out that the mechanism designed in the paper makes the sensing platforms not need to collect the private information of the mobile users. The local optimal problems can be iteratively solved by the sensing platforms and the mobile users. The iterative algorithm is stopped when the demands of the sensing platforms and contributions of the mobile users reach a balance.

The main contributions of this paper are summarized as follows:

1 We formulate the multiple sensing platforms and multiple mobile users crowdsensing application into a social welfare maximization problem. We take the sensing quality of each mobile user into sensing platforms' utility modeling.
2 Dual decomposition method is employed to divide the social welfare maximization problem into local optimal problems, a distributed iterative algorithm is designed which can ensure the privacy of each mobile user. Meanwhile, dividing the complicated global optimization problem into sub optimization problems could greatly reduce the sensing-platforms' computation load.
3 Extensive simulations have validated our theoretical analysis about social welfare maximization problem, simulation results show that the distributed iterative algorithm will quickly converge to a stable state.

The rest of the paper is organized as follows. Literature review has been discussed in Section 2. In Section 3, we present the system model and formulate the problem as a social welfare maximization problem. The detailed incentive mechanism has been designed in Section 4. We evaluate the proposed mechanism via the extensive simulation in Section 5. At last, the conclusion of the paper is given in Section 6.

2. Literature review

Mobile phone sensing is an emerging area of interest for researchers as smartphones are becoming the core communication device in people's everyday live [1]. An iPhone-based mobile crowdsourcing platform, named mCrowd [25], is demonstrated where mobile users can participate and accomplish various tasks