Computer Networks 132 (2018) 1–14

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

A truthful incentive mechanism for mobile crowd sensing with location-Sensitive weighted tasks

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ARTICLE INFO

Article history:
Received 10 June 2017
Revised 27 October 2017
Accepted 24 December 2017
Available online 25 December 2017

Keywords:
Mobile crowd sensing
Location-sensitive
Incentive mechanism
Truthfulness
Auction

ABSTRACT

Mobile crowd sensing has emerged as an appealing paradigm to provide sensing data for its efficient economy. A large number of incentive mechanisms has been proposed for stimulating smartphone users to participate in mobile crowd sensing applications. Different from existing work, in addition to sensing tasks with diverse weights, we uniquely take into consideration the *crucial dimension of location information* when performing sensing tasks allocation. However, the location-sensitive weighted tasks are more vulnerable to the real life where each sensing task has the evident distinction. Meanwhile, the location sensitiveness leads to the increase of theoretical and computational complexity. In this paper, we investigate a truthful incentive mechanism which consists of two main components, winning bids determination algorithm and critical payment scheme. Since optimally determining the winning bids is *NP hard*, a near-optimal algorithm with polynomial-time computation complexity is proposed, which further approximates the optimal solution within a factor of $1 + \ln(n)$, where n is the maximum number of sensing tasks that a smartphone can accommodate. To guarantee the truthfulness, a critical payment scheme is proposed to induce smartphones to disclose their real costs. Through both rigid theoretical analysis and extensive simulations, we demonstrate that the proposed mechanism achieves truthfulness, individual rationality and high computation efficiency.

1. Introduction

Mobile crowd sensing with smartphones [1–4] has gradually bloomed into an appealing paradigm to collect various distributed sensing data for purposes [5]. The main application can be associated with the development and promotion of mobile crowd sensing systems such as the noise map calculation [6], real-time traffic delay prediction [7], citizen emergency monitoring [8] and so forth. Embedded with a variety of sensors, like GPS(Global Position System), microphone, camera, a smartphone can easily collect the essential data for various applications. Especially, smartphones gather ubiquitous data but only claim the little money, probably leading to enormous economic as well as the improvement of life quality [9].

A mobile crowd sensing system typically consists of a platform residing in the cloud, mobile smartphones and the platform users who consume sensing data. An example is illustrated in Fig. 1. The associated sensing tasks with diverse weights are released by the platform once it receives new arriving sensing requests from the platform users. Then the platform determines the appropriate set of smartphones to provide sensing services for new sensing tasks. Once receiving the hiring decision from the platform, the chosen smartphone starts to collect the required sensing data. Later, it submits the collected data to the platform, which aggregates the data to the platform user. Finally, the platform pays for the data. This demonstrates that a mobile crowd sensing system with geographically distributed smartphones can support a wide range of large-scale monitoring applications [8,10].

Motivation: *Stimulating smartphone users to participate in mobile crowd sensing system is fairly significant to the success of mobile crowd sensing with smartphones*. As we know, it incurs some non-negligible cost (*e.g.,* power consumption, bandwidth occupation) in consideration of limited resources when a smartphone provides sensing service for various applications [11,12]. Specifically, for our case, smartphones allocated to sensing tasks with higher weight are paid for more money, in consideration of more spent cost(*e.g.,* time cost). Furthermore, smartphone users may suffer the risk of privacy breach when providing sensing service related to their current location. Thus, smartphone users are usually reluctant to join a mobile crowd sensing system without sufficient incentives as compensation. However, the hypothetical sensing applications fail when no enough smartphone users provide the desired sensing

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https://doi.org/10.1016/j.comnet.2017.12.012
1389-1286/

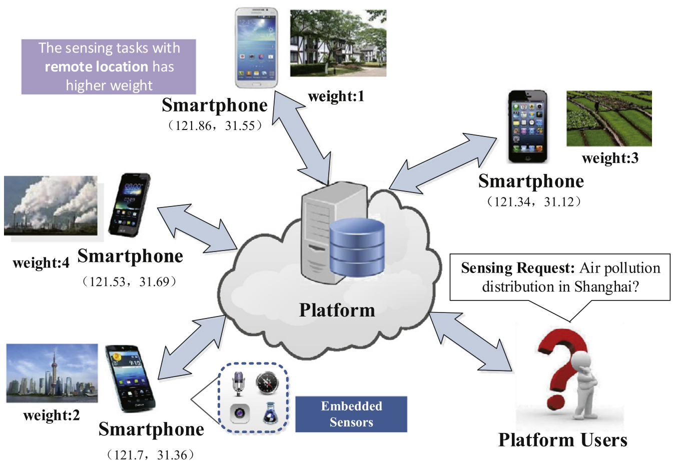

Fig. 1. An example of mobile crowd sensing applications. Smartphones are distributed over a large city. The location of each smartphone is described by a 2-tuple, (*longitude, latitude*). Each sensing task is to collect air pollution data. One with higher weight indicates the location to collect data is more distant. A platform user advertises sensing tasks through the platform residing on the cloud, and smartphones can contribute to the sensing tasks by returning their sensed data (*e.g.*, a photo of its surroundings) to the platform.

service. Unfortunately, although a large number of mobile crowd sensing applications [8,13–15] have been proposed, most of them have assumed that smartphones voluntarily contribute to the mobile crowd sensing system, which is not impractical in the real world.

The problem of stimulating smartphone users to participate in mobile crowd sensing applications is highly complicated because of smartphone user's strategic behaviors. In general, strategic users are selfish and self-interested. Thus, a smartphone user may misreport his real cost for maximizing his utility regardless of others' utility. The mobile crowd sensing system may bear the enormous economic loss in the long term. Furthermore, the cost information is private and unknown to the platform, which has no access to reveal the real value. Thus, designing a truthful incentive mechanism is non-trivial to induce smartphones to disclose their real cost.

There have been several research efforts on developing incentive mechanisms for mobile crowd sensing applications, which can generally be divided into three categories. One category of existing work [16,17] tends to adopt auctions for inducing cooperation from smartphones. In [16], Yang et al. design two incentive mechanisms to maximize the platform utility. Zheng et al. [18] propose a single parameter auction mechanism for the data procurement procedure under the known cost distribution, aiming to minimize the expected payment. The second category of existing work [17,19] utilizes the invisible indicator to stimulate cooperative behaviors of selfish smartphone users. Zhang et al. in [17] provide an incentive mechanism based on the repeated game to model the user's reputation. The final category of the existing work [9,20] designs an incentive mechanism based on the estimations of quality of information (QOI) submitted by smartphone users to avoid the strategy behaviors of smartphones.

In addition to sensing tasks with diverse weights, another significant observation is illustrated that location sensitiveness is central to most mobile crowd sensing application. A sensing task typically specifies the location where the sensing task should be performed. This is because that the desired sensing data are closely related to the specific location. A sensing data collected at an irrelevant location is meaningless or even invalid. This practical consideration on location sensitiveness caters to *more meaning and accurate matching between demands and supplies of sensing services*. Another significant observation is that most smartphone users are only willing to provide sensing service in a crowded area, thus, reluctant to spend more effort for sensing tasks with a remote location. Furthermore, we emphasize that the sensing task in a remote location has higher weight, indicating that it is more significant to incentivize smartphones to participate in such sensing task. Unfortunately, most of existing designs of incentive mechanism [21,22] have neglected this important dimension of location information in their designs.

In this paper, we introduce a practical *reverse auction framework*, in which the platform announces sensing tasks each of which has a location and weight attribute, and smartphones can submit multiple bids for a set of tasks within their service coverage according to the interest. Meanwhile, the corresponding claimed cost is disclosed with each submitted bid. For minimizing the social cost, the platform determines the set of winning bids, allocating all sensing tasks to the associated winning smartphone users. All winning users are paid for the rewards according to their contributions.

To make this reverse auction framework actually work for mobile crowd sensing with location-sensitive weighted tasks, we aim at designing a truthful incentive mechanism by which each smartphone would truthfully disclose its real cost. For our known combinatorial auction problem, *two critical problems* have to be addressed: 1) A task allocation algorithm to determine the cost-efficient bids has to be proposed, and 2) A payment decision scheme to fight against the strategic behavior of smartphones has to be proposed. Unfortunately, we prove that the optimal winning bids determination problem is *NP hard*. Thus, in this paper we design a truthful incentive mechanism which consists of *two main components*, the winning bids determination algorithm and critical payment scheme. The first algorithm approximately determines the set of winning bids, while the second algorithm determines the critical payment for each winning bid. Furthermore, we prove that the near-optimal algorithm can approximate the optimal solution within a factor of $1 + \ln(n)$, where n is the maximum number of sensing tasks that a smartphone can accommodate. As an additional part, we theoretically prove that the number of winning bids from the approximation solution has an upper bound α compared to that of the optimal solution when all smartphone users have the same claimed bid price. After rigorous theoretical proof and extensive simulations, the results demonstrate that our mechanism achieves truthfulness, individual rationality, high computational efficiency and modest overpayment ratio.

We highlight the main intellectual contributions as follows.

- We consider location sensitiveness as well as sensing tasks with diverse weights in the design of a truthful incentive mechanism for mobile crowd sensing with location-sensitive weighted tasks. Especially, the consideration of location information essentially increases the problem complexity of combinatorial auction design.
- We design an algorithmic mechanism for mobile crowd sensing with location-sensitive weighted tasks. We prove that optimally determining the winning bids with location sensitiveness is *NP hard*. The proposed mechanism consists of a *polynomial time and near-optimal task allocation algorithm* and a novel payment scheme that guarantees the truthfulness of the proposed mechanism.
- Through both rigid theoretical analysis and extensive simulations with real trace data sets, we demonstrate that the proposed mechanism achieves the desired properties of truthfulness, individual rationality and high computation efficiency. In addition, we theoretically prove that the number of winning bids from the approximation solution has an upper bound α compared to that of the optimal solution when all smartphone users have the same claimed bid price.