

Deadline-Sensitive User Recruitment for Probabilistically Collaborative Mobile Crowdsensing

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Abstract—Mobile crowdsensing is a new paradigm in which a group of mobile users exploit their carried smart devices to cooperatively perform a large-scale sensing job over urban environments. In this paper, we focus on the Deadline-sensitive User Recruitment (DUR) problem for probabilistically collaborative mobile crowdsensing, in which mobile users perform sensing tasks with certain probabilities, and multiple users might be recruited to cooperatively perform a common task, ensuring that the expected completion time be no larger than a deadline. In order to solve this problem, we propose a greedy approximation algorithm, which can achieve the logarithmic approximation ratio.

Keywords-crowdsensing; mobile social network; probabilistic collaboration; user recruitment

I. INTRODUCTION

Because of the explosive proliferation of smartphones, a new sensing paradigm, called *mobile crowdsensing*, is proposed [2]. Roughly speaking, mobile crowdsensing refers to a group of mobile users being coordinated to perform a large-scale sensing job over urban environments through their carried smartphones. Since mobile crowdsensing can perform sensing jobs that individual users cannot cope with, it has attracted much attention. By far, many user recruitment or task allocation algorithms have been designed for mobile crowdsensing systems [1], [3]–[6].

In this paper, we focus on the Deadline-sensitive User Recruitment (DUR) problem for probabilistically collaborative mobile crowdsensing. More specifically, a requester wants to collect some sensing data from many points of interest (PoIs) in an urban area. Then, it publishes a crowdsensing request to some mobile users via mobile social networks. These mobile users move around in the urban area every day. Each user might pass by (i.e., *cover*) some PoIs, so that it can collect the related sensing data every day with some probabilities, as shown in Fig. 1. In order to improve the probability of success, multiple users can be recruited to cooperatively perform a common task. Moreover, if a mobile user participates in crowdsensing, it will charge a cost from the requester as the reward. Our main concern is determining which users the requester should recruit, so that it can minimize the total cost while ensuring that the

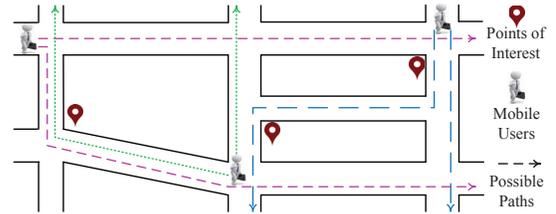


Figure 1. An example of mobile crowdsensing with probabilistic collaboration: three mobile users move around in an urban area, each of which passes by some points of interest (subject to its mobility) and collects sensing data every day with some probabilities, until the data is collected successfully.

expected completion time of the crowdsensing be no larger than the given deadline.

Since our DUR problem is NP-hard, we propose an approximation algorithm, called *gDUR*, to solve the problem. In *gDUR*, we design a utility function, and adopt a greedy strategy to recruit mobile users by maximizing the utility values. Such a greedy strategy can achieve the logarithmic approximation ratio.

II. MODEL & PROBLEM

We consider a mobile crowdsensing, in which a *requester* wants to recruit some users to perform some sensing tasks in an urban area. The candidate users are denoted by a user set $\mathcal{U}=\{u_1, \dots, u_n\}$, and the sensing tasks are denoted as a task set $\mathcal{S}=\{s_1, s_2, \dots, s_m\}$, where each task s_j ($1 \leq j \leq m$) is related to a specific PoI. Time is divided into many equal-length sensing cycles. We use τ to denote a *sensing cycle* for generality. Moreover, we use p_{ij} to denote the *successful probability* of user u_i performing task s_j in each sensing cycle. Additionally, each user u_i will charge a cost c_i from the requester for participating in crowdsensing.

We focus on the DUR problem in the above mobile crowdsensing, i.e., which users in \mathcal{U} the requester should recruit, so that it can minimize the cost of processing these tasks, when given a *deadline* \mathcal{T} . We use set Φ to denote a user recruitment strategy, where $u_i \in \Phi$ indicates that user u_i is recruited. Then, the joint probability of task s_j being processed successfully in each sensing cycle can be denoted as $\rho_j^\Phi = 1 - \prod_{u_i \in \Phi} (1 - p_{ij})$. Further, the DUR problem can

Algorithm 1 The gDUR Algorithm

Require: $\mathcal{U}, \mathcal{S}, \mathcal{P}=\{p_{ij}|u_i \in \mathcal{U}, s_j \in \mathcal{S}\}, \mathcal{C}=\{c_i|u_i \in \mathcal{U}\}, \tau, \mathcal{T}$

Ensure: Φ

- 1: $\Phi = \emptyset$;
 - 2: **while** $f(\Phi) < \frac{m\tau\theta}{\mathcal{T}}$ **do**
 - 3: Select a user $u_i \in \mathcal{U} \setminus \Phi$ to maximize $\frac{f(\Phi \cup \{u_i\}) - f(\Phi)}{c_i}$;
 - 4: $\Phi = \Phi \cup \{u_i\}$;
 - 5: **return** Φ ;
-

be formalized as follows:

$$\text{Minimize : } C(\Phi) = \sum_{u_i \in \Phi} c_i \quad (1)$$

$$\text{Subject to : } \Phi \subseteq \mathcal{U} \quad (2)$$

$$\frac{\tau}{\rho_j^\Phi} \leq \mathcal{T}, \quad 1 \leq j \leq m \quad (3)$$

III. DEADLINE-SENSITIVE USER RECRUITMENT

In this section, we first analyze the complexity of the DUR problem. Then, we propose the gDUR algorithm based on a utility function.

Theorem 1: The DUR problem is NP-hard.

Proof: We consider a special case of the DUR problem: given a probabilistically collaborative mobile crowdsensing, where $p_{ij} = p$ or $p_{ij} = 0$ ($1 \leq i \leq n, 1 \leq j \leq m$), $c_i = 1$ ($1 \leq i \leq n$), and $\mathcal{T} = \frac{\tau}{p}$, determine a set $\Phi \subseteq \mathcal{U}$, such that the requester can minimize $C(\Phi) = \sum_{u_i \in \Phi} c_i = |\Phi|$, while the expected processing time of each task is no larger than \mathcal{T} . Actually, this special DUR problem is to select the minimum number of users from \mathcal{U} who can process all tasks in \mathcal{S} . When we replace each u_i in \mathcal{U} by using the set of tasks that u_i can process, denoted by \mathcal{S}_i , this problem can be seen as a set cover problem, a well known NP-hard problem: given a task set \mathcal{S} , a collection of subset $\{\mathcal{S}_i | 1 \leq i \leq n\}$, find a minimum size of subcollection of $\{\mathcal{S}_i | 1 \leq i \leq n\}$ that covers all tasks in \mathcal{S} . That is to say, the special DUR problem is NP-hard. Consequently, the general DUR problem is also at least NP-hard. Therefore, the theorem holds. ■

Since DUR is NP-hard, we propose a greedy algorithm to solve it. The greedy criterion is that the user who has the largest probability to process the most tasks with the least cost will be recruited and added into the set Φ first, which is based on the following utility function:

Definition 1: Utility function $f(\Phi)$ indicates the utility about the successful probability of the users in set Φ processing all tasks in \mathcal{S} before the deadline, defined as follows:

$$f(\Phi) = \theta \sum_{j=1}^m \min\{\rho_j^\Phi, \frac{\tau}{\mathcal{T}}\}, \quad (4)$$

where $\theta = \max\{\theta_1, \theta_2\}$ is a constant related to the approximation factor of the gDUR algorithm, in which $\theta_1 = \frac{\mathcal{T} \sum_{i=1}^n c_i}{m\tau}$, and $\theta_2 = \max\{\frac{c_i | 1 \leq i \leq n}{\tau - \rho_j^\Phi} | 1 \leq j \leq m, \rho_j^\Phi < \frac{\tau}{\mathcal{T}}, \Phi \subseteq \mathcal{U}\}$.

Based on the utility function, we propose the gDUR algorithm, as shown in Algorithm 1. The gDUR algorithm starts from an empty user set Φ . In each round, it adds the user who has the maximum $\frac{f(\Phi \cup \{u_i\}) - f(\Phi)}{c_i}$ value into Φ . The algorithm terminates when $f(\Phi) = \frac{m\tau\theta}{\mathcal{T}}$. The computation overhead is dominated by Step 3, which is $O(n^2m)$. Note that θ in the utility function $f(\Phi)$ is a constant. It is only related to the approximation factor. Hence, we can simply let $\theta = 1$ in the real implementation of gDUR, since it will not change the comparison results in Steps 2 and 3, and also will not change the final result. Additionally, it can be proved that the gDUR algorithm guarantees an approximate ratio of $(1 + \ln \frac{m\tau\theta}{opt \mathcal{T}})$, where opt is the optimal solution for the DUR problem.

IV. CONCLUSION

We study the DUR problem in the probabilistically collaborative mobile crowdsensing. This is a combining probabilistic set cover problem mixed by non-linear programming. First, we prove its NP-hardness. Then, we design a utility function, based on which we propose the greedy approximation algorithm gDUR. This greedy algorithm can be proved to guarantee a logarithmic approximation ratio.

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