Graduate School of Fundamental Science and Engineering
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博 士 論 文 概 要
Doctoral Thesis Synopsis

論 文 題 目
Thesis Theme

Study on Incentive Mechanism of Crowdsourcing Data Collection for Indoor Localization
クラウドソーシングによる屋内測位データ収集のインセンティブメカニズムの研究

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Both the industry and the academia have witnessed the rapid evolution of indoor location-based services. It benefits to produce a great quantity of applications, i.e., asset tracking, indoor positioning and navigation, location sharing in different scenarios such malls, hospitals, airports and train stations. To achieve location information, diverse indoor localization techniques have attracted considerable interest from the research community. In particular, a large body of indoor localization approaches exploit received signal strength (RSS) as a metric for location determination, since they can utilize the existing network infrastructures deployed in the indoor environment. The RSS fingerprint-based scheme involves a site survey process, where RSS values at known locations are collected and then associated with known physical positions to build the fingerprint database (also termed as radio map) that is used for location estimation.

However, in real-world cases, it is cost-prohibitive, labour-intensive, and time-consuming to perform a site survey for the fingerprint database, which limits the applicable buildings of wireless localization worldwide. Therefore, how to significantly reduce the calibration effort of fingerprint collection is an essential research topic in the area of wireless network communications. In recent years, mobile crowdsourcing has been an attractive solution for massive data collection and data processing. It has a merit to leverage the power of mobile users to complete a complex and tedious task. Thus, extensive studies have been conducted to utilize mobile crowdsourcing to reduce the calibration effort of site survey by allowing common users to contribute fingerprint data in a participatory sensing manner.

The objective of this dissertation is to study the design of incentive mechanism of mobile crowdsourcing-empowered data collection that is used in the application of indoor localization. This dissertation consists of two main chapters preceded by an introduction and terminated by conclusions. All the chapters are described as follows:

Chapter 1 presents an introduction on research background of mobile crowdsourcing-based fingerprint data collection. In addition, this chapter describes the research objectives from the perspective of incentive mechanism design, user privacy protection and sensing quality estimation. What's more, this chapter also summarizes the main contributions and gives an overview and structure of the dissertation for better understanding.

Chapter 2 covers the preliminaries and theories relevant to mechanism design, game theory, as well as differential privacy that are necessary to readers, which are used in the future chapters.

Firstly, a short introduction of mechanism design is presented, which includes basic theories for mechanism design from the perspective of economics, the framework with an example over the mechanism design as well as important foundations.

Then, the preliminary knowledge on game theory is presented. Game theory is a promising

mathematical tool to analyse the strategic interactions among different players. In addition, in this dissertation, in order to characterize the strategic interactions among the roles in mobile crowdsourcing-based systems, Stackelberg game and auction theory are both introduced, as well as some relevant examples for these theories are also described for illustrative purpose.

Furthermore, the issue of users' privacy protection that is encountered in mobile crowdsourcing-based applications is presented. To preserve user privacy, the celebrated differential privacy together with a special case is explained.

Chapter 3 studies the design of incentive mechanism for crowdsourcing-empowered fingerprint data collection without sensing quality consideration. Intuitively, on one hand, the costs to perform this crowdsourcing task, such as the battery usage, data rates, and computational resources, are all paid by the users. Therefore, mobile users are reluctant to take part in the mobile crowdsourcing-based system unless the satisfied reward can be provided to compensate their costs. Accordingly, the design of incentive mechanism is a critical issue in the field of mobile crowdsourcing-based fingerprint data collection for indoor localization, which aims to attract users' participation. On the other hand, the privacy issue has been one of the major concerns for mobile crowdsourcing-based systems due to that mobile users' contributed data may involve personal sensitive information such as location information, identity information and activity record. If these sensed data are leaked, they will suffer privacy threats, which might further limit users' participation. To deal with these issues, this chapter is concerned on the design of incentive mechanism without sensing quality consideration, which aims to attract enough mobile users' participation, as well as protect the privacy of the sensed data of mobile users.

Firstly, this chapter presents the definition of indoor trajectory and proposes a trajectory utility function to characterize the relation between the length of indoor trajectory and the privacy protection achieved by using differential privacy.

Secondly, the fixed reward-driven incentive mechanism is proposed under the incomplete information scenario that the sensitivity level of the privacy of each mobile user's data is unknown to the platform. Subsequently, the strategic interactions between the platform and mobile users are modelled as a two-stage Stackelberg game, where the platform acts the leader and mobile users act as the followers. The objective of this mechanism is to maximize the utilities of the platform and mobile users, respectively, where users' total payment does not violate the fixed reward of the platform.

Thirdly, a variable reward-driven incentive mechanism is further devised under the complete information scenario that the sensitivity level of the privacy of each user's data is public to the platform. Moreover, a demand function is exploited to characterize the relationship among the platform, mobile

users, and service consumers with the goal to reflect the impact of the price fluctuation. The objective of the variable reward-based mechanism is to maximize the profit of the platform.

Eventually, the performance of these two incentive mechanisms are assessed by using numerical simulations. In particular, the fixed reward-driven incentive mechanism is compared with a platform-centric scheme without considering the privacy issue.

Chapter 4 studies the design of incentive mechanism with sensing quality consideration. In practice, it is extremely challenging to quantify the sensing quality of the sensed data shared by mobile users because of the lack of users' historical data and ground truth. Different from Chapter 3, this chapter focuses on the incentive mechanism design with sensing quality consideration.

Foremost, the metric of sensing quality is proposed to characterize the joint impact of privacy protection and the spatial coverage, where local differential privacy is used to protect users' privacy. In addition, given the budget constraint, the sensing quality maximized problem is formulated.

Secondly, a non-truthful incentive mechanism under the budget constraint is proposed to maximize the sensing quality, where the platform does not know whether mobile users would report their costs truthfully. This formulated problem is then transformed into the classical budgeted maximum coverage problem with the goal to prove its NP-hardness. In the meantime, a greedy-based algorithm is proposed to obtain an approximate solution for the budgeted sensing quality maximization problem.

Thirdly, in order to maintain the truthfulness of mobile users' costs, a truthful incentive mechanism based on auction theory is proposed, where the platform act as the auctioneer and mobile users are the bidders. In addition, this scheme incorporates the sensing quality into the valuation function of the platform and the sensing quality maximized problem is transferred into the maximum valuation problem with a budget constraint. Furthermore, an algorithm is designed to solve this problem, which includes the winner selection phase and the payment determination phase. This auction-driven incentive mechanism is theoretically proved to be truthful, budget feasible, individual rational, and computationally efficient.

In the end, numerical simulations are conducted to evaluate the proposed incentive mechanisms. Moreover, extensive experiments based on real-world data are carried out to have an evaluation on the non-truthful incentive mechanism, which concern on the impact of the privacy protection and the budget on the localization performance, respectively.

Finally, Chapter 5 makes the main conclusions of this dissertation, as well as, presents several future research directions.

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International Conference	(3) Wei Li, Zhi Liu, Chang Zhang, and Yoshiaki Tanaka, “Sensing Quality based Mechanism Design for Crowdsourcing-based Indoor Localization,” 20th Asia-Pacific Network Operations and Management Symposium (APNOMS 2019), Matsue, Japan, Paper No.IS1-2, 15 pages, September 2019.
Domestic Conference	(4) Wei Li, Cheng Zhang, Zhi Liu, and Yoshiaki Tanaka, “An Incentive Mechanism of Crowdsourcing Fingerprinting for Indoor Localization with Device Heterogeneity Reduction,” 2018 IEICE General Conference, No.BS-2-27, pp.S-52-S-53, March 2018. (5) Wei Li, Cheng Zhang, Zhi Liu, and Yoshiaki Tanaka, “A Two-Sided Pricing and Privacy Preservation Based Incentive Mechanism for Mobile Crowdsensing,” 2018 IEICE Communications Society Conference, No.BS-7-16, pp.S-54-S-55, September 2018. (6) Wei Li, Cheng Zhang, Zhi Liu, and Yoshiaki Tanaka, “Optimal Two-Sided Pricing-based Incentive Mechanism for Mobile Crowdsourcing with Network Effects,” 2019 IEICE General Conference, No.BS-4-6, pp.S-19-S-20, March 2019.