Incentive Mechanisms for Mobile Crowd Sensing: Current States and Challenges of Work

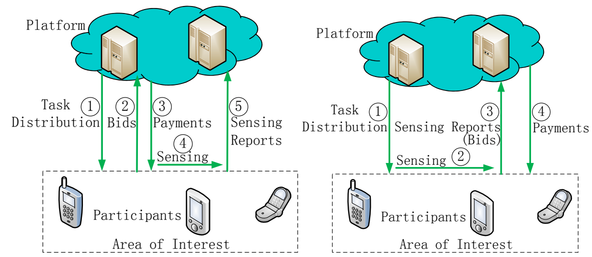
Jiajun Sun and Huadong Ma
Beijing University of Posts and Telecommunications, Beijing 100876, China
Email: jiajunsun.bupt@gmail.com, mhd@bupt.edu.cn

***Abstract*—Mobile crowd sensing (MCS) is a new paradigm which leverages the ubiquity of sensor-equipped mobile devices such as smartphones, music players, and in-vehicle sensors at the edge of the Internet, to collect data. The new paradigm will fuel the evolution of the Internet of Things to three changes as follows: First, the terminal devices at the edge of the Internet change from PCs to mobile phones. Second, the interactive mode extends from the virtual space to the real physical world. Thirdly, the forwarding manner of sensing data are undergoing the transition from the priori to the opportunistic. To better meet the demands of MCS applications at a societal scale, incentive mechanisms are indispensable. In this paper, we will first overview three categories of MCS applications, and then propose a new architecture for MCS applications. Based on the architecture, we discuss various research challenges about incentive mechanism designs for MCS applications, followed by potential future work discussions. Finally, we present potential future works.**

I. Introduction

The increasing ubiquity of sensor-embedded mobile devices (e.g., smartphones) at the edge of the Internet, will result in the evolution of the Internet of Things (IoT) to three changes as follows: First, the terminal devices at the edge of the Internet change from PCs to mobile phones. Second, the interactive mode extends from the virtual space to the real physical world. Thirdly, the forwarding manner of sensing data are undergoing the transition from the priori to the opportunistic. To better meet the demands, mobile crowd sensing (MCS) is a natural fit to achieve good service quality for various social large scale applications, which takes advantage of the pervasive mobile devices to solve complex sensing taskslike VTrack [1] for provide omnipresent traffic information, etc. As well as crowdsourcing, a good incentive mechanism is indispensable crucial factor determining whether MCS applications can achieve good service quality.

Different from the "typical" IoT objects (e.g., static sensor nodes) that are based on a common hypothesis that all users are based on voluntary participation in submitting the sensing data. These mobile devices are controlled by rational users, in order to conserve energy, storage and computing resources, so selfish users could be reluctant to participate in sensing data for MCS applications. Thus, it is indispensable to provide some incentive schemes to stimulate selfish participants to cooperate in MSNs. We believe incentive mechanism's research for MCS will drive a plethora of IoT applications that elaborate our knowledge of the physical world.



(a) (b)

Fig. 1. Comparison among different mobile crowd sensing paradigms.(a)The VCG based mobile crowd sensing process; (b)The mobile crowd sensing process proposed in our paper.

Incentive mechanism's researches for MCS applications can be broadly classified into three categories: extensive user participating incentive, submission sensing quality incentive, and privacy-aware incentive, based on the type of phenomena being sensed. In extensive user participating incentive mechanisms, incentive mechanisms have two system models: the user-centric model where participating users have more control over the payment from the platform they will receive, and the platform-centric model where the platform provides a reward shared by the participating users. For example, traditional incentive mechanisms such as the Vickrey-Clarke-Groves (VCG) mechanism and its variants can implement the above two model to promote the adequate user participation (see Fig. 1(a))

On the other hand, submission sensing quality incentive pertains to an endogenous, strategic choice from participating users, which cannot be easily measured by exogenous entries. Our framework has been proposed to address extensive MCS applications (see Fig. 1(b)). For example, intelligent transportation systems may require traffic congestion monitoring and air pollution level monitoring. These phenomena can be measured accurately only when many individuals provide high speed and good air quality information from their daily commutes, which need participants' to exert efforts to determine highly correct congestion and pollution levels in cities.

Privacy-aware incentive is also popularly indispensable for stimulating user extensive participating for MCS applications. If the privacy of users is not well protected, users will be still reluctant to participate in MCS applications and submit high quality sensing data. For example, some protocols study users' truthfulness to guarantee extensive user participating in traditional VCG based incentive mechanisms, but the required bids and users' preferences will disclose users' personal privacy. Other protocols use the pre-existing social network information to enhance the user social status, however the social network information will also depressively release user's identity privacy and social profile privacy. Since huge security and privacy risks are heavily associated with incentive mechanisms in MCS applications, a good privacy-aware incentive is crucial for the success of MCS applications.

The rest of the paper is organized as follows. In Section II, we will discuss this set of MCS applications in depth in next section. This will be followed by our proposed architecture for MCS applications in Section III. In Section IV, we will then discuss the crucial challenges in incentive mechanism design for MCS applications, followed by the potential future works about incentive mechanism designs in Section V. Finally, Section VI will conclude with final thoughts.

II. Mobile Crowd Sensing Applications

In this section, we will briefly survey existing MCS applications, which provide a basis for discussing various research challenges in the rest of this paper. We classify MCS applications into three different categories based on the type of phenomenon being measured or mapped. These include: urban transportation, health services, public safety.

A. Urban Transportation

Urban transportation including public travel smart navigation, efficient car travels, municipal traffic intelligent management, and other municipal remains a serious global problem in MCS applications. For example, traffic congestion alone can severely impact both the environment and human productivity (e.g., wasted hours due to congestion). In large cities, monitoring road traffic conditions usually takes a lot of manpower and material resources. It is unrealistic to arrange the traffic policemen on duty around every street corner. A large number of cameras are deployed to automatically monitor only if advanced image analysis techniques are combined with it. Some researchers are using mobile phones to monitor people in the movement of public transport to deduce the situation of road congestion. The authors of [2] develop a bus arrival time prediction system based on bus passengers' crowd sensing. Their system solely relies on the collaborative effort of the participating users and is independent from the bus operating companies, so it can be easily adopted to support universal bus service systems without requesting support from particular bus operating companies. The basic idea of the system that passengers taking a bus currently provides real-time information for a backend server, the server compute and predict each bus arrival time of arriving at each bus stop by leveraging information provided by passengers, and then provide these real-time information to people who are waiting for bus or ready to take the bus. The authors of [3] develop a navigation service by applying mobile crowd sensing data to map fuel consumption on city streets, which helps drivers to find the most fuel efficient routes for their driving vehicles between arbitrary end-points. The MIT VTrack project [1] or the Mobile Millennium project (developed by the California Center for Innovative Transportation (CCIT), the Nokia Research Center (NRC), and the University of California (UC) at Berkeley) [4] are being applied to provide fine-grained real-time traffic flow information based on a large scale mobile phone held by users to provide accurate travel time estimation for improving commute planning, etc.

B. Health Services

The sensing information used for personal health care today largely comes from self-report surveys and infrequent doctor consultations. Sensor-equipped mobile phones have the potential to collect continuous sensing data that may dramatically change the way health. As such, wellness are evaluated as well as how care and treatment are delivered. The UbiFit Garden [5], a joint project between Intel and the University of Washington, which applies these technologies and a personal, mobile display to encourage physical activity by relating these on-body sensing information to personal health goals. Open GeoSMS can provide extremely helpful in public health emergency notification and management operations by using mobile phones supporting SMS. These types of systems have proven to be effective in empowering people to curb poor behavior patterns and improve health, such as encouraging more exercise.

C. Public Safety

The authors of [6], develop a crow sensing system, which uses everyday smartphones and low-cost Bluetooth devices to help people recover their bicycles. In the BikeTrack system, a customized Bluetooth tag mounted on a user's bicycle broadcasts a beacon ID for bicycle identification. When the bicycle is loss, participants use their mobile phones to scan Bluetooth tags through a BikeTrack client and report the location of the loss bicycle to the BikeTrack centralized server so that bike's owners can find stolen bicycles. The University of California at Los Angeles (UCLA) PEIR project applies sensors in phones to set up a system which track how the actions of individuals affect both their exposure and their contribution to problems such as carbon emissions to enable personalized environmental impact reports.

III. Mobile Crowd Sensing Architecture

Despite the significant progress in MCS applications, many crucial challenges have not been fully exploited in the above MCS applications, which may make them impractical in real-world MCS scenarios. For example, it is not clear what architectural components should run on the mobile phone and what should run in the cloud with multiple sensing servers. For example, new tools and phone software will be needed to facilitate quick development and deployment of robust context classifiers for the leading phones on the market. New incentive mechanisms will be proposed for guaranteeing extensive user participating. Submission quality need to be guaranteed to

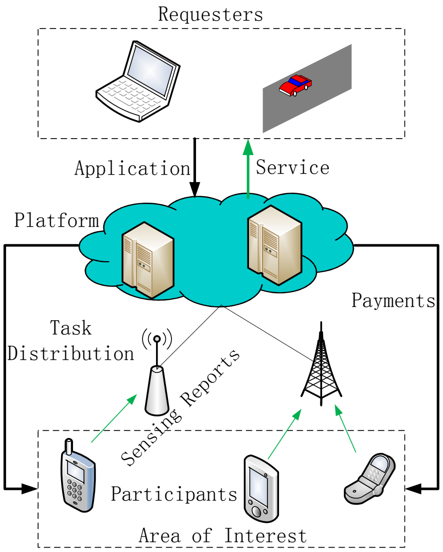


Fig. 2. Our mobile crowd sensing system architecture.

meet the increasing demands of users. New privacy preservation schemes need to be explored to eliminate users' concerns of disclosing privacy. For example, some researchers propose that raw sensing data should not be pushed to the cloud since the cloud may release users' identity privacy and social profile privacy. all these challenges will provide the reader with an idea about the research challenges faced by MCS applications. To more explicitly illustrate these issues, we first analyze the main stages of two-sided markets—*sensing data participants, the MCS monopoly platforms, and sensing data requesters*—on the basis of a typical virtual currency or money supported by MCS applications. Then, we propose a new architecture for MCS applications and the computing cloud for our data aggregations as a platform to discuss the major incentive mechanism design issues that need to be tackled. We do not argue that this is the best framework architecture (see Fig. 2). Rather, it presents a starting point for further discussions, and we expect it will eventually bring about a converging view and move the field forward.

A. Requesters as a Client

Although the sensing data requesters are diverse in terms of preferences towards the content of the sensing data, the aggregated content viewing decisions of all the content requesters can be conveniently characterized by the decision of a representative content viewer as a client. Thus, some researchers adopt the widely-used representative agent model to determine how the total content views are allocated across the content. Specifically, subject to a sensing data content view constraint, the representative content viewer optimally allocates its sensing data content views across the available sensing data content to maximize its utility. On the Internet, it is not uncommon that multiple content platforms offer similar services and the sensing data content requesters have access to the content on any of these platforms. Focusing on the platform's optimal payment decision, researchers do not consider the details of how the sensing data content is produced on the other platforms. Instead, they can assume that the mass of content is available on the other platforms, and then alternatively represent the sensing data content on the other platforms using a unit mass of content with an aggregate quality, without affecting the analysis. As such, the utility maximization problem can be formulated for the representative sensing data content viewer, thereby the optimal sensing data quality for the utility maximization problem can be produced and can be applied to the incentive mechanism design as a feedback for high quality sensing data content submission.

B. Sensing Data Participants

Sensing data participants can be divided into two categories: 1) the fixing number of participants; 2) the varying number of participants. In the MCS application scenes with the fixing number of participants, since some offline data aggregation and analysis methods can be directly used, Most of existing works focus on the offline scenarios, where all participants report their preferences and types, including sensing tasks selection they can complete and the corresponding bids to the MCS application platform in advance, and then the MCS application platform selects a subset of participants after it collects the information of all participants to maximize its utility. In the MCS application scenes with the varying number of participants, where participants arrive in a sequential order and an incentive mechanism must make an irrevocable decision whether or not to procure the sensing service as the user arrives, an online incentive mechanism is a natural fit to stimulate participants to participate in the MCS applications.

Different from the above exogenous factors about the number of participants, endogenous factors are very crucial to submit high quality sensing data for the MCS application platform. For the ease of analysis and emphasizing the endogenous choice without exogenous by whether or not there are the maximum expected total discounted reward, we further assume that participants decide wether or not to be activated based on the concept of subsidy for passivity. To this end, we assume that the monopoly MCS application platform provides the participants with economic incentives (i.e. the subsidy mentioned above) to produce more high-quality contents. As such, the high-quality content attracts more views of sensing data requesters. The content quality produced by participants actually may be obtained by a combination of the well known technical specifical specifications, for instance, video resolution and image processing, etc.

C. Monopoly MCS Application Platforms

To subsidize the participants in the passive state and reward the ones in the active state, monopoly MCS application platforms share with the participants (part of) its advertising profits as an economic incentive like YouTube Parter, and so on. Moreover, monopoly MCS application platforms are responsible for evaluating the sensing data content quality and update the current content quality in terms of the number of times that sensing data requesters view the content with advertisements in order to better reward the participants.

IV. Challenges of Incentive Mechanisms within Our Proposed Architecture

Based on the above our proposed architecture, we further discuss the challenges existing incentive mechanisms faces in the MCS applications. However, mobile devices are controlled by rational users, in order to conserve energy, storage and computing resources, so selfish users could be reluctant to participate in sensing data for crowd sensing applications. Thus, it is indispensable to provide some incentive schemes to stimulate selfish participants to cooperate in MSNs. Only a handful of works focus on incentive mechanism for crowd sensing applications. All of these works apply a regular auction (e.g., a reverse auction) only for off-line crowd sensing applications with the ex-ante payment commonly known as "Free rider problem".

To the best of our knowledge, whether a MCS application is successful or not relies on the solutions of selfish and privacy issues to provide essential information for decision making of the MCS application platforms. However, selfish and privacy issues, two crucial human factors of incentive mechanisms determining whether MCS applications can achieve good service quality, have not been fully exploited in the above mentioned MCS applications, which may make them impractical in real-world MCS scenarios. In the following, we will discuss their current challenges in incentive mechanisms of MCS applications.

A. Selfishness of Participants

At present, most of the current crowd sensing applications are based on a common hypothesis that all users are based on voluntary participation in submitting the sensing data. However, mobile phones are controlled by rational provider, in order to conserve energy, storage and computing resources, so selfish sensing participants could be reluctant to participate in sensing data for MCS applications. Thus, it is indispensable to provide some incentive schemes to stimulate selfish participants to cooperate in MCS applications. Here, we mainly discuss selfish issues from the extensive user participating and submission quality perspectives.

1) Extensive User Participating: In recent years, extensive user participating, one crucial human factor of incentive mechanism designs, has received extensive concerns in MCS applications.most of these concerns focus on how to stimulate selfish participants to enhance user participation levels in MCS applications. For instance, The authors of [7] consider incentive mechanism design problems to enhance user participation levels under a budget constraint. Although they designed truthful mechanisms, which optimized the utility function of the platform under a fixed budget constraint, to incentive extensive user participating, the effects of the online sequential manner, in which users arrive, were neglected.

In practice, recently, there are a few works focusing on both budget constraints and the online sequential manner of users' arrival to enhance user participating levels. For instance, The authors of [8] leveraged threshold price mechanism for maximizing the number of tasks under budget constraints and task completion deadlines. However, they did not consider the effects of participants' budget constraints. Although the mechanism in principle are appropriate to achieve social optimum by some setting, it is often declared that pricing schemes are impractical to free information since they require an accounting infrastructure.

Contrary to the above mentioned pricing schemes, sustaining cooperation incentive schemes have been widely welcomed since social reciprocation provides information about other individuals, and choose to their behavior based on their individual information. Thus it has a potential to form a optimal incentive. For instance, in a reputation-based mechanism, where rewards and punishments are typical determined based on a differential service policy, the authors of [9] introduce incentives to solve the social dilemma existing between the ex-ante payment and ex-post payment, they assume that transmissions are error-free or subject to errors with a small probability. However, the above mentioned assumption is not adapted to the rapidly changing real-life MCS application scenarios.

Although many research works make some promising progresses on the extensive user participation of selfish issues, we believe that extensive user participation still need further researches for meet the service quality of MCS applications.

2) Submission Quality: Different from the extensive user participation issue that influences the incentive mechanism outcomes as an exogenous factor, the submission quality issue is an endogenous factor determining whether participants in MCS applications can be stimulated to produce high quality sensing data for the demand of MCS applications. Compared with the extensive user participation issue, there are only a handful of research works [10] focusing on the effects of submission quality issue on incentive mechanisms for MCS applications. These works stimulate participants to generate high quality sensing contents to achieve good service quality, but do not support the extensive user participation issue. How to simultaneously tackle these challenges to satisfy the requirements of both extensive user participation and high quality sensing content submission is also a challenging issue. Furthermore, realistic MCS applications, in which participants arrive in a online sequential manner, raise a significant challenge to the incentive mechanisms of MCS applications. Our recent works model the issue as an online sequential auction in which each participants who exert the most effort for sensing data service quality to win the more payments over time, and sensing data are submitted sequentially and the users with the high sensing quality contents are selected as the winners. How we do not consider participants time and resource constraints. Thus, how to guarantee submission high quality from participants is still addressed in MCS applications.

B. Privacy of Participants

In addition to the selfish issue, the privacy issue is also challenging in MCS applications. If the privacy of users is not well protected, users will be still reluctant to participate in MCS applications and submit high quality sensing data. In the following, we discuss security and privacy challenges from both privacy preservation and payment verification perspectives in incentive mechanism designs of MCS applications.

1) Privacy Preservation: Nowadays, the privacy issue have been extensively explored in the context of location based services (LBS) in MCS applications. For example, the authors of [11] introduce the spacial and temporal cloaking techniques to preserve participants' privacy. Their schemes blur the participants' location at a specific time in a cloaked area or cloaked time interval to satisfy the privacy requirements. Most of existing works are based on k-anonymity, where a participant's location is cloaked among $k-1$ other participants. Furthermore, the authors of [12] explore the the privacy preserving in MCS applications. They focus on with how participants submit the sensing data to the service provider with revealing their identity. But they neglect the following collusion and chatting, which may still result in more privacy leakage. Different from the process of the above anonymous data collection, the authors in [13] establish secure communication channels by introducing the random number x generated by the initiator and y generated by a destination. However, they do not account for destinations composed of a group of participants. More importantly, their works mainly focus on anonymous matching between the initiator and a destination, which can not be applied directly to MCS applications. The authors of [14] propose the privacy-preserving algorithm that can apply directly to MCS applications. But their algorithm has a high communication overhead, thereby it will fail to survive in a real-life environment, where only one communication round is required and the group of participants change rapidly. Thus, How to preserve participants' privacy for MCS applications in a real-life environment is still an unresolved issue.

2) Payment Verification: In the privacy-aware based incentive mechanism designs for MCS applications, we observe that there is an inherent tension between the privacy preservation and the payment verification: both properties are desirable, but they seem contradictory. The winning participants have the payment due to their truthful efforts, but they are stymied from verifying the payment because their preferences, behavior abilities, and social profiles are usually kept confidential. At first glance, the dilemma between the payment verification and privacy preservation seems hard to avoid: how can we tell whether the platform is making the payment correctly, without knowing what specifically the platform and other participants did? Thus, most of existing incentive mechanisms have tackled one or the other: they either offer good privacy preservation, with correspondingly weak payment verification guarantees, or they preferably trade some privacy for better payment verification guarantees.

However, we believe that MCS applications do not have to make this choice, since it is possible, in a sense, to simultaneously attain both the two important goals. For instance, recently, we propose a bidding-model based privacy-preserving verifiable incentive mechanism for MCS applications (see Fig. 3). But how to efficiently combined payment verification and privacy preservation for incentive mechanism designs in MCS applications still is a very challenging research work.

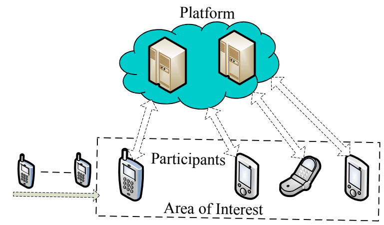


Fig. 3. Our bidding-model based privacy-preserving verifiable incentive mechanism for MCS applications.

V. Potential Future Work Discussions

We believe that this field of incentive mechanisms in MCS applications is still very unexplored. Particularly, there has been almost no good work done on submission quality assessment, and integration of selfishness and privacy.

A. Submission Quality Assessment

We believe that one potential issue in a MCS application system where a large number of "grassroot" participants become the source of the sensing data is submission quality assessment. When participants are not trained in the domain for which they are producing data, there is potential for accidental submissions of bad sensing data or malicious submissions.

The authors of [15] attempt to address this problem by building a reputation system. They account for the reputation to be dependent on comparison to the rest of the submitted sensing data. It may begin to lose the reputation if their sensing data submissions differ too much from the larger body of sensing data submissions. Although they do not fully address the problem, it does take meaningful steps. Our recent works attempt to address the incentive mechanism design problem based on the marginal quality provided by online sensing data requesters to guarantee long-term extensive user participating in MCS applications. But we neglect issues of users being malicious, and accidental bad sensing data. We account for the deeper discussion of this problem outside the scope of the incentive mechanisms in MCS applications.

B. Integration of Selfishness and Privacy

Although both selfishness and privacy issues have been identified as two crucial human factors for realistic MCS applications, many recent research works [7], [14] tend to separately study them in crowd sensing applications. The reason is that, if the extensive user participating and privacy issues are addressed at the same time in realistic MCS applications, the problem would become more challenging. For example, some truthfulness incentive mechanisms [8] explore bidding-model based incentive mechanisms satisfying the requirement of selfishness, the privacy preservation issue are not considered. Some researchers applying some privacy enhanced techniques to hide its identity and location information, but they could make some incentive strategies, especially the reputation-based incentive strategies, hard to implement in realistic MCS applications. Therefore, how to simultaneously address selfish and privacy issues becomes particularly challenging for realistic MCS applications.

VI. Conclusions

In this paper, we first present several MCS applications. And then for the ease of our discusses on the incentive mechanisms, we particularly propose a new realistic MCS application architecture. Furthermore, we make extensive demonstrations about two large areas covering the selfishness and privacy challenges of incentive mechanism designs for realistic MCS applications, in which the current literature does not fully address problems in the field: extensive user participating, submission quality, privacy preservation and payment verification issues. We briefly discuss each of these challenges, and discuss reasons why the current research works in these areas does not completely tackle the question. Finally, we suggest the potential future works for the incentive mechanism design in realistic MCS applications. In particular we believe that how to simultaneously address selfish and privacy issues becomes particularly challenging for realistic MCS applications. Thus, we believe that works about the incentive mechanism design in realistic MCS applications remain to be done.

Acknowledgment

The research reported in this paper is supported by the National Basic Research Program of China (973 Program) under grant No. 2011CB302701.

References

[1] A. Thiagarajan, L. Ravindranath, K. LaCurts, S. Madden, H. Balakrishnan, S. Toledo, and J. Eriksson, "Vtrack: accurate, energy-aware road traffic delay estimation using mobile phones," in *Proceedings of the 7th ACM Conference on Embedded Networked Sensor Systems*. ACM, 2009, pp. 85–98.

[2] P. Zhou, Y. Zheng, and M. Li, "How long to wait?: predicting bus arrival time with mobile phone based participatory sensing," in *Proceedings of the 10th international conference on Mobile systems, applications, and services*. ACM, 2012, pp. 379–392.

[3] R. K. Ganti, N. Pham, H. Ahmadi, S. Nangia, and T. F. Abdelzaher, "Greengps: A participatory sensing fuel-efficient maps application," in *Proceedings of the 8th international conference on Mobile systems, applications, and services*. ACM, 2010, pp. 151–164.

[4] U. of California (UC) Berkeley/Nokia/NAVTEQ, "Mobile millennium," http://traffic.berkeley.edu/, November 2008.

[5] S. Consolvo, D. W. McDonald, T. Toscos, M. Y. Chen, J. Froehlich, B. Harrison, P. Klasnja, A. LaMarca, L. LeGrand, R. Libby, *et al.*, "Activity sensing in the wild: a field trial of ubifit garden," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 2008, pp. 1797–1806.

[6] T. Tsung-Te Lai, C.-Y. Lin, Y.-Y. Su, and H.-H. Chu, "Biketrack: Tracking stolen bikes through everyday mobile phones and participatory sensing."

[7] D. Yang, G. Xue, X. Fang, and J. Tang, "Crowdsourcing to smartphones: incentive mechanism design for mobile phone sensing," in *Proceedings of the 18th annual international conference on Mobile computing and networking (MobiCom2012)*. ACM, 2012, pp. 173–184.

[8] Y. Singer and M. Mittal, "Pricing mechanisms for crowdsourcing markets," in *Proceedings of the 22nd international conference on World Wide Web*. International World Wide Web Conferences Steering Committee, 2013, pp. 1157–1166.

[9] Y. Zhang and M. van der Schaar, "Reputation-based incentive protocols in crowdsourcing applications," in *INFOCOM, 2012 Proceedings IEEE*. IEEE, 2012, pp. 2140–2148.

[10] S. Ren, J. Park, and M. van der Schaar, "Maximizing profit on user-generated content platforms with heterogeneous participants," in *INFOCOM, 2012 Proceedings IEEE*. IEEE, 2012, pp. 612–620.

[11] B. Gedik and L. Liu, "Protecting location privacy with personalized k-anonymity: Architecture and algorithms," *Mobile Computing, IEEE Transactions on*, vol. 7, no. 1, pp. 1–18, 2008.

[12] M. Shin, C. Cornelius, D. Peebles, A. Kapadia, D. Kotz, and N. Triandopoulos, "Anonysense: A system for anonymous opportunistic sensing," *Pervasive and Mobile Computing*, vol. 7, no. 1, pp. 16–30, 2011.

[13] L. Zhang and X.-Y. Li, "Message in a sealed bottle: Privacy preserving friending in social networks," in *ICDCS, 2013 Proceedings IEEE*. IEEE, 2013.

[14] T. Jung, X.-Y. Li, L. Zhang, and H. Huang, "Efficient, verifiable and privacy-preserving combinatorial auction design," *arXiv preprint arXiv:1308.6202*, 2013.

[15] K. L. Huang, S. S. Kanhere, and W. Hu, "Are you contributing trustworthy data?: the case for a reputation system in participatory sensing," in *Proceedings of the 13th ACM international conference on Modeling, analysis, and simulation of wireless and mobile systems*. ACM, 2010, pp. 14–22.