Mobile Crowd Sensing Technologies: A Survey and New Perspectives

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Abstract

Crowd sensing harnesses the data collection capability of individual smartphones, underpinning a variety applications of valuable knowledge discovery, environment monitoring, and decision making. However, ther are many challenges to the design and application development of crowd sensing system, like strong dynamic characterics of system, resource limitation of smart mobile terminals, heterogeneous characteristics of the system, and strong strategy of mobile terminal users. In this paper, we investaget the research state and future development tendency of crowd sensing, and put forword future possible work, which inlcudes researches on efficient sensing task scheduling and resource management explicitly considers the dynamic characteristics of smart mobile terminals and the random arrival characteristics of sensing tasks. We believe that the improvement of crowd sensing computing will accelerate the deveplonent of practical information products and industrialization on crowd sensing, so as to improve social economy and to facilitate people's life.

Keywords

Mobile crowd sensing, Smart phone, Data collection, Resource management.

1. Introduction

With the explosive growth of smart mobile terminals (including mobile phones, tablet computers, etc.) and the rapid growth of mobile Internet acess supported by high-speed mobile networks (3G, 4G, LTE), crowd sensing [1] has emerged and quickly received high attention from academia, industry and government research funding institutions. Crowd sensing uses a large number of ordinary mobile terminals as its basic sensing units, and cooperates through the mobile Internet to implement the distributed sensing tasks, data collection and utilization of data, and finally complete large-scale and complex sensing tasks, so as to solve the complex and difficult problems in real life.

The rapid development of mobile crowd sensing benefits from the rapid development and popularization of intelligent mobile terminals and mobile Inernet access. Since 2010, the smart mobile terminal industry has met an explosivegrowth. According to the survey released by strategy analytics in the United States, the quantities of the smart phones in the third quarter of 2012 has exceeded 1 billion, reaching 1.038 billion. More and more sensing devices are integrated on smart phones, including accelerometer, digital compass, gyroscope, GPS, microphone, camera, as well as wireless communication components such as WiFi and Bluetooth which provide a wireless communication environment. In addition, mobile communication technology develops rapidly. In December 2013, the Ministry of Industry and Information Technology officially issued the fourth generation (4G) mobile communication business license to China Mobile, China Telecom and China Unicom, marking that China's electronic communication industry has officially entered the 4G era. With the comprehensive development of 3G and 4G network, the communication rate of intelligent mobile terminal greatly improved. According to relevant statistics, 4G users in China have reached 660 million before August 31, 2016. By 2021, 79% of the data traffic will come from 4G. According to the white paper repored by Cisco, the number of mobile terminal devices in the world will reach 11.6 billion by 2021. In addition, the "three year action plan for WLAN construction and free use (2015-2017) " has been accelerated in many provinces of China. For example, users in Zhejinag can access "i-zhejiang" through wireless terminals such as mobile phones and use wireless communication services for free. Therefore, the user's mobile terminal is easier to sense the environment than ever before, and share the collected data through the network (including mobile Internet or WiFi, etc.).

There exist many related concepts in “crowd sensing computing”, including crowd sourcing [2], participatory sensing [3-5], crowd sensing, mobile sensing [6], opportunistic sensing, social sensing, etc. The concept of crowdsourcing first appeared in 2006 is used to describe an organizational form that distributes tasks through the Internet to complete creative design, data collection or solve technical problems. The advantage of crowdsourcing is that it can let a large number of professional or non-professional users complete the task at a relatively low cost. It is very suitable for solving some tasks that computers can not solve automatically, but it's very easy for people. With the development of Internet technologies, more and more practical systems and applications with crowd sendsing is deployed in the real world. A typical example of these applications is the Amazon Mechanical Turk [7]. Crowd sourcing and crowd sensing computing use the power of groups to complete tasks, but crowd sourcing emphasizes more on organizational forms, which are used to solve various tasks. In crowd sensing computing, it is more important to collect local information through individuals, and then process the data provided by individuals, so as to better understand the real world and find useful knowledge. Crowd sensing computing is similar to participatory sensing and crowd sensing. Participatory sensing emphasizes more on how to attract users to participate in the task, while crowd sensing emphasizes more on the integrity of the system. Mobile sensing, opportunistic sensing, social sensing, and other concepts emphasize more on some characteristics of sensing nodes.

It is of great practical value to study crowd sensing computing, which has bred a number of important applications and systems, including real-time road conditioan sensing [8], real-time map update [9], bus positioning and tracking [10], precise indoor positioning [11-13], environmental impact research [14], etc. With the continuous progress of crowd sensing computing technologies, more and more high-value applications have been developed and gradually impact all aspects of our social life. It can be predicted that the application of crowd sensing computing will greatly enhance people's ability to sense the environment, improve people's living life, and create social and economic values.

Crowd sensing system has its distinctive characteristics, which brings many challenges to the design and application development as follows: 1) Strong dynamic characteristics of the system: Terminal nodes will dynamically join or leave the system, and the time of joining or leaving the system is random, which challenges the task scheduling and system stability of sensing; when and how the system users submit their sensing tasks are also uncertain. 2) Resource limitation of smart mobile terminal: The computing power, memory, storage and other resources of smart mobile terminal are limited. Although smart mobile terminals have made great progress in computing hardware, but there still exists bottleneck in the battery technology. How to save the power of mobile terminals is an important challenge. 3) Strong heterogeneous characteristics of the system: the sensing system is heterogeneous in many aspects. First of all, the sensing tasks proposed by system users will have differences in sesing objects, time, geographical scope, form, required sensing devices, formed energy consumption, etc.; terminals in sensing task will have differences in sensing ability, node resource level, power margin, ability to accept tasks, incentive mode, mobile range, frequency of participating system, etc. The design and development of the system must consider the challenges brought by these heterogeneous characteristics. 4) Strong strategy of mobile terminal users: The attendence of the sensing terminal are intelligent people with strong strategy. First of all, the nodes are selfish, which requires the nodes to get enough incentive to participate in the perception task. Secondly, the nodes are rational, and the revenue they get must be greater than the cost of participating in sensing. Finally, nodes are strategic. They always choose to maximize their own policies without considering the overall performance and benefits of the system.

There have been some research work on various aspects of crowd sensing computing, including privacy protection mechanisms, terminal node characteristics research and incentive mechanisms, perception data processing method and mining technologies, and various applied algorithms and technologies, including indoor positioning, road condition perception, etc. Although the initial research on crowd sensing has been carried out, the research on complex crowd sensing computing integrating human and computing is in progress. On the one hand, the existing work on task scheduling and resource optimization allocation has not been fully carried out; on the other hand, the existing research on the characteristics of the system has made a greater simplification, the hidden technical challenges have not been studied in depth, and the design method and development technology have great limitations.

In this paper, we briefly overview the research state and future development tendency of crowd sensing, and give some suggestions on the future work about efficient sensing task scheduling and resource management explicitly considers the dynamic characteristics of intelligent mobile terminals and the random arrival characteristics of sensing tasks.

2. Research State and Future Development Tendency of Crowd Sensing

In recent years, relevant papers have been published at high-level international academic conferences, such as MobiCOM, MobiSYS, INFOCOM, SenSYS, etc., showing an increasing trend. In China, Professor Liu of Tsinghua University [1] made a good summary of the concept and related research of crowd sesing computing. In this part, we will introduce an extensive and in-depth study and analysis on crowd sensing computing, and report the research status and future development from the following aspects.

2.1 System and application based on Crowdsourcing

Crowdsourcing [15] is consistent with the idea of crowd sensing which uses the power of the masses to accomplish certain tasks. Hence, some existing research on crowdsourcing can also be used for reference in crowd sensing. A well-known crowdsourcing application is the famous online encyclopedia Wikipedia [16]. It uses Internet users to edit a huge online encyclopedia, which has become an important source of professional knowledge for Internet users.

The idea of crowdsourcing is applied to the improvement of query system. In [17], they proposes to crowdsource the evaluation results of query results to ordinary Internet users, and the results show that crowdsourcing can improve the repeatable and reliable evaluation results. The idea of crowdsourcing is also used to solve security and privacy problems. Some researchers [18] pay attention to the privacy protection of smart phones based on IOS. Many client applications require access to privacy information, such as device tag number, location, etc. They developed a PMP System based on the idea of crowdsourcing. Through the privacy protection settings of a small number of experts, they developed a recommendation engine for privacy protection settings to provide recommendations for ordinary users. In [19], the idea of crowdsourcing and social network is applied to software engineering, and StackeSource 2.0 is designed to identify software requirements and sort.

2.2 System and application based on Crowd Sensing and Participatory Sensing

Crowd sensing based on mobile terminals has supported a large number of valuable applications, including intelligent transportation, indoor positioning and so on.

Intelligent transportation is an important application field of crowd sensing computing, such as traffic condition perception, road travel time estimation, optimal scheduling of traffic lights, positioning and tracking of public transportation tools, bus arrival time prediction, energy-saving navigation, etc. Mobile millennium [20] of the University of California, Berkeley is a project jointly supported by the government of California and Nokia Research Institute. Its basic idea is to collect motion state information from thousands of mobile users, process the data in the cloud server segment, and estimate the traffic state of the whole network road.

Smart city is also an important area of crowd sensing computing. Urban sensing [21] is an important scientific research projectfunded by the European Union. One of the core research contents of the project is the to collect dynamic data, and moble crowd sensing technology is undoubtedly one of the most attractive technologies.

Crowd sensing computing is used to improve the indoor positioning technology and improve the positioning accuracy. In [12], ,a method of using the WiFi intensity measurement value contributed by the sensing node is proposed, which effectively solves the problem of cold start of the traditional method.

Crowd sensing computing based on intelligent mobile terminals is also well used in many other applications, such as content sharing, activity perception, information collection cooperation, real-time image search, news content production, video collection [22], etc.

2.3 Research on the Incentive Mechanism of Crowd Sensing Computing

Crowd sensing computing involves intelligent people. How to encourage nodes to participate in the sensing task to the greatest extent has become an important research topic. In [23] studies the strategic behavior of participants in Crowd sensing computing. The so-called strategy is that the participants are selfish, rational and intelligent, and always adopt strategies that can maximize their own interests. It should be noted that the best performance of the system may not be consistent with the optimal decision of the terminal node.

In [24], aiming at the pricing problem of online crowd sourcing, a pricing method based on purchase budget is proposed, which has the advantages of conforming to the budget, approximately optimal task requester, and incentive compatibility. Aiming at online crowdsourcing market, some researchers [25] designed a framework for dynamic and automatic pricing process. In [26], an incentive mechanism based on dynamic price reverse auction is proposed. Compared with the incentive mechanism based on fixed price random selection, this mechanism can encourage more users to participate in the sensing task. Researchers also [27] studies the incentive mechanism based on the repeated game model. In order to achieve Pareto efficiency, the incentive protocol based on reputation management is further designed. Combined with network optimization and distributed association scheduling technology, We [28] proposed a method to maximize the efficiency of data collection in mobile terminal data collection mechanism.

2.4 Privacy Protection in Crowd Sensing System

In crowd sensing system, the data provided by terminal nodes may contain the privacy information of terminal nodes. Therefore, how to protect the privacy of terminal nodes is also an important research topic. Many works have proposed various privacy protection mechanisms.

Anonymity is an important idea to protect privacy. In reference [29], anonymity and credit management in crowd sensing computing are considered simultaneously, and a set of anonymous trust management method is designed.

Some people concerned with a data aggregation method for privacy protection, while paper [30] studies the privacy protection of tracks in crowd sensing. We [31,32] proposed a privacy to encapsulate and encrypt the data before transmitting, in which he data will goes through several unnecessary routes or clients to achieve the purpose of "confusion".

3. New Perspectives on Mobile Crowd Sesing

In crowd sensing system, access control, task scheduling and dynamic management of network resources are the core issues, which need to be further studied. Future research work mainly focus on the following four aspect at least: 1) Design and analysis of online incentive mechanism for dynamic sensing task and dynamic terminal node; 2) Design and analysis of efficient task scheduling method for time limited sensing task; 3) Online task access control and resource allocation method for system level optimization; 4) Design and implement a real-time crowd sensing application system, which is used to verify the proposed model, evaluate the design methods and key technologies, and promote the practicality of key technologies through demonstration application.

3.1 Online Incentive Mechanism for Dynamic Sensing Tasks and Dynamic Terminal Nodes

In general, terminal users are not willing to provide sensing services for others unconditionally. On the one hand, providing sensing services needs to consume a part of resources, including power, storage, CPU computing time, etc., which is particularly important for an smart mobile terminal with limited resources. On the other hand, when terminal users share data, they face the risk of privacy disclosure. Without the participation of enough intelligent mobile terminals, crowd sensing system is difficult to provide satisfactory sensing data and services.

Sensing tasks arrive at the system dynamically, and the arrival time of these tasks is unpredictable. Therefore, the existing incentive mechanism can not be used in crowd sensing system when considering dynamic sensing nodes and dynamic sensing tasks.

However, when considering the dynamic characteristics of intelligent mobile terminals, the design of incentive mechanism is a particularly difficult problem. First of all, the intelligent mobile terminal may arrive at the system dynamically, and the sensing task may arrive at random. Such uncertainty and unpredictability make the design of incentive mechanism more complex. Secondly, the real cost, arrival time and departure time of an intelligent mobile terminal are all private information that only it knows. Finally, terminal users are rational and strategic. All the decisions of an intelligent mobile terminal are willing to improve its own profits.

In order to overcome these difficulties, researchers begin to focus on an auction mechanism for online random arrival sensing tasks and dynamic terminal nodes, which explicitly considers the dynamic characteristics of intelligent mobile terminals and the random arrival characteristics of sensing tasks.

3.2 Fair and Efficient Task Scheduling with Time Sensitive Tasks

In the process of receiving and completing the sensing task, the sensor nodes involved in crowd sensing computing need to turn on the corresponding sensing devices, sample the data, store and process the sensing data, and then upload the sensing data and task results to the computing platform through 3G / 4G, WiFi and other wireless communication methods. In this process, precious energy resources will be consumed. In addition, the sensing task also has time limit in a variety of crowd sensing applications, because the sensing data must be in real-time.

Dynamic scheduling of sensing tasks to minimize the energy consumption and ensure the fairness of nodes faces many important challenges. First of all, there is an inevitable tradeoff between energy efficiency and energy fairness of nodes. How to achieve a better tradeoff is a challenging problem. Second, the number of sensing tasks and the number of intelligent mobile terminals may be very large. The computation complexity of finding the optimal task scheduling strategy by enumeration is very high. The preliminary analysis shows that it is NP hard. Finally, in the real environment, tasks may arrive at the system at any time, and the arrival process may be arbitrary and unpredictable in advance.

In order to solve the challenges discussed above, further study mainly focus on a fair and high energy efficiency aware task scheduling framework. Based on the framework, two different scheduling scenarios should be studied: offline scheduling and online scheduling. In the off-line assignment model, the crowd sensing computing platform grasps the information of all the sensing tasks, including the tasks to be arrived in the future. It will design an effective approximation algorithm with a high accuracy. Under the online scheduling model, both the sensing task arrival and task scheduling will in real time. An efficient approximate scheduling algorithm with polynomial computing complexity is desirable.

3.3 System Level Optimization Oriented Online Task Access Control and Resource Allocation

With the continuous development and popularization of corwd sensing computing, more and more users will take part in a variety of sensing task requests to collect the sensing data. Crowd sensing system needs to consider not only the performance of sensing tasks and the throughput of system tasks, but also the cost of terminal nodes and the user experience of intelligent terminals. It is necessary to consider the system level performance optimization problem of integrated task performance and terminal node user experience, so as to handle as many requests as possible, provide a good terminal user experience, and maintain good system stability.

However, it is very challenging to achieve the optimal system level performance of a crowd sensing system. First, the request may arrive at the system at any time, which is can not be known in advance, which the controlling process needs to be done in real time. Secondly, the control is coupled, and there is interaction between them. Third, there is an inherent trade-off between system throughput and system stability, as well as the user experience of intelligent mobile terminals. Finally, the sensing request is heterogeneous and should be handled separately during control.

There are few researches on the system level performance optimization of swarm intelligence system. Most of the existing work simply assumes that all the sensing tasks can be completed by the system, i,e., the total demand is lower than the processing capacity of the system, but it is not always the case in reality. Some existing researches have proposed the incentive mechanism under the condition of expected sensing tasks. They usually consider that strategic intelligent mobile terminals will take actions to maximize their own returns. These mechanisms fail to maximize system performance when requests are online. To solve these challenges, it is urgent to design an optimal online access control and resource management method with intelligent terminals.

3.4 Design and implementation of Demonstration Application System

In order to verify the relevant model of crowd sensing computing proposed, design and implement crowd sensing computing platform is an optimal way to evaluate the performance. Besides, applications, like real-time urban noise sensing system based crowd sensing, is of great significance to facilitate people's life.

The crowd sensing system to be developed includes sensing platform in the cloud and the application in the intelligent mobile terminal. The cloud platform manages the current participating sensing nodes, receives the sensing tasks from the end users, and assigns the sensing task to the nodes. After the sensing node completes the sensing task, it is responsible for receiving the sensing data from the node and the corresponding calculation.

To design and implement real-time sensing applications, many new challenges, like data sparsity, should be solved. The main reason is the uneven distribution of sensing nodes in time and space. Given sparse matrix, it is necessary to study and design data estimation methods to minimize the error.

4. Conclusion

Crowd sensing harnesses the data collection capability of individual smartphones, underpinning a variety of valuable knowledge discovery, environment monitoring, and decision-making applications. This article investigated the technologies of crowd sensing, including access control, task scheduling and dynamic management of resources in crowd sensing system. Efficient sensing task scheduling and resource management play an important role in crowd sensing computing.

First of all, it can improve the completion rate of system sensing tasks, improve the quality of sensing data collection, and reduce the operation cost of sensing applications; meanwhile, it can improve the participation of terminal nodes, increase the experience of node users, and reduce the resource consumption of intelligent terminals. Finally, it enhances the stability of the sensing system, balance the distribution of sensing tasks, improve the reliability of the nodes to complete the sensing tasks, and reduce the cost of collecting the sensing data.

We believe that the improvement of crowd sensing computing will accelerate practical information technology products and industrialization on crowd sensing, so as to improve the development of social economy and to facilitate people's life.

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