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Survey of Crowdsensing: Architecture, Classification and Security Challenges

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Abstract—*With the rapid popularization of wireless mobile devices, mobile sensing and crowdsourcing are combined into a new technology called crowdsensing. Crowdsensing is an emerging technology that is used within a large group of applications having mobile devices equipped with embedded sensors. The researcher/industry still has a long way to fully investigate and show the big benefit of using crowdsensing in many life-critical applications. For example, using crowdsensing, a huge amount of data can be used for analysis when it is collectively extracted from different parts of the cloud. However, when developing crowdsensing techniques, a series of challenges and security problems have come to exist. This survey paper focuses on the challenges encountered when developing crowdsensing techniques for several applications. Mainly, the paper assesses the structure and basic classifications of crowdsensing, including platform, incentive mechanism, and typical applications and its applications and security issues of crowdsensing.*

Index Terms—*Crowdsensing architecture; Crowdsensing classifications, Crowdsensing security Challenges.*

I. Introduction

Crowdsensing, often referred to as mobile crowdsensing (MCS), has become an emerging paradigm for large-scale sensing [1]. It empowers ordinary citizens to contribute to the cloud selected data sensed or generated from their mobile devices (e.g., smartphones, wearable devices), which aggregates and fuses the data in the cloud for crowd intelligence extraction and human-centric service delivery [2].

In recent years, people have combined crowdsourcing with mobile device perception and regard the ordinary individual users as basic sensory units, which then carry out conscious or unconscious collaboration through the internet to complete the task of mass awareness [3]. This paper presents:

- The architecture of crowdsensing, including respective layers, which are the application layer, the transmission layer, and the sensing layer.
- Classification of crowdsensing with different features, which are platforms, incentive mechanism, and applications.
- Challenges crowdsensing is faced with, which are privacy, security, authenticity and integrity, and efficiency.

This paper can help people better understand the function and meaning of crowdsensing and the advantage of developing this technology. Also, by showing challenges, it informs people of the key points that the developers should focus on. The remainder of the paper is organized as follows. Section II presents the architecture and classification of crowdsensing. Section III shows five aspects of challenges this technology is facing. Section IV discusses the development of crowdsensing and gives some recommendations. Section V concludes the whole paper.

II. Crowdsensing

A. Architecture

Fig. 1 shows the main architecture of crowdsensing As shown in the figure, according to the data sensing, transmission, and application process, the crowdsensing network can be divided into three layers: the sensing layer,

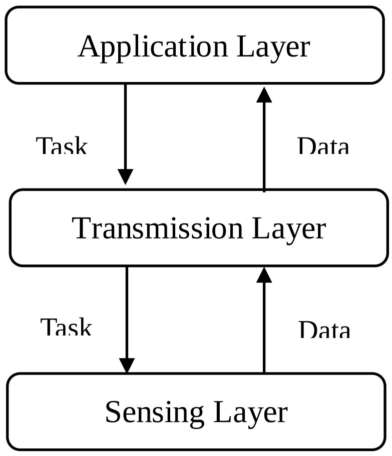

Figure 1 Architecture of crowdsensing

the transmission layer, and the application layer [4].

a) The sensing layer

The sensing layer is the basic and the core layer of data acquisition in crowdsensing networks.

It uses many sensors integrated on mobile devices, such as smartphones, to perceive material properties, environmental status, behavior patterns, and human status. For example, the acceleration sensor can perceive the acceleration of the motion of the object and the flatness of the city road, and the microphone can perceive the level of the city's noise pollution, and the GPS sensor and the WiFi signal detector can perceive the position and speed of the object.

b) The transmission layer

The transmission layer is mainly responsible for transferring the perception data from the lower to the cloud center server. The crowdsensing network uses the deployed network facilities for data transmission. Because the users are numerous and complex, and each user's equipment and the network that connects them are different, the transport layer contains many networks. The Internet and the next-generation Internet are the core networks of the network transport layer, and various wireless networks are also widely used. For example, a wireless wide area network is the main way to transmit a user's mobile sensing data to the central server in a crowdsensing network. With the current large-scale deployment and WiFi use, WLAN can provide a communication network for users in a certain area.

Many sensing data are sent to the cloud center server by various networks in the transmission layer. Wireless personal area networks (such as Bluetooth) can also transfer the sensing data of some users through the relay of other users to the central server.

In the application layer, cloud center servers store and process these perceptual data to achieve various application tasks. However, because many untrained users are the basic sensing units, the perceptual data are inaccurate, incomplete, inconsistent, and untimely. Simultaneously, the diversity of users' perception of devices and the randomness of sensing methods make the quality of perceptual data uneven. It is an important part of realizing the crowdsensing network to process the perceptual data from the false, the true, the error, and the rough. If data are not processed, these inaccurate, unreliable, and incomplete data are difficult to be used in various applications. Therefore, the application layer is an important part of the crowdsensing network.

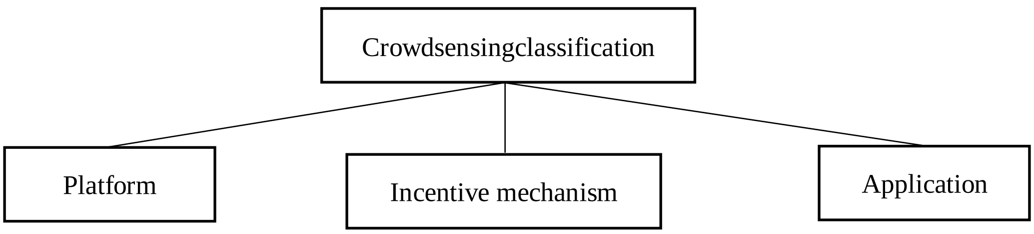

Figure 2 Classification of crowdsensing

B. Classification

As shown in Fig. 2, crowdsensing are classified into three main categories:

- Platform
- Incentive Mechanism
- Application

C) The application layer

a) Platform

Crowdsensing platforms provide crowdsources and users with platforms of information exchanging. Crowdsources can release different tasks on the platforms, and then users can discretionarily take part in the information collecting.

Fig. 3 shows the sub-classification of crowdsensing platforms, and Table 1 presents a comparison of the crowdsensing's platform. As shown in Fig.3, the platform can be sub-classified as follows:

- Crowdsourcing
- Spatial
- Indoor navigate

1) Crowdsourcing

Crowdsourcing means one company or institution outsources a large amount of work that is hard for its own

workers to complete to the unspecific and usually large crowd network based on some incentive mechanism, making the crowd willing to apply for the work.

Wenqian et al. introduced an AHP based crowdsourcing assignment mechanism in [5]. In this model, the system first collects the user's information of social relationship, activity pattern, and network structure to define and compute three factors: SQF (service quality factor), LRF (link reliability factor), and RHF (region heat factor). Then the system uses a kind of AHP (analytic hierarchy process) algorithm to analyze users' preferences. According to the preference, the system gives different users specific assignments. This model is more efficient than the normal random distribution model.

Kazemi introduced a taxonomy crowdsourcing model in [6]. This model provides two assignment modes: Worker Selected Tasks (WST) Mode and Server Assigned Tasks (SAT) Mode. In the SAT model, tasks are assigned to a set of users according to the locations of users. The user sends their location information to the server, and the server assigns them with most nearby tasks to guarantee the objective of maximum task number. Besides, this model also provides a Worker Selected Tasks Mode in which users can select tasks as they prefer without having to coordinate with the server.

Yan introduced a time and space-based crowdsourcing model in [7]. This model is used for location-based services. This model focuses not only on the location information of the users but also analyzes the time pattern of the users and assign tasks to users according to time classification. Thus, the server can collect real-time geographic information then use an average algorithm to ensure the final information.

Sun introduced an agent-based crowdsourcing mechanism in [8]. In this mechanism, the user agent is used to connect to the user database; the local agent is responsible for sending and requesting data; the data-ensuring agent confirms the data received and sends it to the central. The event-listening agent monitors events and then sends messages to other agents. With several agents to improve communications in the platform, this mechanism is highly efficient. Nevertheless, the system is complex, and it needs a special design to compile. Niwat introduced an opportunistic collaboration mechanism in [9]. In this mechanism, the author points out two ways to realize data collection. One is equal assigning, which means it gives up sensing the number of people in a certain area to improve sending efficiency. The second is selection assigning, which means only representatives selected by the system can participate in the system. Both equal assigning and selection assigning reduce data redundancy, but the former needs population information in advance, and the latter needs a complex selection algorithm. Cui introduced a game-theory-based mechanism in [10]. In this mechanism, the author creates a payment system based on the theory of games in which their data's truthfulness determines users' payment. By doing this, users are forced to provide more reliable data

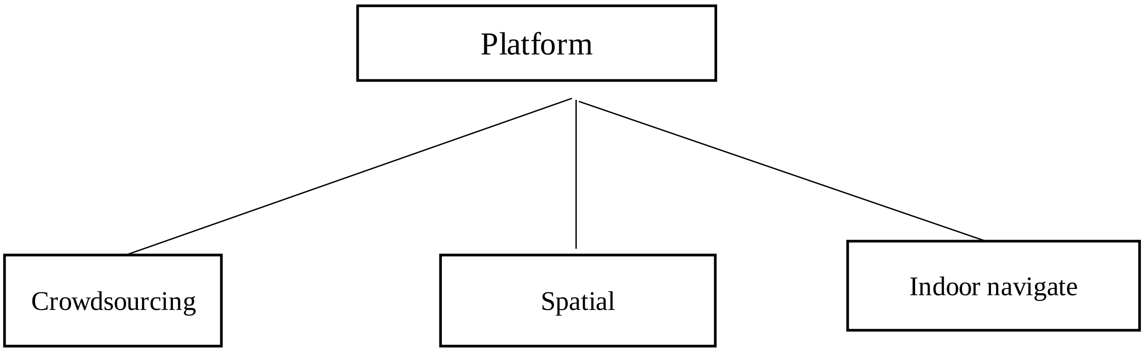

Figure 3Crowdsensing platforms

Table 1 Crowdsensing platforms Comparison

Platform	Recent Work	Efficiency	Accuracy	Cost	Dependability
Crowdsensing	An et al. [5]	✔	✗	✗	✔
	Kazemi et al. [6]	✔	✗	✗	✔
	Yan [7]	✔	✔	✗	✗
	Sun et al. [8]	✔	✔	✔	✗
	Niw et al. [9]	✔	✗	✔	✗
	Cui et al. [10]	✔	✗	✗	✔
Spatial	Gao et al. [11]	✔	✔	✗	✔
	Nan et al. [12]	✗	✔	✗	✗
	L et al. [13]	✗	✔	✗	✔
Indoor Navigation	Qui et al. [14].	✗	✔	✔	✗
	Mutka et al. [17]	✗	✗	✗	✔
	Bahl et al. [20]	✔	✗	✔	✗
	Shou et al. [24]	✔	✔	✔	✗
	Lau et al. [27]	✗	✔	✔	✗
	Basocchi et al. [29]	✔	✗	✗	✔

2) Spatial

Crowdsensing based on a spatial mechanism is currently and widely used. To increase the efficiency of crowdsensing applications, people's participation in crowdsensing needs to be promoted. Some new models like cross-space and Pluralistic Interactionism have been put forward to simplify the problem [11].

Gao introduced a crowdsensing based urban noise map and temporal-spatial feature analysis in [11]. It provides an efficient method to detect urban noise and analyze temporal-spatial features. This method uses mobile devices as sensing terminals to measure and collect noise data. Through synthesizing the data, noise pollution can be measured, and users can check their smartphones to discover the noise condition of other places. The terminal in servers can provide all the necessary information about the noise based on this method; the system compresses a large amount of data independently without communicating between different terminals. It can efficiently reduce the cost of data transmission.

CSII (Cross-Space, multi-Interaction-based dynamic Incentive scheme) is a model used to improve the quality of the data introduced by Nan in [12]. Compared with previous methods, the CSII improves in two ways: Evaluating the cost of the task and crowdsensing task organizing through spatial data analysis. Also, CSII can improve workers' willingness to accept tasks and promote them. The simulation experiment based on the real sign to data set shows that the completion rate of the task is perceived after the use of the CSII incentive mechanism. User participation and perceived data quality have been improved.

Li introduced Vehicular ad-hoc networks in Crowd Sensing and Service in [13]; it is a controllable, manageable, operational, and credible open converged network system based on a multi-person, multi-machine, multi-vehicle environment. By using an advanced technique of information communicating and calculating, it can solve complex problems like the sustainability and extensibility problems in environmental intelligence management and information service. Its advantage is that this technique has various forms for information collecting because of the vehicle's flexibility. Also, a disadvantage of this technique is that it makes it more difficult to handle the data from different terminals, and it increases the cost.

3) Indoor navigation

Qiu introduced UWB (ultra-wideband) in [14]. Its pulse signal is analyzed by multiple sensors using TDOA and AOA location algorithm. Ultra-wideband is a localization technology that is used above all in the industrial environment where accuracies of 10-30 centimeters are expected. Ultra-wideband positioning is most frequently used in asset tracking. The location of the tag is analyzed, the multipath resolution is strong, and the accuracy is high. A server-based method [15] and a client-based method [16] are used here. The positioning accuracy can reach the centimeter level. However, UWB is difficult to achieve for indoor coverage in a wide range, and the mobile phone does not support UWB, so the location cost is very high. Mutka introduced RFID technology in [17] as a navigation mechanism according to an object's position. RFID technology makes it possible to identify and locate objects, people, and animals and read and save data contactless through electromagnetic waves. For RFID position tracking, always need a transponder and a reading device [18]. The transponder can save data.

In most cases, the transponder is passive and has no individual power supply. Depending on the frequency range, the reader must be located within a radius of between a few centimeters and one meter from the transponder (= RFID tag) to interchange data. However, it cannot be used in Real-time positioning, and the accuracy it is low [19].

What is more, it has no communication ability and poor anti-jamming ability. Bahl introduced a WiFi positioning system (WPS) or WiPS/WFPS in [20]. It is used where GPS and GLONASS are inadequate due to various causes, including multipath and signal blockage indoors [21].

Such systems include indoor positioning systems. WiFi positioning takes advantage of the rapid growth in the early 21st century of wireless access points in urban areas [22]. The accuracy depends on the number of positions that have been entered into the database [23].

The WiFi hotspot database gets filled by correlating mobile device GPS location data with WiFi hotspot MAC addresses. The possible signal fluctuations that may occur can increase errors and inaccuracies in the path of the user. To minimize fluctuations in the received signal, certain techniques can be applied to filter the noise.

Shou introduced ZigBee in [24]. This indoor positioning technology uses several blind nodes to locate a reference node and network with a known location. A network is formed between nodes, and each tiny blind node can communicate with each other to achieve all positioning [25]. As a low power and low-cost communication system, the signal transmission of ZigBee is greatly influenced by the multipath effect and the movement, and the positioning accuracy depends on the physical quality of the channel, the density of the signal source, the environment, and the accuracy of the algorithm [26]. The cost of the positioning software is high, and space is greatly improved. Many large factories and workshops have used ZigBee indoor positioning in staff management systems.

Lau introduced Shopkick in [27], proposes a new technique for installing an ultrasonic signal box in the mobile phone. The wind detects acoustic waves to achieve positioning, mainly for shop check-in.

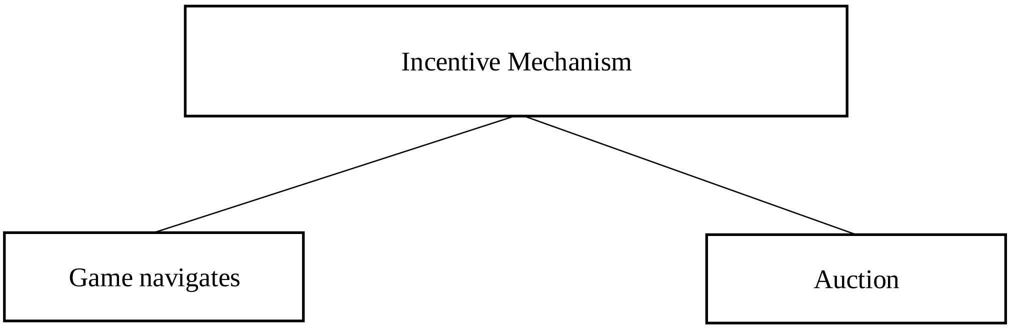

Figure 4Crowdsensing incentive mechanisms

Table 2 Comparison of crowdsensing incentive mechanisms

Mechanisms	Recent Work	Trustworthiness	Privacy	Cost	Effectiveness
Game	Nan et al. [5]	✗	✗	✗	✔
	Guo et al. [5]	✔	✗	✔	✔
	Wu et al. [11]	✔	✗	✔	✗
	Zhang et al. [11]	✗	✗	✗	✔
	Peng et al. [11]	✗	✗	✔	✔
Auction	Line et al. [13].	✔	✔	✗	✗
	Wen et al. [14]	✔	✗	✗	✔
	Wang et al. [15]	✔	✗	✔	✔
	Xu et al. [16]	✔	✗	✗	✗
	Nan et al. [27]	✔	✗	✗	✔

The attenuation of ultrasonic in the air is great, but it is not suitable for large occasions. The reflection range is influenced greatly by the multipath effect and the non-sight distance propagation, which causes the investment of the underlying hardware facilities that need accurate analysis and calculation cost to be too expensive [28].

Barsocchi introduced the LED positioning system in [29]. It is realized through the LED lamps on the ceiling, and the luminaries give out the same code as Moss telegram. The flickering signal is then received and detected by the user’s smartphone camera. The positioning accuracy can be within 1 meter [30].

LED positioning needs to transform LED

lamps and lanterns, which increases the chip and the cost. What is more, the infrared can only spread the sight distance, and the penetrating difference is also easily affected by environmental factors such as light and smoke [31]. The positioning effect is limited. Nevertheless, LED positioning is a potential indoor positioning technology.

b) Incentive Mechanism

Fig.4 shows the incentive mechanisms of crowdsensing.Table2 provides a comparison of crowdsensing incentive mechanisms; the realization of crowdsensing depends on the participation of large scales of individuals. Thus, incentive mechanisms are necessary to promote user participation. Two main incentive algorithms are game-based mechanism and auction-based mechanism. The former focuses on the crowdsourcer, and the latter focuses on the user. As seen in Fig. 4, the incentive mechanism is sub-classified as:

- Game
- Auction

1) Game

Nan introduced Task evaluation in [32]. In this model, the CSII only considers the Spatial-temporal characteristics of the tasks. This method evaluates the task from the time heat and the regional heat. At present, this method is only applicable for a single task. The advantage of this method is that it is easy to implement because of the simplified process. The disadvantage of this method is that it ignores much information such as image, audio, and text.

Guo introduced the task supporting method in [33] to improve the disadvantage of task evaluation. To support the complex task, the method divides the whole task into several simple parts and deals with them like task evaluation. The advantage of this method is that it is possible to solve complex tasks. The disadvantage of this method is that it needs to consider the different number of tasks and the difficulty of each task to pay for the workers.

Wu introduced the Game incentive method in [34]. This method uses a game to encourage the participants to take part in the task. Different rewards are provided according to different amounts of data that are collected. The advantage of this method is that it can appeal to the users to participate in data collecting. The disadvantage of this method is that, according to different users and areas, different game mechanisms need to be designed, which increases the cost.

Zheng introduced the Virtual credit method in [35]. This method differs from the method which pays the money directly. Instead, it gives users a bonus when the users take part in the task. The advantage of this method is that it can guide the user's behavior indirectly and appeal to more participants. The disadvantage of this method is that it is likely that, to get more bonus, the user's behave dishonestly or try to cheat. As a result, the collected data may lose accuracy.

Peng introduced the Social connection encouraging
method in [36]. This method aims to utilize the participants to influence the user. When the users feel they have a social connection with others, they can play a more positive role in finishing the sensing task. The advantage of this method is that the users are more positive and can finish the task better. The disadvantage of this method is that it has high requirements on the social network's reliability, which needs high technique and maintenance.

2) Auction

The Auction-based incentive mechanism is also referred to as the user-centric model. In this kind of incentive mechanism, users are leaders. They can decide how much they should pay for the data they collect.

Lin introduced BidGuard in [37]. In this mechanism, the author designed different score functions for select users. In the paper, the author particularly introduces two functions: linear function and log function. In the process of bidding, when a bidder uploads their costs of service, the BidGuard function transforms the truthful cost information to two values, and only the service buyer or the platform can know the true cost. By doing this, bidders' privacy can be protected. This function can efficiently protect the privacy and guarantee the truth at the same time. Besides, it can minimize the cost.

Wen introduced a quality-driven auction-based incentive mechanism in [38]. In this mechanism, bidders' payment is determined by the quality of information they provide instead of the time they spent in the work. Besides, the author combines this mechanism with an indoor location system using WIFI-fingerprint to guarantee the collected information's truthfulness. This mechanism is individual-rational. What is more, it can guarantee truthfulness and profitability both for the bidder and buyer.

Wang introduced a quality-aware and fine-grained incentive mechanism in [39]. In this mechanism, the author first designs a mathematical model to identify the quality of collected information. Then the author combines the model with a fine-grained mechanism to boost the efficiency by dividing tasks into multiple subtasks in which a bidder can contribute to different subtasks.

This mechanism not only improves the truthfulness and individual ratio but also boost efficiency as tasks are divided into smaller ones.

Xu introduced the SOUS-based mechanism in [40]. In this mechanism, the tasks are divided into two categories: single time window and multiple time window.

For different categories, the mechanism uses MST or MMT accordingly for buyers to select appropriate bidders. This mechanism has high computational efficiency and truthfulness.

Nan introduced A cross-space, multi-interaction-based dynamic incentive mechanism in [41]. In this mechanism, the value of collected information is estimated based on the context of sensing and data in the past. It also uses this information to make decisions on budget and target bidders. Bidders are paid according to what the value system suggests, and the costs bidders inform. This mechanism can effectively improve the payment ratio and utilization of bidders.

c) *Application*

Crowdsensingcan is used in many aspects of our daily life. Including environment (pollution), transportation (routine, traffic jams), city management (infrastructure), security (crime), and social contact.

Fig.5 shows the application of crowdsensing, and Table 3 provides compassion between these applications. As shown in Fig. 5, the crowdsensing application can be sub-classified as:

- Environment
- Transportatio
- City Management
- Social Contact

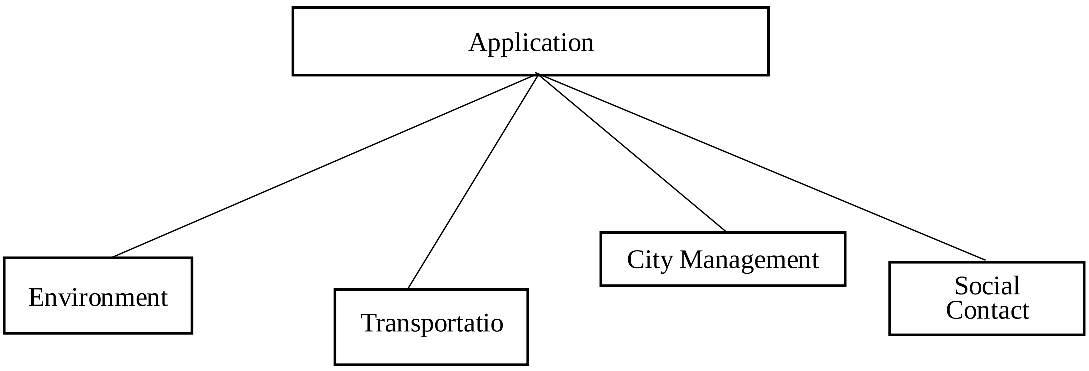

Figure 5 Application of crowdsensing

1) *Environment*

Dutta introduced Common Sense introduced in [42]. It uses handheld air quality sensors to detect air pollution like CO2, NOx situations, and the sensors relate to mobile phones to transport data by Bluetooth. The design of handheld air quality monitors raises a range of research challenges.

Since monitor "deployment" is not a carefully controlled process – different users carry or mount the monitors in different ways – there may be time-varying biases in the readings that must be detected and corrected. Sensor data can be acquired on different timescales, triggered by different actions, and delivered in many different ways.

For example, sensor data may be collected periodically, randomly, or non-uniformly. Sensor data acquisition, and especially GPS position fixes, may be triggered in response to detected motion rather than continue to save battery drain and extend lifetime. Similarly, sensor readings may be delivered via Bluetooth, 802.15.4, or GPRS radios, depending on either user interest or data entropy.

Stevens introduced NolseTube in [43]. It uses a microphone to detect the noise and collect much of the data of users to depict the noise painting. A noise map facilitates the monitoring of environmental noise pollution in urban areas. It can raise citizen awareness of noise pollution levels and aid in developing mitigation strategies to cope with the adverse effects. However, state-of-the-art techniques for rendering noise maps in urban areas are expensive and rarely updated (months or even years), as they rely on population and traffic models rather than on real data

Table 3Comparison of crowdsensing application

Application	Recent Work	Real-time	Privacy	Truthfulness
Environment	Dutta et al. [42]	✔	✗	✔
	Stevens et al. [43]	✔	✗	✗
	Rana [44]	✔	✗	✔
	Kim et al. [45]	✔	✗	✗
Transpiration	Hull et al. [46]	✔	✗	✔
	LaCurts et al. [47]	✔	✔	✗
	Peh et al. [48]	✗	✗	✔
	Ganti et al. [49]	✔	✗	✗
City Management	Sensorly et al. [50]	✔	✔	✗
	Jakob et al. [51]	✗	✔	✔
	Mohan et al. [52]	✗	✔	✗
	Mathur et al. [53]	✗	✔	✔
Social Contract	Eisenman et al. [57]	✔	✗	✔
	Hyman et al. [58]	✔	✗	✔

Rana introduced Ear-phone in [44] that, for the first time, leverages Compressive Sensing to address the fundamental problem of recovering the noise map from incomplete and random samples obtained by crowdsourcing data collection. Earphone, implemented on Nokia N95 and HP iPAQ mobile devices, also addresses the challenge of collecting accurate noise pollution readings with a mobile device. Extensive simulations and outdoor experiments demonstrate that Earphone is a feasible platform to assess noise pollution, incurring reasonable system resource consumption with mobile devices and providing high reconstruction accuracy of the noise map.

Kim introduced CreekWatch in [45]. It uses photos taken by users or their texts to describe the quality of water and water levels in different places to track water pollution. It explores the application of HCI methods to ensure that the data itself is useful. It allows volunteers to report information about waterways to aid water management programs. Working with state and local officials and private groups involved in water monitoring conducts a series of contextual inquiries to uncover what data people wanted, what data people could immediately use, and how to deliver that data to people most effectively.

2) *Transportation*

Hull introduced CarTel in [46]. CarTel is a distributed mobile sensor computing system. It works by gathering sensor readings, processing local data, and delivering it to a sensor portal. It can provide a simple API, handle intermittent network connectivity and large heterogeneous data.

LaCurts introduced VTrack in [47]. It can use an alternative, less energy-hungry but noisier sensors like WiFi to estimate the user's trajectory and travel time along the route when driving. It uses a hidden Markov model (HMM)-based map matching scheme and travel time estimation method to identify the closest or suitable road segments for the driver and calculate the time required for the journey.

Peh introduced SignalGuru in [48]. SignalGuru is a new software service that relies on a collection of mobile phones to detect and predict the traffic signal. It enables GLOSA (Green Light Optimal Speed Advisory) and other new applications.

SignalGuru can leverage the windshield equipped with phones to detect current traffic signals with their cameras; by recording and learning traffic signal schedules, SignalGuru can predict their future schedule.

Ganti introduced GreenGPS in [49]. GreenGPS collects user's car information and fuel consumption records on the city street by analyzing these data. It allows drivers to find the most fuel-efficient routes for their vehicles to the destination.

3) *City Management*

Sensorly is introduced in [50]. The sensory uses mobile phones to test the quality of a WiFi or mobile network. In the system, the network performance information is anonymously collected. Then the information is used to analyze the quality and accuracy of the network. It considers several factors to do data cleanup to improve the quality of the analysis.

Jakob introduced The Pothole Patrol in [51]. The system is used to detect and report road surface conditions. The system uses the mobility of vehicles to collect data from GPS sensors and analyze the data to assess road surface conditions. The system also uses a simple machine-learning approach to identify anomalies from accumulated data. The system has a low misidentified rate.

Mohan introduced Nericell in [52]. This system is used to monitor complex road conditions in developing countries. The system is set on mobile phones in the normal course. It uses an accelerometer, microphone, radio, and GPS sensors to detect conditions like potholes, bumps, and braking. It can overcome the problem of arbitrary orientation and uses energy efficiently.

Mathur introduced ParkNet in [53]. The system is used to obtain statistics of parking availability. The system collects information from a GPS receiver and a passenger-side-facing ultrasonic rangefinder equipped on vehicles to determine parking occupancy. Then clients can search for real-time parking spot information. The system also uses an environmental fingerprinting approach to improve location accuracy.

2.2.3.5 Social Contact

Eisenman introduced BikeNet in [57]. It provides a multifaceted sensing system by sensing personal, bicycle, and environmental information. It promotes the cycling community by sharing real-time and cycling data like carbon dioxide conditions or traffic conditions to help clients to find better routes.

Hyman introduced Dietsense in [58]. The system uses Image_Scape to collect and analyze many images. It automatically documents participant's dietary choices on a network platform. Then health care professionals can compare and analyze their diet and help them to control bad diet and give health advice. Table 3 shows the characteristics of an application.

III. Security Challenges in Crowdsensing

Weppner introduced Blue Tooth Scanning in [54]. People can quickly estimate population density in public places by using. Sensing platform Medusa can report and track events in time like the "Occupation Movement" in the USA. The ubiquity of smartphones and their onboard sensing capabilities motivates crowd-sensing, a capability that harnesses the power of crowds to collect sensor data from many mobile phone users. Unlike previous work on wireless sensing, crowd-sensing poses several novel requirements: support for humans-in-the-loop to trigger sensing actions or review results, the need for incentives, as well as privacy and security.

Ryong introduced Medusa in [55]. It provides high-level abstractions for specifying the steps required to complete a crowd-sensing task and employs a distributed runtime system that coordinates the execution of these tasks between smartphones and a cluster on the cloud.

Simoens introduced GigaSight in [56]. It can collect a large amount of information about videos and pictures captured by users to help find lost children or help police to catch criminals like the suspects of the Boston Marathon bombing. It achieves scalability by decentralizing the collection infrastructure using cloudlets based on virtual machines. Based on time, location, and content, privacy-sensitive information is automatically removed from the video. This process is executed in a user-specific VM on the cloudlet. Users can perform content-based searches on the total catalog of denatured videos. As a new sensing model of the internet, mobile crowdsensing provides a new way and means to realize deep social perception, but it also brings new challenges to the research of theory, technology, and application.

A. User privacy protection

In mobile crowdsensing networks, the collected sensing data contain many sensitive and private information of mobile terminal users. For example, the user's precise location information can be obtained by acquiring the sensing data of a user's location related sensor (such as GPS, electronic compass, magnetic field sensor.) on the acquisition device. After monitoring and analyzing the location information for a long time, the sensitive information of the user's family and work address, the scope of daily activities, the common traffic route, can be found. Although the sensitive sensing data can analyze and excavate important, valuable information, these perceived data seriously threaten the user's privacy upon disclosing the data [59].

B. Data and platform security

As the mobile crowdsensing network converges many perceptive data containing user sensitive and private information, it can also excavate valuable information, which greatly increases the risk of hacker attacks and confidential data leakage. How to better protect the security of data and platform has become a prominent and urgent concern. Because of the data's security, cryptographic encryption technology can be used to encrypt the perceptual data. Because of the security of the platform, the available technologies include user authorization and identity authentication technology. However, these security technologies based on cryptography require establishing key distribution and management mechanisms for complex encryption calculations that consume a large number of resources [60].

C. Data authenticity and integrity

Building a highly efficient mobile crowdsensing network relies on users to provide reliable sensing data. However, in gathering data, malicious users may submit false perceived data or, in the process of data transmission, may lose part of the data, which may lead to excavating wrong information and making wrong decisions [61].

D. Common platform of crowdsensing network

At present, the academic and industrial community has designed and developed a wide range of intelligent sensing applications, which usually have similar or partially overlapping functions that require the same or interrelated data. At this stage, the independent development mode is very inefficient, resulting in a great waste of resources. Therefore, building a common platform of crowdsensing networks is a fundamental and urgent problem[61].

E. High-efficiency transmission

Many crowdsensing applications need to collect the perceptual data continuously and transmit them to the data center. This transmission mode is based on the mobile cellular network and the internet to report the perceptual data to consume. This requires much power and data traffic of the user equipment and can cause great pressure on the mobile cellular network. Therefore, a design of an energy-efficient data transmission method is needed [62].

IV. Discussion and Recommendation

There are some research problems in crowdsensing. Before choosing an incentive, the designers of crowdsensing systems need to consider the trade-offs, including the type of sense, the desired Spatio-temporal properties of the data, the level of data reliability required, the monetary cost, the user effort, and finally, the user privacy and the resource consumption on mobile devices. The trend our team is seeing is that worthy projects build systems that consider all the above factors and guide the crowdsensing to the right incentive for the situation.

Discussed below are two different possibilities to incentivize individuals for mobile sensing purposes; computer scientists, businesses, and analysts must consider innovating data collection and crowdsensing. Finding ways to balance privacy concerns with data mining benefits is an essential practice for modern computer scientists.

The local analytics running on mobile devices only analyze data on the given device. MCS applications rely on analyzing the data from a collection of mobile devices, identifying the patterns in the long term to reduce congestion. By collecting many data samples about air pollutants such as car exhaust, one can not only monitor the concentration of pollution but also detect patterns to model how the concentration evolves spatially and temporally as temperature, humidity, and wind change. These models can help the environmental authority forecast and provide alerts to the public. The challenge in identifying patterns from a large amount of data is usually application-specific, and it involves certain data mining algorithms. Depending on the amount of incoming data, and the delay sensitivity of applications, there are two possible approaches for data mining. One is a traditional approach where data is stored in a database first, and then one can apply various mining algorithms against the database to detect patterns. However, if the amount of continuous data input is too much for storage or the application requires fast detection of patterns, stream data mining algorithms may be required. Such algorithms input continuous data streams and identify patterns without the need first to store the data. Data mining algorithms are domain-specific, and the exact algorithms will be closely related to the application and are out of the scope of this paper.

V. Conclusion

In conclusion, we have identified a category of applications that rely on data collection from many mobile sensing devices such as smartphones, which we termed mobile crowdsensing (MCS). We presented several crowdsourcing, spatial, indoor navigation applications, such as WiFi, ZigBee, CSII, AHP. We then identified their unique characteristics, presented several security challenges, and briefly discussed their solutions. We also note the significance of incentive mechanisms, but we have not presented all the existing work (in terms of applications and the individual research challenges).

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