Mobile Crowd Sensing for Internet of Things: A Credible Crowdsourcing Model in Mobile-sense Service

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***Abstract* —Various types of micro-sensors in smart communication devices can measure a significant amount of potentially useful information. Mobile Crowd Sensing (MCS) between users with smart mobile devices is a new trend of development in Internet of Things. With the powerful sensing capability of smart device and user mobility, various services could be provided by building a trusted chain between service requesters and suppliers. In this paper, we first analyze and summarize the current status of the MCS technology, and a novel credible crowdsourcing service model is proposed based on MCS according to mobility, sociality and complexity of mobile users. Then, some key technologies of model are given in details. Finally, we give the focus of future research work.**

***Keywords* — Mobile crowd sensing; Internet of Things; Credible interaction; Crowdsourcing service model.**

I. INTRODUCTION

As the development of technologies such as the Internet of Things (IoT) and the Big Data continues, mankind has entered an unprecedented information age. Intelligent terminals, social networks, 3G/4G networks and other new media and network access technologies have become an indispensable part of people's daily life, entertainment, office, and so on, which enhanced the breadth and depth of people's collection, analysis and utilization of data. The Gartner released the *Top 10 Predictions of 2014*, in which it predicates that IoT will be the fastest-growing, largest market potential and the most attractive emerging economy, therefore becoming the focus of attention in the field of networking [1].

Mobile Crowd Sensing (MCS) refers to the technology that uses mobile terminals like smart phones to collect and analyze the information of people and surrounding environments, analyzes statistical characteristics and activity patterns of social groups based on the mass of information, then mines the data to reveal hidden information of group behaviors, dynamic evolution of the network structure and service related attributes, and ultimately provides useful information and services to end users [2]. MCS provides a new way of perceiving the world, by involving anyone in the process of sensing, to greatly extend the service of IoT and build a new generation of intelligent networks that interconnect things-things, things–people and people-people.

The decision-making role of people in crowd sensing will inevitably lead to a new revolution of networking technology [3]. As a service provider and consumer, people are not only the traditional consumer of information, but also the participants and decision-makers. The network composed of mobile devices carried by people will be the main platform for future networking applications. In this network, the mobility, randomness and space-time complexity of the people bring technical challenges in data sensing and data transferring, as is described in detail in the following aspects.

Firstly, at present, 190 million of Twitter's 250 million global users use mobile devices, while Facebook has 900 million mobile users among its grand tally of 1 billion. The use of mobile phones, tablets and other mobile intelligent terminals will have a huge impact on the growth of Internet users. With the powerful capabilities of sensing and computing, intelligent terminals can quickly collect multi-source, heterogeneous information of mobile users and their service interactions, but this also results in the "information overload" problem. How to study the relationship among sensing data from multiple sources to unveil hidden information like groups behavior patterns, network architecture and services attributes is critical to ultimately provide the services that meet user preferences [4].

Secondly, the behavior of mobile nodes in terms of activities carried out in certain social relations is a reflection of the relationship among mobile subjects, revealing the inherent nature of the relationship between the mobile users. In addition, a mobile node has a social nature that refers to the characteristics of a person appeared as one of the society engaging in social interaction activities, such that the movement trajectories and activity patterns are not aimless or disorganized [5].

Finally, in MCS, data collection, delivery and service interaction are all based on mobile nodes. Recent researches [6-8] usually assumed that sensor nodes have mutual trust and can receive, forward, and pass any data between each other. But in real life, there is no such pre-existing trust relationship among mobile nodes, thus a node only forwards data or perception requests to familiar nodes and ignores the requests or data from unfamiliar nodes. One of the main problems of the crowd sensing service in the future will be to study the credible crowd sourcing and incentive mechanism of mobile nodes to further expand the breadth and depth of data perception [9].

In summary, the leading role of mobile nodes (user) in the crowd sensing will inevitably cause evolutions of related technologies. How to provide high-quality, diverse, customizable mobile sensing service to meet specific preferences of users in a mobile, dynamic and distributed

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environment will be the new challenge of crowd sensing of IoT in the future. This problem was rarely studied in the past; therefore we need a whole new approach to research a suitable solution.

A. *Summary of Key Contributions*

Based on the analysis above, we propose a credible crowdsourcing service model based on crowd sensing. This model analyzes the activity patterns relationships and network structure among nodes. It also finds and selects the mobile nodes that can provide target area sensing service. In addition, the model is based on the trust relationships among nodes within the same community, hence it can establish a credible interactive link from the service provider and service requester to achieve reliable delivery and efficient distribution of sensing tasks, and ultimately solve the sensing-hole problem of sparse network to improve the reliability of real-time context-awareness services.

B. *Paper Organization*

The remainder of the paper is organized as follows: Section II introduces the related work of MCS techniques; Section III first analyzes and compares existing crowd sensing service models, and then proposes a credible IoT group-awareness service crowdsourcing model; Section IV describes main functions and key technologies of each modules in the model in detail; Finally, Section V summarizes the paper and discusses the problems of the model and future research focus.

II. RELATED WORK

Although the research of MCS of IoT has a wide scope, works related to this paper are mainly in the following two aspects: MCS technology and MCS applications.

A. *MCS Technology*

The biggest difference between MCS and traditional sensor network is that the MCS is user-centric. People participate and play an important role in the mobile sensing process. The concept of mobile crowd intelligent sensing was first proposed in 2006 by Burkel et al [10]. By comprising the public and expert users through mobile devices we use every day (such as mobile phones), it uses mobile phones to perform sensing tasks, analyzes and shares local information, and forms the participatory sensor networks of sensing, analysis and sharing data. [11-13] analyzed and summarized the role of people in MCS, emphasized the importance of the people as services beneficiaries, and declared the principles and research focus of the user-centric sensing. [14-19] did a research in depth on the key techniques of crowd sensing such as perception of social relations, nodes activity patterns, service preferences and network structure through collecting user information and its interactive information from the mobile terminals they carry. These information sources are particularly important for analysis of mobile nodes social characteristics and service recommendation based on context information. According to MCS patterns, [2, 20, and 21] divided the MCS models into two categories: participatory sensing and opportunistic sensing. In terms of participatory sensing, people participate in the perception process actively and decide how, when, where, and what kind of sensing data to collect independently. Opportunistic sensing is the perception that, when people do not take active intervention, the application would automatically detect the terminal context, and automatically start a background process to perform sensing tasks in the right contexts. Table 1 compares the two sensing modes from three aspects: user burden, sensing accuracy and task complexity. As can be seen, the participatory sensing has a lower real-time perception than opportunistic sensing, but the opportunistic sensing has more difficulties in collecting accurate data than participatory sensing. The two modes have their own advantages in different application scenarios [22]. In addition, considering the importance of the user in MCS, to solve the problem of how to obtain sensing data in the user-centric mobile perception, Tuncay et al. [23] proposed a distributed data acquisition system using opportunistic sensing to realize a rapid distribution of sensing tasks. Based on game theory, Yang et al. [24] designed the master-slave and distributed data collection incentive system to achieve the distribution and acquisition of sensing tasks.

B. *MCS Application*

The concept of mobile crowd sensing has attracted widespread attention in the academia, resulting in the emergence of a variety of MCS applications. MCS can be widely used in many fields such as transportation, environmental monitoring, health care, mobile social networks, etc. In this paper we divide them into three main areas: environment sensing, infrastructure sensing and social sensing. The environment sensing is mainly used for natural science research and environment monitoring, with animals and the natural environment as sensing objects. The typical applications include The Movebank [25], Common Sense [26] and the Creek Watch [27].

CarTel [28] and Vtrack [29] are two examples of infrastructure sensing. Social sensing aims to provide people with higher-quality and more convenient daily life services and has daily life information as perception object. People upload their own perception data over the network. Then certain knowledge (collective wisdom) is formed through aggregating and analyzing these data in the server to provide people with daily life services. The typical service sensing applications include GeoLife [30], BikeNet [31] and CitySense [32]. From the aforementioned typical MCS applications we can see that, different applications have different characteristics. Environment sensing applications generally use participatory sensing mode, and their data types are usually images, video, text, etc. They require relatively high data accuracy, at the same time the data types are relatively complex and different users have different ways of collecting data, hence producing uneven quality of sensory data and making data processing relatively difficult on the server.

Table **I.** PARTICIPATORY SENSING AND OPPORTUNISTIC SENSING

Sensing mode	**Participatory sensing**	**Opportunistic sensing**
Data accuracy	High	low
User burden	Heavy	Light
Sensing complexity	Little	Big
Data types	Image, video, text	Location, acceleration, direction and humidity
Typical applications	Creek Watc [27], GeoLife [30], The MoveBank [25]	Car Tel [28], Ear-Phone [34]

Table II. COMPARISON OF THE THREE MODELS

Model category	**Cluster modeling**	**Knowledge modeling**	**Service modeling**
Service object	User	Perception data	Service
Degree of realization	Easy	Difficult	Difficult
Key technology	Perception of node behavior	Analysis and handing of massive data	Definition and discovery of service
Representative model	HGSM [19]	MCKC [35]	SOA [36]

Participatory sensing and opportunistic sensing are both appropriate for infrastructure sensing; the main sensing data types in this case are GPS location, images, etc. The range of applications is currently limited to the application of road transport and can be extended to urban construction planning, distribution of infrastructure, green construction and other areas in the future. In general, social sensing uses participatory sensing mode to form a collective intelligence through analyzing and integrating the perception data from a large crowd, and to provide better services for users.

III. CROWDSOURCING SERVICE MODEL

In the IoT crowdsourcing service based on MCS, the sensing service in the target area is no longer achieved depending on a single fixed node. In sparse network, trusted links from the service requester to the service provider are built based on the mobility and sociality of nodes to achieve efficient distribution and reliable delivery of crowdsourcing service requests. The aim of the crowd sensing in IoT environment is to get rid of the traditional and inherent interaction patterns that have "perception device" as the main body, and to form a "mobile node (user)" centric computing interactive mode. While summarizing the characteristics of the mobile sensing of IoT, we need to consider the following aspects in modeling process.

Pervasive: The Internet of things emphasizes the integration of the physical world and the information world, the traditional integration of people and Internet making ubiquitous computing network, sensor devices and pervasive services effectively integrated in people's life, so that people can have more convenient, efficient and effective enjoyment of a variety of services to build a real people-to-things, things-to-things, and people-to-people interconnected intelligent network.

Mobility: Mobility is one of the most fundamental factors that an IoT realizes by sharing of resources and services any time at any place. Only the mobility of people, vehicles, objects and other terminals can achieve the coverage and comprehensive perception of the physical world and make up for the sparse network deficiency brought by traditional sensor devices.

Heterogeneity: The sensing environment of IoT includes a variety of heterogeneous resources that can be either physical (mobile terminal, perception equipment, etc.), or logical (social software, social networking, etc.). Its heterogeneity exists in different network structures, hardware platforms and application environments. Even the interaction protocols between different devices and applications are incompatible. The ultimate goal of mobile sensing service model is to achieve a seamless integration and collaborative work of heterogeneous devices and resources, to unify various protocol standards and different applications, and to build a transparent interactive environment for users.

Dynamic: The center of MCS is the users and the mobile sensing terminals they carry. Considering that in the IoT the nodes sensing service are mobile and social, data are spatial and temporal, relevant, massive and non-structural, etc., the objective of crowd sensing is to provide users with transparent, effective, continuous sensing services, create a dynamic interaction between service requesters and providers through combinations of intelligent services and scheduling mechanisms.

Context-awareness: Context-awareness is an important means to achieve crowd sensing. Through a variety of mobile devices, sensing terminals and social software, a system can conditionally obtain information about user behavior and interaction patterns in the case of reducing user intervention. In the IoT, the ubiquitous mobile nodes and sensing devices can provide the necessary context information to users, making the access of perception information easier and more convenient, thus providing the possibility for the realization of pervasive service.

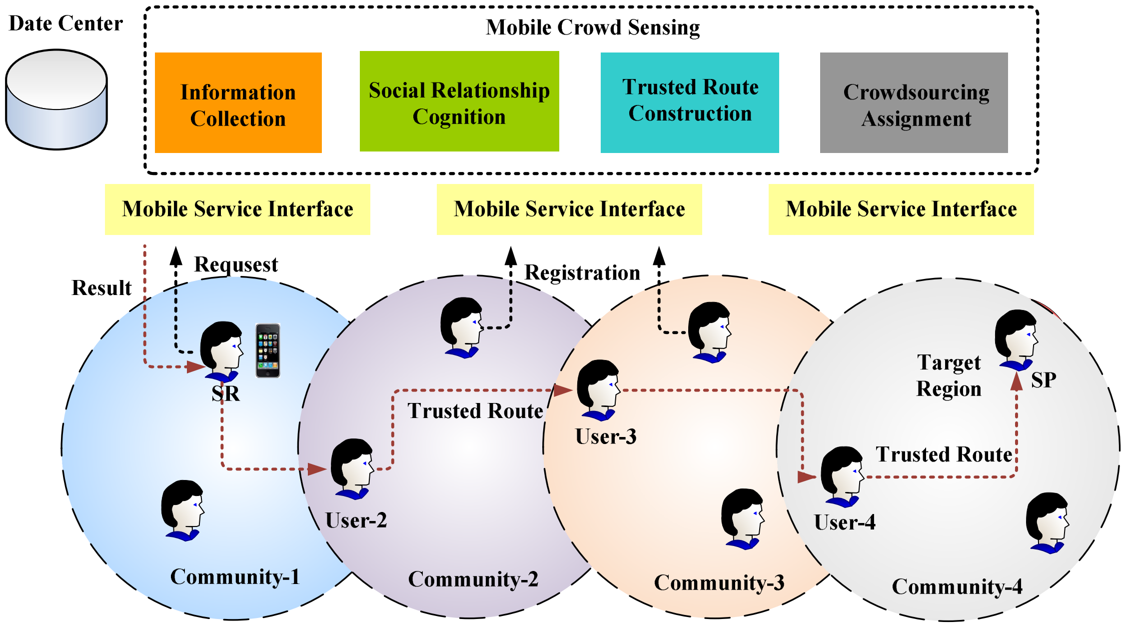


Fig.1. The framework of credible crowdsourcing model

In summary, keeping in mind the diverse, heterogeneous and dynamic character of the IoT environment, this paper breaks the traditional hypothesis of mutual confidence among nodes by default and proposes a service-oriented architecture (SOA), which interconnects different functional units with intrinsic service interfaces and protocols through loosely coupled and reusable construction methods. As shown in Figure 1, the credible crowdsourcing service model based on crowd sensing is a service computing form that has IoT as background, MCS as basis, and intelligent terminals as carriers.

Fig.1 illustrates a use case of our study scenarios, and the framework of crowdsourcing model. For example, Alice is a service requester (SR), who is interested in the context information (like traffic conditions) about a specific target area. Bob is a service provider (SP), who's in that specific area, and should provide information about it. The focus of our model is to establish a trusted service route between SR and SP, and realize the effective assignment of crowdsourcing service. The model mainly includes the following parts.

- Mobile service interface

Mobile service interface consists of two parts, service registration and context registration. Service registration allows SP to register the services it provides. Registration information may include service ID, service location and service type, etc. Context registration further details the services of users. For example, service capacity, GPS, user preferences and social relationship. Mobile service interface can be described the service request of SR when the request is initialized, and further to find and match the right candidate crowdsourcing service nodes to SR.

- Data center module

As its name suggests, this modules serves as the storage center in our model. Social attributes, activity patterns and community relationships of users are stored in the data center. Effective assignment of sensing tasks from SR to SP is achieved by mining the trust relationship between users and their service preferences.

- Mobile crowd sensing module

Crowd sensing module is the core of our model. It gathers real-time activity and interaction data (like GPS trail, external environment data) from mobile devices that user carries. Users can also register and publish service information and service capacity, through interacting with the mobile service interface, which is provided by mobile devices. Then crowd sensing module analyzes the peers' social characteristics and network structure, by applying machine learning and data mining methods to the raw data gathered. This information could be used to provide decision-making basis for the subsequent process of crowdsourcing service assignment.

As Figure 1 shows, the credible crowdsourcing service is implemented using cluster computing and other technologies to collect node relevant social information, to mine the social relevance among different nodes, and to build a credible route from service requester to the provider through collective intelligence among nodes. As can be seen from the figure, the construction of crowdsourcing services has the following three main steps.

Measurement and prediction of social relations of crowd sensing nodes: This step consists of obtaining node information such as activity patterns and interaction records in real-time from a variety of body sensing devices (cell phone, tablet, etc.) carried by the mobile node, analyzing the key factors that influence the social relationship, and exploring their internal relationship to have quantitative calculation and predictive analysis on social relations.

Discovery of service community in a directed weighted network: By use of the panorama formed by mobile nodes and their social relationship values, the service community in a complex network is discovered, providing decision basis to build credible transmission routes.

Discovery and selection of crowdsourcing service nodes: It is to find and select the crowdsourcing service nodes in the target area based on the service requests for the service nodes, and to build credible links to accomplish crowdsourcing service through service community.

IV. KEY TECHNOLOGIES OF MODEL

As shown in Figure 2, the completion of credible crowdsourcing service in our research scenario involve following key technologies. This section will make a detailed description of these technologies based on our preliminary work.

A. *Multi-source Perception Information Collection*

As computing and sensing capabilities of the mobile terminals continue to increase, besides the traditional instant calls, messaging and other functions, various mobile applications and on-line social network on intelligent terminal have become significant features of the mobile Internet. The social information of nodes recorded in these mobile devices reflects users' activity patterns, behavioral characteristics and service preferences. Therefore, reasonable and effective use of perception data to perform cluster analysis, to study the associated attributes between social features and services, to mine the patterns of potential network relationship models, and to build social graphs, can provide the basis for decision making in perception crowdsourcing services.

Based on the node information type, information can be divided into equipment information and mobile application information. The equipment records the node activities and interactive information such as call recording, message logging, geographic information, environmental information, etc. in real time through its various sensors. The mobile applications mainly record information which is generated in the context and on-line services.

B. *Social Relationship Cognition*

Existing crowdsourcing service model are based on the assumption that users trust each other, and can receive or forward any data. This assumption does not hold true in real-world applications. In fact, trust relationships do not exist by default, nor should a user forward the data that comes from an unverified source. Therefore, in the process of crowdsourcing service, the problems of "how to deliver the requests to trusted SP" and "how to deliver the data response to SR" become the primary concerns of crowdsourcing service model.

According to the analysis above, in our case, crowdsourcing service is achieved by constructing credible route between communities. The structure of community changes with the social attributes of internal members, which process can be generalized as the evolution of social relationships. Therefore, we [36] defined different decision factors to quantize the social relationship between users in the previous study, which including location factor, interaction factor, service evaluation factor, and feedback aggregation factor. These factors try to reflect the complex, dynamic, asymmetric and transitive features of social relationships, and could overcome the limitation of simplicity in other models.

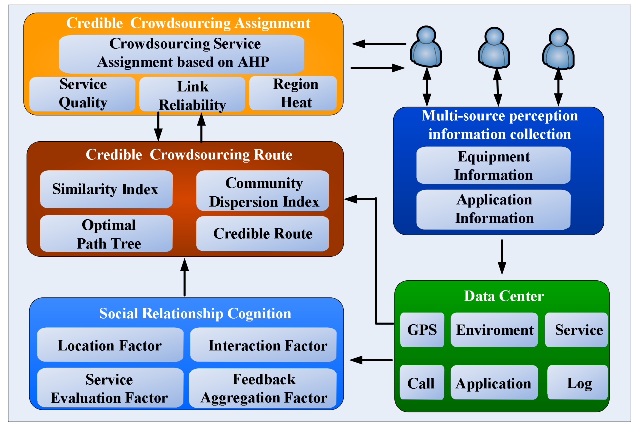


Fig.2. Key technologies of model

C. *Credible Route for Crowdsourcing Service*

Community structure is a set of users which have relatively strong social relationship, and close contact with each other. Users within same community usually have similar social attributes and service preferences, and they are not strangers to each other, but with a certain trust relationship between themselves. In [37], the optimal path tree, similarity index and community dispersion index are defined and calculated to achieve the community detection, and an effective partitioning algorithm is proposed for weighted and directed network. Therefore, we can further establish a credible route from SR to SP, and realize the effective forwarding of crowdsourcing requests by utilizing the users in overlapped areas between two communities.

During the process of establishing credible route, if SR and SP belong to the same community, the trusted route can be established by utilizing internal trust relationships between users in same community. Otherwise, it can be established via the trust transition in two communities, which could exist in overlapping users and marginal associated users. Service sponsors can choose an adjacent user, and forward its request to that one, according to its social relationships. The receiver of the request does the same thing until the request reaches the target user. Finally, a trusted route of crowdsourcing service between SP and SR is established according to the existing social relationships in different communities.

D. *Crowdsourcing Service Assignment based on AHP*

This section focuses on how to realize the credible crowdsourcing assignment. The process of crowdsourcing service assignment can be summarized as below.

- Detection of crowdsourcing service candidates

In order to realize crowdsourcing service in target area, the set of users that can provide services need to be discovered. Actual service users should be chosen from this set. If target region does not contain any candidates, the users which most likely to arrive target region should be considered based on their moving patterns.

Trails of movement directly reflect users' activities. Collecting and analyzing trail information should provide guideline for the detection of crowdsourcing service candidate users. Through the observation of a user's everyday activity and the analysis of its pattern, [38] came to the conclusion that user's movement is event-driven. By collecting the activity information from a specific time period, a user's location within a certain time is rather fixed. For example, a student may frequent arrive dormitory, playground, canteen, classroom and laboratory throughout a day. According to this conclusion, we can analyze a user's movement pattern by collecting and analyzing its location information.

- Crowdsourcing decision-making factors

The mobility and sociality of mobile nodes will bring new challenges to crowdsourcing service. The success of crowdsourcing service not only depends on the service capacity of provider, but also depends on the service environment, like the route reliability and the location information of target area. In order to achieve the crowdsourcing service based on users' preferences, we defined different decision factors, which including Service Quality Factor (SQF), Link Reliability Factor (LRF) and Region Heat Factor (RHF). These factors could be used for describing the different attributes of user service preferences.

SQF is the objective evaluation of a user's historical quality of services. In our model, SQF is determined by user's satisfaction ratio, service's rate of success and service delay.

The mobility and complexity of mobile users should bring revolution to crowdsourcing service patterns. The success of crowdsourcing assignment will not only decided by provider's service capabilities, but also related with service route. The reliable service route will be more help to the ultimate success of the service. Therefore, in addition to provider's capacity, link reliability should be taken into consideration when selecting crowdsourcing service providers. In this paper, LRF is determined by link stability, attenuation factor and the number of forwarding users.

The completion of crowdsourcing assignment is based on different target regions. The RHF represents how many users are going on in specific region at a given time. RHF is decided by the number of arrivals of users, and their duration time at the specific region.

- Crowdsourcing service based on AHP

Three decision-making factors in our paper are SQF, LRF and RHF, and these factors describe user preferences from different perspectives. The Analytic Hierarchy Process (AHP) is a structured technique for organizing and analyzing complex decisions, which based on the mathematics and psychology. It was proposed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then [39].

E. *Credible Crowdsourcing Services Platform*

Our team constructed a credible crowdsourcing service prototype system for IoT based on the research presented in this paper. The system can be divided into different functional modules according to the tasks they perform; each module realizes a specific function and can be joined together to work as a whole. The client-side can have the data such as mobile node location, call records, and sensing information, uploaded to the server; the server-side displays real-time location of each node in tables, tree structures and topologies to present the node social relations, community structure, credible links and other information. For instance, when a node requests a crowdsourcing service, the client-side will submit a service request (including the target area of perception, crowdsourcing content, services preferences, etc.) for the user. After receiving the perception service request from the client, the server-side first analyzes the nodes that may appear in the target area within the time threshold according to the mobile node historical location, call and other information, then measures and predicates the social relationship combining the service interaction information, then divides reasonable community structures and builds a credible request delivery path, finally selects and returns to the client the optimal paths based on user preferences to realize a request and response of credible crowdsourcing service.

Fig.3. Credible crowdsourcing services platform

V. PERFORMANCE EVALUATION

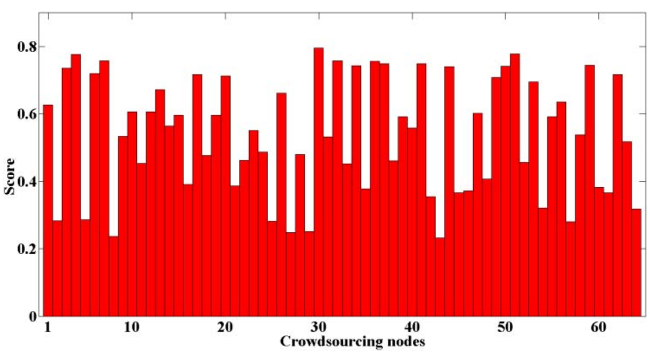
To prove the correctness, effectiveness, and robustness of the model, simulations are conducted based on MCS platform developed by our team (as shown in Fig.4). Raw data is gathered from the standard dataset, and Reality Mining is provided by MIT [40]. By utilizing service information from the users in the dataset, we can simulate the process of initiating crowdsourcing service requests, by detecting and selecting service providing users. Experimental parameters are set as follows.

Table IV. Experimental parameters setting

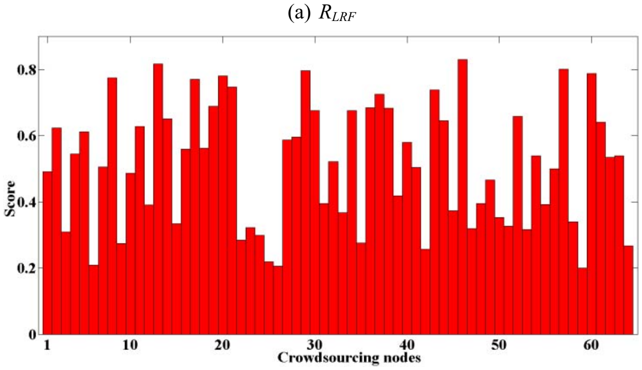
Parameter	Value	Description
N	64	Number of mobile users
d	180d	Time period
T	30min	Sampling period of location
H	7	History of service records
α	10min	Effective time of service request

In this section, we categorize the users into four types according to their preferences. 1) Those who have the highest requirements of SQF, which is represented by R_{SQF}; 2) those who have the highest requirements of LRF, which is represented by R_{LRF}; 3) those who have the highest requirements of RHF, which is represented by R_{RHF}; 4) those who do not have a specific preference, which is represented by R_{com}. Assuming that we have 64 candidate users, the following paragraphs illustrate different results for different categories of users.

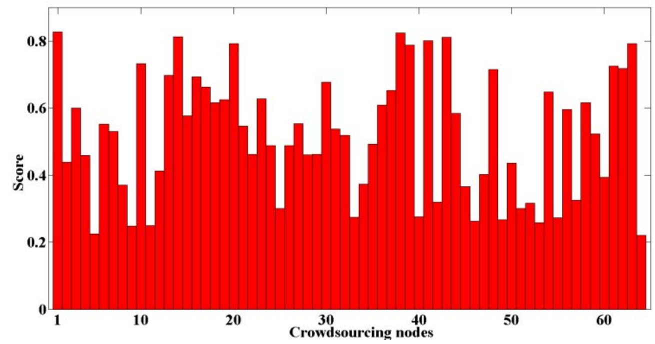
By adjusting crowdsourcing preferences, and assigning weight for each preference setting, the scores of 64 candidates can be calculated. The results for four types of users are given in Fig.4. For R_{LRF}, user 4, 30, and 51 have the highest score, and 1, 13, and 38 are the most likely candidate users for R_{RHF}. However, for users with no specific preferences, 28, 36, and 40 are the best choices.



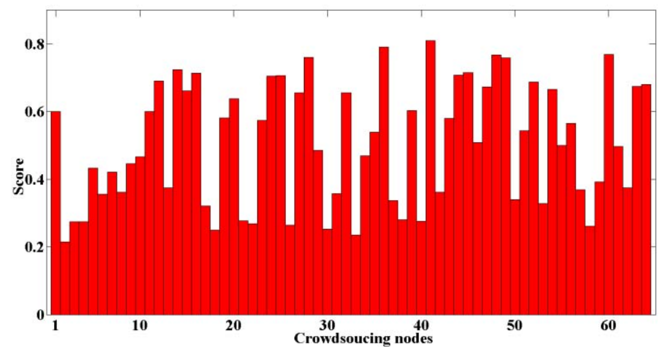
(a) R_{LRF}



(b) R_{SQF}



(c) R_{RHF}



(d) R_{COM}

Fig.4. Correctness analysis of model

VI. CONCLUSION

This paper builds a credible crowdsourcing service model for crowd sensing on the basis of the features of terminal intelligence, sociality of service node and massive sensing data under IoT environment. A general and integrated service model and key techniques are provided, which is useful for the analysis of the social characteristics of mobile nodes, services preferences mining, and service mode decision, etc. It can be seen as a theoretical and technical support for further researches and applications.

MCS has garnered a lot of attention as a new research field in recent times. With more and more sensing information being collected by mobile terminals, the researches and applications around mobile terminals will be expanded and extended in the future.

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