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Research on Task Allocation of Geographic Location Related Mobile Sensing System

Jie Yang[1], Hua-Zhong Li[2], Wan Li[1], Xiao-Bing Liu[1]

[1]School of Electronics and Information Engineering,
Hunan University of Science and Engineering, Yongzhou, Hunan, China, 425199
[2]Institute of Computer Engineering, Shangqiu University
Shangqiu, Henan,476000 China

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Abstract. *With the popularity of smart phone applications, mobile sensing technology has been considered as an efficient and low-cost way to collect environmental data. The optimal task allocation problem in mobile sensing system is a NP hard problem. In order to solve this problem, we propose a polynomial time approximate optimal task allocation algorithm. Firstly, this algorithm introduces the idea of mobile partition in the unit disk model, divides the whole monitoring geographic space into several sub regions, and makes the optimal allocation scheme set up in the sub region. It is shown that the designed approximation algorithm is a polynomial time approximation machine. Subsequently, we prove that the optimal task allocation problem is polynomial time solvable in each sub region, and the optimal solution of the problem is designed by the enumeration algorithm. Finally, the simulation results show that the actual performance of the approximate optimal task allocation algorithm is consistent with the theoretical analysis.*
Keywords: Mobile sensing; Task allocation; Divide; Geographic location related.

1. **Introduction.** With the continuous development of new kinds of micro sensor, Wi-Fi, 3G and 4G technology, smart phones terminals and other types of mobile devices have gradually developed into the daily life of the people in the mainstream of computing and communication devices. According to statistics, sales of smart phones in the fourth quarter of 2010 for the first time exceeded the sales of notebook computers. Worldwide smartphone ownership will reach about 980 million units in 2015 [1]. This means that smart phones have become an important carrier of the development of mobile Internet. At the same time, powered by Android, Windows Phone, IOS mobile operating system of intelligent mobile client programming features and a large number of powerful embedded sensing devices (such as camera, gyroscope, GPS, accelerometer, vibration sensor, sensor noise and angle speed sensor, etc.) the use of [2], but also makes the scope of application of smart phones to further expand.

However, limited by many factors such as mobile phone energy, and not too many mobile phone users are willing to complete the task of the release of the platform for free, which is the main problem facing the current mobile platform. Therefore, we need to design a certain incentive mechanism to attract more mobile users to join the perception task. In order to solve the problem that the Arizona State University Yang et al in the MobiCom 2012 [1], respectively in a platform as the center and to mobile phone users as the center of two different sensing system model design and model to adapt to the incentive mechanism. Most of the existing sensing tasks are related to the location of the mobile phone users, such as urban noise map real-time rendering, road traffic status monitoring, etc. From the perspective of the platform, it will want to spend the least cost to complete the desired task, such as a complete map of the city's noise figure. It is clear that too many mobile phone users who are too many to choose a location in such a task are not suitable. However, the existing research does not consider how to choose the mobile phone users to maximize the benefits of the platform when assigning the geographic location related perception tasks.

With sensor technology, embedded people technology, wireless communication technology, high performance calculation is related to the field of rapid development, networking emerged as a new generation of intelligent network, and has become an important part of a new generation of information technology, known as is the second computer, Internet and telecommunications networks for the third time the world wave of information.

Due to the networking of the sensing area more widely by funds, environmental factors, geographical features, maintenance and factors of influence, may not like the traditional sensor networks that deploy a large number of redundant nodes, but should is a widely distributed and nodes in sensing and relatively sparse network. Sparse network has the characteristics of saving money, easy maintenance, but it will inevitably cause the perception of empty, while reducing the cost of serious damage to the Internet of things. Therefore, how to solve the problem of perception empty will become a new problem in the study of the perception of the Internet of things. Sensor is a physical device, capable of detecting, feel the outside signals, physical conditions (such as light, heat, humidity), and the discovery of information transfer to other device or organ. By calling the method to obtain the location information and it is not to set specific query requirements. The method returns an object that has the information such as latitude and longitude, and then analyzes it to obtain useful information.

Although we by calling the obtained position information and the data of equipment, but method call just active query location information, if necessary after the changes in the geographical location information automatic notification system must also be to add a listener.

In view of the problem of the perception hole caused by sparse network, the concept of mobile service based on intelligent terminal is introduced to solve the problem of the blind area of the target area, and to improve the quality of the service. First of all, the paper analyzes the technical difficulties of mobile sensing, introduces the overall framework of the system; secondly, the real-time acquisition of the perception information. In order to solve the problems existing in the actual system, we will in order to maximize the income platform for optimization goal, according to the characteristics and location of monitoring tasks, design and adapted to the task allocation algorithm. Because such optimal task assignment problem is a classical NP hard problems. Therefore, this paper introduces the division and movement of thought to design our polynomial time approximation algorithms, as much as possible in order to guarantee the performance of the allocation algorithm. In the proposed approximate optimal task allocation algorithm, we first divide the whole monitoring region into several sub regions. And then we find the optimal solution of each sub interval, and the union of these optimal solutions as the final task allocation scheme.

Finally, we demonstrate the performance of the proposed algorithm through theoretical analysis and simulation.

2. Related Works.

Perception of movement (mobile sensing) as networking applications is one of the key technologies to smart phones, personal digital assistant (personal digital assistant, PDA) through the attachment in the human body a variety of mobile devices in a more widely within the sensing area to obtain real-time user interest information [3-5]. Some large-scale sampling tasks, such as noise monitoring, intelligent urban traffic management, often need to collect a large number of sampling data, so as to obtain a credible result. The traditional sampling method is often used by the special instrument in the selected location and specific time sampling, this is not only a very limited number of sampling, and the cost of collecting data is also very high. Difference to traditional wireless sensor network (WSN) technology, the mobile sensing technology with powerful smart phone terminal for data acquisition, large scale data collection tasks is completed by the large scatter of the mobile phone users. This can not only ensure the quality of the data sampling task, but also reduce the task execution time and reduce the task cost. In recent years, the rapid popularity of smart phones also makes mobile sensing related applications can be truly realized.

At present, the research on mobile sensing system is increasing year by year. Literature [2, 6] summarizes the application system of mobile sensor in the intelligent transportation system (Intelligent Transportation), social networks, environmental monitoring, environment monitoring and health monitoring (healthcare) in different areas. Next, we will focus on some of the existing mobile sensing field related work. Thiagarajan *et al.,* in Institute of Technology (MIT) automobile running track and delay calculation using intelligent mobile terminal GPS sensor, introducing hidden Markov model (HMM (hidden Markov model (HMM) technology, designs a precise energy-saving road traffic congestion measuring system called as VTrack [7]. University of New South Wales, Australia Rana et al in the Nokia N95 platform realized an end to end of the noise of the city rendering system Ear-Phone, for monitoring the growing urban noise pollution problem [8]. Noise Tube system was proposed by Stevens *et al.*, [9]. Pothole Patrol system was designed by Eriksson *et al.,* in MIT [10]. System uses the built-in auto vibration sensor and GPS devices, from simple machine learning methods (machine learning) in the Boston area effectively collected a large number of urban road condition data. In addition, the reference region [11-15] was also put forward some sensing technology based on the mobile application system.

3. **Problem model.** The system in Figure 1 consists of a mobile sensing platform and a number of smart phone users. Platform cycle will perception and monitoring tasks assigned to smartphone users, in each task period, first of all by the platform released perception task, if the task is related to the geographical location of smartphone users, we call this task is related to the geography (location based). For example, the government wants to describe the noise index of a city, so it is necessary to select some of the mobile phone users to complete the sensing task in each geographical location that needs to be monitored. Otherwise, the task has nothing to do with the location of mobile phone users, such as medical research institutions to monitor the patient's physical sign data to complete the relevant research. We call this task a geographic independent (location free) perceptual task. In this paper, we only discuss the geographic relevance of the perceptual task system.

Hypothesis in finished reading platform to release the task description (sensing tasks Intro), n users are still interested in the task, then the n users will develop their perception scheme (sensing plan), and perception is uploaded to the platform. Mobile phone users to develop a sense of planning, including their location, the completion of the task of the offer (bid), etc. After receive the program for these users, platform will be based on a task allocation algorithm to select the users complete the task, and computing the corresponding payment (payment) for each is selected for mobile phone users. We call these selected users as a winner. In the end, all the winners upload their collected information

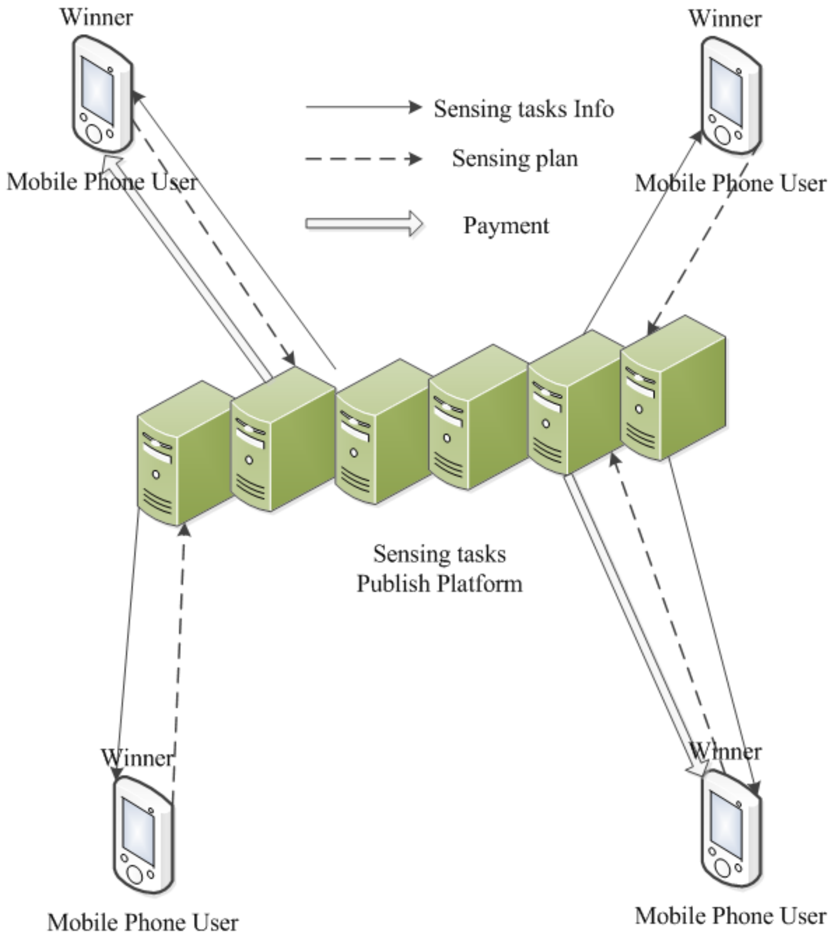

FIGURE 1. Mobile sensing system model

to the platform, while the platform to complete the payment, the task distribution and the end of the phone's perception process.

Obviously, in this platform centric mobile sensing system, the purpose of the platform is to maximize its own revenue.

Assuming $U = 1, 2, 3, \ldots, n$ is the sense of mission in smartphone users set, b_i of the user i is the unit price, the winner of the set W, then the platform for the payment of all user i can be expressed in form as:

$$p_i = \begin{cases} b_i, if i \in W \\ 0, otherwise \end{cases} \tag{1}$$

The revenue of the platform can be defined as:

$$u_p = \sum_{i \in W} (v_i - p_i) \tag{2}$$

Among them, v_i is the value of the information collected by the users on the platform. Usually, for a geographically related task, the data collected by 2 distant mobile phone users is clearly more valuable than the data collected by users of the 2. Therefore, the platform in order to ensure its own revenue will be as far as possible to avoid the choice of too close to the location of mobile phone users to complete the perception task, in order to reduce the perceived redundancy of the received information. Based on the above considerations, we assume that there is a conflict between the user radius r, when the distance between the 2 users is less than *2r*, you think that they are in conflict, will not be selected at the same time. At the same time, we also reasonably assume that all mobile phone data acquisition function is the same, so the collected data on the value of the platform is the same, that is, v_i equal. Make $v = v_i$, then the platform's benefits can be redefined as:

$$u_p = \sum_{i \in W} (v - b_i) \tag{3}$$

4. **Task allocation algorithm based on mobile partition.** In this section we will discuss how to design the optimal sensing task allocation mechanism in the first section, which is based on the mobile phone model.

4.1. **Optimal task assignment problem.** In order to describe the conflict between the user's perception of the data, the relationship between them can be modeled as a conflict graph $G = (V, E)$. Among them, the node in the conflict graph represents the intelligent mobile phone users; there exist side (v_i, v_k) in the conflict graph, which indicates that there is a conflict between v_i and v_k in 2 users. Further use the matrix to represent the conflict relationship in figure G. When , $(v_i, v_k) \in E, y_{i,k} = 1$; otherwise $y_{i,k} = 0$, then the optimal task allocation can constraint shown in the linear equation:

$$\begin{aligned} &\max \sum_{i \in U} x_i(v - b_i), \\ &s.t. x_i + \sum_{k \neq i} y_{i,k} x_k \leq 1, \forall i \in U; \\ &x_i \in \{0, 1\}, \forall i \in U. \end{aligned} \tag{4}$$

Among them, the x_i platform is the task of assigning tasks to the user i. The problem can be summarized as the maximum weighted independent set problem. The weight of each node is $v - b_i$. In order to solve the NP hard problem, we will use mobile division shifting method [16, 17] for the model design of an approximation to the optimal task allocation scheme.

4.2. **Mobile partition algorithm.** Our approximate optimal task assignment algorithm is mainly divided into 2 parts: the monitoring region partition based on the moving of the grid and the sub interval optimal allocation. In the monitoring region division algorithm, we introduce the idea of mobile partition, and the specific design method is as follows:

Without loss of generality, assume that the conflict radius between mobile phone users $r = 1/2$. The whole monitoring area is divided into a number of small grid of 1×1 with the interval of $2r = 1$. At the same time, the lower left corner of the monitoring area is the coordinate origin. A square region consisting of an adjacent $m \times m$ small grid is defined as a sub region. So when in the monitoring area for vertical separation line $x = i \times m$ and horizontal separation line $y = j \times m$ (where *i, j* = 0, 1, ...) , the monitoring area will be divided into several sub ranges. The shadow part of the $m = 6$, divided into 1 sub ranges. When the vertical separator for $x = i \times m + r$. Split horizon line is $y = j \times m + s$, and satisfying $0 \leq r, s \leq m - 1$, we said the division for (r, s) - division.

In a $D(r, s)$ - division, each sub region is formed by 2 adjacent vertical lines and 2 horizontal lines. Due to any mobile phone users between the conflicts radius is equal, then each user can be abstracted to its geographic location for circle center and radius is 1/2 of the unit disk. The platform revenue maximization problem can also be abstracted

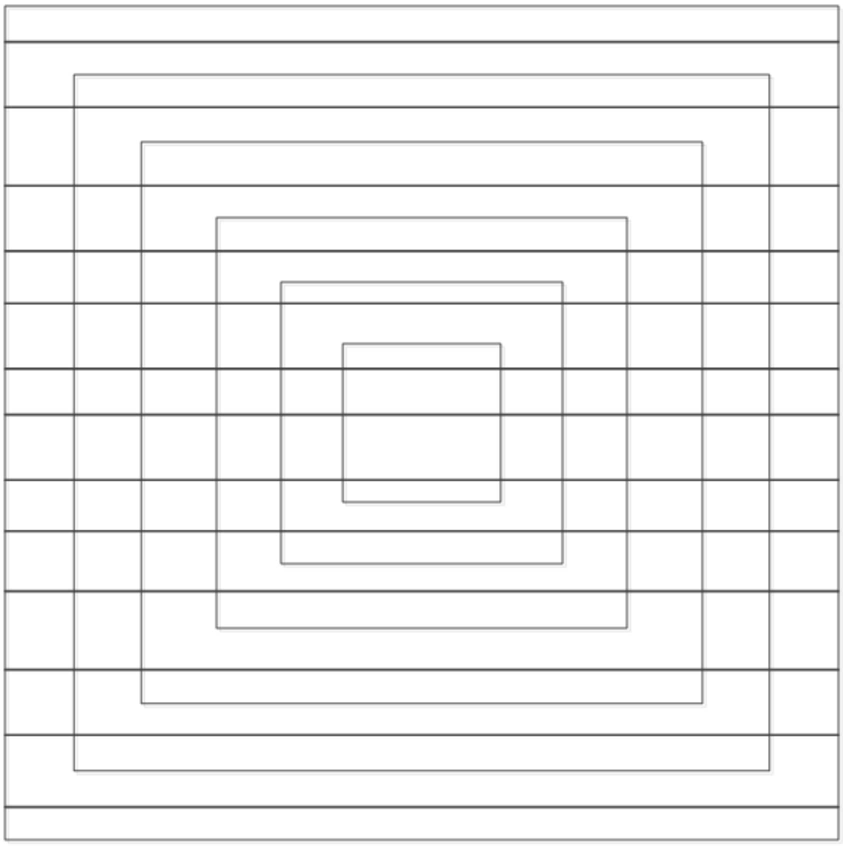

Figure 2. Grid

as a set of units from the entire disk to select a set of non-conflicting units of the disc, so that the total weight of all the selected units of the disc is the largest.

We use $D(r,s)$ on behalf of G in figure to remove all of the area of the intersection of the boundary of the unit disk after the remaining disc. And $D(r,s)$ is in the disc for the effective disc. Obviously, the effective disk is not in conflict with each other. So that we can first in each sub interval calculated a locally optimal task allocation scheme, and the union of all sub interval optimal allocation scheme as the ultimate global allocation scheme. We are able to prove the existence of at least one (r,s) - division that we finally obtained the optimal solution $OPT(D(r,s)$ of weight at least is the global optimal solution weight of $(1-1/m)^2$ times.

Theorem 1. Given the unit disk graph G, we use *OPT(G)* to the maximum weight independent set of figure G, use —*OPT(G)*— to represent the weights of the *OPT(G)*, then there is at least an *(r, s)* - division, where $0 \le r,s \le m-1$, meet the:

$$|OPT(G)| \ge |OPT(D(r,s))| \ge \ (1-\frac{1}{m})^2 \times |OPT(G)| \tag{5}$$

Proof. We assume that the set S is the global maximum weighted independent set of graph G. We assume that $V_r \subseteq S$ is and vertical separation line $x = i \times m + r (i = 0,1,\cdots)$ set intersection disc, and $H_s \subseteq S$ represents the horizontal line $y = j \times m + s (j = 0,1,\cdots)$ of the intersection of the set of the disc, then we can get:

$$\begin{cases} \bigcup_{r=0}^{m-1} V_r \subseteq S \\ \bigcup_{s=0}^{m-1} H_s \subseteq S \end{cases} \tag{6}$$

Easy to get: a unit disk only with a vertical separator line intersect, therefore between different $V_r(0 \leq r \leq m-1)$ intersection is empty. Similarly, $H_s(0 \leq s \leq m-1)$ are disjoint from this:

$$\begin{cases} \sum_{r=0}^{m-1} |V_r| \leq S \\ \sum_{s=0}^{m-1} |H_s| \leq S \end{cases} \tag{7}$$

By the definition of V_r and H_s can be further derived:

$$\min\{|V_r||0 \leq r \leq m-1\} \leq \frac{1}{m}|S| \tag{8}$$

So there is at least one $r0$ that makes:

$$|V_{r0}| \leq \frac{1}{m}|S| \tag{9}$$

$S_{r0} = S - V_{r0}$, then:

$$|S_{r0}| = |S| - |V_{r0}| \geq |S| - \frac{|S|}{m} = (1 - \frac{1}{m})|S| \tag{10}$$

$S_{r0,S0} = S_{r0} - H_{s0}$, similarly available:

$$|S_{r0,s0}| = |S_{r0}| - |H_{s0}| \geq (1 - \frac{1}{m})|S_{r0}| \geq (1 - \frac{1}{m})^2 |S| \tag{11}$$

Obviously, $OPT(D(r_0, s_0))| \geq |S_{r0,s0}|$, which can be:

$$OPT(D(r_0, s_0))| \geq (1 - \frac{1}{m})^2 \times |S| \tag{12}$$

If let $m = \frac{1+\varepsilon+\sqrt{1+\varepsilon}}{\varepsilon}$, then $OPT(D(r_0, s_0)) =\geq (1 + \frac{1}{\varepsilon})|S|$, we can obtain a polynomial time approximation algorithm (polynomial time approximation scheme PTAs).

We has proven given m, there exists at least a *(r, s)* - division, $OPT(D(r,s)) \geq (1+\frac{1}{\varepsilon})|S|$. We test all the feasible division of m^2, and find the approximate optimal solution of each partition. Finally, we select the total weight of the entire partition scheme as the final allocation scheme.

The idea of division and movement is with a small amount of calculation, the local optimal solution of the union substitute calculation of huge amount of global optimal solution, and to ensure that the performance of the final result.

4.3. **The optimal solution of the interval praying.** Within a given subinterval optimal task assignment algorithm before, we need to first prove that in each of the $m \times m$ square sub range up to $2m^2/\sqrt{3}$ mobile phone users are selected.

Theorem 2. In the $m \times m$ square area and can hold up to $2m^2/\sqrt{3}$ interference radius is 1/2 of the circular discs do not interfere with each other. Proof. This disc distribution is the most compact. Disk area is $A_1 = \pi r^2 = \pi/4$, while the void area:

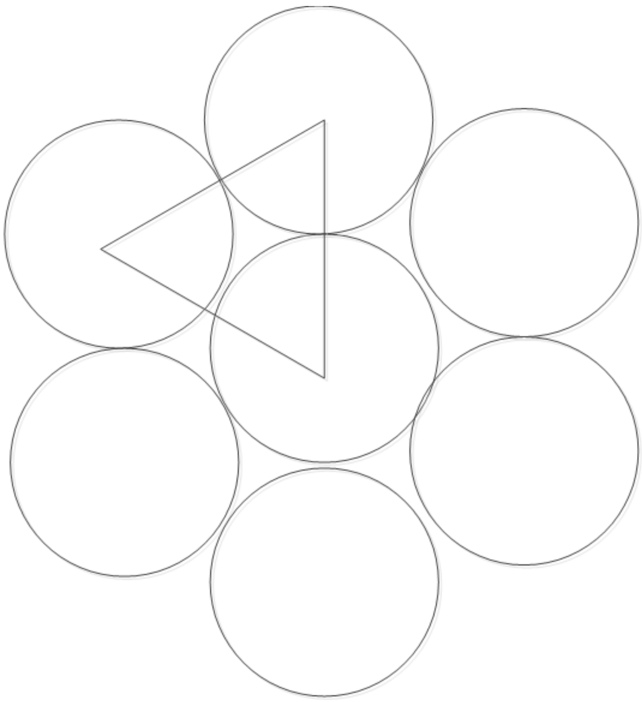

FIGURE 3. Schematic diagram of compact disc

$$A_2 = 1 \times \frac{\sqrt{3}}{2} \times \frac{1}{2} - 3 \times (\frac{(\pi \times 0.5^2)}{6}) = \frac{2 \times \sqrt{3} - \pi}{8} \tag{13}$$

Consists of 3 segments and 1 void, while the area of the 3 sector is , and thus the coverage rate of the disc area is the most closely covered.

$$\rho = A_1/(A_1 + 2A_2) = \pi/2\sqrt{3} \tag{14}$$

In the square area, we in the closest case coverage can only reach $\pi/2\sqrt{3}$ and disc is do not interfere with each other, can accommodate up to the disc number $C = \rho m^2/A_1 = 2m^2/\sqrt{3}$.

If U_j said the j sub division of the range of mobile phone users set $U_{j,N}$ said U_j in the number of mobile phone users is less than N subsets of the set, where $N = \min\{|U_j|, 2m^2/\sqrt{3}\}$. Praying in the interval of optimal task allocation algorithm is first traversal U_j all subsets of $U_{j,N}$, determine the U_j, if there is a conflict between them in any two mobile phone users, if there is conflict between users, abandon the subset; otherwise, in all there is no conflict between users subset found the general weight as the a subset, select the subset as the optimal solution.

Up to a maximum of N mobile phone users in this range, only the number of subsets of the user set N is enumerated and judged in the algorithm, which satisfies the upper limit of the number of subsets of the U_j:

$$C^1_{|U_j|} + C^2_{|U_j|} + \cdots + C^N_{|U_j|} \leq |U_j|^N \tag{15}$$

$N \leq 2m^2/\sqrt{3}$, where m is a constant. Thus, the algorithm is polynomial time solvable.

5. **Experiments.** In this section we will give the results of the simulation of the design algorithm, and then analyze and verify the actual performance of the algorithm. First of all, the algorithm mentioned in this paper approximation ratio (social efficiency ratio) is

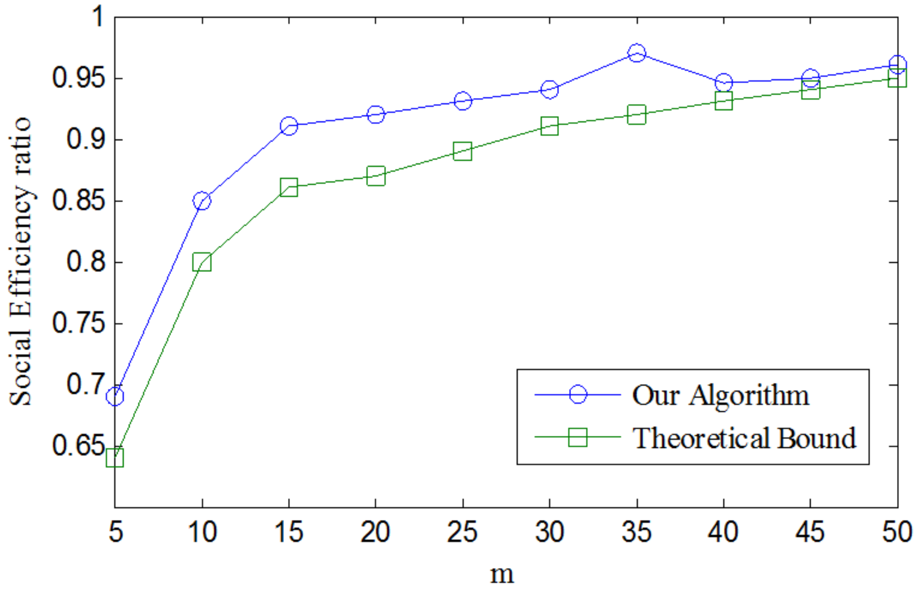

FIGURE 4. The effect of sub interval size on the approximation ratio of the algorithm

equal to the design of approximation algorithm in the platform the actual income (u_p) and the optimal assignment algorithm can get revenue (u_{OPT}) ratio:

$$socialefficiencyratio = \frac{u_p}{u_{OPT}} \tag{16}$$

In the simulation experiment, we choose Java as the development tool, and set the price of each mobile phone users evenly distributed in the 0, 1 range, the conflict between the user radiuses is set to 0.5.

5.1. **Simulation experiment of fixed monitoring area.** In the first part of the simulation experiment, we assume that all the mobile phone users are evenly distributed in a monitoring area.

Figure 4 shows the number of users for 300 of the conditions, the interval size change algorithm to approximate ratio of the change curve. It is not difficult to see that the algorithm of approximation ratio with the m value increase and improve the m represents has been divided into sub interval size. This is because the m value is big, there will be less in the division of discarded mobile phone users, and get the approximate optimal solution is close to the global optimal solution. At the same time, we also compared the different m values approximate than the theoretical lower bound algorithm and practical operation results. It is not difficult to see, the actual performance of the algorithm designed in this paper has been higher than the given a theoretical lower bound, which further verify the correctness of the theoretical analysis.

Between the numbers of mobile phone users in their competition is more intense, it will further affect the performance of the algorithm design. Given sub interval sizes were 20, 30, 40, and 50, than curve approximation algorithm for number of users changes.

It can be seen from the Figure 5, with the gradual increase of mobile phone users the number of approximation ratio will decrease slowly; and when the user number reaches a certain value, the approximate ratio decreased slowly. This is because when the user density is too little, there are only a small amount of mobile phone users to delete the partition scheme, the approximate algorithm performance close to the optimal solution; and when the user density increases, the number of users of the intersection with the

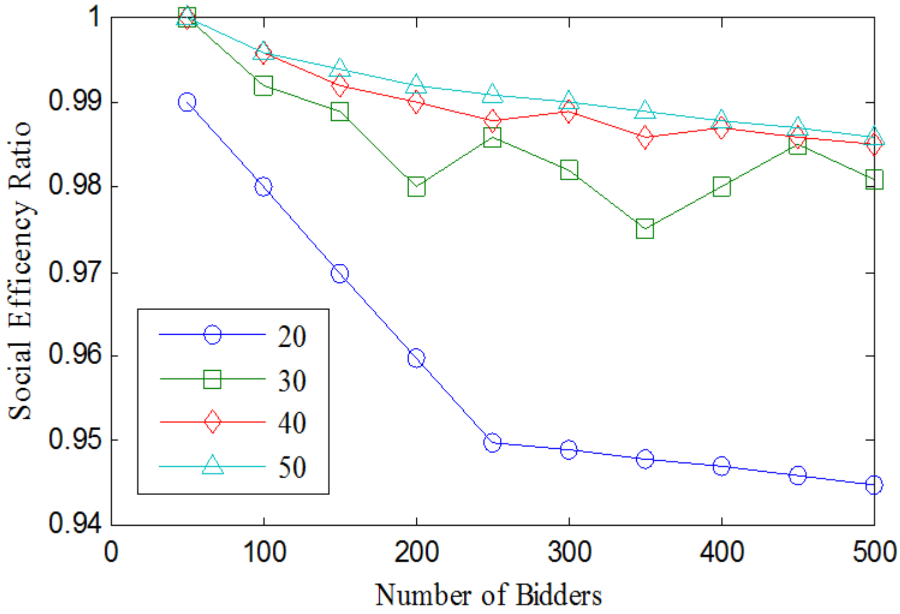

FIGURE 5. The impact of changes in the number of buyers on the approximation ratio of the algorithm

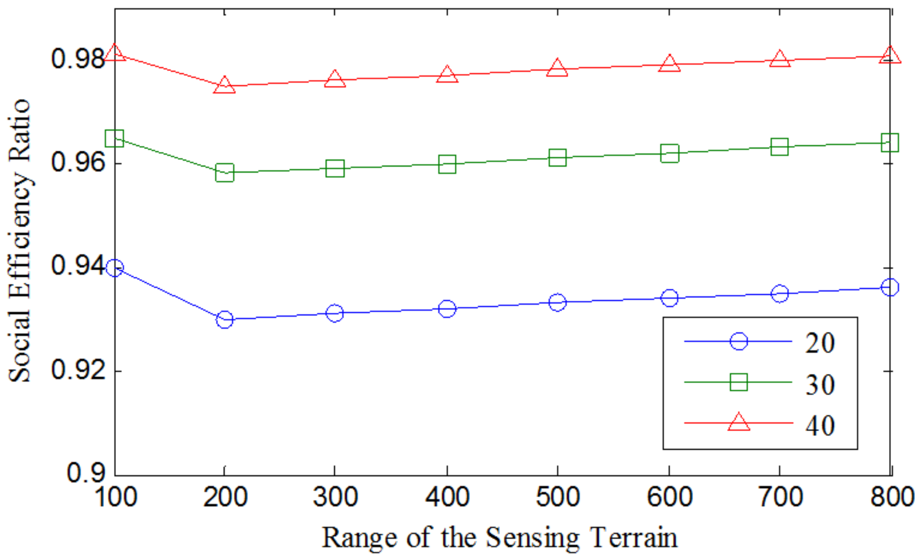

FIGURE 6. The effect of monitoring sub region size on the approximation ratio of the algorithm

interval boundary has gradually increased, the approximation ratio will gradually decline, will gradually close to the theoretical lower bound algorithm. When the m value can be expected, it remains unchanged; the number of users' increases to a certain degree, the number of users' increase of algorithm with approximation ratio has little influence, this approximation ratio stable on the theoretical lower bound of a constant. In addition, we also found that the number of mobile phone users has less influence on the approximation ratio and the shadow ring is far lower than that of designated molecular interval size m of the algorithm approximate ratio influence.

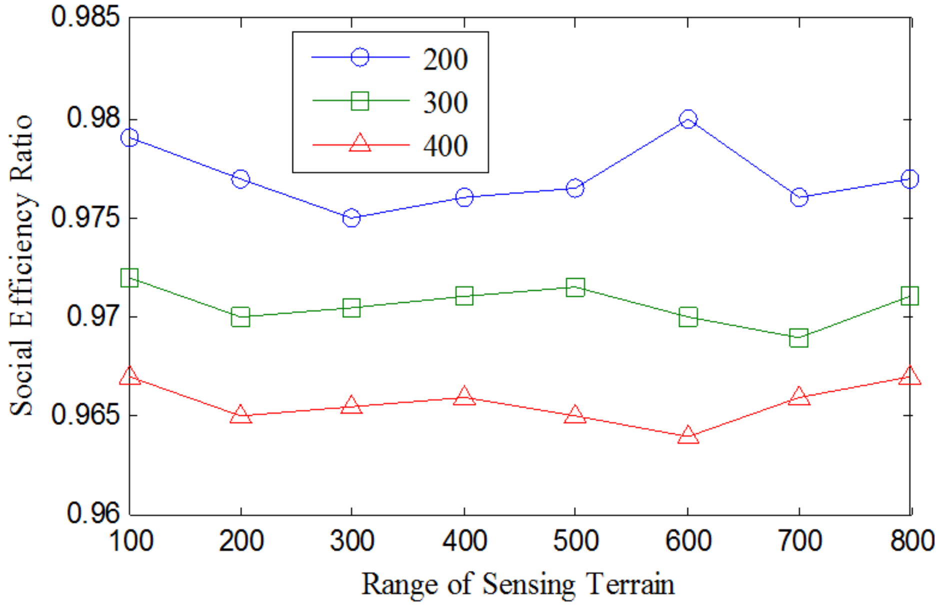

FIGURE 7. The influence of the monitoring area size and the number of users on the approximation ratio of the algorithm

5.2. **Simulation experiment of variable monitoring area.** The sub interval sizes are 20, 30, 40, and the number of users is 400 in Figure 6. The change curve of the algorithm is similar to the change of the algorithm.

Figure 7 is given a number of users were 200, 300, 400, sub interval size m remained under 30 and the conditions of constant and change the size of the regional monitoring algorithm to approximate the ratio change curve. From the graph we can see, when the interval size or the number of users is constant, the change of regional monitoring to approximate than almost had no effect. This is because we in the algorithm using a small amount of calculation, the local optimal solution by the union of the alternative calculation of huge amount of global optimal solution method, unit of the actual implementation of the algorithm is sub interval. Monitoring area the size of approximation ratio has almost no effect; the results further verify the correctness of the theoretical analysis.

6. **Conclusion.** The characteristics of this mobile phone sensing task for geography related, to maximize the benefits of the platform as the optimization goal, proposed a polynomial time approximate optimal task allocation mechanism. The optimal sensing task allocation protocol based on geographical location for the unit disk model under the maximum weighted independent set problem; and then introduce the mobile division the idea, through the monitoring area is divided into several sub regions, and find the optimal solution of each sub interval, design approximation ratio is approximate optimal algorithm; finally, the theoretical analysis and simulation results show the approximate optimal algorithm running time design e becomes larger when the longer, the actual performance is also higher.

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