

## *Retraction*

# **Retracted: A Task Allocation Algorithm for Coal Mine Mobile Crowd Sensing Based on Weighted Undirected Graph**

## **Security and Communication Networks**

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

## **References**

- [1] Z. Wang, W. Chen, H. Jiang, S. Xiao, and H. Yang, "A Task Allocation Algorithm for Coal Mine Mobile Crowd Sensing Based on Weighted Undirected Graph," *Security and Communication Networks*, vol. 2021, Article ID 9999798, 14 pages, 2021.

## Research Article

# A Task Allocation Algorithm for Coal Mine Mobile Crowd Sensing Based on Weighted Undirected Graph

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Existing applications of mining intelligent mobile terminals are all for the sensing of individual terminals, without considering the group attributes of terminal carriers and the cooperation opportunities brought by terminal movement, which is unable to complete large-scale and complex sensing tasks. In this article, mobile crowd sensing and mine safety monitoring are combined to construct the mobile crowd sensing network for coal mine. Aiming at the task allocation problem, a task allocation mechanism based on a weighted undirected graph is proposed. First, considering the similarity of task completion location and time and quality of data collected, the reputation evaluation model of miners is designed. In order to optimize the reputation of miners participating in the task, an emergency task allocation algorithm based on the weighted undirected graph is proposed. Second, based on the fatigue degree of miners and the residual energy of intelligent mobile terminals, the miner status evaluation model is constructed, which is combined with the reputation model to design a nonemergency task allocation algorithm, aiming at further optimizing the task allocation results. The simulation results show that the proposed algorithm has better performance in allocation time for sensing task, task allocation success rate, average reputation, and status value of miners.

## 1. Introduction

Intelligent mobile devices (mobile phones and tablet computers) can not only be used as mobile devices for daily communication but also used as a sensing unit because of its embedded sensors, such as the acceleration sensor, digital compass, gyroscope global positioning system (GPS), microphones, and cameras. It is possible to share the sensing data by using these sensors. Mobile crowd sensing is such a new kind of sensing network which uses the sensors of mobile devices of ordinary users.

At present, the research on mobile crowd sensing mainly focuses on the following aspects: (1) the application system research of mobile crowd sensing in different fields such as collaborative location and environment detection and (2) sensing task allocation. Participants are the basic units to

complete the sensing tasks, which need participants to complete. Different participants have different abilities and different degrees of positivity, which will lead to different completion quality of the tasks. Therefore, in order to improve the task completion efficiency, it is very important to establish a reputation evaluation model in the mobile crowd sensing system to reasonably select participants according to the sensing task requirements.

China is a big country of coal resources, and the energy structure dominated by coal will be difficult to change in the short term. The underground roadway structure is complex, and the working environment of miners is harsh. In recent years, with the development of intelligent phones and mobile communication technologies, how to combine mobile crowd sensing with traditional coal mine safety monitoring to create a new networked and intelligent coal

mine safety monitoring system is a research hotspot [1]. Mine explosion-proof mobile phones with intelligent phones as the core are gradually being promoted and applied in the field of underground safety monitoring and control. Through the mine explosion-proof mobile phone, we can realize the voice and video communication on the well and underground [2], gas dynamic inspection [3], mechanical and electrical equipment operation status detection [4], and integrated management of safety production information [5]. In the mine with better mining conditions and higher information level in Western China, all underground miners hold an intelligent phone [6] intelligent phone certified by mine safety standard. At the same time, the intelligent information mine lamp with a stronger function is also promoted and applied in coal mines, which not only has the functions of environmental parameter detection, telephone call, personnel positioning, and photography but also has the function of health diagnosis of miners [7]. However, the existing applications based on mine intelligent terminals are all individual-oriented terminal sensing, without considering the group attribute of terminal carriers, which is unable to complete the large-scale and complex sensing task oriented to mine safety, and cannot realize the intelligent mine construction goal of ubiquitous sensing and intelligent decision-making [8].

In view of this situation, this article puts forward the task allocation problem of mobile crowd sensing for mine safety detection and constructs a miner reputation evaluation model related to miners' task location, task completion time, and task completion quality. According to the actual environment of the mine, an emergency task allocation algorithm is designed and proposed, based on the weighted undirected graph. Finally, a miner status value evaluation model related to fatigue degree of miners and residual energy of equipment is constructed. On this basis, the non-emergency task allocation algorithm is designed and put forward. In the simulation experiment, the proposed algorithm is compared with the MARL algorithm, heuristic algorithm, and HTA algorithm, and the results show that the emergency task allocation algorithm reduces the allocation time under the same allocation success rate and maintains a high reputation under different number of participants. In the nonemergency task allocation algorithm, the average status value of participants is higher than that of the same algorithm, which optimizes the allocation of miners and equipment.

## 2. Related Work

*2.1. Research on Mine Safety Monitoring Based on Mobile Intelligent Terminal.* With the improvement of coal mine automation and informatization, especially the development of Internet of things technology, wireless transmission technology, and mobile detection technology, the core research content in the field of coal mine is to promote the upgrading and transformation of the coal mine safety monitoring system by means of mobile crowd sensing, wireless transmission, downlink transmission of detection data, intelligent control, and so on. Mining intelligent

mobile terminals with intelligent phones as the core are gradually being promoted and applied in different areas of underground safety monitoring [9], as shown in Figure 1. In [10], in view of the problems, the manual inspection data in the gas inspection management cannot be uploaded in real time, and the data processing results cannot be fed back to the site in time, designed, and developed a mine gas dynamic inspection and control system, which is based on an intelligent phone and multiparameter gas detector. Literature [11] is also oriented to the application of coal mine gas monitoring and early warning. Aiming at solving the two-way synchronization problem between the underground outburst prevention information collection systems based on an android explosion-proof mobile phone and the ground information database, a database synchronization scheme based on the sync framework is proposed to realize the on-demand two-way synchronization of the outburst prevention dynamic information database. Literature [12] proposes miner situational information modeling and uses various existing information system resources to provide miners with timely and effective information services to avoid potential safety hazards. The literature [13] classifies wearable devices. Through the application of different types of wearable devices and the use of intelligent phones to realize information collection, the vital signs of miners can be sensed more comprehensively and the safety of underground operations in coal mines can be enhanced. However, the existing research has not considered the group attributes of terminal carriers and the collaboration opportunities brought by terminal mobility and also failed to make full use of the growing scale effect of underground intelligent mobile terminals, which cannot meet the large-scale, fine-grained, and comprehensive requirements of intelligent mining sensing requirements. Therefore, it is necessary to combine mine safety monitoring with mobile crowd sensing, take underground miners and equipment carrying intelligent mobile terminals as the sensing source, and use its wide distribution, flexible mobility, and opportunity connectivity for sensing to complete mine safety monitoring large-scale and complex sensing tasks.

*2.2. Research on Task Allocation Mechanism of Mobile Crowd Sensing.* An appropriate selection of participants can ensure the efficient and accurate completion of the sensing task. Therefore, the task allocation mechanism has always been one of the key issues in the mobile crowd sensing research. Zhang et al. [14] studied the heuristic algorithm and introduced the reference value of the current worker's ability to work. In order to maximize the expected task quality under the premise of controlling the budget, that article comprehensively studies the credit, ability, interest, and hobby of workers and the position discount function of workers and tasks. Xu et al. [15] studied the HTA algorithm. The main idea is to screen out the central node and the corresponding subordinate nodes based on the social attributes. When the task distributor meets the central node, the task allocation of the subordinate node is determined at the same time. The central node is also responsible for task

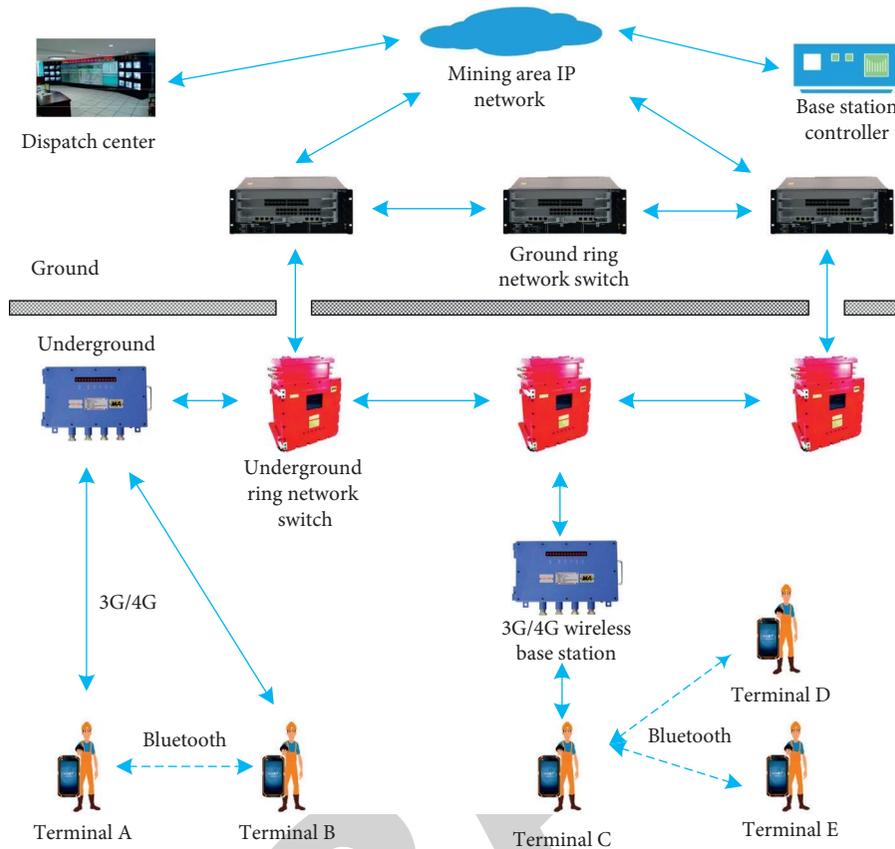


FIGURE 1: Mine network coverage.

allocation and result recovery. Han et al. [16] studied the MARL algorithm, combined with the idea of Q-learning, and optimized the task allocation time based on the heterogeneity of different participants and tasks under the premise of satisfying quality constraints. A real-world multitask allocation method based on multiagent reinforcement learning is proposed, and the optimization goal is defined as the pursuit of shorter task allocation time under the premise of satisfying quality constraints. Mingchu Li et al. [17] proposed a Pareto optimal particle swarm optimization algorithm to solve the multitask and multi-optimization objective problem under the limited number of people. Wang Yanan et al. [18] designed a heuristic MIA algorithm to solve the problem of user selection for coverage equilibrium with budget constraints. Weiping Zhu et al. [19] proposed a greedy discrete particle swarm optimization algorithm based on the genetic algorithm, which fully considers the heterogeneity between users, and aim at maximizing the number of known completed tasks while satisfying certain constraints.

However, these task allocation methods are mostly suitable for task allocation in general conditions and do not take the actual situation of coal production into consideration. In the general situation, the task allocation methods are more to consider the wishes of the participants and whether the cost is overspending, the participants can subjectively choose the tasks they want to participate in. These task allocation methods need not consider the factors

of participants and equipment. If a participant is selected, participants can reject the task allocation on the system platform, and in general cases, the ultimate goal is to minimize the cost, which is quite different from the task allocation strategy in the background of coal mine production.

Mobile crowd sensing without special deployment use existing sensing devices and deployed communication networks, thereby greatly reducing deployment and maintenance costs. At the same time, due to the natural mobility of mobile terminals such as mobile phones carried by users, it can promote sensing coverage and data transmission and realize fine-grained sensing; therefore, more crowd sensing applications need to be explored. With the improvement of coal mine informatization and intelligence, the configuration scale of intelligent mobile terminals for mining will continue to expand, and the terminal's sensing, calculation, and communication capabilities will continue to increase. The combination of mobile crowd sensing and mine safety monitoring can further tap the sensing potential of existing mining intelligent mobile terminals, expand group sensing applications based on intelligent mobile terminals, and realize large-scale and complex sensing tasks.

Based on the actual background of the mine, in order to realize the reasonable allocation of mine tasks and miners, this article puts forward the problem of task allocation of mobile crowd sensing for mine safety monitoring. First, the reputation evaluation model of miners is constructed by the

time, place, and quality of tasks to evaluate the reputation of miners. On this basis, an algorithm of emergency task allocation based on weighted undirected graph is designed with the optimization goal of maximizing the reputation of participants in the specified task time. Finally, the status value evaluation model of miner is constructed, related to miner fatigue, and equipment residual energy is constructed, and a nonemergency task allocation method is designed.

### 3. Reputation Evaluation Model of Miners

This article defines the reputation of participants as  $R(u_i)$ , which is quantified as the value of  $[0, 1]$ , the reputation value of 0 means that the miner is completely untrustworthy, 0.5 is uncertain, and 1 is completely trusted. Meanwhile, the initial reputation of participants who participate in the sensing task for the first time is set to 0.5, which indicates that the reputation is uncertain at the beginning. In order to make the reputation evaluation model of miners accurately reflect the miner's completion of the task, this article designs a reputation update mechanism, which updates the reputation of miners according to the completion of tasks. In this article, the reputation evaluation model of miners is composed of three parts: task completion location similarity  $l(u_i, m_j)$ , task completion time similarity  $p(u_i, m_j)$ , and task completion quality  $q(u_i, m_j)$ . The model is through three dimensions comprehensive evaluation of the completion of a task of miners.

The logistic regression method is adopted in this study to determine the weight of the three factors. The final classification result of miners can always be divided into trustworthy or untrustworthy. Miners can be trusted, that is, the dependent variable  $y_{u_i} = 1$  in expectation  $E(y_{u_i})$  when the reputation is greater than 0.5. Miners cannot be trusted, that is, the dependent variable  $y_{u_i} = 0$  in expectation  $E(y_{u_i})$  when the reputation is less than 0.5. So the value of the dependent variable  $y_{u_i}$  in the model is 0 or 1, which conforms to the 0, 1 binomial distribution. Therefore, the coefficients of the three independent variables in the case of miners' trustworthiness can be obtained by setting the dependent variable  $y_{u_i} = 1$ , and the reputation model can be established, as shown in the following equation:

$$E(y_{u_i}) = c(u_i, m_j) = f(\beta_0 + \beta_1 \cdot l(u_i, m_j) + \beta_2 \cdot p(u_i, m_j) + \beta_3 \cdot q(u_i, m_j)), \quad (1)$$

where  $f(x)$  is a logistic function,  $f(x) = e^x / (1 + e^{-x})$ , and  $c(u_i, m_j)$  is the reputation of miner  $i$  participating in task  $j$ .

$$\text{Order } x = \beta_0 + \beta_1 \cdot l(u_i, m_j) + \beta_2 \cdot p(u_i, m_j) + \beta_3 \cdot q(u_i, m_j). \quad (2)$$

Substitute the above formula and take the logarithm to obtain the logistic regression model of one task reputation:

$$\ln\left(\frac{c(u_i, m_j)}{1 - c(u_i, m_j)}\right) = \beta_0 + \beta_1 \cdot l(u_i, m_j) + \beta_2 \cdot p(u_i, m_j) + \beta_3 \cdot q(u_i, m_j). \quad (3)$$

According to the logistic regression calculation method, let  $E(y_{u_i} = 1) = c(u_i, m_j)$ , using maximum likelihood estimation to calculate the coefficients. By bringing in three groups of independent variables, the coefficients of the three variables and constant values can be calculated. The reputation evaluation model can be obtained by substituting different independent variables into different sensing tasks.

In this article, in order to avoid the difference in the number of miners participating in the tasks affecting the calculation of reputation, therefore, the miner's reputation is summed up, and then, taking the average, the formula of the miner's reputation is shown in the following equation:

$$R(u_i) = \frac{1}{n} \sum_{j=1}^n c(u_i, m_j), \quad (4)$$

where  $n$  is the total number of tasks completed by miner  $i$  in history.

**3.1. Similarity of Task Completion Location.** The similarity of the task completion location is calculated as follows:

$$l(u_i, m_j) = \begin{cases} 0, & |x_j - x_i| > \Delta x, |y_j - y_i| > \Delta y, \\ \frac{u_i \cdot m_j}{\|u_i\| \|m_j\|} = \frac{x_i * x_j + y_i * y_j}{\sqrt{x_i^2 + y_i^2} * \sqrt{x_j^2 + y_j^2}}, & |x_j - x_i| < \Delta x, |y_j - y_i| < \Delta y, \\ 1, & x_i = x_j, y_i = y_j, \end{cases} \quad (5)$$

where  $u_i(x_i, y_i)$  and  $m_j(x_j, y_j)$  represent the location vector of the miner  $i$  and the task  $j$ .  $x_i, y_i$ , respectively, represent the vertical and horizontal coordinates of the location when miner  $i$  completes the task and submits data.

$x_j, y_j$  represent the position coordinates required by the task.

Since the data task of measuring a certain section of roadway or position often appears in the mine, when a task

occurs, if the location of the data measured by the miner is very close to the task point but not on the coordinates required by the task, the data which miner obtained are often also feasible. Therefore, judging the position of the miner's task by just one coordinate point is obviously not in line with the actual characteristics of the mine task. For this reason, this article also specially sets the coordinate position variables  $\Delta x$ ,  $\Delta y$ , which can be used to adjust the actual scope of participation for different tasks, as shown in Figure 2, and  $\Delta x > 0$ ,  $\Delta y > 0$ . This article uses the cosine similarity method to describe the similarity between the task location and the miner's location. The closer the similarity is to 1, the closer the location of the miner to the task location and the more reliable the data submitted by the miners. Otherwise, the reliable is low.

**3.2. Similarity of Task Completion Time.** The task completion time similarity is calculated as follows:

$$p(u_i, m_j) = 1 - \frac{D(u_i m_j^b, m_j^b) + D(u_i m_j^e, m_j^e)}{2n}, \quad (6)$$

where  $u_i m_j^b$  is the time when the miner  $i$  starts the task  $j$ ,  $u_i m_j^e$  is the time when miner  $i$  ends task  $j$ ,  $m_j^b$  is the start time of the task  $j$  required by the system,  $m_j^e$  is the end time of task  $j$  required by the system, and  $D$  indicates the difference of time.

The degree of difference between users starting to perform sensing tasks can be measured by the time difference between users participating in the task [20, 21]. First, convert the start time  $m_j^b$  of the sensing task and the start time  $u_i m_j^b$  of each sensed user into numerical data. Then, calculate the absolute difference of the start time between the sensing task and different users, and  $D(u_i m_j^b, m_j^b) = |u_i m_j^b - m_j^b|$ . The minimum and maximum absolute difference of start time between tasks and different users can be expressed by the interval  $[\theta_1, \theta_n]$ . Divide the interval into  $n - 1$  equidistant cells:  $\{[\theta_1, \theta_2], [\theta_2, \theta_3], \dots, [\theta_{n-1}, \theta_n]\}$ . The difference degree value is  $\{0, 1, \dots, n - 1, n\}$ , when the absolute difference of the start time between the sensing user and the sensing task falls between one of the cells. By using the same calculation method, we can get the difference degree of the user and task in end time. Add the task start time difference and the task end time difference and then divide by the difference interval to calculate the time difference degree of miner  $i$  to task  $j$ .

**3.3. Task Complete Quality.** Data quality reliability is calculated as follows:

$$\phi_{m_j} = \frac{\sum_{i=1}^n ds(u_i, m_j)}{n}, \quad (7)$$

$$q(u_i, m_j) = 1 - \frac{|ds(u_i, m_j) - \phi_{m_j}|}{|ds(u_i, m_j)_{\max} - \phi_{m_j}|},$$

where  $\phi_{m_j}$  is the average numerical of the task,  $ds(u_i, m_j)$  represents the value of the miner upload task,  $ds(u_i, m_j)_{\max}$  represents the maximum value of uploaded data for all

participating miners to complete the task  $m_j$ , and  $n$  is the total number of miners involved in the task.

A common task in mines is the sensing task that requires data collection. This type of sensing task usually requires miners to collect some data information, such as gas concentration in roadways and chambers. In this article, the average value of the data uploaded by the miners participating in the task is used as the real data of the task, and the reliability of the data provided by the miners is determined by comparing the difference between the values collected by different miners and the real data. When the value provided by the miner is closer to the real data, the reliability of the uploaded data is high. In the data quality reliability formula  $q(u_i, m_j)$ , the value is closer to 1; otherwise, the closer it is to 0, the data collected by the miner is far from the real data, that is, the deviation from the real data has a deviation, and the reputation is low.

#### 4. Emergency Weighted Undirected Graph Task Allocation Algorithm

There are  $n$  sensing tasks,  $M = \{m_1, m_2, m_3, \dots, m_n\}$ , where  $m$  can be represented as a 4-tuple:  $m_j = \{p_{m_j}, tb_{m_j}, te_{m_j}, tr_{m_j}, s_{m_j}\}$ , where  $p_{m_j}$  is the number of miners required for the task, and  $p_{m_j} \geq 1$ .  $tb_{m_j}$ ,  $te_{m_j}$ , respectively, represent the start time and end time of the task,  $tr_{m_j}$  indicates that the system estimates the time required to complete the task, and  $tr_{m_j} \leq te_{m_j} - tb_{m_j}$ .  $s_{m_j}$  represents the type of task. There are  $r$  participants  $U = (u_1, u_2, u_3, \dots, u_r)$  in which  $u_i = \{R(u_i), v_{u_i}, x_i, y_i, u_i^e\}$ ,  $v_{u_i}$  is expressed as the moving speed of the miner  $i$ , and  $v_{u_i} > 0$ .  $(x_i, y_i)$  represents the position of miner  $i$ .  $u_i^e$  represents the type of the historical task processed by miner  $i$ .

According to the task type and constraint of the sensing time of task, this article uses gray coding to divide the task type  $s_{m_j}$ . Draw the task type tree according to the task type requirements, as shown in Figure 3.

Suppose that a numerical sensing task in a mine can be divided into four subtypes: {gas 00, noise 01, wind speed 11, negative pressure 10}. According to the requirements of sensing task urgency in this article, the task can be further refined into two subtypes: {emergency 01, nonemergency 10}. Then, a numerical sensing task can be described by matrix  $E$ :

$$E = \begin{pmatrix} E0001 & E0010 \\ E0101 & E0110 \\ E1101 & E1110 \\ E1001 & E1010 \end{pmatrix}, \quad (8)$$

where  $E0001$  is a numerical gas emergency task,  $E1110$  represents the numerical wind speed type nonemergency task, and other types of sensing tasks can be analogized.

First of all, we take each underground roadway as the edge of the undirected graph. The connection point of the tunnel and each chamber are taken as the node of the

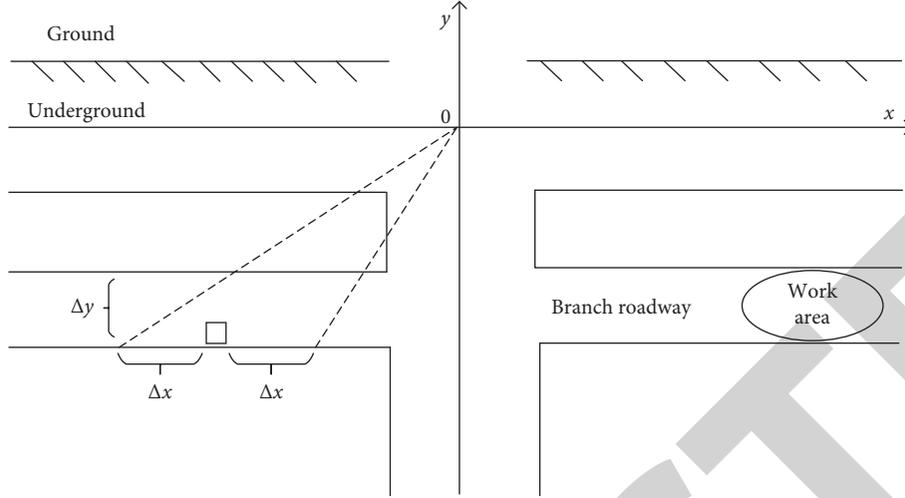


FIGURE 2: Sketch map of task location similarity.

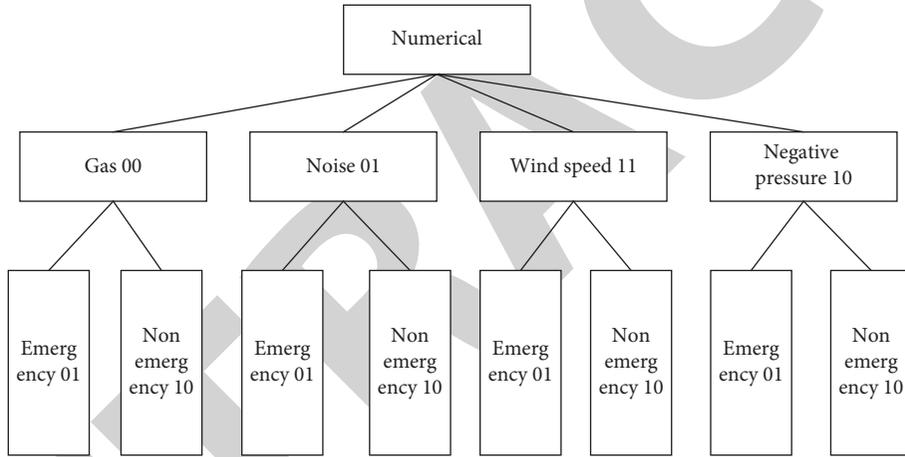


FIGURE 3: Schematic diagram of gray coding.

undirected graph. Get the movement speed of each miner  $v_{u_i}$ . In this study  $\text{dis}(d_i, d_j)$  represents the adjacent nodes  $d_i, d_j$  of the mine. According to the edge length of undirected graph and miner's speed, the weight  $w(d_i, d_j)$  between adjacent nodes is determined, and  $w(d_i, d_j) = \text{dis}(d_i, d_j) / v_{u_i}$ . At the beginning of the algorithm, the task node is added to the undirected graph. After joining the task node, we get the type and location information of the task. According to the task type and whether the miners have engaged in similar tasks in history, we can select the miners who can meet the requirements of solving such tasks from all the miners to obtain the candidate set. By taking the task node as the center, it spreads outward along the connected edge and accumulates the weight of the edge that has passed during the diffusion process. Since it takes a certain time to complete the task itself, we subtract the time required to complete the task itself on the basis of the task weight specified by the system.  $w_{m_j} = tb_{m_j} - te_{m_j} - tr_{m_j}$  is the final weight of task. When the path reaches the required weight, the whole path planning is obtained with the task node as the center within the specified constraint time. Then,

the miners in the path are sorted according to their reputation, and the first several miners are selected first to carry out the task.

Considering the time limit of the task and the location information of miners, the objective of this article is to find out the miners who meet the requirements of the task and may have high reputation to complete the task within the specified time constraints.

This article represents this problem as an optimization problem.

$$\begin{aligned} \text{Maximize : } & \sum_{i=1}^{P_{m_j}} R(u_i) \quad \text{in which } u_i \in U, \\ \text{Subject to : } & w(l_{u_i}, l_{m_j}) < w_{m_j}, \end{aligned} \quad (9)$$

where  $w(l_{u_i}, l_{m_j})$  represents the sum of the weights of the time elapsed from the miner's position to the task position, and  $w_{m_j}$  is the time weight required by task  $j$  (Algorithm 1).

The weighted undirected algorithm flowchart is shown in Figure 4.

```

(i) Input: set of users  $U$ , node coordinates  $(x_j, y_j)$ , add task node  $m_j$ , define task type  $s_{m_j}$ , get task time weight  $w_{m_j}$ , initial task path weight  $w_\eta = 0$ , initialize
(ii) Output: selected participants  $U_c$ 
(iii) For  $i = 1$  to amount  $U$  do
(iv)   For  $j = 1$  to amount of  $u_i^e$  do
(v)     If  $u_i^e = s_{m_j}$ , then
(vi)        $U_1 \leftarrow$  record miner;
(vii)     End if
(viii)  End for
(ix)   End for
(x)   Make the initial node the task node  $m_j$ ;
(xi)  Get and record the nodes adjacent to the current node;
(xii) Calculate the weight of the current node and adjacent node  $w(d_i, d_{i+1})$ ;
(xiii) If  $w(d_i, d_{i+1}) \geq w_{m_j} \parallel d_{i+1} \rightarrow \text{next} == \text{null}$ , then
(xiv)  Coordinate  $(x_j, y_j) \leftarrow$  record the coordinates of the farthest position;
(xv)  Else
(xvi)  Record the weight of the path, update node  $d_i$  to the next adjacent node  $d_{i+1}$ , and return to step (11);
(xvii) End if
(xviii) Obtain the position coordinates of miners in miner set  $U_1$  ;
(xix)  For  $i = 1$  to amount  $U_1$  do
(xx)   If  $u_i(x_i, y_i) \in \text{coordinate}(x_j, y_j)$ , then
(xxi)   $U_2 \leftarrow$  record miner
(xxii) End if
(xxiii) End for
(xxiv)  $R(u_i) \leftarrow$  calculate amount of value;
(xxv) Sort  $U_2$  based on  $R(u_i)$  in the decreasing order;
(xxvi)  $U_c \leftarrow$  number of people before selection;
(xxvii) Return  $U_c$ ;

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ALGORITHM 1: Emergency weighted undirected graph algorithm.

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(i) Input: set of users  $U$ , node coordinates  $(x_j, y_j)$ , add task node  $m_j$ , define task type  $s_{m_j}$ , get task time weight  $w_{m_j}$ , initial task path weight  $w_\eta = 0$ , initialize
(ii) Output: selected participants  $U_c$ .
(iii) For  $i = 1$  to amount  $U$  do
(iv)   For  $j = 1$  to amount of  $u_i^e$  do
(v)     If  $u_i^e = s_{m_j}$ , then
(vi)        $U_1 \leftarrow$  record miner;
(vii)     End if
(viii)  End for
(ix)   End for
(x)   Make the initial node the task node  $m_j$ ;
(xi)  Get and record the nodes adjacent to the current node;
(xii) Calculate the weight of the current node and adjacent nodes  $w(d_i, d_{i+1})$ ;
(xiii) If  $w(d_i, d_{i+1}) \geq w_{m_j} \parallel d_{i+1} \rightarrow \text{next} == \text{null}$ , then
(xiv)  Coordinate  $(x_j, y_j) \leftarrow$  record the coordinates of the farthest position;
(xv)  Else
(xvi)  Record the weight of the path, update node  $d_i$  to the next adjacent node  $d_{i+1}$ , and return to step (11);
(xvii) End if
(xviii) Obtain the position coordinates of miners in miner set  $U_1$  ;
(xix)  For  $i = 1$  to amount  $U_1$  do
(xx)   If  $u_i(x_i, y_i) \in \text{coordinate}(x_j, y_j)$ , then
(xxi)   $U_2 \leftarrow$  record miner
(xxii) End if
(xxiii) End for
(xxiv)  $rs(u_i) \leftarrow$  calculate amount of value;
(xxv) Sort  $U_2$  based on  $rs(u_i)$  in the decreasing order;
(xxvi)  $U_c \leftarrow$  number of people before selection;
(xxvii) Return  $U_c$ ;

```

ALGORITHM 2: Nonemergency weighted undirected graph algorithm.

## 5. Nonemergency Weighted Undirected Graph Task Allocation Algorithm

As the underground working environment is relatively poor, if the task time is emergency, facing the needs of safety production, we should not only be quick in time but also need to complete the task with high quality. For the non-emergency task, compared with the emergency task, the time is relatively broad. Therefore, this article constructs a status value evaluation model related to fatigue degree of miners and residual energy of equipment, trying our best to achieve the reasonable allocation of miners and equipment. When assigning nonemergency tasks, a comprehensive fatigue value reflecting the miner's own status is constructed [22], according to the feedback information of the intelligent equipment carried by the miner, such as heart rate and age, as shown in the following equation:

$$k_i = \sum_{j=0}^{t_i} 1.929b_j + 0.4755a + 1.073h - 323.62, \quad (10)$$

where  $b_j$  is the heart rate (beats/min);  $h$  is the miner's height (cm);  $a$  is the miner's age (years), and  $t_i$  is the length of time the miner works (min).

On this basis, the sensing platform directly obtains the residual equipment energy of the miner's equipment  $E_{u_i}$ , and  $E_{u_i} \in [0, 100]$ . The status value evaluation model is constructed, as shown in the following equation:

$$st(u_i) = \alpha_1 \frac{k_{u_i} - k_{\min}}{k_{\max} - k_{\min}} + \alpha_2 \frac{E_{u_i} - E_{\min}}{E_{\max} - E_{\min}}, \quad (11)$$

where  $E_{\max}$  and  $E_{\min}$  are the maximum and minimum values of the residual energy of the equipment, and  $0 \leq \alpha_1 \leq 1, 0 \leq \alpha_2 \leq 1$ .

Due to the different characteristics of residual equipment energy and fatigue degree of miner, when calculating the status value, this article hopes to weigh the proportion of each according to their characteristics. When a participant miner has a higher residual equipment energy but a higher degree of fatigue, the fatigue degree of the miner will be more considered. When a participant miner has lower residual equipment energy and lower fatigue, more consideration is given to the equipment carried by the miner. In order to achieve the above purpose, the values of  $\alpha_1$  and  $\alpha_2$  are defined as follows:

$$\alpha_1 = \frac{E_{u_i} - E_{\min}}{E_{\max} - E_{\min}}, \quad (12)$$

$$\alpha_2 = 1 - \alpha_1.$$

After obtaining the status value of each participating miner, standardize it, as shown in the following formula:

$$ST(u_i) = \frac{st(u_i) - st_{\min}}{st_{\max} - st_{\min}}, \quad (13)$$

where  $st(u_i)$  represents the state value of miner  $u_i$ ,  $st_{\min}$  represents the minimum state value of the participating

miners, and  $st_{\max}$  represents the maximum state value of the participating miners.

Based on the miner status evaluation model  $ST(u_i)$  and the miner reputation evaluation model, the miner evaluation function is constructed as shown in the following equation:

$$rs(u_i) = \alpha R(u_i) + \beta ST(u_i), \quad (14)$$

where  $0 < \alpha < 1, 0 < \beta < 1, \alpha + \beta = 1$ , and  $rs(u_i)$  represents the miner evaluation function.

For nonemergency tasks due to time window comparatively broad scope, on the basis of the reputation evaluation model, constructed the status value evaluation model, and combining the two models, on the basis of meeting the requirements of time as far as possible do miners, equipment and task distribution, further optimize the task allocation results.

Nonurgent task problems can be formulated as shown in the following equations Algorithm 2:

$$\text{Maximize: } \sum_{i=1}^{p_{m_j}} rs(u_i), \quad \text{in which } u_i \in U, \quad (15)$$

$$\text{Subject to: } w(l_{u_i}, l_{m_j}) < w_{m_j}, \quad (16)$$

The main parameters in this study are given in Table 1.

## 6. Experiment and Result Analysis

**6.1. Simulation Experiment Environment.** This study uses MATLAB to compare and demonstrate the mechanism of participant selection. Because there are many working faces in the mine, it takes a lot of time to cross different working faces, which cannot meet the requirements of task time. Besides, miners of different working faces generally do not interact with each other. Therefore, this study chooses one of the working faces, abstracting it into an undirected graph with 30 nodes, which can simulate the real scene of task assignment in the mine. In addition, in order to verify the effectiveness of the proposed model strategy and solution in the article, the upper limit of the total number of users  $M = 100$  and the upper limit of task number  $N = 25$  are set. Moreover, the reputation value  $R(u_i)$  of each participant and the perceived quality of each user obey the uniform distribution on  $[0, 1]$ . The specific experimental grouping and parameter setting are given in Table 2.

In this article, the goal of the emergency task allocation strategy is to make the task be processed and completed as soon as possible, that is to say, this allocation strategy can obtain a higher proportion of task allocation in a shorter period of time. For nonemergency tasks, this article prefers to choose the participating miners with low fatigue and sufficient equipment energy to complete the task. Therefore, it is very important to select suitable miners with different requirements for different types of tasks. In this article, the MARL algorithm, heuristic algorithm, and HTA algorithm are selected as the experimental reference algorithm.

In the process of simulation, each type of experiment is carried out 10 times, and the average value of 10 times of

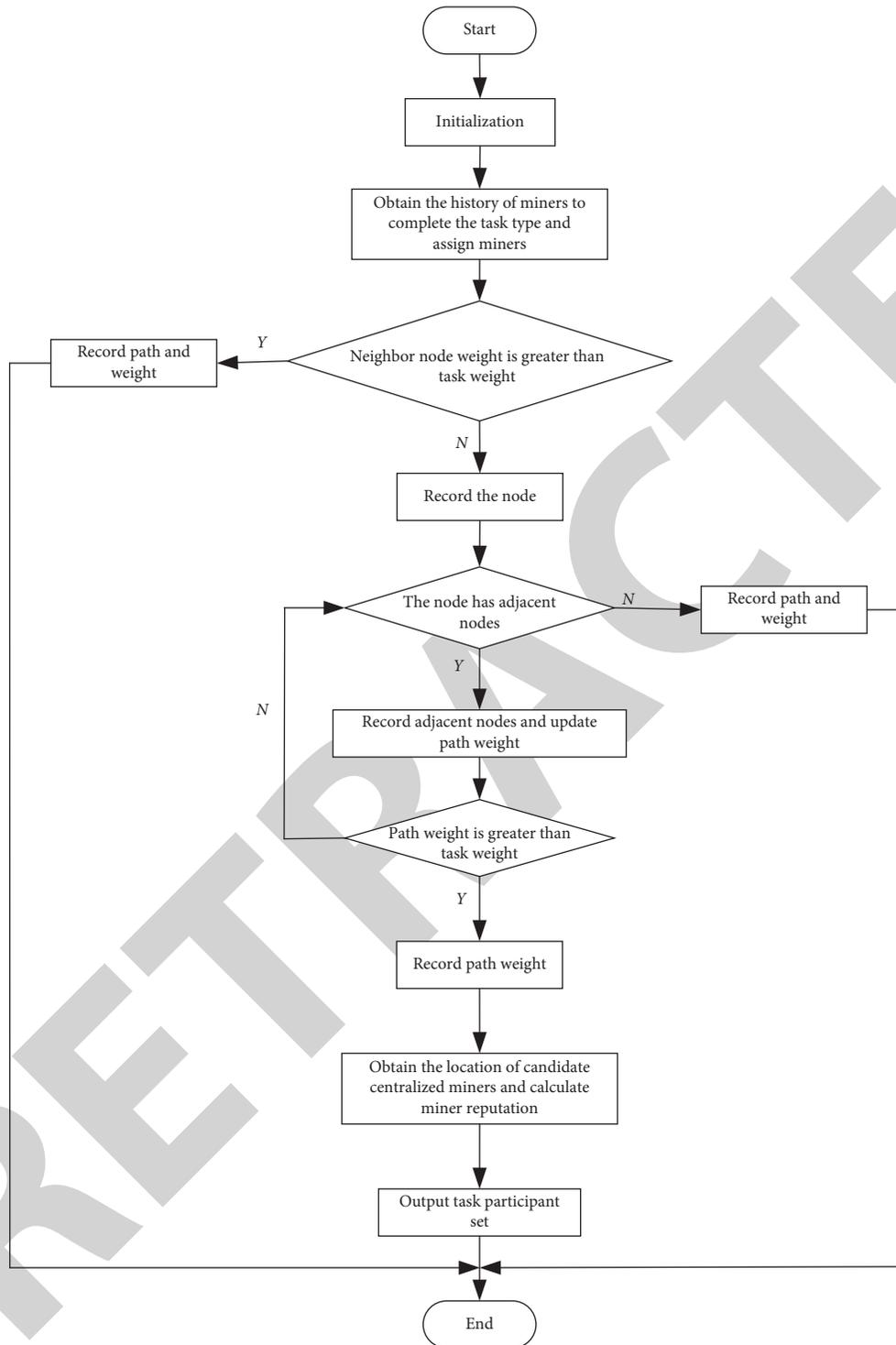


FIGURE 4: Weighted undirected graph algorithm flowchart.

experimental results is taken as the simulation result. In the following simulation experiment, the time of task allocation, the number of mobile users, the sum of reputation, and the related indicators of fatigue are mainly examined.

6.2. *Experimental Results and Analysis.* It can be seen from the comparison of this configuration that, in the case of a small number of participants, the allocation time of the four algorithms has a small difference, as shown in Figure 5. With the continuous increase of participating miners, the three

TABLE 1: Parameter list.

$m_j$	Sense of task $j$
$P_{m_j}$	Perceive task demand number of participants
$tb_{m_j}$	Perceive the start time of the task
$te_{m_j}$	Perceive the end of the task
$tr_{m_j}$	Performing perceptual tasks takes time
$s_{m_j}$	Perceptual task type
$R(u_i)$	Miner reputation
$v_{u_i}$	Miner's velocity
$u_i^e$	Miner history complete quest types
$l(u_i, m_j)$	Task completion site similarity
$p(u_i, m_j)$	Task completion time similarity
$q(u_i, m_j)$	Quality of task completion
$D(u_i m_j^b, m_j^b)$	Degree of difference between miner start time and start time of the task
$D(u_i m_j^e, m_j^e)$	Degree of difference between the miner's latest end time and the end time required by the task
$\phi_{m_j}$	Perceived task data mean
$w(d_i, d_j)$	Edge weights between adjacent nodes of a weighted undirected graph
$k_{u_i}$	Miner fatigue value
$E_{u_i}$	Miner equipment power
$ST(u_i)$	Miner status value
$rs(u_i)$	Miner evaluation function

TABLE 2: Simulation parameters.

Number of participating miners $M$ /pcs	[0, 100]
Number of tasks $N$ /pcs	[1, 25]
Credit value $R(u_i)$ of participants	[0, 1]
Number of nodes/pcs	[0, 30]
The number of participants required for a single task/pcs	[1, 5]
The deadline for the task/min	[5, 30]
The speed of movement of the participant/( $\text{km}\cdot\text{h}^{-1}$ )	[10, 50]
Residual energy of equipment/(%)	[0, 100]

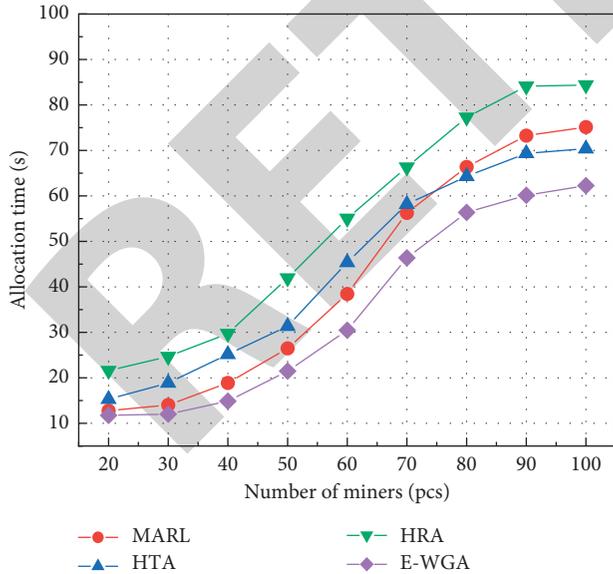


FIGURE 5: Average allocation time of the task.

algorithms traversal all miners in each task allocation, and the amount of data that the heuristic task algorithm and MARL algorithm need to consider and calculate also increases correspondingly. Since the HTA algorithm needs to

determine the central node and analyze the related attributes of the subordinate node, and only when the central node and the subordinate node meet, the task will be assigned, thus increasing the time of task allocation. The emergency weighted path algorithm is proposed in this study; in the process of the growing number of only considering the task time window within the scope of the candidate miners, time of task allocation is obviously better than the other three algorithms, when the participants reached one hundred people, average task allocation time stability in the 60s, compared with other three algorithms, has a degree of improvement.

By increasing the scale, this study can verify the allocation time of the algorithm for miners of different sizes. The allocation of emergency tasks requires not only speed but also high quality. Another key index of the emergency task algorithm is the reputation of participants. Therefore, this experiment also verified the average reputation of participants who chose miners in different numbers.

As can be seen from Figure 6 of the experiment, the average reputation of miners selected by the weighted undirected graph algorithm is approximately maintained at the level of 0.83–0.75 with the increasing number of people. The heuristic algorithm also takes the creditworthiness of participants as an important optimization index, so it also stays at a high level and finally stabilizes at about 0.75 with the

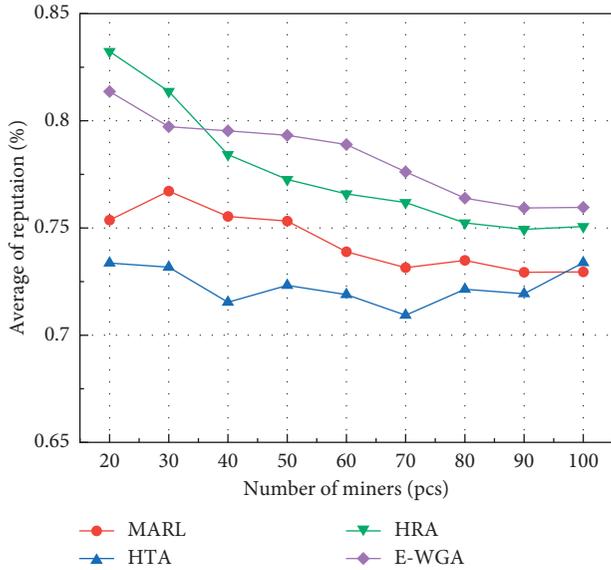


FIGURE 6: Average reputation of miners.

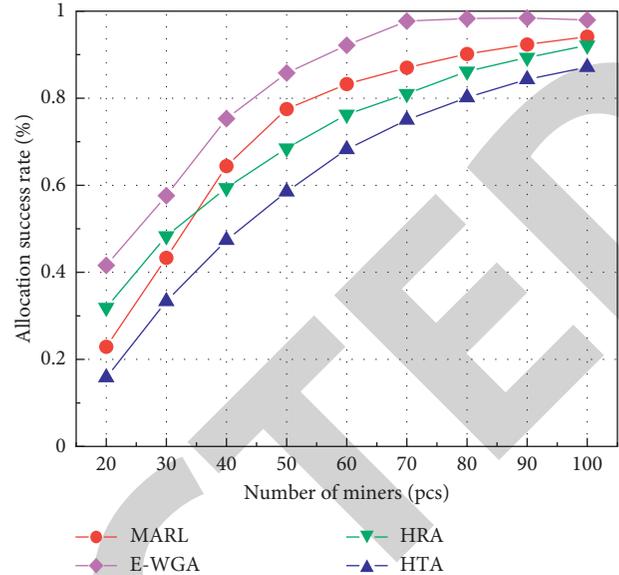


FIGURE 7: Success rate of emergency task allocation.

increase of the number of participants. It can be seen from the experiment that the reputation of the weighted undirected graph algorithm is slightly lower than that of the heuristic algorithm due to the randomness of the distribution of miners when the number of miners is small. However, with the increase of the number of miners, when the number of participants reaches 40, the weighted undirected graph algorithm is better than other algorithms.

However, the HTA algorithm and MARL algorithm, which focus on the center node and the subordinate node, do not measure the reputation, so their performance in the reputation evaluation is poor, and there are large fluctuations.

As an algorithm related to task allocation, the success rate of task allocation is also an index that we focus on. Figures 7 and 8, respectively, observe the allocation ability of the weighted path algorithm in emergency situations from two aspects: the number of participants of different sizes and the number of tasks of different sizes. It can be seen from the experimental results that the allocation success rate is higher than the other three algorithms.

As can be seen from Figure 7 of the experiment, the success rate of each allocation algorithm increases with the increase of the number of participants. When the number of participants is greater than 50, the success rate stabilizes at more than 80%. When the number of participants is small, the weighted undirected path algorithm can still maintain a success rate of nearly 45%, and because other algorithms rely too much on some indicators, such as miners' position and miners' interest preference, the HTA algorithm relies on the meeting between the central node and the subordinate node, so the success rate of task allocation is obviously lower. Experimental Figure 8 shows the weighted undirected graph in task allocation ability under different numbers of tasks; the task number is small, four kinds of algorithms can keep the call high success rate of task allocation, with the increase of number of tasks, task allocation rate declined, but the undirected graph algorithm basic maintains 90% success

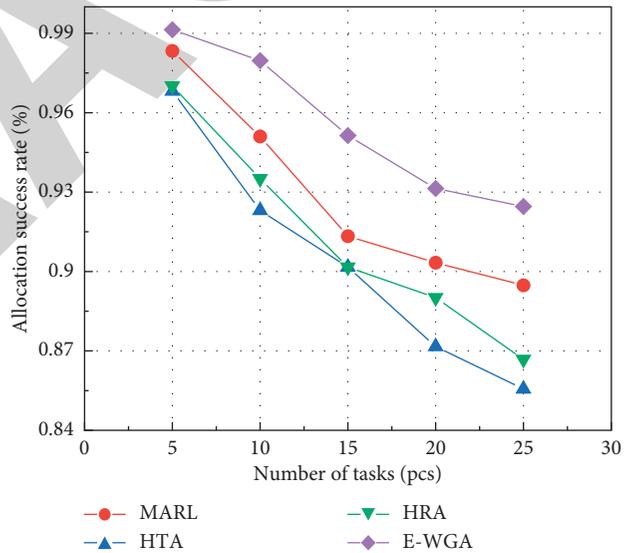


FIGURE 8: Success rate of emergency task allocation.

rate of task allocation, compared to a benchmark algorithms. There is a certain degree of improvement.

The success rate for nonemergency allocations is also an indicator we need to consider. Figures 9 and 10 also observe the allocation ability of the weighted path algorithm in nonemergency situations from two aspects: the number of participants of different sizes and the number of tasks of different sizes.

As can be seen from the experimental results, the task allocation and success rate in nonemergency situations are both higher than those of the other three algorithms. As can be seen from Figure 9, when the number of people is constantly increasing, the success rate of the nonemergency weighted undirected path algorithm is roughly the same as

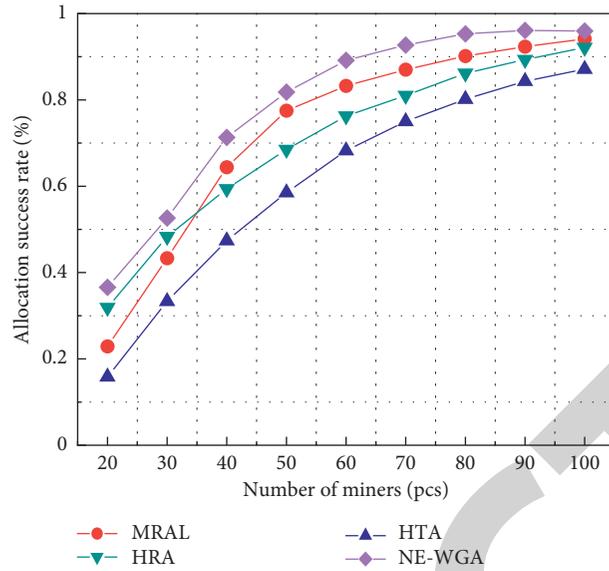


FIGURE 9: Success rate of nonemergency task allocation.

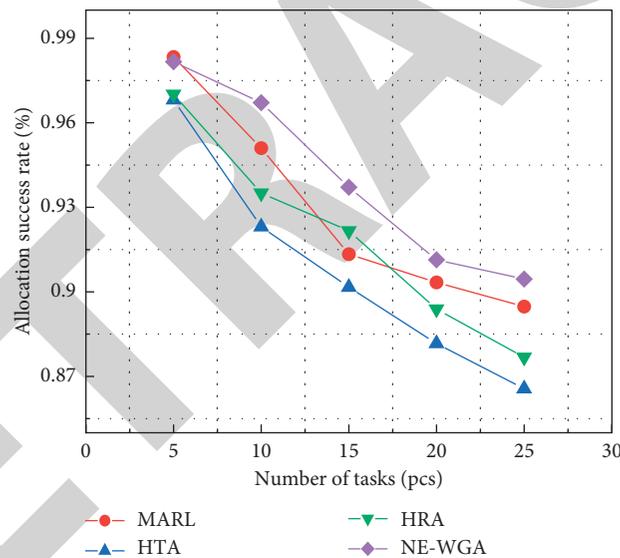


FIGURE 10: Success rate of nonemergency task allocation.

that of the emergency situation and slightly lower than that of the emergency task allocation algorithm.

When the participants are small, the success rate of the weighted path algorithm is still nearly 40%, which is significantly higher than that of the other three algorithms. Figure 10 shows the success rate of nonurgent tasks under different numbers of tasks. As the HTA algorithm relies excessively on central node to distribute tasks, the success rate of allocation is low in the experiment. In addition, when the number of tasks is small, the four algorithms perform well, but when the number of tasks increases, all of them decrease to different degrees. However, the undirected graph algorithm proposed in this study is better than the benchmark algorithm in terms of the success rate of task

allocation, and the final success rate of task allocation is roughly stable at 0.9, which is a great improvement compared with the HTA algorithm.

For the weighted undirected graph algorithm in the state of nonemergency task, participants are preferred to be selected from other dimensions. In the experimental Figures 11 and 12, we further compared the average status value of selected miners in the state of nonemergency task and the average electric quantity of selected participants.

It can be seen from the experiment in Figure 11 that nonemergency tasks of miners state value at 0.6 on average have better performance, while the other three algorithms to mine scenarios miners, equipment state constraints are not put forward, so the status value is below 0.5. Therefore, the

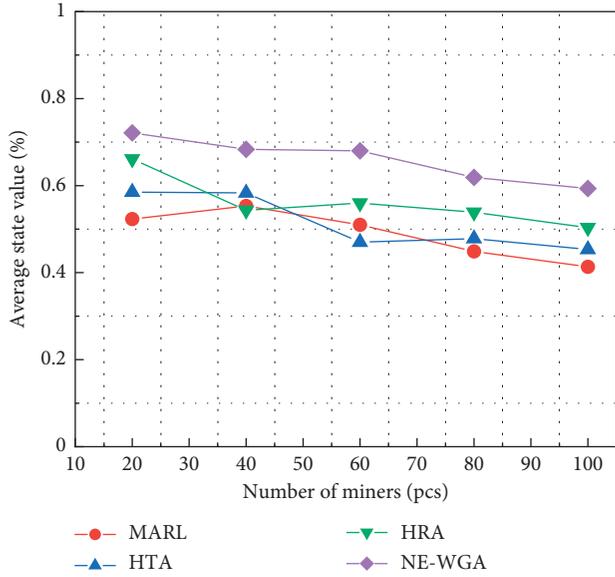


FIGURE 11: Average status value of participating miners.

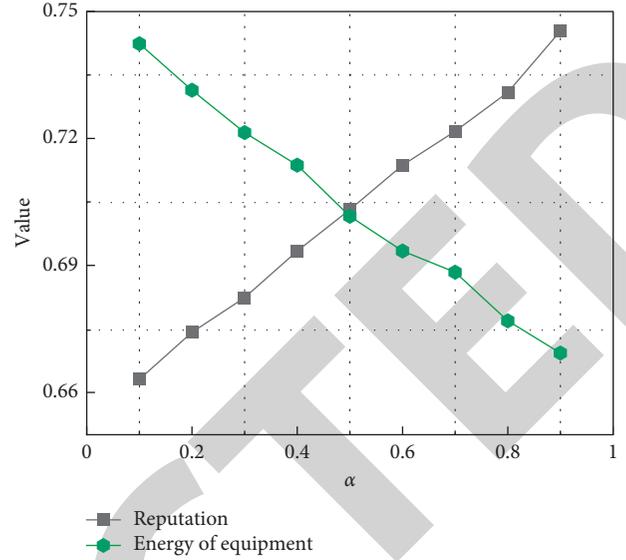


FIGURE 13: The influence of parameter  $\alpha$  on reputation and equipment power.

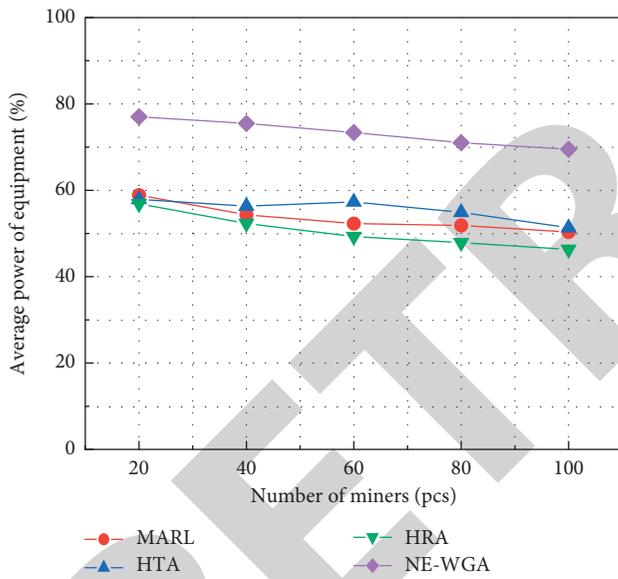


FIGURE 12: Average residual energy of equipment.

weighted undirected graph algorithm compared with other three algorithms in miner has nearly 10% of the ascension status value.

As can be seen from Figure 12 of the experiment, the remaining power of the equipment of the participants selected by the status value increases by 15% on average. It can be seen that the miners selected by the nonemergency algorithm are better than the other three algorithms in terms of fatigue state and the remaining power of the equipment. Therefore, this algorithm can better select miners with low fatigue and high equipment power to participate in the task.

This study also makes a simulation analysis on the reputation of selected miners and the remaining energy of equipment with different values of parameter  $\alpha$  in the nonemergency algorithm, as shown in Figure 13. As can be

seen from the experimental results, with the increasing value of  $\alpha$ , the reputation of selected participants keeps rising and the power of equipment carried by miners keeps dropping. When the parameter  $\alpha$  is near 0.5, the selected participants are more balanced in terms of reputation and the remaining power of the device.

## 7. Conclusion

In the research of task allocation of mobile crowd sensing, most of the research aims at the lowest cost or the highest task quality, and most of them are based on the background of universal environment. However, there are few research studies on the completion time of tasks and the status of participants themselves, as well as in some specific environments. In this article, based on the background of the mine, the real-time task allocation problem is researched. According to the mine working environment and the actual production requirements, the task is divided into emergency and nonemergency tasks. In this article, the reputation evaluation model of miners related to miners' location, task time, and task quality is constructed. With time as constraint, according to the emergency of tasks, we design and propose an emergency task allocation algorithm based on an undirected weighted graph, which can achieve the matching of tasks and miners with less time and relatively efficiently, and provide a new idea for underground task allocation. According to the load of miners and the electric quantity of equipment carried by them, the status value constructed model of miners is established. On this basis, the non-emergency task allocation algorithm is proposed, so that the relevant factors of miners and their equipment can be considered more in the nonemergency task status. Finally, the feasibility of the proposed algorithm is verified by comparing the experimental simulation with similar algorithms; in the emergency task allocation algorithm, the

allocation time is reduced at the same allocation rate, and the average reputation maintained high level at different participants, which effectively guarantees the completion of the mine task. In the nonemergency task allocation algorithm, the comprehensive status value of selected participants is higher than that of similar algorithms, which optimizes the matching of miners, equipment, and tasks.

The following improvements are still needed in the future work. This article only studies the task allocation mechanism and does not give the incentive mechanism. Adding reasonable incentive mechanism needs further research in the future work. In the construction of the status value constructed model, only height, weight, working hours, and other factors are considered. In future work, more parameters related to the body mechanism such as blood oxygen and blood pressure can be added.

### Data Availability

The data used to support the findings of this study are included within the article.

### Conflicts of Interest

The authors declare that they have no conflicts of interest.

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