Edge Network Resource Synergy for Mobile Blockchain in Smart City

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***Abstract*—Blockchain has broad application prospects in Smart City, and the technical characteristics of the blockchain itself can solve the problems of mistrust of network resource production relations and unfair distribution of revenue. However, most of the devices in Smart City are mobile devices with insufficient resources. The demand for computing power of the mining process cannot be met. For this, we introduce mobile edge computing, deploy edge servers on the edge side, and provide resources for mobile devices. We build an edge network resource allocation model for mobile blockchain to realize the effective application of blockchain technology in mobile environments. The resources required by the mining process can be obtained from neighboring resource sharing devices or edge servers. The resource allocation between adjacent devices can be modeled as a two-way auction model, and the Bayesian-Nash equilibrium is solved to determine the optimal price, while considering the trusted value of the device; the process of the mobile device acquiring resources from the edge server can be modeled as a two-stage Stackelberg game. Finally, simulation experiments show that this mechanism achieves a higher personal utility than an existing model that only considers requesting resources from an edge server.**

***Keywords*—blockchain, edge computing, mobile devices, mining, resource synergy**

I. Introduction

With the advent of the 5G era, the Internet of Things (IoT) technology has developed rapidly, and the smart city, smart home, and smart grid derived from the IoT technology have also emerged [1-2]. The smart city aims to reduce public management costs, make full use of public resources, and improve living and working methods by using information and communication technology (ICT). The smart city includes multiple application scenarios such as waste management, smart transportation, smart campuses and so on. In each scenario, there are so many IoT terminals that communicate with each other and share data. Taking smart transportation as an example, by deploying lots of terminal devices and collecting traffic information, we can realize perception, interconnection, analysis, prediction and control of traffic conditions. However, at the same time, the following problems exist. First, the cost of the link between the devices is high, and it is difficult to establish trust, and the security privacy has hidden dangers. Then, the network bandwidth of the traditional centralized network is difficult to meet the requirements of the huge intelligent terminals in the smart city for data processing, and the cost is relatively high. The blockchain provides a decentralized, trusted technical paradigm that can solve the problems encountered in the development of the smart city [3-4]. And the technical characteristics of the blockchain itself can solve the problems of mistrust of network resource production relations and unfair distribution of revenue [5-7].

Due to the large number of terminal devices, when introducing blockchain technology, the main-side-chain architecture can be built to reduce the burden on the main chain and improve data sharing efficiency [8-9]. Because the proof of work (PoW) mechanism is more classic and be widely used, we still use the public chain method to construct the main-side-chain, and the terminals act as the participating nodes of the blockchain to support the side chain operation [10-11].

The key to ensure data integrity and validity in the blockchain is a computational process defined as mining [12]. However, most terminals in the smart city are mobile, and mobile devices cannot directly participate in the mining and consensus process due to resource constraints, which makes the application of blockchain technology in the smart city is greatly limited. This prompted us to further rethink the mining strategy and resource management in the mobile environment, and meet new opportunities for the development of blockchain in mobile applications.

We can provide computing and communication resources for mobile blockchain by deploying cloud computing services on the "edge" side of the mobile internet [13-14]. Y. Jiao et al. modeled the resource allocation in edge computing as a two-way auction process [15-16]. Y. Zhang et al. proposed a game model that considers edge computing as a network driver of the mobile blockchain [17-18]. However, these tasks only focus on the resource allocation between the mining devices and the resource service provider, ignoring the situation that the mobile device can request resources from the neighboring resource sharing device, and the mining cost is higher. Considering the above two situations, we can build a model such that devices can not only access edge servers to gain computing resources but also obtain idle computing resources by cooperating with other mobile devices in the same local area network [19]. The mining device can obtain the reward of mining through the consensus mechanism, while the edge server and the resource sharing device need to obtain

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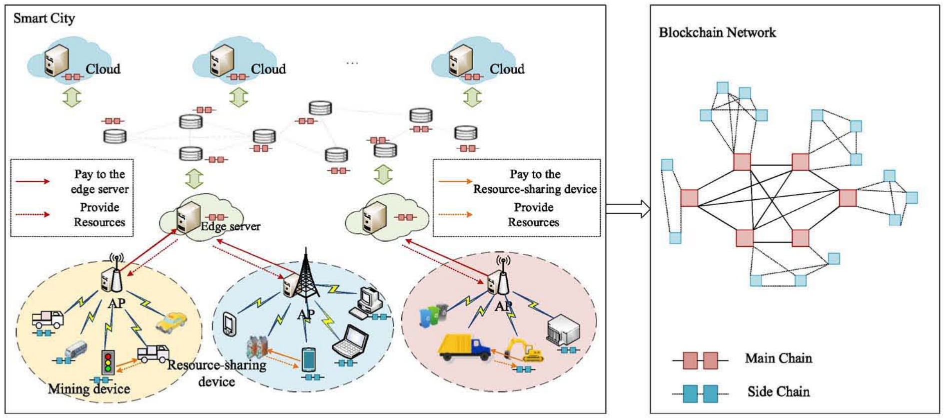

Fig. 1. System scenario

incentives from the miner node, thus generating pricing problems of computing resources.

II. SYSTEM MODEL

In this section we will give the system model and objective formulation. Then how to solve the objective equation will be shown in detail in the next section.

A. Network model overview

As shown in Fig.1 the mobile devices can form a resource sharing network with its neighboring devices. In the resource sharing network, the blockchain node performs mining. When the resource of the node are insufficient, it can be acquired from the resource sharing devices. Miners can also request resource from the edge servers when the resources in the resource sharing network cannot meet the mining needs.

In the resource sharing network, there are N mining devices $N = \{1,2, \ldots, \mathrm{N}\}$. The amount of resources required by the mining device to complete the task is $\mathrm{R} = \{r_1, r_2, \ldots, r_N\}$. The amount of resources that the mining device itself has is $\Lambda = \{\lambda_1, \lambda_2, \ldots, \lambda_N\}$. There are M resource sharing devices and the amount of resources each resource sharing device has is $\mathrm{C} = \{c_1, c_2, \ldots, c_N\}$. If the resource from the resource sharing devices still cannot meet the mining demand, it will be requested from the edge server. The amount of resource requested from edge server is $y_i = \max\{r_i - \lambda_i - \sum_{j'} c_j, 0\}$,where $r_i \in [\underline{r}, \overline{r}]$,define $\underline{r_i}$ as the amount of resources that the mining device itself has and define $\overline{r}$ as the maximum amount of resources that the edge server can provide.

During the mining process, the miners competed to mine to obtain new blocks. The relative computing power of mining equipment i can be expressed as:

$$\alpha_i = \frac{\omega_i r_i}{\sum_{j \in N} \omega_j r_j} \qquad (1)$$

where $\sum_{i \in N} \alpha_i = 1$ and ω_i is miner's mining capacity parameter. When a new block is successfully mined, it is broadcast to the blockchain network and verified by other miners to achieve consensus. After reaching a consensus, the miners are considered to be successful in mining and receive mining reward incentives. If the block propagation and consensus time is too long, the block will become an isolated block, and the probability of the isolated block can be expressed as: $Porphan(s_i) = 1 - e^{-\lambda z s_i}$. Where s_i represents the size of the block and z represents the delay parameter. Obviously, the probability of successful mining and dissemination of mining device i can be expressed as:

$$P_i(\alpha_i, s_i) = \alpha_i\big(1 - Porphan(s_i)\big) = \alpha_i e^{-\lambda z s_i} \qquad (2)$$

After successful mining, the mining device will receive certain mining rewards. The mining reward consists of fixed reward R and variable reward $r \times s_i$. However, mining device needs to pay resource fees to resource sharing devices and edge server, so the personal utility of mining device can be expressed as:

$$u_i = (R + r \times s_i)P_i(\alpha_i, s_i) - p_i y_i - \lambda_i B_i - \textstyle\sum_j p_{ij} c_j \quad (3)$$

The revenue of the resource-sharing device is mainly paid by the mining device. The personal utility of the resource-sharing device can be expressed as:

$$u_j^s = \textstyle\sum_i c_j^i p_{ij} - c_j B_j \qquad (4)$$

The profit of the edge server can be expressed as:

$$\Pi = \textstyle\sum_{i \in N} (p_i - B)\, y_i \qquad (5)$$

B. Resource allocation within the resource sharing network

Within the resource sharing network, the miner obtains the computing resources of the resource sharing device through competition. We model this process as a two-way auction model.

In the two-way auction model, first, the buyers and the sellers quote, and then the edge server adjusts the price according to the trusted value of each node, and finally executes the auction process, and the buyers and the sellers conduct the transaction.

In our scenario, the mining devices are buyers and the resource sharing devices are sellers.

Suppose that there are n buyers, m sellers, after the buyer and the seller quote, the auction node will adjust the quotation to the equivalent quotation according to the quotation and the trust value. And the buyer (mining device) will be arranged in descending order according to the equivalent quotation $b_i' = f_b(t_i)b_i$.The seller (resource sharing device) will be arranged in ascending order according to the equivalent quotation $s_j' = f_s(t_j)s_j$ .Then we look for a value k such that $b_k' > s_k'$ and $b_{k+1}' < s_{k+1}'$. Then, the kth buyer and the first k sellers match the resources. Arrange $\Delta_{k'}^{k} = |R_k^b - R_{k'}^s|$ in ascending order, taking the smallest $\Delta_{k'}^{k}$ then the kth buyer and the kth sellers trade with each other, and the transaction price is $p_{kk'} = \frac{b_k' + s_{k'}'}{2}$. After the transaction, if $R_k^b > R_{k'}^s$, $R_k^b = \Delta_{k'}^k$, then remove k', and k enters the next round of auction, if $R_k^b < R_{k'}^s$, $R_{k'}^s = \Delta_{k'}^k$, then remove k, and k' enters the next round of auction until one party is empty, then the auction ends.

For the buyer k, its benefits can be expressed as $u^b = v_k - \frac{b_k' + s_{k'}'}{2}$, where v_k represents the profit that the unit resource can create for the buyer; for the seller k', its benefits can be expressed as $u^s = s_{k'} - B_{k'}$, where $B_{k'}$ represents the cost of the seller's unit resource consumption.

Since the buyer's bid is not public, they are unable to understand the price strategy of others and will not know the match until the auction ends. So it is a static game with incomplete information, and Bayesian Nash Equilibrium (BNE) exists. We analyze BNE to maximize the expected utility.

For buyers, they maximize their own interests by adjusting their bidding strategies:

$$\max_{b_i}\ u^b = (v_i - b_i) \times P\{b_i \geq s_j(B_j)\} \tag{6}$$

For sellers, they maximize their revenue by adjusting the asking price strategy:

$$\max_{s_j}\ u^s = (s_j - B_j) \times P\{b_i(v_i) \geq s_j\} \tag{7}$$

C. Resource allocation between mining devices and the edge server

The edge server is profitable by charging the fees paid by the mining equipment. Therefore, its profit can be obtained by payment of mining devices minus the cost of the edge server's resources:

$$\Pi = \sum_{i \in N} (p_i - B)\, y_i \tag{8}$$

In order to adjust the computing resource requirements and usage prices, the process can be modeled as a Stackelberg game.

For miner i, it adjusts its resource demand to maximize its own personal utility by price p_i given by the edge server, which can be expressed in the following mathematical formula:

$$\begin{aligned} max_{r_i}\ \ u_i = (R + r \times s_i) \frac{\omega_i r_i}{\sum_{j \in N} \omega_j r_j}\ e^{-\lambda z s_i} \\ -p_i(r_i - C) - \lambda_i B_i - D \end{aligned} \tag{9}$$

For the edge server, it wants to maximize the benefits from miners:

$$max_{\boldsymbol{p}}\ \Pi(\boldsymbol{p}, \boldsymbol{r}) = \sum_{i \in N} (p_i - B)(r_i - C) \tag{10}$$

Where p_i can be a unified pricing, or it can be different discriminatory pricing according to the different needs of the miners.

III. Model Solving

A. Setting the price adjustment function

During the mining process, some nodes will have some malicious behavior. In order to reduce the competitiveness of these malicious nodes, the edge server will combine the trust value of the node with the bid in the auction process to transform into a comprehensive competitiveness based on the historical integrity record to reduce the impact of malicious nodes.

Let t_j denote the credibility of the node j, which is available from the algorithm 1, and the trusted value t_j takes a value between 0 and 1, which is dimensionless.

For the buyer, the higher the trusted value t_j and the higher the bid, the more competitive advantage; for the seller, the higher the trusted value t_j and the lower the asking price, the more competitive advantage. Therefore, we cannot simply multiply t_j and quotation to obtain comprehensive competitiveness. We use the price adjustment function to calculate the comprehensive competitiveness of buyers and sellers respectively, and use T_0 to represent the benchmark trust. The comprehensive competitiveness is equivalent to the credible value. The unit price $\mathrm{f}(t_j)p_j$ is reported for the node of T_0, where $\mathrm{f}(\cdot)$ is a function of trust. The quotations of each node with different trusted values are mapped to the equivalent price under T_0, and the comprehensive competitiveness is measured by the equivalent price.

For buyers, the price adjustment factor should satisfy:

1) When $t_j = 0$, the equivalent quote is 0; when $t_j = T_0$, the equivalent quote is unchanged, so we have

$$f_b(0) = 0,\ f_b(T_0) = 1 \tag{11}$$

2) $f_b(t_j)$is continuously steerable, and the value does not change.

3) $f_b(t_j)$ increases monotonically, the larger the confidence value t_j is, the greater the comprehensive competitiveness should be, so the adjustment factor should also increase, ie

$$\frac{df_b}{dt_j} > 0 \tag{12}$$

4) Near T_0, the quotation adjustment is relatively small. Correspondingly, $f_b(t_j)$ should be relatively flat. When t_j approaches 1, the comprehensive competitiveness should be greatly increased, and the price adjustment coefficient increases greatly, that is, when $T_0 < t_j \leq 1$, the derivative of $\frac{\mathrm{d}f_b}{dt_j}$ is greater than 0. When t_j approaches 0, the comprehensive competitiveness should be greatly reduced, and the price adjustment coefficient is greatly reduced, that is, when $0 \leq t_j < T_0$ The derivative of $\frac{\mathrm{d}f_b}{dt_j}$ is less than zero. The following conditions can be obtained:

$$\begin{cases} \frac{d^2 f_b}{dt_j^2} < 0,\ \ 0 \leq t_j < T_0 \\ \frac{d^2 f_b}{dt_j^2} = 0, \qquad t_j = T_0 \\ \frac{d^2 f_b}{dt_j^2} > 0, T_0 < t_j \leq 1 \end{cases} \tag{13}$$

From the above conditions, we can first find the basic elementary function $f_0(t)$ that meets the condition, and then construct the price adjustment function $f_b(t_j)$ by translating and scaling the $f_0(t)$. Here, we take the inverse hyperbolic tangent function as $f_0(t)$:

$$f_0(t) = arctan\,h(t) = 0.5\ln(1+t)/(1-t) \tag{14}$$

Then, first $f_0(t)$ is stretched $(1+\varepsilon)T_0$ times, and then translational transformation. We can get:

$$f_b(t_j) = \frac{f_0\left(\frac{t_j - T_0}{(1+\varepsilon)T_0}\right) - f_0\left(-\frac{1}{(1+\varepsilon)}\right)}{-f_0\left(-\frac{1}{(1+\varepsilon)}\right)} \tag{15}$$

Similarly, for the seller, we can get:

$$f_s(t_j) = -f_b(t_j) + 2 \tag{16}$$

B. Double auction model

According to the double auction model listed above, we obtain the best auction price in the self-organizing network by calculating Bayesian Nash Equilibrium (BNE)..

To simplify the auction process, we assume that the mining device (buyer) and the resource sharing device (seller) are bidding in a linear strategy. Buyers must consider the value of computing resources as a basis for bidding before participating in an auction, so the bidding strategy can be expressed as:

$$b_i = \eta_b + k_b \times v_i \tag{17}$$

Where v_i is the value of completing the unit task, $v_i = (R + r \times s_i)P_i(\alpha_i, s_i)/\beta_i$.

The seller considers the cost of the unit resource as the basis for the asking price, so the seller's bidding strategy can be expressed as:

$$s_j = \eta_s + k_s \times B_j \tag{18}$$

Based on historical transaction records, we assume that the largest auction price available is P_{max} and the minimum allowed auction price is P_{min}. Assume that the cost and profit of unit resources follow a uniform distribution:

$$B_j \sim u[P_{min}, P_{max}]$$
$$v_i \sim u[P_{min}, P_{max}] \tag{19}$$

Equations (6) and (7) can be rewritten to take into account the nature of the uniform distribution:

$$\max_{b_i}\{v_i - \frac{1}{2}\left[b_i + E\left(s_j(B_j)\middle|b_i \geq s_j(B_j)\right)\right]\} \cdot P\{b_i \geq s_j(B_j)\} \tag{20}$$

$$\max_{s_j}\{\frac{1}{2}\left[s_j + E\left(b_i(v_i)\middle|b_i(v_i) \geq s_j\right)\right] - B_j\} \cdot P\{b_i(v_i) \geq s_j\} \tag{21}$$

And we have:

$$E\left(s_j(B_j)\middle|b_i \geq s_j(B_j)\right) = \frac{\int_{\eta_s + k_s P_{min}}^{b_i} \frac{1}{(P_{max} - P_{min})k_s} x dx}{P\{b_i \geq s_j(B_j)\}}$$

$$= \frac{1}{2}(b_i + \eta_s + k_s \times P_{min}) \tag{22}$$

$$P\{b_i \geq s_j(B_j)\} = P\left\{B_j \leq \frac{b_i - \eta_s}{k_s}\right\} = \frac{b_i - (\eta_s + k_s \times P_{min})}{(P_{max} - P_{min})k_s} \tag{23}$$

Bring the above two formulas into (20), and (20)can be rewritten as follows:

$$\max_{b_i}\{v_i - \frac{1}{2}\left[b_i + \frac{1}{2}(b_i + \eta_s + \xi_s \times P_{min})\right]\} \cdot \frac{b_i - (\eta_s + k_s \times P_{min})}{(P_{max} - P_{min})k_s} \tag{24}$$

Similarly, we can get:

$$\max_{s_j}\{\frac{1}{2}\left[s_j + \frac{1}{2}(s_j + \eta_b + k_b \times P_{max})\right] - B_j\} \cdot \frac{(\eta_b + k_b \times P_{min}) - s_j}{(P_{max} - P_{min})k_b} \tag{25}$$

Solving the first derivative and the second derivative of (24) and (25), we can find that the function is a concave function, so that the first derivative is equal to 0, the following results can be obtained:

$$b_i = \frac{2v_i + \eta_s + k_s P_{min}}{3} \tag{26}$$

$$s_j = \frac{2B_j + \eta_b + k_b P_{max}}{3} \tag{27}$$

Substituting equations (17) and (18) into the above equations, we can find the equilibrium point:

$$\eta_s = \frac{P_{min}}{12} + \frac{P_{max}}{4}, k_s = \frac{2}{3} \tag{28}$$

$$\eta_b = \frac{P_{max}}{12} + \frac{P_{min}}{4}, k_b = \frac{2}{3} \tag{29}$$

Bringing the equilibrium point into (17) and (18) can get the best bidding strategy for buyers and sellers. The buyer's best bidding strategy is linear with the resource value. The best bid strategy is linear with resource costs.

$$b_i^* = \frac{2v_i}{3} + \frac{P_{max}}{12} + \frac{P_{min}}{4} \tag{30}$$

$$s_j^* = \frac{2B_j}{3} + \frac{P_{min}}{12} + \frac{P_{max}}{4} \tag{31}$$

C. Stackelberg Game

In this section, we propose the discriminatory pricing for resource management in the mobile blockchain, in which edge server can set different unit prices for the resource needs of different miners, which is $\boldsymbol{p} = (p_1, p_2, \dots, p_N)$.

(1) Miners demand game: $\Gamma = \{\mathrm{N}, (r_i)_{i\in N}, (u_i)_{i\in N}\}$

Similar to the proof process in [17], the Nash equilibrium of miners' demand game exists and is unique. Similarly, in the miner's demand game $\Gamma = \{\mathrm{N}, (r_i)_{i\in N}, (u_i)_{i\in N}\}$, the unique Nash equilibrium of miner i is given by:

$$r_i^* = \frac{N-1}{\omega_i \sum_{j\in N} \xi_j^d} - \frac{\xi_i^d}{\omega_i}\left(\frac{N-1}{\sum_{j\in N} \xi_j^d}\right)^2, \forall i\in N \tag{39}$$

Where, $\xi_j^d = \frac{p_j e^{\lambda z s_i}}{(R + r s_j)\omega_j}$.

(2) Edge server profit maximization

Theorem 1. Under the discriminatory pricing scheme, when $r_i \in [\underline{r_i}, \bar{r}]$, there is a unique optimal bidding strategy that maximizes the profitability of the edge server.

Proof. First, take the equation (39) into the equation (10), and then calculate the first derivative of Π with respect to p_i in equation (10).

$$\frac{\partial \Pi}{\partial p_i} = \frac{\sum_{j\in N} B(N-1)\frac{e^{\lambda z s_j}}{(R+rs_j)}}{\left(\sum_{j\in N}\frac{p_j e^{\lambda z s_j}}{(R+rs_j)}\right)^2} - C \tag{40}$$

Then we solve the second derivative of Π with respect to p_i, and the second-order partial derivatives of p_i and p_j.

$$\frac{\partial^2 \Pi}{\partial p_i^2} = \frac{-2\frac{e^{\lambda z s_i}}{(R+rs_i)}\sum_{j\in N} B(N-1)\frac{e^{\lambda z s_j}}{(R+rs_j)}}{\left(\sum_{j\in N}\frac{p_j e^{\lambda z s_j}}{(R+rs_j)}\right)^3} \tag{41}$$

$$\frac{\partial^2 \Pi}{\partial p_i p_j} = \frac{-2\frac{e^{\lambda z s_j}}{(R+rs_j)}\sum_{j\in N} B(N-1)\frac{e^{\lambda z s_j}}{(R+rs_j)}}{\left(\sum_{j\in N}\frac{p_j e^{\lambda z s_j}}{(R+rs_j)}\right)^3} \tag{42}$$

From this we can get the Hessian matrix of $\Pi(\boldsymbol{p})$:

$$\nabla^2\,\Pi(\boldsymbol{p}) = \frac{-2\sum_{j\in N} B(N-1)\frac{e^{\lambda z s_j}}{(R+rs_j)}}{\left(\sum_{j\in N}\frac{p_j e^{\lambda z s_j}}{(R+rs_j)}\right)^3} * \begin{bmatrix} \frac{e^{\lambda z s_1}}{(R+rs_1)} & \frac{e^{\lambda z s_2}}{(R+rs_2)} & \cdots & \frac{e^{\lambda z s_N}}{(R+rs_N)} \\ \frac{e^{\lambda z s_1}}{(R+rs_1)} & \frac{e^{\lambda z s_2}}{(R+rs_2)} & \cdots & \frac{e^{\lambda z s_N}}{(R+rs_N)} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{e^{\lambda z s_1}}{(R+rs_1)} & \frac{e^{\lambda z s_2}}{(R+rs_2)} & \cdots & \frac{e^{\lambda z s_N}}{(R+rs_N)} \end{bmatrix} \tag{43}$$

Since the second derivative of Π with respect to p_i (42) and the second-order partial derivatives (43) for p_i and p_j are both less than 0, the Hessian matrix of $\Pi(\boldsymbol{p})$ is semi-negative. Therefore, $\Pi(\boldsymbol{p})$ is a concave function and there is a unique optimal price vector for maximum profit.

IV. SIMULATION

In this section, we simulate the algorithm to evaluate the performance of the resource allocation mechanism for mobile blockchain proposed in this paper. We use Hyperledger Fabric version 1.4 to build the blockchain and use Fabric chaincode to write smart contracts. In the simulation, we set 100 resource nodes in the resource sharing network, in which there are 60 mining nodes.

Firstly, we change parameters to study the impact on miners and the edge server's earnings. Secondly, the mechanism studied in this paper and the pricing-based edge computing resource management method (PECRM) in the literature [17] are compared to study the benefits of miners and the edge server under the two methods.

As shown in Fig.2, in terms of the number of miners, the auction price within the resource sharing network decreases as the number of miners increases, as the mining device will bid based on its expected profit. As the number of mining devices increases, the number of resource-sharing devices decreases, so that the amount of available resources decreases, and expected profit reduction. At the same time, as the delay effect increases, the possibility of successful mining declines, so the auction price drops.

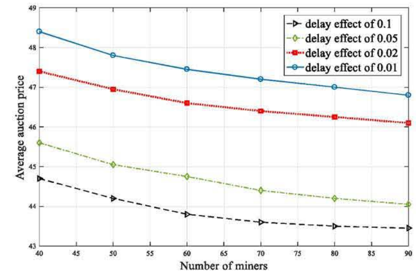

Fig. 2. Impact of the number of miners on auction prices.

As shown in Fig.3, under the differentiated pricing, the optimal price is slightly lower than the highest price, and gradually approaches the limit as the density of miners increases. Due to differentiated pricing, the edge server can dynamically adjust the optimal price based on different resource requirements. And the competition of more miners will push up the best price.

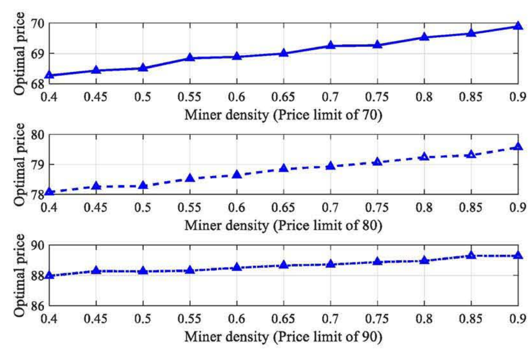

Fig. 3. The pricing strategies of the edge server.

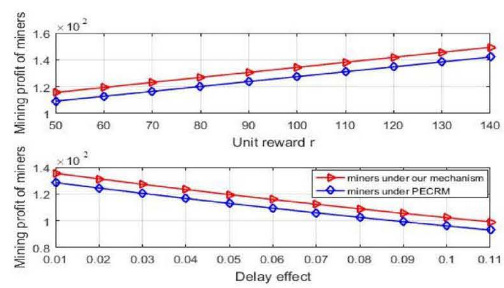

Fig. 4. Miner's personal utility compared with PECRM.

Then we compare the individual utility of the miners under our mechanism and the PECRM mechanism, considering the effects of delay effects and unit returns under differentiated pricing. According to Fig.4, the miner's personal utility under this mechanism is slightly higher than that of PECRM. This is because that we support mining device to request resource from neighboring mobile devices in the resource sharing network. The top image shows that the higher the unit reward, the higher the utility of the miner. The bottom image shows that under different delay effects, the advantages of this mechanism are still higher than PECRM.

We also observed the trend of edge server profits under the mechanism and PECRM with delay effects and unit rewards.

According to Fig.5, the edge server's profit increases with the increase of unit rewards, because higher unit rewards stimulate more resource demand. Conversely, as the delay effect increases, the edge server's profit decreases. As the delay effect increases, the miners' resource requirements decrease, which reduces the profit of edge server. We also compare the edge server's profits under this mechanism with PECRM. Due to the increased internal resources sharing in the resource sharing network, the mining cost is reduced, and the resource demand to edge server is less. Therefore, the profit of edge server under this mechanism is lower than that of PECRM. This is reasonable because this article is more focused on determining the optimal resource allocation and getting the miner's maximum profit based on the optimal price of the edge server.

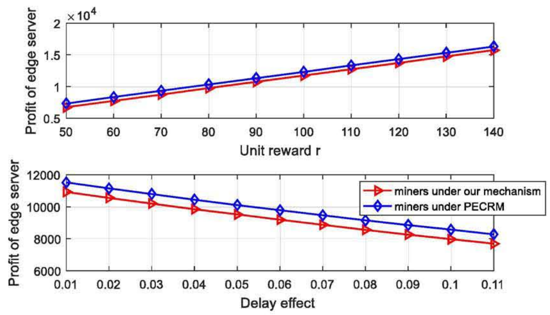

Fig. 5. Edge server's profit compared with PECRM.

V. CONCLUSION

In order to realize the application of blockchain in the smart city, we design and study a kind of edge network resource allocation mechanism for mobile blockchain, which aims to make up for the shortage of resources of mobile devices itself to support the mining process. In this paper, we aim at maximizing system revenue and being constrained by edge network resources constraints to design an edge network resource allocation mechanism for mobile blockchain. Finally, through simulation experiments, we can see that the mechanism we designed has higher personal benefits for miners. However, we simplified the actual network environment during the research process, and only considered a simple static environment. To be applied to reality, the next step is to consider more actual network requirements, such as the mobility of each node, dynamic access, dynamic exit, and other issues to further improve the mechanism.

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REFERENCES

[1] P. Kumar, "Future Internet & Internet of Things," 2017 International Conference on Innovations in Electrical Engineering and Computational Technologies (ICIEECT), Karachi, 2017, pp. 1-1.

[2] Devaki Chandramouli; Rainer Liebhart; Juho Pirskanen, "Next Generation Network Architecture," in 5G for the Connected World , , Wiley, 2019, pp.127-223.

[3] Y. Xu, "Section-Blockchain: A Storage Reduced Blockchain Protocol, the Foundation of an Autotrophic Decentralized Storage Architecture," 2018 23rd International Conference on Engineering of Complex Computer Systems (ICECCS), Melbourne, VIC, 2018, pp. 115-125.

[4] Q. K. Nguyen and Q. V. Dang, "Blockchain Technology for the Advancement of the Future," 2018 4th International Conference on Green Technology and Sustainable Development (GTSD), Ho Chi Minh City, 2018, pp. 483-486.

[5] Q. K. Nguyen, "Blockchain - A Financial Technology for Future Sustainable Development," 2016 3rd International Conference on Green Technology and Sustainable Development (GTSD), Kaohsiung, 2016, pp. 51-54.

[6] F. Tschorsch and B. Scheuermann, "Bitcoin and beyond: A technical survey on decentralized digital currencies," IEEE Communications Surveys Tutorials, vol. 18, no. 3, pp. 2084–2123, thirdquarter 2016.

[7] I. Eyal, "Blockchain technology: Transforming libertarian cryptocurrency dreams to finance and banking realities," Computer, vol. 50, no. 9, pp. 38–49, 2017

[8] Z. Ma, W. Huang, W. Bi, H. Gao and Z. Wang, "A master-slave blockchain paradigm and application in digital rights management," in China Communications, vol. 15, no. 8, pp. 174-188, Aug. 2018.

[9] W. Viriyasitavat, L. D. Xu, Z. Bi and D. Hoonsopon, "Blockchain Technology for Applications in Internet of Things—Mapping From System Design Perspective," in IEEE Internet of Things Journal, vol. 6, no. 5, pp. 8155-8168, Oct. 2019.

[10] H. Tam Vo, Z. Wang, D. Karunamoorthy, J. Wagner, E. Abebe and M. Mohania, "Internet of Blockchains: Techniques and Challenges Ahead," 2018 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData), Halifax, NS, Canada, 2018, pp. 1574-1581.

[11] R. M. Parizi, S. Homayoun, A. Yazdinejad, A. Dehghantanha and K. R. Choo, "Integrating Privacy Enhancing Techniques into Blockchains Using Sidechains," 2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE), Edmonton, AB, Canada, 2019, pp. 1-4.

[12] H. Cho, "Asic-resistance of multi-hash proof-of-work mechanisms for blockchain consensus protocols," IEEE Access, vol. 6, pp. 66210–66222, 2018.

[13] Y. Zhang, L. Liu, Y. Gu, D. Niyato, M. Pan and Z. Han, "Offloading in software defined network at edge with information asymmetry: A contract theoretical approach," Journal of Signal Processing Systems, vol. 83, no. 2, pp. 241–253, May 2016.

[14] Z. Xiong, S. Feng, W. Wang, D. Niyato, P. Wang and Z. Han, "Cloud/Fog Computing Resource Management and Pricing for Blockchain Networks," in IEEE Internet of Things Journal, vol. 6, no. 3, pp. 4585-4600, June 2019.

[15] Y. Jiao, P. Wang, D. Niyato and Z. Xiong, "Social Welfare Maximization Auction in Edge Computing Resource Allocation for Mobile Blockchain," 2018 IEEE International Conference on Communications (ICC), Kansas City, MO, 2018, pp. 1-6.

[16] Y. Yue, W. Sun and J. Liu, "A Double Auction-Based Approach for Multi-User Resource Allocation in Mobile Edge Computing," 2018 14th International Wireless Communications & Mobile Computing Conference (IWCMC), Limassol, 2018, pp. 805-810.

[17] Z. Xiong, S. Feng, D. Niyato, P. Wang and Z. Han, "Optimal Pricing-Based Edge Computing Resource Management in Mobile Blockchain," 2018 IEEE International Conference on Communications (ICC), Kansas City, MO, 2018, pp. 1-6.

[18] Z. Xiong, Y. Zhang, D. Niyato, P. Wang and Z. Han, "When Mobile Blockchain Meets Edge Computing," in IEEE Communications Magazine, vol. 56, no. 8, pp. 33-39, August 2018.

[19] K. Suankaewmanee, D. T. Hoang, D. Niyato, S. Sawadsitang, P. Wang and Z. Han, "Performance Analysis and Application of Mobile Blockchain," 2018 International Conference on Computing, Networking and Communications (ICNC), Maui, HI, 2018, pp. 642-646.

[20] Y. Zhang, L. Liu, Y. Gu, D. Niyato, M. Pan and Z. Han, "Offloading in software defined network at edge with information asymmetry: A contract theoretical approach," Journal of Signal Processing Systems, vol. 83, no. 2, pp. 241–253, May 2016.