Stackelberg Game Based Resource Pricing and Scheduling in Edge-Assisted Blockchain Networks

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Outline

- Background & Motivation
- Model & Problem
- Challenge
- Solution
- Simulations
- Conclusion

Bitcoin Mechanism

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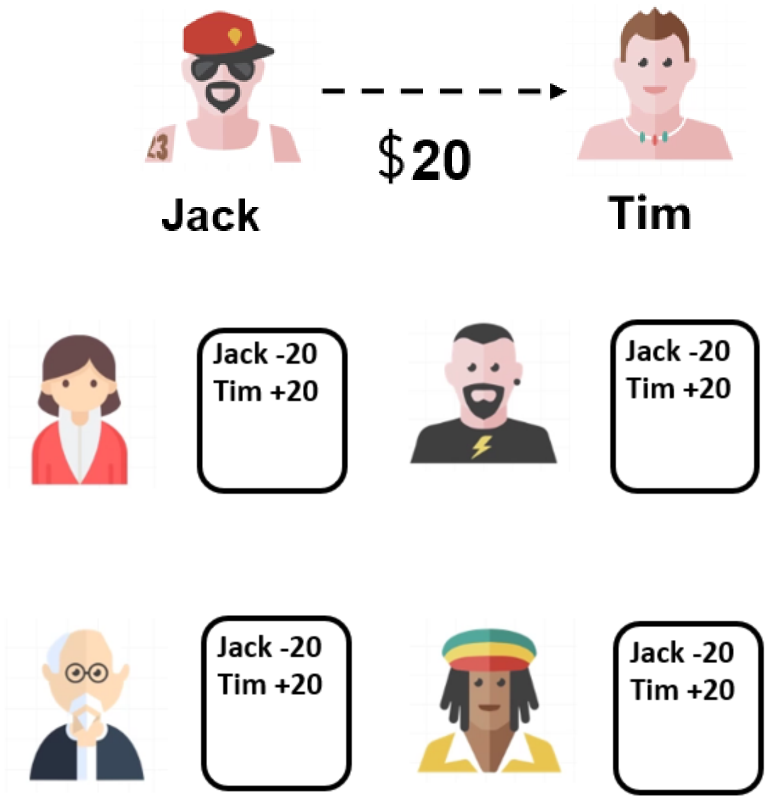
- **Traditional currency (relies on government or third-party issuance)**
  - **Additional cost of transactions**
  - **Risk of account being frozen**
  - **Risk of financial crisis**

- **Bitcoin (decentralized electronic currency)**
  - **No third-party financial institutions**
  - **Global currency**
  - **Security, irrevocability and privacy**

Bitcoin Mechanism

- **Transaction in network** → **Happen all the time!**
  - **Point to point**

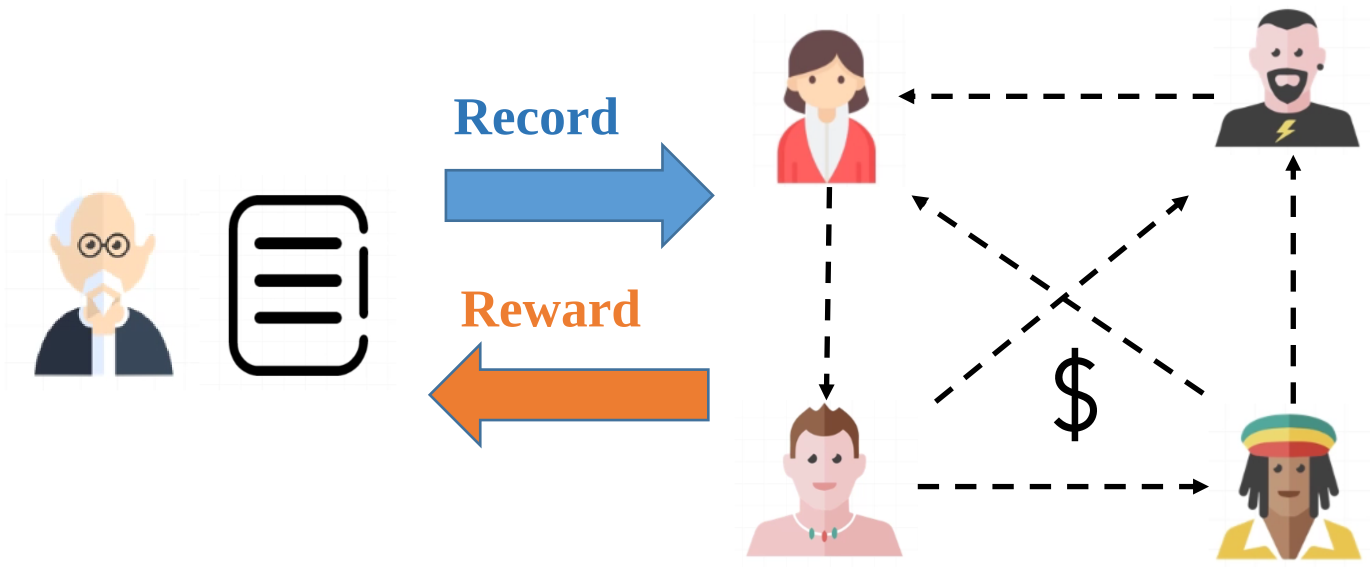


- **Ledger**
  - **Unchangeable**
  - **Identical, public**
  - **Update in real time**

When the transaction occurs, every user in the network will record the transaction in their local ledger

Bitcoin Mechanism

- Recorder: the user who selected to record the all transaction happened in **a time slot**

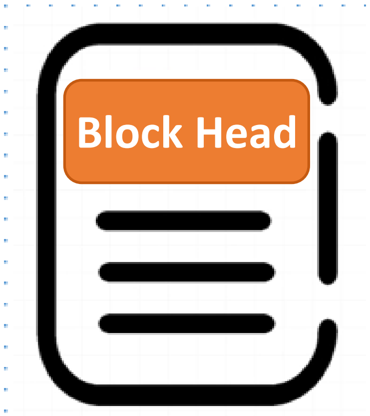


Recorder will receive a bit of money for each transaction as reward

Proof of Work (PoW)

- **Block: The ledger contains the transactions in a time slot**

- **Block head: Hash value**
  - **Simplify, identify, anonymize and verify the information**



Head of Last Block
+
Transactions in a Time Slot
+
Timestamp
+
Random Number

Hash (SHA 256) → 256-bit Binary Hash Value

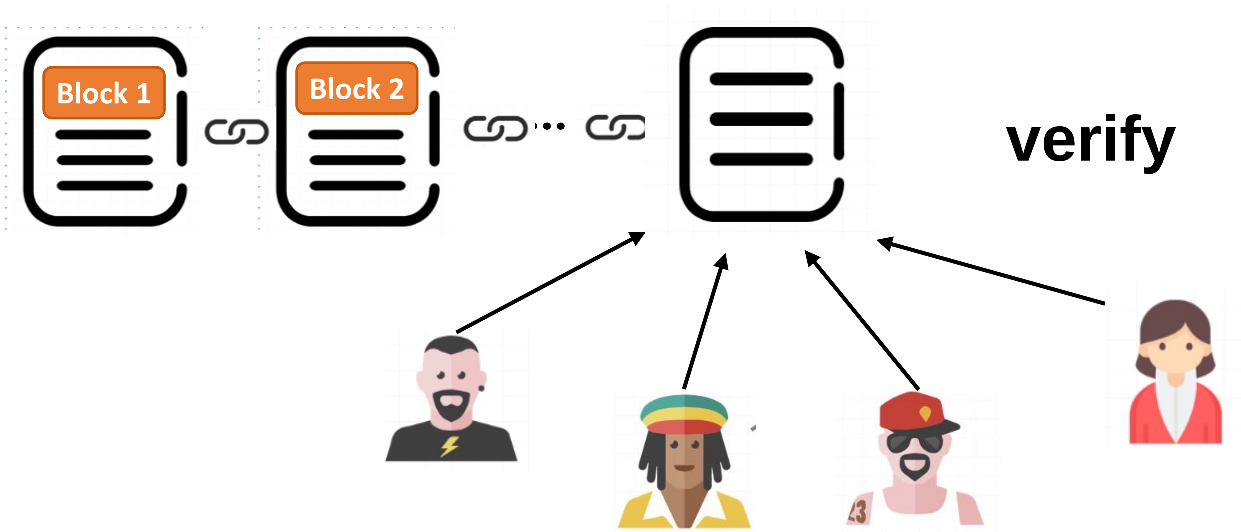
Only the hash value that meets the requirements will be accepted by the blockchain

Ledger Verification

- **Leger verification**
  - Correctness and consistency

verified by majority of people

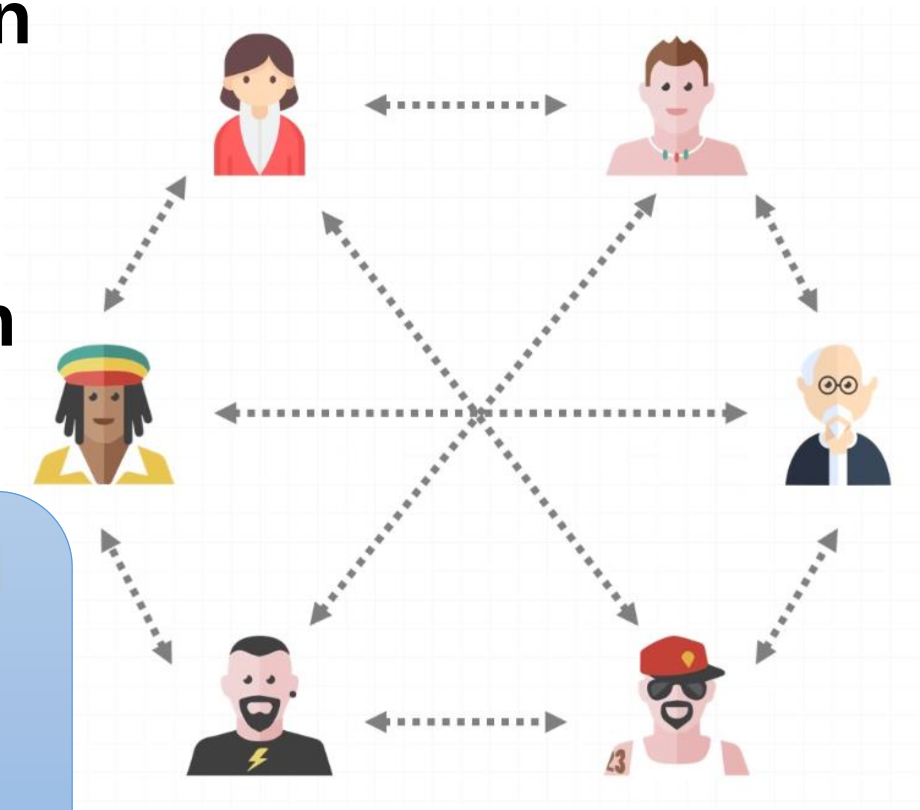
- **Blockchain**
  - Block be linked to Blockchain



Block Convergence

- Block broadcasting in P2P network

- Flooding propagation



The process of verifying and broadcasting the ledger can be regarded as the process of block propagation convergence

Mining Process

- **Solve the PoW problem**
  - Great number of computation and storage resources.
- **Block convergence**
  - Propagation delay
  - Geographical location

It's hard to be satisfied with terminal devices

Speed game !!

Appending a Block to the Current Blockchain = Solve the PoW Problem + Block Convergence

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Reward

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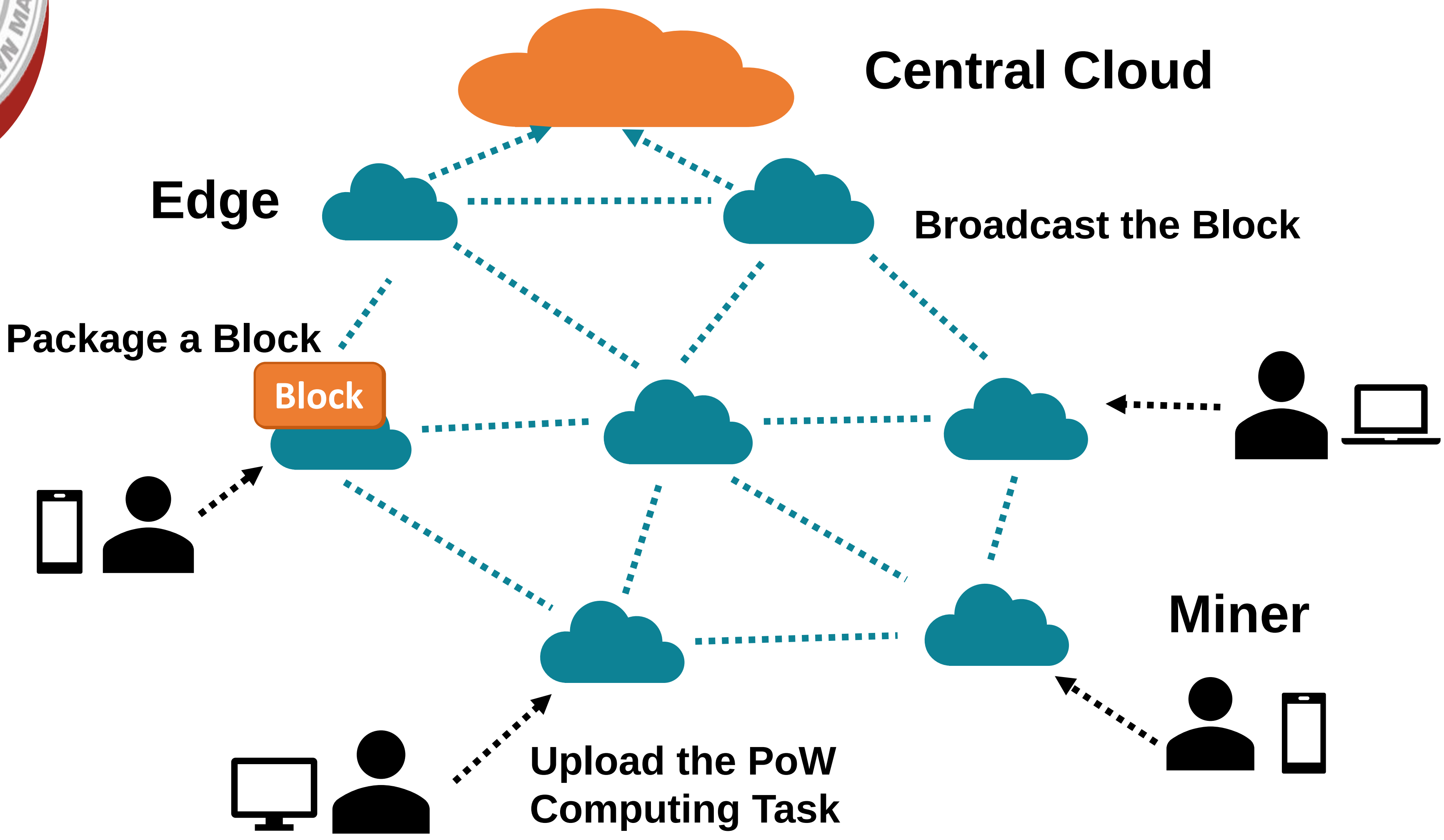
Edge-Assisted Blockchain Networks



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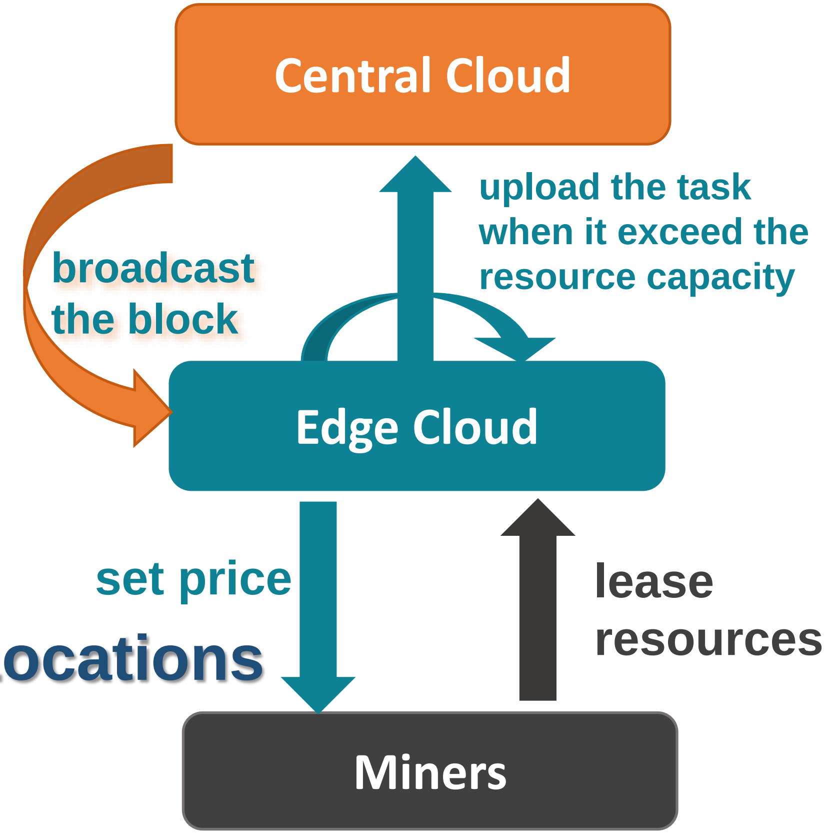
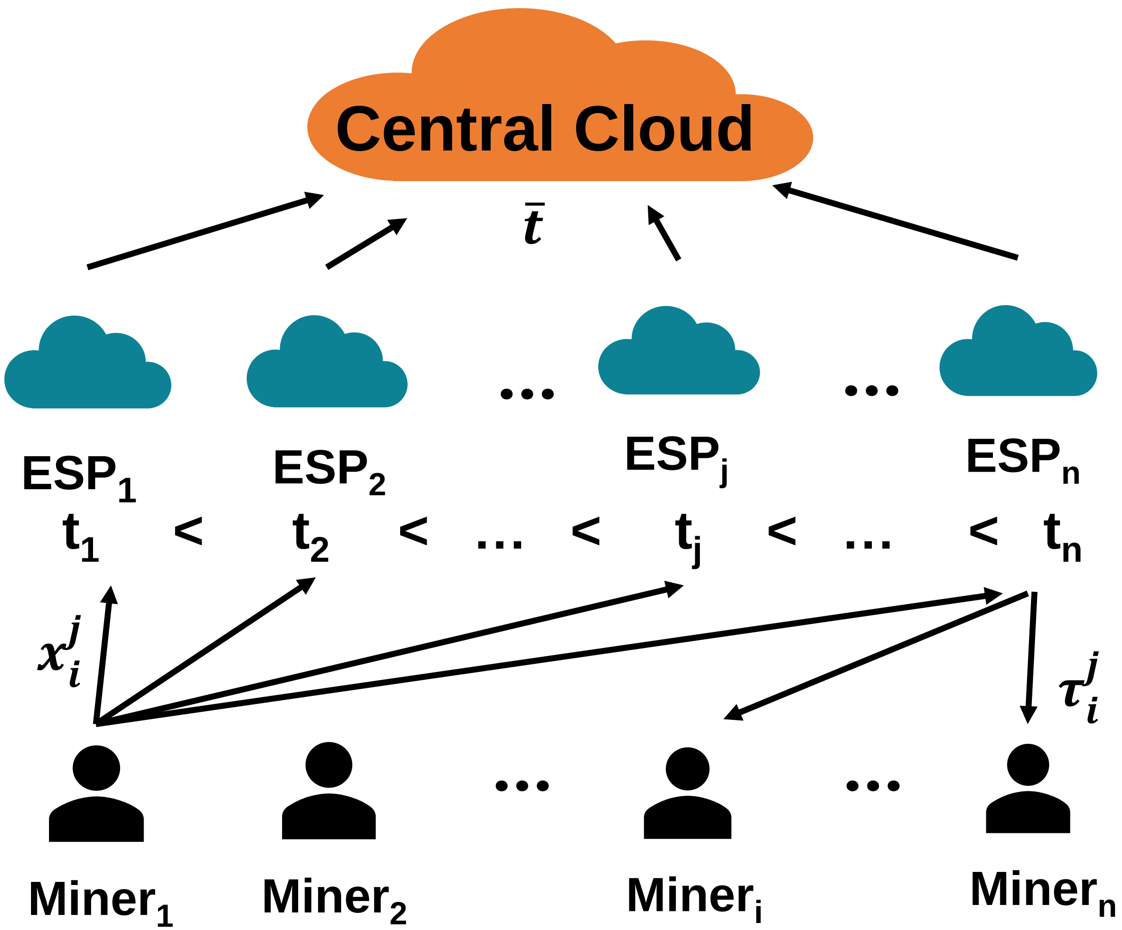
Two-stage Stackelberg Game

- **Central cloud**
  - Amount of Computing Resources
  - Fixed Price
  - Remote Location
- **Edge cloud: leader**
  - Limited Resources
  - Variable Prices
  - Different Geographic Locations
- **Miners: follower**
  - Selfish and rational



Problem Formulation



τ_i^j=0: ESP j upload the request of miner i to CSP due to the limited resource

Propagation delay

τ_i^j=1: ESP j accept the request of miner i

Request of Miner i $X_i = (x_i^1, x_i^2, \ldots, x_i^n)$

Problem Formulation

Miner Side Utility in Stage I | **ESP Side Utility in Stage II**

Hash power

$$\alpha_i^j = \frac{x_i^j}{\sum_{i\in\mathcal{M}}\sum_{j\in\mathcal{N}}\tau_i^j x_i^j}.$$

orphaning probability on the propagation delay tj

$$P_{\text{orphan}}(t_j) = 1 - e^{-\lambda t_j}$$

$$W_i^j = \alpha_i^j(1 - P_{\text{orphan}}(t_j)) = \frac{\tau_i^j x_i^j}{E_{all}} e^{-\lambda t_j}$$

winning probability of mining game for miner i on ESP j

$$W_i^{j\prime} = \frac{(1-\tau_i^j)x_i^j}{C_{all}} e^{-\lambda \bar{t}}.$$

winning probability for miner i on the CSP

$$W_i = \sum_{j\in\mathcal{N}}\left(\frac{\tau_i^j x_i^j}{E_{all}} e^{-\lambda t_j} + \frac{(1-\tau_i^j)x_i^j}{C_{all}} e^{-\lambda \bar{t}}\right).$$

winning probability of miner i on all service providers

$$\begin{aligned} &\textit{maximize} \quad U_i = R\cdot W_i - \sum_{j\in\mathcal{N}} p_j\cdot x_i^j \\ &\textit{subject to} \quad \sum_{j\in\mathcal{N}} p_j\cdot x_i^j \le B_i \end{aligned}$$

miner i 's utility

$$\begin{aligned} &\textit{maximize} \quad V_j = (p_j - c)\cdot E_j + (p_j - h)\cdot C_j \\ &\textit{subject to} \quad \sum_{i\in\mathcal{M}} \tau_i^j x_i^j \le K_j \end{aligned}$$

ESP j 's utility

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Contributions

Existing Study for Blockchain:

- Only consider the case of one edge service provider (ESP)
- Each ESP has consistent price
- Assumed that all ESPs have a uniform propagation delay
- Did not consider the delay factor due to geographical location

⇩

Our Work:

- We consider the interaction between the multi-users and multi-ESPs
- Each ESP sets variable price
- Consider the orphan probability in propagation process
- Consider the propagation delay due to the different geographical locations of ESPs

Challenges

- **Multi-Leader and multi-follower Stackelberg game**
  - **Existence and uniqueness of Nash Equilibrium**
  - **Variable prices**
  - **Multiple requests from one user**
- **Variable winning probabilities brought about by different geographical locations delay**
- **Central Cloud Participation**

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Solution for Nash Equilibrium

- Step1: ESPs choose random feasible price strategy

- Step2: Every miner predicts other miners' optimal requests and adjusts his demand according to the prices of ESP $x_i^{j(k)} = x_i^{j(k-1)} + \Delta \frac{\partial U_i(X_{-i}^{(k-1)}, X_{-i}^{(k-1)}, P)}{\partial x_i^j}$

- Step3: ESPs update the price with a step and predict whether the new price will bring more profit, and then adjust the pricing strategy $p_j^{(k)} \leftarrow p_j^{(k-1)} + \delta$

- Repeat step2 and step3 until the difference of the price strategy in two rounds is less than a given threshold $\| P^{(k)} - P^{(k-1)} \| < \epsilon$

Solution for Nash Equilibrium

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Algorithm 1 Asynchronous Best Response

Input: Any feasible price $P = \{p_1, p_2, \ldots, p_n\}$, miners' demands $X = \{X_1, X_2, \ldots, X_m\}$, and the threshold ϵ

for iteration k **do**
  storing last iteration $P^{(k-1)}$;
  for each miner i **do**
    receiving the pricing strategy $P = \{p_1, p_2, \ldots, p_n\}$;
    predicting the optimal requests of other miners;
    calculating $x_i^{j^{(k)}} = x_i^{j^{(k-1)}} + \Delta \frac{\partial U_i \left(X_{-i}^{(k-1)}, X_i^{(k-1)}, P \right)}{\partial x_i^j}$;
    deciding his request $\mathbf{x_i^{(k)}} = \{x_i^1, x_i^2, \ldots, x_i^n\}$;
  for each ESP j **do**
    update the price with a step δ;
    predicting miners' optimal requests $\mathbf{x}^*$ for each ESP;
    if the new price brings more profit **then**
      $p_j^{(k)} \leftarrow p_j^{(k-1)} + \delta$;
  if $\|P^{(k)} - P^{(k-1)}\| < \epsilon$ **then**
    return $P^{(k)}$ and $\mathbf{x}^*$;
  else
    $k \leftarrow k + 1$;

User adjusts strategy

Gradient iteration algorithm

ESP pricing adjustment

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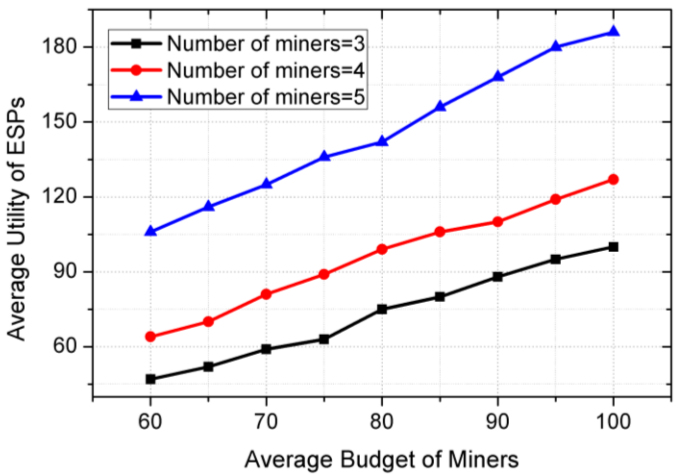
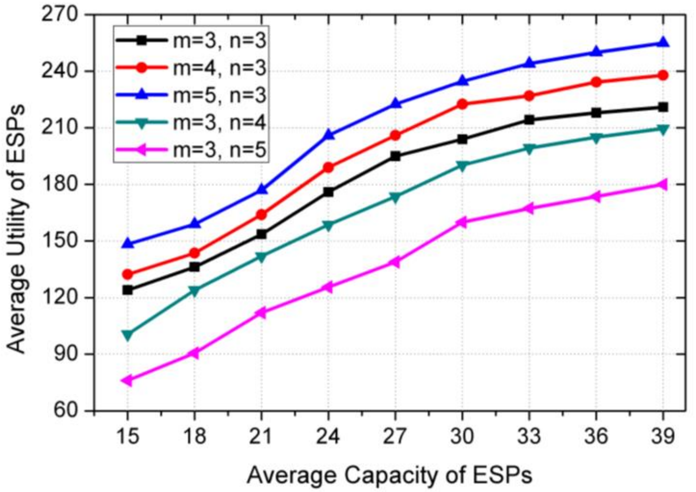
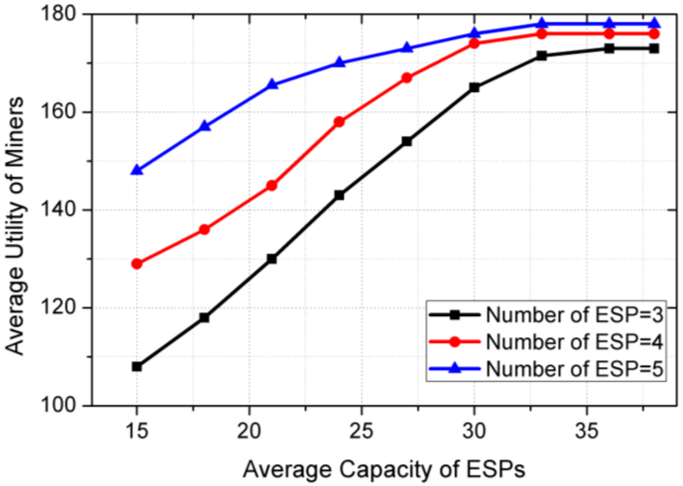
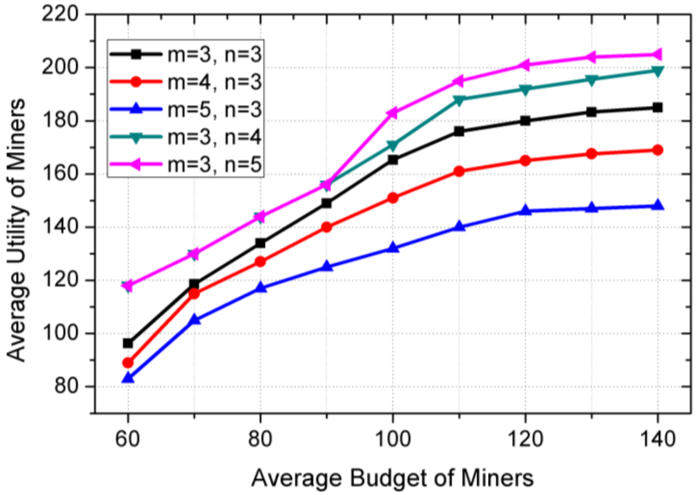
Result: Utility in Two Stages

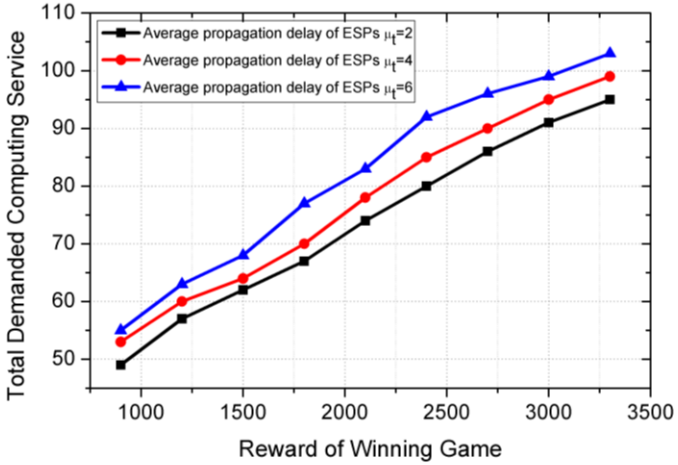


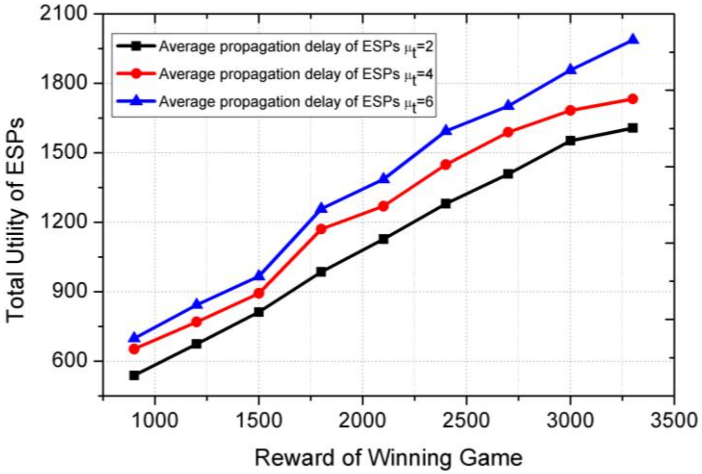


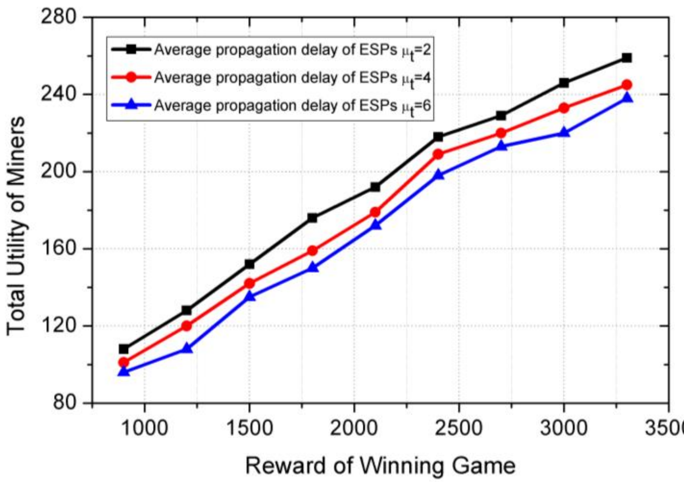


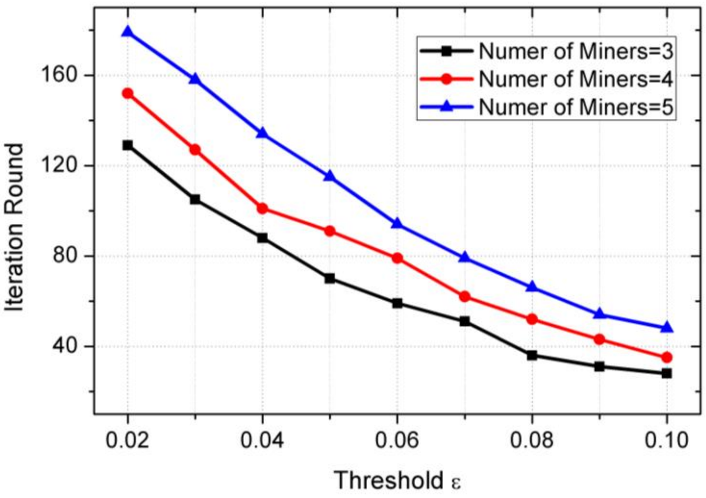


Result: System Performance









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Conclusion

- We investigate the resource pricing and scheduling problem in the edge-assisted blockchain mining networks by using the multi-leader multi-follower Stackelberg game theory.
- We propose the edge computing model where ESPs has different propagation delays according to his geographical location.
- We analyze the utility of both miners and ESPs and further discuss the existence and the uniqueness of Stackelberg Equilibrium (SE).
- We conduct extensive simulations to validate the convergence as well as evaluate the network performance.

@ Contact Me

Thank You!

Q & A

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