A Repeated Stochastic Game Approach for Offload Mining in Distributed Applications in a Permissionless Blockchain Network*

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1. Introduction

With the proliferation of decentralized applications (DApps) based on the blockchain, a mining process has been important for secure DApp operations. Since most DApp users, however, own only devices with the limited resources, e.g., mobile devices, which make it difficult to perform computationally intensive mining. Therefore, the DApp aims at operating securely by offloading the computational task required by the users for mining to the cloud and/or edge, i.e., cloud service provider (CSP). Under such background, there have been studies on the offload mining [1]. Too many miners using a single CSP may cause the service congestion and the increase of service price while a few miners may weaken the robustness of the blockchain network. In this paper, we formulate the CSP selection problem for the offload mining in which each user (miner) selects which CSP from the available candidates as a repeated stochastic game and propose an offloading method so as to achieve a coarse correlated equilibrium (CCE) among the DApp users, inspired by [2]. A CCE is an equilibrium in which no user can increase his/her own utility by deviating from the suggestion from a game manager if all users obey the suggestion. Through the numerical experiment, we demonstrate the effectiveness of the proposed method.

2. Proposed Model

We formulate the CSP selection problem as the repeated stochastic game. In the repeated stochastic game, we assume that there are N users $\mathcal{N} = \{1, \dots, N\}$ and M CSPs $\mathcal{M} = \{1, \dots, M\}$ and a game manager. For each time slot t ($t = 1, \dots, T$), each user $i \in \mathcal{N}$ selects an action (i.e., a CSP) $\alpha_i(t) \in \mathcal{A}$ from an action set $\mathcal{A} = \{0\} \cup \mathcal{M}$ and offloads his/her computational demand to the CSP $\alpha_i(t)$, where 0 means no offloading. Let $\boldsymbol{\alpha}(t) = (\alpha_1(t), \dots, \alpha_N(t))$ be an action vector. Each CSP $j \in \mathcal{M}$ has the resource capacity C_j and decides the service price p_j and the congestion state $c^j(t) \in \{0, 1\}$. $c^j(t) = 1$ (resp. $c^j(t) = 0$) means that the CSP j is unavailable (resp. available), which is determined according to the congestion probability $q_j(t) = \sum_{i \in \{k \in \mathcal{N} | \alpha_k(t) = j\}} d_i(t)/C_j$ (resp. $1 - q_j(t)$).

In the repeated stochastic game, for each time slot t, each user $i \in \mathcal{N}$ notifies his/her computational demand $d_i(t)$ to the game manager to select a CSP from the action set $\mathcal{A}$. Given $d_i(t)$ $(i \in \mathcal{N})$, $\boldsymbol{\omega} = (c^1, \dots, c^M)$, and p_j $(j \in \mathcal{M})$ as inputs, the game manager suggests an action $S_i(t) \in \mathcal{A}$ such that CCE is achieved under the utility function $u_i(\boldsymbol{\alpha}(t), \boldsymbol{\omega}(t)) = \frac{d_i(t)}{\sum_{j \in \mathcal{N}} d_j(t)}(R + r) - d_i(t) p_{\alpha_i(t)}(t)$, where R and r stand for the mining reward and transaction fee, respectively. The first term of the right-hand side in the utility function means the expected reward by mining and the second term means payment cost at a CSP. If $c_{\alpha_i(t)} = 1$ or $\alpha_i(t) = 0$, $u_i = 0$. Each user i offloads the computational demand d_i to the CSP $S_i(t)$ by following the suggestion $S_i(t)$. Since it is difficult to directly solve the repeated stochastic game in terms of the computational complexity, we compute the suggestion so as to achieve the CCE by using the Lyapunov optimization.

3. Numerical Experiments

We evaluate the effectiveness of the proposed method in terms of the time average utility $\overline{u} = \frac{1}{TN} \sum_{t=1}^{T} \sum_{i \in \mathcal{N}} u_i(t)$. For comparison purpose, we prepare a random method where each user randomly selects a CSP from the available CSP candidates for each time slot t. We confirm that $\overline{u}$ of the proposed method (resp. the random method) is 1.5×10^{-2} (resp. 4.7×10^{-3}). The proposed method has the 3.19 times higher $\overline{u}$ than the random one.

4. Conclusion

In this paper, we proposed a method for offloading mining tasks to the cloud and/or edge so as to achieve the CCE among DApp users. Through the numerical experiments, the proposed method achieved the 3.19 times higher time average utility than the random one.

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