# Graph-Based Computing Resource Allocation for Mobile Blockchain

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***Abstract*— Since it first appears in 2008 as the underlying technology of the Bitcoin payment system, Blockchain has gained further interests, since it offers a distributed peer-to-peer ledger where non-trusting members can interact with each other ,in addition, members can now run applications without the need for a central authority with the same level of certainty. however blockchain suffers from certain limitations and challenges, specifically ,when combined with Internet of things (iot) infrastructure, namely the high cost needed in the mining process due to restricted computation resources of iot devices, in this paper we will focus on a survey on three of most relevant papers that discuss resources management in mobile blockchain then we we will propose a matching model based on graph theory for optimal resources allocation between services offered by an Edge service provider and demands from miners of a blockchain network.**

***Index Terms*—Blockchain, Internet of things, resources allocation, mobile blockchain.**

## I. Introduction

In the last decade cryptocurrencies which are based on blockchain technology have noticed a significant growth, this popularity has been inherited from the fact that blockchain offer the possibility of executing a payment applications without relying on trusted third parties like central banks, blockchain allows this decentralization through a consensus mechanism ,thus enabling a secure and trust-less decentralized database management.

Today blockchain serves as key technology in various fields such as smart grid, finance, cognitive radio and Internet of things and according to several estimations, revenue of enterprises will reach 20$ billion with the implementation of blockchain solutions by 2025.

The consensus mechanism by which blockchain reaches decentralization is based on a proof of work (PoW) process that randomly select one node in the network to propose the next block and append it to the current chain, in fact , a group of nodes called miners compete with each other in order to solve a computationally difficult problem, i.e, PoW puzzle, this whole process is called mining, to solve the PoW puzzle miners need to collect and select transactions broadcasted by other nodes, then when solving the puzzle , the block that combines all those transactions will be sent to all other miners for verification and if approved by the majority of them, this block will be added to the blockchain and the winning miner (who solve the puzzle and appends the chain) receives a fixed reward.

Nevertheless, the implementation of blockchain in mobile devices is a challenging work due to the fact that computational resources of those devices are limited and cannot satisfy the PoW needs of power and energy, as a result authors in [1] prpose a solution in which the PoW puzzle is offloaded to a nearby Mobile edge computing servers, e.g, base stations of radio access networks, this will allow mobile users to access and utilize resources or computing services in the edge to enhance their computing capability,However, edge computing services are deployed by an Edge Service provider (ESP) whose first goal is to maximize his own benefits, thus a pricing scheme was provided using a Two-Stage Stackelberg Game to model the interaction between the ESP and miners.Another economic model was adopted by authors in [2] based on auction theory in which an ESP try to make practical sale strategies, the process is as follow, first the ESP announces its services to mobile users then the mobile users submit their valuations of the offered services, lastly the ESP selects the winners and notify all users of the current allocation, as an enhancement of this proposed model authors in [3] introduce a deep learning approach to find the optimal auction by finding the optimal allocation rules, i.e., winning probabilities of the miners, and the conditional payment rule to the miners, in the other side, and in order to optimize the ESP profit a neural network training was implemented.

This paper is organized as follow, in part I we will make a review on papers discussed earlier and provide ideas that may lead to enhancements of the proposed models, in part II a matching model based on graph theory to find optimal resources allocation will be proposed .

## II. papers review

Actually, deployment of blockchain applications in mobile devices is facing a big challenge due to high computing power and energy needed to solve the PoW puzzle which is considered as the key feature of the consensus mechanism that allows decentralization in blockchain based technologies, as a result an inevitable solution was to make use of edge computing resources to give mobile users capabilities to run blockchain applications as done by authors in [1],indeed, the ideas of this paper was organized as follow: In order to allow the deployment of blockchain in mobile architectures Mobile edge computing enabled blockchain system is considered which allows miners to offload their PoW puzzle to a nearby Edge service provider, therefore a two-Stage Stackelberg Game is formulated in order to manage pricing and resources allocation

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by the ESP toward incoming service demands, It is a leader vs follower game where an ESP set a price $p$ then based on that price miners decides on its computing service demand $x_i$ and by a backward induction process the leader find its optimal price that help maximize his own profit, further the provider adopt two pricing schemes, namely, uniform pricing and discriminatory pricing, in the uniform pricing miners are charged with the same service price, however the provider charges each miner with exclusive service price for the discriminatory pricing scheme, authors claim that the discriminatory pricing can help the ESP achieve highest profit compared with the uniform one.
From our point of view we can make some remarks about the proposed work:

- Firstly, for a small number of miners the Edge Service Provider accept all miners demand whatever the amount of service demanded,thus, given the mining difficulty fixed by the blockchain owner and the time needed to mine the next block, defining a threshold that ensures rationality of miners is required, in fact this is not possible until a coordination between the blockchain owner from one side, and the Edge Service Provider from the other side in order to exchange necessary information and later use them to efficiently manage resources allocation .
- Second,over time, the difficulty of blockchain mining is increased, as a result miners need more services to solve the PoW puzzle, therefore, if few miners dominate the hole services others may not gain access to the ESP offers, so the social welfare will vanishes, another important fact to consider here is a security impact known as 51% attack where a miner (attacker) control the majority of the computing power on the network, this attacker or group of attackers can interfere with the process of recording new blocks. They can prevent other miners from completing blocks, theoretically allowing them to monopolize the mining of new blocks and earn all of the rewards, thus a security strategy must be implemented in order to try to prevent this weakness.
  When considering a scenario where miners offload their PoWs puzzle toward an Edge Service Provider the problem seems to be more complicated, in effect and as we discuss before coordination between blockchain owners and Edge Service Providers can lead to interesting results and theoretically it may prevent such an attack. The Edge Service Provider can prevent a miner from dominating the hash power of a private blockchain network provided that he knows total resources allocated to it, as long as its difficulty level.
- lastly, this one leader Stackelberg Game can be a basis for a more realistic model, since practically a Multi-Leader Multi-Follower Stackelberg Game may appears more interesting.

Another economical model was adopted by authors in [2] where a second price auction was presented, where the winner pays the second highest bid rather than their own, the idea is organized in the following manner, a group of miners try to access an Edge Service Provider services to record and verify the transactions of a blockchain network , the ESP launches an auction to sell its services, first it announces its services then bidders, e.g, mobile users or IoT devices submit their resource demand and corresponding bids or valuations, the Edge Service Provider selects the winners with highest bids and notifies other users with the current allocation and service price. finally, the winners make the payment and access the edge computing services. The main objective of the ESP is to maximize the social welfare (profits of miners), knowing that bids of users are nothing but their expected rewards(estimated), the effective value is affected by the network effect [4]. this auction mechanism must be truthful and individually rational, the Myerson's well-known characterization and the VCG properties respectively guarantees those requirements.
We introduce the following remarks about this proposed paper:

- The Edge Service Provider services are considered to be delivered to one blockchain network, indeed, miners diversity or when users from multiple blockchain networks are trying to access the service is not taken into account.
- Individual rationality takes effect only when a large number of miners are participating in the mining task, for a few number of users rationality of users is not guaranteed ,thus, a threshold of service that take into account the difficulty level of the blockchain network must be defined in order to ensure rationality of miners.
- The network effect function and their parameters and how they affect the expected reward should be more explained.
- Demands from miners are considered to be the same, in fact, those demands are always different and this requirement should be considered.
- Miners will never get their expected reward due to the network effect, unless reaching its top value which is very unlikely to happen.
- There is no way to encourage miners to use more services when their total number is weak.

In the next part, we introduce a model based on matching in graph theory to find an optimal matching between users demand and services offered by an Edge Service Provider.

## III. A MATCHING MODEL FOR RESOURCES ALLOCATION USING GRAPH THEORY

The main task for an Edge service provider is to find the optimal matching between demands of a group of miners and the total amount of resources that he can provide or allocate, the provided algorithm in this part that find a matching between demands and offers can be combined in both economical models discussed earlier, thus in [1] the matching process can be done in a one by one manner but in [2] a slot of users is served in each round.
the main objective of an Edge Service Provider is to make high revenue, and this is not possible until an efficient and

optimal matching is implemented to guarantee the best possible resources allocation for mobile users.

in this part we will focus on the the case where a group of miners try to access resources of an Edge Service Provider simultaneously as done in the auction models, in fact , given the total resources of an ESP $R$ and the total demand of miners $D$ the matching between these two disjoint sets can be simulated as a Bipartite Graphs matching .

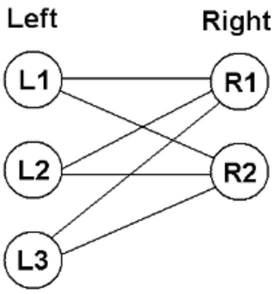


Figure 1. Bipartite Graphs matching

### A. Problem formulation

Let $R$ be the maximum quantity of computing resources that ESP can offer and $D$ the sum of all miners demand We define a bipartite graph $G$ where $E$ and $H$ are the left and right disjoint sets of vertices.
Vertices of left set $E$ are resources demand $d_i$ for each miner such that:

$$\sum d_i = D$$

Vertices of right set $H$ are expected resources $r_i$ that must be allocated to each user demand $d_i$ where :

$$\sum r_i \leq R$$

In other word, we should find a matching between vertices from $H$ and $E$ taking into account the total resources available $R$:

Find the matching:

$$\{(d_i; r_i)\}$$

Such that :

$$R - D \geq 0$$

A matching of a graph G is complete if it contains all of G's vertices, as a result all requests were met.
**Definition 1.** *Consider a subset $S \subseteq L$ of left vertices of bipartite graph G. Let n be the number of right vertices the set S is connected to. Then the deficiency Df of set S is defined as:*

$$Df(S) = \begin{cases} |S| - n, & \textit{positive} \\ 0, & \textit{otherwise} \end{cases} \quad (1)$$

*We Define the left deficiency $Df_L$ of a bipartite graph as the maximum such $Df(S)$ taken from all possible subsets S, Right deficiency $Df_R$ is similarly defined.*
**Definition 2.** *Hall's marriage condition holds when $Df_L(G) = 0$ or ($Df_R(G) = 0$) for a bipartite graph G.*

### B. A matching solution

*1) Case 1: $D \leq R$*: demand is less or equal than the total resources, in this case the matching is simple and can be achieved since it meets Hall's Marriage conditions, since the cardinal of subset of resources $R$ is great that the cardinal of demand subset $|E| \leq |H|$ and each vertex from $E$ connects to one vertex from $H$, then $Df_L(E) = 0$, thus the optimal matching can be achieved.

*2) Case 2: $D \geq R$*: demand is greater than the total resources, in this case we have to find a set $E$ such that $|E| \leq |H|$ in order to get a null left deficiency.
We propose an algorithm to find the optimal matching between $E$ and $H$, and maximizing total resources allocation,we should note here that rather than finding the set $E$, we propose an algorithm that match directly vertices from $E$ and $H$, and that the same algorithm can be used to find the ideal set $E$,The main steps in this algorithm are as follow:
To begin this algorithm, start with the first vertex in $E$ , the set of left vertices in G, Go ahead and match it to first vertex in $H$, Now look at the next vertex in $E$ , and if possible,match it to an unpaired vertex in $H$, If it impossible, just skip that vertex for now. Continue this process for all of $E$.

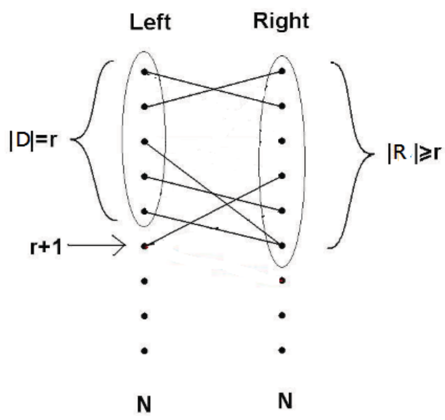


Figure 2. A complete matching, Resources are greater than Demands

The algorithm terminates in at most $|D|$ rounds,thus the hole process can be performed in polynomial time with complexity $O(N)$ taking into account that we assume that the set of demands is already sorted in descending order, this algorithm can optimally integrated in the Social Welfare Maximization Auction algorithm in paper [2].

**Algorithm 1:** Optimal matching algorithm

**Data:** Total resources $R$, Set of demands $D = \{d_1, d_2, ..., d_i\}$ sorted in a descending order

**Result:** Optimal matching between $R$ and $D$

initialization:Reminder of service $R_m$ = $R$, $i = 1$;

**while** $R_m \neq 0$ *Or* $|D| \neq \emptyset$ **do**

  **if** $R_m \geq d_i$ **then**

    Allocate resources to miner $i$;

    Subtract allocated resources from $R_m$ ;

    Move to next miner $i$++ ;

  **else**

    Move to next miner $i$++ ;

  **end**

**end**

## IV. Conclusion

In this paper, we have investigated papers that discuss the edge computing services for mobile blockchain and propose some enhancements to those works, reader must be have a good understanding of the content of papers [1], [2] and [3] in order to get the most benefits from this work later an optimal matching algorithm was proposed to efficiently match an ESP resources with demands from blockchain miners with a reasonable efficiency . The proposed algorithm fix some weakness founded in the allocation process proposed in papers [2]

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