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Performance Analysis and Application of Mobile Blockchain in Mobile Edge Computing Architecture

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***Abstract*—Blockchain is a system that allows the track process of the sending and receiving of some types of information over the internet. They are pieces of code generated online that carry information connected – like blocks of data that form a chain. As the technology blockchain continues to evolve, it has ever-increasing opportunities to help applications for mobile devices increasing the security aspects coming of the security characteristics of these networks. This is interesting for mobile security, as it has become increasingly important due to the growth in the use of mobile applications for financial transactions. In this paper, a blockchain benchmark study is carried out in mobile devices, illustrating its process with the help of architecture that allows the best blockchain performance on mobile devices using edge computing. With this benchmark, with regard to the performance achieved, it is possible to compare the difference between use of blockchain in a mobile edge computing architecture and without that architecture. So, we validate that adding edge computing to the mobile blockchain mining process increases its efficiency.**

I. Introduction

As BLOCKCHAIN technology continues to evolve, it has increasing opportunities to help mobile applications with their secure network. In this sense, this is interesting for mobile security, as it has become increasingly important due to the growing use of mobile applications for financial transactions [1].

In light of this scenario, although blockchain has been widely adopted in many applications (e.g. finance, healthcare and logistics), its application in mobile services is still limited. This is due to the fact that blockchain users have to solve predefined proof-of-work puzzles to add new data (i.e. a block) to the blockchain. Solving the proof of work, however, consumes substantial resources in terms of CPU time and power, which is not suitable for mobile devices with limited resources [2].

Among the existing approaches to solve this reported performance problem, in the mobile blockchain, one that is currently used is edge computing. This is because, for a mobile user, it is unrealistic to continuously run such a computationally difficult program that it requires a large amount of energy and time. Due to the outstanding characteristics of edge computing such as low latency, mobility and wide geographic distribution; it is considered to transfer the mining tasks to Edge Servers [3].

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In this sense, this paper brings results that confirm the efficiency of edge computing in improving the performance of mobile blockchain. These results come from a benchmark performed using mobile devices and edge computing technologies. With this in mind, the work is divided into 6 sections, including this introduction section. The next section is dedicated to concepts. It describes the main important concepts for a better understanding of this paper. In the third section, the works related to this area are placed, including the following topics that relate to each other: blockchain, mobile devices and edge computing. The fourth section describes the performance evaluation methodology used in the work, as well as architectures, devices and metrics. In the fifth section, the results of the performed benchmark are shown and analyzed. Some tests are done by varying metrics, devices, and edge computing technologies. Correlations of the results are also made for a better understanding of them. Finally, the sixth section is the conclusion that contains the achievements of the paper and ideas for future works.

II. Concepts

A. Information Security

According to Lyra [4], information security is characterized by the proper application of protection devices on an asset or a set of assets in order to preserve the value that it has for organizations. The application of these protections seeks to preserve confidentiality, integrity and availability, not only being restricted to systems or applications, but also information stored or transmitted in different media besides electronic or paper.

B. Blockchain

The technology known as blockchain was first revealed by Satoshi Nakamoto in his article “Bitcoin: A Peer to Peer ATM System”[1], which established the mathematical basis for the Bitcoin cryptocurrency. While this was a groundbreaking article, it was never actually submitted to a traditional peer-reviewed journal, and the true identity of the author is unknown. Blockchain technology is not only at the foundation of all cryptocurrencies, but has found wide application in the more traditional financial sector. It also opened the door to new applications such as smart contracts [5].

[1] https://bitcoin.org/bitcoin.pdf

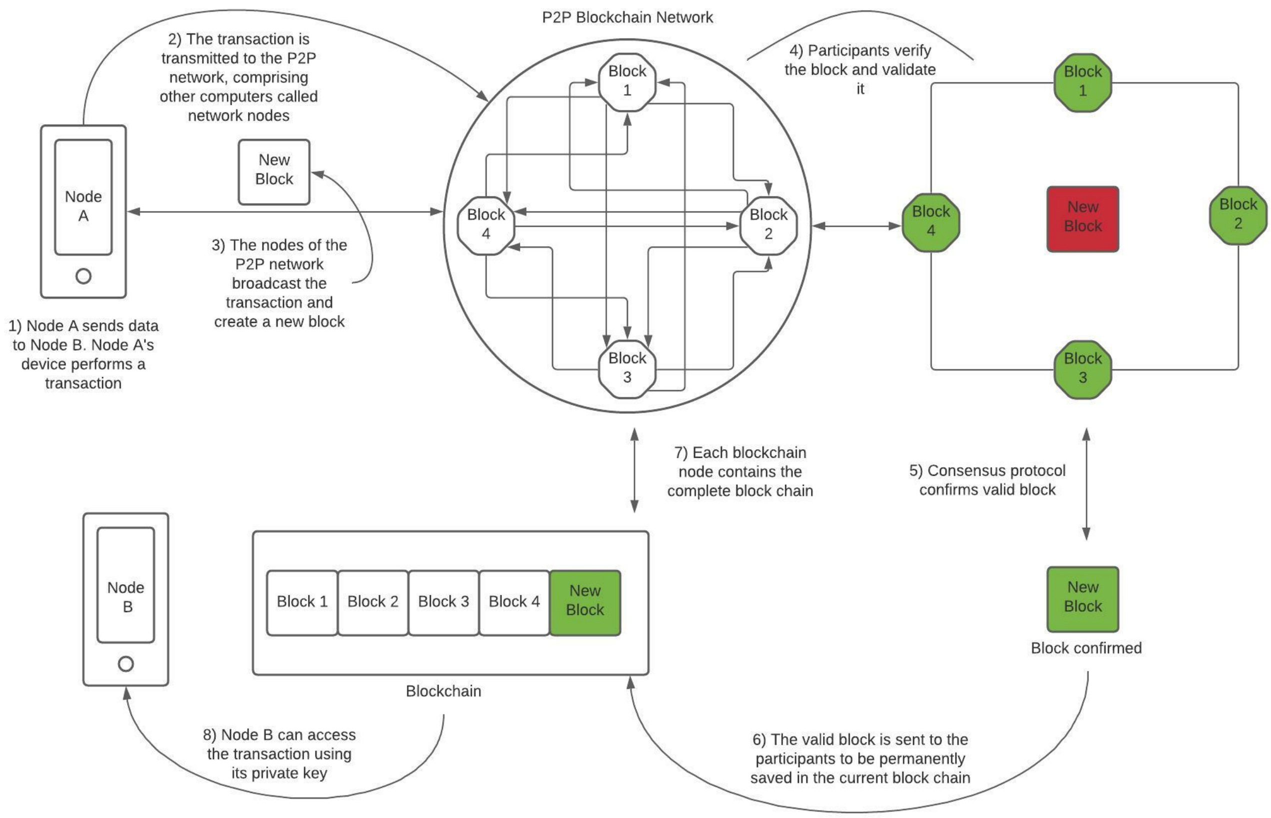

Fig. 1. Blockchain network with mobile nodes

C. Difficulty

The concept of difficulty is the measure that determines how difficult it is to mine a specific block for a given cryptocurrency. A high difficulty means that additional computing power will be needed to verify transactions entering the blockchain network. For a higher difficulty, higher is the security of the blockchain network, and more computing power will be required for breaking into the network [6].

In this sense, in this paper, the difficulty is adjusted every 2016 blocks. Blockchains adjust the difficulty automatically. For example, Bitcoin difficulty is adjusted every 2016 blocks or every 2 weeks. Ethereum's difficulty, on the other hand, is adjusted in every block, in approximately 15 seconds [7].

D. Proof of Work

The concept of "proof of work" (PoW) is defined as a consensus algorithm in which it is expensive and time consuming to produce a piece of data, but in the other hand, it is easy for others to verify that the data are correct. Bitcoin, the main cryptocurrency on the market, uses the Proof of Work Hashcash system [8].

In order for a block to be accepted by the network, miners need to complete a proof of work to verify all transactions on the block. The difficulty of this job is not always the same, it keeps adjusting so that new blocks can be generated in every 10 minutes. There is a very low probability of successful generation, so it is unpredictable which network employee will produce the next block [9].

E. Mobile Blockchain

Blockchain can be used to develop applications with mobile devices. However, to support the blockchain-based service, there is a set of miners continuously running a consensus protocol to confirm and secure data or distributed transactions in the background. Digital miners are required to solve a PoW puzzle. The mining process is conducted in a tournament structure, and miners chase each other for the solution. The figure 1 better illustrates how this process occurs on mobile devices.

F. Edge Computing

The Mobile Edge Computing (MEC) architecture was introduced to leverage the computing power available in mobile environments. On-premises data centers and servers are deployed by a service provider at the "edge" of mobile networks, such as base stations on radio access networks. MEC is the key technology to meet the stringent low latency requirements of fifth generation (5G) networks.

Mobile devices can access edge servers to enhance their computing power (e.g. processing IoT detection data). With this feature, edge computing becomes a promising solution for mobile blockchain applications whose benefits are as follows. First, by incorporating more miners, the robustness of the blockchain network is naturally improved. Second, mobile users have an incentive from the reward obtained in the consensus process.

However, edge computing services are deployed by the provider to maximize their benefits. As such, a question of price for edge services arises. Likewise, given the price adopted by the edge computing service provider, miners also need to optimize their demand for edge computing service to solve PoW and maximize their earnings [10].

III. Related Works

In [11], it is argued that it is a challenge to apply the blockchain technique to mobile applications, since mobile devices cannot afford the computing resources required by mining processes. However, edge computing architectures can help mobile blockchain applications. The figure 2 shows some possible architectures.

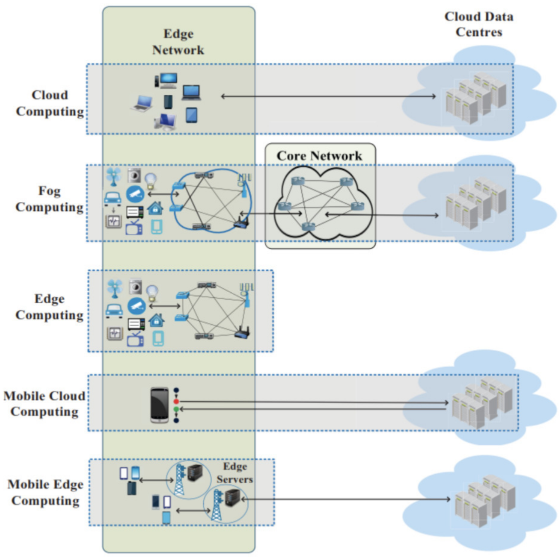

Fig. 2. Edge Computing Architectures - Source: [16]

This article proposes a mechanism based on a combinatorial double auction to offload the mining process from miners to edge servers. The mechanism is formulated as a resource allocation problem. Corresponding allocation algorithms and payment scheme are proposed to allocate resources and calculate trade prices, respectively. Furthermore, this article proves that the proposed mechanism is efficient in terms of calculation, and satisfies three properties of economic auction which are budget balance, individual rationality and veracity. Experimental results show that the proposed mechanism is capable of yielding higher total utility along with good scalability.

In [12], it is said that blockchain development in mobile apps is restricted as well. In this article, edge computing is considered as the network enabler for mobile blockchain. In particular, we study the management of edge computing resources based on optimal pricing to support mobile blockchain applications where the mining process can be offloaded to an edge computing service provider (ESP). In this way, a two-stage Stackelberg game is adopted to jointly maximize the ESP profit and the individual utilities of different miners.

In [13], blockchain is discussed as an effective security solution applied to many mobile devices. But due to storage limits and computational capabilities, it is difficult for mobile devices to run blockchain applications locally. To solve this challenge, blockchain applications are offloaded to edge servers with mobile edge computing (MEC). However, most of the existing auction mechanisms on the mobile blockchain are unable to utilize parallel execution and long-term performance has not been handled well.

Thus, this paper investigates the offloading problem of mobile blockchain computing task to improve the total utility of auction participants. An auction mechanism called POEM+ solving an NP-hard multiple-choice multidimensional knapsack problem is proposed.

In [14], it is discussed that in a mobile blockchain network, many mobile devices have insufficient computing power to perform computationally intensive tasks locally. To solve this problem, blockchain tasks can be transferred to edge servers with the help of an auction. However, most auction engines on the mobile blockchain ignore automatic parallel execution and long-term performance. This article aims to solve the problem of offloading computing on a mobile blockchain network.

This problem has been transformed into a multiple choice multidimensional knapsack problem that is NP-hard. To improve the total utility of auction participants, this paper proposes a smart contract-based dual auction mechanism called long-term auction for mobile blockchain (LAMB). Subtasks can be offloaded from a mobile device to heterogeneous edge servers. Furthermore, LAMB satisfies the economic properties of an auction engine.

The experimental results demonstrate that the utility to utilization ratio can be achieved by 130.55% higher and 138.64% higher, respectively, compared to the existing WBD auction algorithm. Furthermore, the proposed LAMB can guarantee long-term performance for offloading tasks and can achieve automatic execution in an autonomous and secure environment.

IV. Performance Evaluation Methodology

"In computing, benchmark is the act of running a computer program, a set of programs, or other operations in order to assess the relative performance of an object, typically by running a series of standard tests and trials on it. The term -benchmark - is also commonly used for the (benchmark) programs themselves developed to execute the process. Typically, benchmark is associated for evaluating the performance characteristics of a computer hardware, for example, the performance of a CPU's

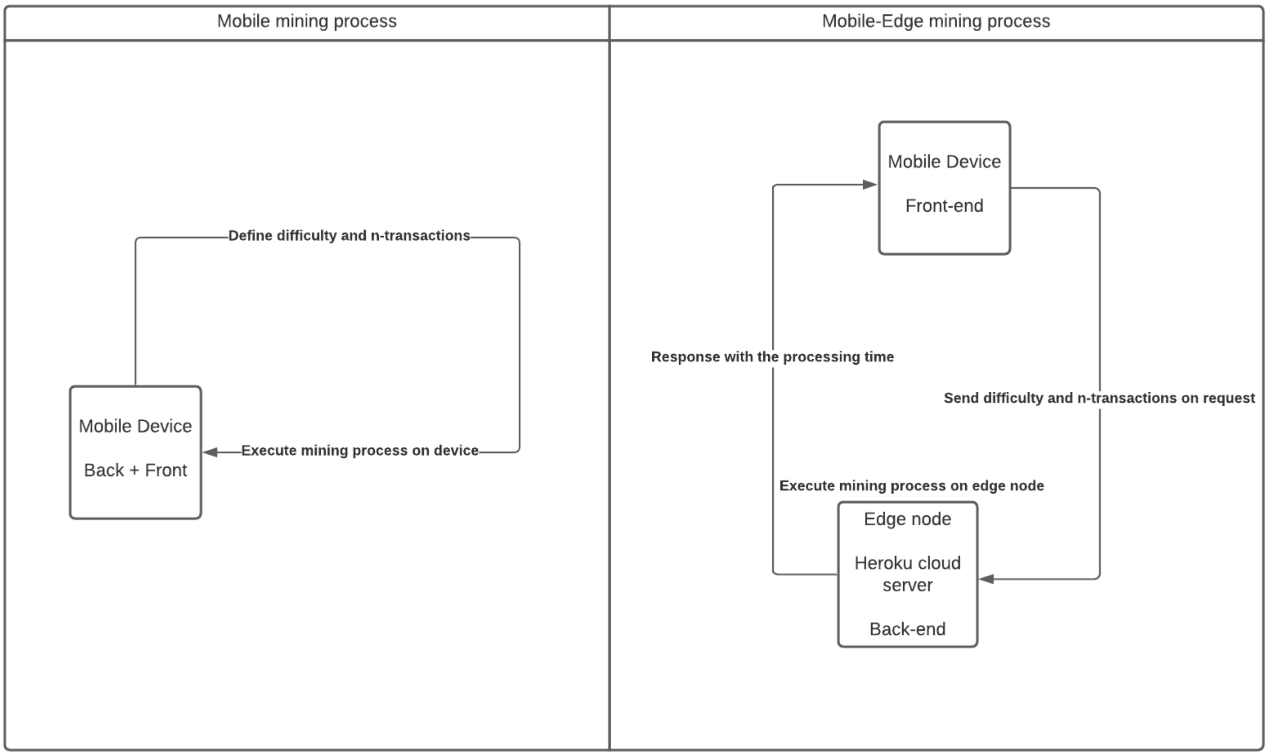

Fig. 3. Used architectures

floating point operation, but there are circumstances where the technique is also applicable to software." [15]

In this work, the circumstance is the performance evaluation of the mobile blockchain in two (2) different architectures and three (3) hardware with different specifications.

During the tests performed, 1 physical device, 1 Android device emulated through Android Studio and 1 IOS device simulated through XCode were used, both in an AVELL A62 MUV machine. In addition to these devices, the Back4App, Firebase and Heroku platforms were used, platforms as a service that provided the edge nodes in the edge computing architecture used in this work.

A. Architectures

For the present work, two architectures were considered. They are compared to see which one performs better.

On the left side of figure 3, we have the standard architecture of the mobile blockchain mining process on a mobile device. In this case,we used wallet back-end and front-end which are concentrated on the mobile device. In the application itself, the difficulty and number of transactions involved in the mining process are defined. After that, the mining process is done on the mobile device itself.

On the right side of figure 3, we have the mobile edge computing architecture. Only the front-end of the virtual wallet is kept in the application, while the back-end is on an edge node, and a server in the cloud.

B. Devices, softwares and technologies used

TABLE I
DEVICES AND SPECIFICATIONS

Device	CPU	RAM
Xiaomi Redmi 7 (Physical device)	Octa-core Max. 1.80GHx	3GB
Avell A62 MUV	Intel Core i7-9750H	64GB
Pixel 3A (Emulated)	Intel Core i7-9750H	4GB
Iphone 12 (Simulated)	Intel Core i7-9750H	4GB

*1) **Physical device - Xiaomi Redmi 7**:* the physical device used in the benchmark of this work was the Xiaomi Redmi 7. This device has a RAM of 3 GB and an Octa-core CPU with Max. 1.80GHx.

*2) **AVELL A62 MUV Machine**:* the Workstation used in this work was an Avell A62 MUV Machine. This machine was used to run the Android device program and emulator as well as the IoS device program and simulator. Both Android and IoS devices, as well as their programs, are discussed further on. This machine features an Intel® Core™ i7-9750H Coffee Lake Refresh CPU, with 12MB Cache (2.6 GHz up to 4.5 GHz with Intel® Turbo Boost) and a 64GB memory (2666MHz).

*3) **Android Studio**:* Android Studio is the development environment used to develop programs for devices using the Android operating system. In it, there is an aggregate of tools that help in this process. One of them is AVD Manager, a program responsible for providing emulators for Android devices.

*4) **Android device Emulated in AVD Manager - Pixel 3A**:* an Android Pixel 3A device with an Intel® Core™ i7-9750H Coffee Lake Refresh CPU, 12MB Cache (2.6 GHz up to 4.5 GHz with Intel® Turbo Boost) and 4GB (2666 MHZ) of memory was emulated using the AVD Manager. allocated. The decision to use emulation was thought to be able to make use of different hardware specifications.

*5) **XCode**:* Xcode is an open source and integrated development environment from Apple Inc. for managing projects related to the macOS operating system. Xcode has tools for the user to create and improve their applications. Through XCode, it is possible to simulate some IOS devices, among them is the iPhone 12, used in this work.

*6) **Simulated IOS Device - iPhone 12 with IOS 14.4**:* using XCode, an IPhone 12 device with IOS 14.4, Intel® Core™ i7-9750H Coffee Lake Refresh CPU, 12MB Cache (2.6 GHz to 4.5 GHz with Intel® Turbo Boost) and allocated memory of 64GB (2666 MHZ) was simulated.

*7) **Heroku**:* Heroku is a PaaS (Platform as a Service) and is one of the pioneers of cloud service providers. Before it came on the scene, there was a huge challenge in building and configuring servers, not to mention the downside of shared hosting and the various complexities that come with hosting and deploying any strategies in the cloud. Heroku brought a system that made building, scaling and deploying apps so easy that it didn't take long for it to become a household name in the developer community.

*8) **Back4App**:* Back4app is a back-end platform for mobile apps. The company automates back-end development and allows companies to bring their applications to market faster and scale without infrastructure issues.

*9) **Firebase**:* by pairing the Cloud Functions service and Firebase Hosting, the users can build REST APIs as microservices. Cloud Functions for Firebase lets to developers automatically run back-end code in response to HTTPS requests. Thus, the code is stored in the Google cloud and runs in a managed environment.

C. Metrics

The metrics considered relevant to this benchmark were:

- **CPU and memory consumption of the physical device:** these measures should indicate the efficiency of the physical device used in this work in relation to its computational capacity;
- **Battery consumption:** this measurement is measured in the physical device used in this work;
- **Number of transactions:** this measure indicates the number of times that a new block of information was added to the blockchain network;
- **Difficulty:** difficulty is a measure of how difficult it is to extract a block of information or, in more technical terms, to find a hash value below a given target;
- **Time:** time is used to measure performance according to the variation of other metrics used in this work.

V. Results

In this section we present the results. We have used two scenarios. The figure 4 shows the mobile architecture without edge computing and figure 5 shows the scenario using mobile edge computing.

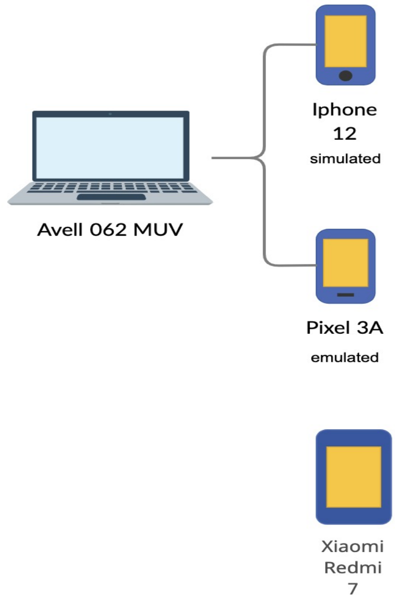

Fig. 4. Mobile architecture scenario without edge computing

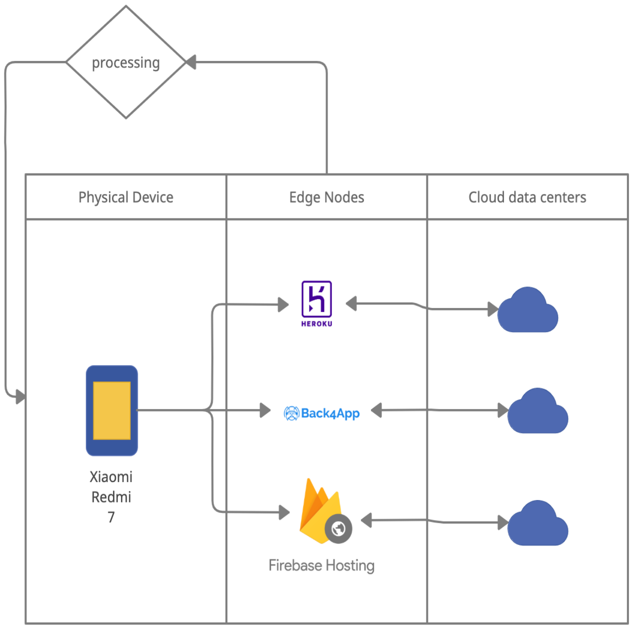

Fig. 5. Mobile edge computing architecture scenario

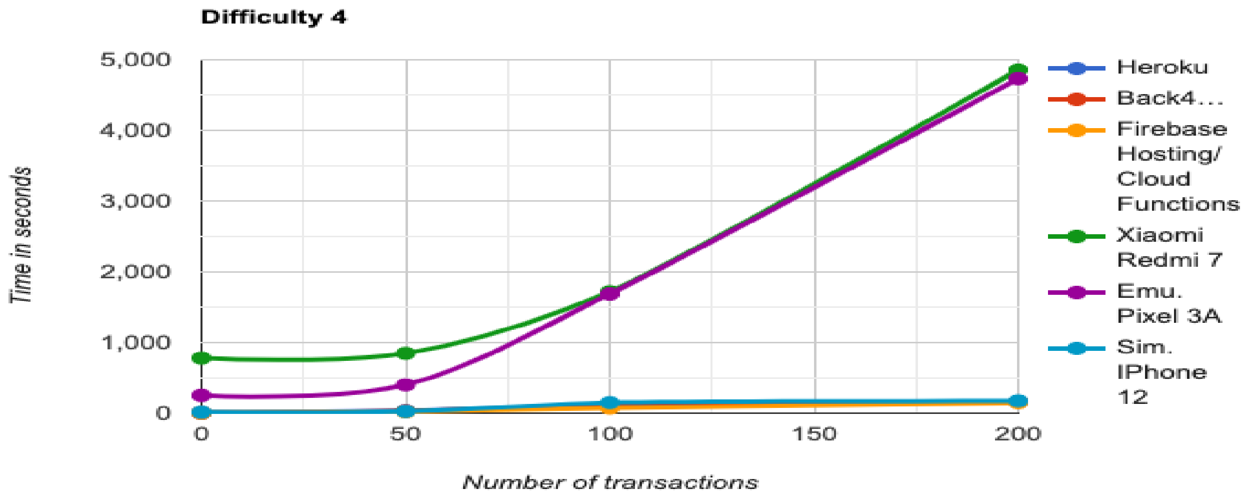

Fig. 6. Comparison between architectures - number of transactions per time in seconds with difficulty 4

A. Comparison of performance between the two architectures

1) Time and number of transactions: it is possible to compare the performance by placing the time reached by each device used without the aid of edge computing and the time achieved using Xiaomi Redmi 7 that used the mobile edge architecture for the difficulty 4, varying the number of transactions from 10 to 200. The figure 6 shows the difference that becomes evident when an edge node service is used versus not using it during blockchain network processing.

2) CPU consumption and memory consumption: it is also possible to compare the CPU and memory consumption of the physical device architecture when using these two scenarios: architecture without edge computing and when using edge computing. The figures 7 and 8 illustrate this, consecutively.

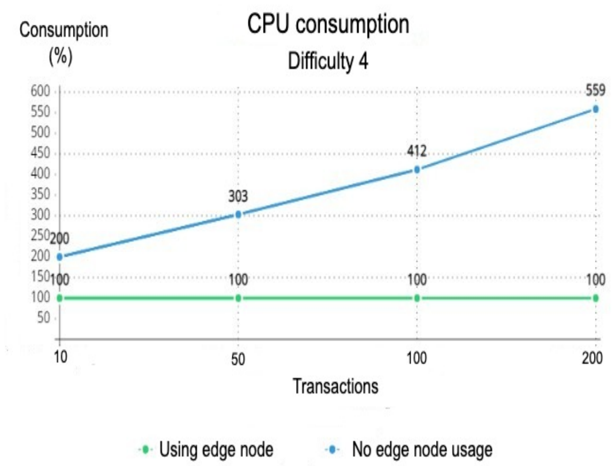

Fig. 7. Architectures comparison - CPU consumption with difficulty 4

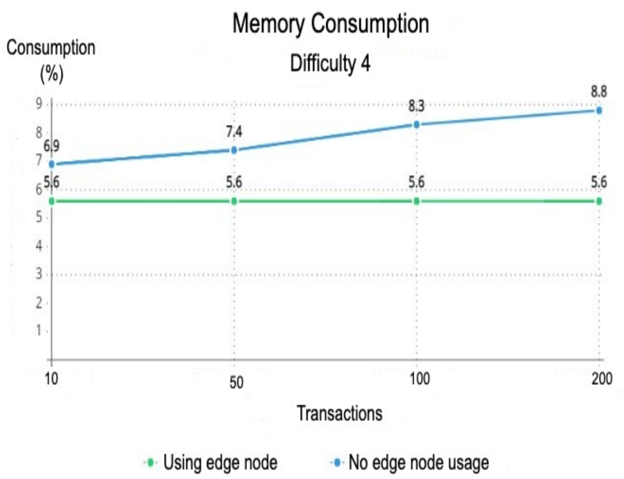

Fig. 8. Architectures comparison - Memory consumption with difficulty 4

3) Battery consumption: as far as battery consumption is concerned, this can be compared by isolating the most demanding case: difficulty 4 with 200 transactions. When using edge computing in the blockchain network mining process, the battery remains without level loss since it is not necessary to have the device always on and performing this processing on the physical device. This assignment, unlike the architecture that does not use the edge node, leaves the physical device (which becomes just a visual interface) and goes to the edge node. When there is no use of the edge node, the battery drops proportionally to the execution time, memory usage and CPU spent in the mining operation being performed on the physical device. The figure 9 demonstrates this behavior. With the passage of time, as expected, the battery level tends to decrease.

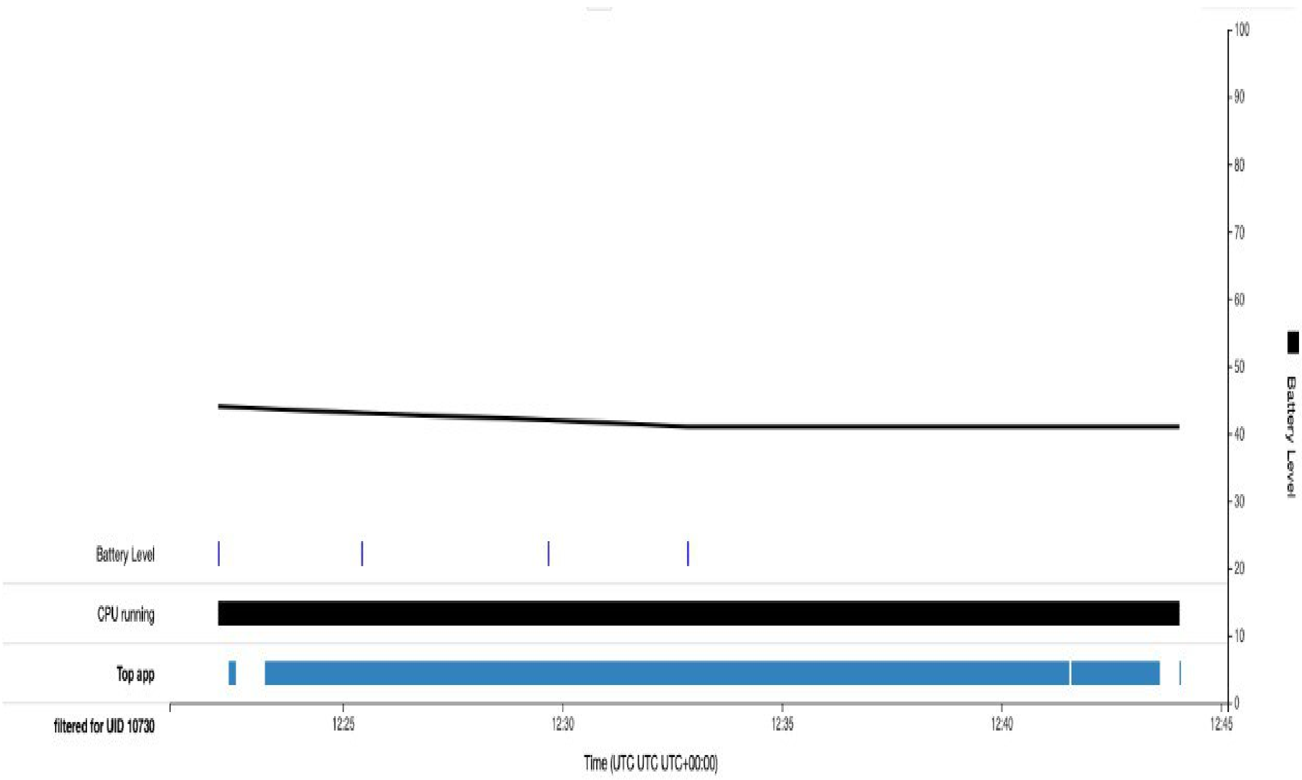

Fig. 9. Difficulty 4 - battery drain with 200 transactions without an edge node

VI. CONCLUSION

Finally, the conclusion drawn from this benchmark is the greater the difficulty of the blockchain network, more efficient the use of edge computing to assist in the mining process. This is more evident in our experiments since it is possible to notice the considerable difference in mining time when using the edge computing architecture compared to not using it. In this paper we showed the impact evaluating three metrics (time processing, memory and battery consumption). For future works, a prototype of the mobile blockchain application can be developed with the aim of to show how is the application of blockchain in a voting system using mobile devices.

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