# ENHANCED INTERNET OF THINGS LOAD BALANCING ALGORITHM WITH AWARENESS IN RESOURCES AVAILABILITY

MASSOLIHEN BIN DASUKI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy

School of Computing
Faculty of Engineering
Universiti Teknologi Malaysia

APRIL 2022

## ACKNOWLEDGEMENT

First of all, thanks to Allah for the continues blessing and for giving me the strength and chances to complete this thesis. In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main supervisor, Professor Madya Dr. Mohd Yazid bin Idris and co-supervisor Dr. Mohd Fo'ad Bin Rohani, for encouragement, guidance, and critics. Without his continued support and interest, this thesis would not have been the same as presented here.

I am also indebted to Zamalah Universiti Teknologi Malaysia (UTM) for funding my Master Phil study almost three semesters. My fellow postgraduate student should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have helped at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family member.

# ABSTRACT

Internet of Things (IoT) backed by blockchain preserves data from being tampered on peer-to-peer network communication between the IoT devices. Unfortunately, blockchain is an intensive computing process because of the consensus algorithm. Hence IoT device is not suitable for blockchain because IoT device is mostly a low computing device and made up with limited resources. This study propose the Awareness in Resources Availability (AIRA) algorithm that apply with weight least connection (WLC) algorithm at IoT blockchain platform. The purpose of the algorithm is to reduce the usage of resources on the IoT nodes; the parameters that will be compared are CPU percentage, RAM usage, and network throughput. The research methodology using three types of experiment in order to evaluate the AIRA algorithm performance and the experiment performs with a different type of load balancing. The load balancing algorithms used to compare with the AIRA algorithm are weight round-robin (WRR) and weight least connection (WLC). It was discovered that with a limited amount of resources at the low computing of IoT nodes, in most cases, the AIRA algorithm performs better compare to WRR and WLC in terms of reducing the CPU utilization, RAM usage, and network throughput. In conclusion, the AIRA algorithm is the best method to reduce the resources consumption of node at IoT-blockchain platform base on result, the average reduction of CPU utilization is 56 percent, the average reduction of RAM usage is 16 percent, the average reduction of network throughput for receive is 72 percent and finally the average network throughput for send is 81 percent.

# ABSTRAK

Internet Benda (IB) yang disokong oleh blok rantai memelihara keselamatan pada komunikasi rangkaian rakan ke rakan antara peranti IB. Malangnya, blok rantai adalah proses pengkomputeran yang intensif oleh kerana algoritma konsensus. Oleh itu peranti IB tidak sesuai untuk blok rantai kerana peranti IB kebanyakannya adalah peranti pengkomputeran rendah dan mempunyai sumber terhad. Oleh itu, dalam kajian ini, kami mencadangkan algorithma Kesedaran dalam Ketersediaan Sumber (KKS) yang di gunakan bersama pengimbang beban sambungan terkecil berwajaran (STB). Tujuan KKS adalah untuk mengoptimumkan kemampuan IB; parameter yang akan dibandingkan adalah peratusan CPU, penggunaan RAM, dan daya pemprosesan rangkaian. Bagi menilai prestasi algorithma KKS, eksperimen telah di jalankan dengan pengimbangan beban yang berbeza. Algoritma pengimbang beban yang kami gunakan untuk menilai algoritma KKS adalah robin pusingan berwajaran (RPB) dan STB. Keputusan menunjukan bahawa dengan jumlah sumber yang terhad pada nod pengkomputeran rendah, dalam kebanyakan kes, algoritma KKS berkerja lebih baik berbanding STB dan RPB dalam mengoptimumkan peratusan CPU, penggunaan RAM, dan daya pemprosesan rangkaian. Kesimpulannya, algoritma KKS dapat mengurangkan penggunaan sumber IB di IB-block rantai, di mana ia dapat mengurangkan purata peratusan CPU sebanyak 56 peratus, kemudian pengurangan purata penggunaan RAM sebanyak 16 peratus, dan akhir sekali pengurangan purata daya pemprosesan rangkaian untuk menerima sebanyak 72 peratus dan pengurangan purata daya pemprosesan rangkaian untuk menghantar sebanyak 81 peratus.

## TABLE OF CONTENTS

## LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AIRA | - | Awareness In Resources Availability |
| CPU | - | Control Processing Unit |
| FIFO | - | First In First Out |
| IOT | - | Internet of Things |
| RAM | - | Random Access Memory |
| VM | - | Virtual Machine |
| P2P | - | Peer to Peer |
| PB | - | Petabytes |
| WLC | - | Weight Least Connection |
| WRR | - | Weight Round Robin |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Overview

Internet of Things (IoT) refers to interconnected objects that allow people or things to be connected, has different characteristics that consist of computation and storage capabilities (Rachedi *et al.*, 2017). There is a drawback for this IoT or edge node to sharing data using a peer-to-peer (P2P) network. This is due to IoT connections will raise an issue of security, where the connection may create leakage of privacy of user information (Jong-Hyouk and Kim, 2017).

IoT connectivity has security problems that have urged worldwide researchers to combine IoT and blockchain technology. This blockchain technology seems capable of solving security issues for IoT, as blockchain characteristics are distributed, transparent, persistent, and secure (Songara and Chouhan, 2017). Blockchain is a distributed peer-to- peer network that can prevent the single point of failure situation (Zheng *et al.*, 2017) and enable interaction for non-trusting members with each other without a trusted intermediary, in a cryptographically verifiable method (Es-samaali, Outchakoucht and Leroy, 2017).

There is awareness among researchers about IoT and blockchain combination which is excellent and could be used to transform many industries. This combination gives IoT devices the ability to carry out autonomous data exchange through smart contracts. Implementation of blockchain on IoT could overcome the problems associated with the centralize IoT applications approach (Kshetri, 2017). This is because if centralization occurs at IoT application, it could bring to a single point of failure.

Although the combination of IoT and blockchain might improve from the standpoint of protection, blockchain technology is computation expensive. In addition, IoT devices are designed with poor flash memory and Random Access Memory (RAM) compared to the traditional digital scheme (e.g. PC, Laptop, etc.), and the devices use lightweight version of General Purpose Operating System (GPOS) or Real Time Operating System (RTOS) (Hossain, Fotouhi and Hasan, 2015).

This IoT has resources limitations,  where most IoT devices have limited resources, including bandwidth, computation (Buccafurri *et al.*, 2017), and memory, which is incompatible with the requirements of complex security solutions (Dorri *et al.*, 2017b). Blockchain needs heavy computation process to participate in the consensus algorithm, but resources constraint at IoT devices will restrict the number of blocks that can be generated.

## 1.2 Research Background

The use of blockchain technology in the IoT environment opens up a variety of possibilities. For example, the IBM Autonomous Decentralized Peer-to-Peer Telemetry project (ADEPT) uses the blockchain to create a distributed network of devices (Daza *et al.*, 2017). Currently, researchers focus on redesigning the blockchain paradigm to improve blockchain performance while maintaining its decentralized nature (Bano, Al-Bassam and Danzis, 2017). Enormous effort has been made to improve storage limitation on IoT, to utilize blockchain technology. For example, by building the blockchain infrastructure in distributed cloud architecture, creating a smart home as a cluster, using virtual resources to host a blockchain, implementing sidechain, separated cluster, and creating a hierarchical architecture.

A blockchain decentralized ledger begins with an initial block, often known as the genesis block. When a new block is created, the previous block's hash values are entered. Any modifications to a prior block would result in a different hash code and be immediately accessible to all blockchain participants once a new block is generated. As a result, blockchains are regarded as tamper-resistant distributed transaction ledgers (Samaniego and Deters, 2016). Bitcoin, for example, adopts the Proof-of-Work (PoW) method (also known as mining), in which distributed nodes pool the computer resources to participate in a mathematical puzzle with frequently adjusted complexities (Yuan and Wang, 2016). However blockchains are computationally intensive and include significant bandwidth overhead and latency, making them unsuitable for IoT devices (Dorri, Salil S. Kanhere and Jurdak, 2016).

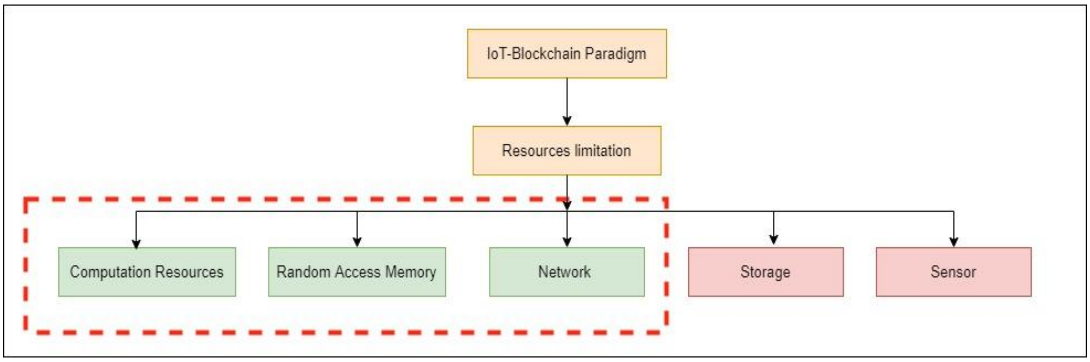


Figure 1.1 IoT-blockchain Resources Limitation

As shown in figure 1.1, IoT base blockchain resources limitation can be categorized into five classifications. The first is the computational power of IoT devices (Binara N.B. Ekanayake, Halgamuge and Syed, 2018). The second is constrained available memory in terms of Random Access Memory (RAM) (Cirani *et al.*, 2014).The third is network bandwidth, where IoT must communicate among heterogeneous devices (Yi, Li and Li, 2015). The fourth is the storage capacity (Bao, Chen and Guo, 2013) of IoT devices to store created blockchain blocks after the vast data exchange had occurred. The fifth is the sensor, where an IoT device also typically limited by a single receiver unit (Fafoutis *et al.*, 2015).

IoT backed by blockchain might solve security issues on a peer-to-peer network. Unfortunately, IoT device has resources limitation which they are typically restricted in terms of functionality for computational power (Sharma and Park, 2018) and available bandwidth (Samaniego and Deters, 2017a). Furthermore, a cheaper IoT device is more widespread with large number of nodes. However a cheaper IoT device is provided with smaller RAM (Malina *et al.*, 2016). Moreover, a scalable system is considered a success if it can handle an increase in work, e.g. an increased computations (Hagström, Dahlquist and Hagström, 2017). As seen in Figure 1.1, this study emphasizes on the IoT resources limitation of computation power, random access memory and network throughput. This study involves resources allocation, at the same time, it engage with reducing resources consumption of IoT nodes backed by blockchain.

## 1.3 Problem Statement

Security and privacy of information at IoT devices are naturally garnering much attention from the research community (Dorri, Salil S. Kanhere and Jurdak, 2016). Researchers agreed that the combination of IoT and blockchain will solve security issues on a peer-to-peer network (Dorri, A., Kanhere and Jurdak, 2017) and will help many industries. Moreover, IoT integrated blockchain is tamper-resistant due to public ledger shared to every participant and transactions can happen without middleman involvement (Yeow *et al.*, 2017).

Numbers research had been done to solve IoT resources limitations, so that IoT devices can utilize blockchain technology. A few types of research carried to resolve limited storage at IoT devices, for example, the first one is by creating a cluster of a smart home as a point of storage for a blockchain ledger (Dorri, Salil S Kanhere and Jurdak, 2016). The second example is by creating virtual memory on the cloud as a second resource for IoT devices to store blockchain ledger (Stanciu, 2017). The third example, by using lightweight consensus to execute transactions or smart contracts during data exchange between IoT devices (Dorri *et al.*, 2017b). Although much research is made to solve IoT limited storage for integrating blockchain, only a few studies resolve IoT resources limitation on computation power, random memory access, and bandwidth.

Although blockchain-based methods enable decentralized security and anonymity, they come with a lot of energy, latency, and computation overhead, making them unsuitable for most IoT devices with limited resources (Dorri *et al.*, 2017a). Next, the increase of user will lead to connection created towards

IoT devices grow unboundedly and furthermore the workload to validate the blokchain transaction will consume the IoT device’s resources. Afterwards if the connections are not distributed fairly between devices which some devices might have high number of connection while other devices are idle will lead to performance issues during peak time. Therefore a method must be used to minimise workload variances between IoT devices in order to achieve the optimum performance outcomes (Soklic, 2002) . Furthermore, the load balancing can increase the performance of the system by helps to execute the task in minimum time  (Kumar and Sharma, 2017).

Next, to understand how load balancing works, examination on the work of other researchers in load balancing and IoT has been conducted. For example, the (Nababan, Primananda and Bakhtiar, 2021) implement weight least connection at MQTT broker of IoT device. Because each IoT device has different specifications, the weighted least connection is more efficient because it can determine the weight in comparison to the round robin algorithm. According to the findings of the study, the weight least connection can reduce CPU usage when handling the publish-subscribe process with 1000 clients. Afterward, the author (Qiu *et al.*, 2018) designing a multi-core Task-Efficient Sink Node (TESN) based on heterogeneous architecture, it improves processing speed, achieves load balance, and avoids large-scale congestion of sink nodes in IoT sensor networks. The TESN base on WLC can balance the load on each core and reduce network congestion. Next study made by Hellani (Hellani *et al.*, 2021) performed task allocation between the nodes by introducing an enhanced resource allocation scheme based on the weight least connection (WLC).

Moreover, researchers also use WRR on their study for example the author (Ting-Dong and Xuan-Rong, 2017) propose improved weighted round robin (IWRR) method to schedule the traffic data, IWRR optimized the scheduling of real-time and non real-time mixed traffic data by creating a temporary transmitting queue with a priority borrowed. The IWRR method can enable real-time traffic data to be transferred better in a continuous and timely manner, while also having a shorter average transmission delay of the traffic data on the whole, according to simulation results. Afterward, research made by (Alsmadi *et al.*, 2021) had propose new fog computing environment and use WRR scheduling algorithm to solve the task scheduling problem. The fog computing paradigm's fundamental goal is to connect a large number of smart objects. Hence, WRR algorithm role is to assigns tasks to fog nodes based on their available processing capacity and remaining energy. Then, another study (Abed and Younis, 2019) proposed a load balancing in cloud computing, so it able to dynamically distribute the workload across nodes to avoid overloading any individual resource, by combining weight round robin (WRR) with an adaptive firefly algorithm.

In addition, designing new distributed architectures is one of the important objectives in securing the IoT network (Sharma, Chen and Park, 2018). According to the author (Sahoo *et al.*, 2020), to achieve optimal overall system performance, certain resources such as CPU, memory, and bandwidth must be optimised. Due to high demand from the forwarding plane, resource consumption becomes unbalanced in terms of CPU, memory, and bandwidth. Furthermore, resource allocation management of the edge device is basically based on the assessment of power, CPU, and memory on nodes resources (Babou *et al.*, 2020) and poor resources allocation management will lead to node overload due to excessive CPU, memory and network (Singh, Korupolu and Mohapatra, 2008). Hence, the CPU utilization, memory usage and network throughput is crucial parameter to be use to evaluate the resources consumption at IoT device. Furthermore, the author (Jutadhamakorn *et al.*, 2017) evaluate the performance of cluster IoT devices base on their CPU utilization, memory usage, and amount of network traffic as well.

After all, the goal of this study is to propose an algorithm that assists IoT devices reduces resources consumption at blockchain platforms. Then, the Awareness in Resources Availability algorithm has been proposed which applies at the IoT node, and AIRA's role is to determine CPU utilisation prior to transaction validation on the blockchain. As mentioned before, the IoT device has a constraint on its resources, but the blockchain is an intensive computation process. Hence, the AIRA algorithm avoids the CPU, RAM, and network throughput at the node from getting overloaded due to the blockchain validation process. It is important to prevent the resources from getting overloaded because if resources consumption is not being reduced at the node, then the performance of the overall platform will decrease. Furthermore, blockchain operates in a decentralized manner, and then any transaction must be validated by multiple nodes, and if there is a failure on the single node, then the transaction is not validated. Moreover, this study uses BigchainDB as a blockchain platform because it is a lightweight blockchain (Rasolroveicy and Fokaefs, 2020), making it suitable for IoT devices with limited storage.

Next, a suitable load balancing algorithm for the IoT and blockchain platforms need to be identified. Based on the literature review, WLC and WRR are well-known among researchers, particularly in the IoT field. Additionally, the weight round-robin is known as static load balancing and the weight least connection is known as the dynamic load balancing. Besides, the load balancing algorithm's role is to allocate the workload among the IoT nodes. Then, experiment is done to evaluate the WRR and WLC performance in IoT-blockchain platform, and the experiment results show that the WLC works better than WRR. Hence, the Awareness in Resources Availability (AIRA) algorithm is applied at the node, which the IoT blockchain platform operates using WLC. Then, the performance of AIRA algorithm in reducing resources consumption at the node is verified using parameter of CPU, RAM, and network throughput at each node. These parameters are frequently chosen based on the related work mentioned above.

Furthermore, these parameters are selected because our experiment uses a virtual machine, hence there are no power resources involved such as batteries. Moreover, the node’s storage is not evaluated because BigchainDB is known as a lightweight blockchain. It is assumed that the AIRA algorithm would reduce resource consumption at each node, and it would lowering CPU utilization, RAM consumption, and network throughput, thereby addressing the issue of IoT device resource constraints.

## 1.4 Research Question

The research questions of the study are:

i) What is the performance of WLC and WRR for the CPU, RAM and network throughput of IoT at the blockchain platform?

ii) How to improve the resources consumption of IoT node at blockchain platform that utilize the WLC algorithm?

iii) How much reduction on CPU, RAM and network throughput of IoT node by using AIRA algorithm?

## 1.5 Research Objectives

This study objective is to reduce the resources consumption at node in IoT blockchain platform. To achieve the main objective, the sub-objectives are needed as follows.

(a) To investigate the performance of weight round robin (WRR) and weight least connection (WLC) load balancing on distributing workload at IoT-blockchain nodes.

(b) To develop the AIRA algorithm that aware on resource availability in purpose to reduce the resources consumption of the node at IoT-blockchain platform.

(c) To verify the AIRA algorithm performance on CPU, RAM and network throughput by comparing with the WRR and WLC as the benchmark.

## 1.6 Scope of Study

The scopes of the study are:

i) Experimentation by virtual machine as the IoT node at the blockchain platform.
ii) Focus on the four nodes of virtual machine as the IoT nodes. Each node has 2 Cores of CPU 3.40 GHz, 2 GB RAM.
iii) Focus on the IoT node resources and the parameters of CPU, RAM and network throughput.
iv) Each node installed with BigchainDB and its operation system is Ubuntu 18.04 LTS
v) Focal points at reducing the resources consumption of IoT node in the IoT blockchain platform.

## 1.7 Significances and Original Contributions of This Study

In this research, a significant problem based on the literature study is the integration of IoT and blockchain which currently faces an issue of resources constraint at IoT devices. Blockchain is computationally intensive, which less effective on IoT devices with constrained resources. Hence, the load balancing that give capability for IoT-blockchain to allocate workload is applied.

Although, the allocation of workload among nodes is successful, the node resources overload may happen especially on CPU, RAM, and network. Afterward, this study has few contributions:

i) Development of AIRA algorithm that aware on resources availability at IoT node.
ii) New architecture consisting of data layer, service layer and consensus layer to assist AIRA algorithm in purpose to reduce the resources consumption at IoT node.

## 1.8 Thesis Structure and Organization

This research proposal is divided into five chapters and presented as follows:

In chapter 1, the introduction of the fundamental concept of this research is given to explain few essential components such as IoT, blockchain, safety benefit for IoT to be backed by the blockchain and IoT limited resources for blockchain. Then, mainly sections of the research like problem background, problem statement, research goal and objectives, research scope and significance are discussed specifically.

Then, chapter 2 discusses the literature review regarding the research domain where a basic understanding of the Internet of Things, blockchain, IoT-blockchain and load balancing. This chapter also includes a review of the related works and a discussion on trends and tendencies related to this research.

Then, chapter 3 discussed details regarding the research methodology. The operational research framework is explained with research materials such as software and operating systems environment setting. This chapter discussed detail on each experiment setup that done in this study.

Chapter 4 will be discussed AIRA algorithm overview and reasoning behind this algorithm. Moreover, this chapter also discusses in detail the node architecture, the pseudocode, mathematical equation, sequence diagram and whole IoT blockchain platform.

Chapter 5 will show the experiment results of WRR and WRR load balancing and the proposed architecture. The focus parameters in this chapter are the CPU, RAM, and network. Then, AIRA algorithm result is compared with of WRR and WLC load balancing result. Lastly, the AIRA algorithm needs to verify its effectiveness in reducing the resources consumption of IoT node.

Lastly, chapter 6 concluded this research by explaining the research remarks, the contribution of the study, limitation of the study and future works.

# REFERENCES


Abed, M. M., & Younis, M. F. (2019). Developing load balancing for IoT - Cloud computing based on advanced firefly and weighted round robin algorithms. *Baghdad Science Journal*, *16*(1), 130–139. https://doi.org/10.21123/bsj.2019.16.1.0130

al Nuaimi, K., Mohamed, N., al Nuaimi, M., & Al-Jaroodi, J. (2012). A survey of load balancing in Cloud Computing: Challenges and algorithms. *Proceedings - IEEE 2nd Symposium on Network Cloud Computing and Applications, NCCA 2012*, 137–142. https://doi.org/10.1109/NCCA.2012.29

Alakeel, A. M. (2010). A Guide to Dynamic Load Balancing in Distributed Computer Systems. *IJCSNS International Journal of Computer Science and Network Security*, *10*(6), 153–160. http://paper.ijcsns.org/07_book/201006/20100619.pdf

Alam, T. (2019). Blockchain and its Role in the Internet of Things (IoT). *International Journal of Scientific Research in Computer Science, Engineering and Information Technology*, *5*(1), 151–157. https://doi.org/10.32628/cseit195137

Al-fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). Internet of Things : A Survey on Enabling Internet of Things : A Survey on Enabling Technologies , Protocols and Applications. *Ieee*, *17*(November), 2347–2376. https://doi.org/10.1109/COMST.2015.2444095

Ali, M. S., Dolui, K., & Antonelli, F. (2017). IoT data privacy via blockchains and IPFS. *Proceedings of the Seventh International Conference on the Internet of Things - IoT '17*, *October*, 1–7. https://doi.org/10.1145/3131542.3131563

Alsmadi, A. M., Aloglah, R. M. A., Abu-Darwish, N. J. S., al Smadi, A., Alshabanah, M., Alrajhi, D., Alkhaldi, H., & Alsmadi, M. K. (2021). Fog computing scheduling algorithm for smart city. *International Journal of Electrical and Computer Engineering*, *11*(3), 2219–2228. https://doi.org/10.11591/ijece.v11i3.pp2219-2228

Ambili, K. N., Sindhu, M., & Sethumadhavan, M. (2017). On federated and proof of validation based consensus algorithms in blockchain. *IOP Conference Series:*

*Materials Science and Engineering*, *225*(1). https://doi.org/10.1088/1757-899X/225/1/012198

Babar, S., Stango, A., Prasad, N., Sen, J., & Prasad, R. (2011). Proposed embedded security framework for Internet of Things (IoT). *2011 2nd International Conference on Wireless Communication, Vehicular Technology, Information Theory and Aerospace and Electronic Systems Technology, Wireless VITAE 2011*, 1–5. https://doi.org/10.1109/WIRELESSVITAE.2011.5940923

Banafa, A. (2018). *IoT and Blockchain Convergence : Benefits and Challenges*. IoT and Blockchain Convergence: Benefits and Challenges - IEEE Internet of Things.

Bandyopadhyay, D., & Sen, J. (2011). Internet of things: Applications and challenges in technology and standardization. *Wireless Personal Communications*, *58*(1), 49–69. https://doi.org/10.1007/s11277-011-0288-5

Bano, S., Al-Bassam, M., & Danzis, G. (2017). The Road to Scalable Blockchain Designs. *Bano, Shehar Al-Bassam, Mustafa Danezis, George*, *42*(4), 31–36. http://sheharbano.com/assets/publications/usenix_login_2017.pdf

Bao, F., Chen, I.-R., & Guo, J. (2013). Scalable, adaptive and survivable trust management for community of interest based Internet of Things systems. *2013 IEEE Eleventh International Symposium on Autonomous Decentralized Systems (ISADS)*, 1–7. https://doi.org/10.1109/ISADS.2013.6513398

Bertino, E., Choo, K.-K. R., Georgakopolous, D., & Nepal, S. (2016). Internet of Things (IoT): Smart and Secure Service Delivery. *ACM Transactions on Internet Technology*, *16*(4), 1–7. https://doi.org/10.1145/3013520

Buccafurri, F., Lax, G., Nicolazzo, S., & Nocera, A. (2017). Overcoming Limits of Blockchain for IoT Applications. *Proceedings of the 12th International Conference on Availability, Reliability and Security - ARES '17*, 1–6. https://doi.org/10.1145/3098954.3098983

Cerbulescu, C., & Cerbulescu, C. M. (2017). Proposed Architecture to manage critical states predictions in IoT applications. *Proceedings of the 8th Balkan Conference in Informatics on - BCI '17*, 1–4. https://doi.org/10.1145/3136273.3136279

Chen, W. C., Chen, Y. H., Wu, C. L., & Fu, L. C. (2014). An efficient data storage method of NoSQL database for HEM mobile applications in IoT. *Proceedings - 2014 IEEE International Conference on Internet of Things,* *IThings 2014, 2014 IEEE International Conference on Green Computing and Communications, GreenCom 2014 and 2014 IEEE International Conference on Cyber-Physical-Social Computing, CPS 20, iThings*, 336–339. https://doi.org/10.1109/iThings.2014.62

Cirani, S., Davoli, L., Ferrari, G., Léone, R., Medagliani, P., Picone, M., & Veltri, L. (2014). *Scalable and Self-Configuring Architecture for Service Discovery in the Internet of Things*. *1*(5), 508–521.

Daniel, J., Sargolzaei, A., Abdelghani, M., Sargolzaei, S., Amaba, B., & Martin, L. (2017). *Blockchain Technology , Cognitive Computing , and Healthcare Innovations*. *8*(3), 194–198. https://doi.org/10.12720/jait.8.3.194-198

Datta, A. K., & Patel, R. (2014). CPU Scheduling for power/energy management on multicore processors using cache miss and context switch data. *IEEE Transactions on Parallel and Distributed Systems*, *25*(5), 1190–1199. https://doi.org/10.1109/TPDS.2013.148

Daza, V., di Pietro, R., Klimek, I., & Signorini, M. (2017). CONNECT: CONtextual NamE disCovery for blockchain-based services in the IoT. *IEEE International Conference on Communications*. https://doi.org/10.1109/ICC.2017.7996641

Desai, T., & Prajapati, J. (2013). A Survey of Various Load Balancing Techniques and Challenges in Cloud Computing. *International Journal of Scientific & Technology Research*, *2*(11), 158–161. http://www.ijisi.org/final-print/nov2013/A-Survey-Of-Various-Load-Balancing-Techniques-And-Challenges-In-Cloud-Computing.pdf

Dorri, A., Kanhere, S. S., & Jurdak, R. (2016). Blockchain in internet of things: Challenges and Solutions. *Cryptography and Security (Cs.CR); Computers and Society*. http://arxiv.org/abs/1608.05187

Dorri, A., Kanhere, S. S., Jurdak, R., & Gauravaram, P. (2017a). Blockchain for IoT Security and Privacy : The Case Study of a Smart Home. *2ND IEEE PERCOM Workshop On Security Privacy And Trust In The Internet of Things 2017 Fig.*

Dorri, A., Kanhere, S. S., Jurdak, R., & Gauravaram, P. (2017b). *LSB : A Lightweight Scalable BlockChain for IoT Security and Privacy*. https://arxiv.org/pdf/1712.02969.pdf

Ekanayake, B. N. B., Halgamuge, M. N., & Syed, A. (2018). Review: Security and privacy issues of fog computing for the internet of things (iot). *Lecture Notes on Data Engineering and Communications Technologies*, *14*, 139–174. https://doi.org/10.1007/978-3-319-70688-7_7

Es-samaali, H., Outchakoucht, A., & Leroy, J. P. (2017). A Blockchain-based Access Control for Big Data. *International Journal of Computer Networks and Communications Security*, *5*(7), 137–147.

Fafoutis, X., Mauro, A. di, Vithanage, M. D., & Dragoni, N. (2015). Receiver-initiated medium access control protocols for wireless sensor networks. *Computer Networks*, *76*, 55–74. https://doi.org/10.1016/j.comnet.2014.11.002

Fox, A., Eichelberger, C., Hughes, J., & Lyon, S. (2013). *Spatio-temporal Indexing in Non-relational Distributed Databases*. 291–299. http://www.ccri.com/wp-content/uploads/2013/10/accgeo.pdf

Hagström, L., Dahlquist, O., & Hagström, L. (2017). *Scaling blockchain for the energy sector*.

Hellani, H., Sliman, L., Samhat, A. E., & Exposito, E. (2021). Computing resource allocation scheme for DAG-based IOTA nodes. *Sensors*, *21*(14), 1–18. https://doi.org/10.3390/s21144703

Herlihy, M., & Moir, M. (2016). *Enhancing Accountability and Trust in Distributed Ledgers*. http://arxiv.org/abs/1606.07490

Hossain, Md. M., Fotouhi, M., & Hasan, R. (2015). Towards an Analysis of Security Issues, Challenges, and Open Problems in the Internet of Things. *2015 IEEE World Congress on Services*, 21–28. https://doi.org/10.1109/SERVICES.2015.12

Huh, S., Cho, S., & Kim, S. (2017). Managing IoT devices using blockchain platform. *International Conference on Advanced Communication Technology, ICACT*, 464–467. https://doi.org/10.23919/ICACT.2017.7890132

Jiang, Y., Wang, C., Wang, Y., & Gao, L. (2019). A cross-chain solution to integrating multiple blockchains for IoT data management. *Sensors (Switzerland)*, *19*(9), 1–18. https://doi.org/10.3390/s19092042

Jong-Hyouk, L., & Kim, H. (2017). Security and Privacy Challenges in the Internet of Things. *IEEE CONSUMER ELECTRONICS MAGAZINE, July*, 134–136.

Kakavand, H., Kost De Sevres, N., & Chilton, B. (2016). The Blockchain Revolution: An Analysis of Regulation and Technology Related to Distributed Ledger Technologies. *Ssrn*. https://doi.org/10.2139/ssrn.2849251

Kanakala, V. R. T., Kumar, K. P., & Kavitha, S. (2016). *A Hybrid Heuristic Algorithm to Enhance Load balancing in Cloud Environment*. *11*, 129–132.

Karafiloski, E. (2017). Blockchain Solutions for Big Data Challenges. *IEEE EUROCON 17th International Conference*, *July*, 763–768. https://doi.org/10.1109/EUROCON.2017.8011213

Karger, D. R., & Ruhl, M. (2004). Simple efficient load balancing algorithms for peer-to-peer systems. *Proceedings of the Sixteenth Annual ACM Symposium on Parallelism in Algorithms and Architectures SPAA 04*, *39*(6), 36. https://doi.org/10.1145/1007912.1007919

Khan, M. A., & Salah, K. (2018). IoT security: Review, blockchain solutions, and open challenges. *Future Generation Computer Systems*, *82*, 395–411. https://doi.org/10.1016/j.future.2017.11.022

Khare, A., Merlino, G., Longo, F., Puliafito, A., & Vyas, O. P. (2019). Toward a Trustless Smart City: The #SmartME Experience. *Proceedings - 2019 IEEE 28th International Conference on Enabling Technologies: Infrastructure for Collaborative Enterprises, WETICE 2019*, 204–207. https://doi.org/10.1109/WETICE.2019.00051

Kjellby, R. A., Johnsrud, T. E., Loetveit, S. E., Cenkeramaddi, L. R., Hamid, M., & Beferull-Lozano, B. (2018). Self-Powered IoT Device for Indoor Applications. *Proceedings of the IEEE International Conference on VLSI Design*, *2018-January*, 455–456. https://doi.org/10.1109/VLSID.2018.110

Konstantinou, I., Tsoumakos, D., Mytilinis, I., & Koziris, N. (2013). DBalancer: distributed load balancing for NoSQL data-stores. *Proceedings of the 2013 International Conference on Management of Data - SIGMOD '13*, 1037–1040. https://doi.org/10.1145/2463676.2465232

Kosba, A., Miller, A., Shi, E., Wen, Z., & Papamanthou, C. (2016). Hawk: The Blockchain Model of Cryptography and Privacy-Preserving Smart Contracts. *Proceedings - 2016 IEEE Symposium on Security and Privacy, SP 2016*, 839–858. https://doi.org/10.1109/SP.2016.55

Kshetri, N. (2017). Can Blockchain Strengthen the Internet of Things? *IEEE Computer Society. IEEE Headquarters, August*.

Kumar, M., & Sharma, S. C. (2017). Dynamic load balancing algorithm for balancing the workload among virtual machine in cloud computing. *Procedia Computer Science*, *115*, 322–329. https://doi.org/10.1016/j.procs.2017.09.141

Mahgoub, A., Ganesh, S., Meyer, F., Grama, A., & Chaterji, S. (2017). Suitability of NoSQL systems - Cassandra and ScyllaDB - For IoT workloads. *2017 9th International Conference on Communication Systems and Networks, COMSNETS 2017*, 476–479. https://doi.org/10.1109/COMSNETS.2017.7945437

Maiti, A., Raza, A., Kang, B. H., & Hardy, L. (2019). Estimating service quality in industrial internet-of-things monitoring applications with blockchain. *IEEE Access*, *7*, 155489–155503. https://doi.org/10.1109/ACCESS.2019.2948269

Malina, L., Hajny, J., Fujdiak, R., & Hosek, J. (2016). *On perspective of security and privacy-preserving solutions in the internet of things*. *102*, 83–95. https://doi.org/10.1016/j.comnet.2016.03.011

Manikandan, N., & Pravin, A. (2018). An efficient improved weighted Round Robin load balancing algorithm in cloud computing. *International Journal of Engineering and Technology(UAE)*, *7*(3.1 Special Issue 1), 110–117. https://doi.org/10.14419/ijet.v7i3.1.16810

Mayur, S., & Chaudhary, N. (2019). Enhanced weighted round robin load balancing algorithm in cloud computing. *International Journal of Innovative Technology and Exploring Engineering*, *8*(9 Special Issue 2), 148–151. https://doi.org/10.35940/ijitee.I1030.0789S219

Mcconaghy, T., Marques, R., Andreas, M., Jonghe, D. de, Mcconaghy, T. T., Mcmullen, G., Henderson, R., Bellemare, S., & Granzotto, A. (2016). *BigchainDB : A Scalable Blockchain Database*. http://www.the-blockchain.com/docs/bigchaindb-whitepaper.pdf

Mhaisen, N., Abazeed, O., al Hariri, Y., Alsalemi, A., & Halabi, O. (2018). *Self-Powered IoT-Enabled Water Monitoring System*.

Moly, M. I., Hossain, A., Lecturer, S., & Roy, O. (2019). Load Balancing Approach and Algorithm in Cloud Computing Environment. *American Journal of Engineering Research (AJER)*, *8*(4), 99–105.

Nababan, D. T., Primananda, R., & Bakhtiar, F. A. (2021). *Implementasi Load Balancing pada Broker MQTT dengan Algoritme Weighted Least Connection menggunakan Raspberry Pi*. *5*(3), 867–875.

Nakamoto, S. (2008). *A peer-to-peer electronic cash system* (pp. 1–9).

Nguyen, Q.-T., & Schultz, N. (2013). Evolution of Telecommunication Services : The convergence of Telecom and Internet: Technologies and Ecosystems. In *Lecture notes in Computer Science*. https://doi.org/http://dx.doi.org/10.1007/978-3-642-41569-2_5

Nguyen, V.-G., Grinnemo, K.-J., Taheri, J., & Brunstrom, A. (2018). *Load balancing for a Virtual and Distributed MME using Weighted Round Robin*. 5–8.

Nijeholt, H. L. À., Oudejans, J., & Erkin, Z. (2017). DecReg: A Framework for Preventing Double-Financing using Blockchain Technology. *BCC 2017 - Proceedings of the ACM Workshop on Blockchain, Cryptocurrencies and Contracts, Co-Located with ASIA CCS 2017*, 29–34. https://doi.org/10.1145/3055518.3055529

Nsofor, D. (2018). *Kora Network Token Model*. 1–18.

Özyılmaz, K. R., & Yurdakul, A. (2017). Integrating low-power IoT devices to a blockchain-based infrastructure. *Proceedings of the Thirteenth ACM International Conference on Embedded Software 2017 Companion - EMSOFT '17*. https://doi.org/10.1145/3125503.3125628

Paethong, P., Sato, M., & Namiki, M. (2016). Low-power distributed NoSQL database for IoT middleware. *Proceedings of the 2016 5th ICT International Student Project Conference, ICT-ISPC 2016*, 158–161. https://doi.org/10.1109/ICT-ISPC.2016.7519260

Qiu, T., Zhao, A., Ma, R., Chang, V., Liu, F., & Fu, Z. (2018). A task-efficient sink node based on embedded multi-core SoC for Internet of Things. *Future Generation Computer Systems*, *82*, 656–666. https://doi.org/10.1016/j.future.2016.12.024

Rachedi, A., Rehmani, M. H., Cherkaoui, S., & Rodrigues, J. J. P. C. (2017). EDITORIAL IEEE ACCESS SPECIAL SECTION EDITORIAL : THE PLETHORA OF RESEARCH IN INTERNET OF THINGS ( IOT ). *IEEE Access*, *4*, 9575–9579.

Radojevic, B., & Zagar, M. (2011). Analysis of issues with load balancing algorithms in hosted (cloud) environments. *2011 Proceedings of the 34th International Convention MIPRO*, 416–420.

Rajguru, A., & Apte, S. (2012). A Comparative Performance Analysis of Load Balancing Algorithms in Distributed System using Qualitative Parameters.

*International Journal of Recent Technology and ...*, *3*, 175–179. http://www.ijrte.org/attachments/File/v1i3/C0278071312.pdf

Ramachandran, G. S., & Krishnamachari, B. (2019). A reference architecture for blockchain-based peer-to-peer IoT applications. *ArXiv*, *May*.

Ramachandran, G. S., Wright, K. L., & Krishnamachari, B. (2018). Trinity: A distributed publish/subscribe broker with blockchain-based immutability. *ArXiv*, 1–8.

Randles, M., Lamb, D., & Taleb-Bendiab, A. (2010). A comparative study into distributed load balancing algorithms for cloud computing. *24th IEEE International Conference on Advanced Information Networking and Applications Workshops, WAINA 2010*, 551–556. https://doi.org/10.1109/WAINA.2010.85

Rasolroveicy, M., & Fokaefs, M. (2020). Performance evaluation of distributed ledger technologies for IoT data registry: A comparative study. *Proceedings of the World Conference on Smart Trends in Systems, Security and Sustainability, WS4 2020*, 137–144. https://doi.org/10.1109/WorldS450073.2020.9210358

Rautmare, S., & Bhalerao, D. M. (2017). MySQL and NoSQL database comparison for IoT application. *2016 IEEE International Conference on Advances in Computer Applications, ICACA 2016*, 235–238. https://doi.org/10.1109/ICACA.2016.7887957

Rostampour, S., Bagheri, N., Hosseinzadeh, M., & Khademzadeh, A. (2018). A Scalable and Lightweight Grouping Proof Protocol for Internet of Things Applications. *Journal of Supercomputing*, *74*(1), 71–86. https://doi.org/10.1007/s11227-017-2106-7

Samaniego, M., & Deters, R. (2016). *Using Blockchain to push Software-Defined IoT Components onto Edge Hosts*.

Samaniego, M., & Deters, R. (2017). Blockchain as a Service for IoT. *Proceedings - 2016 IEEE International Conference on Internet of Things; IEEE Green Computing and Communications; IEEE Cyber, Physical, and Social Computing; IEEE Smart Data, IThings-GreenCom-CPSCom-Smart Data 2016*, 433–436. https://doi.org/10.1109/iThings-GreenCom-CPSCom-SmartData.2016.102

Saraiva, A., Almeida, B., & Barroso, S. (2015). *Secure Transactions without Mining or Central Authority*.

Sarkar, C., Nambi, S. N. A. U., Prasad, R. V., & Rahim, A. (2014). A scalable distributed architecture towards unifying IoT applications. *2014 IEEE World Forum on Internet of Things, WF-IoT 2014*, 508–513. https://doi.org/10.1109/WF-IoT.2014.6803220

Services, G., Science, C., Science, C., & Processing, D. (2016). *Blockchain Challenges and Opportunities : A Survey Zibin Zheng Shaoan Xie Hongning Dai Xiangping Chen Huaimin Wang*. 1–25.

Sharma, P. K., Chen, M. Y., & Park, J. H. (2018). A Software Defined Fog Node Based Distributed Blockchain Cloud Architecture for IoT. *IEEE Access*, *6*(c), 115–124. https://doi.org/10.1109/ACCESS.2017.2757955

Sharma, P. K., & Park, J. H. (2018). Blockchain based hybrid network architecture for the smart city. *Future Generation Computer Systems*, *86*, 650–655. https://doi.org/10.1016/j.future.2018.04.060

Sharma, S., Singh, S., & Sharma Meenakshi. (2008). Performance Analysis of Load Balancing Algorithms. *International Journal of Civil and Environmental Engineering*, *2*(2), 367–370. https://waset.org/publications/5537/performance-analysis-of-load-balancing-algorithms

Shengsheng, Y. U., Lihui, Y., Song, L. U., & Jingli, Z. (2002). *Least-Connection Algorithm based on variable weight for multimedia transmission College of Computer Science*.

Simic, M., Sladic, G., & Milosavljević, B. (2017). A Case Study IoT and Blockchain powered A Case Study IoT and Blockchain powered Healthcare. *The 8th PSU-UNS International Conference on Engineering and Technology (ICET-2017)*. https://doi.org/10.1177/1558689815570092

Simic, M., Sladic, G., & Milosavljevic, B. (2017). A Case Study IoT and Blockchain powered Healthcare. *The 8th PSU-UNS International Conference on Engineering and Technology (ICET-2017), Novi Sad, Serbia, June 8-10, 2017 University of Novi Sad, Faculty of Technical Sciences, June*.

Singh, G., & Kaur, K. (2018). *An Improved Weighted Least Connection Scheduling Algorithm for Load Balancing in Web Cluster Systems*. 1950–1955.

Soklic, M. (2002). Simulation of load balancing algorithms: a comparative study. *ACM SIGCSE Bulletin*, *34*(4), 1–7. http://dl.acm.org/citation.cfm?id=820186

Songara, A., & Chouhan, L. (2017). Blockchain : A Decentralized Technique for Securing Internet of Things. *International Conference on Emerging Trends in Engineering Innovations & Technology Management (ICET: EITM-2017), October*.

Spasovski, J., Eklund, P. W., Spasovski, J., & Eklund, P. (2017). *Proof of Stake Blockchain : Performance and Scalability for Groupware Communications Proof of Stake Blockchain : Performance and Scalability for Groupware Communications*. *November*.

Stanciu, A. (2017). Blockchain Based Distributed Control System for Edge Computing. *Proceedings - 2017 21st International Conference on Control Systems and Computer, CSCS 2017*, 667–671. https://doi.org/10.1109/CSCS.2017.102

Suo, H., Wan, J., Zou, C., & Liu, J. (2012). Security in the internet of things: A review. *Proceedings - 2012 International Conference on Computer Science and Electronics Engineering, ICCSEE 2012*, *3*, 648–651. https://doi.org/10.1109/ICCSEE.2012.373

Ting-Dong, Y., & Xuan-Rong, P. (2017). Research on scheduling method for collaborative detection traffic in the bottom of IOT. *Proceedings - 2017 Chinese Automation Congress, CAC 2017*, *2017-Janua*, 7699–7703. https://doi.org/10.1109/CAC.2017.8244171

Tsai, C. W., Lai, C. F., Chiang, M. C., & Yang, L. T. (2014). Data mining for internet of things: A survey. *IEEE Communications Surveys and Tutorials*, *16*(1), 77–97. https://doi.org/10.1109/SURV.2013.103013.00206

Wood, G. (2014). Ethereum: a secure decentralised generalised transaction ledger. *Ethereum Project Yellow Paper*, 1–32.

Wortmann, F., & Flüchter, K. (2015). Internet of Things: Technology and Value Added. *Business and Information Systems Engineering*, *57*(3), 221–224. https://doi.org/10.1007/s12599-015-0383-3

Yeow, K., Gani, A., Ahmad, R. W., Rodrigues, J. J. P. C., & Ko, K. (2017). Decentralized Consensus for Edge-Centric Internet of Things: A Review, Taxonomy, and Research Issues. *IEEE Access*, *6*(8), 1513–1524. https://doi.org/10.1109/ACCESS.2017.2779263

Yi, S., Li, C., & Li, Q. (2015). A survey of fog computing: Concepts, applications and issues. *Proceedings of the International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc)*, *2015-June*, 37–42. https://doi.org/10.1145/2757384.2757397

Yuan, Y., & Wang, F. (2016). Towards Blockchain-based Intelligent Transportation Systems. *2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)*, 2663–2668.

Yue, X., Wang, H., Jin, D., Li, M., & Jiang, W. (2016). Healthcare Data Gateways: Found Healthcare Intelligence on Blockchain with Novel Privacy Risk Control. *Journal of Medical Systems*, *40*(10). https://doi.org/10.1007/s10916-016-0574-6

Zenon, C., Venkatesh, M., & Shahrzad, a. (2011). Availability and Load Balancing in Cloud Computing. *International Conference on Computer and Software Modeling IPCSIT Vol.14 (2011) IACSIT Press, Singapore*, *14*, 134–140. https://doi.org/10.1109/TST.2013.6449405

Zheng, Z., Xie, S., Dai, H.-N., & Wang, H. (2017). Blockchain Challenges and Opportunities: A Survey. *International Journal of Web and Grid Services*, *January*, 1–24. https://doi.org/10125/41338

Zhu, P., & Zhang, J. (2017). Load Balancing Algorithm for Web Server Based on Weighted Minimal Connections. *Journal of Web Systems and Applications*, *1*(1), 1–8. https://doi.org/10.23977/jwsa.2017.11001