

# Blockchain Technology Aimed at Solving Internet of Things Challenges: A Systematic Literature Review

Alfredo Daza Vergaray<sup>1</sup>, Handerson Joel Farfan Rosales<sup>1</sup>, Rafael López Cordova<sup>1</sup>

<sup>1</sup> Faculty of engineering and Architecture, School of Systems Engineering, Universidad César Vallejo, Lima, Perú

**Abstract** – The main objective of this work is to conduct a systematic review of the literature on IoT technology (internet of things) and the application of blockchain technology. For this, an exhaustive research was carried out and when analyzing the documentation of aspects such as: area of study on the integration of technologies, most used consensus techniques and the benefits of technology were considered. The results of the study indicated blockchain technology with IoT being implemented in companies and industries; with the most consensus techniques being POW and POS, while the benefits are manifested in terms of improved scalability and security of companies.

**Keywords** – Blockchain, IoT, security, privacy, trust.

## 1. Introduction

Today, the Internet of Things (IoT) is considered an evolving technique that was born with a scope when applying engineering, thus solving difficulties without intervening the force of human capital [1]. It enables an intelligent workforce, i.e. it creates an interaction between humans and machines, as well as between machines [2].

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**Corresponding author:** Alfredo Daza Vergaray,  
Faculty of engineering and Architecture, School of Systems Engineering, Universidad César Vallejo, Lima, Perú  
**Email:** [adazave@ucvvirtual.edu.pe](mailto:adazave@ucvvirtual.edu.pe)

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Although the IoT facilitates the realization of the processes, the security of the information stored in the devices is not 100% reliable, because the data can be altered, intercepted or filtered on the way to a database or when they are stored within it.

This becoming one of the biggest challenges that IoT technology has and it has not yet been able to give a definitive solution [3].

The privacy and security of information revealed its importance since the beginning of the internet as we know it, since data began to circulate in this virtual medium, and in this scenario, unauthorized people can intercept that information without the need for anyone's permission.

Although there are security protocols to try to avoid it [4], the servers on which the information is hosted remain vulnerable, since they work under a centralized architecture.

At all times the IoT service provider company is in control and can either be the victim of a malicious attack or improperly manipulate that information of its customers [4]. Therefore, companies that do not provide security, where they can alter the information provided based on their own interests, so they are not 100% reliable, which arises the need of the verified data and check if it has not been modified, this being practically impossible with existing technology [5].

In short, once the information is sent to the network, the user automatically loses control and it can also spread to unimagined limits considering how big and vast the internet is [6].

Andrew Lee, who was the CEO of ESET in 2015, said: "Can we fight data immortality? Do we know where they are stored and in whose hands?" [7], emphasizing the lack of security and privacy in our data, since once they enter internet traffic, they are exposed all the time.

The most appropriate way to manage and solve the problem is using blockchain technology; in which it has the potential to increase good governance, as well as transparency and privacy [50], this provides the security and privacy that is needed, in addition, it working in a decentralized way.

Blockchain (BC) is a distribution of information that is shared with the nodes of the network [8]. Similarly, the cryptography used in BC is a key feature, because it provides authentication in all interactions [8].

PANARELLO, for its research on the integration of blockchain with IoT, in 2018 tells us, "*several security technologies and cryptographic functions have been exploited, [...] being one of those the BC, [which] is exploiting different scenarios, considering it's a technology that evolves every day*" [9].

In the previous paragraph, the author indicates the potential that blockchain has regarding the security and privacy in offering the services that integrate this technology to handle the sending and receiving of information [10].

This study seeks to determine what is the best way for blockchain to be integrated with the internet of things, what kind of technologies within the blockchain can be the best in taking advantage of and which are those that are not so efficient and should be discarded [11], the consensus techniques that best adapt in order to integrate blockchain technology with the IoT and how this model will be better than the traditional model or architecture of IoT used today [12].

Taking into account the above issues, the objective of this article will be to conduct an analysis of the application of blockchain to the Internet of Things. The purpose of this article is to find out what are the main challenges to overcome in IoT and how blockchain technology can help to overcome them. This work will also analyze main authors on the subject, the most relevant articles and the possible challenges and gaps in the field of exploration (Blockchain + IoT) to be developed. This literature review aims to strengthen the current theoretical framework for the purpose of supporting future research related to blockchain technology and IoT devices. To this end, a systematic review will be implemented, which will include literature from 2016 to 2022.

The work is divided into six sections. The following section represents the methodology used for systematic literature review and raises questions for research. Next, in section 3, the results are presented, in section 4 the analysis of the results, so that in section 5 the discussions of the findings and conclusions are shown, and finally in section 6 the limitations are found and future research is needed.

## 2. Methodology

In the present systematic review we will use the guideline established by Kitchenham and Charters [13], which consists of three important phases, as shown in Figure 1:

- Review planning: in this part it is necessary to verify the need to carry out the review, in relation to the questions of the investigation.
- Conducting the review: here the primary studies are chosen, in relation to the criteria that allows to include or exclude an article found.
- Results of the review: finally, the statistical results and the study of the articles are shown.

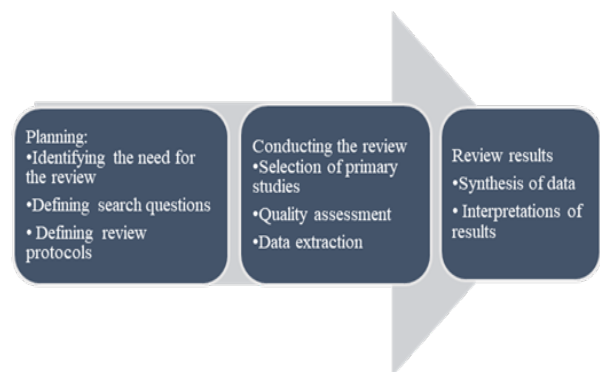


Figure 1. Process of systematic literature review Adapted from Rudas [14].

### 2.1. Planning the review

To get a clear idea of the extent to which blockchain technology is being used in IoT devices, whether its usage generates benefits or not, or what mechanisms and methods are most suitable to achieve a positive effect, it is necessary to review evidence in existing research on blockchain technology and IoT. For that reason, the systematic review planning process provides the best methods for collecting and analysing primary research [13].

Reference was made to the following indexed research article files: Springer Link, ScienceDirect, Scopus, IEEE Xplore. An assessment protocol was also developed to identify research needs, by defining the scope of research on blockchain technology and IoT. Thus, in Table 1, the research questions on information retrieval are presented.

Table 1. Research Search Questions

ID	Research Question	Motivation
Q1	What studies exist on the integration of blockchain technology with the IoT?	Identify studies on the integration between blockchain technology and IoT
Q2	What consensus techniques are used in integrating blockchain technology into the Internet of Things?	Reveal the different consensus techniques that have been used in blockchain to improve IoT security.
Q3	What are the benefits of integrating blockchain technology into the IoT?	Identify the improvements that technology made with blockchain technology to the IoT

2.2. Performing the review

2.2.1. Initial Search

The research began on April 20, 2022, when the first search queries linked the terms "blockchain", "Internet of Things", "security", "privacy", "blockchain and IoT" in the following databases: ScienceDirect, Springer Link, IEEE Xplore, Scopus, SciELO and repositories of national and international universities. These searches yield a very good amount of results, many are repeated or barely used, but they give a general idea of the spectrum in words that would be most effective for that search. In addition, they assured that no systematic reviews were found for the topic "The challenges of IoT and Blockchain technology as a possible solution" [21]. Since the results of SciELO were scarce and did not seem to contribute to future research, nor were they included in other databases, we decided to withdraw them from the systematic review.

2.2.2. Systematic Search

With the use of systematic research applied within the IEEE research banks Xplore, Springer Link, ScienceDirect and Scopus, the results of the publications found between 2016 and 2021 were limited. Table 2 shows the combination of words that gave the best results.

Table 2. Search string

Question	Search string
Q1	((BLOCKCHAIN AND IOT)AND INTEGRACION))
Q2	((BLOCKCHAIN AND IOT) AND PROOF OF STAKE))
Q3	((ADVANTAGES OF BLOCKCHAIN AND IOT) AND SECURITY)

Table 3 also presents the criteria used to filter the articles:

Table 3. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Publications related to the integration of blockchain technology in the IoT.	Articles that do not meet the inclusion requirements.
Publications related to the consensus techniques used to integrate blockchain technology into the IoT.	Bulletins, books, manuals or articles that are too summarized are excluded.
Publications that mention the benefits that blockchain technology gives to the IoT.	Items related to bitcoin are excluded.

2.2.3. Additional Filters:

For a larger selection of items, the following refined filters, as shown in Table 4:

Table 4. Additional filters

First filter	Second filter
Reading of title and abstract: It is submitted to reading and revision.	Finally, we proceed to the reading and complete analysis of the studies that passed the first filter.

Once the filters mentioned above have been applied, we use convenience sampling that aims to find objects of study that represent the topic in general and meets our interests. In this way, we intentionally choose the articles that are most related to the topic investigated [15]. Therefore, Figure 2 shows the process of searching for articles, namely those that can contribute more or for better content for a systematic review and that were not found by the initial search.

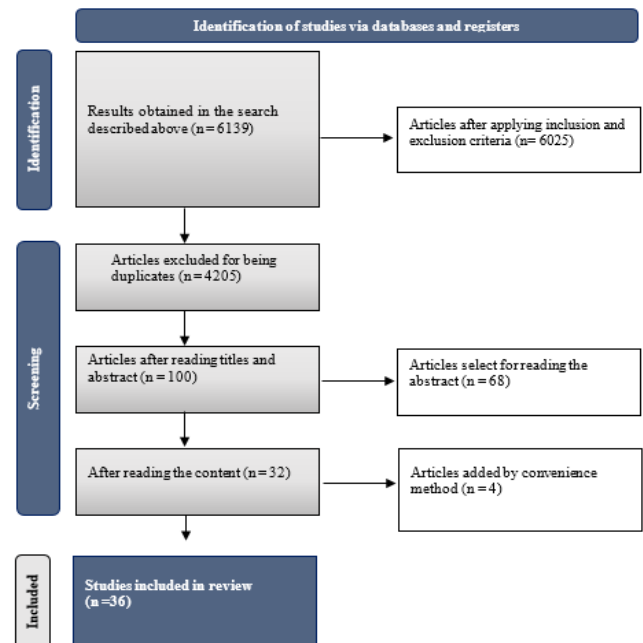


Figure 2. Article Search process

Of the 6139 articles that were found, the aforementioned criteria were applied to choose the right articles. Then, we improved accuracy with more specific filters and the use of the methodology at convenience in order to eliminate articles that do not contribute enough to this systematic review.

### 3. Results

Table 5 shows the 35 studies that were found to provide a substantial amount of relevant information regarding blockchain technology being applied to the Internet of Things.

Table 5. Results found

Author-Year	Reference	Description
Zhen et al. (2018).	[16]	A survey is conducted on the blockchain, first the blockchain technology and key features are explained, then it is discussed about which typical consensus algorithm the blockchain uses, concluding that blockchain technology is highly appreciated for its architecture, which is applied in different areas, demonstrating its potential in the transformation of the sector for its main points of being: auditable, persistent, autonomous and anonymous.
Bao, et al. (2018).	[17]	This work demonstrates how the Blockchain architecture achieves identity authentication, access control and storage integrity of IoT security, which utilized the POW and PBFT consensus technique, with blockchain technology benefiting from improved security, concluding that blockchain manages to control accessibility and identify secure patterns, with minimal Internet of Things traffic in any scene.
Reyna, et al. (2018).	[10]	This article tries to investigate the challenges of applying blockchain technology and how it potentially improves the IoT within companies, also has benefits in the improvement of security, with conclusion that when adopting measures it is important to include IoT and blockchain in government architectures, evidencing the rapid interaction between inhabitants as well as for mining procedures.
Novo (2018)	[18]	It addresses the problem of scalability of managing the billions of IoT devices, in the industrial field, making use of POW and POS consensus techniques, having the benefits of improvement in security with the adaptation of different IoT environments, obtaining as a conclusion that blockchain is flexible when interconnecting with several systems, since it achieves the adaptation in contexts of the Internet of Things in its maximum expression.
Kumar & Mallick, (2018)	[1]	Introduces blockchain (BC) technology to the IoT and studies how it contributes to security of the IoT network, studying the applications of BC regarding to business sectors and categories focused on improving security, concluding that this technology addresses solutions to problems, being more flexible in the accessibility of information.
Dong, Luo & Liang (2018)	[20]	An architecture backed by IoT and blockchain technology is proposed, with particularities that are reliable and decentralized, while using POW and POS consensus techniques, which has great viability in future advanced ICT systems by improving security, concluding that blockchain has presented characteristics, with potentials that make them have an indispensable role in information of technology systems.
Acurio (2021)	[12]	In the project, IoT and blockchain technologies were implemented together within the home, in order to demonstrate the influence of blockchain on IoT devices in a smart home. Making use of the Web3.py library, as well as the Vyper language, the POA consensus technique was used, having as a benefit the efficiency in the consumption of resources, obtaining as a conclusion that the implemented technology is more secure, being inflexible to DoS and Man-in-middle(MITM) attacks, thus controlling access to information.

Vairam,et al. (2018)	[22]	ApproxBC, an alternative blockchain, is proposed, which can be compatible with devices that have limited space and resources. The usability of the BC is demonstrated by creating two sample applications and analyzing whether it needs any corrections, concluding that this technology decreases the ability to store and process the usual blockchain with filters, that is necessary in order to obtain records of activities in 8x and 2x.
Liu, Yuan & Yu (2021)	[23]	It explores the security convenience of IoT based on blockchain technology, where it was demonstrated that IoT service architecture helps in resource consumption efficiency, raising accuracy and security, having as a conclusion that technology proves to be effective and safe to connect it with the Internet of Things, with being good combination of both and orienting it to its application.
Matsuura (2019)	[24]	The main concepts were analyzed and a blockchain was designed as digital evidence to apply Fintech technology, obtaining as a benefit the improvement of security, having as a conclusion that blockchain is advantageous, since by using a random procedure it adapts the generalization of architectures, in less time of secure sealing.
Uddin, et al. (2021)	[25]	The article proposes CBCIoT, a consensus algorithm for applications that help in optimizing the adaptability of verification and validation, demonstrating that the algorithm is efficient with respect to the moment of generating the blocks per second, concluding that the technology is reliable and competitive, and since a delay is required to collect maximum information in the Internet of Things, it is a good alternative for its use in other contexts.
Hammi, et al. (2018)	[26]	An approach called trust bubbles were developed, in which safe zones are created, can communicate securely, can be applied in various IoT scenarios in industries, is based on a BC for the security it provides. Solid security against attacks were shown, in addition to a study on the time and energy of the BC, using POW, POS and PBFT consensus techniques, thus improving scalability, concluding that the system showed solid security against attacks, as well as efficiency in the time and energy of the BC.
Salah, et al. (2019)	[27]	He determined how blockchain technology is adaptable to apply in artificial intelligence and its challenges that address privacy, scalability and consensus techniques, such as: POS and POA, having benefits by improving the security of smart contracts, which concludes that although the adoption of technology still lacks to be the best, but it's equal and advantageous to store data in a decentralized way, improving the problems of artificial intelligence.
Puthal & Mohanty (2019)	[28]	It analyzes how blockchain can be efficiently integrated into IoT networks, working effectively in computing scenarios, using the following consensus techniques: POW, POS and POA, it concludes that blockchain is an innovative technology that integrates networks efficiently, in relation to the internet of things and systems.
Yeow , et al. (2018)	[29]	Study that examined the structure of blockchain and DAG technology, and how this can be the answer to the problems that IoT has, using the following consensus techniques: POW, POS and PBFT, obtaining as a benefit the improvement of scalability, concluding that technology is a good option to deal with the scale of the Internet of Things and the importance of small payments of low magnitude with decentralized architecture.
Rejeb, Keogh & Treiblmaier (2019)	[30]	It shows how the combination of blockchain with IoT can improve supply chain integrity and operational performance, obtaining as a benefit the improvement of security, concluding that this technology has the advantage of immutability, and it was proven that the difficulties of scalability and privacy are eliminated through the use of the blockchain, minimizing the consumption of resources.

Ramezan & Leung (2018)	[31]	The BCR protocol is proposed in an IoT network within a company in Vancouver - Canada, the result shows that it reduces routing overhead compared to AODV, it is also seen that it resists Greyhole and blackhole attacks, it is also applicable in ad-hoc networks, having as a benefit the improvement of security, therefore, it is concluded that the proposed protocol is advantageous for the reduction of overload and attacks, based on networks with nodes.
Singh & Vardhan (2019)	[32]	A blockchain network is proposed to improve dispatch time and to reduce manpower in the procedure of requesting a check. With the tests carried out it is seen that the time is reduced by 25% making use of PoS compared to the traditional way, obtaining as a benefit the improvement of response time, concluding that this technology is adaptable to the current bank system with a little effort to integrate them.
Zhaoxin, et al. (2022)	[33]	The proposed framework gives reasonable results, the load allocation is balanced and higher performance than the baseline with various system parameters, having as a benefit the improvement of scalability, concluding that by assigning cluster and validating them, the set of processes is more balanced, with improved scalability, based on criteria of the environment.
Wang, et al. (2019)	[34]	The usage of blockchain to solve data security problems in IoT was analyzed, in order to optimize capacity and security, using the PBFT consensus technique, obtaining as benefits that it helps improve security, concluding that the technology analyzed unlike others is more applicable to contexts related to the Internet of Things.
Ma, Shi & Li (2019)	[35]	A simulation of a multi blockchain structure was performed, which resulted in substantially improved performance of the system, which allows optimizing the performance and capacity of the system for various environments, having as a benefit the power to save costs, concluding based on the results that multiblockchain architecture is good with respect to scalability in different contexts.
Amritanand & Vipin (2019)	[36]	A literature review of blockchain-based IoT control architectures, whose area of study was home, was proposed. As a result, access to IoT devices is only allowed by legitimate users, but not by any other individual who wants to break the security of the network, also managing in a more secure way the information that is handled within the network, obtaining as a benefit the improvement of scalability, which concludes that the processes used manage the token are much better with secure accessibility, which solved the problems of control failures.
Abdelmabou, et al. (2022)	[37]	In this study, the thematic taxonomy for IoT using a blockchain was discussed, focusing on the most important issues. In addition, the following consensus techniques were used: POW, POS, POA and PBFT, as well as the benefit of improved scalability, concluding that a large part of the Internet of Things systems have difficulties with being secure in their privacy in computer attacks, blockchain being a fairly good alternative for its characteristics of decentralization and intelligence elements.
Liang (2020)	[38]	The architecture of blockchain was studied and tested and it can provide the required security to the IoT through private keys. In addition, with the public keys corresponding to each IoT device, it is stored through a chain of blocks, it is also not difficult to manipulate and provides convenience, obtaining as a benefit that improves safety, concluding that the technology studied is a fundamental element in the public sector since it is not easy to manipulate, it provides security and comfort to users on their devices.
Ding, et al. (2019)	[39]	An accessibility control architecture is proposed using blockchain technology for optimization when managing IoT devices in the business sector with limited resources. Security was also analyzed, concluding that the scheme is safe, as well as solving the problem of lack in reliability and strengthening the device, contemplating an efficient scheme with respect to practical applicability and complies with the accessibility control of the Internet of Things.

Zhang, et al. (2020)	[40]	It proposes an access control called PoA (Proof-of-Authentication), for IoT devices based on the blockchain so that it can work correctly with limited resources in its distributed system, the results show that it is efficient, in addition to resisting attacks and scalable which is convenient to comply with a high level of concurrency, obtaining as benefits the improvement of response time and cost savings.
Xu, et al. (2018)	[41]	It proposed a decentralized IoT security system based on the use of a blockchain, which had the benefit of improved security, concluding that the BlendCAC is a competent guide in providing a scalable and easy accessibility control for the Internet of Things and networks, ensuring effective and efficient compliance with distribution.
Christidis & Devetsikiotis (2016)	[42]	The IoT was combined with the blockchain, being secure and in addition, the chain of blocks provides a resilient and distributed peer-to-peer system, having the ability for an audible interaction, having as a benefit the improvement of security, so it is concluded that combining both technologies automates the work that consumes too much time, obtaining cryptography verification, as well as reducing costs and time of the procedures.
Dorri, et al. (2017)	[11]	It described many main elements of the Smart Home degree, analyzing different operations and processes in IoT devices. It was also discussed with respect to security and privacy. The results, in addition, it was seen that the costs decreased, having as a benefit the improvement of security, concluding that the system proved to be secure and in order protect the privacy of the information you have, being the resources adaptable to the Internet of Things.
Košťál, et al. (2019)	[43]	It provides a solution to manage the configuration of IoT devices in industries, it also gives you the option to verify the configuration of the implementation and you can see the irrefutable record by the characteristics of blockchain, obtaining benefits such as cost savings, therefore, it is concluded that the technology used is integral and helps to keep the nodes interrelated in a secure way, showing to be reliable with respect to the messages.
Dorri, Kanhere & Jurdak (2017)	[44]	It is proposed to adapt the chain of blocks for IoT technology and thus be able to solve security and privacy, in this publication it is announced that the security provided by the blockchain is robust and that it resisted several attacks, it has benefits such as improved security, concluding that the proposed technology did not require mining, had no delays in processing the activities formed and reduced costs, as well as being reliable.
Ouaddah, Elkalam & Ouahman, (2017).	[45]	A framework is proposed that takes advantage of the consistency offered by the blockchain to solve the accessibility difficulty of the Internet of Things in industries, providing more solid and transparent access to control tools, using the POA consensus technique, obtaining as a benefit the efficiency in the consumption of resources, concluding that BC technology has consistency provided by cryptocurrencies based on the blockchain solved problems of accessibility control of the Internet of Things, being FairAccess a compact and transparent tool.
Venkatraman & Parvin (2022)	[46]	It proposed a prototype to manage IoT IDs based on Blockchain technology, along with smart contracts that give security, privacy and trust of the required information, obtaining as a benefit the improvement of security, concluding that blockchain is a viable and practical system, being adaptable and extensive in commercial procedures of large magnitude.
Al Ahmed, et al. (2022)	[47]	It proposed a system based on the structured blockchain for identification through Internet of Things devices, using the PBFT consensus technique, which concludes that the proposed technology is demanding in devices with limited sources such as the Internet of Things.

Romashkov a, Komarov & Ometov (2021)	[48]	The requirements and characteristics of both systems were mapped, highlighting the main challenges of coexistence in technology to integrate the blockchain and the internet of things, for this the POA consensus technique was used, obtaining as a benefit the efficiency in the consumption of resources.
Tian, et al. (2020)	[19]	An authentication system for IoT devices using blockchain technology is proposed. The results obtained show that by using an authentication system, a better registration of devices and servers is achieved, concluding that technology proves to be fast in transaction processes, being millions per second, also evidencing high, efficient and effective identification requests.

In Table 6, the research articles collected, show an increased interest in integrating blockchain technology with the Internet of Things.

Table 6. Number of articles per year of publication.

Year	Number	Related Studies
2016	1	[42]
2017	3	[11], [44], [45]
2018	12	[27], [41], [18], [20], [29], [18], [16], [26], [31], [10], [1], [17]
2019	9	[36], [35], [43], [28], [30], [24], [32], [39], [34]
2020	3	[19], [38], [40]
2021	3	[21], [48], [23]
2022	3	[33], [46], [37]

#### 4. Analysis of the results

With the results shown about the blockchain proposed as a solution to the challenges that the Internet of Things has to overcome today, the results will be analyzed with respect to the questions that were previously raised.

##### 4.1. Studies on the integration of blockchain technology with IoT

According to the studies collected, we already have an idea about the areas or services where blockchain technology is generally integrated with the IoT, and these are presented in Table 7.

Table 7. Articles on the integration of blockchain technology with the IoT

Environment	Related Studies
Home	[21], [11], [36]
Companies	[31], [10], [1], [39]
Industry	[45], [43], [26], [18]

Nowadays it is taken into account that IoT technology is implemented in many tasks in order to optimize processes and help people, companies or organizations [49].

In this way we can have a clearer idea of how the integration of blockchain technology helps the IoT.

IoT devices that are used within a smart home are already being adopted more and more in everyday life [21], thus this being one of the areas that have been mostly studied previously [11], [36].

In the field of companies, IoT devices help with the optimization of processes by facilitating manual tasks that were previously performed by workers [1], [39]. Blockchain technology is a very valuable point in that sector given that companies want to have a level of trust of information, privacy and security, this technology could provide those points that companies require [31], [10].

On the industrial side, IoT technology helps a lot with the automation of processes, since there is a technology that is aimed at Industrial Internet of Things (IIoT) sector [26].

The integration of BC could also help in this sector since in the same way, it seeks complete control of its devices safely, and it can be done through smart contracts, as well as it can help automate IIoT devices [45], [43], [18].

##### 4.2. Consensus techniques used to integrate blockchain technology into the IoT

These techniques or architectures are used in the integration of blockchain-IoT technology, they have to be taken into account, since to a greater extent the proper functioning and better response time will depend on this, when the network based on said integration is executed. So, Table 8 shows the articles about the most commonly used consensus techniques.

Table 8. Articles on the consensus techniques used to integrate blockchain technology into the IoT

Consensus techniques	Related Studies
POW	[17], [18], [20], [26], [28], [29], [37]
POS	[18], [20], [26], [27], [28], [29], [37]
POA	[27], [28], [37], [45], [21], [48]
PBFT	[17], [34], [47], [26], [29], [37]



According to the results obtained, one of the consensus protocols mostly used by blockchain technology is POW or proof of work [17], [18], [20], since it is the most used protocol for cryptocurrencies, but in this case this protocol could not be used, because of the feature that consumes too many resources [26], [28], [29], [37].

One of the protocols that provides the greatest advantages in order to integrate the blockchain to the IoT is the POS or Proof of Stake consensus protocol, for its acronym in English [28], [29], [37]. Many tests were conducted to see how blockchain technology and IoT works with this protocol [18], [20], [26], [27].

Proof of authority, known by its acronym POA [27], is considered as a protocol by which some blockchain projects such as Hyperledger Fabric, are used to make this fusion of technologies a reality and so far significant advances are seen [28], [37].

On the other hand there is talk of the PBFT consensus protocol or Practical Byzantine Fault Tolerance [17], [34], [47], it is also an option to join these two technologies, but it is still being tested for some disadvantages that it may have according to these articles [26], [29], [37].

**4.3. Benefits of integrating blockchain technology into the IoT**

As can be seen, there are several benefits of integrating blockchain technology to the IoT, so in table 9, the most important are presented.

*Table 9. Articles about the benefits of integrating Blockchain technology to the IoT*

Benefits	Related Studies
Improved scalability	[26], [33], [29], [36], [37]
Improved security	[34], [27], [41], [18], [20], [44], [42], [11], [31], [10], [1] ,[17] ,[30], [24] ,[38] ,[46]
Improved response time	[40], [32]
Cost savings	[35], [43], [40]
Efficiency in the consumption of resources	[23], [45], [21], [48]

As can be seen, one of the benefits of blockchain technology is security [1], [10], [11], [17], [18], [20], [24], [27], [30], [31], [34], [38], [41], [42], [44], [46], evidenced by the way blockchain works, its ease of usage and the reliability it provides to users.

Another benefit is seen in scalability [26], since by increasing the number of existing technological devices that are used within a company, as well as the data transaction, it must be able to support those amounts of transactions generated, and therefore that with the implementation of a good protocol the BC determines that point can be improved [29], [36].

The improvement of response time is also a benefit [40] since thanks to consensus protocols, latency can decrease and that makes the response time between devices as short as possible [32].

Another benefit that was seen is the cost savings [40], since through the smart contracts that have the blockchain, the devices can be programmed and can be executed automatically and generated while reducing expenses [35], [43].

In addition, the reduction in physical infrastructure is going to be used by computational power of thousands of computers around the world.

Efficiency in the consumption of resources is also one of the benefits that blockchain technology can provide [23]. Since some protocols such as POA are considered eco-friendly, they do not need too much energy in order to function [45], [21], [48].

**5. Discussions and Conclusions**

According to the research presenting the articles regarding to the use of blockchain technology, it can be said that the IoT is important, since it allows to solve and even overcome those challenges that it has today, in addition to providing many advantages when applying it but effectively and efficiently, starting from a safer approach.

Several implementations and application of tests were found where blockchain technology is integrated with the IoT, thus demonstrating that these two technologies together do work and not only provided a better way to save data and maintain communication between devices and clients, but increases security to a level practically impossible to penetrate.

Regarding consensus techniques, for the design and development of IoT networks on a distributed blockchain, these must be used so that the nodes reach an agreement which would save resources and maintains the efficiency of the network.

According to our systematic review, some consensus protocols cannot be applied to the Internet of Things efficiently like POW, studied in the period from 2018 to 2022. If it were to be applied in this case, inefficient results would be obtained.

Therefore, POS and PBFT that were the most recommended to use when you want to implement IoT with blockchain technology.

So it is important to test larger functional blockchain networks in order to more accurately determine each aspect of improvement that this technology is capable of providing to the IoT.

We can conclude that this technology contributes positively in the area of security, so it is evident in the improvement of network scalability, allowing the implementation of a larger IoT network by making use of the computing power of all the nodes that belong to the network to optimize performance by allowing all connected devices not to lose service.

The most appropriate protocol is based on trust and the choice of nodes responsible for allowing or denying transactions within the IoT, improves response time by 25% compared to the use of a traditional consensus protocol such as POW, which takes 25% less time to receive and send information on a computer using this technology [32].

It saves costs by 30%, potentially saving banks between 8 to 12 million and thus demonstrating the efficiency it represents in its low consumption of resources compared to the current IoT infrastructure.

Finally, we emphasize that it should be considered that the predictions of growth when applying the blockchain in different areas of society represents a great opportunity to continue researching about it.

## 6. Limitations and Future Research

Some limitations were considered in the first instance, the amount of research was not as expected, and some additional research helped us gather more information. In the second instance, within the systematic review, it could be observed that not many articles were found on the subject, which made it difficult to discuss them, so the study was limited. Finally, this article focused on the integration, techniques and benefits that blockchain would bring to the Internet of Things.

Therefore, we hope that this research will help in more increased interest of this technology and insist on investigating more of the subject treated.

Since the IoT is in different sectors such as: Health [51], [52], education [53], [54], construction [55], agriculture [56], energy [57], [58], etc., and necessary to have requirements that must be met so that the information that the IoT handles, is safe and reliable. On the other hand, future research should be related to how blockchain technology would benefit IoT technology apart from its security in order to the control and manage these devices.

From our point of view we came to the conclusion that a possible solution to the problems presented, would be the implementation of blockchain technology.

## References

- [1]. Kumar, N.M., & Mallick, P.K. (2018). Blockchain technology for security issues and challenges in IoT. *Procedia Computer Science*, 132, 1815-1823.
- [2]. Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. *Computer Networks*, 54(15), 2787–2805.
- [3]. Panarello, A., Tapas, N., Merlino, G., Longo, F.; & Puliafito, A. (2018). Blockchain and iot integration: A systematic survey. *Sensors*, 18(8), 2575.
- [4]. Restrepo Escobar, E.A., & Olaya Urrego, D.A. (2018). *Desarrollo de un prototipo basado en Blockchain aplicado a la plataforma IoT sobre un sistema embebido* [Tesis de pregrado, Universidad Distrital Francisco José de Caldas] Repositorio Udistrital. Retrieved from: <https://repository.udistrital.edu.co/handle/11349/13878> [accessed: 12 January 2023]
- [5]. Kim, S., Chandra, G., & Editors, D. (2020). *Advanced Applications of Blockchain Technology*. Springer Nature Singapore.
- [6]. Romero, M.I., Figueroa, G.L., Vera, D.S., Álava, J.E., Parrales, G.R., Álava, C.J., Murillo, Á.L., & Castillo, M.A. (2018). *Mecanismo Correctivos en seguridad informática: Introducción a la seguridad informática y el análisis de vulnerabilidades*. 3Ciencias.
- [7]. ESET LATINOAMÉRICA (2017). *La inmortalidad de los datos (y de las personas) en la era digital*. We live security. Retrieved from: <https://www.welivesecurity.com/la-es/2015/03/10/inmortalidad-de-los-datos-era-digital/> [accessed: 24 January 2023].
- [8]. Narbayeva, S., Bakibayev, T., Abeshev, K., Makarova, I., Shubenkova, K., & Pashkevich, A., (2020). Blockchain Technology on the Way of Autonomous Vehicles Development. *Transportation Research Procedia*, 44, 168-175.
- [9]. Panarello, A., Tapas, N., Merlino, G., Longo, F., & Puliafito, A. (2018). Blockchain and iot integration: A systematic survey. *Sensors*, 18(8), 2575.
- [10]. Reyna, A., Martín, C., Chen, J., Soler, E., & Díaz, M. (2018). On blockchain and its integration with IoT. Challenges and opportunities. *Future Generation Computer Systems*, 88, 173–190.
- [11]. Dorri, A., Kanhere, S. S., Jurdak, R., & Gauravaram, P. (2017). Blockchain for IoT security and privacy: The case study of a smart home. *2017 IEEE International Conference on Pervasive Computing and Communications Workshops, PerCom Workshops 2017*, 618–623.
- [12]. Acurio Conteron, O. D. (2021). *Sistema de Smart Home Aplicando IoT y Blockchain* [Tesis de pregrado, Universidad Tecnica de Ambato]. Repositorio Uta. Retrieved from: <https://repositorio.uta.edu.ec/handle/123456789/33158>. [accessed: 20 January 2023]
- [13]. Kitchenham, B., & Charters, S. (2007). Guidelines for performing Systematic Literature Reviews in Software Engineering. *Software Engineering Group*, 1-66.
- [14]. Rudas, J.S., Gómez, L.M., & Toro, A.O. (2013). Revisión sistemática de literatura. Caso de estudio: Modelamiento de un par deslizante con fines de predecir desgaste. *Prospectiva*, 11 (1), 50-58.
- [15]. Hernández, C.E., & Carpio, N. (2019). Introducción a los tipos de muestreo. *ALERTA Revista Científica del Instituto Nacional de Salud*, 2(1) 75-79.
- [16]. Zhen, Z., Xie, S., Dai, H.N., Chen, X., & Wang, H. (2018). Blockchain challenges and opportunities: a survey. *In International Congress on Big Data*, 14 (4), 352-375.

- [17]. Bao, Z., Shi, W., He, D., & Chood, K.-K. R. (2018). IoTChain: A Three-Tier Blockchain-based IoT Security Architecture. *Computer Science*, 1-23.
- [18]. Novo, O. (2018). Blockchain Meets IoT: An Architecture for Scalable Access Management in IoT. *IEEE Internet of Things Journal*, 5(2), 1184–1195.
- [19]. Tian, Z., Yan, B., Guo, Q., Huang, J., & Du, Q. (2020). Feasibility of Identity Authentication for IoT Based on Blockchain. *Procedia Computer Science*, 174, 328–332.
- [20]. Dong, Z., Luo, F., & Liang, G. (2018). Blockchain: a secure, decentralized, trusted cyber infrastructure solution for future energy systems. *Journal of Modern Power Systems and Clean Energy*, 6(5), 958–967.
- [21]. Makhdoom, I., Abolhasan, M., & Ni, W. (2018). Blockchain for IoT: The challenges and a way forward. In *ICETE 2018-Proceedings of the 15th International Joint Conference on e-Business and Telecommunications*, 428-439.
- [22]. Vairam, P. K., Mitra, G., Rebeiro, C., Ramamurthy, B., & Veezhinathan, K. (2018). ApproxBC: Blockchain Design Alternatives for Approximation-Tolerant Resource-Constrained Applications. *IEEE Communications Standards Magazine*, 2(3),45-51.
- [23]. Liu, T., Yuan, Y., & Yu, Z. (2021). The service architecture of Internet of things terminal connection based on blockchain technology. *The Journal of Supercomput* 77(11), 12690-12710.
- [24]. Matsuura, K. (2019). Token model and interpretation function for blockchain-based Fintech applications. *IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences*,102(1), 3–10.
- [25]. Uddin, M., Muzammal, M., Hameed, M.K., Javed, I.T., Alamri, B., & Crespi, N. (2021). CBCIoT: A Consensus Algorithm for Blockchain-Based IoT Applications. *Applied Science*, 11(22), 11011.
- [26]. Hammi, M. T., Hammi, B., Bellot, P., & Serhrouchni, A. (2018). Bubbles of Trust: A decentralized blockchain-based authentication system for IoT. *Computers and Security*, 78, 126–142.
- [27]. Salah, K., Nizamuddin, N., Al-Fuqaha, A., Salah, K., Rehman, M. H., Nizamuddin, N., & Al-Fuqaha, A. (2019). Blockchain for AI: Review and Open Research Challenges. *IEEE Access*,7,10127-10149.
- [28]. Puthal, D., & Mohanty, S. P. (2019). Proof of Authentication: IoT-Friendly Blockchains. *IEEE Potentials*, 38(1), 26–29.
- [29]. Yeow, K., Gani, A., Ahmad, R. W., Rodrigues, J. J. P. C., & Ko, K. (2018). Decentralized Consensus for Edge-Centric Internet of Things: A Review, Taxonomy, and Research Issues. *IEEE Access*, 6, 1513–1524.
- [30]. Rejeb, A., Keogh, J. G., & Treiblmaier, H. (2019). Leveraging the Internet of Things and blockchain technology in Supply Chain Management. *Future Internet*, 11(7),161.
- [31]. Ramezan, G., & Leung, C. (2018). A Blockchain-Based Contractual Routing Protocol for the Internet of Things Using Smart Contracts. *Wireless Communications and Mobile Computing*, 1-14.
- [32]. Singh, N., & Vardhan, M. (2019). Blockchain based E-Cheque clearance framework. *Scalable Computing: Practice and Experience*, 20(3), 511–526.
- [33]. Zhaoxin, Y., Ruizhe, Y., Meng, L., Fei, Y. R., & Yanhua, Z. (2022). A load balance optimization framework for sharded-blockchain enabled Internet of Things. *High Technology Letters*, 28(1), 10-20.
- [34]. Wang, X., Zha, X., Ni, W., Liu, R. P., Guo, Y. J., Niu, X., & Zheng, K. (2019). Survey on blockchain for Internet of Things. *Computer Communications*, 136, 10–29.
- [35]. Ma, M., Shi, G., & Li, F. (2019). Privacy-Oriented Blockchain-Based Distributed Key Management Architecture for Hierarchical Access Control in the IoT Scenario. *IEEE Access*, 7, 34045–34059.
- [36]. Amritanand, C., & Vipin, P. (2019). A survey on blockchain based access control for IoT. *Proceedings of International Conference on Recent Trends in Computing, Communication & Networking Technologies (ICRTCCNT)*, 618-623.
- [37]. Abdelmaboud, A., Ahmed, A. I. A., Abaker, M., Eisa, T. A. E., Albasheer, H., Ghorashi, S. A., & Karim, F. K. (2022). Blockchain for IoT Applications: Taxonomy, Platforms, Recent Advances, Challenges and Future Research Directions. *Electronics*,11(4),630.
- [38]. Liang, N. (2020). Security transmission and storage of internet of things information based on blockchain. *IOP Conference Series: Materials Science and Engineering*, 750(1),012164.
- [39]. Ding, S., Cao, J., Li, C., Fan, K., & Li, H. (2019). A Novel Attribute-Based Access Control Scheme Using Blockchain for IoT. *IEEE Access*, 7, 38431-38441.
- [40]. Zhang, Y., Li, B., Liu, B., Wu, J., Wang, Y., & Yang, X. (2020). An attribute-based collaborative access control scheme using blockchain for IoT devices. *Electronics*, 9(2),285.
- [41]. Xu, R., Chen, Y., Blasch, E., & Chen, G. (2018). BlendCAC: A BLockchain-ENabled Decentralized Capability-based Access Control for IoTs. *2018 IEEE International conference on Internet of Things (iThings) and IEEE green computing and communications (GreenCom) and IEEE cyber, physical and social computing (CPSCom) and IEEE Smart Data (SmartData)*,1027-1034.
- [42]. Christidis, K., & Devetsikiotis, M. (2016). Blockchains and Smart Contracts for the Internet of Things. *IEEE Access*, 4, 2292-2303.
- [43]. Košťál, K., Helebrandt, P., Belluš, M., Ries, M., & Kotuliak, I. (2019). Management and monitoring of IoT devices using blockchain. *Sensors*, 19(4),856.
- [44]. Dorri, A., Kanhere, S. S., & Jurdak, R. (2017). Towards an optimized blockchain for IoT. *2017 IEEE/ACM 2nd International Conference on Internet-of-Things Design and Implementation, IoTDI*, 173-178.
- [45]. Ouaddah, A., Elkalam, A. A., & Ouahman, A. A. (2017). Towards a novel privacy-preserving access control model based on blockchain technology in IoT. *Advances in Intelligent Systems and Computing*, 523-533.
- [46]. Venkatraman, S., & Parvin, S. (2022). Developing an IoT Identity Management System Using Blockchain. *Systems*, 10(2), 39.

- [47]. Al Ahmed, M. T., Hashim, F., Hashim, S. J., & Abdullah, A. (2022). Hierarchical blockchain structure for node authentication in IoT networks. *Egyptian Informatics Journal*, 23(2), 345-361.
- [48]. Romashkova, I., Komarov, M. & Ometov, A. (2021). Demystifying Blockchain Technology for Resource- Constrained IoT Devices: Parameters, Challenges and Future Perspective, *IEEE Access*, 9, 129264-12927, 2021.
- [49]. Ortega, J.M., (2021) *Ciberseguridad. Manual práctico*. Editorial Paraninfo.
- [50]. Thoppae, C., & Praneetpolgrang, P. (2021). An analysis of a blockchain-enabled e-government Document Interchange Architecture (DIA) in Thailand. *TEM Journal - Technology Education Management Informatics*, 10(3), 1220-1227.
- [51]. Valsalan, P., Baomar, T. A. B., & Baabood, A. H. O. (2020). IoT based health monitoring system. *Journal of critical reviews*, 7(4), 739-743.
- [52]. Kashani, M. H., Madanipour, M., Nikravan, M., Asghari, P., & Mahdipour, E. (2021). A systematic review of IoT in healthcare: Applications, techniques, and trends. *Journal of Network and Computer Applications*, 192, 103164.
- [53]. Al-Emran, M., Malik, S. I., & Al-Kabi, M. N. (2020). A survey of Internet of Things (IoT) in education: Opportunities and challenges. *Toward social internet of things (SIoT): Enabling technologies, architectures and applications*, 197-209.
- [54]. Kassab, M., DeFranco, J., & Laplante, P. (2020). A systematic literature review on Internet of things in education: Benefits and challenges. *Journal of computer Assisted learning*, 36(2), 115-127.
- [55]. Elghaish, F., Hosseini, M. R., Matarneh, S., Talebi, S., Wu, S., Martek, I., ... & Ghodrati, N. (2021). Blockchain and the 'Internet of Things' for the construction industry: research trends and opportunities. *Automation in construction*, 132, 103942.
- [56]. Maroli, A., Narwane, V. S., & Gardas, B. B. (2021). Applications of IoT for achieving sustainability in agricultural sector: A comprehensive review. *Journal of Environmental Management*, 298, 113488.
- [57]. Hossein Motlagh, N., Mohammadrezaei, M., Hunt, J., & Zakeri, B. (2020). Internet of Things (IoT) and the energy sector. *Energies*, 13(2), 494.
- [58]. Siddique, A. H., Tasnim, S., Shahriyar, F., Hasan, M., & Rashid, K. (2021). Renewable energy sector in Bangladesh: The current scenario, challenges and the role of IoT in building a smart distribution grid. *Energies*, 14(16), 5083.