

Exploring the Blockchain Technology: Issues, Applications and Research Potential

<https://doi.org/10.3991/ijoe.v17i07.22803>

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Abstract—The blockchain is revolutionizing the current IT industry by increasing its integration with other prominent technologies like Artificial Intelligence, Internet of Things, Big Data and Cloud Computing to name a few. It works as a distributed network with no central authority, where the data is continuously added in the form of blocks. The blocks are validated by the network itself, which makes it transparent and secure. It was first used as a ledger for the transactions of a crypto currency named bitcoin, but with time, innumerable industries have started to implement it. And because of its promising future, it would not take much time to spread in all the IT related areas globally. The blockchain technology is contemplated to be a technology that is still in its infancy and needs a thorough research so that it can be utilized to its full capacity. Consequently, in order to provide a thorough analysis, this paper gives a systematic and comprehensive review of architecture and working of the blockchain along with its types and important characteristics. This paper also discusses about the prominent blockchain platforms available today along with the description of diverse blockchain supported application areas. Based on our analysis, the issues related to the blockchain technology and the areas in which the work can be done in future are also pointed in this paper, which would be helpful for practitioners and researchers who are willing to work on this fast-growing platform.

Keywords—Blockchain, Distributed Ledger, Crypto Currency, Smart Contracts, Data Management

1 Introduction

The concept of Blockchain Technology was first introduced by Satoshi Nakamoto, almost a decade ago [1]. It was the first time when a distributed network was integrated with the cryptology in order to carry out the peer-to-peer transactions of a crypto currency named bitcoin in a secure and transparent manner. Initially, the usage of blockchain was restrained because of its complexity and unpredictability, but with time it has gained the global attention. And if we talk about today's scenario, "The Economist" has compared it with "trust machine" and has predicted, "the blockchain will redefine the world", also the Gartner Report rated the blockchain as one of the highest "inflated expectations" among all the developing technologies [2,9]. The blockchain is a model that utilizes the several technologies like smart contracts, peer-to-peer transactions, decentralized and distributed network along with the cryptographic algorithms [3,4].

Basically, a blockchain is a data structure that is used during the transactions, which stores the information or data in the form of blocks, and these blocks are connected chronologically to make a chain of blocks called blockchain. It is the duty of the nodes within the network to connect these blocks to one another, with the help of the hash values that present in the block itself, each block has its own hash value along with the hash of the previous block, that helps in making the block connections [4]. The blocks are in encrypted form to assure the security and integrity of the data, and the network itself does the validation of the blocks. The blockchain is still in its development phase, and has fascinated governments, researchers and organizations, as it has the potential of making the transactions safer, faster as well as cheaper. The number of crypto currencies based on the blockchain architecture has reached almost 2000 and still continues to grow [5]. And the landscape of blockchain is also evolving at a high pace in other areas beyond crypto currency. In fact, the usage and implementation of blockchain has left the crypto currency platform far behind it, and has become the best choice of various industries that needs decentralization in an immutable way with all the historic information. The blockchain is a novel methodology that uses the consensus in a distributed manner for creating, verifying, processing and updating the data. The data is stored using the block structures, while it is manipulated using smart contracts [7].

The smart contracts in the blockchain plays a vital role; it was first defined by Szabo [6] as "a computerized transaction protocol that executes the terms of a contract", that eliminates the need of any external element during transaction and reduce the risks related to security. Essentially, a smart contract is an agreement among the parties that might not trust one another completely but have agreed upon certain terms and conditions enforced by the contract, in blockchain the smart contracts are scripted and runs on the decentralized network without trusting any central authority or third party [8]. Since the blockchain infrastructure is decentralized and uses distributed networking, it can be very useful for many application areas, and is expected to change the entire face of the Internet and human behaviors over Internet. The growth of blockchain has gained attention from several prominent IT industries and has given them opportunity of expanding their businesses. IBM has introduced BaaS (Blockchain as a Service) that is a service platform provided to the consumers to work on the blockchain and develop their own businesses or perform researches [10]. NASDAQ also launched a trading platform

called Linq that is based on the blockchain framework. Microsoft, Amazon and Google have also joined the business of BaaS. The Information Technology is evolving and reaching towards the level where efficient techniques and tools are being developed and deployed so as to handle the large amounts of heterogeneous data called Big Data. The amount of data being generated online has promoted the learning based on information provided by this data itself, as the data is growing exponentially. As per a study, Google receives more than 4 million queries every minute, while the number of mails being and sent and received is around 200 million. Around 72 hours long videos are being uploaded on the YouTube and thousands of pictures are uploaded on Instagram, thousands of tweets shared on twitter, millions of messages are exchanged on WhatsApp, all this information is generated and circulated in just one minute, and maintained on the cloud-based environments [75,76,79]. It has been said by International Data Corporations that the digital data being generated is rapid and is going to be ten times of the amount of data in 2013, by the end of 2020 [77, 78]. Since, the decisions are based on the information received from this huge chunk of data, it has become necessary to handle this Big Data in a way that is efficient along with secure, tamperproof and transparent so that no unauthorized person can access the data. Since, the blockchain supports the distributed architecture, the data is made available and accessible to every node on the network. Moreover, the new data block can only be added to the chain after being validated by entire network. This makes the decision making reliable and trustworthy. Furthermore, the data on the blockchain is in encrypted form, which eliminates the risks of data breaches or leakages.

In order to identify the research and work that has already been done in the field of blockchain technology, a systematic analysis of several research papers and scholarly articles is done. The overarching objective of this paper is to focus on the existing information related to the architecture and working of the blockchain and its implementation in various application domains. The paper also gives insight about the open issues and the future research areas in the field of blockchain. The rest of this paper is organized as follows. In section 2, a brief overview of the blockchain technology is outlined in which the architecture and working of blocks and blockchain, different types of available blockchains, its distinct characteristics and the available blockchain platforms are summarized. Next section 3 discusses about the various application areas in which the blockchain-based systems have been applied successfully. The issues in the blockchain and the possible future trends are discussed in section 4, which is followed by the conclusion in section 5.

2 Blockchain Overview

A blockchain is a time stamped, distributed network with peer-to-peer connectivity that validates itself, and because of its uniqueness it is gaining attention progressively. The complete development of the blockchain can be divided into three stages as shown in Figure 1 below [11]. The first stage is called Blockchain 1.0 that includes the crypto currencies available in the market, second stage is Blockchain 2.0, which consists of ledger agreements like smart contracts and consensus protocols and the third stage is

Blockchain 3.0 that consists of applications areas beyond the other two stages including IoT, healthcare, education, security etc. which is going to transform the lives of people and the IT industry.

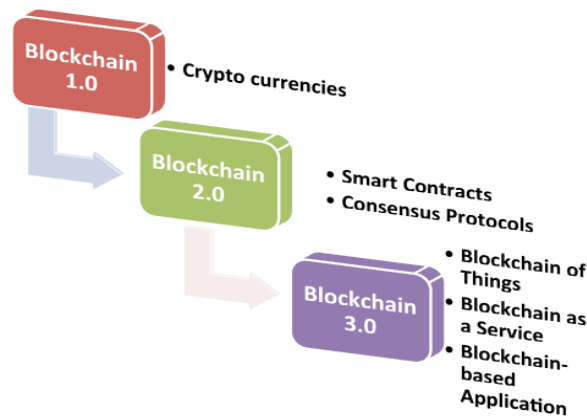


Fig. 1. Development stages of Blockchain

Blockchain 1.0 consists of crypto currencies including bitcoin which is the first ever crypto currency that gave the concept of blockchain technology. The basic blockchain structure solved the security, integrity and authenticity concerns that made it so popular [12]. The transactions are secured by using digital signatures and hash values. The fundamental technology behind Blockchain 2.0 was smart contracts, which has two main properties the digitization of assets and mapping of real-world logic to these assets through scripting languages. This has made it more popular as real world can be traced on the blockchain network and the origin as well as the authenticity of the content can be traced. The third stage of the development phase of Blockchain is still under progress and the definition is quite ambiguous and totally dependent on its future scope and potential. The blockchain is going through a rapid developing phase; the next gen could have many aspects like integration and inter operation with other dominant IT technologies like cloud computing, IoT, artificial intelligence, big data etc. [13,14]. The Blockchain 3.0 uses the decentralized network structure and consensus mechanisms for the new developments in technology. This generation of Blockchain development phase would transform both the IT industry as well as Human computer interaction with the help of blockchain of things and blockchain as a service.

2.1 Blockchain architecture & working

Blockchain is a type of data structure that is used to store the transaction data in the form of blocks and connect these blocks to one another to form a chain called blockchain. The size of this chain grows with the number of transactions, as with every transaction a new block is generated and added to the chain as shown in Figure 2. In the

blockchain-distributed network every member of the network is responsible for maintaining, approving and updating of the entries. There is no central authority, which means every participant ensures the validation and security of the network. The members might not trust one another but had to agree through a common consensus to maintain reliance.

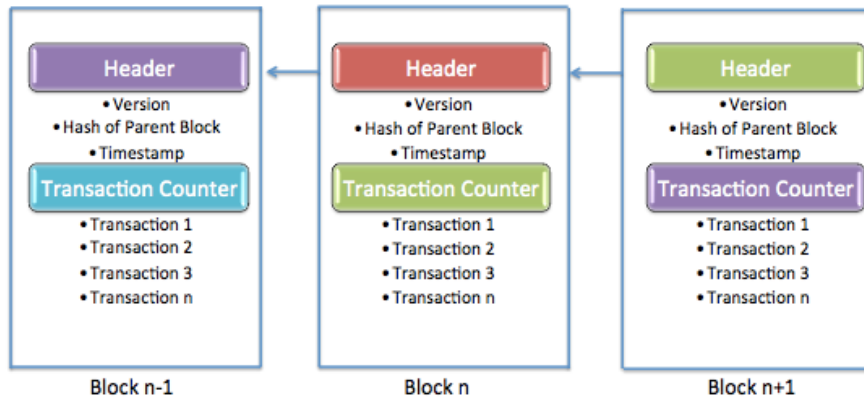


Fig. 2. Blockchain with sequence of Blocks

Following are the basic architectural components of the blockchain architecture, although there could be more than these components, but for the basic understanding of the working blockchain technology these components are very important:

Block: A block is the basic data structure element of the blockchain that is divided into two parts: header and transactions as shown in Figure 3. The header consists of the information such as the index number, hash of the parent block, time stamp etc. that validates the existence of the block. The first block of the blockchain is called ‘genesis block’, and it does not have the hash for the previous block as it does not have any parent block. These blocks are created by any of the node within the network and must be accepted by all other nodes in order to be added into the blockchain. The blocks could be of three types, the blocks that are added to the longest blockchain, are called “main branch blocks”. The blocks that have the hash of the previous block, which is in another chain or the chain that is not the longest in the network, are called as “side branch blocks”. These blocks are not considered to be the part of the main blockchain, but if in future more blocks are mined and referenced to these side chain blocks, then there is a chance that this chain containing the side branch blocks become longer and considered as main chain. While if the block is pointing to a parent block which is not in the knowledge of the current node, then that block is called “orphan block”.

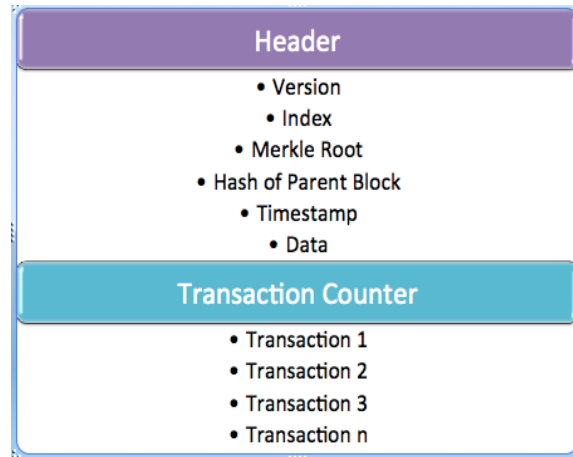


Fig. 3. Structure of a Block

Transaction: The transactions are the basic building blocks of the blockchain platform. The transactions contain the address of the recipient and sender along with the data. The sender of the data sends it after applying the digital signature to the hash of the previous transaction. After that, the transaction is broadcasted to the entire network, and all the nodes of the system have their copy of the blockchain, and they calculate the current state using all the transactions of the blockchain. As the transactions are publicized, each of the nodes verifies it. All these transactions are time stamped, that keeps the track of the time at which it was generated. Also, when a block is manipulated in the blockchain, instead of changing the existing block, a new block is created and added, this ensures that all the information created so far is untouched and maintains the integrity of the system.

Peer-to-peer network: Blockchain works on the peer-to-peer network; it is a distributed system that does not have any central controlling authority, which means all the nodes are equally important and have the equal influence, which is assured by the consensus protocol. These peers are responsible for providing the storage and computation powers to the network, also since they are not centralized, there do not exist any single point of failure. The blockchain could be permission-less or permission-based, in which the addition of nodes will be dependent on the permission from the other nodes available in the network.

Consensus protocol: In blockchain distributed peer-to-peer network the copy of each and every transaction is available to all the available nodes. It is the consensus protocols that make the blockchain secure. As it is the duty of the consensus mechanism to ensure that every individual has the updated, identical and consistent copy. And the new block is added only after the approval by all the available nodes. The goal of the consensus is to make an agreement between the nodes throughout the network with equal rights, co-operation and participation. The popularly available consensus mechanisms include Proof of Work (PoW), Proof of Stake (PoS) etc. [81].

Working: From the above discussion we know so far that blockchain is basically a chain of blocks that are connected together using cryptographic algorithms. Each block of the blockchain consists of the hash of previous/parent node, timestamp and the transaction data. It is not possible to modify the data of blockchain, because the transactions are done through a publicly available distributed network, and the changes made are permanent, as they cannot be altered. All the nodes agree to a consensus agreement that works as the trust mechanism among the various parties. The blockchain is a self-verified network, which assures the validity and authenticity of the transactions. The transaction in a blockchain network is a multi-step procedure as shown in Figure 4 and described below.

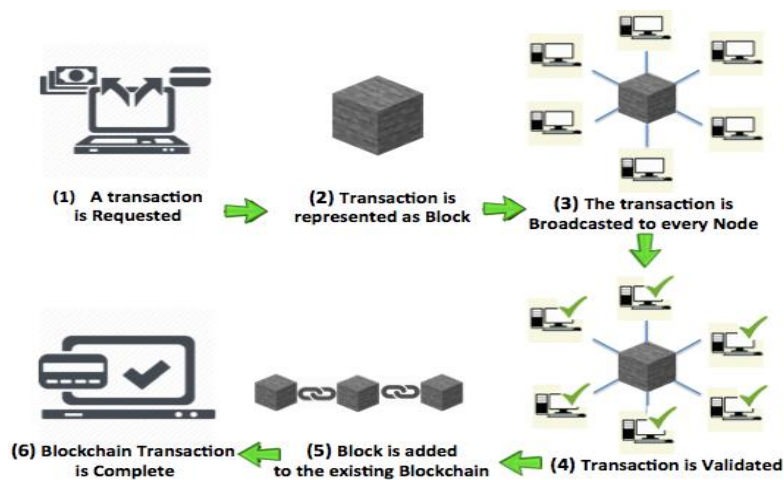


Fig. 4. Working of Blockchain

Blockchain platform is used to carry out the transactions on a distributed decentralized network in a secure manner. When a transaction is requested by a node, it is first represented as a block containing all the necessary information like time stamp, transaction details, data, hash of previous node to which it would be connected etc. or in simple terms it is a block of digital data. This block is then broadcasted to all the nodes present in the network, these nodes verify whether or not the transaction is genuine and follows the consensus. After the verification of the block, the block is added to the existing blockchain and the transaction is completed. The blockchain is basically a giant track of the records and transactions happened so far. It is considered to be secure than any other platform available today and has fault tolerance capability because of its distributed nature.

2.2 Blockchain types

The blockchain technology is being adapted by various industries and can have numerous applications. It can be used in different domains in different ways; following are the types of blockchain networks that can be selected by the users on the basis of

their requirements as shown in [15-18]. All these types of blockchain are different from one another, but they have commonalities such as peer-to-peer connections, distributed-decentralized network structure and block-based time-stamped transactions.

Public blockchain: A public blockchain is a permission-less distributed network that does not have any types of restrictions. Anyone who wants to get access of the blockchain can join the network and become an “authorized node”. This node has the right to perform transactions, access the past records and historical transactions, and can verify the blocks of data. The public blockchains are usually used for the transactions of crypto currencies, which are secure if the users follow the protocols strictly. The users can trust the public blockchain because they do not need to know the by themselves, the proof-of-work ensures it. Since, anyone can become the part of a public blockchain, its size is usually very large, that makes it more secure because larger the chain, more distributed are the records. Moreover, it is transparent as the ledger of all the records is open and available to all the authorized nodes.

But with all these benefits, there are few shortcomings of public blockchain including slow speed of processing the transactions, because the number of nodes is large in the network, and for every transaction the verification and proof of work consumes more time, that also makes it difficult for adding more nodes to the network and hence the scalability is also a concern. Furthermore, the amount of energy consumed in such networks for proof-of-work is also very excessive that is neither efficient economically nor environmentally.

Examples of Public Blockchain are Bitcoin, Litecoin and Ethereum.

Private blockchain: A private blockchain is a permission-based distributed network that has a few restrictions and only works within a closed network. These blockchains are usually preferred by the organizations that want only the restricted members to access and participate in the network. And no one from outside the network can access the information [19]. The total control of all the aspects is in the hands of the organization’s authorities. Such networks can be used for managing identity, ownership management of assets, managing supply chain etc.

The advantages of private blockchains over public blockchains are its speed and scalability. As the number of nodes in this type of networks is restricted, the speed is higher because the verification and consensus procedures do not take much time, that makes it possible for the networks to make thousands of transactions per second. Additionally, the number of nodes can be decided as per the requirements and makes the network more scalable and flexible. However, this blockchain is not an open and publically available network, therefore only trustworthy members are added to the network and the trust is also maintained throughout the lifetime because the information being transmitted is confidential. Furthermore, the number of nodes is lesser that may lead to security easier data breach or hacking of the entire network.

Examples of Private Blockchain are Corda, Fabric and Sawtooth.

Consortium blockchain: It is a type of blockchain that is controlled by some of the nodes. In this, a group of representatives of several organizations called “consortium” come together to take the decisions for the betterment of the network. These networks are used mainly in the banking sectors and government organizations. In such networks, some of the nodes are responsible for controlling the consensus procedures while some

of them are allowed for participation in the transactions. It might be seen as a combination of public and private blockchain, as the network consists of multiple nodes like public blockchain and the restriction on these nodes like private blockchain [20].

Examples of Consortium Blockchain are Energy web foundation and R3.

2.3 Blockchain characteristics

The blockchain network has several salient characteristics that make it the best choice for the transactions in secure and transparent manner. Some of its relevant features are listed below:

Decentralization: A blockchain network is a peer-to-peer connection oriented distributed network that can be used to store the transactions [21]. The information is distributed among all the nodes of the network automatically without any third-party involvement [22]. Moreover, decentralization means that there is no single central authority, which means there does not exist any single point of failure [23,24]. Also, the data is totally under control of its owner with the usage of private key and can be transferred to anyone anytime.

Time stamping: Every transaction of the blockchain is created in the form of a blocks that gets the time stamping in chronological order. This provides the complete history of the transactions to the users and assures the transparency and traceability [25]. It not just promises the originality of the data, but supports the permanent nature of the blocks. With its help the existence of the block can be validated without any doubt.

Immutability using cryptographic hashing: The blocks in the blockchain cannot be altered, if someone wants to modify any data, then a new block is generated instead. This assures that the data once registered within the network would never get deleted or modified [11]. This also ensures the integrity of the network, because if any of the blocks gets deleted or modified then the hash of the previous node gets affected and the entire network is notified and the transaction would not be approved [26].

Consensus protocols: Consensus protocols are said to be the core part of the blockchain technology. It is a mutual agreement between all the nodes of the network that tells how the transactions will be validated [21]. It provides a way to maintain trust between the unknown nodes of the network and deliver reliability to the platform. There are several types of consensus methods available today like proof-of-work and proof-of-stake.

Smart-contracts: Smart contracts are basically the source code that is implemented on the blockchain when the required conditions are satisfied. They have been in the market even before the blockchain and works as a contract, which does its work without the need of any third-party intervention. The data is released only after the mentioned requirements are met. They are the core concept behind the Blockchain 2.0 generation and have the capacity to process and manage the digital assets [27].

2.4 Prominent blockchain platforms

Ever since the bitcoin was proposed and implemented using blockchain network, the technology has gained huge popularity and several platforms working on the mechanism of blockchain have been anticipated. In this section, a brief description of few most famous ones is given below:

Ethereum: Ethereum was founded in 2013, it provides an open-source platform based on blockchain distributed computing network. It is used for implementing smart contracts on customized blockchain. It offers Ethereum Virtual Machine (EVM) for smart contracts working, and every node of the network is asked to run the EVM application. It is a public blockchain and works on proof-of-work that makes it a bit slower. The users of Ethereum are charged in the form of Ethers.

Hyperledger fabric: It uses the modular architecture for building blockchain-based applications. The flexibility is provided to the users to add the components as per their choice, which makes this platform different from others. This is a permission-based system that means the node needs to ask for the permission to be a part of the network and only the known systems can participate in the transactions.

Corda: R3 consortium is world's largest financial organization that has developed the R3 Corda, a blockchain based platform. It allows several organizations to perform business transactions with one another directly without needing any intermediary. It is also a permission based blockchain network that allows only the authorized participants to access the data. It was first designed for application in financial industry, but is now being used in various application domains.

Ripple: It is a platform that focuses on connecting the banks, digital assets providers, exchanges etc. to communicate via blockchain based distributed network called RippleNet. It also promotes a crypto currency called Ripple, and the transactions are made through this. It uses the probabilistic voting technique to implement the consensus among the nodes and is considered to be faster and scalable.

Quorum: Ethereum developers along with the J.P. Morgan founded the blockchain-based network called quorum, which is an extension of Ethereum that mainly focus on enterprises. Since, it is an extension of Ethereum, it is also an open source and free of cost platform. It implements the vote-based approach to process the transactions. The nodes of this network are not publicly accessible, as it works on the permission-based ledger.

There are several other blockchain-based platforms available in the market today, but the above five are the most popular ones, a summarized view of these platforms is given in Table 1 below:

Table 1. Summary of Blockchain Platforms

	Ethereum	Hyperledger Fabric	Corda	Ripple	Quorum
Industry-Focus	Cross-Industry	Cross-Industry	Financial Services	Financial Services	Cross-Industry
Ledger-Type	Permission-less	Permissioned	Permissioned	Permissioned	Permissioned
Consensus Algorithm	Proof of Work	Pluggable Framework	Pluggable Framework	Probabilistic Voting	Majority Voting
Smart Contract	Yes	Yes	Yes	No	No
Governance	Ethereum Developers	Linux Foundation	R3 Consortium	Ripple Labs	Ethereum Developers & J P Morgan Chase

3 Blockchain Application Areas

Blockchain is a platform for maintaining the transactions and records that can be used by any application domain. It is a transparent way of protecting and securing the data, and keeping it indestructible. Since, the blockchain is a distributed network, the data is broken into pieces and distributed among all the nodes of the network, and hence it is impossible for anyone to tamper it. This has made the blockchain the hero and is being adapted by several industries to make their business more secure, cheaper and faster. A few of them are depicted graphically in Figure 5, and discussed in this section below:

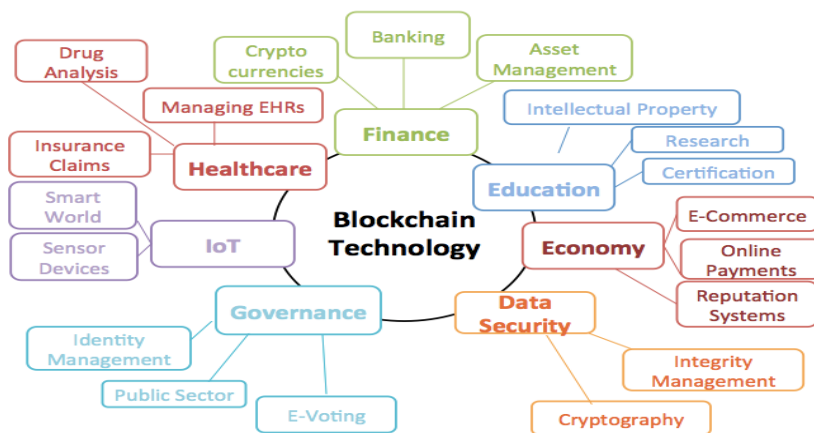


Fig. 5. Different applications of Blockchain Technology

- **Crypto currencies & Finance:** The blockchain technology is being used in various financial areas nowadays including banking, settlement of assets, prediction marketing etc. [28]. If we talk about the banking industry, thousands of transactions takes place every second and involves the money and other assets, this make the blockchain an ideal choice for this sector. The blockchain can be beneficial for the banking in terms of storage, speed as well as electricity consumption [29]. Blockchain offers a variety of applications in finance industry like loan management [30], digital payments [31], financial auditing [32], banking services [29], crypto-currencies etc. [33,34]. Blockchain provides a secure and safe way of money exchange and allows the user to work on the transparent platform with very low operational cost. It also eliminates the need of any intervening party that makes it more cheaper because managing all the mediators is quite costly. Furthermore, with more and more number of persons in between means more vulnerable and error prone the system is, so blockchain eliminates all these vulnerabilities from the finance network.
- **Education & Innovation:** Education is another area in which the blockchain is making progress and several researchers are being conducted to promote online education and training [82,83]. The blockchain networks are known for their immutable record generation process that might help in the education and development sector to keep a track of all the activities and researches across various learning institutions and research organizations [35]. The blockchain could also be used for keeping the record of the courses studied by the students and the degrees and certificated issued to them [36], so that no one can generate or show any fraudulent certification or degree. It can also help in carrying out the research in a protected manner, as one can use the blockchain network to keeping and maintain the intellectual properties. Since the network itself, on the basis of the timestamps, verifies the blockchain, the intellectual property would be safe and maintain its origin by itself. The researcher can also work on this platform to keep their research safe and maintain its integrity throughout the entire process. In the regard of research papers, a blockchain platform is proposed in [37], that keeps a track of the contributions made by the authors on the basis of the editing.
- **Healthcare & Welfare:** Healthcare industry is one of the industries that might have the most possible use cases of blockchain in order to develop a transparent infrastructure for storage and analysis of healthcare data [38]. It can also help in development of new medicines and also a less costly healthcare diagnosis. Several researches have been conducting in this area focusing on secure data management [39], medical image sharing [40], digital contact tracing [80, 84] and general medical records storage [41]. Apart from the patient diagnosis and the medical records, the blockchain can also help in analyzing the data generated by intelligent devices, tracing the origin of the drugs, records of side effects of a particular drug etc. Moreover, the pharmacies could also use the blockchain platform to keep the supply chain information traceable among the producer, consumer and the seller [42]. Blockchain can also improve the state of art of the insurance sector, from putting the quotation to claiming the expenses; the blockchain can provide a transparent way and reduce the fraudulent requests.

- **Security & Privacy:** The data available today in any sector is huge in amount and heterogeneous in nature, and demands the security and privacy. And using the blockchain technology, the security aspect can be enhanced [43], and the system can become more scalable and flexible. One of the main aspects to maintain the security in blockchain is to use cryptography and secure the transactions among the users. Since, the blockchain uses the hash values of parent nodes to connect the new blocks and also each block has the timestamp along with the encrypted data, it becomes impossible for the hacker or any outsider to break into the network and hence, the security and privacy is maintained. Several blockchain-based platforms are already available in the market today like are Namecoin [44] and Alexandria [45] that gives privacy, efficiency along with the censorship resistance.
- **Business & Economy:** The potential of the blockchain platform can be utilized in the field of managing the business processes using the blockchain based communication. The blockchain can be exploited in managing the supply chain of the business products, satisfying the supply and demand [46], automatic payments using verifications [47] etc. The blockchain can be used in e-commerce for commercial marketing [48], verifying the product ownership [49] and identifying the fraudsters [50]. Apart from the electronic purchase, the physical vending machines can also be managed by the blockchains, by maintaining the correct and updated information regarding the availability of products. Another aspect of e-markets is online payments, which can also use the blockchain platform to work properly. The rating of sites and the products also plays an important role in e-business, and blockchain can be used in that direction as well. This rating procedure is known as reputation system that can be done either by using a scale of 1to5 or by writing the reviews in human language [51].
- **Governance & Citizenship:** The government has always maintained the records and the official documents of the citizens and government-based organizations. The blockchain can be used to provide a platform for securely integrating the government infrastructures. The goal of blockchain governance is to provide the same facilities and services to the citizens in a decentralized way. Some of the services that come under blockchain governance are registration of marriages, legal documents, contracts, voting etc. [11]. A passport service system called World Citizen Project [52] is an implementation of distributed blockchain network that identifies the citizens globally. Since the technology and Internet is becoming ubiquitous in human lives and in order to maintain the personal records like name, credit score and personal characteristics, blockchain based platform could be an intelligent choice as it would integrate these details securely [53]. Blockchain can be used in public sector as well, for e-resident platform [54], taxation procedures [55], property management [56] etc. E voting is also a prominent area that can apply the blockchain; this would not only reduce the cost of conducting the polling but also prevent the fake voting [57]. However, the existing e-voting systems are there, but a central authority maintains them, which can be hacked or breached easily by simply taking over that central point. Therefore, adapting the distributed environment would make it secure, and particularly blockchain will make the entire polling transparent as well as traceable.

- **Internet of Things & Data Management:** Internet of Things (IoT) is one of the most widely used IT domains that have gained huge popularity in the past two years. It is estimated that the number of devices connected to the IoT is going to increase with time and would reach about 500 billion in the coming decade. The implication of IoT has not just remained restricted to the smart devices and smart homes; in fact it is going to cover almost every possible industry at a very large scale. And in future the world will become a smarter and densely connected network. In today's scenario, any failure in the IoT environment would cause the loss of personal data that would affect the individuals as well as the organizations. The main security areas of IoT are the transactions and connections among the devices and with the database storages. In order to make the smart world a sustainable option, IoT can be merged with blockchain for the safe and secure transactions, and because of its decentralized nature, there would not have any single point of failure that would cause the loss of personal data [58]. The integration of IoT and blockchain would return good more trust among the parties; faster transactions because of the distributed nature and require no intermediary that would give a low-cost system.

4 Open Issues and Research Potentials

The blockchain has been in the market for almost a decade and since then it has been applied to various application areas as we have discussed so far in this paper. However, there are still some issues that might arise while working on the blockchain. In this section, we will be focusing upon some of the limitations of this emerging technology and also throw light on its future research potentials.

- **Consensus Protocols:** Blockchain is a combination of various technologies like distributed network, decentralized mechanism, cryptographic algorithms, time stamping, consensus procedures etc. And in order to effectively utilize the blockchain platform, we need to improve the technicalities behind these technologies. If we talk about the transactions of a blockchain-based system, the consensus procedure is the core component that imposes rules to the nodes and consumes time and resources [59]. Since, the transactions need to be faster in blockchain, an improvement could be made to the application of consensus mechanisms so that the throughput of the system improves. Several researches are analyzing the different protocols for the same, so that the system could have more security, scalability with low cost and power consumption [16].
- **Scalability:** In blockchain a block is made whenever a data is generated or modified, besides it keeps the history of all the transactions, moreover a copy of the data is distributed to all the nodes within the network. All these features provide a high level of transparency, openness, security and guarantee of availability of data. This entire mechanism generates a huge amount of data and requires a huge storage for the same [16]. So, in order to generate blockchains that are efficient, more effective solutions are required. As the number of transaction increases, it becomes difficult for a single node to handle such huge amount of data, so a reconstruction of blockchain or ex-

pansion of the storage is required [60]. Another way to manage the data on blockchain could be to delete the transactions after a certain time and keep the blockchain lighter; this would fasten the validation step [61]. Ethereum have also proposed a mechanism of sharding in which the blockchain would be divided into shards and each shard would be considered as an individual blockchain to overcome problem of performance.

- **Regulations:** However, the blockchain has changed the entire ecosystem of IT industry, it has also confronted various aspects of governance and laws. It has been elicited by a series of regulations because of its exceptional nature [62]. In order to improve the situation of rules and regulations imposed on the blockchain technology, a thorough understanding is needed. Several countries have already started working in this direction and are trying to work on the anonymity, Internet identity management, jurisdiction and legal issues, legal rights etc. The legal tools can be replaced by the blockchain technology because of its cost effectiveness. Also, the secure and verifiable nature of the distributed network of blockchain would facilitate the new government models [63].
- **Interoperability:** The applications based on the blockchain technology are growing at a very high rate and provides solutions to several heterogeneous types of problems. Many organizations are working on bringing the bitcoin to the trade market, and if it happens then the entire face of trading would be changed, by letting the users and several types of international organizations to invest in crypto-currencies. However, with more and more transactions on crypto-currencies, the chances of hacking are also increasing and needs certainty to assure the malicious exchanges [64]. The currently available platforms for the operation of crypto-currencies are very distinctive and difficult to use, so several researchers have proposed resolutions to work on these problems and make the interoperability easier [65,66]. Software and hardware solutions are provided by Blockstream [67], that allows the different blockchains to coordinate. Not all types of organizations are embracing the blockchain technology because of the lack of certain regulations but still there are more organizations that need this technology because of the growing need of digitization of assets and their management in secure way.
- **Data Management:** The concern of privacy and security of the data over any platform has always been a concern for the users as well as the organizations. Withstanding all the benefits and applications, the blockchain still lacks in providing the required security and confidentiality to the data because of the data residing on the ledger that is publicly available [68, 84]. Several systems have been proposed for blockchain-based applications that maintain the data, but none of these are application independent, which means they are all reliant on the context in which they will be used, and in case of IoT based applications the demand of data security is very high [69]. Several models suggest different mechanisms for ensuring the data privacy, but the eminent problem in this context is the traceability and privacy during the transactions [70]. The most common one is using the smart contracts, but they also have their vulnerabilities themselves require frameworks for verification of their correctness.

- **Integration with other Prominent Platforms:** The world has seen various applications of Cloud Computing, IoT, Big Data and Artificial Intelligence, and almost every time we are working on the Internet, we are using at least one of these famous technologies. If the blockchain would be integrated to any of these platforms, the resultant infrastructure would yield facilities like never before, in the most efficient manner. The cloud can be integrated to the blockchain to provide the blockchain as a service model to the users in a cost-effective manner with minimal labor effort [71]. The IoT works on the intelligent devices that are connected together to analyze the incoming data and respond accordingly in a smarter way. If the blockchain based IoT is developed, the security of the data increases because usually the data generated by the intelligent devices is very private and sensitive like healthcare data, and needs proper confidentiality that could be achieved with the blockchain based infrastructure [72]. Everyone knows the wide application areas of Artificial Intelligence, and if merged with the blockchain, the results it would yield will be glorifying. The public ledger of blockchain would provide a scalable network for the AI applications to provide the results more accurately in several application domains [73]. The secure nature of blockchain makes it a good candidate for application of big data analysis and management [74]. Although handling the big data over blockchain would be a hectic thing to do but if it is implemented properly then it would be the most effective and efficient way for big data handling.

5 Conclusion

The blockchain platform works around several computing algorithms and frameworks like distributed ledger, decentralized network, cryptography, time-stamps, consensus protocols, smart contracts, peer-to-peer connections etc. and the integration of all these concepts make the blockchain an ideal choice for several application areas like banking, healthcare, education, e-commerce, governance, data management etc. by providing faster and cheaper transactions along with maintaining the immutability and confidentiality of the data. Furthermore, with the time passing the technology would become more mature and the range of its application domain would also increase. In this paper, we identified the various application domains in which the blockchain-based platform has been implemented successfully and also identified the areas that still need some work to make the implementation of blockchain based infrastructures fruitful and provides the researchers with the possible potential areas for future works.

6 Acknowledgement

This work was carried out during the tenure of ERCIM Alain Bensoussan Fellowship Program.

7 References

- [1] S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system," 2008.
- [2] Y. Lu, "The Blockchain: State-of-the-Art and Research Challenges," *Journal of Industrial Information Integration*, 2019.
- [3] M. Crosby, P. Pattanayak, S. Verma, V. Kalyanaraman, "Blockchain technology: beyond bitcoin", *Appl. Innov.* 2, 2016, pp. 6–10.
- [4] Y. Lu, "Blockchain and the related issues: a review of current research topics", *J. Manag. Anal.* 5 (4), 2018, pp. 231–255.
- [5] CoinMarketCap, 2017. Cryptocurrency Market Capitalizations, <https://coinmarketcap.com/>
- [6] Szabo, N., 1994. Smart contracts.
- [7] A. Wright, P. De Filippi, "Decentralized blockchain technology and the rise of Lex cryptographia", Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2580664
- [8] K. Christidis, M. Devetsikiotis, "Blockchains and smart contracts for the internet of things", *IEEE Access* 4, 2016, pp. 2292–2303. <https://doi.org/10.1109/access.2016.2566339>
- [9] Gartner Report, "Top trends in the Gartner hype cycle for emerging technologies", 2017. Online Available: <https://www.gartner.com/smarterwithgartner/top-trends-in-the-gartnerhype-cycle-for-emerging-technologies-2017/>
- [10] M. Samaniego, U. Jamsrandorj, R. Deters, "Blockchain as a Service for IoT", In 2016 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), 2016, pp. 433-436. <https://doi.org/10.1109/ithings-greencom-cpscom-smartdata.2016.102>
- [11] M. Swan, "Blockchain: Blueprint for A New Economy", O'Reilly Media, Inc., Sebastopol, CA, USA, 2015 Beijing, Cambridge, Tokyo.
- [12] F. Tschorsch, B. Scheuermann, "Bitcoin and beyond: A technical survey on decentralized digital currencies", *IEEE Communications Surveys & Tutorials*, 18(3), pp. 2084–2123. <https://doi.org/10.1109/comst.2016.2535718>
- [13] Idrees, S. M., Alam, M. A., & Agarwal, P. (2019). A study of big data and its challenges. *International Journal of Information Technology*, 11(4), 841-846. <https://doi.org/10.1007/s41870-018-0185-1>
- [14] Y. Lu, "Industry 4.0: A survey on technologies, applications and open research issues", *Journal of Industrial Information Integration*, 6, 2.17, pp. 1–10.
- [15] M. Nofer, P. Gomber, O. Hinz, D. Schiereck, "Blockchain", *Business & Information Systems Engineering*, vol. 59, 2017, pp. 183-187. <https://doi.org/10.1007/s12599-017-0467-3>
- [16] Z. Zheng, S. Xie, H. Dai, X. Chen, H. Wang, "An overview of blockchain technology: Architecture, consensus, and future trends," in 2017 IEEE International Congress on Big Data (BigData Congress), 2017, pp. 557-564. <https://doi.org/10.1109/bigdatacongress.2017.85>
- [17] Z. Zheng, S. Xie, H.-N. Dai, X. Chen, and H. Wang, "Blockchain challenges and opportunities: A survey," *International Journal of Web and Grid Services*, vol. 14, 2018, pp. 352-375.
- [18] M. Niranjanamurthy, B. Nithya, S. Jagannatha, "Analysis of Blockchain technology: pros, cons and SWOT," *Cluster Computing*, 2018, pp. 1-15. <https://doi.org/10.1007/s10586-018-2387-5>
- [19] E. Androulaki, A. Barger, V. Bortnikov, C. Cachin, K. Christidis, A. De Caro, et al., "Hyperledger fabric: a distributed operating system for permissioned blockchains," in *Proceedings of the Thirteenth EuroSys Conference*, 2018, p. 30. <https://doi.org/10.1145/3190508.3190538>

- [20] Buterin, V., 2015. On public and private blockchains, Ethereum Blog 7.
- [21] braham, I., Mahlkhi, D, “The blockchain consensus layer and BFT”, Bulletin of EATCS 123, 2017, pp. 1–22. Available online at: <https://dahliamalkhi.files.wordpress.com/2016/08/blockchainbftbeatcs2017.pdf>
- [22] S. Kiyomoto, M. S. Rahman, A. Basu, “On blockchain-based anonymized dataset distribution platform,” in 2017 IEEE 15th International Conference on Software Engineering Research, Management and Applications (SERA) (London, UK: IEEE), pp. 85–92. <https://doi.org/10.1109/sera.2017.7965711>
- [23] K. Croman, et al., “On scaling decentralized blockchains”, Proceedings of the 3rd Workshop Bitcoin Blockchain Research, 2016, pp. 106–125.
- [24] N. Kshetri, “Blockchain’s roles in meeting key supply chain management objectives”, Int. J. Informat. Manage. 39, 2018, pp. 80–89. doi: 10.1016/j.ijinfomgt.2017.12.005. <https://doi.org/10.1016/b978-0-323-89934-5.00002-7>
- [25] B. Gipp, N. Meuschke, A. Gernandt, “Decentralized trusted timestamping using the crypto currency bitcoin,” in Proceedings of the iConference 2015 (Newport Beach, CA).
- [26] A. Gervais, G. O. Karame, K. Wüst, V. Glykantzis, H. Ritzdorf, S. Capkun, “On the security and performance of proof of work blockchains,” in Proceedings of the 2016 ACM SIGSAC Conference on Computer and Communications Security (CCS ’16) (Vienna), 2016, pp. 3–16. <https://doi.org/10.1145/2976749.2978341>
- [27] L. Luu, D.-H. Chu, H. Olickel, P. Saxena, A. Hobor, “Making smart contracts smarter”, Proceedings of the 23rd ACM SIGSAC Conference on Computer and Communications Security, 2016, pp. 254–269. <https://doi.org/10.1145/2976749.2978309>
- [28] M. Haferkorn, J. M. Quintana Diaz, “Seasonality and Interconnectivity Within Cryptocurrencies – An Analysis on the Basis of Bitcoin, Litecoin and Namecoin”, Springer International Publishing, Cham, 2014, pp. 106–120. https://doi.org/10.1007/978-3-319-28151-3_8
- [29] L. Cocco, A. Pinna, M. Marchesi, “Banking on blockchain: Costs savings thanks to the blockchain technology”, Future Internet, 9 (3), 2017, p. 25. <https://doi.org/10.3390/fi9030025>
- [30] H. M. Gazali, R. Hassan, R. M. Nor, H. M. M. Rahman, “Re-inventing PTPTN study loan with blockchain and smart contracts”, In: ICIT 2017–8th International Conference on Information Technology, Proceedings pp. 751–754. <https://doi.org/10.1109/icitech.2017.8079940>
- [31] G. Papadopoulos, “Blockchain and Digital Payments: An Institutional Analysis of Cryptocurrencies”, 2015, pp. 153–172.
- [32] J. Dai, M. A. Vasarhelyi, Toward blockchain-based accounting and assurance. J. Inf. Syst. 31 (3), 2017, pp. 5–21.
- [33] D. Cawrey, “37Coins Plans Worldwide Bitcoin Access with SMS-Based Wallet”, Online Available: <http://www.coindesk.com/37coins-plans-worldwide-bitcoin-access-sms-based-wallet/>
- [34] P. Rizzo, “How Kipochi Is Taking Bitcoin into Africa”, Online Available: <http://www.coindesk.com/kipochi-taking-bitcoin-africa/>
- [35] P. Ocheja, B. Flanagan, H. Ogata, “Connecting decentralized learning records: A blockchain based learning analytics platform,” in Proc. ACM Int. Conf. Ser., 2018, pp. 265–269. <https://doi.org/10.1145/3170358.3170365>
- [36] Y. Xu, S. Zhao, L. Kong, Y. Zheng, S. Zhang, Q. Li, “ECBC: A high performance educational certificate blockchain with efficient query,” in Theoretical Aspects of Computing–ICTAC (Lecture Notes in Computer Science). Cham, Switzerland: Springer, 2017, pp. 288–304. https://doi.org/10.1007/978-3-319-67729-3_17

- [37] M. S. M. Pozi, G. Muruti, A. A. Bakar, A. Jatowt, and Y. Kawai, “Preserving author editing history using blockchain technology,” in Proc. 18th ACM/IEEE on Joint Conf. Digit. Libraries (JCDL), New York, NY, USA, Jun. 2018, pp. 165–168 <https://doi.org/10.1145/3197026.3197068>
- [38] T. Nugent, D. Upton, M. Cimpoesu, “Improving data transparency in clinical trials using blockchain smart contracts,” *F1000Research*, vol. 5, Oct. 2016, Art. no. 2541 <https://doi.org/10.12688/f1000research.9756.1>
- [39] Q. Xia, E. B. Sifah, A. Smahi, S. Amofa, and X. Zhang, “BBDS: Blockchain-based data sharing for electronic medical records in cloud environments,” *Information*, vol. 8, no. 2, p. 44, Jun. 2017. <https://doi.org/10.3390/info8020044>
- [40] V. Patel, “A framework for secure and decentralized sharing of medical imaging data via blockchain consensus,” *Health Inform. J.*, doi: 10.1177/1460458218769699.
- [41] A. Azaria, A. Ekblaw, T. Vieira, and A. Lippman, “MedRec: Using blockchain for medical data access and permission management,” in Proc. 2nd Int. Conf. Open Big Data (OBD), Aug. 2016, pp. 25–30. <https://doi.org/10.1109/obd.2016.11>
- [42] Archa, B. Alangot, and K. Achuthan, “Trace and track: Enhanced pharma supply chain infrastructure to prevent fraud,” in *Ubiquitous Communications and Network Computing (Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering)*. Cham, Switzerland: Springer, 2017, pp. 189–195. https://doi.org/10.1007/978-3-319-73423-1_17
- [43] Idrees SM, Nowostawski M, Jameel R, Mourya AK. Security Aspects of Blockchain Technology Intended for Industrial Applications. *Electronics*. 2021; 10(8):951. <https://doi.org/10.3390/electronics10080951>
- [44] M. Haferkorn, J. M. Quintana Diaz, “Seasonality and Interconnectivity Within Cryptocurrencies – An Analysis on the Basis of Bitcoin, Litecoin and Namecoin”, Springer International Publishing, Cham, 2015, pp. 106–120. https://doi.org/10.1007/978-3-319-28151-3_8
- [45] The Decentralized Library of Alexandria, 2015. Online Available, <http://www.alexandria.io/>
- [46] J. Liu, P. Jiang, J. Leng, “A framework of credit assurance mechanism for manufacturing services under social manufacturing context,” in Proc. 13th IEEE Conf. Automat. Sci. Eng. (CASE), Aug. 2017, pp. 36–40. <https://doi.org/10.1109/coase.2017.8256072>
- [47] M. Król, S. Reñé, O. Ascigil, I. Psaras, “ChainSoft: Collaborative software development using smart contracts,” in Proc. 1st Workshop Cryptocurrencies Blockchains Distrib. Syst. (CryBlock), New York, NY, USA, 2018, pp. 1–6. <https://doi.org/10.1145/3211933.3211934>
- [48] W. Ying, S. Jia, W. Du, “Digital enablement of blockchain: Evidence from HNA group,” *Int. J. Inf. Manage.*, vol. 39, 2018, pp. 1–4.
- [49] P. Y. Chang, M. S. Hwang, C. C. Yang, “A blockchain based traceable certification system,” in *Security with Intelligent Computing and Big-data Services (Advances in Intelligent Systems and Computing)*. Cham, Switzerland: Springer, 2017, pp. 363–369. https://doi.org/10.1007/978-3-319-76451-1_34
- [50] K. Toyoda, P. T. Mathiopoulos, I. Sasase, T. Ohtsuki, “A novel blockchain-based product ownership management system (POMS) for anti-counterfeits in the post supply chain,” *IEEE Access*, vol. 5, 2017, pp. 17465–17477. <https://doi.org/10.1109/access.2017.2720760>
- [51] A. Schaub, R. Bazin, O. Hasan, O. L. Brunie, “A trustless privacy-preserving reputation system”, In *IFIP International Conference on ICT Systems Security and Privacy Protection, 2016*, pp. 398–411 Springer, Cham. https://doi.org/10.1007/978-3-319-33630-5_27
- [52] R. McMillan, “Hacker Dreams Up Crypto Passport Using the Tech Behind Bitcoin”, Online Available: http://www.wired.com/2014/10/world_passport/
- [53] V. L. Lemieux, “Trusting records: is blockchain technology the answer?” *Records Manage. J.* 26 (2), 2016, pp. 110–139. <https://doi.org/10.1108/rmj-12-2015-0042>

- [54] C. Sullivan, E. Burger, E., “E-residency and blockchain”, *Computer Law Secur. Rev.* 33 (4), 2017, pp. 470–481.
- [55] N. N. Pokrovskaja, "Tax, financial and social regulatory mechanisms within the knowledge-driven economy. Blockchain algorithms and fog computing for the efficient regulation." In *2017 XX IEEE International Conference on Soft Computing and Measurements (SCM)*, IEEE, 2017, pp. 709-712. <https://doi.org/10.1108/rmj-12-2015-0042>
- [56] F. Pichel, “Blockchain for land administration”, *GIM Int.* 30 (9), 2016, pp. 38–39.
- [57] P. Boucher, “What if blockchain technology revolutionised voting?” Scientific Foresight Unit (STOA), European Parliamentary Research Service, 2016.
- [58] M. Samaniego, R. Deters, “Blockchain as a Service for IoT”, In: *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*, pp. 433–436. <https://doi.org/10.1109/ithings-greencom-cpscom-smartdata.2016.26>
- [59] L. S. Sankar, M. Sindhu, M. Sethumadhavan, “Survey of consensus protocols on blockchain applications”, In *Proceedings of the 4th International Conference on Advanced Computing and Communication Systems (ICACCS)*, IEEE, 2017, pp. 1–5. <https://doi.org/10.1109/icaccs.2017.8014672>
- [60] I. Eyal, A.E. Gencer, E.G. Sirer, R. van Renesse, “Bitcoin-NG: a scalable blockchain protocol”, 2015, Online Available: <http://arxiv.org/abs/1510.02037>
- [61] J. Bruce, “Purely P2P crypto-currency with finite mini blockchain’, 2013, Online Available: <https://pdfs.semanticscholar.org/3f64/123ce97a0079f8bea66d3f760dbb3e6b40d5.pdf>
- [62] Y. Lu, “Artificial intelligence: a survey on evolution, models, applications and future trends”, *J. Manag. Anal.* 6 (1), 2019, pp. 1–29.
- [63] J. C. Bertot, P. T. Jaeger, D. Hansen, “The impact of polices on government social media usage: issues, challenges, and recommendations”, *Gov. Inform. Q.* 29 (1), 2012 pp. 30–40. <https://doi.org/10.1016/j.giq.2011.04.004>
- [64] P. Rochard, “Speculative attack”, Online Available: <http://nakamotoinstitute.org/mempool/speculative-attack/>
- [65] A. Kosba, A. Miller, E. Shi, Z. Wen, C. Papamanthou, “Hawk: the blockchain model of cryptography and privacy-preserving smart contracts”, In: *2016 IEEE Symposium on Security and Privacy (SP)*, pp. 839–858, 2016. <https://doi.org/10.1109/sp.2016.55>
- [66] F. Casino, T. K. Dasaklis, C. Patsakis, “A systematic literature review of blockchain-based applications: current status, classification and open issues,” *Telematics and Informatics*, 2019, pp. 55-81. <https://doi.org/10.1016/j.tele.2018.11.006>
- [67] “Blockstream”, The blockstream company, 2014, Online Available: <https://www.blockstream.com/>
- [68] I. C. Lin, T. C. Liao, « A survey of blockchain security issues and challenges”, *IJ Network Security* 19 (5), 2017, pp. 653–659
- [69] K. Christidis, M. Devetsikiotis, “Blockchains and smart contracts for the internet of things” *IEEE Access* 4, 2016, pp. 2292–2303. <https://doi.org/10.1109/access.2016.2566339>
- [70] Subramanian, H., “Decentralized blockchain-based electronic marketplaces”, *Communications of the ACM*, 61(1), 2017, pp.78-84. <https://doi.org/10.1145/3158333>
- [71] C. Xu, K. Wang, P. Li, S. Guo, J. Luo, B. Ye, M Guo, “Making big data open in edges: a resource-efficient blockchain-based approach”, *IEEE Trans. Parallel Distrib. Syst.* 30 (4), 2019, pp. 870–882. <https://doi.org/10.1109/tpds.2018.2871449>
- [72] S. Ullah, H. Higgins, B. Braem, B. Latre, C. Blondia, I. Moerman, S. Saleem, Z. Rahman, K.S. Kwak, “A comprehensive survey of wireless body area networks”, *J. Med. Syst.* 2010; 36:1065–1094. <https://doi.org/10.1007/s10916-010-9571-3>

- [73] T. McConaghy, “How blockchains could transform artificial intelligence”, Online Available: <http://dataonomy.com/2016/12/blockchains-for-artificial-intelligence/>
- [74] E. Karafiloski, A. Mishev, “Blockchain solutions for big data challenges: a literature review”, In: 17th IEEE International Conference on Smart Technologies, EUROCON 2017 – Conference Proceedings, pp. 763–768. <https://doi.org/10.1109/eurocon.2017.8011213>
- [75] X. Chen, J. Ji, C. Luo, W. Liao, P. Li, “When Machine Learning Meets Blockchain: A Decentralized, Privacy-preserving and Secure Design,” In 2018 IEEE International Conference on Big Data (Big Data), IEEE, Dec 10, 2018, pp.1178-1187. <https://doi.org/10.1109/big-data.2018.8622598>
- [76] S. Seebacher, R. Schüritz, “Blockchain technology as an enabler of service systems: A structured literature review,” In International Conference on Exploring Services Science, Springer, Cham. 2017, pp. 12-23. https://doi.org/10.1007/978-3-319-56925-3_2
- [77] A. Brandão, H. São Mamede, R. Gonçalves, “Systematic review of the literature, research on blockchain technology as support to the trust model proposed applied to smart places,” In World Conference on Information Systems and Technologies, Springer, Cham, 2018, pp. 1163-1174. https://doi.org/10.1007/978-3-319-77703-0_113
- [78] C. Shen, F. Pena-Mora, “Blockchain for Cities—A Systematic Literature Review,” IEEE Access, Nov 12, 2018, Vol. 6, pp.76787-76819. <https://doi.org/10.1109/access.2018.2880744>
- [79] Idrees, S. M., Nowostawski, M., Jameel, R., & Mourya, A. K. (2021). 7 Privacy-Preserving. *Data Protection and Privacy in Healthcare: Research and Innovations*, 109. <https://doi.org/10.1201/9781003048848-7>
- [80] S. M. Idrees, M. Nowostawski, R. Jameel, “Blockchain-Based Digital Contact Tracing Apps for COVID-19 Pandemic Management: Issues, Challenges, Solutions, and Future Directions”, JMIR Medical Informatics. 2021 Feb 9;9(2): e25245. <https://doi.org/10.2196/25245>
- [81] Y. Ma, Y. Fang, “Current Status, Issues, and Challenges of Blockchain Applications in Education”, *International Journal of Emerging Technologies in Learning (iJET)*, 15(12), 2020, pp. 20-31. <https://doi.org/10.3991/ijet.v15i12.13797>
- [82] J. Liu, T. Zhu, “Application of Blockchain Technology in Cultural and Creative Design Education”, *International Journal of Emerging Technologies in Learning*, 16 (4), 2021.
- [83] H. Sun, X. Wang, X. Wang, X, “Application of Blockchain Technology in Online Education” *International Journal of Emerging Technologies in Learning*, 13(10), 2018.
- [84] Idrees, S. M., & Nowostawski, M. (2020). Mobile Phone Based Contact Tracing Applications for Combating Covid-19 Pandemic. *Biomedical Journal of Scientific & Technical Research*, 32(4), 25194-25197. <https://doi.org/10.26717/bjstr.2020.32.005286>

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Article submitted 2021-03-21. Resubmitted 2021-04-16. Final acceptance 2021-04-16. Final version published as submitted by the authors.