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Blockchain Technology: Challenges and Opportunities

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Abstract

Blockchain is a revolutionary digital, distributed network technology which has the power to replace third party trusted with mathematical concept and algorithms. It is considered as a change in every aspect in the life of humans. It is basically the peer-to-peer connection within a decentralized database. Blockchain provides us with the features of security, privacy, accessibility as well as immutability. Blockchains are mostly used for registering transactions, authenticating and validating digital assets, governing interactions, managing identities as well as recording data among multiple parties. These processes are conducted in a decentralized, secure, distributed and tamper-proof manner ensuring data integrity and fostering trust among users. Blockchain also provides anonymity and enhances operational efficiency, further solidifying its role as a transformative trust-based technology. In recent years, blockchain has gained substantial popularity, becoming a critical tool for managing sensitive digital transactions and documentation. In this paper, we aim to identify the key challenges, arising opportunities, and implementation. We aim to classify them for clearer understanding and enumerate future research opportunities to lead industry and researchers in an informative and effective direction.

Keywords: Applications, blockchain, decentralized, documentation, trust-based

INTRODUCTION

Blockchain is a distributed network technology which has the power to replace third parties and provide us with the features of security, privacy immutability and accessibility. The notion of blockchain has become so ubiquitous that most professionals are predicting it as the next premier attention-seeking transformative technology. Blockchains are a considerable original way for technical development, empowering protected transactions without the necessity for authority and centralization [1]. Blockchain is an exclusive trust-based mechanism which is gaining popularity in recent years and now it is increasing more efficiently and effectively in the areas of healthcare, cryptocurrency, etc. It is basically a fundamental technology which is distributed as well as decentralized in nature and is uplifting and persuading the functioning or working of Bitcoin, the digital money. This technology enables the formation of currencies that are distributed, self-operational digital smart contracts and intellectual digital assets that can be governed over the internet while touching upon peer-to-peer networking. It also permits for the action and links of diverse smart contracts where several smart contracts can be collected and organized to create distributed enterprises that function conferring to explicit instructions and measures well-defined by code based smart contracts and codes [2].

Hashing is one of the most important building-block of blockchain as it compresses the output which means that the output of a function is shorter

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than the input to the function. Proof of work, proof of stake, and various other algorithms are playing very important role for ensuring and maintaining the privacy and security of blockchain by organizing a computerized and digitally ledger-based transitions, which are secure. Every time a valid new transaction takes place, it is added to the chain of blockchain otherwise it is rejected.

Blockchain is just a technique of securely sharing and archiving information. It develops trust via cryptographic process by permitting diverse groups to securely exchange information without the use of central agency or middleman. It is one of the necessary technologies for structuring and developing a new trust structure and evolving digital economy in the coming new era [3, 4].

Blockchain technology has diverse applications, enabling the development of trustless systems by removing intermediaries and lowering expenses, thanks to its decentralized structure. Self-executing contacts known as "smart contacts" have specified conditions incorporated into the contact's code. Smart contracts are self-executing contracts with predefined rules which offer opportunities for enabling business transactions. Blockchain technology enables the automation of these contracts when certain predefined conditions are met.

The other prominent application of blockchain technology is supply chain management as supply systems based on blockchain technology can reduce counterfeiting, reduce frauds, and improve overall trust and performance among stakeholders. Blockchain also ensures security and safety in the financial sector as the process of transferring and receiving data is secured with the help of blockchain. Financial systems are centralized, inefficient, and prone to fraud. Enabling of blockchain technology emphasis data-security, stability, privacy, affordability, interoperability as well as vulnerability [5–7].

Beyond finance and supply system, blockchain has found its applications in the field of healthcare, intellectual property rights, data management, voting system and decentralized identities. In healthcare, blockchain helps in managing database records of the patients by providing privacy and security to the system. Blockchain technology establishes ownership records and safeguards creators' rights in the digital realm. Ongoing efforts aim to design protocols and frameworks that enhance interoperability, enabling seamless communication and information sharing between different blockchains.

BLOCKCHAIN BACKGROUND

A blockchain is termed to be a decentralized and distributed database, which is meticulously orchestrating a continuous stream of records known as blocks. Each block is like a brick in a digital fortress, securely linked to its predecessors through the intricate web of cryptography. Each block includes a cryptographic hash of the previous block, a timestamp, and transaction data. The main advantage of this technology lies in its ability to function as a database for recording transactions.

Each block accurately documents and verifies the time and order of transactions, integrating them into the blockchain within a distinct network governed by rules established by its participants. Blockchain technology is advancing at a remarkable speed, driving innovative ideas ranging from shared storage solutions to the foundation of social networks. With respect to the purpose of security we are breaking new grounds. Building security into the core of blockchain applications is paramount, laying the foundation for a resilient and trustworthy system. Blockchain has demonstrated its potential to revolutionize traditional industries through its core features: decentralization, permanence, anonymity, and auditability. In this paper, we are presenting a comprehensive overview to blockchain technology, where innovation meets security and tradition merges with the future [8].

Mostly Used Technical Terms in Blockchain

Node

It is a system that captures an independent copy of ledger and performs operations on blockchain. Nodes are responsible for performing tasks such as validating transactions, managing the ledger, and engaging in consensus processes. Nodes in blockchain may also refer as individual participant or system.

Chain

It is the arrangement of block in sequential order where each block contains a set of transactions which are linked in chronological order. The chain basically ensures the continuity and integrity of the ledger. Whenever a new transaction occurs in the process, a new block is added at the end of the chain.

Decentralized

It is the system where data are stored in distributed form all over the network. In blockchain, data is stored in distributed form which generally functions in increasing security, transparency and resilience.

Transaction

These are basically the smallest blocks of blockchain which holds information, records, etc., serves the main objective of blockchain. The primary goal of blockchain is to guarantee the validity and security of transactions.

Transparent

It is the function where every block can see the complete information of ledger transitions. The transparency feature of blockchain fosters trust and accountability. Every block in the ledger has access to the full transaction history.

Miners

These are specialized nodes that perform the block verification process before incorporating anything into the structure. Miners validate transactions, create new blocks, and secure the network. They execute the block verification process through various mining algorithms such as proof of work.

Fundamentals of Blockchain

The basic fundamentals of blockchain are

- *Peer to Peer Connections*: Blockchain operates on a decentralized network where participants (nodes) directly interact with each other. Transactions are verified and documented without relying on intermediaries such as banks or central authorities. This decentralized structure guarantees transparency and security.
- *Irreversibility of Records:* Once a transaction is added to the blockchain, it becomes permanent, meaning it cannot be changed or erased. This immutability fosters trust and helps prevent fraud.
- *Distributed Database:* The blockchain database is spread across multiple nodes in the network, with each node holding a copy of the entire ledger. This duplication improves reliability and safeguards against failures or attacks.
- *Computational Logic:* Smart contracts, which are self-executing pieces of code, are essential in blockchain. They automate processes, enforce rules, and facilitate interactions between parties. These logical constructs enhance efficiency and reduce reliance on manual intervention.

Types of Blockchain

Public Blockchain

These are open networks that are permissionless, allowing anyone to join and participate as shown in Figure 1. The key features of a public blockchain include:

- Full decentralization
- No single owner
- Visible by anyone and everyone

Private Blockchain

The blockchain which is owned and governed by an organization where authorized participants can participate and can access the information. The characteristics features of private blockchain are:

- Use privileges to govern
- Permissioned blockchain

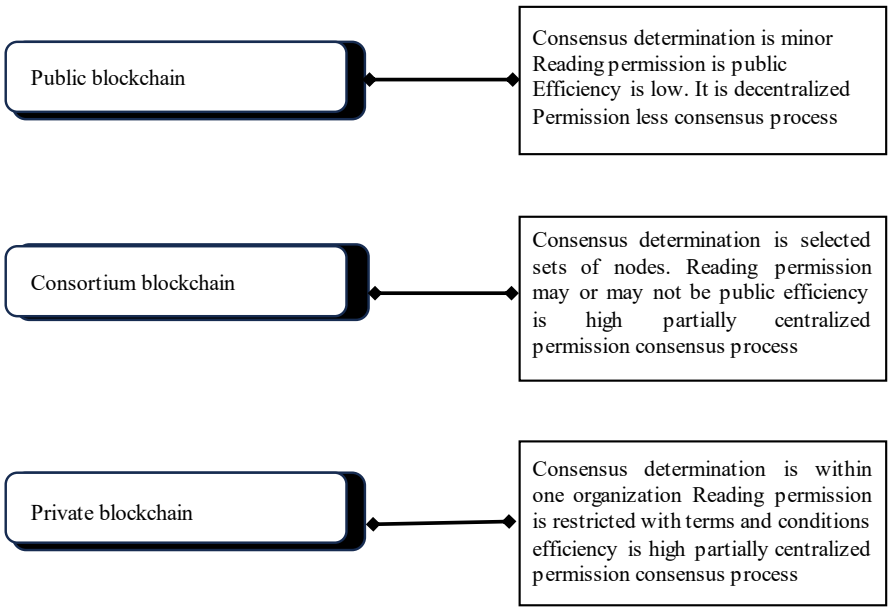

Figure 1. Comparison among public blockchain, consortium blockchain, and private Blockchain [9, 10].

Consortium Blockchain

The blockchain which is governed by multiple organizations, basically is a type of distributed blockchain. The characteristics features of consortium blockchain are:

- Network is partially distributed
- Agreement for the set of rules and regulations, instructions and guidelines must be agreed upon by all the parties.
- Limited to privileged cluster and have public characteristics [9].

Components of a Blockchain

- *Ledger*: It is a blockchain transaction invocations which contains the current state of ledgers. The ledger is the central repository for all transactions within the blockchain. Each transactions updates the ledger, ensuring transparency and accountability as shown in Figure 2.
- *Smart Contract*: It captures business network transactions and automatically executes actions when predefined conditions are satisfied. Smart contracts are technically termed to be self-executing programs that automate business processes.
- *Consensus Network*: It is responsible for maintaining consistently replicated ledger. It ensures agreement among all nodes in the blockchain. It maintains a consistently replicated version of the ledger across the network.
- *Membership*: It manages transactions and identity certificates. It oversees transactions related to identity certificates, access control, and authorization. Proper membership management ensures secure and authorized participation.
- *Events*: Event plays a very significant role in notifying participant about the significant operations. These notifications enhance the transparency and allow external systems to react to blockchain events.
- *System Management*: It provides the ability to manage blockchain components. Basically, it helps in managing the functionality of core components of blockchain technology. It oversees the functionality of core elements, including consensus algorithms, smart contract deployment, and network configuration [8].
- *Wallet*: Wallets allow users to engage with the blockchain while protecting their assets. It helps in managing security. It securely manages user's security by storing cryptographic keys used for transactions.

- *System Integration*: It is responsible for integrating Blockchain to bi-directionally with external components. Integration is crucial for real-world adoption and interoperability.

Advantages and Disadvantages of Blockchain

In the vast landscape of digital innovation, the blockchain emerges as a titan among technologies – a distributed and decentralized database. The advantages and disadvantages of blockchain technology underscores its transformative potential but also highlights the need for addressing challenges related to scalability, energy consumption, accessibility, privacy and regulating uncertainty. Finding solutions to these challenges will shape the future evolution and adoption of blockchain across various industries and applications [11].

Advantages of Blockchain Technology

- *Security*: It is basically a great advantage of blockchain technology as each task or performed action is assigned with a unique ID which is known as the hash code. Hash code is 64 to 128 digits numeric key code which is used to encrypt and decrypt the message.
- *Reliability:* The distributed nature of blockchain technology reduces the likelihood of failure.
- *Decentralization:* Blockchain is the decentralized, distributed technology which removes the need of middleman in transactions and also make our process easy, fast and secure [12].
- *Transparency:* The shared digital ledger contains all the information of everything containing date, time, actual source, destination etc. where everyone has the access to see the complete ledger [13].
- *Easy Accessibility*: Data is stored in distributed form which enables everyone to access the data with accuracy [13].
- *Data Integrity*: Whenever any new transaction is added or deleted it cannot be directly altered in blockchain technology, basically changes are made after applying consensus. By strengthening regulatory compliances participants can reduce fraud.
- *Processing Time*: Processing time of transactions also gets reduced with the help of blockchain technology [14].

Ledger		Contains the current world state of the ledger and a Blockchain of transaction invocations
Smart Contract		Encapsulates business network transactions in code, transaction invocations result in gets and sets of ledger state
Consensus Network		A collection of network data and processing peers forming a Blockchain network. Responsible for maintaining a consistently replicated ledger
Membership		Manages identity and transaction certificates, as well as other aspects of permissioned access
Events		Creates rectifications of significant operations on the Blockchain (e.g. a new block), as well as notifications related to smart contracts. Does not include event distribution.
Systems Management		Provides the ability to create, change and monitor Blockchain components
Wallet		Securely manages a user's security credentials
System Integration		Responsible for integrating Blockchain bi-directionally with external system, Not part of blockchain, but used with it.

Figure 2. Core components of blockchain technology [15].

Disadvantages of Blockchain Technology

- *Volatility*: Blockchain technologies are highly volatile in nature.
- *Modification of Data is Difficult*: As once any type of data is added in node, it is very difficult to delete it.
- *High Expenses Issues*: The users have to pay for the services like transactions as well as computation power.
- *Resource Waste*: For complex tasks of mining and verifications it requires huge amount of power for computation as the energy used in the mining of Bitcoin is nearly around $14 million per day [16].
- *Issue in Latency*: As we know that blockchain is very secure technology, but the time taken for verifying and validating the transactions is more [14].

Applications of Blockchain

- *Blockchain in Cybersecurity*: The practice of shielding and safeguarding the networks and systems from attacks is the most important role of cybersecurity. Blockchain helps in preventing the software and systems from cyber-attacks with the help of various features as [17, 18].
- *Consensus and Decentralization:* As we know that blockchain is a peer-to-peer connection and a distributed as well as decentralized system where nodes are created and any up-dation and verification requires valid algorithms to go through. For any addition or deletion in the nodes requires valid algorithms [1].
- *Unchangeable*: Changes in the data of blockchain are very difficult as once data is added in the chain it cannot be tampered by anyone. This property is known as the immutable property of blockchain [19].
- *Vehicle Industries*: The centralized blockchain-based technology supply chain with trusted distribution is the way we construct, procure and secure the vehicles for our day-to-day life [20].
- *Voting*: Blockchain is also playing a very effective role in voting as the cast votes cannot be changed due to the immutable nature of blockchain. With the help of its feature of security it is difficult to access or track the votes of individuals. Blockchain also helps in reducing the counting time of votes and also prevent wastage of papers as paper ballots involve very high expenditure [21, 20].
- *Blockchain in Food Industry*: With the help of blockchain the entire food process becomes safe and transparent and strengthen the safety of products, also produce less waste and proper records of manufacturing and expiring of products can be maintained [8, 21].
- *Blockchain in Healthcare*: Blockchain is also playing a very important role in the field of medicines and healthcare by keeping the records of reports and needs of every individual which make it easy for doctor to analyze the history of diseases of the patients. The various applications of blockchain used in the field of healthcare are:
- *Electronic Medical Report (EMR)*: EMR is a very important feature of the blockchain which is playing very efficient role in the field of medical and healthcare. As we know, blockchain is based on distributed network which help to keep the records of all the medical reports, pathology reports, lab reports, medicines reports, etc. in very well organized and systematic manner.
- *Tokenization*: The tokenization property of blockchain is very effective as it prevents the diseases and treatment of patients incentivized [16, 22].

COMPARATIVE STUDY OF LITERATURE REVIEW

The literature review emphasizes the impact of blockchain technology including trade finance, remittances while addressing challenges of interoperability and regulatory compliances as shown in Table 1.

Blockchain for Financial Services

This includes involvement of blockchain technology in banking sector which helps to determine the banking services smoothly including payments, trade finance etc.

Table 1. Comparative study of literature review.

Title	Author/Year/Tools	Evaluation
Research on Information Security Technology Based on Blockchain	Liang Liu et al./ 2018/ Diffie-Hellman (D-H), Elliptic Curve Cryptography (ECC), Rivest-Shamir-Adleman(RSA) [1].	Blockchain uses cryptographic algorithms, hashing methods and other mechanisms for providing security.
An Overview of Blockchain Applications and Attacks	Rahul Rao Vokerla et al. / 2019/ Digital Signature, Elliptic Curve Digital Signature Algorithm (ECDSA), Consensus Method [9].	For providing security and reliability of data, blockchain uses various algorithms.
Simulating a Blockchain Network with Sim Block	Ryohei Banno et al./ 2019/ SimBlock [2].	Evaluated average network delay between each pair of regions, block generation capacity of each block
Blockchain Technology: A Review of the Current Challenges of Cryptography	Diego Valdeolmillos et al. / 2020/ Practical Byzantine Fault Tolerance (PBFT), Proof of Work, Proof of Stake [17].	By applying different mining algorithms different cryptocurrencies were evaluated.
Digital Signature Scheme for Information Non-repudiation in Blockchain: A State of the Art Review	Weidong Fang et al./ 2020/ Bilinear mapping and Elliptic curve discrete algorithm [13]	According to the security analysis, the potential forgery of the attacker cannot be realized.
Blockchain and crypto-currency are database for contract management in construction engineering	API chart Boonpheng et al./ 2021/ AHP's Principles [23].	Main factors that were evaluated are: cost, time management, efficiency, and speed.

This review paper assists in examining the potential applications of blockchain technology by improving and securing the trustworthiness and interoperability of internet of things (IoT) devices.

Blockchain in Healthcare

This paper helps in discussing the privacy, security and difficulties that are surrounding the possible application of blockchain technology in healthcare sector by ensuring the clinical trials, data exchange and record management.

Blockchain based Supply Chain Management

In the field of chain management system, the application of blockchain helps in enhancing the security, privacy, transparency and traceability along with the challenges and difficulties that are associated with the software.

Blockchain in Business Data Privacy and Threads

Blockchain stores data in higher encrypted format which ensures higher level of data security and privacy as well as helps in reducing the chances of vulnerability and error in data. Blockchain decentralized servers ensures uninterrupted services even in the case of occurrence of attacks [24, 25, 26].

CHALLENGES FACED BY BLOCKCHAIN TECHNOLOGY

Blockchain is used extensively on the internet for a variability of determinations. The literature review highlights a combination of technical and non-technical challenges.

The major challenges faced by blockchain are summarized as follows:

- *Scalability*: Blockchain networks can control a higher bit of proceedings on sizeable standard. Data processing services are indispensable for ascendable blockchain work because higher group action process definite quantity cosmopolitan data processing work. Because of its capacity to grow many resources for blockchain activities are provided through the cloud. Many blockchains struggle to support countless users on that machine. Due to increase in clients and users, Bitcoin and Ethereum, the major blockchain systems experienced the modest exchange rates and higher exchanges fees [1, 10].

- *Complexity:* Blockchain is an analyzable application which definite quantity a high steady of technological skillfulness to instrumentality and keep. Blockchain's simplicity can also evidence to errors and skillfulness in execution.
- *Interoperability:* The quality and capacity of blockchain networks to interact and act with each other, is also a very critical challenge. This lack of collaboration in communication can lead to inefficiencies, the fragmentation behind this can also suppress invention and forbid the coherent transaction of data and values between different blockchain ecosystems. By dismantling barriers and encouraging collaboration across various blockchain platforms, industries can work towards creating an efficient and inclusive digital ecosystem that benefits developers. Lee et al. (2021) proposed an integrated digital twin and blockchain solution to enable accountable information sharing in construction projects [27]. The framework was tested through a case study, where data was transmitted to the digital twin in real-time and recorded on the blockchain using timestamps. McNamara and Sepasgozar (2021) explored the application of blockchain and smart contracts in the digitalization of the construction industry, identifying a three-dimensional model for adopting the iContract system [28].

OPPORTUNITIES IN FUTURE

Blockchain helps to provide security to the database and helps to manage the data efficiently and securely. The classification of challenges in research suggests various future research opportunities.

Smart contracts and numerous disputes of blockchain are the area of concern for the rules and blockchain laws. This policy enables blockchain related relations in practice. There are various suitable approaches essential to solve and assess this policy. Scalability in blockchain is the area of concern for researchers, industrialists and workers. Various researchers have suggested to address the scalability [29, 30].

Blockchain in effective integration with traditional legacy systems and current business processes is required in the literature. Vigilant analysis and productive methods are needed to ease the integration of blockchain. Blockchain ability towards immutability and security is also be used for storing highly sensitive personal data [30]. Blockchain and artificial intelligence (AI) are new technologies and are depend on future in 2021 [31].

CONCLUSION

Blockchain is a technology of peer-to-peer connections which is having the features of distribution and decentralization that empower protected transactions without the necessity for an authority and centralization. Blockchain bid everyone with identical opportunity of the technology as it is having the feature of transparency, permission less and borderless nature. The transactions are generally protected with the hashes generated using cryptography, and transactions are digitally signed and validated by means of public/private pairs of keys. The applications of blockchains are still in its nascent phase, but it has developed extensively comprehensive cryptographic rules and established methods. Economic establishments are expected to be the industries most affected by blockchains as it is utilized to resolve the fresh sets of difficulties. Digitization of the virtual assets is also now possible using blockchain. New businesses such as attorneys and digital solicitors can demonstrate that a person had entrée to an explicit portion of information by maintaining hash value of corresponding blockchain technology. A blockchain trusts on current network, cryptographically and accounting technologies, but utilize them in a novel manner. Blockchain has the authority to interrupt many businesses. Mining process of coins in electronic wallet requires lot of computation process which requires a lot of time for verifying and computing complex data

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