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COMPREHENSIVE REVIEW OF BLOCKCHAIN TECHNOLOGY: APPLICATIONS, CHALLENGES, AND FUTURE DIRECTIONS

Abstract. *The objective of this research is to provide a systematic literature review on the topic of blockchain technology. In addition to avoid bias in their review and employ Python code to search the databases available online. The article under discussion offers the reader a detailed description of the nature, peculiarities, and use of blockchain in various spheres. The primary purpose is to determine the important research issues in different application fields and propose the future trends. The analysis covers over 50 articles from 2019 to 2024, which demonstrates the new directions in research on financial management, educational security, healthcare, IoT, and government uses. Also, there is a discussion of privacy protection measures and the discussion of the challenges and further steps for the successful application of blockchain.*

Keywords: *blockchain, cryptocurrency, consensus, decentralized bitcoin.*

Introduction

The technology of blockchain are consists of multiple blocks of hash functions that connected to gather and provide the data in a decentralized, traceable, and immutable method [1, p. 7-12]. Firstly, it was introduced in 2008 in order to tracking the transaction of the decentralized currency. Several digital currency transaction are verified which are includes (distributed, decentralized) database, and can be updated via several nodes in the architecture of peer-to-peer [2, p. 609-617]. Every time a transaction takes place, a new block is created that contains newly collected data and is assigned a unique hash value derived from intricate calculations. The format of the blocks is highly encrypted and chained together. These days, the main problem with all types of transaction is the privacy. Blockchain technology is becoming more and more popular in the supply chain management, financial services, and cloud computing sectors because it has the potential to drastically alter privacy and authentication [3, p. 257-260], smart contracts, consumer credit transactions, government services, and research. Resource allocation, security, and risk management issues might be resolved by integrating this technology. Since the data in a blockchain cannot be changed, neither a central database nor the assistance of a third-party service are required. This eliminates the overhead associated with overseeing intermediary services provided by various businesses and organizations [4, p. 341].

The main features of blockchain technology are that having different applications in fields like transportation, business management, supply chain, energy, and health care etc. Figure 1 illustrates the blockchain applications.

Fig. 1. Blockchain recent distribution and applications

Contribution of This Work

The primary contribution of this review is the data and information are collected from mutable research in the field of blockchain technology and its application. The issues and tasks such as challenges, and future direction are also pointed in this review. The main contribution of this study summarized as follows:

- Several studies and reviews that related to blockchain applications were summarized from publication date 2019 to 2024.
- The development tools and specific industries are also determined.
- The benefits of combined blockchain technology and its effects in different categorical lives were also pointed out.
- The challenges and our point of view are also been pointed.
- Future directions for applying the blockchain based on the recent studies.

In addition, this study makes a significant innovation in the term of case study to reduce the time of search in the scope of blockchain technology and its related topics. helping the researchers to stakeholders across sectors as it helps them understand and make strategic decisions related to blockchain technology.

Historical Background of Blockchain

The technology has roots dating back to the early 1990s, when Stuart Haber, W. Scott Stornetta made a research into recording digital documents to ensure their immutability and validity [5, p. 117134-117151]. This study served as the foundation for what we now know as blockchain technology. However, until 2008 the blockchain did not emerge in its current form. Satoshi Nakamoto published a white paper introducing Bitcoin, a decentralized digital currency, and the concept of blockchain. Nakamoto combined the principles of cryptographic hashing with the work of Haber and Stornetta to create a public ledger to record Bitcoin

transactions. In January 2009, Nakamoto mined the first block, known as the "genesis block" or "block 0," which marked the beginning of the Bitcoin blockchain. The blocks refer to a message of economic instability to time. This innovation lies in the decentralized currency, and started the blockchain technology, which ensure that transaction are vailed by a network of nodes through the mining process, increasing transparency and security without the need for intermediaries such as banks. The success of Bitcoin has spurred the development of alternative cryptocurrencies and expanded the exploration of blockchain's potential beyond cryptocurrencies. In 2015, Vitalik Buterin and his team introduced Ethereum, which introduced smart contracts and made it possible to create programmable contracts and applications on the blockchain. Ever after, blockchain are developed rapidly, finding application in a variety of industries such as supply chain management, healthcare [6, p. 1211-1220], real state, and e-government [7, p. 1-9]. Its potential to transform data storage, sharing, and security has spurred extensive research and development, making blockchain a key technological innovation of the 21st century [8, p. 85-100].

Literature survey

A blockchain-based smart transportation and logistics framework (BCTLF) was proposed by Humayun et al. [9, p. 58-62] to optimize transportation logistics. The privacy risks associated with traditional car communication systems can be reduced by the decentralization and the feature distribution of the blockchain, which overcome the current solutions [10, p. 80390-80403]. Whereas in [11, p. 1-7], they introduce protocols for the management and synchronizing of traffic networks between blockchain and IoT, and evaluate the bandwidth of network connectivity. In this study [12, p. 227-239], the authors proposed a model for identifying the best number of blocks. They created an algorithm utilizing hashmaps for sending blocks in IoT applications, and the results show that IoT network monitoring is more dependable and faster. In this paper [13, p. 403-419], they propose an authentication algorithm using blockchain to solve point failure of IoT in smart city. In [14, p. 574-582], authors proposed a lightweight consensus algorithm based on the blockchain for the industrial IoT for secure data transmission that is utilized for a smart factory. A technique called Trust Chain (TC) was proposed in [15, p. 184-193; 16, p. 12-23] to optimize chain integrity and decrease the ability of tracing. This method is utilized to check interactions between supply chain participants, depending on the results of interactions, the trust points, and reputation were selected. In this paper [17, p. 650-655], the researcher proposes a hybrid architecture-based proof-of-work scheme to optimize the efficiency of the system. A JavaScript-based smart contract model for electronic health records was presented in [18, p. 5779-5789]. A blockchain and artificial intelligence (AI) hybrid self-testing system was presented by [19, p. 198]. Using Ethereum oracles and smart contracts. In this paper [20, p. 9895-9911], the researchers proposed a blockchain that based of the data collected and implemented in the tracking system of Covid-19. While in [21], they proposed a platform based on certificate management implemented in blockchain.

Applications of blockchain

There are several applications in the blockchain that utilized in our modern life, here are some of the most common applications that have recent trends.

Blockchain Technology for Transportation

With the development of technological innovations, blockchain can also be used in transportation systems. In addition, to saving money, time, and resources, the application of a smart framework in transportation can significantly enhance the automation and traffic management processes [22, p. 21].

Online Payment

Many countries have already adopted mobile payment systems. Blockchain technology can be used to handle all transportation-related payments, including car registration, parking costs, and bus or light rail ticket purchases [23, p. 439-453].

Blockchain-based Internet of Things (IoT)

Recently, IoT-based technology has become increasingly popular in various industries [24, p. 32979-33001], including smart homes, cities, healthcare systems, education, e-government, and social networking applications. Figure 2 shows the blockchain in IoT.

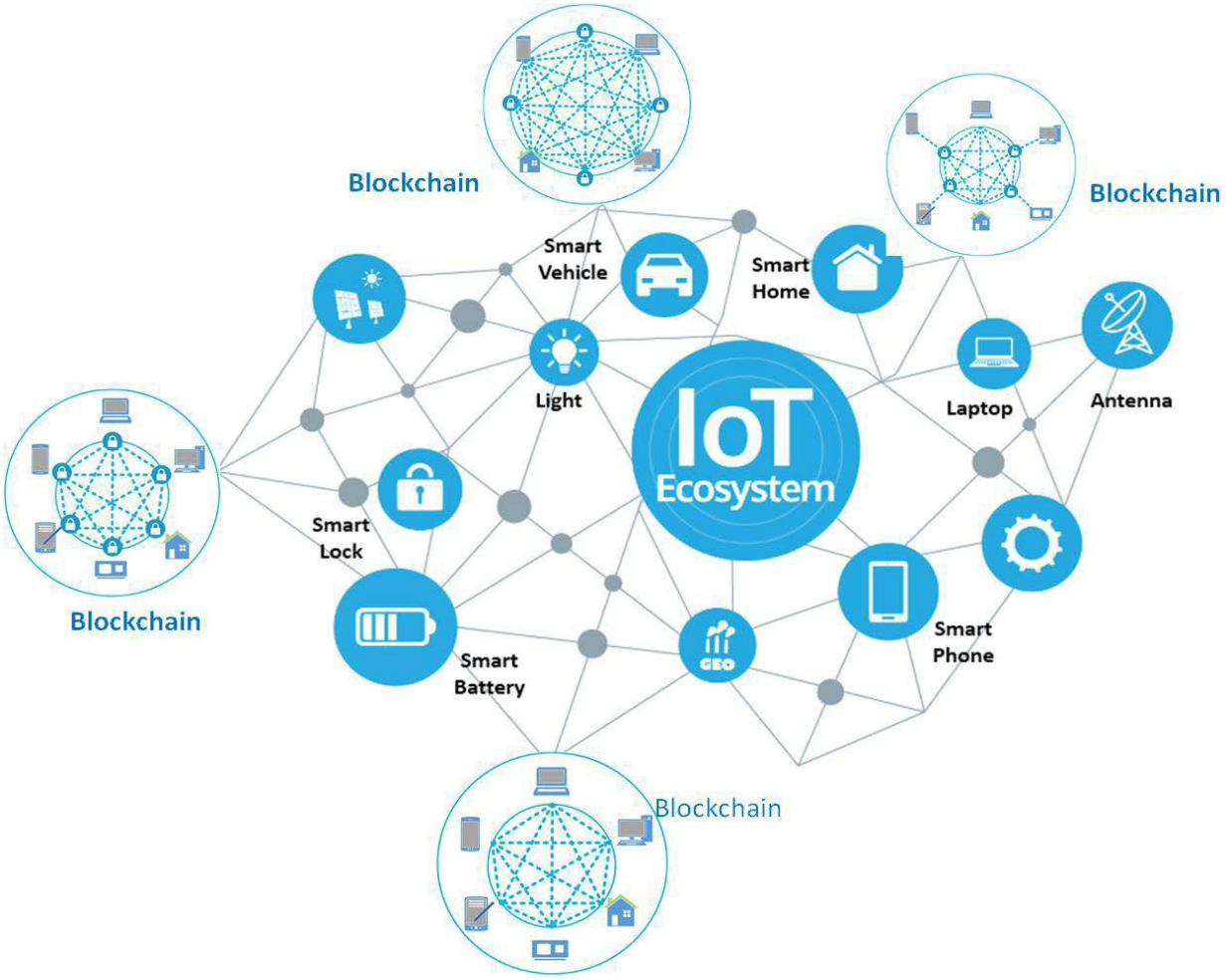

Fig. 2. The blockchain-based IoT

Smart City

The applications of smart cities also contain a network based on the IoT that provides security solutions for individuals. It rely on collecting, analyzes, and digitizing information [25, p. 2794-2830].

Trust Management

The need for a trust mechanism in IoT applications [26, p. 365-374; 27, p. 1-4] is essential to ensure the integrity of data and communications. the architecture consists of three layers: the blockchain, data, and application layer. The data layer involves collecting samples from IoT platforms and other resources, which are then hashed and stored in blocks of the blockchain layer. This layer records all transactions that interact with the previous layer, providing the services to the end user [28, p. 1495-1505].

Blockchain in Security and Privacy

The blockchain technique is utilize in terms of privacy and ensuring the security of the system [29, p. 2405-2416], which are the most challenging aspects in recent years. This model takes minimal effort to secure in cloud architecture [30].

Medical Care

Blockchain technology is useful for storing patient medical records, documents, videos, computer vision, and images [31, p. 380-396; 32]. Since these kinds of information are all sensitive, they must be kept extremely private and secure while still being accessible to those who require them. Data security and privacy can be preserved with the use of blockchain technology [33, p. 470]. In addition, this technique was utilized in the pandemic of covid19 by quickly identify and tracking cases in multiple places.

Defense Industry

Hackers can launch cyberattacks at any time on the majority of tools that used in the defense industry [34, p. 2602-2618]. Blockchain can lessen these threats by encrypting sensitive information. Additionally, the data are transmitted via consensus and secure hashing techniques, which improve the data's authenticity in the communication mode [35, p. 1-8].

Educational Systems

The managing of academic credentials has been the focus of numerous blockchain applications for educational systems [36, p. 191-200]. It is possible

to handle all records without the help of outside parties.

Challenges

Blockchain while promising, faces several challenges and must address various future directions to reach its full review covering:

- Scalability: As the number of transactions are grows, scalability becomes the major issue. Current blockchain networks often struggle to handle a high volume of transactions quickly and efficiently.
- Energy Consumption: Many blockchain networks, especially proof-of-work in cryptocurrency mining, require large amounts of energy, raising environmental concerns. Developing energy-efficient consensus mechanisms is vital.
- Regulatory Frameworks: The lack of clear and standardized regulations globally is a hindrance to widespread blockchain adoption. They are legal perspectives of the society and enable the regulatory frameworks to come in and fasten the trust.
- Privacy and Security: The approach that blockchain has taken to make data virtually tamper proof, how does one ensure the data is protected from prying eyes without compromising the data itself? There is a need for inventions such as new forms of protocols that respect the private life of a person.
- Cost-Efficiency: There is still a high barrier to the fees and computational power required for the transactions within the blockchain and these have to be adjusted so that blockchain becomes cheaper and can attract more users.
- Governance and Decentralization: Striking the right balance between decentralization and effective governance is a challenge. Governance models that ensure fairness, security, and decentralization need further research and development.
- Sustainability: Ensuring the long-term sustainability and development of blockchain projects and networks is crucial. Establishing sustainable business models and community engagement is essential.

Future directions:

Integration with AI and IoT: Leveraging the synergy between blockchain, artificial intelligence (AI), and the Internet of Things (IoT) can lead to powerful applications. Integrating these technologies will be a key focus.

Tokenization of the Assets: can revolutionize traditional financial systems and create new investment opportunities.

Enhanced Consensus Mechanisms: Research and development of consensus mechanisms that improve scalability, security, and energy efficiency, such as proof-of-stake (PoS) and sharding, will continue.

Cross-Industry Applications: Exploring blockchain applications in diverse sectors beyond finance, such as healthcare, supply chain, and education, to unlock innovative solutions and drive efficiency.

Decentralized Finance (DeFi): The advancement of DeFi applications, including decentralized exchanges, lending platforms, and asset management, to create a more inclusive and open financial ecosystem.

Sustainability Initiatives: Incorporating sustainability and green practices within blockchain networks to mitigate environmental concerns and ensure long-term viability.

Quantum-Resistant Algorithms: Developing and adopting quantum-resistant algorithms to safeguard blockchain networks from potential threats posed by quantum computing.

Education and Research: Continued investment in education and research to drive innovation, address challenges, and train a skilled workforce to support blockchain advancements.

Community Collaboration: Encouraging collaboration and open-source contributions to foster a strong community and drive collective efforts toward addressing challenges and advancing the technology.

Conclusions

Blockchain technology also has great potential in the application of various fields in computer science. Some of its application areas are in the supply chain, protection of patents and copyrights, banking and finance, and medicine. But, the problems of scalability, compatibility, protection, and legislation must be solved to achieve the maximum potential of the blockchain. It is possible to expect further advancements in the field of blockchain as more and more scientists, IT specialists, and politicians are involved in the process, which leads to creating revolutionary changes in the field of computer science and other branches.

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