A Review on Blockchain-Based Systems and Applications

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Abstract. Blockchain technology is a combination of distributed data storage, peer-to-peer network, consensus mechanism, timestamp technology, encryption algorithm and other computer technologies. It provides a new solution for the secure distributed cloud data storage system. Blockchain can provide a decentralized secure storage architecture that does not require the accumulation of trust, and it can provides new solutions for cloud storage security and can be applied in time-sensitive areas. This paper summarizes the existing blockchain-based systems and applications, and we mainly review the applications of blockchain traceability technology in various fields, the blockchain decentralized applications, and other blockchain applications in data security protection, respectively. This work may bring new opportunities and challenges for the development of various industries in the future.

Keywords: Blockchain technology · Distributed storage · Cloud storage security

1 Introduction

The blockchain is essentially a distributed database over peer-to-peer networks [1]. It stores all transactions on a peer-to-peer network in a secure, verifiable, and transparent manner [2]. A complete blockchain system includes many technologies (e.g., the consensus algorithms, proof-of-work mechanisms, digital signature, timestamp technology [3]). The blockchain system has the following characteristics: (1) Decentralization; (2) Reliable database; (3) Collective maintenance; (4) Security and credibility; (5) Anonymity; (6) Open source programmable. It provides a new solution for the secure distributed cloud data storage system.

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Generally, the development process of blockchain is divided into three stages, which are called blockchain 1.0, blockchain 2.0 and blockchain 3.0 respectively. Table 1 compares three different stages of blockchain. In the blockchain 1.0 stage, the main focus is on peer-to-peer transactions, and Bitcoin is the most famous application. In the blockchain 2.0 stage, The traceability of blockchain technology and the tamper-resistance of data provide a decentralized and trusted environment for intelligent contracts. In December 2013, Vitalik Buterin [4] developed a public blockchain platform with intelligent contract function – Ethereum application platform, Blockchain 2.0 stage is also known as the Ethereum blockchain stage. The blockchain 3.0 focuses on the integration of blockchain technologies and other fields (e.g., financial industry, Internet of Things (IoT)). Enterprise-level blockchain platform becomes the focus of research.

Table 1. Comparison of each blockchain development stage.

	Bitcoin blockchain	Ethereum blockchain	Hyperledger fabric
Issues to improve	The financial crisis, traditional centralized financial institutions	The limited application scenarios of Bitcoin	Slow transaction speed of public blockchain, unguaranteed transactions
Consensus mechanism	Proof of Work (PoW)	PoW, Proof of Stake (PoS)	Practical Byzantine Fault Tolerance (PBFT)
Network layer protocol	TCP-based p2p	TCP-based p2p	HTTP/2-based p2p
Programming language	Bitcoin script, Ivy	Solidity, Serpent, Mutan, LLL	Go, Java, JavaScript
Data model	Transaction-based UTXO model	The account-based model (includes contract accounts and external accounts)	The account-based model
Application scenarios	Bitcoin trading, asset delivery	Decentralized applications, ether trading, smart contracts	Supply chain management, property registration, asset management, etc.

In the remaining of this paper, Sect. 2 introduces the combination of blockchain, and traceability technology, and the applications in the field of property rights and asset delivery. In Sect. 3, the decentralized applications in blockchain systems are introduced. Section 4 introduces the blockchain applications in data security and data privacy protection. Section 5 summarizes the work of this paper.

2 The Applications of Blockchain Traceability Technology

Traditional traceability technology adopts centralized data storage to manage product information. This centralized management lacks the trust of consumers to conduct reliable data tracking. Blockchain technology has the characteristics of decentralization and distribution, which can solve the problem of lacking trust in centralized systems. Meanwhile, the introduction of timestamp technology in blockchain can add a time dimension to blockchain-based internet. That makes data easier to trace back, and the timestamp can be used as an important basis for proof of existence.

2.1 Blockchain Applications for Supply Chain Traceability Systems

The traditional supply chain management system is insufficient to meet the requirements of consumers for product quality. And many companies and governments are looking for a safer and more efficient way to track products. Through blockchain, a shared distributed ledger, we can make product information transparent. The information stored in the blockchain will not be tampered with, and the commodity's locations in the supply chain can be tracked in real time, providing extraordinary transparency and security. Therefore, the combination of blockchain traceability technology and supply chain management has attracted the attention of researchers. The traceability application model of the product blockchain platform developed with the e-commerce is shown in Fig. 1.

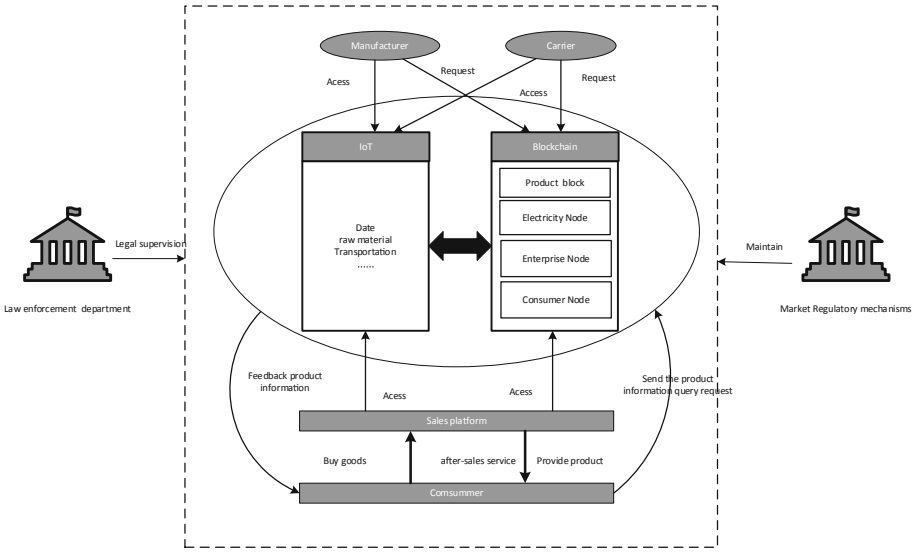

Fig. 1. Traceability application model of the product blockchain platform.

In the supply chain management process, it is urgent to introduce new technologies to improve the security, transparency and integrity of supply chain data. Therefore, it is very important to study the specific operational mechanism and application value of applying the blockchain to the supply chain traceability management. Fu et al. [5] proposed a blockchain technology solution, which uses blockchain technology to track inter-organizational business processes in an enterprise. In order to implement blockchain technology correctly in the supply chain, Perboli et al. [6] analyzed the needs and goals of different participants and combined with blockchain technology to create a business model that can highlight and simultaneously solve problems in economy and customer satisfaction. In terms of solving the fraud problems of enterprise entities and market supervision problems, Lin et al. [7] proposed a blockchain-based food safety traceable system service, and a new blockchain data management architecture. In order to avoid fraud, Figorilli et al. [8] adopted a synergistic method of RFID technology and blockchain to realize a wood chain electronic tracking online information system based on RFID sensor and open source technology within a blockchain architecture.

2.2 Blockchain Applications of Intellectual Property Protection

The existing research proves that the applications of blockchain technology to copyright management can effectively improve the problem of intellectual property rights. It mainly utilizes the openness, traceability, tamper-resistance, decentralization, anonymity and autonomy of the blockchain to solve issues (e.g., the rights attribution certificate, the copyright circulation traceability, the intelligent tracking situation, intellectual property protection and deposit certificates).

The intellectual property protection in the multimedia field is very weak, and the characteristics of blockchain technology (e.g., credibility, transparency, decentralization) make it compatible with the basic principles of copyright to deal with the above problem [9]. [10] proposed a decentralized data management framework, which uses a new blockchain data protocol to control user data. A new secure data protection method based on data hiding and blockchain technology provides basic security services for digital video network transmission [11]. In this paper, the improvement of digital copyright protection system based on digital watermark mainly focuses on the algorithm which ignores the generation and storage of watermark information. Meng et al. [12] proposed a blockchain copyright management system design scheme based on digital watermark information. In order to effectively improve anti-counterfeiting issues in the supply chain, Toyoda et al. [13] proposed a product ownership management system based on radio frequency identification technology for product anti-counterfeiting. This work further realized a proof-of-concept experimental system based on a blockchain decentralization application platform.

2.3 Blockchain Applications for Asset Delivery

Currently, asset delivery usually relies on third-party trust institutions to supervise and prove the transaction process. Such centralized trust institutions have trust problems

such as missing transaction information and information being tampered with. The blockchain solution provides proof for the asset delivery transactions traded between the two individual parties. The interactive relationship of each role in the asset delivery management system based on blockchain is shown in Fig. 2.

At present, some researchers have used blockchain technology to improve the asset delivery certification system. Hasan H.R et al. [14] proposed a decentralized proof of delivery (PoD) solution for PoD of digital assets. [15] presented a blockchain based POD solution of shipped physical items that uses smart contracts of Ethereum blockchain network, and the solution incentivizes each participating entity including the seller, transporter, and buyer to act honestly, and it totally eliminates the need for a third party as escrow. [16] presented a solution and a new general framework using the popular permissionless Ethereum blockchain to create a trusted, decentralized proof of delivery system that ensures accountability, auditability, and integrity. The proposed solution uses Ethereum smart contracts to prove the delivery of a shipped item between a seller and a buyer irrespective of the number which intermediate transporters needed. Utz et al. [17] addressed the energy production, consumption structure changes, and the coordination of assets, equipment, and stakeholders in the energy market by introducing a blockchain-based smart contract ecosystem. Based on existing research, the work in [18] introduces a built-in mechanism to reduce the transaction risks caused by the irreversibility of transactions in blockchain systems. This mechanism can replace a trust-based, centralized, bureaucratic registration with a tamper-proof and autonomous transactional database system that includes secure registration and transaction process. Furthermore, the authors proposed a novel approach to mitigate adverse selection effects in lemon markets by providing a reliable, transparent, and complete record of each marketable asset history information.

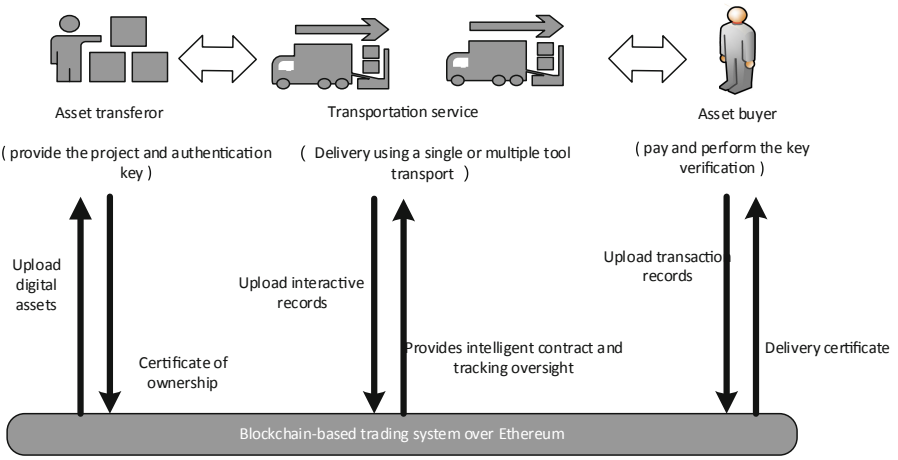

Fig. 2. Delivery management system based on blockchain

3 Decentralized Applications Based on Blockchain

Blockchain has the characteristics of distributed data storage, so it is suitable for the field of decentralized applications such as decentralized voting. Applying the blockchain to the electoral field can mainly eliminate the possibility of potential intended manipulation, and ensure the safety and fairness in addition. It will also improve the convenience of the electoral process. Because voters do not have to pay more time and energy, the participation rate will inevitably increase. Therefore, voting with the blockchain technology can also reflect the main public opinion as much as possible. The decentralized voting application model is shown in Fig. 3. Utilizing the decentralized distributed nature of the blockchain, users can vote for specific candidates in an untrusted distributed environment, and each vote is recorded on the blockchain.

There are many methods for electronic voting, but most of them lack transparency and auditability. Currently, many papers have proposed solutions for this problem by using blockchain technology. Pawlak et al. [19] introduced an auditable blockchain voting system (ABVS), which described the electronic voting process and components of a supervised network voting system with audit and verification functions. On this basis, [20] studies the applications of multi-agent systems and intelligent agent in ABVS. In order to solve the problems of voting fraud and hacking in election and administrative management, [21] proposed a new voting model to solve these problems, which provides a fast, safe and high-throughput voting system. To prevent tampering, Shukla et al. [22] designed a private blockchain by creating a peer-to-peer network, which maintain a shared distributed ledger with voting transactions. This method also designed an application that hides the complexity of the underlying architecture from users to improve security. To facilitate decision-making in a decentralized and secure manner, Zhang et al. [23] proposed a local blockchain voting protocol, which allows peers to vote on the existing blockchain network. [24] introduced a new electronic voting system based on blockchain, which improves the security and reduces the cost of holding national elections. Fusco et al. [25] proposed a new electronic voting system based on blockchain technology. The system is called password voting system, aiming to improve the traceability of voting operations and audit methods. [26] applied blockchain technology's resistance to double spending to prevent double voting on electronic voting systems, and this work proposed a new electronic voting system to ensure credible sources to realize end-to-end verifiable electronic voting scheme. [27] took an in-depth evaluation of the end-to-end verifiable electronic voting scheme, and proved the effectiveness of the proposed method in realizing the end-to-end verifiable electronic voting scheme.

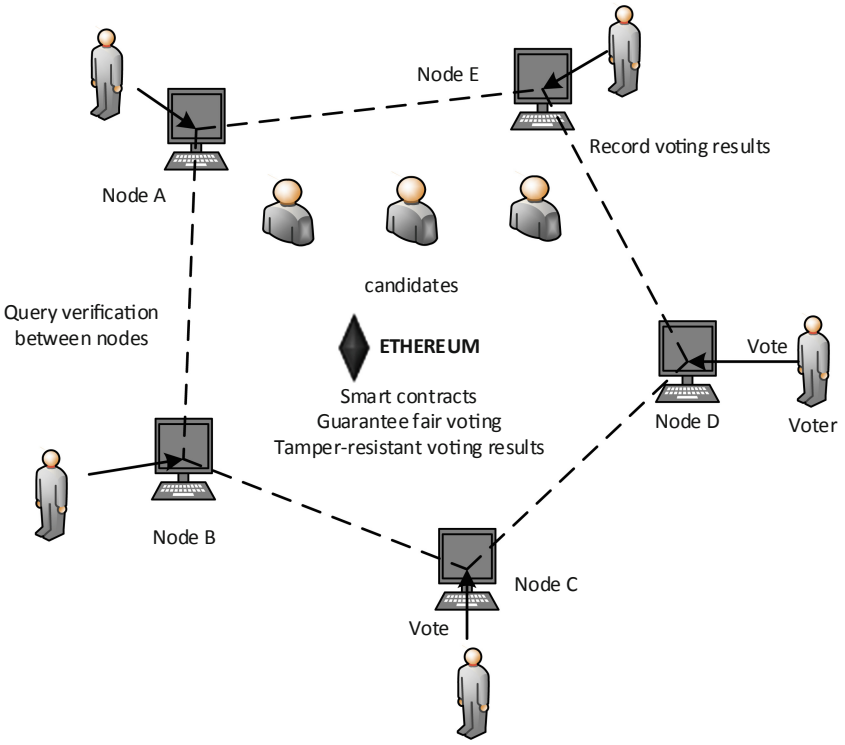

Fig. 3. Decentralized voting system model based on blockchain

4 Decentralized Applications in the Field of Data Security

The rise of cloud storage has led to the explosive growth of data scale in all walks of life. However, trust has become the biggest problem of big data, which will hinder the safe data transmission. Blockchain technology provides a new solution to the problem of data security and privacy protection, which combines the features of tamper-resistance and traceability with smart contracts that automatically execute default instructions [28] to ensure the safe storage and transmissions of data resources. This section reviews the research in finance, Internet of Things and healthcare, and summarizes relevant technologies and development prospects.

4.1 Data Protection in the Financial Industry

Due to various advantages of blockchain, its applications in the financial industry has been widely used. Compared with traditional payment, blockchain payment can directly realize end-to-end payment for both sides of the transaction without involving intermediary institutions, and it can greatly improve the speed.

In the study of how to apply blockchain technology to auctions to maximize social welfare, researchers made the following work. [29] proposed an optimal auction method of marginal resource allocation based on deep learning in the blockchain network. Based on the typical auction security requirements, Blass et al. [30] proposed a new auction protocol running on top of blockchains and guaranteeing bid confidentiality against malicious parties. The inherent transparency and the resulting lack of privacy pose a huge challenge to many financial applications. To solve the above problems, [31] proposed a sealed bidding auction smart contract that can be verified on Ethereum blockchain. To solve the traditional payment problems, a lot of work has been done based on the combination with blockchain. The paper [32] proposed a blockchain-based digital payment scheme that can deliver reliable services on top of unreliable networks in remote regions. Real-time gross settlement system is the cornerstone of inter-bank payment business, and Wang et al. [33] introduced an end-to-end inter-bank payment system prototype based on Hyperledger Fabric enterprise blockchain platform. The prototype supports gross settlement, gridlock resolution, and reconciliation for inter-bank payment business. In the existing online payment systems, information such as reputation could be manipulated by the malicious. For this problem, [34] proposed Reptor, a model for calculation of trust and reputation with the values stored on a blockchain-based payment system's ledger. Zhao et al. [35] studied data security and privacy problem for reliable cyber physical system, and proposed a new secure pub-sub system that uses fairness payment with reputation based on blockchain.

4.2 Internet of Things Data Access Management

IoT equipment installation and deployment in the family in each industrial fields, including transportation, oil, natural gas, energy and manufacturing [36]. The deployment of the IoT equipment range is very wide, and people already know that they are vulnerable to various attacks. As the growth of the importance of privacy, people begin to pay close attention to reliable Internet equipment safety management and access control problem [37]. Blockchain technology has been leading to the birth of many new solutions since 2018. Numerous reports and articles have pointed out that blockchain may be the next key development, and by 2019, nearly 20% of all IoT deployments may have basic blockchain services.

IoT devices can be registered using blockchain to efficiently and reliably organize, store and share data streams. In terms of data security management, Chao et al. [38] proposed a design of blockchain connection gateway, which can adaptively and safely maintain the user privacy preference of IoT devices in the blockchain network. To solve the security and reliability of IoT cloud storage, [39] studied the typical security and privacy issues in the IoT, and developed a new framework to integrate the blockchain with the Internet of Things. The proposed method can provide great guarantee for the data and various functions in the Internet of Things with the ideal scalability, which support authentication, decentralized payment, etc. [40] proposed an

out-of-band two-factor authentication scheme for IoT devices based on Blockchain infrastructure. they implemented the IoT and Blockchain integrated system with Eris Blockchain and equivalent computing devices to emulate IoT devices. Alblooshi et al. [41] presents a general framework and solution to manage and trace back the true origin of ownership for an medical IoT devices (MIoT). Alblooshi et al. [42] proposed a new threshold Internet of things service system based on blockchain: Beekeeper. It is still challenging to apply blockchain to IoTs due to resource constraint characteristics of embedded devices and significant delays in processing and validating transactions.

4.3 Healthcare Data in Blockchain Systems

At present, there are mainly two ways to protect the privacy of medical data [45]. One way is to store medical data in a local database and set up a database access control strategy, other way is to encrypt medical data with the patient's key and share the key when needed. However, both of the above ways have defects. Blockchain is a highly secure distributed data storage platform, which is changing the way how healthcare information is stored and shared [43]. It makes the work more convenient and reduces the maintenance cost while paying attention to the security and accuracy of data. In the healthcare field, blockchain technology has obvious advantages over other existing technologies, and will play a greater role for the applications of blockchain technology in the healthcare field in the future.

In order to ensure the integrity and traceability of medical data, the paper [46] proposed a secure electronic health record system based on cloud computing by using blockchain technology. Another work [47] proposed a blockchain-based secure and privacy-preserving personal health information sharing scheme for diagnosis improvements in e-Health systems. As IoT devices and other remote patient monitoring systems increase in popularity, security concerns about the transfer and logging of data transactions arise. In order to handle the protected health information generated by these devices, [48] utilized blockchain-based smart contracts to facilitate secure analysis and management of medical sensors. There is also a challenge to guarantee the security and the privacy of locations recorded in a blockchain system. Healthcare systems based on blockchain have advantages in terms of decentralization and openness to deal with the above issue. The paper [49] introduced a blockchain-based multi-level privacy-preserving location sharing scheme for telecare medical information systems. Li et al. [50] proposed a blockchain-based medical data preservation system, and they leveraged the blockchain framework to provide a reliable storage solution and ensure the primitiveness, verifiability of stored data while preserving privacy for users.

Table 2 summarizes the situation of the combination with blockchain in the fields of finance, IoT and healthcare. In general, the application of blockchain technology in various fields in the future has a broad prospect, and it is also full of challenges.

Table 2. The combination summary for blockchain and various applied fields

	Blockchain and finance	Blockchain and IoT	Blockchain and Healthcare
Traditional disadvantages	Lack of trust, slow cross-border payment speed, low data security	Lack of privacy, vulnerability to attacks	Data tampering, separated data storage, incomplete patient information
Advantages of combination	Decentralized, improved transaction speed, improved data security	Privacy protection, data storage security, access control protection	High data security, complete patient information
Current development situation	Early development, deployed in most blockchain projects	Begins from 2015, for the management and security of IoT devices	Late start, less applications
Application scenarios	Bitcoin trading, hyperledger, justice and charity, etc.	Smart city, Internet of Vehicles, etc.	Electronic health record, DNA wallet, protein folding, etc.
Blockchain stage	Blockchain1.0, 2.0, 3.0	Blockchain3.0	Blockchain3.0
Reference index	[29–35]	[36–42]	[43–50]

5 Conclusion

As an untampered, time-sequentially verifiable chain-like storage architecture, blockchain can provide a new solution for the secure distributed cloud data storage system, and it is becoming one of the current hottest research fields. This paper summarizes the relevant applications and research of existing blockchain technology. We mainly review the applications of blockchain traceability technology in various fields, the blockchain decentralized applications, and other blockchain applications in data security protection, respectively. As investigated by the above studies, blockchain will contribute to improving the solutions in multiple fields such as the Internet of Things, smart city and supply chain. It will also bring new opportunities and challenges for the development of various industries in the future.

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