Blockchain Applications in Smart City: A Survey

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Abstract. Smart cities bring new ideas to solve the social, economic, and environmental problems existing in traditional cities. However, the services of smart cities suffer from centralized data storage and untrustworthiness. As a decentralized distributed database, blockchain provides distributed and trusted infrastructure technology for the construction of smart cities. In this survey, we conduct a brief survey of the literature on blockchain applications in smart cities. We review the application of blockchain in smart cities from the four main application scenarios of energy, transportation, medical care, and manufacturing. Then, we discuss the realization of blockchain-based smart cities from the perspectives of privacy and storage. We believe this survey provides new ideas for the development of smart cities.

Keywords: Blockchain · Smart City · Smart Contract · Distributed Storage

1 Introduction

With the continuous increase of urban population, the medical level, convenient transportation, education level and living environment have been dramatically improved in cities. A large number of citizens are mitigating to bigger-sized cities for seeking a better living. However, a large growth of urban population also has brought many issues, for example, the limited energy resource, traffic congestion, air pollution, lack of medical resource, and manufacturing shortage. Constructing a digital transformation towards smart city, i.e., integrating Information Technology (IT)-based solutions with city infrastructure, is an alternative solution to solving some known city issues. The goal of the smart city is to build

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Table 1. Summary of the application of blockchain in specific fields

Ref.s	Fields	Description
[6]	Smart grid	Blockchain-based data protection model; strengthening the defense of smart grid against external network attacks
[7]	Medical	Hybrid storage model; improving the scalability of blockchain for the medical field
[8]	Transportation	Blockchain-based Internet of Vehicles trust system; realizing transportation detection management
[9]	Supply sys	Ethereum-based supply chain system; ensuring the security and traceability of the information

a sustainable city through new technologies. New technologies (e.g., blockchain [1,2]) provide technical supports for the construction of smart cities. This survey focuses on new adoptions of blockchain in smart city.

Blockchain [3–5] is known as a distributed data ledger that jointly maintains system tamper-proof, immutability, and traceability in a decentralized and trustless manner. Blockchain-based smart cities can solve some existing city issues. For example, decentralization and trustless mechanisms secure the execution of distributed environments without a trusted third party; immutability ensures security of data transmissions; traceability is conducive to the realization of the full life cycle management of block storage data; the deployment of smart contracts, moreover, realizes automated executions of transactions and expand applications in various fields in smart city.

Many prior researches have explored blockchain applications from various dimensions, for instance, as shown in Table 1. However, investigations targeting at blockchain adoptions in smart city are rare. To make up for the application gap in this field, this survey mainly synthesizes blockchain-based smart city solutions from perspectives of transportation, medical, energy [10], and manufacturing. In addition, we further discuss major factors of blockchain-based smart city in order to provide a fundamental view of the blockchain adoptions in smart city.

The rest of this survey is organized in the following order. Section 2, 3, 4, 5 elaborate on the four main application scenarios of blockchain-based smart cities, namely medical, transportation, energy and manufacturing, respectively. The discussions of the smart city are presented in Sect. 6. Finally, we concluded the work in Sect. 7.

2 Blockchain-Based Smart Energy

Energy is a crucial foundation for urban economic development. The traditional centralized energy system is no longer appropriate for the current situation, and the energy system is gradually evolving from centralized to dispersed [11]. Blockchain includes attributes like anonymity, decentralization, and traceability that can be utilized to change the way the energy system operates.

The smart grid [12] is a new grid infrastructure that supports the two-way delivery of energy and information. A smart grid must effectively manage the data related to distributed energy. To ensure the secure sharing of distributed energy data, a safe and auditable data exchange system [13] for smart grids based on blockchain was proposed, which establishes a framework for data exchange that includes fine-grained access control, computation of sensitive data, and data traceability. Furthermore, to ensure the security of private information, an out-of-chain smart contract based on the trusted execution environment is designed in this scheme.

The smart grid is vulnerable to cyberattacks because network communication technology based on TCP/IP and Ethernet protocols exposes it to the public network. To strengthen the smart grid's defenses against outside cyberattacks, a distributed data protection model [6] based on blockchain was presented. In this model, smart meters are used as nodes in the blockchain to capture and store power data to ensure data security. Aiming at the security problems of smart grids in an open environment, Bera et al. [14] proposed a blockchain-based access control for the smart grid, which provides anonymity and non-traceability.

The decentralization of blockchain is consistent with distributed energy trading. There are many designs that combine blockchain and energy trading [15–18]. To ensure privacy in smart grid energy transactions, Gai et al. [15] presented a consortium blockchain-based energy trading system. To defend against linking attacks and malicious data mining algorithm attacks, this scheme protects private data such as energy trading trends by building an account mapping mechanism on the smart contract.

In addition, some scholars have been interested in the efficiency of the energy trading process. Ali et al. [16] proposed an adaptive network model for P2P energy trading. In this model, the smart contract is used to create and manage prosumer groups, which improves the scalability of the prosumer grouping mechanism and eventually improves the overall system performance. For distributed energy, the use of P2P energy trading can reduce energy consumption costs. Khalid et al. [17] designed a hybrid P2P energy trading model based on blockchain. This scheme makes use of three smart contracts to realize a complex energy trading market. Among them, the master smart contract manages all energy trading operations, the P2P smart contract is used to control the relevant information between producers and consumers. The prosumer-to-grid (P2G) smart contract is used to manage the data related to the main power grid. AlSkaif et al. [18] constructed a full P2P energy trading model based on blockchain for residential energy systems with different distributed energy types. In this scheme, two new trading strategies are proposed, one is the matching strategy of supply and demand, and the other is the matching strategy based on distance. In the supply and demand matching strategy, the transaction coefficients are calculated according to the power demand and excess power. In the distance-based matching strategy, P2P trading between nearby participants is encouraged to reduce the loss of long-distance transmission, thus improving energy efficiency.

3 Blockchain-Based Smart Medical

In current city life, medical data is basically stored and managed by each hospital separately. However, the centralized storage of medical data will cause certain security problems. As a distributed ledger, blockchain provides distributed and secure medical data storage.

Blockchain provides an efficient and low-latency method for data storage. For example, Gaetani et al. [19] use blockchain to ensure data integrity. They design a database based on blockchain to solve the low throughput and high latency in the original cloud computing environment. However, the medical data of patients are stored separately in each hospital, resulting in the fragmentation of the medical data storage of patients, which brings inconvenience for patients to seek medical treatment across hospitals.

To build a full life cycle of medical data storage management for patients, Yue et al. [20] proposed a Healthcare Data Gateway based on blockchain, which guarantees patients to control their private information. The complete data storage framework was built through the blockchain, which built a lifelong traceable and tamper-proof data record for patients. Since all data in a single blockchain system has been stored. However, the data storage capacity of the current blockchain is limited. To improve the scalability of blockchain, Sun et al. [7] proposed a hybrid storage mode based on blockchain pluses IPFS. Therefore, in the face of massive medical data, the hybrid storage model can safely and irreversibly store medical data in blockchain and IPFS without violating the concept of blockchain distributed and trusted storage, which satisfies big data storage requirements to a certain extent.

In addition, there is a problem with privacy disclosure in the process of sharing medical data. To realize the safe and reliable sharing of medical data under the premise of ensuring user privacy, Kumar et al. [21] proposed a patient-centered framework and a data access control mechanism for PHRs stored in semi-trusted servers. This scheme uses ABE technology to encrypt the PHR files of each patient. However, the ABE system needs additional computing overhead to perform attribute revocation and encrypt the data again. To reduce costs, Gu et al. [22] proposed a more effective ABS scheme using monotone predicates, but it cannot solve the problems caused by access control modifications. In this regard, Guo et al. [23] introduced a signature scheme with multiple permissions to ensure the effectiveness of medical data in the blockchain.

In the smart medical system, blockchain can effectively solve the problems of data isolation. In addition, it can tamper with the current medical data storage, and relieve the pressure on data storage caused by massive medical data.

4 Blockchain-Based Smart Transportation

In this section, several of the newly developed blockchain applications that relate to the transportation industry will be thoroughly discussed. Transportation serves as both the urban development's infrastructure and the heartbeat of the city. Promoting the establishment of smart cities requires the development of smart transportation. Smart transportation scenario refers to the industry developed by using cutting-edge technologies (e.g., blockchain etc.) combined with the traditional transportation industry.

Traditional transportation system has two main problems. First, the level of intelligence and digitalization of traditional transportation infrastructure is low, and the capability of controlling information is weak. Second, some data-centric transportation applications, such as vehicular ad-hoc networks (VANETs), suffer from the lack of a fixed infrastructure and dynamic information communication. Blockchain can assist in building a distributed, secure and trustworthy smart transportation system. Applying blockchain technology to the transportation industry can achieve borderless connectivity and flat sharing of transportation system data.

Currently, many related research [8,24,25] are applying blockchain technology to various aspects of transportation. In the aspect of big data management. To solve the serious road safety problem caused by the easy modification of car odometer data, Preikschat et al. [24] proposes a blockchain-based distributed database. This distributed database enables data sharing of odometers and ensures that data is protected from tampering. This scheme enhances the public transparency of odometer data to a certain extent.

In the aspect of transport detection management, Yang et al. [8] give an implementation of an IoV trust management system using blockchain. The scheme focuses on verifying the received information by the Bayesian model and calculating the trust offset value of the received information. It realizes the combination of data and blockchain. Additionally, Liu et al. [25] assert that blockchain technology might be used to plan the charging and discharging of electric vehicles. In this scheme, electric vehicles firstly place charging and discharging orders to the public blockchain trading platform of the smart grid. Then, matching orders are processed and authenticated by peer nodes within the blockchain network. Finally, both organizations save the confirmed requests in a distributed manner. All the above researches prove that blockchain provide some technical support to ITS, thus improving the distributed capability as well as the security of the system.

Some related research has shown that blockchain can help build vehicular VANETs and manage vehicle communications. Conventional VANETs suffer from the lack of fixed infrastructure and dynamic information communication. It has been demonstrated that dynamic VANETs can be safely managed using software-defined VANETs [26]. Following that, it is incorporated with blockchain technology to offer distributed control over the entire network. Moreover, To improve the interactive security of electric vehicles in VANETs, data coins and energy coins stimulated by blockchain can be defined as a new type of cryptocurrency and can be applied to the vehicles [27]. This literature focuses on workload proofs using data contribution frequencies and energy contribution amounts to achieve distributed consensus among vehicles. In addition, a significant problem that needs to be resolved is how to store and transmit data securely in VANETs environment. It has been demonstrated [28] that the issue of safe data storage on VANETs can be resolved by implementing a distributed transaction storage method based on a blockchain.

Further, to address the consistency and non-tamperability of transmitted data, Zhang [29] proposed a data sharing and storage system based on blockchain. The system allows having digital signatures in a self-organizing onboard network. Roadside units (RSU) can also execute smart contracts to define the parameters of data exchange and store replica sensor data in a distributed method.

All the above applications prove that blockchain technology can bring certain technical support to the transportation field, thus making transportation under smart cities more efficient and safer.

5 Blockchain-Based Smart Manufacturing

Smart manufacturing achieves production optimization and improves production efficiency by utilizing new-generation information technologies, including but not limited to the Industrial Internet of Things (IIoT) and automation [30,31]. However, smart manufacturing is currently facing challenges such as security, interoperability, privacy protection, and traceability [32,33]. As a decentralized and trustless distributed data ledger, blockchain provides new ideas for solving the problems existing in smart manufacturing. Next, the applications of blockchain in IIoT and supply chain management are discussed below.

IIoT is an application of the IoT in industry and one of the core technologies of smart manufacturing. However, the traditional IIoT has problems of high cost, high communication overhead, low security, and high latency. The distributed storage of blockchain can effectively solve the problems of a single point of failure in centralized IIoT and improve its robustness of it [34].

A variety of solutions have been proposed by researchers in response to the problems existing in IIoT. Huo et al. [35] proposed a trusted identifier co-governance architecture with the fusion of blockchain and Handle technology. The architecture is divided into three levels. In the second level, blockchain is introduced to provide efficient and stable identity resolution services. The proposed solution not only further improves the performance of identity resolution services, but also ensures data security and reliability. Although blockchain can make IIoT securer, there are still shortcomings in communication efficiency. Wang et al. [36] attempted to replace the Merkle tree in the blockchain with incremental aggregator subvector commitment, which realizes the aggregation proof of multiple data blocks. It effectively solves the problem of low communication efficiency caused by verifying data. In addition, the combination of blockchain and other technologies (e.g., cryptography, machine learning, artificial intelligence) can better ensure the security of IIoT. Tan et al. [37] proposed an IIoT key data protection scheme based on blockchain, where the private key is split and encrypted through the Shamir secret sharing algorithm. They also publish it on the blockchain. Besides, Mansour [38] proposed an Intrusion

Detection System for IIoT, which not only improves the accuracy of intrusion detection, but also uses blockchain to achieve secure data transmission. The above applications show that the deep integration of blockchain and IIoT can solve the problems of insecure data transmission, low communication efficiency, which improves the security and stability of the IIoT equipment.

Supply chain is an important part of smart manufacturing and is moving towards digitization. However, it faces challenges and problems in information sharing, data security, traceability and enterprise interconnection [9,39]. Blockchain provides new ideas for optimizing the management of smart manufacturing supply chain.

Many studies focus on blockchain-based solutions to the supply chain. For example, Wu and Zhang [40] investigated the problem of supply chain trust management. They proposed a framework for trust management utilizing blockchain to make the interactions among supply chain entities more reliable. The improved EigenTrust algorithm used in it optimizes the trust management model. Specifically, the malicious nodes are identified by calculating the trust value of the node. Thus, the influence of malicious nodes, who may give a negative evaluation, can be reduced.

To achieve supply chain transparency and traceability, Xu et al. [9] put forward a supply chain management system based on Ethereum. The combination of traditional database technology and blockchain enables producers, managers, and customers to obtain the required information according to their needs, and ensures the correctness and credibility of the information. In addition, Weaterkamp et al. [41] designed a supply chain system with traceability utilizing smart contracts. In contract, the ingredients of products are defined as recipes. Every ingredient is a token, which represents a batch of real goods. The token is unique and unforgeable. When products are manufactured, the input tokens are consumed and new tokens are created. It is more convenient to trace the conversion process of products.

The above applications show that blockchain effectively solves problems in the supply chain. It makes the smart manufacturing supply chain more secure, reliable and transparent and improves its efficiency.

6 Discussions

While blockchain brings convenience to smart cities, we also hope to protect citizens' data security and privacy. However, there are some privacy leakage issues with the blockchain. For example, users participating in the construction of the blockchain cannot guarantee complete anonymity, resulting in the disclosure of user identity data. This is because the blockchain is open and transparent, and all network participants can see all the information stored on the blockchain. Although the blockchain maps network participants to pseudonymous addresses in order to ensure anonymity. However, attackers can use the combination of public information stored in the blockchain and external information to track the actions of users, so as to obtain the real identity of the user, resulting in the disclosure of user privacy. Therefore, it is crucial to study the anonymity of the blockchain to ensure the privacy of users.

In addition, the scalable storage of smart blockchains is a prerequisite for future urban applications. In smart cities, various data collection devices will generate a large amount of data, which requires blockchain technology to process. However, each node in the traditional blockchain contains complete transaction information, which cannot store all transaction information due to the limited storage space of the blockchain. Therefore, it is impossible to directly apply the blockchain to smart cities. We need to study the scalability of the blockchain to meet the application needs of massive data in smart cities. In addition, we can use decentralized storage methods in the blockchain system to increase its storage, thereby providing the possibility for a wide range of applications in smart cities.

7 Conclusion

This survey explored the application of blockchain technology in smart cities. First, we discussed in detail the relevant applications of blockchain technology in smart cities from the perspectives of medical, transportation, energy and manufacturing. Further, we also discussed the privacy and scalability of blockchain-based applications in smart cities. To sum up, the application of blockchain to smart cities improve people's quality of life. Moreover, we also believe that this survey provides new ideas for the development of smart cities.

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