

Research progress of encrypted keyword search based on blockchain

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ABSTRACT

In recent years, with the development of IOT and the use of new energy, the information security problems of energy big data are gradually revealed, to further improve the privacy and security of data, the open and transparent blockchain technology is introduced. At present, some scholars have introduced blockchain technology into big data query, and the query types are also various. This paper mainly summarizes the research on keyword search based on blockchain in recent years, and analyzes its application potential in energy information security. The general structure of this paper includes a brief introduction to blockchain, the research progress of keyword search based on blockchain. Finally, this paper makes some prospects on the storage and resource consumption of keyword search based on blockchain.

Keywords: blockchain technology, energy information security, keyword search, searchable encryption, smart contract

1. INTRODUCTION

Blockchain is a distributed ledger. In 2008, Nakamoto of Japan first proposed the design concept of decentralized cryptocurrency bitcoin, which was put into practice in 2009. Blockchain has great potential, with the birth of blockchain development platforms, such as Ethereum and Hyperledger fabric, as well as the development of many decentralized applications, the application of blockchain has extended from the initial digital currency to many fields such as finance, IOT, intelligent manufacturing, etc[27].

Because the blockchain is decentralized, the storage of big data has become an urgent problem to be solved, and due to its sharing characteristics, the data on the blockchain may be leaked. After that, cloud computing is added. Although the problem of storage and

computing is solved, the privacy and accuracy of data is another big problem.

To ensure the integrity and security of users' search data, many scholars have carried out further research on the combination of blockchain technology and traditional search query technology. In 2017, Chengjun Cai et al. [1] used blockchain to strengthen distributed keyword search, enabling users to search encrypted data; in 2019, Muhammad El Hindi et al. [2] introduced the database layer by using blockchain as the storage layer, which reduces the organizational complexity of the blockchain in data sharing, realizes the scalability and improves the performance of the system; Muzammal Muhammad et al. [3] proposed an open source system that integrates blockchain and database, which combines the security and reliability of blockchain with the advantages of distributed database; In the same year, Yanchao Zhu et al. [4] designed SEBDB: (Semantics Empowered BlockChain DataBase) solves the problem that the blockchain platform cannot easily and efficiently model complex tasks .

2. RELATED WORK

2.1 Blockchain query work

Blockchain covers a variety of technologies, and its four core technologies are distributed storage, consensus mechanism, cryptography and smart contract. These technical concepts are easy to be confused, and the application scenarios are various and complex. Therefore, some current literature mainly summarizes the technical architecture, technical challenges, application scenarios and existing security issues. [5] summarized the characteristics of the service architecture of blockchain, it also elaborated the current challenges and future development trend; at present, the use of blockchain technology to achieve query also has further research progress. Figure 1 is a brief introduction to the current blockchain query work,

due to the length limitation of the article, only the following three types of queries are introduced.

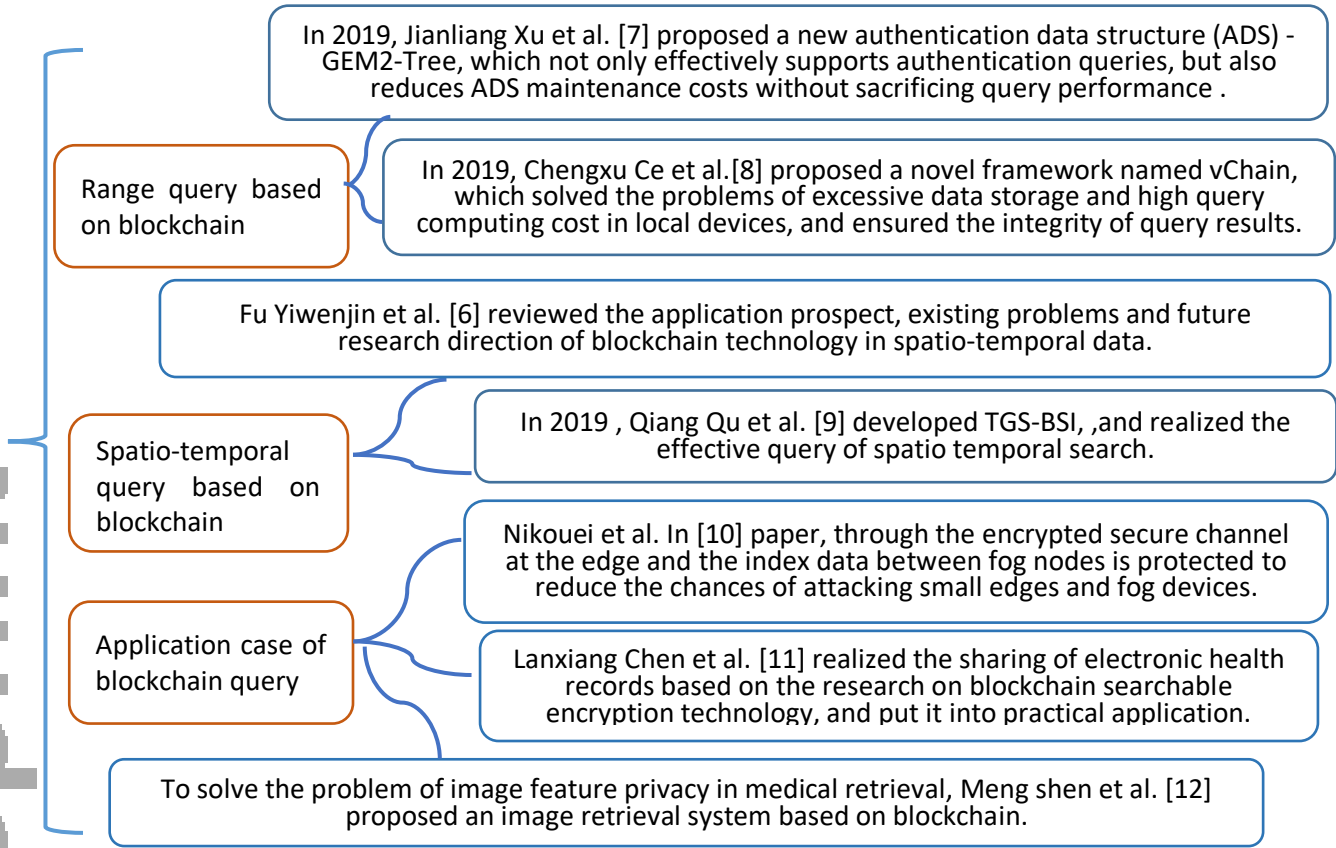


Figure 1 Some research on blockchain query

2.2 Analysis on the application potential of energy information security

With the development of IOT and the extensive use of green energy resources, the development of new energy industry has also shown a trend of diversification. It has also promoted the integration of information technology and industrialization. However, with the increasing size of energy data, the security problems of energy data are gradually emerging. The backup data flowing through the network has the risk of being stolen, the privacy and security of data storage and query can't be guaranteed. To solve this problem, we introduce blockchain technology.

At the same time, because the operation mode, topology, security protection and other aspects of the blockchain are consistent with the idea of the natural energy Internet, it can complement the energy big data well and effectively solve the problem of energy information security.

At present, scholars have carried out a series of research on energy security based on blockchain. Qiuxiang Li et al. [23] comprehensively analyzed the security of energy data and proposed a multi-source collaborative mechanism, finally, established a system model of energy data supervision and trading based on blockchain. Yujia Yang et al. [24] proposed a blockchain network algorithm for the confidentiality, anti-attack and security of transaction information of microgrid transactions. M. M. esfahani et al. [26] proposed a blockchain based energy trading framework for the contemporary power system, and proved that it has more advantages than the traditional trading framework. Erica svetec et al. [25] summarized the application of blockchain in renewable energy microgrid.

As can be seen from the above-mentioned documents, blockchain technology has great potential in energy information, especially in energy data security and privacy protection. The effective storage and

correct query of energy data using blockchain will be a major focus of future research.

3. BLOCKCHAIN INTRODUCTION

3.1 Structures of blockchain and types of blockchain

As shown in Figure 2, blocks are linked by hash values, that is to say, the next block has the hash value of the previous block connected to it. If you want to add a new data record, you need to put it into a new block. The hash value of the new block will be calculated to determine whether this block is legal. If a block changes, it needs to be changed in turn as shown in the Figure 2. This is very time-consuming and laborious, which also ensures the no-tampering of the blockchain.

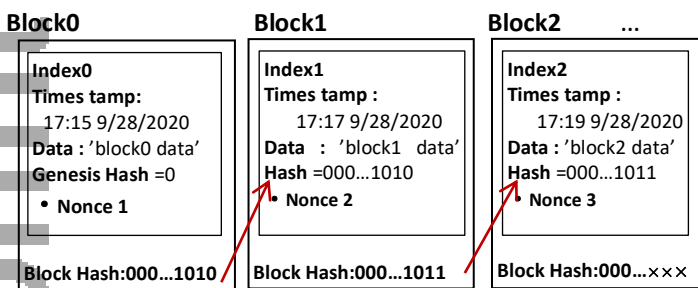


Figure 2 Blockchain structure

From the perspective of the openness of blockchain, blockchain can be divided into three types:

- Public chain-----①
- Private chain-----②
- Alliance chain-----③

sort order:

1. According to the degree of decentralization and openness:
①>③>②
2. According to the utilization rate of blockchain:
②>③>①
3. In terms of resource consumption:
①>③>②

Generally speaking, the public chain has the lowest entry threshold, while the private chain and alliance chain are limited in the degree of openness.

3.2 Technical framework of each layer of blockchain

This section shows the general hierarchical technology structure of blockchain, The detailed architecture is shown in Figure 3.

Figure 3 [26] shows the layer structure of the blockchain (application layer- I , control layer- II ,

consensus layer-III, data layer-IV, network layer- V) and the key technologies used in each layer structure.

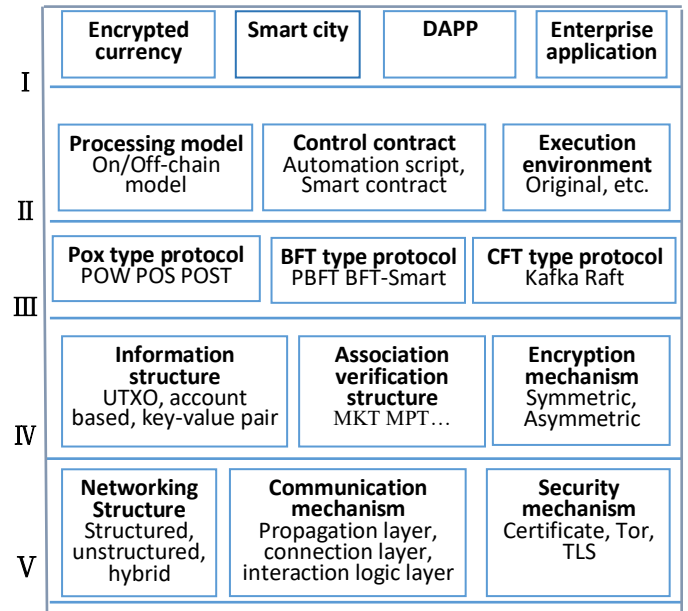


Figure 3 General hierarchical technology structure of blockchain

4. RESEARCH PROCESS OF KEYWORD SEARCH BASED ON BLOCKCHAIN TECHNOLOGY

4.1 Searchable encryption scheme based on blockchain

The current searchable encryption system also faces the problem that cloud servers may send incorrect or incomplete search information to users, in order to save computing resources [13]. With the development and application of blockchain, the encryption technology based on blockchain is also put into research. The latest research shows that searchable blockchain can not only provide reliable search service in encrypted distributed storage system, but also ensure the privacy and security of users and data information.

In 2018, Y. Zhang et al. [14] introduced a fair payment framework (BPay) for cloud computing outsourcing services, and further proposed dynamic provable data ownership scheme based on blockchain, searchable symmetric encryption scheme based on blockchain, etc; in 2018, C.Cai et al. [15] used smart contracts to record encrypted search (also known as evidence) logs on the blockchain, in addition it designed a specific scheme for a dynamic and efficient searchable encryption scheme. This encryption search scheme not only retains the search ability of the system, but also enhances the robustness of the system in the search process. In the same year, S.Hu et al. [16] constructed a decentralized privacy protection search scheme by exploiting the potential of smart contracts (a new

blockchain technology), replacing the central server with smart contracts, so that users can receive more accurate information without worrying about malicious servers. In 2019, L. Chen et al. [17] proposed a new searchable encryption scheme based on blockchain for the sharing of EHR. In the same year, Y.Wu et al. [18] did not use centralized cloud servers, but used smart contracts to provide reliable and transparent matching search schemes, effectively realizing data confidentiality and identity anonymity. In September 2019, Y. Yang et al. [19] proposed a blockchain based multi-keyword ranking search scheme BMFP. It also uses smart contracts to store encrypted files and verify search results, ensuring the correctness and integrity of search results.

4.2 Research on multi-keyword search based on blockchain

Research shows that searchable blockchain can not only ensure the privacy of users and search data, but also provide reliable search service on encrypted distributed storage system. However, Some search schemes can only search for single keyword in the blockchain, such as those mentioned in section 4.1 [14][15][16][17][18]. Although it can be extended to

multi-keyword search scheme by using the set of single keyword search results executed multiple times, this kind of expansion has great privacy insecurity and low efficiency. In 2019, Shan Jiang et al.[20] designed a data management system with dynamic update of database settings and multi-keyword search, adopted SSE to protect privacy, and proposed a multi-keyword search protocol with Bloom filter. The system finally realized efficient multi-keyword search of encrypted data on block chain, and privacy was guaranteed. Y.Yang et al.[19] proposed a scheme named BMFP based on blockchain, in this scheme, the multi-keyword sort inverted index data structure and efficient query table are designed, which not only realizes the efficient search of multi-keywords, but also realizes the keyword ranking search, such as "the top k search", at last, the scheme realizes the effective verification of the search results by using smart contract. Peng Jiang et al. [28] proposed a search framework (Searchain) based on OKS and OMS, however, OKS can only realize single keyword search, so the search framework can only realize single keyword search. As shown in Table 1, we compare the search schemes from the number of search keywords, whether the search can be sorted, the blockchain platform, and the result verification.

TABLE 1 Comparison of different schemes

Properties	[14]	[15]	[16]	[17]	[18]	[20]	[19]
Multi-keyword	×	×	×	×	×	✓	✓
Result ranking	×	×	×	×	×	×	✓
Result Verification	✓	✓	✓	✓	✓	✓	✓
Blockchain	Bitcoin	Ethereum	Ethereum	Ethereum	Ethereum	Ethereum	Ethereum

4.3 Other aspects of keyword research based on blockchain

In addition to the above research on blockchain based encryption technology and multi-keyword, there are some other aspects of research on blockchain based keyword search. Due to the space limitation, this paper briefly introduces the research on storage and two-side verification.

From the storage of keywords, generally, there are two forms of storage, one is on-chain storage, the other is off-chain storage. Because the storage space of the blockchain is relatively small, the storage off the chain is widely used. Chengjun Cai et al. [21] designed a private keyword search secure data storage system based on blockchain. The system uses the blockchain as the backbone to access the data storage under the chain, grant permissions and generate search tokens, and supports private keyword search for encrypted data

sets. S. Jiang et al. [20] used smart contract to realize database setting and data management in blockchain. Y. Yang et al. [19] designed the inverted data index structure of multi keyword sorting and efficient query table. The storage structure realized the mapping of keywords to documents and accelerated the search process.

From the perspective of two-side verification, at present, there are also two-side verification research using blockchain in keyword search. The TKSE scheme proposed by Y.Zhang et al. [14] realized two-side verification to ensure fair payment for the first time, after that Priya N et al. [22] proposed a two-side verification method which does not rely on any third party for malicious cloud servers, and realized keyword search of two-side verification by smart contracts.

5. CURRENT DIFFICULTIES AND FUTURE DEVELOPMENT

From the perspective of blockchain, the current development of blockchain technology is still in its infancy. It solves the problems of trust construction and privacy protection of multi organizations participating in complex production environment with low cost, but there are still many deficiencies in technology and security. From the technical point of view, many key technologies have narrow application scope, the combination of many blockchain and traditional technology is still immature. From the perspective of security, there are security defects in all levels of the blockchain architecture, and further research and exploration are needed in the aspects of consensus mechanism, privacy protection, regulatory mechanism, cross chain technology, etc [26]. In addition, the cost of the whole node is relatively large, how to reduce the cost of data storage and improve its scalability needs further research.

From the perspective of keyword search based on blockchain, the searchable encryption technology based on blockchain has been developed to a certain extent. Although blockchain can be used to realize keyword search and expand from single keyword search to multi keyword search, the consumption of smart contract needs to be further optimized, and the concurrency mechanism is fully utilized to enhance contract execution. The efficiency of the line requires further research on multi-keyword search and keyword ranking search (k-ranking search) in the blockchain. In addition, there is no search for historical keywords in the blockchain, for example, traceability search, the traditional database system does not fully support the traceability query, which is also an important task.

From the perspective of energy information security, the use of blockchain technology has a lot of room for improvement in energy data storage, query, and fair trade. In the future, more and more traditional energy systems will be improved by using blockchain technology.

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REFERENCE

- [1] Cai Chengjun, Yuan Xingliang , Wang Cong. Hardening Distributed and Encrypted Keyword Search via Blockchain. 119-128. 10.1109/PAC.2017.36.
- [2] El-Hindi Muhammad , Binnig Carsten, Arasu Arvind, Kossmann Donald, Ramamurthy Ravi. BlockchainDB: a shared database on blockchains. Proceedings of the VLDB Endowment 2019; 12. 1597-1609.
- [3] Muzammal Muhammad, Qu Qiang, Nasrulin Bulat. Renovating blockchain with distributed databases: An open source system. Future Generation Computer Systems 2019; 90:105-117.
- [4] Yanchao Zhu, Zhao Zhang, Cheqing Jin, Aoying Zhou, Ying Yan. SEBDB: Semantics Empowered BlockChain DataBase. IEEE 35th ICDE, 2019.
- [5] Yang Wenli, Aghasian Erfan, Garg Saurabh, Herbert David, Disiuta Leandro, Kang Byeong. A Survey on Blockchain-based Internet Service Architecture: Requirements, Challenges, Trends and Future. IEEE Access.2019; P. 1-1.
- [6] FU Yiwenjin, CHEN Huahui, QIAN Jiangbo, et al. Survey of blockchain research for spatiotemporal data. Computer Engineering, 2020; 46(3):1-10.
- [7] Zhang Ce, Xu Cheng, Xu Jianliang, Tang Yuzhe, Choi Byron. GEM²-Tree: A Gas-Efficient Structure for Authenticated Range Queries in Blockchain. IEEE 35th ICDE, 2019.
- [8] Cheng Xu, Ce Zhang, Jianliang Xu. vChain: Enabling Verifiable Boolean Range Queries over Blockchain Databases. Amsterdam, Netherlands, 2019; SIGMOD'19.
- [9] Qiang Qu, Ildar Nurgaliev, M. Muza-mmam, Christian S.Jensen c, Jianping Fan. On spatiotemporal blockchain query processing. Future Generation Computer Systems 2019; 98:p. 208-218.
- [10] Seyed Yahya Nikouei, Ronghua Xu, Nagothu. Real-Time Index Authentication for Event-Oriented Surveillance Video Query using Blockchain. IEEE International Smart Cities Conference (ISC2), 2018.
- [11] Lanxiang Chen, Wai-Kong Lee, Chin-Chen Chang, Kim-Kwang Raymond Choo, Nan Zhang. Blockchain based searchable encryption for electronic health record sharing. Future Generation Computer Systems 2019; 95:p. 420-429.

- [12] Meng Shen, Yawen Deng, Liehuang Zhu, Xiaojiang Du, Nadra Guizani. Privacy-Preserving Image Retrieval for Medical IoT Systems: A Blockchain-Based Approach. IEEE Network (Vol.33 , Issue: 5 , Sept.-Oct.) 2019; p.27-33.
- [13] Zhiguo Wan, Robert H. Deng. VPSearch: Achieving Verifiability for Privacy-Preserving Multi-Keyword Search over Encrypted Cloud Data. IEEE Trans. Dependable Secure Comput. 2018; vol. 15, no. 6, p. 1083-1095.
- [14] Yinghui Zhang, Robert H. Deng , Jiangang Shu, Kan Yang, Dong Zheng. TKSE: Trustworthy Keyword Search Over Encrypted Data With Two-Side Verifiability via Blockchain IEEE Access, vol. 6, 2018; p. 31077-31087.
- [15] C.Cai, J. Weng, X. Yuan, C. Wang, Enabling Reliable Keyword Search in Encrypted Decentralized Storage with Fairness. IEEE Transactions on Dependable and Secure Computing (Early Access) ; 2018.
- [16] S. Hu, C. Cai, Q. Wang, C. Wang, X. Luo, K. Ren Searching an encrypt cloud meets blockchain: A decentralized, reliable and fair realization. in Proc. IEEE INFOCOM, IEEE Conf. Comput. commun.,2018; p.792-800.
- [17] L.Chen, W.-K.Lee, C.-C. Chang, K.-K.R.Choo, N.Zhang. Blockchain based searchable encryption for electronic health record sharing. Future Gener: Comput,2019;Syst., vol. 95, p. 420- 429.
- [18] Y. Wu, S. Tang, B. Zhao, and Z. Peng, BPTM: Blockchain-Based Privacy-Preserving Task Matching in Crowdsourcing. IEEE Access, vol. 7, 2019; p.45605- 45617.
- [19] Yang Yang, HongRui Lin, XiMeng Liu, Wenzhong Guo, Xianghan Zheng, Zhiquan Liu. Blockchain based Verifiable Multi-keyword Ranked Search on Encrypted Cloud with Fair Payment. IEEE Access, 2019; p.140818-140832.
- [20] Shan Jiang, Jiannong Cao, Julie A, McCann, Yanni Yang, Yang Liu, Xiaoqing Wang, Yuming Deng. Privacy-Preserving and Efficient Multi-Keyword Search over Encrypted Data on Blockchain. IEEE International Conference 2019.
- [21] Chengjun Cai, Jian Weng, Xingliang Yuan, Cong Wang. Enabling Reliable Keyword Search in Encrypted Decentralized Storage with Fairness. IEEE Transactions on Dependable and Secure Computing ,2018.
- [22] Priya N, Dr. Ponnaivaikko M. Keyword Search With Two-Side Verification in encrypted data using blockchain. International Conference on Computer Communication and Informatics (ICCCI), 2020.
- [23] Qiuxiang Li , Zhiyu Liu , Yanru Chen , Gangjun Gong , Sheng Yang , Nawaraj Kumar Mahato, Energy Data Security and Multi-Source Coordination Mechanism Based on Blockchain. IEEE Sustainable Power and Energy Conference (iSPEC), 2019.
- [24] Yujia Yang , Bin Duan , Xiangxiang Xiao, Research on Power Transaction Information Security of Microgrid Blockchain Network. IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), 2019.
- [25] Erica Svetec, Lucija Nađ, Robert Pašičko, BorisPavlin.Blockchain application in renewable energy microgrids:an overview of existing technology towards creating climate - resilient and energy independent communities. 2019 16th International Conference on the European Energy Market (EEM), 2019.
- [26] M. M. Esfahani, Osama A. Mohammed. Secure Blockchain-Based Energy Transaction Framework in Smart Power Systems IECON 2018 44th Annual Conference of the IEEE Industrial Electronics Society.
- [27] ZENG Shiqin, HUO Ru, HUANG Tao, LIU Jiang, WANG Shuo, FENG Wei. Survey of blockchain: principle, progress and application. Journal on Communications, Vol.41 No.1, January 2020.
- [28] Peng Jiang, Fuchun Guo, Kaitai Liang, Jianchang Lai, Qiaoyan Wen. Searchain: Blockchain-based private keyword search in decentralized storage. Future Generation Computer Systems 2020; 107: p.781-792.