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Bibliometric Analysis of the Blockchain Scientific Evolution: 2014–2020

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ABSTRACT As one of the disruptive technologies in the fourth industrial revolution, Blockchain has irrevocably changed how people live and work. Many scholars have studied the Blockchain, and the number of related publications has increased over time. Bibliometrics is an excellent method to study the development trend of a specific field. However, few scholars have used bibliometrics to research Blockchain; the inheritance and evolution among its different research themes have not yet been fully understood. This study emphasizes the scientific evolution and research focus of Blockchain through bibliometric analysis. We analyzed 2993 publications from 2014 to 2020 using co-word analysis and cluster analysis with bibliometric tools such as the SciMAT. The most productive author, country, institutions and leading research areas were identified, outlining the Blockchain field's fundamental developments. The results show the changes in keywords regarding Blockchain summarize the research hotspots in different periods. The study discusses the evolution process of various themes in each period, providing a meaningful reference for scholars to identify research hotspots and future research directions in the Blockchain field.

INDEX TERMS Bibliometric analysis, blockchain, co-word analysis, scientific evolution, SciMAT.

I. INTRODUCTION

Blockchain is a distributed ledger, and its storage is characterized by transparency, decentralization, anonymity, and immutability. Its essential feature, decentralization, is widely used in the Internet of things (IoT) [1], [2]. The Blockchain's transparency and traceability are of particular interest to the supply chain [3]–[5]. Its anonymity can be used to protect information such as location privacy [6], transactions [7], and health records [8]. Besides, consensus mechanisms, such as Proof of Work (PoW), Proof of Stake (PoS), and Delegated Proof of Stake (DPoS), have also received increasing attention as tools for ensuring data integrity [9], [10].

Making use of the Blockchain in all industries can provide an absolute advantage. Therefore, in recent years, various aspects of society have shown interest in Blockchain technology and actively explored the innovative model of "Blockchain+." Scholars have begun addressing multiple industries that make use of the Blockchain. For example, Joo *et al.* [11] comprehensively reviewed the contribution of Blockchain technology in the financial field. Mubarakali [12] proposed a Blockchain-based healthcare system to supervise healthcare services in the Cloud. Additionally, IoT [13]–[15],

healthcare [16]–[18], and education [19]–[21] have also been integrated with the Blockchain.

In this paper, a bibliometric analysis was adopted. Bibliometrics, a method to quantify the research object, is often employed to determine the literature's law. Unlike traditional narrative commentary that relies on researchers' experience and knowledge, the bibliometric analysis takes science as a knowledge generation system [22]. It indirectly reflects the correlation between different types of content, gradually demonstrating its advantages. Moreover, bibliometrics provides author keyword analysis to provide better current or future research trends, reflecting the recent trends in a particular field [23], [24]. Many scholars use bibliometrics to study the development status, hot issues, or future research directions of a topic, such as the field of neuroscience [25] and recommendation systems [26]. Even more exciting topics, for example, multiple risks [27] and emerging interest in water research and collaboration [28], are analyzed through bibliometrics. This article uses bibliometrics software for modeling to explore the Blockchain field's development status and future research trends.

Although bibliometrics is widely used by researchers [29]–[31], academic research on the Blockchain has addressed only a limited number of topics. Darabseh and Martins [32] used VOSviewer to perform content analysis

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on the literature in the Blockchain field and employed statistical data to evaluate its maturity in the construction literature. Klarin [33] employed VOSviewer to analyze the cryptocurrency-related literature and clustered four main streams. Mussigmann *et al.* [34] used Gephi to conduct citation network analysis and co-citation analysis of Blockchain-related literature to assess Logistics and Supply Chain Management (LSCM). Joao [35] employed R to analyze Blockchain technology's recent progress, limitations, and future trends. Anjum *et al.* [36] used VOSviewer to draw an expanded diagram of scientific and academic research on Blockchain-related healthcare studies to identify research trends. Wang and Su [37] analyzed Blockchain's development status in the energy field using the bibliometric method. Miao and Yang [38] reviewed the Blockchain literature from 2008 to March 2017 from space and time dimensions. Gupta and Dhawan [39] conducted a quantitative and qualitative analysis of Blockchain publications from 2010 to 2018 and identified the most productive countries/regions, authors, and journals, among other aspects.

Most scholars used bibliometrics to investigate the Blockchain's use in a specific field, and few studies have used it to address the overall trend of Blockchain development. The changes in keywords, the transformation of research hotspots in different periods, and the inheritance of various topics in the Blockchain field have not yet been investigated. However, with bibliometrics' help, we can summarize the current research status of Blockchain, the changing law of hot topics, and predict future trends through co-word analysis and visual analysis of documents published by other researchers Blockchain field.

Therefore, the main contributions of this study are:

1) We summarize the research hotspots in different periods in the Blockchain field and discuss the internal connections between hotspots in each period.

2) We examine the development context of various topics in the Blockchain field across periods and summarized five groups of evolution paths.

3) We discuss the future development trends in Blockchain and possible research directions.

The remainder of this paper is organized as follows. Section 2 describes the research design and the data retrieval and processing steps. Section 3 presents the results of the descriptive analysis. Section 4 discusses the results of clustering. Finally, Section 5 summarizes the study's contributions and identifies future research hotspots.

II. METHODOLOGY

A. BIBLIOMETRIC ANALYSIS

The origin of bibliometrics can be traced back to the 19th century. As a part of scientometrics, bibliometric analysis uses mathematical and statistical tools to analyze scientific activities in a certain research field [40]. Bibliometric analysis is a tool for quantitatively researching scientific publications used to assess leading trends, discover research hotspots, and describe the relationship between countries/regions,

institutions, research fields, and author collaboration [41]. The use of bibliometric analysis has been increasing rapidly. Researchers have conducted bibliometric research in a wide range of fields, including microplastics [42], finance [43], medicine [44], supply chain management [45], operations research and management science [46], business [47], and physics [48].

Scholars such as [49]–[51] divided bibliometric research into two categories: descriptive and evaluative research [52]. The former analyzes the author, journal, geography, period, and discipline, while the latter examines citations and references. Zupic and Cater [53] summarized the five main bibliometric methods: citation, co-citation, bibliographical coupling, co-author, and co-word analysis. Co-word analysis examines the relationship between research topics in a specific field by studying the co-occurrence of topic words in literature [54]. Co-word analysis is the most important and commonly used method in bibliometric analysis. Compared with other methods that only use bibliographic metadata, the co-word analysis addresses a concept [55] to study its scientific evolution.

Scientific mapping is closely related to co-word analysis. It illustrates a scientific field's structure and dynamics [53]. Most existing software, such as VOSviewer, Gephi, Bibexcel, CiteSpace II, Science of Science (Sci²) Tool, and SciMAT, can perform scientific mapping analysis. SciMAT is a powerful scientific mapping software based on co-citation and co-word analysis, combining the many advantages of standard science mapping software [56]. It provides three essential functions: a preprocessing module, bibliometric methods, and a wizard for configuration analysis [57]. Additionally, science mapping can be used to express the cognitive structure of a research field [55], a form of spatial representation that reflects how disciplines, fields, professions, documents, or authors are related to each other. Its spatial characteristics help understand conceptual relationships and developments [58]. In this study, we employ SciMAT for scientific mapping; Fig. 1 provides an example of such mapping.

Fig. 1a provides an example of keyword evolution. The number in the circle represents the number of keywords in this period. The inward arrow indicates the number of newly emerging keywords in the same period. The outward arrow represents the number of disappearing keywords in the period, and the horizontal arrow indicates the number of keywords covered in the adjacent period. The number in brackets reflects keyword consistency.

In SciMAT, strategic diagram and thematic network are two methods used to achieve theme visualization. A strategic diagram (Fig. 1b) is a graph with two dimensions: density and centrality [40]. Centrality measures the internal connection between themes. High centrality indicates that a theme has a robust internal connection with other themes and plays an essential role in developing the research field. Density measures the external relationships between themes. High density indicates that a theme is highly developed [55], [59]. Thus, a strategic diagram divides essential themes into four

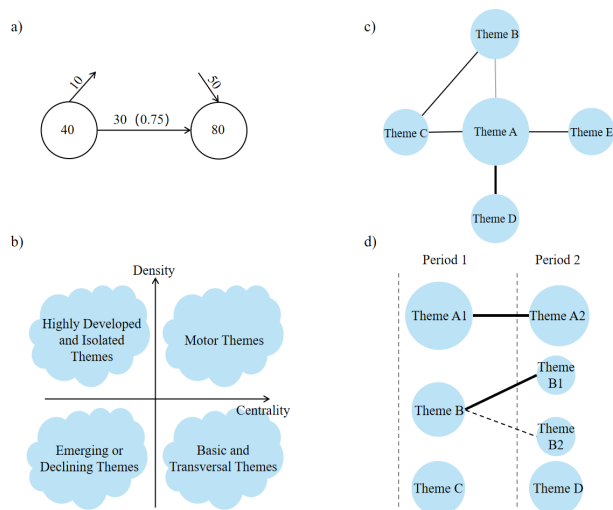


FIGURE 1. Overlay graph; strategic diagram; thematic network; thematic evolution.

classes: *motor themes* (well-developed and critical); *highly developed and isolated themes* (well-developed but less crucial); *emerging or declining themes* (both weakly developed and marginal); and *basic and transversal themes* (critical for the discipline but not developed). The thematic network is shown in Fig. 1c, which indicates that several themes are interrelated. The circle size is proportional to the number of documents corresponding to each theme. The thicknesses of the lines between the circles are proportional to the specified index.

Fig. 1d represents the thematic evolution. The circles represent clustering themes. The size of the circles is proportional to the number of documents related to the themes. The solid line between the circles in the adjacent period represents the inheritance relationship, and the dotted line indicates the theme differentiation. The thickness of the line is directly proportional to the relevance between the themes measured by the specified index. Theme C represents a dead theme, and Theme D indicates a newly emerging theme.

SciMAT can visualize the interrelationships between themes, as well as the evolution of keywords and themes. Thus, this research uses SciMAT to build a thematic analysis of Blockchain’s significant themes using co-word analysis. It examines the evolution of the theme of the Blockchain using various indexes. It draws the overlay graph, strategic diagram, and the thematic evolution map through SciMAT to explore the changes in concept subdomains related to Blockchain in different periods and analyzes Blockchain’s scientific evolution.

B. DATA

1) DATA SOURCES

The bibliometric databases used for analysis are Scopus, CSA Illumina, Google Scholar, and Web of Science (WoS). The success of bibliometric analysis primarily depends on sufficient documentation in the research field, usually obtained

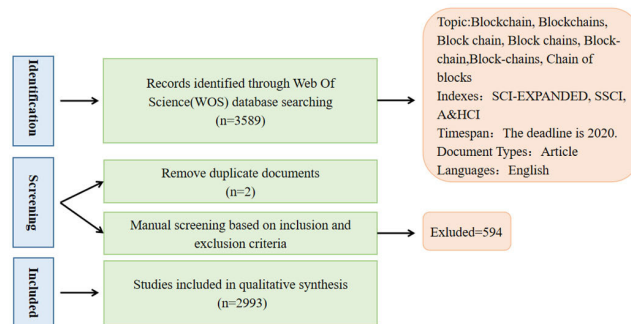


FIGURE 2. Flow diagram of publications retrieval.

through the citation index provided by WoS. Moreover, the most significant advantage of WoS compared with the databases mentioned above is that it contains social science literature [60]. As a comprehensive search engine, WoS includes detailed information on each document and provides complete search results, helping with research and analysis of a specific field.

We screened the information several times to obtain the original data more accurately (Fig. 2).

The first search on WoS followed five steps.

1. We selected the database for documentary analysis (Web of Science Core Collection).
2. We set up a basic search (“BLOCKCHAIN” or “BLOCK CHAINS” or “BLOCK CHAIN” or “BLOCK-CHAIN” or “BLOCKCHAINS” or “BLOCKCHAINS” or “CHAIN OF BLOCKS” [TOPIC]. All keywords were enclosed in quotation marks to ensure that they were not split during the retrieval process, except for “BLOCKCHAIN” and “BLOCKCHAINS”).
3. We cut the search time to 2020 without setting the start time.
4. We chose the relevant citation indexes (“SCI-EXPANDED” and “SSCI” and “A&HCI”).
5. We limited the file type to “ARTICLE” and the language to “ENGLISH.”

A total of 3589 publications were retrieved. To optimize the search results, we manually screened the literature identified by WoS according to Table 1.

After the second search, we obtained 2993 publications used to analyze the Blockchain’s scientific evolution.

C. DATA PROCESSING

After obtaining the initial data, we processed 2993 documents in SciMAT in the following way.

As the quality of science mapping results depends on the data quality, data preprocessing is one of the most critical steps [59]. The data preprocessing methods used in this research were keyword merging and de-duplication. We used word merging to unify singular and plural words and combined words with the same concept. For example, “CRYPTOCURRENCY” and “CRYPTOCURRENCIES” were merged into “CRYPTOCURRENCY” and

TABLE 1. Inclusion and exclusion criteria.

Inclusion Criteria	Rationale for Inclusion
Papers directly discussing Blockchain	To conduct a systematic review, it was vital to review articles focused on Blockchain.
Papers' title does not include Blockchain, but the content is closely related to it.	Although many articles on the consensus mechanism (e.g., PoW, PoS and DPoS) and the characteristics of the Blockchain's transparency, decentralization, anonymity, and immutability do not directly mention the Blockchain, its essence is to study the Blockchain technology.
Exclusion Criteria	Rationale for Exclusion
Papers not related to Blockchain itself	Only research on Blockchain technology, its unique functions, and its applications are relevant to this research. For example, articles that use bibliometrics to study the field of Blockchain will be deleted.
Papers related to blocks on the chemical and physical chain	The terminology of some disciplines will involve the chain, but they have nothing to do with the Blockchain

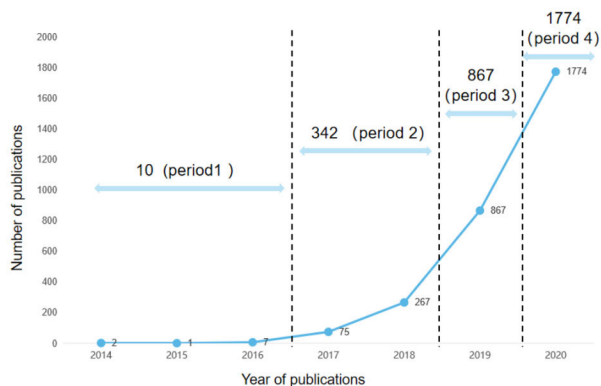


FIGURE 3. Annual publication volume.

“BLOCK-CHAIN” and “BLOCKCHAIN” were merged into “BLOCKCHAIN.” Finally, we removed keywords with high frequency and broad meaning and meaningless keywords, such as “SYSTEM” and “0.”

D. RESEARCH PERIOD DIVISION

Blockchain research is relatively new. The first Blockchain-related article on WoS was published in 2014 (Fig. 3). Although Nakamoto [61] proposed the concept of Bitcoin in 2008, it did not receive too much attention from the academic community in the early years. It was not until 2014 that the concept of Blockchain began to appear frequently. Therefore, we use 2014 as the starting point for time division.

Until 2017, only a few studies were published, but the number of publications has increased since then, and a sharp rise has been observed in the past two years. To study the scientific evolution of the Blockchain themes more accurately, to avoid the monotony of data, and to ensure comparability across periods, the entire period (2014-2020) was divided into four consecutive phases: 2014-2016, 2017-2018, 2019,

TABLE 2. Parameter configuration.

Configuration	Values
Analysis unit	Author's words; Source's words
Frequency	1; 3; 4; 3
Matrix type	Co-occurrence
Co-occurrence union value	1; 1; 3; 4
Normalization measures	Equivalence index
Clustering algorithm	Simple centers algorithm; Maximum size:12; Minimum size:3
Document mappers	Core mapper; Union mapper
Quality measures	h-index; sum citations; max citations
Evolution measures	Jaccard index
Overlapping measures	Jaccard index

and 2020. As shown in Fig. 3, 10 studies were published in the first period, 342 in the second, 867 in the third, and 1774 in the fourth. This increasing trend can also be observed in the number of publications in each period, which went up approximately 34.2, 2.53, and 2.05 times from the first to the second period, the second to the third, and the third to the fourth period, respectively.

E. PARAMETER CONFIGURATION

Parameter settings affect the final result of SciMAT. The parameters selected in this research are reported in Table 2.

III. RESULTS

Analysis of the most productive authors, countries, institutions and leading research areas contribute to scholars' understanding of Blockchain development.

A. MOST PRODUCTIVE AUTHORS

Table 3 shows the top 10 authors in terms of productivity. The number of publications between them is minimal. There are three authors whose publication volume is more than 30—they are Choo Kim-Kwang Raymond, Guizani Mohsen, and Yu Fei Richard; six authors with a work of 20–30 articles, and only one author's work is below 20.

An analysis of the most productive authors shows that they published a similar number of documents. The result is inconclusive because of the short period of analysis. However, in terms of the number of publications, the most productive author is Choo Kim-Kwang Raymond. He mainly studies privacy and security [62]–[65], and the topics account for one-third of his published literature. The second most productive author is Guizani Mohsen, who primarily studies specific issues by constructing models [66]–[69]. Similarly, each author has a research direction, and researchers can read according to their research topic.

B. MOST PRODUCTIVE COUNTRIES AND INSTITUTIONS

In line with Table 4, Fig. 4 locates the top 10 countries in terms of productivity and shows the geographic distribution

TABLE 3. Most productive authors.

Authors	TP ^a
Choo Kim-Kwang Raymond	33
Guizani Mohsen	32
Yu Fei Richard	31
Du Xiaojiang	29
Salah Khaled	26
Kumar Neeraj	26
Zhang Yan	22
Park Jong Hyuk	21
Zhu Liehuang	20
Niyato, Dusit	19

^aTP=Total Publications

TABLE 4. Number of publications by top 10 countries.

Country	TP ^a
China	1314
USA	599
South Korea	264
England	262
Australia	198
India	194
Canada	162
Italy	120
Saudi Arabia	102
Germany	101

^aTP=Total Publications

of 2993 publications researching Blockchain. Table 4 lists the top 10 countries in terms of publication volume. China is the most productive country, with 1314 articles published, twice the USA’s publications. The difference in the number of documents published by the first and tenth countries is very vast, as China’s productivity is 13 times that of Germany’s. Chinese scholars have conducted the most extensive research effort on the Blockchain globally.

A total of 2648 institutions contributed to 2993 publications. We discussed the 10 institutions with the highest volume of publications (as shown in Table 5). It is worth noting that 6 universities, 1 research institute and 3 university systems are involved. And it is not difficult to find that the top ten institutions are from China (6), the USA (3) and Saudi Arabia (1), of which China accounts for 60%. According to Table 5, the *Beijing University of Posts and Telecommunications* contributed the most with the highest number of publications (96), frequency of citations (1614), and h-index (21). Besides, there are the *University of Electronic Science Technology of China* and the *University of Texas System* with higher citation frequency and h-index. Other prolific institutions included the *Chinese Academy of Sciences* (73) and *Xidian University* (60).

An analysis of the number of papers by country shows that countries in Europe and Asia have more research on Blockchain. Combined with the analysis of the top ten influential institutions, China is a well-deserved leader, contributing about 43% of the research literature.

TABLE 5. The top 10 influential institutions.

Institution	Country	TP ^a	TC ^b	%TP ^c	H-index
Beijing University of Posts and Telecommunications	China	96	1614	3.21	21
Chinese Academy of Sciences	China	73	760	2.44	13
Xidian University	China	60	678	2.01	14
University of Electronic Science Technology of China	China	59	1109	1.97	14
University of Texas System	USA	52	912	1.74	14
Beijing Institute of Technology	China	49	621	1.64	15
King Saud University	Saudi Arabia	48	566	1.61	14
University of California System	USA	42	362	1.40	10
Pennsylvania Commonwealth System of Higher Education	USA	40	670	1.34	12
Peshe Education	USA	40	670	1.34	12
Tsinghua University	China	39	427	1.30	8

^aTP=Total Publications; ^bTC= Total Citations; ^c%TP= (TC=Total Citations /All Citations) *100%

C. MAIN RESEARCH AREAS

Fig. 5 presents the top 10 research areas addressed by global scholars in the field of Blockchain. Five of the main areas are related to computer science. The top three — *computer science*, *information systems* (28%), *engineering electrical & electronic* (25%), and *telecommunications* (22%) — accounted for more than 20% of the total research areas. The proportions of other research fields were all below 10%.

An analysis of the leading research fields shows that computer science is still the most popular research direction, and researchers are more interested in *computer science*, *information systems* [70]–[74], *engineering electrical & electronic* [75]–[77], and *telecommunications* [78]–[80].

IV. DISCUSSION

Based on the 2993 documents collected by the WoS database, this study summarizes the Blockchain research through bibliometrics. Firstly, we used Gephi for keyword clustering to discuss the research content of each community. After configuring all necessary parameters (Table 2), overlapping maps, thematic diagrams, and the thematic evolution map were developed to conduct a longitudinal analysis of the Blockchain.

A. BIBLIOMETRIC AND CONTENT ANALYSIS

In this paper, keywords with a frequency greater than 13 are selected for visual analysis and clustering, close keywords in the visual network are analyzed and summarized, and research characteristics in Blockchain are further analyzed. Judging from the community division results of the subject-related network, the current Blockchain field has formed five research directions (or subject communities) of

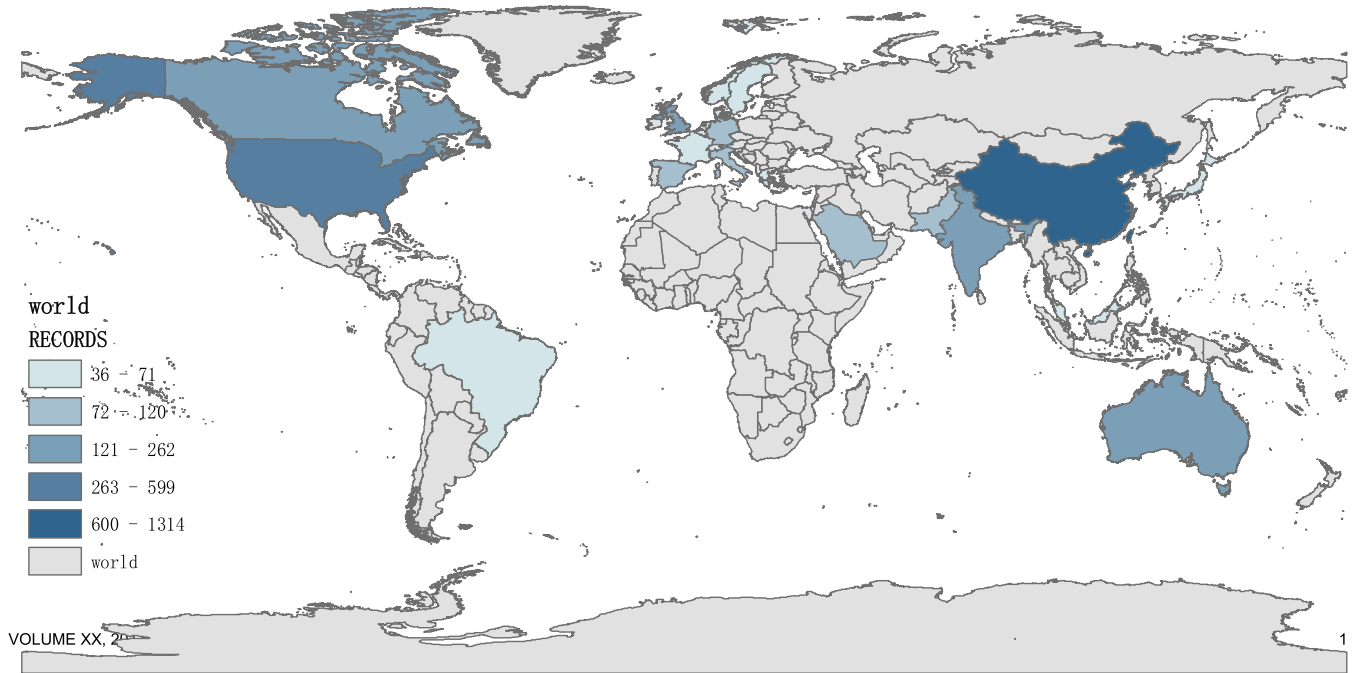


FIGURE 4. Top 10 most productive countries/regions.

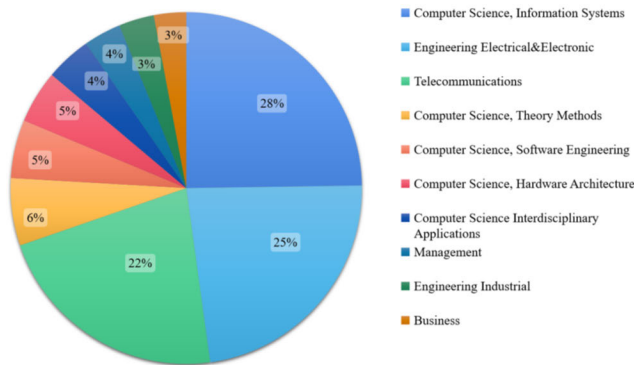


FIGURE 5. Main research areas.

different scales, namely: data security and privacy protection, new algorithms, Blockchain’s characteristics and applications, new technology research and researches on Cloud technology, as shown in Fig 6 and Table 6.

B. CLUSTER 1 (RED): DATA SECURITY AND PRIVACY PROTECTION

Blockchain’s current privacy protection technology is at an early stage of development, and there are still many risks of privacy leakage. With the development of big data, a large amount of data is gradually stored in the Cloud, prone to privacy leakage [81]. Blockchain is considered a technology that may provide a powerful solution to network security and a high level of privacy protection [82]. Such as encryption and signature algorithm [83], k-anonymity [84] and transparency [85] of Blockchain can effectively protect privacy.

Data security and privacy protection are challenges to be accepted in the explosive growth of data and rapid technology development.

C. CLUSTER 2 (PINK): NEW ALGORITHMS

In this community, Blockchain frameworks based on some new algorithms (federated learning, machine learning and deep learning) are applied to address privacy and security issues. Federated learning (where data is kept on the owner’s device and updates to the model are summarized through security protocols) is the latest technology to support secure multi-party machine learning [86], has recently been introduced as an efficient solution for achieving privacy protection [87]. Federated learning can solve the problem of “data silos”, featuring privacy protection and efficient processing, while Blockchain provides incentives that are robust against poison attacks in a completely decentralized manner [88]. These three algorithms tend to build a concrete application model. With the gradual prominence of data security and privacy issues, it will be more meaningful to study the utility size of specific models to solve the problem.

D. CLUSTER 3 (YELLOW): BLOCKCHAIN’S CHARACTERISTICS AND APPLICATIONS

This is a huge community. The public understood bitcoin and Blockchain, but it was not universally accepted, from 2013 to 2015. Subsequently, the wealth creation effect of Bitcoin, as well as the transaction overflow caused by the congestion of the Bitcoin network, led to the explosion of other virtual currencies and various Blockchain

TABLE 6. Clusters of keywords.

Topic clustering	Keywords
Cluster 1 (red) Data security and privacy protection	Authentication, contracts, data privacy, data sharing, privacy, access control, privacy-preserving, electronic medical records, interoperability, consortium Blockchain, encryption, security, data security, decentralized, public key, 5G mobile communication, medical services, Internet
Cluster 2 (pink) New algorithms	Security and privacy, distributed databases, industrial Internet of things, federated learning, deep learning, permissioned Blockchain, data models
Cluster 3 (yellow) Blockchain's characteristics and applications	Consensus, consensus algorithm, peer-to-peer computing, Hyperledger fabric, innovation, decentralization, proof of work, smart city, cryptocurrency, consensus mechanism, network security, microgrid, crowdsourcing, Blockchain, healthcare, game theory, cybersecurity, IPFS, smart grid, smart contract, incentive mechanism, bitcoin, fairness, Ethereum, energy trading, data mining, distributed ledger, fintech, transparency, sustainability, consensus protocol, distributed systems, technology
Cluster 4 (blue) New technology research	Big data, supply chain management, artificial intelligence, supply chain, traceability, industry 4, reputation, trust, Blockchain technology, logistics, Cloud
Cluster 5 (green) Research on Cloud technology	Resource management, protocols, fog computing, computer architecture, Internet of vehicles, cryptography, computational modeling, task analysis, Internet of things, scalability, servers, reliability, pricing, monitoring, cloud computing, games, edge computing, data integrity, performance evaluation, trust management, collaboration, optimization, cloud storage, quality of service, mobile edge computing

TABLE 7. Core documents count in four periods.

Period	Theme	Core documents	H-index	Sum citations
1	COSTS	1	1	34
	HEALTHCARE	1	3	98
	BITCOIN	3	1	1652
	BLOCK-CHAIN-TRACEABLE-GRAPH	1	1	1
	TREE	1	1	302
2	INTEGRATION	11	8	2193
	INTERNET	92	38	9391
	SECURE	19	13	3958
	CRYPTOCURRENCY	7	6	2177
	SUSTAINABILITY	7	7	1706
	BIG-DATA	6	5	2296
	CONSORTIUM-BLOCKCHAIN	4	3	1126
	QUALITY	3	3	417
	CONSENSUS	3	3	445
	3	BLOCKCHAIN	444	38
SUPPLY-CHAIN		41	20	3204
CLOUD		36	18	2585
PEER-TO-PEER-NETWORK		9	6	847
AUTHENTICATION		12	5	1624
SUPPLY-CHAIN-MANAGEMENT		4	4	845
PRIVACY-PRESERVING		6	4	644
DESIGN		6	5	893
BLOCKCHAIN		1035	23	4313
TASK-ANALYSIS		45	8	582
ADOPTION		36	8	594
CLOUD-COMPUTING		49	5	521
AUTHENTICATION		70	8	661
TRUST		72	10	1037
BIG-DATA		56	10	1285
CONTRACTS		39	5	757
FRAMEWORK		39	7	1086
CRYPTOCURRENCY		39	6	794
SMART-GRID		10	6	275
4		INDUSTRIAL-INTERNET	10	4
	SCALABILITY	9	2	118
	HEALTHCARE	7	3	137
	WIRELESS-COMMUNICATION	6	2	135
	GAMES	6	3	115
	PROOF-OF-WORK-(POW)	8	3	160
	DIRECTED-ACYCLIC-GRAPH	5	3	111
	INDUSTRIAL-INTERNET-OF-THINGS	6	2	221

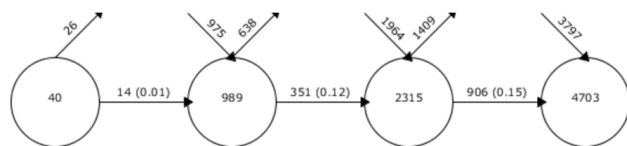


FIGURE 7. Overlay graph.

Fig. 7 shows the changes in the number of keywords in the Blockchain field in different periods. In the first period, 40 keywords are observed; 26 keywords disappear at the end of the period, and the remaining 14 keywords enter the next period. In the second period, 975 newly emerging keywords are observed. Together with those from the previous period, they amount to 989 keywords. At the end of the period, 638 keywords disappear. The remaining 351 keywords enter the next period. In the third period, 1964 newly emerging keywords are observed. With the remaining keywords in the second period, 2315 keywords are observed in this period. However, 1409 keywords disappear at the end of the period, and the remaining 906 keywords enter the next period. There are 3797 newly emerging keywords in the fourth period. In addition to the remaining keywords from the third period, 4703 keywords are observed in this stage. Furthermore, the keywords' consistency between the four periods is 0.01, 0.12, and 0.15.

The analysis of keyword evolution shows that the number of keywords in the Blockchain field has significantly

increased during the entire sample period. The number of newly emerging keywords and the total number of keywords in each period continue to grow, indicating that researchers have tried many different research directions in each period. However, according to the coefficient between each period, only a few keywords were retained, and the evolution of keywords in the Blockchain field has not yet stabilized.

H. THEMATIC STRUCTURE

We draw a strategic diagram of the four periods to analyze the Blockchain's most critical themes for each literature period. The analysis of strategic diagrams can explore the research

hotspots in different periods and their changes. The motor theme of each period is the hot topic of research in that period.

In the strategic diagram, the node size is related to the h-index associated with each research topic. The h-index names authors' research quality based on the number of articles published in scientific journals and the number of citations received [56]. In the thematic network, we use the Jaccard index to represent the similarity between the themes: the thicker the line between the two themes, the stronger the correlation. Table 7 shows the number of core documents, h-index, and sum citations for each topic in different periods.

1) FIRST PERIOD (2014-2016)

As shown in Fig. 8a, five major research themes of this period related to Blockchain are presented: HEALTHCARE, BLOCK-CHAIN-TRACEABLE-GRAPH, COSTS, TREE, and BITCOIN. HEALTHCARE and TREE are motor themes in this period, with one core document showing strong centrality and high density. COSTS is a highly developed and isolated theme, with only one core document. BLOCK-CHAIN-TRACEABLE-GRAPH is an emerging or declining theme, and its total citation frequency is only one. BITCOIN is a basic and transversal theme related to Blockchain, with three core documents. The literature behind the topic TREE studies the healthcare data gateway, from which we can infer that HEALTHCARE is undoubtedly the research hotspot in this period. Scholars have studied human body channels and e-health [95] and healthcare data [96].

It is worth noting that although BITCOIN is not yet perfect in this subperiod, the frequency of sum citations (1652) is much higher than other topics, reflecting that people have done more research on it in the later period. According to Nakamoto [61], the "most beautiful part" of cryptocurrencies like Bitcoin is their "mining," a term he proposes. In 2015, academic research on Bitcoin had reached a peak. Some scholars began to turn their research direction from bitcoin to Blockchain. For example, Kiviat [97] conducted research based on regulating Blockchain transactions to improve the legal community's understanding of Blockchain technology.

Additionally, based on Blockchain's decentralized characteristics, scholars used it in IoT [98], medical [96], and other fields in this period to solve security and privacy issues. Fig. 10a shows BITCOIN's thematic network, exploring the research directions. Among the 11 related topics, Blockchain has the largest circle, which means that the number of documents related to it is the largest. The significance of bitcoin to Blockchain is proved from the reverse side.

Hence, in the first subperiod, HEALTHCARE and BITCOIN are the focus of attention.

2) SECOND PERIOD (2017-2018)

Fig. 8b shows nine entirely new significant themes of this period related to Blockchain: INTERNET, INTEGRATION, SECURE, SUSTAINABILITY, CRYPTOCURRENCY, BIG-DATA, QUALITY, CONSORTIUM-BLOCKCHAIN, and CONSENSUS. INTERNET,

INTEGRATION, and SECURE became research hotspots in this period, with 92, 11, and 19 core documents, respectively. QUALITY and BIG-DATA are newly emerging themes, with three core and six core documents. CONSORTIUM-BLOCKCHAIN and CONSENSUS are highly developed and isolated themes, implying that it has developed but still has low importance in this period. SUSTAINABILITY and CRYPTOCURRENCY are basic and transversal themes, suggesting significant themes but have not yet been fully developed.

In line with the first period, the motor themes of the second period underwent tremendous changes. The last five themes disappeared, and newly emerging themes were observed. Research hotspots, in this period, were become INTEGRATION, INTERNET, and SECURE. INTERNET has the highest number of core documents (92), h-index (38) and total citation frequency (9391). There is no doubt that it is a research hotspot in this period, and it also has an important impact on future research in Blockchain. Then SECURE and INTEGRATION also received great attention, and the three indicators were in the top five.

With the development of cryptocurrency, more and more platforms have launched their cryptocurrency. BITCOIN, which showed significant importance in the last period, has also been replaced by CRYPTOCURRENCY in this period. Researchers are no longer limited to bitcoin. In 2018, the Bitcoin circle faced a bear market challenge, and the price of Ethereum fell from \$480 to less than \$200. Within a month and a half, Ethereum's fall began attracting scholars' attention [99]–[101]. Moreover, breakthroughs were made in the Blockchain's core technology during this period, and research on secure [102] and privacy-preserving [103] further deepened and developed.

In terms of sum citation frequency, BIG-DATA ranked third, indicating that later scholars paid more attention to this theme. Big data reached its propaganda climax in 2012 and 2013. After 2014, the conceptual system gradually took shape, and its cognition became more rational. With the maturity of theoretical concepts, the research of BIG-DATA in the field of Blockchain appeared in front of the public in the form of new themes. As shown in Fig. 10b, there were few pieces of research on big-data-related themes in this period, such as cyber-physical system [104], Blockchain technology [105], and access control [66]. It is proved from the side that the research on big data in Blockchain is still developing and improving, and it still needs further precipitation.

Consequently, during this period, it is clear that INTERNET, SECURE and INTEGRATION are the research focus of researchers in the Blockchain field. Also, BIG-DATA, as a potential research hotspot, has attracted the attention of later researchers.

3) THIRD PERIOD (2019)

Fig. 9a shows eight major research themes of this period related to Blockchain: BLOCKCHAIN, SUPPLY-CHAIN, CLOUD, DESIGN, SUPPLY-CHAIN-MANAGEMENT,

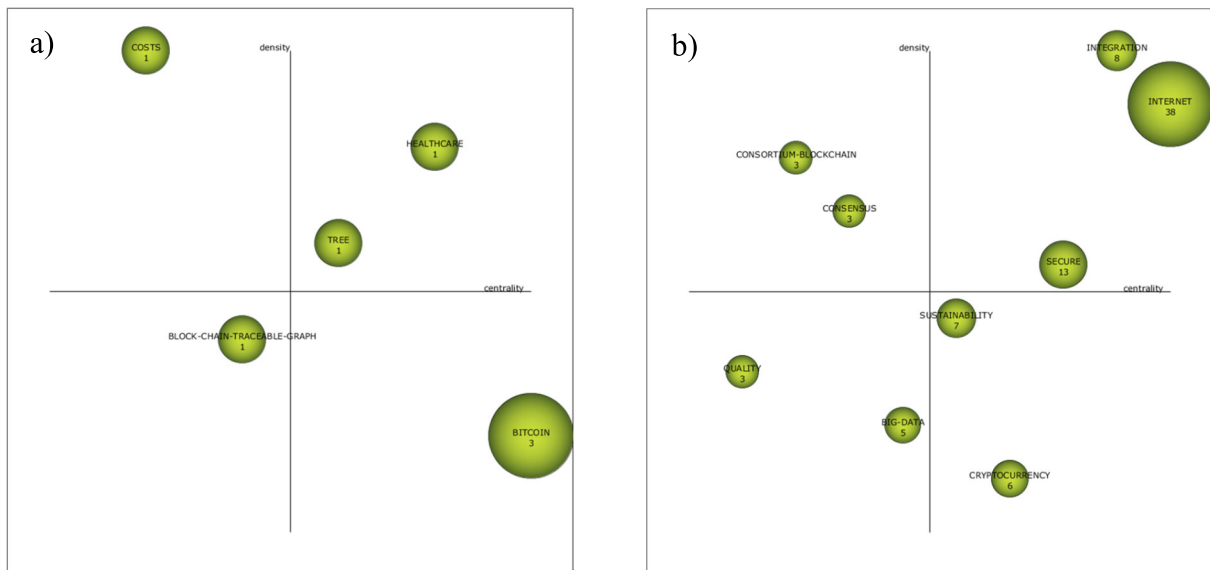


FIGURE 8. a) The strategic diagram of 2014-2016, b) The strategic diagram of 2017-2018.

PEER-TO-PEER-NETWORK, AUTHENTICATION, and PRIVACY-PRESERVING. Among them, BLOCKCHAIN, SUPPLY-CHAIN, and CLOUD are three motor themes. DESIGN is a highly developed and isolated theme. PEER-TO-PEER-NETWORK and PRIVACY-PRESERVING are two newly emerging or declining themes. AUTHENTICATION is a basic and transversal theme. SUPPLY-CHAIN-MANAGEMENT lies between four themes, with four core documents.

Compared with the sluggishness of 2018, the third period was marked by ups and downs. BLOCKCHAIN became a research hotspot, and SUPPLY-CHAIN and CLOUD were also the research focus of this period. Their three major indicators (core documents, h-index, and sum citations) are all in the top three, which is a hot issue for researchers in the third period.

SUPPLY-CHAIN and CLOUD became hot issues during this period, possibly because of the capabilities given to them by the development of The Times. For one thing, the supply chain can realize the control of information flow, logistics and capital flow. As it matures, it also faces problems such as data visualization and product traceability. Every transaction information on the Blockchain (transaction parties, transaction time, transaction content, etc.) can be recorded on a block. It is stored on the distributed ledger of each node on the chain, ensuring the integrity, reliability, and transparency of the information. The features of Blockchain bring many advantages to the supply chain field, which is bound to excite the research enthusiasm of scholars.

For another, with the development of various features in the Cloud, the cloud era has gradually entered the field of vision. CLOUD has become one of the research hotspots in this period. As shown in Fig. 10c, there are 11 topics related to CLOUD: edge-computing, data-sharing, edge, mobile-computing, fog, algorithm, fog-computing,

industrial-internet-of-things, protocols, artificial intelligence, and challenges. Thus, it can be seen that the topics related to the Cloud are mostly in the field of computers, which is inextricably linked with Blockchain technology.

In 2019, Facebook launched *Libra*, which attracted global governments' attention and pushed the Blockchain concept to a new level. Many scholars began addressing Blockchain, exploring its role in various industries [106]–[108]. With the advent of the cloud age, the importance of Cloud was gradually recognized, and CLOUD formed in-depth and wholly developed motor themes in this period. As shown in Fig. 10c, extensive research on themes, such as edge computing [109], mobile edge computing [110], and industrial IoT (IIoT) [111], all show strong similarities with CLOUD.

From the perspective of core documents (12) and total citations (1624), AUTHENTICATION has also gained a certain degree of attention in the third period. At this point, the research themes related to it are still limited to a few topics, such as secure [112] and digital signature [113]. But its total citation frequency (1624) also hints to a certain extent that scholars will pay attention to it in the next period.

As a result, regardless of the concept of Blockchain itself, SUPPLY-CHAIN and CLOUD are the research focus of the third subperiod, and AUTHENTICATION can be considered a potential research hotspot.

4) FOURTH PERIOD (2020)

Fig. 9b shows the 19 major research themes of this period related to Blockchain: BLOCKCHAIN, TASK-ANALYSIS, AUTHENTICATION, ADOPTION, TRUST, BIG-DATA, CLOUD-COMPUTING, CONTRACTS, FRAMEWORK, CRYPTOCURRENCY, HEALTHCARE, SMART-GRID, INDUSTRIAL-INTERNET-OF-THINGS, INDUSTRIAL-INTERNET, GAMES, SCALABILITY,

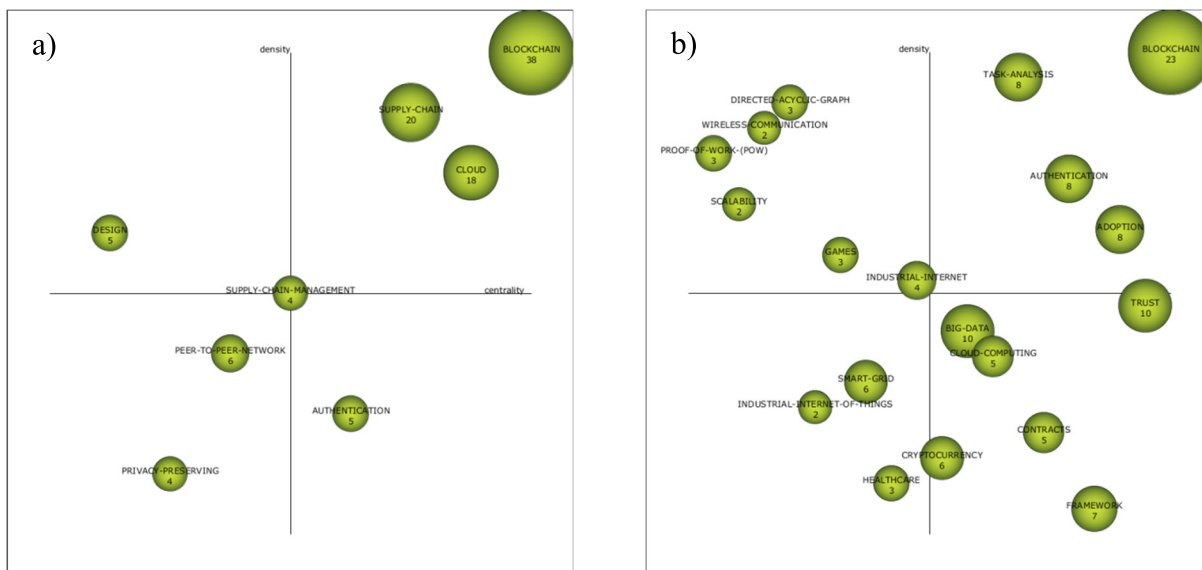


FIGURE 9. a) The strategic diagram of 2019, b) The strategic diagram of 2020.

PROOF-OF-WORK-(POW), WIRELESS-COMMUNICATION, and DIRECTED-ACYCLIC-GRAPH.

The four motor themes of this period are BLOCKCHAIN, TASK-ANALYSIS, AUTHENTICATION, and ADOPTION. Six highly developed and isolated themes are observed: DIRECTED-ACYCLIC-GRAPH, GAMES, WIRELESS-COMMUNICATION, INDUSTRIAL-INTERNET, PROOF-OF-WORK-(POW), and SCALABILITY. TRUST, CONTRACTS, FRAMEWORK, CLOUD-COMPUTING, BIG-DATA, and CRYPTOCURRENCY are basic and transversal themes. HEALTHCARE, SMART-GRID, and INDUSTRIAL-INTERNET-OF-THINGS are newly emerging or declining themes.

In 2020, there were four research hotspots: ADOPTION, BLOCKCHAIN, TASK-ANALYSIS, and AUTHENTICATION. Compared with the previous period, only the Blockchain remains. ADOPTION and TASK-ANALYSIS (three indicators of which the advantages are not obvious) are themes focusing on the application of Blockchain technology and research methods. Facts have proved that AUTHENTICATION, a potential research hotspot discussed in the third period, developed into one of the focus issues in this period. In terms of the number of core documents, h-index and total citation frequency, TRUST (72,10,1037), BIG-DATA (56,10,1285), FRAMEWORK (39, 7, 1086) show better performance except for BLOCKCHAIN. As shown in Fig. 10, comparing b and d, the subjects related to BIG-DATA in this period became very rich. They began to expand to information [114], artificial intelligence [90], network [115] and so on. With the development of the big data era, cloud era and supply chain technology, the amount of information grows explosively. How to safely store and process information will also stimulate the attention to trust mechanism. And as far as Fig. 9b is concerned, TRUST is very close to the first quadrant.

It is worth mentioning during this period that healthcare received close attention from people in this period, and HEALTHCARE [116]–[118] as a newly emerging or declining theme returned to researchers’ vision. During this period, researchers’ research on healthcare was mainly data interoperability [119] and electronic medical records [120]. This change may be related to COVID-19. Due to the long-term impact of the epidemic, research on HEALTHCARE may grow further.

Therefore, in this period, BLOCKCHAIN and AUTHENTICATION are relatively important hot issues. BIG-DATA and TRUST, as potential hot topics, deserve the attention of scholars. Besides, during this period, we also need to pay attention to the development of HEALTHCARE, which is perhaps one of the themes strongly influenced by the current context.

I. THE THEMATIC EVOLUTION MAP

We used SciMAT to map the thematic evolution of the Blockchain concept (Fig. 11), used the Jaccard index to measure the interrelationships between different themes, and observed that the circle changes’ size proportion to the h-index. Our study explored the theme’s evolution by analyzing the evolution map and predicting the future development trend.

As shown in Fig. 11, the themes that died out in the evolution process are TREE, BLOCK-CHAIN-TRACEABLE-GRAPH and CONSENSUS; the new themes are CRYPTOCURRENCY, SUSTAINABILITY, CONSORTIUM-BLOCKCHAIN, INDUSTRIAL-INTERNET, SCALABILITY, HEALTHCARE, WIRELESS-COMMUNICATION, GAMES, PROOF-OF-WORK-(POW), and DIRECTED-ACYCLIC-GRAPH.

The theme of extinction centers on the first and second periods. Blockchain technology has just entered people’s

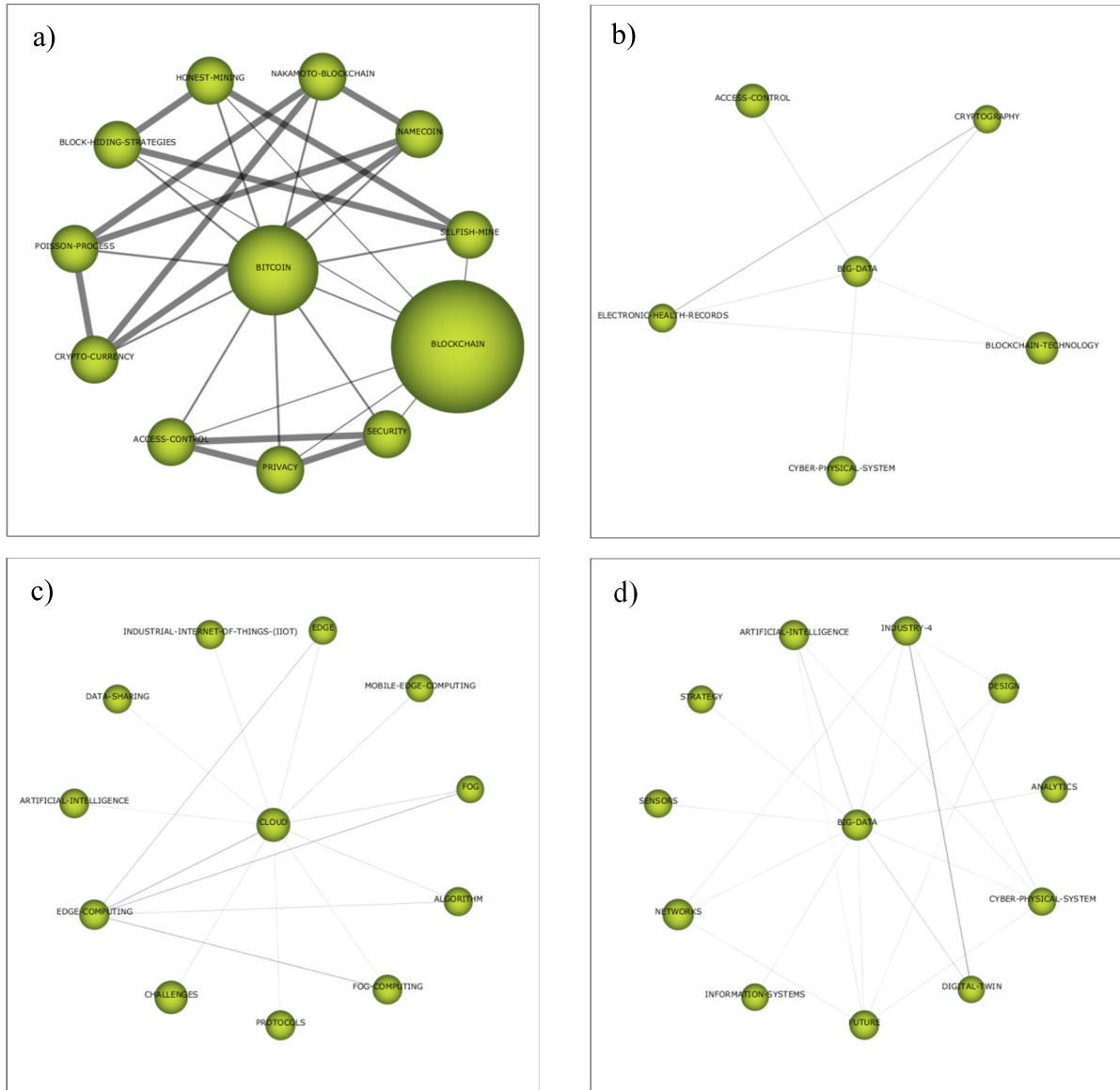


FIGURE 10. a) The thematic network of BITCOIN; b) The thematic network of BIG-DATA for the second period (2017-2018); c) The thematic network of CLOUD; d) The thematic network of BIG-DATA for the fourth period (2020).

vision at this stage, and the research on it is not stable, and the number of researches is also small. Li *et al.* [121] used a heavy subgraph to study the traceability of Blockchain. This is a study on the characteristics of Blockchain, which was very popular among scholars in the early days when the concept of Blockchain was put forward. With the gradual maturity of technology, the research focus is gradually shifting to the traceability research of specific products [122], [123] and industries [124] based on Blockchain. As for the theme TREE, Yue [96] referred to the multi-dimensional binary search tree proposed by Bentley [125], and used the Blockchain platform to ensure the sharing and security of medical and healthcare data. Topic CONSENSUS evolved from HEALTHCARE, and again focused on the privacy protection of healthcare data. Gradually, the issue

of privacy protection is no longer confined to the medical field [126]–[128], and privacy-preserving has appeared in front of people as an independent research topic.

Many new themes were born in the fourth period, which is inseparable from the development of Blockchain technology in this period. 2020 has created excellent conditions for the development of Blockchain. First of all, 2019 is the first year of 5G applications, the starting point of the IoT. The active exploration of the central bank’s digital currency by the People’s Bank of China and the Federal Reserve will greatly promote the popularization of digital currency [129]. Next, Blockchain 3.0 technology (all the attributes obtained through the decentralization of Blockchain distrust (such as immutability, transparency and no intermediary) transplanted to other systems built on Blockchain technology) [130] can

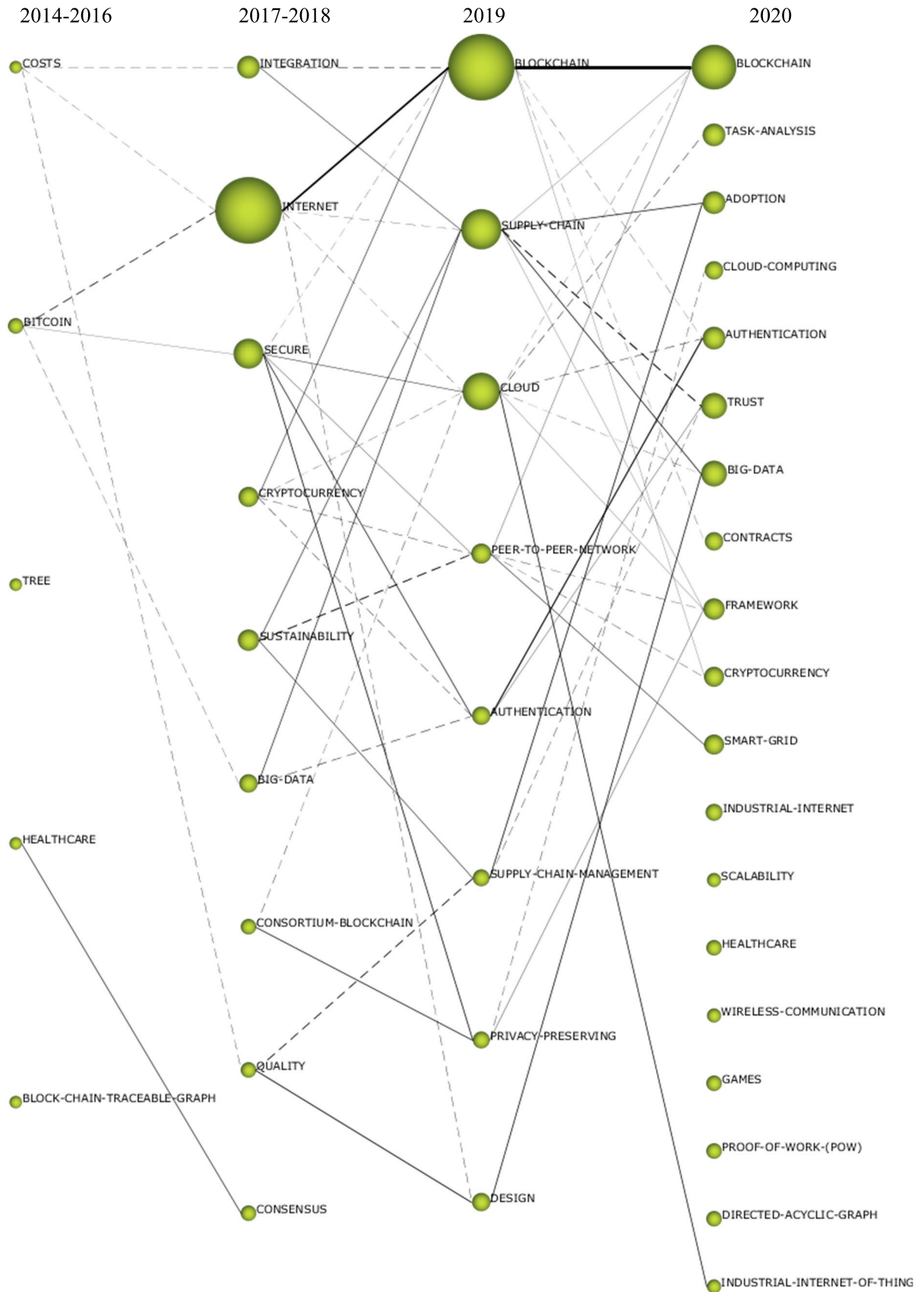


FIGURE 11. The thematic evolution of 2014-2020 with H-index.

improve the Blockchain’s performance, improve the ease of use, operability, and scalability. Most of these technologies will enter the mature stage in 2020. Finally, China, Singapore, and the United States have promoted Blockchain technology and promoted its development. Broadening the research field of Blockchain will help promote its application, bring positive impact to enterprises [131], [132] and facilitate people’s life [133].

The demise, rebirth and integration of the theme reflect the change of researchers’ research on Blockchain from concrete to abstract to concrete. To explore the interrelationships between themes in different periods, we referred to the results of keyword clustering and the hot themes presented in the strategic diagrams, and divided all paths into five categories (see Table 8), namely, cryptocurrency, privacy preserving, Cloud technology, supply chain, and others.

1) CRYPTOCURRENCY

Several paths in this category are relatively simple and revolve around bitcoin, Blockchain and cryptocurrency. It is worth noting that nearly half of the paths involve a peer-to-peer network. P2P will come to a close in China in 2019, with the number plummeting by 70% to 343, and leading platforms have transformed. Academic research on it has gradually faded after the surge in 2019. We need to pay attention to that in paths 12 and 13, PEER-TO-PEER-NETWORK has evolved into SMART-GRID. Blockchain has some excellent features that make it a promising application in the smart grid paradigm [134]. Smart grid is the development trend of the next-generation grid, and the introduction of Blockchain technology can meet its development needs [135]. However, the smart grid development in the world is still in its infancy, which provides a very good research environment for most scholars.

In short, for the evolution path of this category, researchers can pay more attention to the application of Blockchain to the smart grid.

2) PRIVACY

Only four paths are summarized in this category, and the path structure is relatively simple. PRIVACY-PRESERVING evolved from the two directions of BITCOIN to SECURE and CONSORTIUM-BLOCKCHAIN, and it evolved into FRAMEWORK and CLOUD-COMPUTING in the fourth period. Since bitcoin transactions are public on the entire network, for a transfer transaction, the transaction amount and the addresses of both parties to the transaction can be viewed and monitored by anyone. Otherwise, the consortium Blockchain can conduct distributed user data storage and effectively solve a single point of failure and data tampering. It guarantees users’ privacy to a certain extent and has confidentiality and unforgeability [136]. This will stimulate people’s research on privacy protection. In the decade since

TABLE 8. Evolutionary path classification.

Category	Paths
Cryptocurrency	1) Bitcoin → internet → Blockchain → cryptocurrency
	2) Bitcoin → secure → Blockchain → cryptocurrency
	3) Bitcoin → secure → peer-to-peer-network → cryptocurrency
	4) Cryptocurrency → Blockchain → cryptocurrency
	5) Cryptocurrency → peer-to-peer-network → cryptocurrency
	6) Costs → integration → Blockchain → cryptocurrency
	7) Costs → internet → Blockchain → cryptocurrency
	8) Cryptocurrency → peer-to-peer-network → framework
	9) Bitcoin → secure → peer-to-peer-network → framework
	10) Bitcoin → secure → peer-to-peer-network → Blockchain
	11) Cryptocurrency → peer-to-peer-network → Blockchain
	12) Bitcoin → secure → peer-to-peer-network → smart-grid
	13) Cryptocurrency → peer-to-peer-network → smart-grid
Privacy preserving	14) Bitcoin → secure → privacy-preserving → framework
	15) Consortium-Blockchain → privacy-preserving → framework
	16) Bitcoin → secure → privacy-preserving → cloud-computing
	17) Consortium-Blockchain → privacy-preserving → cloud-computing
Cloud technology	18) Costs → internet → cloud → IIOT
	19) Bitcoin → internet → cloud → IIOT
	20) Bitcoin → secure → cloud → IIOT
	21) Cryptocurrency → cloud → IIOT
	22) Consortium-Blockchain → cloud → IIOT
	23) Consortium-Blockchain → cloud → authentication
	24) Costs → internet → cloud → authentication
	25) Cryptocurrency → cloud → authentication
	26) Bitcoin → secure → cloud → authentication
	27) Bitcoin → internet → cloud → authentication
	28) Costs → internet → cloud → big-data
	29) Bitcoin → internet → cloud → big-data
	30) Bitcoin → secure → cloud → big-data
	31) Cryptocurrency → cloud → big-data
	32) Consortium-Blockchain → cloud → big-data
	33) Costs → internet → cloud → framework
	34) Bitcoin → internet → cloud → framework
	35) Bitcoin → secure → cloud → framework
	36) Cryptocurrency → cloud → framework
	37) Consortium-Blockchain → cloud → framework
	38) Costs → internet → cloud → task-analysis
	39) Bitcoin → internet → cloud → task-analysis
	40) Bitcoin → secure → cloud → task-analysis
	41) Cryptocurrency → cloud → task-analysis
	42) Consortium-Blockchain → cloud → task-analysis
	43) Costs → internet → cloud → Blockchain
	44) Bitcoin → internet → cloud → Blockchain
	45) Bitcoin → secure → cloud → Blockchain
46) Cryptocurrency → cloud → Blockchain	
47) Consortium-Blockchain → cloud → Blockchain	
	48) Costs → integration → supply-chain → framework
	49) Costs → internet → supply-chain → framework
	50) Bitcoin → internet → supply-chain → framework
	51) Sustainability → supply-chain → framework
	52) Costs → integration → supply-chain → Blockchain
	53) Costs → internet → supply-chain → Blockchain
	54) Bitcoin → internet → supply-chain → Blockchain
	55) Sustainability → supply-chain → Blockchain
	56) Costs → integration → supply-chain → adoption
	57) Costs → internet → supply-chain → adoption
	58) Costs → quality → supply-chain-management → adoption
	59) Bitcoin → internet → supply-chain → adoption

TABLE 8. (Continued.) Evolutionary path classification.

Supply chain	60) Sustainability → supply-chain → adoption
	61) Sustainability → supply-chain-management → adoption
	62) Costs → integration → supply-chain → trust
	63) Costs → internet → supply-chain → trust
	64) Costs → quality → supply-chain-management → trust
	65) Bitcoin → internet → supply-chain → trust
	66) Sustainability → supply-chain → trust
	67) Sustainability → supply-chain-management → trust
	68) Costs → integration → supply-chain → big-data
	69) Costs → internet → supply-chain → big-data
	70) Bitcoin → internet → supply-chain → big-data
	71) Sustainability → supply-chain → big-data
	72) Costs → integration → Blockchain → Blockchain
	73) Costs → internet → Blockchain → Blockchain
	74) Bitcoin → internet → Blockchain → Blockchain
	75) Bitcoin → secure → Blockchain → Blockchain
	76) Cryptocurrency → Blockchain → Blockchain
	77) Cryptocurrency → Blockchain → contracts
	78) Costs → integration → Blockchain → contracts
	79) Costs → internet → Blockchain → contracts
	80) Bitcoin → internet → Blockchain → contracts
81) Bitcoin → secure → Blockchain → contracts	
82) Costs → internet → design → big-data	
Others	83) Costs → quality → design → big-data
	84) Bitcoin → internet → design → big-data
	85) Bitcoin → internet → Blockchain → authentication
	86) Bitcoin → secure → Blockchain → authentication
	87) Bitcoin → secure → authentication → authentication
	88) Cryptocurrency → Blockchain → authentication
	89) Cryptocurrency → authentication → authentication
	90) Costs → integration → Blockchain → authentication
	91) Costs → internet → Blockchain → authentication
	92) Cryptocurrency → authentication → trust
	93) Bitcoin → secure → authentication → trust
	94) Healthcare → consensus

the concept of cloud computing was first proposed, the technology has matured. It is distributed computing, network storage and other technologies that can be well aligned with Blockchain, providing new ideas to solve privacy issues.

If researchers want to research privacy issues in the Blockchain field by analyzing these paths, they can consider starting some new computing methods, such as cloud computing.

3) CLOUD

In this category, we have summarized 30 paths. According to the evolution results of different paths in the fourth period, it can be roughly divided into four categories: IIoT, authentication, big data, and research methods.

First of all, cloud computing or edge computing, which is closely related to the Cloud, can greatly improve the computing efficiency of IIoT systems [137]. As far as IIoT is concerned, there are still many unsolved issues, such as the privacy and security of data storage [138] and the efficiency of data sharing [139]. Second, 5 paths involve CLOUD’s evolution to AUTHENTICATION. Users should first conduct identity authentication for cloud data users and then obtain the required services from the Cloud [140]. And in 2020, the research on authentication has expanded to multiple aspects such as mutual authentication [89], authentication scheme [141] and fog computing [142]. The research on it has continued from the third period to the fourth period and has

TABLE 9. Identifying research directions in Blockchain research.

Category	Research direction
Cryptocurrency	It is recommended to pay attention to the application of Blockchain in the smart grid. Here are some examples: <ul style="list-style-type: none"> • Design Blockchain-based access control [151] • Research data security based on Blockchain [152] • Energy transaction in Blockchain-based smart grid [153]
	Consider starting with some new algorithms to research privacy issues in the Blockchain field. For example: <ul style="list-style-type: none"> • Cloud computing security attacks [154] • Protect privacy in Blockchain through federated learning [155] • Try to build a deep learning model using Blockchain [156] • Fusion of Blockchain and distributed learning [157]
	It is recommended to pay attention to IIoT and big data with appropriate attention to authentication. The following perspectives can be referred to: <ul style="list-style-type: none"> • Introduce the algorithm to IIoT in combination with Blockchain [158] • Effective storage and management of data based on Blockchain [159] • Blockchain-based applications of online and offline integration [160]
Cloud technology	Try looking at supply chain issues based on big data and using Blockchain technology’s characteristics to solve these problems. Examples of reference are as follows: <ul style="list-style-type: none"> • Focus on the key Blockchain-based applications of the supply chain in different fields [161] • Supply chain traceability based on Blockchain [162] • Analyze the performance of Blockchain in the supply chain [163]
Supply Chain	Pay due attention to the design of smart contracts. Such as: <ul style="list-style-type: none"> • Design a system based on Blockchain and smart contract [164] • The problem with smart contracts [165]
Others	

gradually matured. In addition, the two themes of CLOUD and BIG-DATA also show inheritance. Big data and the cloud era are coexisting, and related research emerges endlessly.

In general, there are still gaps in the research of the Industrial Internet of Things (IIoT), and authentication has received close attention for two consecutive periods. It is inferred that the possibility of continuing to become a research hotspot in the future is low, and some breakthroughs may need to be combined. Finally, big data is a contemporary development trend and can be used as a basic topic for scholars to study.

4) SUPPLY CHAIN

In this group, there are a total of 24 paths. According to the results of their evolution in the fourth period, they can be simply classified into 5 directions: framework, Blockchain, adoption, trust and big data. At present, supply chain management is the world’s top 500 enterprises to maintain a strong competition indispensable means. The concept of the supply chain is no longer the traditional sales chain. It has gone beyond the boundaries of enterprises, from an operational tool to a management method system, a kind of operation management thinking and mode.

What we need to pay more attention to is big data, which appeared in the second period. The previous chapter compared BIG-DATA’s thematic network of two periods (period 2 and period 4). We can see that the research on BIG-DATA is

becoming mature and developing. In the digital era, the role of big data is proliferating. All fields have shown extensive attention to it, and the supply chain field is no exception [143]. The process of integrating big data into the supply chain is to put the internal and external data, structured data and unstructured data of the enterprise into the framework of data analysis. Judging from the current research results, there are still research gaps, such as sustainable supply chain management [144], [145], the source of big data in the supply chain, and the impact of bad data on supply chain performance [146], waiting for future scholars to explore. Furthermore, multiple studies have shown that supply chains face challenges due to a lack of trust in data sharing [147]. Blockchain technology can alleviate the trust problems faced by supply chains in different fields.

In conclusion, researchers can try to study supply-chain issues based on big data (for example, focusing on trust) and try to solve them with the characteristics of Blockchain technology.

5) OTHERS

In this group, in addition to BIG-DATA, AUTHENTICATION, and TRUST mentioned earlier, we need to look at the path about CONTRACTS. The path presented in this article, it is all evolved from BLOCKCHAIN, and related topics include cryptography [148], data privacy [149], 5g mobile communication [150], and others. Most of these studies are based on the application of smart contracts, and there are not too many studies in each aspect, and it is worthwhile for scholars to further in-depth.

J. FUTURE RESEARCH DIRECTIONS

Based on the strategic diagram and the thematic evolution map, Table 9 proposes five future research directions for Blockchain, and we provide readers with some reference directions.

V. CONCLUSION

This research examined keywords evolution, changes in research hotspots in different periods, and inheritance and evolution among themes related to Blockchain from 2014 to 2020, based on publications in the WoS database. Although this study is not the first to analyze the Blockchain theme using bibliometric methods, it is the first to explore its scientific evolution. Hence, it offers a reference for researchers to discover research hotspots in the field quickly.

This analysis identified the top 10 most productive authors, countries, institutions, and central research areas. The results showed that the most effective author is Choo Kim-Kwang Raymond, the most productive country is China, the most influential institution is *Beijing University of Posts*. The main research field is *computer science, information systems*. A noteworthy finding related to these studies is that China has a low amount of research conducted per researcher, which needs to be increased despite being the most productive country.

Based on the classification of keywords by Gephi, it is found that the current research mainly focuses on the application of Blockchain, the combination of cloud technology, new algorithms and some other new technologies with Blockchain, as well as the research on data security and privacy.

According to the proposed overlay graph, although the number of keywords has shown an upward trend as a whole, keywords inheritance between two adjacent periods is not high. Several newly emerging and dying keywords are observed in each period. Blockchain research had shown rapid growth, the research team has expanded rapidly, and the research themes have become more abundant. However, its evolution has not yet stabilized.

The proposed strategic diagram shows that the Blockchain field is expanding as a whole, and the research direction is continuously enriched. The update iteration speed of most themes is still very rapid, consistent with the disappearance of keywords in different periods. Themes, such as PEER-TO-PEER-NETWORK, appear only in one period. The joint analysis of the thematic networks indicates that themes such as SECURE and those closely related to it predict future research directions to a certain extent.

Regarding the conceptual evolution of the field, we divide all the evolutionary paths into five groups (cryptocurrency, privacy preserving, Cloud technology, supply chain, and others) and discuss each group separately to predict future research directions. Firstly, Blockchain application development will shift from a single technology to the comprehensive application of multiple technologies. Scholars can pay attention to the integration of cloud computing, fog computing and other computing methods with Blockchain. Secondly, the application of Blockchain and smart contracts can be studied to solve the pain points of traditional industries, such as smart grid, IoT and IIoT. Finally, the topic of authentication can be appropriately concerned.

Researchers have increasingly realized that Blockchain research is related to its characteristics and is inseparable from its background. Blockchain can exert various advantages in different fields. In the future, as the Blockchain technology system becomes clearer, the degree of cross-domain integration and innovation will further increase. Moreover, more precise infrastructure changes production relations, an increasing number of economic and social affairs and intermediary agencies will be replaced by program codes and algorithms. A programmable society may become a reality. These phenomena are expected to attract researchers' attention to the Blockchain field.

The study has some limitations. First, they are the limited number of documents found on the Web of Science and covered a relatively short reference period. Next, this research is mainly based on SciMAT. The keyword classification steps in SciMAT were discussed by several of our authors. There may still be individual improper classification, but it does not affect our final research results.

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