Review of Computation Offloading in Fog Computing: A Bibliometric Analysis

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Abstract

Computation offloading is one of the promising solutions for resource-restricted devices in the fog computing environment. It overcomes the limitations of cloud computing by reducing network traffic and latency of offloading requests. However, offloading faces some issues in a fog computing distributed environment. Therefore, the optimality of task offloading is the core focus of fog computing research. Businesses and academics are currently doing lots of research on computing offloading strategies and methodologies in the fog computing environment. Researchers have published many review papers. However, no bibliometric analysis has been done to assess the popularity of computation offloading in the fog computing environment. This paper provides a bibliometric analysis of computation offloading in fog computing to identify the most popular journals, authors and hotspots. The research result also presented the performance metrics used by different authors for evaluation purposes. The paper concludes with the research challenges of computation offloading problems.

Keywords: Energy Consumption, Swarm Intelligence, Computation Offloading, Fog Computing, Bibliometric Analysis

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1. Introduction

The Internet of Things (IoT) has been deeply integrated into our daily life by supporting various applications such as web optimization, smart city, smart grid, healthcare, video streaming, intelligent transportation system applications, etc[1]. IoT devices generally lack computing resources or have very little processing power[2]. It leads to the development of computation offloading techniques to overcome resource constraint problems. Earlier, cloud computing was used for the remote execution of resource-intensive part of applications. It leads to higher latency and network traffic because of the distant centralized location of cloud resources[3]. Various new technologies came to light to overcome cloud computing issues, like mobile cloud computing, fog computing, mist computing and edge computing [4].

Fog computing is a new paradigm for providing resources to IoT devices at the edge of the network. According to the open fog consortium, fog computing is a:

"A horizontal, system-level architecture that distributes computing, storage, control and networking functions closer to the users along a cloud-to-thing continuum[5]".

End devices can offload their data or resource-intensive application to nearby fog nodes available in the fog layer as an alternative to the distant cloud[6]. Fog computing follows multi-layer architecture. In three-layer architecture, the fog layer is positioned between the resource-rich cloud data centres and the sensors, allowing the collection and loading of data to occur near the end devices[7]. The most accepted and practical fog devices are routers, gateways, switches, micro data centres, etc. The fog nodes execute processing tasks, reduce network traffic, and increase transit speed. But fog nodes have limited computation power and storage capacity compared to cloud data centres. On the other hand, computation offloading should consider various dimensions for optimal offloading, like what to offload, where to offload, how to offload, and why to offload, making this an np hard optimization problem[8], [9].

In order to respond to the question of what to offload. Various researchers have used application partitioning approaches to identify the resource-intensive part of the application. Application partitioning can be static or dynamic. Offloading tasks problem can be broken down into two categories: (I) Full offloading, in which the entire task is transferred to a remote server such as fog nodes or cloud VM layers; (II) partial offloading, in which the task is partitioned into subtasks, and the only resource-intensive task is transferred to other layers; and (III) hybrid offloading, in which a combination of both full and partial offloading is used.[10], [11].

In order to respond to the question of where to offload. The decision engine is responsible for determining where the task should be offloaded. The decision engine analyzed parameters such as available bandwidth, latency, VM utilization, etc., to determine if the task should be offloaded to a local fog server, a remote fog server, or a cloud server. To identify a solution, several researchers have employed metaheuristic decision-offloading techniques[12], [13].

Due to uncertainties of the environment on both sides, i.e., the user side or network side, the decision engine should decide when the computation is offloaded to higher layers to meet the desired QoS. Optimal time scheduling of offloading calculations has been used to overcome this issue[14]. Because of the multidimensionality of the problem, there are no best algorithms that may generate optimal solutions within the polynomial time for such problems. The main objective of the paper is to present a bibliometric analysis of the existing literature on computation offloading in fog computing. To be precise, the subsequent points emphasize the major contributions of this review paper.

1. Upon assessing the state of the art on computation offloading in fog computing, we realized the lack of a bibliometric analysis in computation offloading in fog computing. Thus we summarize the existing literature on the a) most popular journals, b)the most productive authors, c) most published countries, and d) the hotspots in fog computing.
2. To identify the quality of service parameters used for evaluation of the offloading algorithms.
3. We interpreted the research findings and discussed research challenges in the computation offloading scope.

The remaining sections of the paper are organized as follows: Section 2 presents a bibliometric study of literature relating to computation offloading in fog computing. Section 3 represents the interpretation and research challenges for computation offloading. Section 4 presents the summary and conclusions of this work

2. Bibliometric Analysis of Computation Offloading in Fog Computing

To demonstrate the widespread adoption of computation offloading in fog computing, this section provides a bibliometric analysis of related literature. The rise in popularity of bibliometric analysis in business research over the past few years [14] can be attributed to (1) the advancement, accessibility, and approachability of bibliometric software such as Gephi, Leximancer, and VOSviewer, as well as scientific databases such as science direct, scopus, ACM digital library and web of science, etc. Bibliometric analysis helps in managing a large amount of scholarly literature. The research questions addressed by the study are as follows:

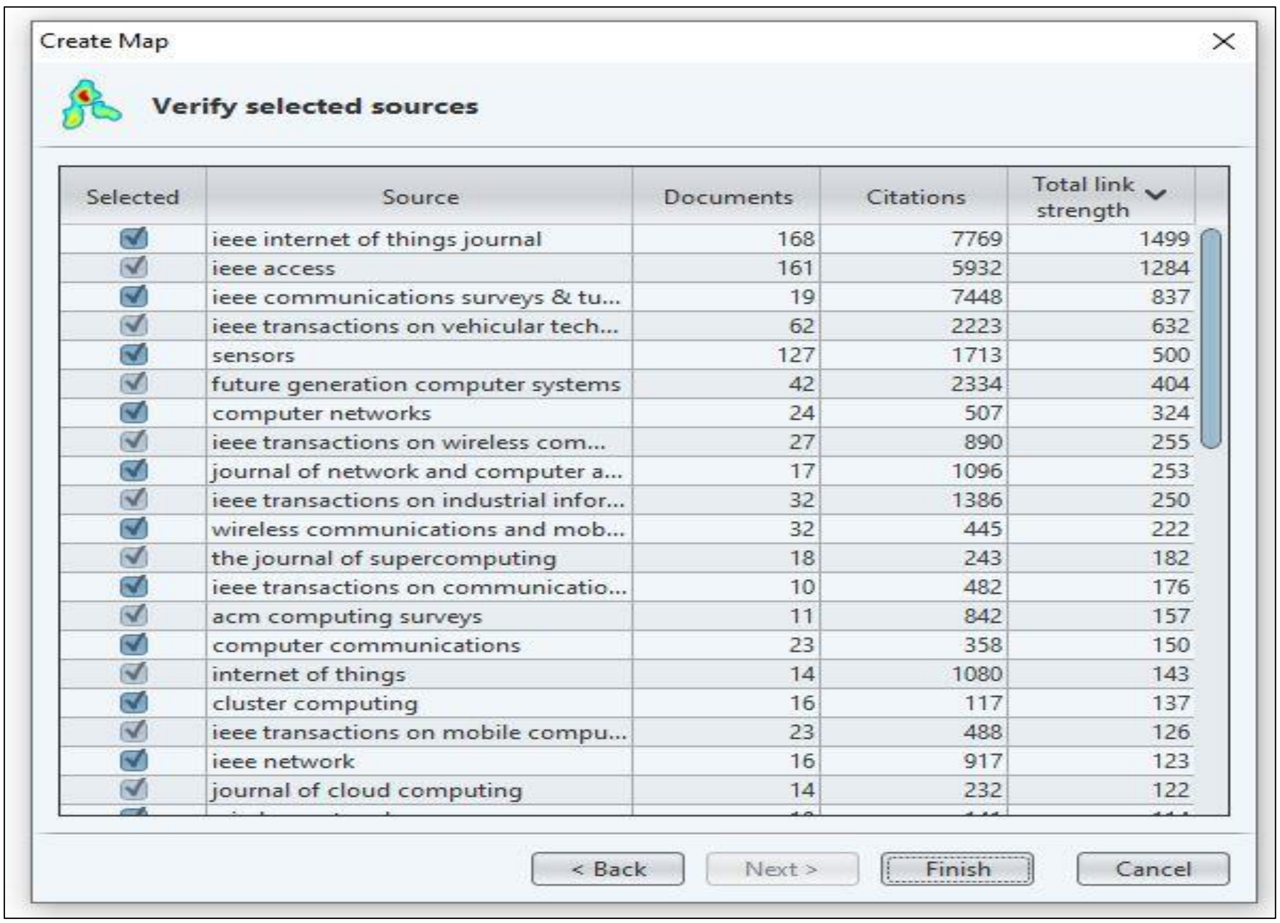
Table 1 Research Questions

Research Questions(RQ)	
RQ1	Which journals are the most popular in computation offloading in the fog computing field?
RQ2	Which authors are the leading solver for the computation offloading problem in fog computing?
RQ3	What is the research status of computation offloading in fog computing in countries/ regions around the world?
RQ4	What are the fog computing hot spots?
RQ5	Which quality of service parameters are used for the evaluation of offloading algorithms?

The first four research questions are addressed by using VOS viewer bibliometric analysis tool.

RQ1: Analysis of core journals in the field of computation offloading in fog computing

As the primary disseminators of the research process, journals play a crucial role in the progress of the research topic. Figure 1 lists the journals with the highest number of publications in the field of task offloading in fog computing. Most articles about computation offloading in fog computing are published in the two most prominent journals in this area, IEEE Access and IEEE Internet of Things Journal, as shown in Figure 1. IEEE Internet of Things Journal has published 168 studies, placing it in the first position. However, IEEE Access has published 161 literature reviews in this field, placing it in second place.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Verify selected sources

Selected	Source	Documents	Citations	Total link strength
✓	ieee internet of things journal	168	7769	1499
✓	ieee access	161	5932	1284
✓	ieee communications surveys & tu...	19	7448	837
✓	ieee transactions on vehicular tech...	62	2223	632
✓	sensors	127	1713	500
✓	future generation computer systems	42	2334	404
✓	computer networks	24	507	324
✓	ieee transactions on wireless com...	27	890	255
✓	journal of network and computer a...	17	1096	253
✓	ieee transactions on industrial infor...	32	1386	250
✓	wireless communications and mob...	32	445	222
✓	the journal of supercomputing	18	243	182
✓	ieee transactions on communicatio...	10	482	176
✓	acm computing surveys	11	842	157
✓	computer communications	23	358	150
✓	internet of things	14	1080	143
✓	cluster computing	16	117	137
✓	ieee transactions on mobile compu...	23	488	126
✓	ieee network	16	917	123
✓	journal of cloud computing	14	232	122

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Fig 1 Journals with the highest number of publications in computation offloading

Next, the journal citation, i.e., the journal with the most citations and the journal most frequently cited by the same source. The minimum number of journal citations was set to 50 in VOSviewer. Figure 2 is a picture of the network of journals that cite each other. In Figure 2, the number of times each item was cited is represented by its size relative to the other dots and words. The greater the size of the dots and words, the greater the number of times that they are cited. Figure 2 reveals that IEEE Access and IEEE Internet of Things is the most frequently cited journals, indicating that these two publications significantly impact the computation offloading field. In addition, the third-ranked sensor has been cited much less frequently.

RQ2: Analysis of core authors in fog computing

The most productive authors are the core authors. They are the academics who have written a plethora of literature reviews for their respective fields. Analyzing and locating credible offloading experts is facilitated by examining the core authors.

Figure 3 indicates that Yang is the most prolific author. However, scientometrics has conducted extensive research on accurately quantifying academic findings' publication. Their view is that while counting works of literature is one approach, citing counts provide more insight. The minimum number of author citations in VOSviewer was set to 14. Then, 20 of the 6198 authors meet this criterion.

Figure 4 depicts an overlay visualization of the author citation network. The sizes of the dots and words in Figure 4 represent the cited times. The authors with the most citations are Zhang and Yan in the first place, whereas Raj Kumar Buyya is second. This indicates that their work is widely recognized and significantly impacts the computation offloading in fog computing.

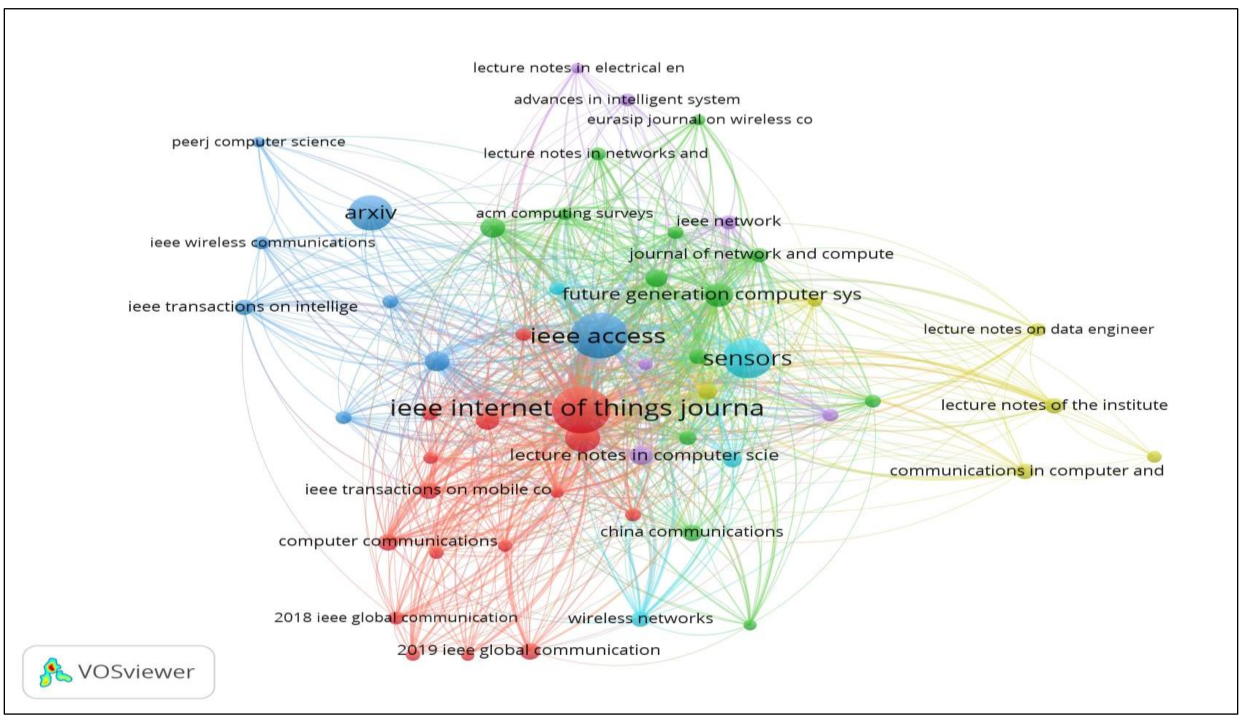
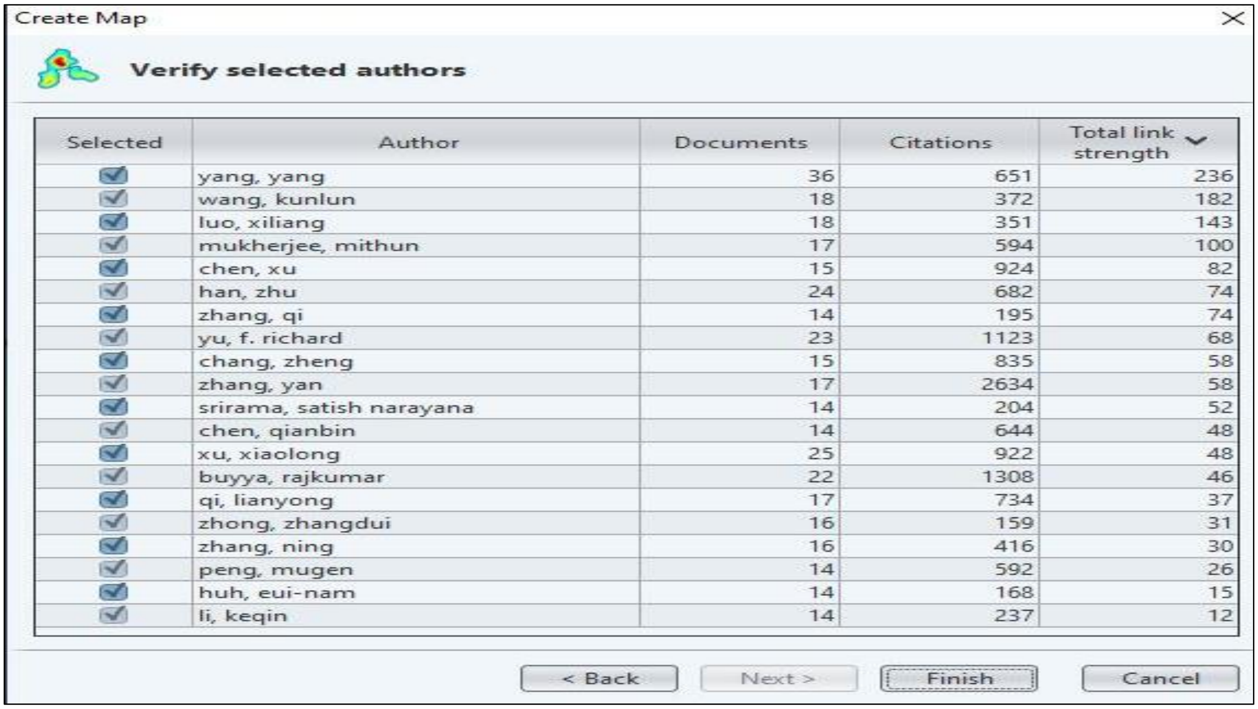


Fig **Error! No text of specified style in document.** Visualization of journal citation network



Create Map

Verify selected authors

Selected	Author	Documents	Citations	Total link strength
✓	yang, yang	36	651	236
✓	wang, kunlun	18	372	182
✓	luo, xiliang	18	351	143
✓	mukherjee, mithun	17	594	100
✓	chen, xu	15	924	82
✓	han, zhu	24	682	74
✓	zhang, qi	14	195	74
✓	yu, f. richard	23	1123	68
✓	chang, zheng	15	835	58
✓	zhang, yan	17	2634	58
✓	srirama, satish narayana	14	204	52
✓	chen, qianbin	14	644	48
✓	xu, xiaolong	25	922	48
✓	buyya, rajkumar	22	1308	46
✓	qi, lianyong	17	734	37
✓	zhong, zhangdui	16	159	31
✓	zhang, ning	16	416	30
✓	peng, mugen	14	592	26
✓	huh, eui-nam	14	168	15
✓	li, keqin	14	237	12

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Fig 3 Authors with the highest number of documents and citations

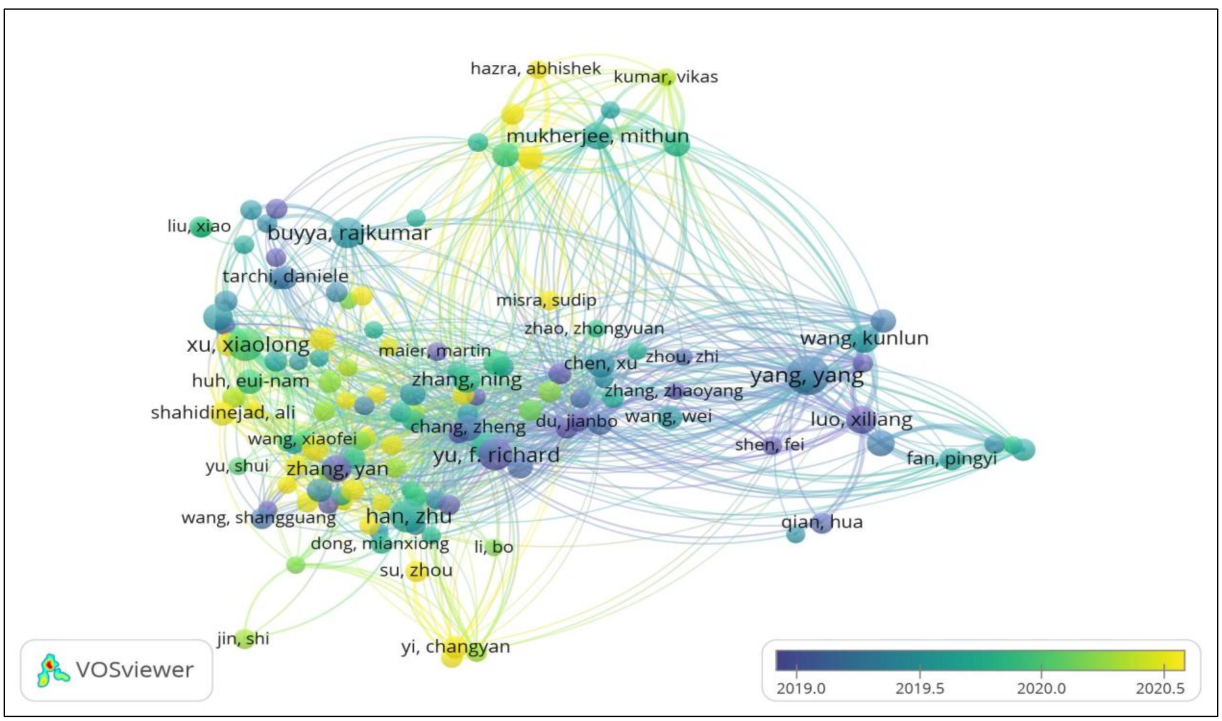

Fig 4 Visualization of author's citation network

RQ3: Analysis of countries and regions in fog computing

Significant efforts have been made to encourage the growth of computation offloading in fog computing. Figure 5 depicts the nations with the most publications. Figure 5 demonstrates that China has the highest productivity, having produced 1142 literature studies with 27768 citations. It is followed by the United States, which contributed 294 literature studies with 10235 citations. Then followed by India, which contributed 271 studies with 3120 citations. Figure 6 represents density visualization of the most popular countries that have published articles in computation offloading in literature studies, providing a solid foundation for this work. If the country's citation count is higher, the text will be lighter and the words will be larger. This puts these countries at the forefront of fog computing research and provides a brighter future for the growth of fog computing applications.

RQ4: Hotspot analysis in fog computing

Keywords are essential to the literature because they greatly condense its content. Research hotspots can be effectively revealed through the co-occurrence network analysis of keywords. There were four groups of related high-frequency keywords generated. A representation of the co-occurrence network of keywords is shown in Figure 7.

Cluster 1: It is the study of definite challenging fog computing problems, as indicated by the red node region. Some of the problems with fog computing are managing resources, allocating resources, offloading computations, using too much energy, and latency.

Cluster 2: Cluster 2 is the study of the overall fog computing architecture, as depicted by the green node region. Privacy and safety will be improved even further as a direct result of the overall architecture being subjected to optimization and innovation.

Cluster 3: Blue node region represents the study of fog computing applications. Combining mobile computing with big data technology and artificial intelligence algorithms makes fog computing more applicable to smart grids, smart homes, modern health care systems, smart cities, and other applications.

Cluster 4 is the investigation of edge computing with 5G, as indicated by the yellow node area. The development of 5G promises a higher availability of bandwidth.

Create Map

Verify selected countries

Selected	Country	Documents	Citations	Total link strength
✓	china	1142	27768	11703
✓	united states	294	10235	4818
✓	india	271	3120	3208
✓	canada	157	5801	2869
✓	united kingdom	149	4549	2807
✓	south korea	136	3586	2241
✓	australia	138	4773	2224
✓	finland	50	3288	1583
✓	iran	71	1224	1495
✓	pakistan	76	1443	1430
✓	saudi arabia	77	1897	1292
✓	norway	28	3053	998
✓	japan	60	2016	955
✓	qatar	19	2953	864
✓	germany	42	1833	754
✓	france	46	857	658
✓	singapore	27	1141	640
✓	italy	61	968	636
✓	malaysia	29	1572	614
✓	portugal	29	701	585

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Fig 5 Countries with the highest number of documents and citations.

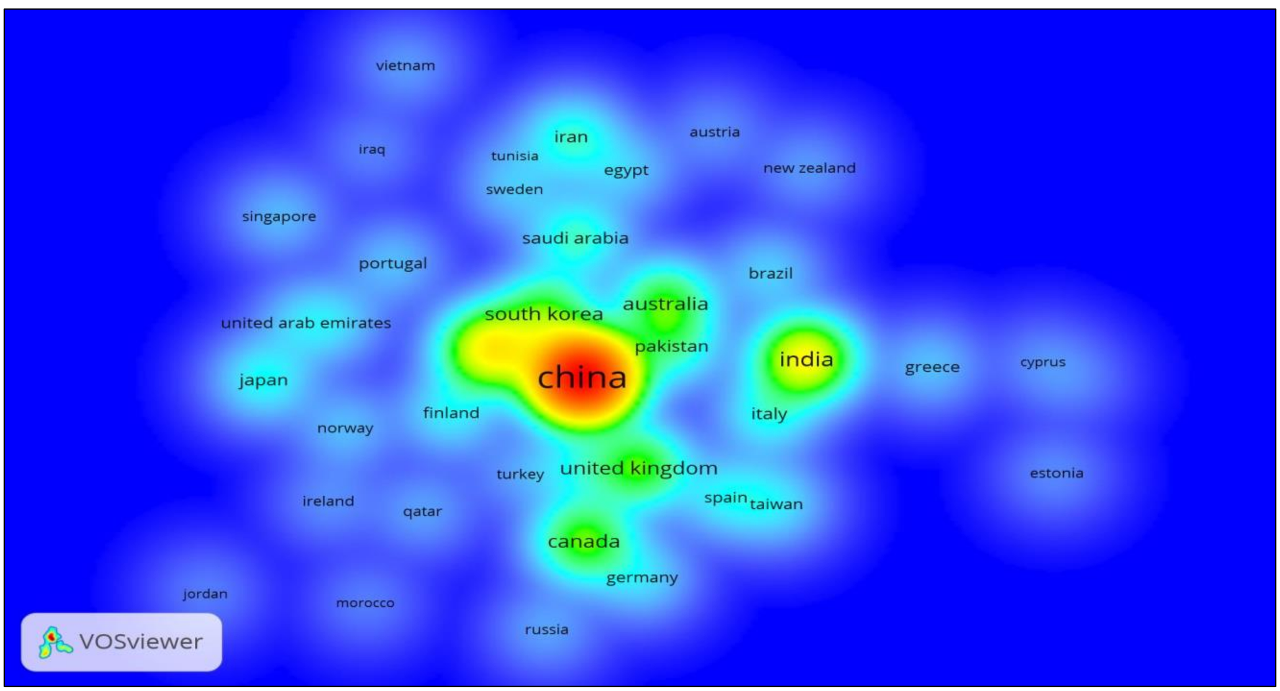

Fig 6 Density visualization of contributions of different countries for computation offloading

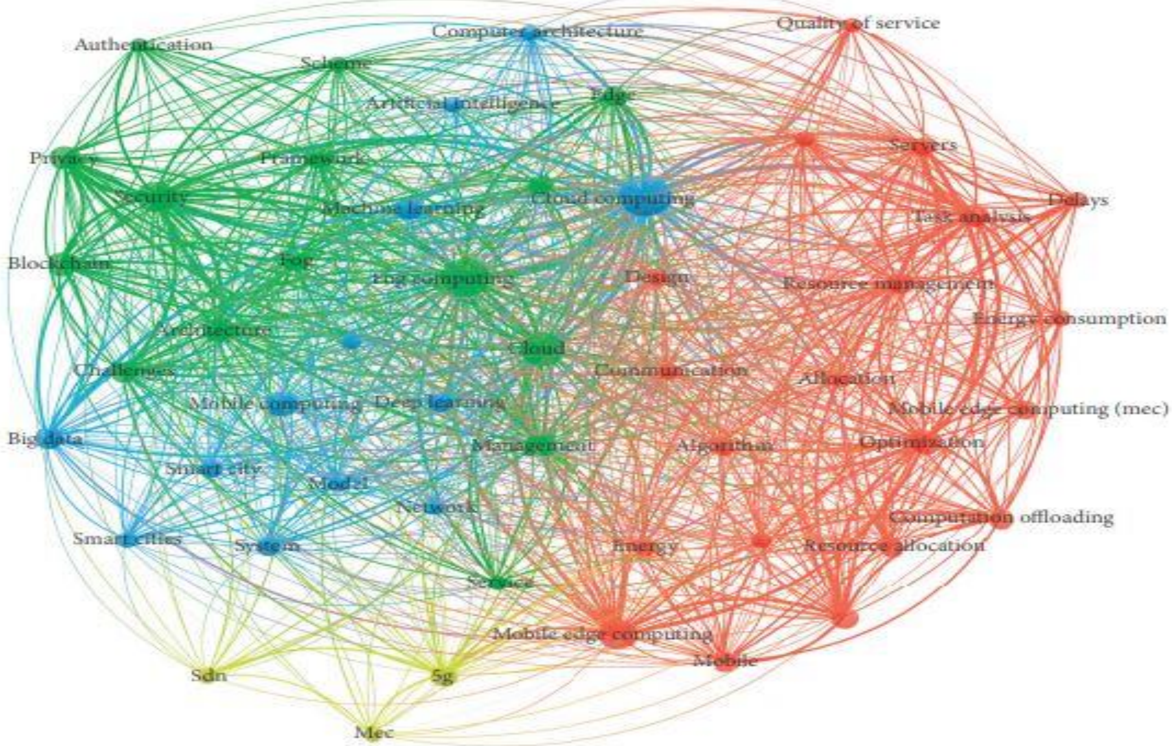

Fig 7 Hotspot analysis of fog computing

The fog computing research hotspots are understood through the statistics of frequently co-occurring keywords. In summary, it consists of four components: specific challenging problems, overall architecture, applied research, and collaborative research with 5G. Consequently, it is plausible that future research will focus on fog computing issues pertaining to resource management, resource allocation, computation offloading, load balancing, energy consumption, and delay. With the gradual maturation of fog computing technology and 5G, fog computing will be promoted and popularized further in smart grid, smart healthcare smart cities, smart transportation, and other areas.

RQ5 Performance metrics for offloading problem

The provision of a high-quality experience, as well as a high-quality service, is intended to be the result of offloading systems. In order to accomplish this objective, the design of the offloading system needs to have a solid understanding of how the quality of experience and quality of service are evaluated. Table 2 presents the quality of service parameters used by different authors for the evaluation of offloading algorithms. Figure 8 presents the percentage metrics for different quality of service parameters used in the literature. 24% of the researchers use the energy consumption parameter for evaluation. It is the sum of transmission energy and computational energy. The transmission energy is consumed in sending and receiving back offloading data, while computational energy is calculated as energy consumed in the execution of a particular task over a resource. 8% of researchers have considered latency parameters for evaluation purposes. 11% of researchers have used resource utilization, and another 15% have used cost for offloading algorithm evaluation purposes. Few researchers only address mobility, scalability, and throughput parameters, and these parameters need attention for the future of fog computing.

Table 2 Performance metrics used for evaluation of offloading algorithms

References	Energy Consumption	Response Time	Computation Time	Delay	Latency	Cost	Resource Utilization	Mobility	Scalability	Throughput
[16]	√	√	√	×	×	×	×	×	×	×
[17]	×	√	×	×	×	√	×	×	×	×
[18]	√	×	√	×	×	×	×	×	×	×
[19]	√	×	×	×	×	√	×	×	×	×
[20]	√	×	×	×	√	×	×	×	×	×
[21]	√	×	×	√	√	×	×	×	×	×
[22]	×	×	√	×	×	×	×	×	×	×
[23]	×	×	×	×	×	√	√	×	×	×
[24]	√	×	√	×	×	×	×	×	×	×
[25]	×	√	×	×	×	×	×	×	×	√
[26]	√	√	×	×	×	√	×	×	×	×
[27]	×	√	×	×	×	×	√	×	√	×
[28]	×	√	×	×	×	√	×	×	×	√
[29]	√	√	×	×	×	√	×	×	√	×
[30]	√	√	×	×	×	√	×	×	×	×
[31]	√	√	×	×	×	×	×	×	×	×
[32]	√	×	×	×	×	×	×	×	×	×
[33]	×	√	×	×	×	×	√	×	×	×
[34]	√	√	×	×	×	√	×	×	×	×
[35]	√	√	×	×	×	√	√	×	×	×
[36]	√	√	×	×	×	√	√	×	×	√
[37]	√	√	×	×	×	×	×	×	×	×
[38]	×	×	×	×	×	×	×	√	×	×
[39]	×	×	×	×	×	×	×	√	×	×
[10]	√	√	×	×	×	×	×	√	×	×
[40]	×	×	×	×	×	×	×	×	×	×

[16]	×	×	×	×	√	×	×	×	×	×
[41]	×	×	×	×	√	×	×	×	×	√

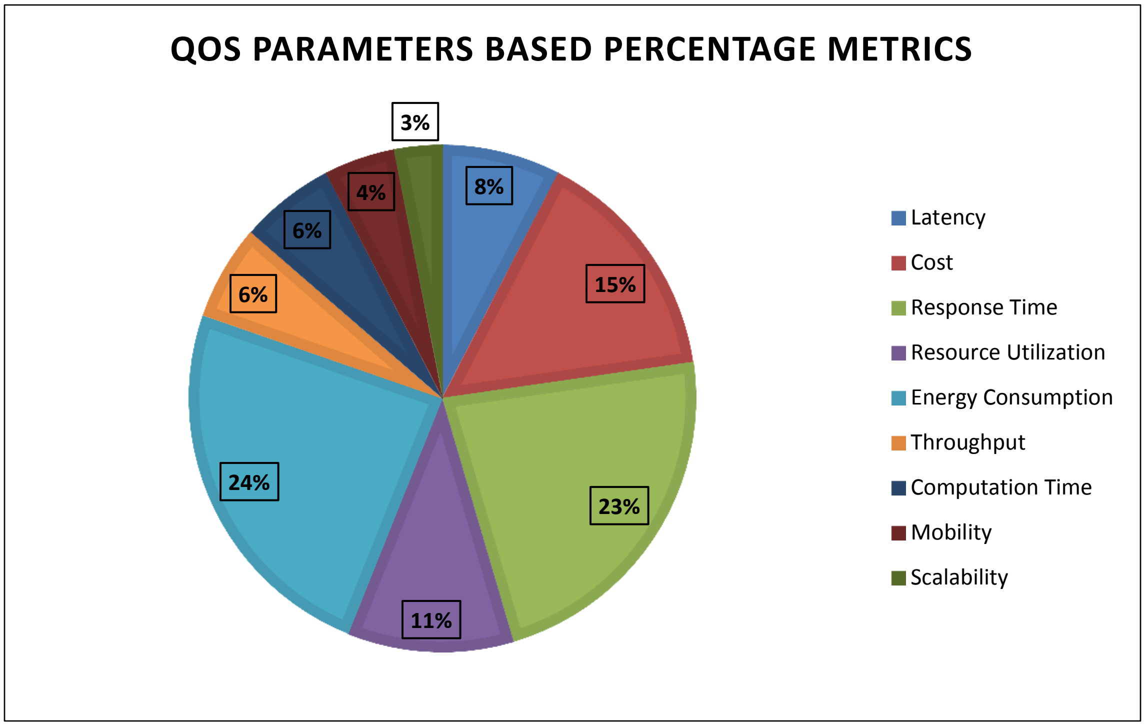

Fig 8 Percentage metrics for quality of service parameters

3. Research Challenges

The following research challenges have been identified for computation offloading in fog computing by going through the literature.

(a) Hierarchical Architecture

The fog paradigm is essentially a hierarchical network structure where latency-sensitive jobs are processed at the fog or edge nodes while latency-insensitive tasks are sent to the cloud. Although the cloud and fog can be used to speed up and parallelize the execution of a task, doing so is a challenging undertaking that requires careful planning. Therefore, reliable partitioning strategies and prediction algorithms need to be developed.

(b) Unbalanced Load on Fog Node

In the literature, most of the authors have offloaded the task to the nearest fog node. But in the crowded region, this approach may cause the overloading of the fog servers. On the other hand, a remote fog server does not have offloading requests, which results in the underutilization of resources. The offloading task may increase the devices' processing cost and energy consumption in such cases.

(c) Testbed for Evaluation

The fog computing environment comprises of various heterogenous devices in a hierarchical way. So the development of a testbed for evaluation purposes is very complex and costly. The majority of studies utilise simulation software such as iFogSim[42], YAFS[43], CloudSim, MobFogSim[44], FogTorchII[45], and FogNetSim++[46] . Consequently, it is of the utmost importance to construct testbeds that can conduct large-scale studies of real-time fog computing environments.

(d) Limited Resources
Fog nodes have less processing power and less storage space than the cloud. Therefore, it is difficult for researchers to coordinate among these diverse and limited resources.

(e) Offloading Decision
There is a lack of adaptive offloading decisions, which should be taken by considering the user parameters, remaining resources and current network condition. In the literature, it is observed that many approaches for offloading decisions have considered either one or two parameters for optimal decision-making.

(f) Security
Since fog nodes are susceptible to a variety of attacks and threats to the data, fog computing necessitates the utilization of computation offloading strategies that protect users' privacy.

Authentication on several levels in the fog layer is still another key difficulty that necessitates the development of an ideal solution to support security.

(g) Quality of Service
In future research, one of the most significant difficulties will be determining how to offload tasks and allocate resources based on QoS factors such as stability, scalability, mobility, fairness, waiting time, and task success ratio. According to the most recent study, it is essential to give due consideration to these QoS needs in an appropriate manner. This ensures that the workload will be assigned to the most effective resources to avoid overloading or underloading fog resources.

Conclusion

A bibliometric analysis was conducted to find the best journal, the most productive author, and the contribution of countries and fog computing hotspots to represent the research topic's popularity. Then a brief overview of the quality of service parameters is given in detail. In the literature, authors focused on various performance matrices like energy consumption reduction, service completion time, execution cost reduction, average resource utilization, etc. Based on the bibliometric analysis, various interpretations were made, and several research challenges were identified. Since fog computing technology supports IoT devices, there is a large scope for future research in the IoT environment.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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