Heliyon 8 (2022) e09510

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Examining the developments in scheduling algorithms research: A bibliometric approach

Temidayo Oluwatosin Omotehinwa *

Department of Mathematics and Computer Science, Federal University of Health Sciences, Otukpo, Nigeria

HIGHLIGHTS

- Scheduling algorithms research has an annual scientific production growth rate of 16.62%.
- The keyword "scheduling" is the most relevant keyword. It has the highest betweenness centrality of 101.94.
- Buyya Rajkumar is the most productive author in scheduling algorithms research.
- Edge Computing is the most discussed topic concerning scheduling algorithms research in 2020 and 2021.
- Institutional collaborations have not been well-established in this field.

ARTICLE INFO

Keywords:
Bibliometric analysis
Scheduling algorithms
Bibliometrix
Science mapping
Biblioshiny

ABSTRACT

This study examined the developments in the field of Scheduling algorithms in the last 30 years (1992–2021) to help researchers gain new insight and uncover the emerging areas of growth for further research in this field. This study, therefore, carried out a bibliometric analysis of 12,644 peer-reviewed documents extracted from the Scopus database using the Bibliometrix R package for bibliometric analysis via the Biblioshiny web interface. The results of this study established the development status of the field of Scheduling Algorithms, the growth rate, and emerging thematic areas for further research, institutions, and country collaborations. It also identified the most impactful and leading authors, keywords, sources, and publications in this field. These findings can help both budding and established researchers to find new research focus and collaboration opportunities and make informed decisions as they research the field of scheduling algorithms and their applications.

1. Introduction

Scheduling is allocating resources to tasks to optimize certain performance measures such as waiting time, throughput, and makespan. The study of scheduling spans over 60 years in various fields such as Operations Research, Management, Computer Science, Industrial Engineering, and Health (An et al., 2012; Burdett and Kozan, 2018; Kumar et al., 2018; Sharma et al., 2021a, 2021b; Yan et al., 2021). Its advent in the field of Computer Science resulted from the need to solve scheduling problems arising from the development of the Operating Systems (OS) (Leung, 2004). The development of OS led to the need for efficient scheduling algorithms to manage computational resources such as CPU time, Storage, Memory, and I/O devices in computer systems. Some of the scheduling algorithms are First Come First Serve (FCFS), Shortest Job First (SJF), Priority scheduling, Shortest Remaining Time (SRT), Round Robin, Min-Min, Max-Min, and Multilevel queue. The major goal is to ensure fairness in allocating resources to tasks. Different variants of these algorithms have been developed (Chandiramani et al., 2019; Nazar et al., 2019; Omotehinwa et al., 2019a, 2019b; Sharma et al., 2021a) and the area of application of these algorithms cuts across different domains; load balancing in Cloud Computing (Das et al., 2017; Ghosh and Banerjee, 2018), cost minimization in fog computing, and energy-balancing in the Internet of Things (IoT) (Choudhari et al., 2018; Tychalas and Karatza, 2020). This study aims to carry out a bibliometric analysis of the developments of scheduling algorithms in the last 30 years. According to Verbeek et al. (2002), bibliometric analysis is "the collection, the handling, and the analysis of quantitative bibliographic data, derived from scientific publications". In science and applied sciences, bibliometric analysis has become an acceptable standard for descriptive and evaluative measures of the impact of research outputs. It is also a key

* Corresponding author.
E-mail address: oluomotehinwa@gmail.com.

https://doi.org/10.1016/j.heliyon.2022.e09510
Received 17 August 2021; Received in revised form 19 January 2022; Accepted 16 May 2022
2405-8440/© 2022 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Table 1. Differences, advantages, and disadvantages of bibliometric analysis and systematic review study.

	Bibliometric Analysis Study	Systematic Review Study
Differences	- It is targeted at eliciting emerging trends, performance analysis, and social and intellectual structures from a field of study or topic.	- The goal is to analyze and summarize empirical studies to establish isolation or association in aims, methods, results, and variables from existing literature that supports generalizable knowledge or presents new research opportunities.
	- It is applicable when the scope of review is wide.	- It is appropriate for the concept, method, and theory-specific reviews with a narrow scope.
	- It relies on quantitative techniques and data.	- Qualitative techniques and data are used in a systematic review.
	- A large amount of data is required.	- Small data is required.
	- The analysis is done with software.	- It requires manual analysis and, in most cases, by more than one person.
Advantages	- The quality and quantity of research outputs, authors, sources, and institutions can be verified quickly with bibliometric analysis.	- Its specific nature makes it easier for researchers to quickly find the overall results and open research topics in a specific area of study.
	- The possibility for graphical visualization of results enhances the presentation and understanding of the results of the studies.	- Answers to specific research questions can be obtained quickly via systematic review studies.
	- Results of the bibliometric analysis are easily reproducible.	- If quality works of literature are reviewed without bias, results are very reliable.
Disadvantages	- The data repositories usually used in sourcing bibliographic data are not explicitly designed for bibliometric analysis; therefore, missing values or incorrectly entered data can affect the analysis results. - Its quality measure is associated with parameters such as citation counts, h-index, and g-index, which cannot measure impacts in terms of breakthroughs in the field. A paper or author may have fewer citations but has groundbreaking research output.	- A lot of time is required to review each piece of literature carefully. - The interpretation and findings of systematic reviews are subject to researcher bias. - The quality and reliability of the findings are dependent on the quality of literature selected for review.

component of research evaluation methodology (Ellegaard and Wallin, 2015). The use of bibliometrics in different disciplines has continued to increase. Studies similar to this study (Dao et al., 2017; Rahimi et al., 2022; Shishido and Estrella, 2018; Yu et al., 2018) have carried out a bibliometric analysis of the genetic algorithm, grids, and clouds, Cloud Computing Technology, and Non-dominated Sorting Genetic Algorithm II (NSGA II). The systematic review helps to gain new insight and uncover meaningful knowledge from cumulative data of a research field (Radhakrishnan et al., 2017). Bibliometric tools make the extraction of new knowledge from an enormous amount of literature very fast and less cumbersome when compared to attempting to uncover this knowledge through the traditional systematic literature review. A brief overview of the bibliometric analysis study and systematic review study is presented in Table 1.

It is important to note that these two methods can complement research. For example, the result of a bibliographic coupling produced through bibliometric analysis could be subject to content analysis using a systematic review to draw inferences on the clusters presented in the bibliographic coupling.

Scheduling algorithms have vast areas of application, and it will be a tedious work to carry out a traditional systematic literature review to find out the leading sources, most relevant authors and institutions, authors and country collaborations, emerging thematic areas, top keywords, and the scientific production of researchers in this area. This information can help both established and budding researchers in getting improved search results as the top keywords in this area can be identified quickly, most relevant authors, articles, and sources can guide on where to publish, top publications to review, potential research collaborators, emerging thematic areas can create a new focus for researchers. Existing survey papers have not focused on the general landscape or developments in this field. They have largely taken a narrow path that either focus on specific topics or area of applications of scheduling algorithms. These studies (Almansour and Allah, 2019; Arora and Banyal, 2022; Arunarani et al., 2019; Ghafari et al., 2022; Kumar et al., 2019; Sana and Li, 2021) focused on the extensive review of scheduling techniques in cloud computing (Agrawal et al., 2021; Davis and Burns, 2011; Olofintuyi et al., 2020), focused on the review of operating system scheduling algorithms while other studies such as (Maipan-Uku et al., 2017; Prajapati and Shah, 2014; Yousif et al., 2015) focused on scheduling in grid computing. A general overview of scheduling algorithms is necessary at this time to understand the trends over time and to discover a new research focus. It is also worthy of note that there is no study on bibliometric analysis of scheduling algorithms at the time of this writing. Therefore, this study is very important at this time. To

Table 2. Main information and summary of the dataset.

Description	Results
Timespan	1992–2021
Sources (Journals, Books, etc.)	3,609
Documents	12,644
Average years from publication	8.88
Average citations per document	14.27
Average citations per year per documents	1.568
References	245,972
Document Types	
Article	5,689
Book	7
Book chapter	98
Conference paper	6,802
Erratum	1
Review	47
Document Contents	
Keywords Plus (ID)	28,744
Author's Keywords (DE)	15,793
Authors	
Authors	17,958
Author Appearances	39,794
Authors of single-authored documents	580
Authors of multi-authored documents	17,378
Authors Collaboration	
Single-authored documents	726
Documents per Author	0.704
Authors per Document	1.42
Co-Authors per Documents	3.15
Collaboration Index	1.46

Table 3. Rate of production of articles per year and the annual growth rate.

S/N	Year	No. of Articles Published per Year	Percentage of No. of Articles Published Per Year	Cumulative growth of Published Articles Per Year	Cumulative Percentage of No. of Articles Published Per Year	Annual Growth Rate (AGR) of Published Articles Per Year (%)
1	1992	8	0.06	8	0.06	
2	1993	15	0.12	23	0.18	87.5
3	1994	26	0.21	49	0.39	73.3
4	1995	46	0.36	95	0.75	76.9
5	1996	55	0.43	150	1.19	19.6
6	1997	65	0.51	215	1.70	18.2
7	1998	58	0.46	273	2.16	-10.8
8	1999	71	0.56	344	2.72	22.4
9	2000	60	0.47	404	3.20	-15.5
10	2001	85	0.67	489	3.87	41.7
11	2002	120	0.95	609	4.82	41.2
12	2003	145	1.15	754	5.96	20.8
13	2004	188	1.49	942	7.45	29.7
14	2005	219	1.73	1,161	9.18	16.5
15	2006	305	2.41	1,466	11.59	39.3
16	2007	413	3.27	1,879	14.86	35.4
17	2008	425	3.36	2,304	18.22	2.9
18	2009	601	4.75	2,905	22.98	41.4
19	2010	763	6.03	3,668	29.01	27.0
20	2011	804	6.36	4,472	35.37	5.4
21	2012	772	6.11	5,244	41.47	-4.0
22	2013	861	6.81	6,105	48.28	11.5
23	2014	871	6.89	6,976	55.17	1.2
24	2015	790	6.25	7,766	61.42	-9.3
25	2016	766	6.06	8,532	67.48	-3.0
26	2017	762	6.03	9,294	73.51	-0.5
27	2018	951	7.52	10,245	81.03	24.8
28	2019	1,016	8.04	11,261	89.06	6.8
29	2020	692	5.47	11,953	94.53	-31.9
30	2021	691	5.47	12,644	100.00	-0.1
		12,644	100			

understand the landscape of scheduling algorithms research, this study set out to answer the following questions:

i. What is the annual scientific production growth rate in scheduling algorithms research?
ii. What is the scientific production of authors? Which are the most relevant publications, most relevant sources globally and locally in scheduling algorithms research?
iii. What are the emerging, evolving, developed, and underdeveloped thematic areas in scheduling algorithms research?
iv. What is the country's scientific production like? How established is the collaboration network of authors, institutions, and countries in scheduling algorithms research?
v. What are the trends in topics, top keywords, and co-occurrence network of keywords in scheduling algorithms research?

2. Methodology

The methodology used in this study is a bibliometric analysis which is a widely used methodology for the statistical evaluation of scientific outputs. The bibliometric analysis is done using Bibliometrix. Bibliometrix is an open-source science mapping analysis tool for statistical measurement of productivity within a research domain (Aria and Cuccurullo, 2017). According to Dervis (2019), "Bibliometrix is an R statistical package for analyzing and visualizing the bibliometric data from Web of Science and Scopus databases. It is written in R language, which operates under the GNU operating system". It was developed by Aria, Massimo from the University of Naples, and Cuccurullo, Corrado from the University of Campania, both in Italy (Aria and Cuccurullo, 2017). Other bibliometric tools include Pajek, ScientoTex, CiteSpace, BibExcel, and VOSviewer. However, they are not as comprehensive, and the analysis is not easily reproduced as in Bibliometrix. Moral-Muñoz et al. (2020) stated that Bibliometrix is outstanding in the variety of analysis that can be carried out with it.

In this section, the standard workflow for bibliometrics: Study design, Data collection, Data analysis, Data visualization, and interpretation as presented in the study by (Zupic and Čater, 2015) and the procedure for bibliometric analysis itemized by (Donthu et al., 2021) was followed.

2.1. Study design

This study was designed to examine the developments in scheduling algorithms within the last 30 years, specifically from 1992 to 2021. The specific questions answered by this study are enumerated in section 1.

2.2. Data collection

The data used in this study were extracted from the Scopus database. Scopus is a repository for abstracts and citations of peer-reviewed literature such as Journals and conference proceedings. According to its blog (Scopus, 2020), Scopus is the largest of such repositories. The literature search process involves defining search strings containing keywords commonly used and/or related to scheduling algorithms research. The search string; (TITLE-ABS-KEY ("Scheduling Algorithm*") AND TITLE-ABS-KEY ("Multilevel queue" OR "Round Robin" OR "Shortest Job First" OR "First Come First Serve" OR "Shortest Remaining Time" OR

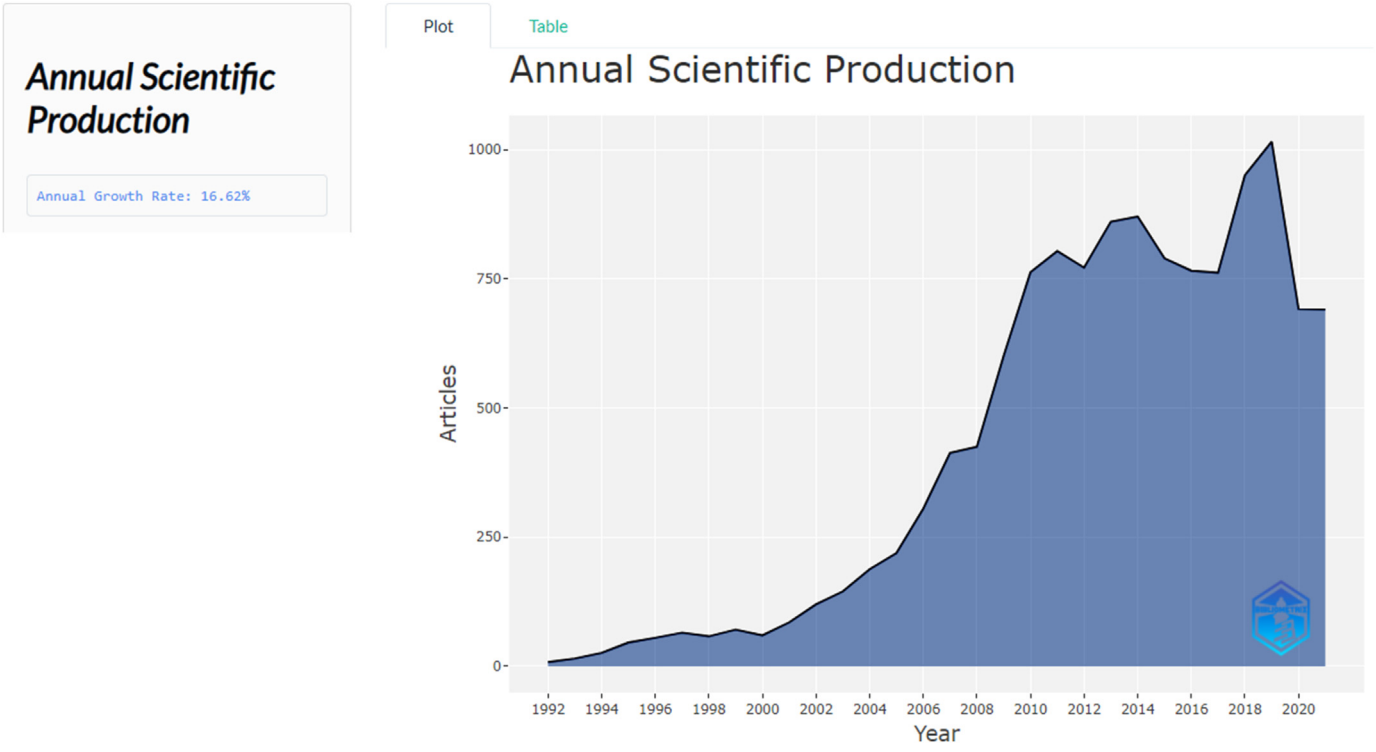

Figure 1. Annual scientific growth of scheduling algorithms research.

"Priority queue" OR "Makespan" OR "average waiting time" OR "turnaround time" OR "Context Switch*" OR "Completion time" OR "Resource allocation" OR "Time Quantum" OR "Grid computing" OR "Cloud Computing" OR "Edge Computing" OR "Fuzzy Computing" OR "Evolutionary Computing" OR "Green Computing")) AND (EXCLUDE (SRCTYPE, "Undefined")) AND (EXCLUDE (PUBSTAGE, "AIP")) AND (LIMIT-TO (PUBYEAR > 1991 AND PUBYEAR < 2022)) AND (LIMIT-TO (LANGUAGE, "English")) returned 12,881 documents. The wild card asterisk (*) ending the keyword "Scheduling algorithm" in the search ensures that 0 or more characters may complete the keywords. For example, "Scheduling algorithm*" means the search should select if available Scheduling algorithm or Scheduling algorithm s. There are Inclusion Criteria (IC), and Exclusion Criteria (EC) imposed on the search such that the result should include only documents written in the English language, excluding all articles in press "AIP". The 12,881 records were exported to CSV via the Scopus document search interface. It is impossible to export more than 2,000 records at a time; hence, the records were exported in batches and merged using Microsoft Excel. The web interface provided for no coding use of Bibliometrix called Biblioshiny was used to filter documents of type "Letter", "Note", "Editorial", "Retracted", and documents tagged "Na N – No Author Name" were removed. Also, some of the documents with language; English/Croatia and English/Japanese, were removed. The filtering returned 12,644 documents analyzed in this study. The search was conducted on 21st March 2022. Table 2 presents the summary of the main information about the data. The literature in this dataset is composed of six types of documents which are Articles (n = 5,689), Book (n = 7), Book chapters (n = 98), Conference papers (n = 6,802), Erratum (n = 1), and Review papers (n = 47). Information about the document contents includes Author's Keywords (DE) and Keyword Plus (ID). The author's keywords showed the total number of keywords contained in all documents. In contrast, the keywords plus is the total number of keywords generated by Scopus from titles, keywords, and

Table 4. Top 10 most productive authors in scheduling algorithm research.

Authors	No. of Articles	No. of Articles Fractionalized	No. of Articles as First Author	No. of Articles as Corresponding Author	Area of research interests
Buyya, Rajkumar	65	21.07	4	4	Cloud Computing; Virtual Machine; Edge Computing;
Wang, Jibo	61	24.08	30	29	Deteriorating Jobs; Scheduling Problems
Cheng, Tai Chiu Edwin	57	15.90	11	7	Deteriorating Jobs; Scheduling Problem; Due Window; Supply Chain Coordination
Yuan, Jinjiang	56	21.25	4	33	Deteriorating Jobs; Scheduling Problem; Due Window; Batch Scheduling
Zandieh, Mostafa	47	16.75	3	35	Flow Shop Scheduling; Fuzzy TOPSIS; Supplier Selection
Zomaya, Albert Y.	46	12.71	0	3	Cloud Computing; Edge Computing; Internet of Things; Location Awareness
Li, Kenli	43	10.88	6	18	Task Scheduling; Heterogeneous Computing; DAG
Wu, Chin Chia	39	10.00	8	18	Deteriorating Jobs; Scheduling Problem; Due Window; Flow Shop Scheduling
Pan, Quanke	37	10.28	11	17	Flow Shop Scheduling; Makespan; Genetic Algorithm
Wang, Ling	36	10.57	7	10	Flow Shop Scheduling; Permutation Flowshop; Scheduling Problem

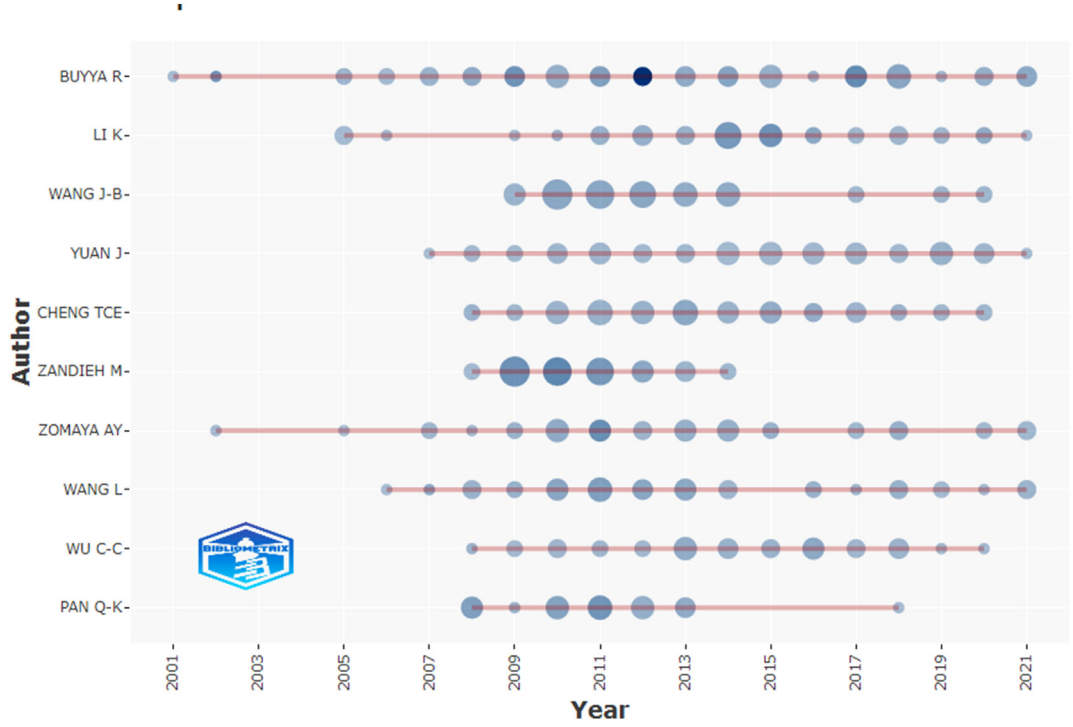

Figure 2. Top 10 authors' publications over time. The bubble size indicates the number of documents produced per year by the authors. The lines represent the span of production over time (timeline). The number of citations determines the intensity of the colour of the bubble; deeper colour indicates higher citations.

abstracts of documents in this dataset (Aria and Cuccurullo, 2017). Other information includes the total number of authors in the entire document in this dataset, co-authors per document, and collaboration index. On successful cleaning of the data from Scopus, the function biblioshiny() was invoked in R studio to launch the biblioshiny web interface after loading the bibliometrix package with the function library("bibliometrix"). The CSV file containing the data extracted from Scopus was loaded through the biblioshiny interface. The Keyword Co-occurrence Network, Thematic Map, Collaboration Network, Trend Topics, Source, Document, and Author impact analyses were carried out.

2.3. Data analysis

The file containing the 12,644 documents was converted into bibliographic data frames for analysis after uploading through the Biblioshiny web interface accessed through the browser. In this study, descriptive analysis was carried out to determine the most relevant authors, most cited authors, and most productive countries based on the first author's affiliation, top journals, and top keywords based on the frequency of occurrence. Citation analysis was done to determine the most cited references. Co-occurrence, collaboration, and co-word analysis were also carried out. The results are presented as networks.

2.4. Data visualization and interpretation

Data visualization and interpretation are presented in section 3.

3. Results and discussion

A preliminary analysis with a limited sample size yielded very different results. This implies that a sample size not large enough will lead to extremely biased results. Therefore, the sample size must be representative of the population size, and the methodology must be carefully designed to capture both broad and narrow themes in the field being researched. These will ensure negligible bias in the outcome.

In this section, the analysis results are presented based on the questions in the study design section.

3.1. What is the annual scientific production growth rate in scheduling algorithms research?

Table 3 shows the frequency of production for each year from 1992 to 2021. The highest number of production of publications in scheduling algorithm research was recorded in 2019, representing 8.04% (1,016) of the total number of publications. The sudden decrease in the number of publications in 2020 and 2021 could result from the global impact of the COVID-19 pandemic. The lowest annual growth rate of -31.9% was recorded in 2020 (Table 3).

It can be observed from Figure 1 that scheduling algorithms research has an annual scientific production growth rate of 16.62% (Eq. (2)). This growth rate is exponential and going by the "Rule of 70" (Eq. (1)) (Mahajan, 2021); this annual growth rate is expected to double in 4 years.

Rule of 70:

$$t \approx \frac{70yr}{f/1\%} \tag{1}$$

t is the doubling time; f is the annual percentage growth rate.

The annual percentage growth rate is determined thus:

$$\left(\frac{Total\ no.\ of\ publications\ in\ start\ year}{Total\ no.\ of\ publications\ in\ end\ year}\right)^{\left(\frac{1}{No.\ of\ years-1}\right)-1} \tag{2}$$

The AGR is determined by calculating the percentage increase in the number of publications for each year (Eq. (3)).

$$AGR = \left(\frac{TCY - TPY}{TPY}\right)*100 \tag{3}$$

Where TCY is the total number of publications in the current year and TPY is the total number of publications in the previous year.

Table 5. Top 10 most cited publications based on local and global citations. The local citation measures the number of times each publication was cited by other publications within the dataset analyzed in this study. The global citations (total citations) measure the number of times each of the publications was cited across the entire Scopus database.

Authors & Year of Publication	Publication Title	Scheduling Algorithms proposed/ applied/reviewed/Hybridized	Source Title	Global Citations	Local Citations	Research Area
(Beloglazov et al., 2012)	Energy-aware resource allocation heuristics for efficient management of data centres for Cloud computing	Modified Best Fit Decreasing (MBFD) algorithm	Future Generation Computer Systems	1,943	153	Virtual Machine | Data Center | Cloud Computing
(Yoo and Goldsmith, 2006)	On the optimality of multi-antenna broadcast scheduling using zero-forcing beamforming	Round-robin Zero-Forcing Beamforming (ZBFB) and Proportional-fair ZBFB	IEEE Journal on Selected Areas in Communications	1,609	16	Beamforming | Multiuser MIMO | Block Diagonalization
(Buyya and Murshed, 2002)	GridSim: A toolkit for the modelling and simulation of distributed resource management and scheduling for grid computing	Time-shared and Space-shared schedulers: that runs allocation scheme such as First Come First Served (FCFS) and Shortest Job First Served (SFJS)	Concurrency and Computation: Practice and Experience	1,087	147	Computational Grids | Resource Allocation | Heterogeneous Computing
(Kwok and Ahmad, 1999)	Static Scheduling Algorithms for Allocating Directed Task Graphs to Multiprocessors	Reviewed 27 Directed Acyclic Graph (DAG) scheduling algorithms such as Hu's Algorithm for Tree-Structured DAGs, Coffman and Graham's Algorithm for Two-Processor Scheduling, etc.	ACM Computing Surveys	985	192	Task Scheduling | Heterogeneous Computing | DAG
(McKeown, 1999)	The iSLIP scheduling algorithm for input-queued switches	iSLIP: Iterative, Round-robin algorithm	IEEE/ACM Transactions on Networking	984	48	Switch | Multicast | Scheduler
(Buyya et al., 2009)	Modelling and simulation of scalable cloud computing environments and the cloudsim toolkit: Challenges and opportunities	Time-shared and Space-shared algorithms for scheduling tasks and virtual machines.	Proceedings of the 2009 International Conference on High-Performance Computing and Simulation, HPCS 2009	755	118	Cloud Computing | Data Center | Simulator
(Bini and Buttazzo, 2005)	Measuring the performance of schedulability tests	Rate Monotonic (RM) and Earliest Deadline First (EDF)	Real-Time Systems	581	8	Schedulability Analysis | Computer System | Earliest Deadline First
(Leung, 2004)	Handbook of scheduling: Algorithms, models, and performance analysis	Stochastic Scheduling	CRC Press	560	5	Production Control | Order Release | Job Shop
(Liu et al., 2016)	Delay-optimal computation task scheduling for mobile-edge computing systems	Stochastic Computation Task Scheduling Policy	IEEE International Symposium on Information Theory - Proceedings	479	30	Edge Computing | Internet of Things | Location Awareness
(Dhinesh Babu and Venkata Krishna, 2013)	Honey bee behaviour inspired load balancing of tasks in cloud computing environments.	Honey Bee Inspired-Load Balancing (HBB-LB) algorithm	Applied Soft Computing Journal	478	86	Cloud Computing | Scientific Workflow | Execution Costs

Table 6. The most relevant recent research is based on the total number of citations. The relevance of a research constituent, such as author, publication, source, institution, and so on, is measured by the frequency of document production and/or citations.

Authors	Title	Scheduling Algorithms Proposed/ Applied/Reviewed/Hybridized	Source Title	Total Citation	Research Area
(Chen et al., 2021)	Uncertainty-Aware Online Scheduling for Real-Time Workflows in Cloud Service Environment	unceRtainty-Aware Online Scheduling Algorithm (ROSA)	IEEE Transactions on Services Computing	54	Cloud Computing | Scientific Workflow | Execution Costs
(Goudarzi et al., 2021)	An Application Placement Technique for Concurrent IoT Applications in Edge and Fog Computing Environments	Weighted Cost Model	IEEE Transactions on Mobile Computing	43	Edge Computing | Internet of Things | Location Awareness
(Lv et al., 2021)	Intelligent edge computing based on machine learning for smart city	Alternating Direction Method of Multipliers (ADMM) distributed task scheduling algorithm	Future Generation Computer Systems	39	Edge Computing | Internet of Things | Location Awareness
(Gatti and Shivashankar, 2021)	Improved resource allocation scheme for optimizing the performance of cell-edge users in LTE-A system	Improved Resource Allocation Scheme (RAS)	Journal of Ambient Intelligence and Humanized Computing	31	Long Term Evolution (LTE) | Local Thermodynamic Equilibrium | Packet Scheduling
(Yuan et al., 2021)	Be objective Task Scheduling for Distributed Green Data Centers	Simulated-annealing-based Bioobjective Differential Evolution (SBDE) Algorithm	IEEE Transactions on Automation Science and Engineering	31	Virtual Machine | Data Center | Cloud Computing
(Yang et al., 2020a)	Scheduling Policies for Federated Learning in Wireless Networks	Random Scheduling (RS), Round-Robin (RR), and Proportional-fair (PF)	IEEE Transactions on Communications	142	Distributed Machine Learning | Function Computation | Federated Learning
(Liu et al., 2020)	Distributed Set-Membership Filtering for Multirate Systems under the Round-Robin Scheduling over Sensor Networks	Round-Robin (RR) algorithm	IEEE Transactions on Cybernetics	95	Controller | Network-Induced Delay | Mean-Square Stability
(Yang et al., 2020b)	Multi-UAV-Enabled Load-Balance Mobile-Edge Computing for IoT Networks	Deep Learning-based task scheduling algorithm	IEEE Internet of Things Journal	52	Drone | Unmanned Aerial Vehicles | Base Stations
(Cheng et al., 2019)	Space/Aerial-Assisted Computing Offloading for IoT Applications: A Learning-Based Approach	Deep actor-critic-based online computing offloading algorithm	IEEE Journal on Selected Areas in Communications	244	Edge Computing | Internet of Things | Location Awareness
(Sundararaj, 2019)	Optimal Task Assignment in Mobile Cloud Computing by Queue Based Ant-Bee Algorithm	Hybrid-Queue Ant Colony-Artificial Bee (Ant-Bee) algorithm	Wireless Personal Communications	200	Edge Computing | Internet of Things | Location Awareness

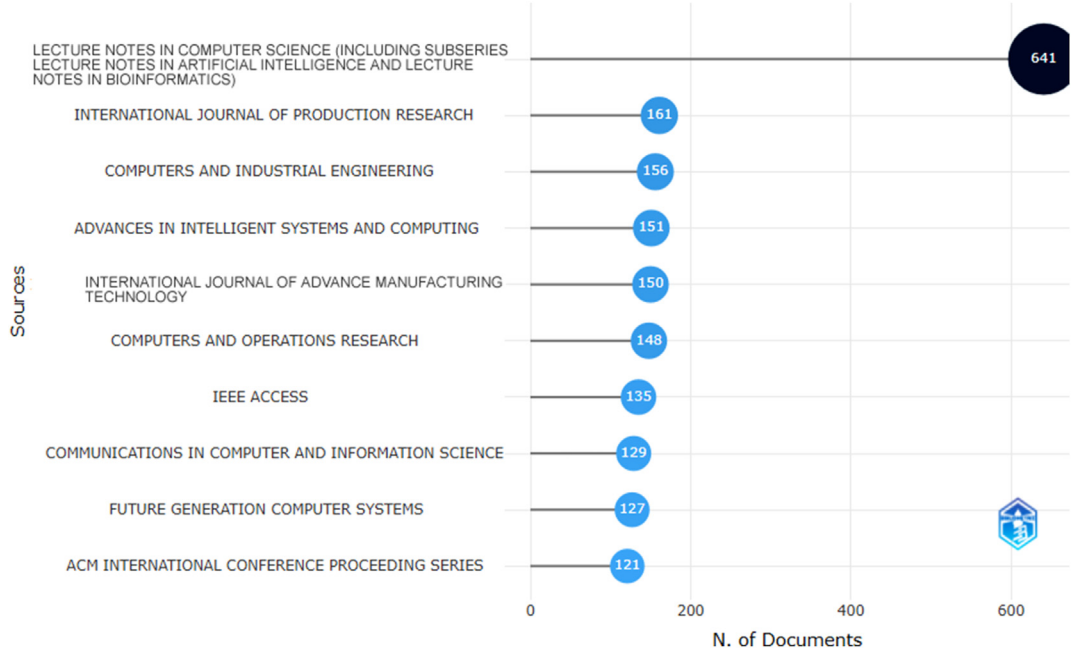

Figure 3. Top 10 Most relevant sources based on the number of publications. The number of publications determines the intensity of the colour of the ball and its size; deeper colour and bigger size indicate a higher number of publications.

3.2. What is the scientific production of authors? Which are the most relevant publications, most relevant sources globally and locally in scheduling algorithms research?

In Table 4, the top 10 most productive authors in the scheduling algorithms research are based on the number of publications and contributions of authors to a publication. Fractional counting measures the contributions of authors to publications with more than one author (Sivertsen et al., 2019). In normalized fractional counting (Sivertsen et al., 2019), for an n-authored paper, the contribution of the author is $1/n$. The sum of the fractional contribution of the author for all papers by the author is the number of articles fractionalized. For example, in the last two years, an author has had a publication with four authors and another publication with three authors. The number of articles fractionalized is $0.25(\frac{1}{4}) + 0.33(\frac{1}{3}) = 0.58$.

The first or lead author of a research article is considered the most valuable contributor. In contrast, the corresponding author is the most senior researcher or principal investigator who owns the design for

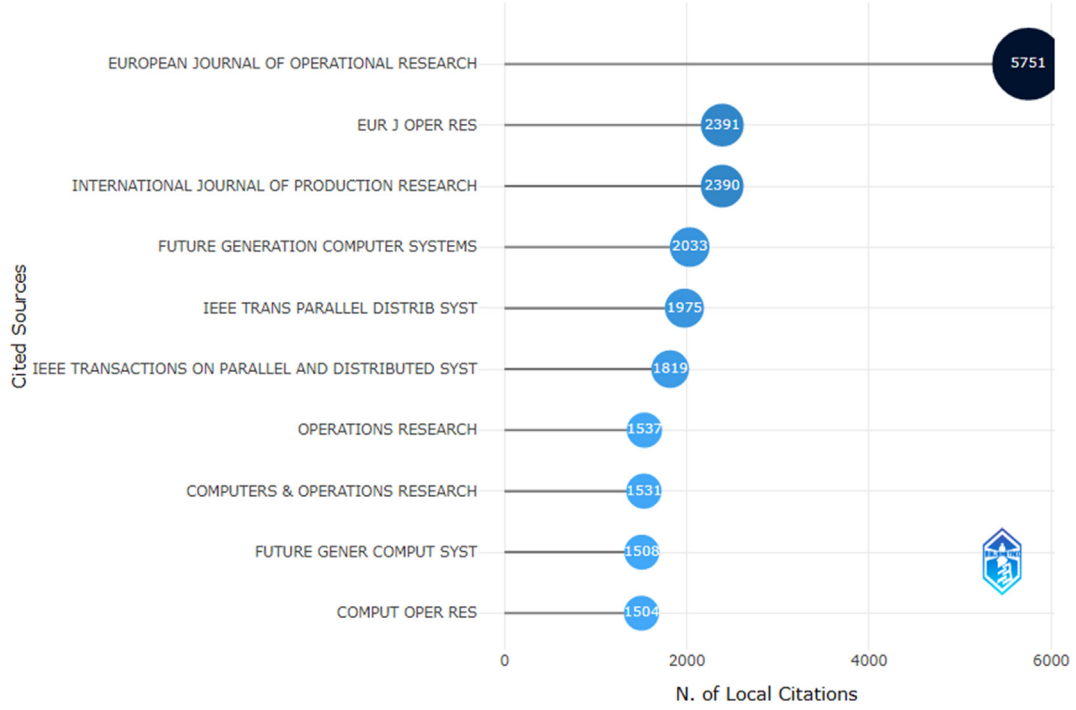

Figure 4. Top 10 Most locally cited sources. The local citation measures the number of times each source was cited by publications within the dataset analyzed. The number of publications determines the intensity of the colour of the ball and its size; deeper colour and bigger size indicate a higher number of publications.

Figure 5. Thematic map of concepts in scheduling algorithms research. The themes/sub-themes are generated from Keyword Plus (ID); author keywords, keywords in articles, and other essential keywords within the abstract of the literature. The upper-right quadrant (Q1) shows the driving or motor themes, the lower-right quadrant (Q2) shows the basic themes, the lower-left quadrant (Q3) shows the emerging or declining themes, and the upper-left quadrant (Q4) shows the developed themes less used and possibly understudied.

Table 7. Top 10 most productive countries based on the frequency of appearance in publications in scheduling algorithms research.

Country	Continent	Frequency of Appearance	Total Citations	Average Article Citations
China	Asia	14,055	44,248	13.36
USA	North America	4,581	25,807	28.71
India	Asia	4,464	8,585	9.81
Iran	Asia	1,282	10,449	25.61
South Korea	Asia	1,065	3,567	11.51
France	Europe	1,059	3,085	13.59
Canada	North America	912	3,477	16.40
UK	Europe	765	2,381	16.42
Germany	Europe	743	2,751	16.47
Japan	Asia	721	1,501	10.01

which the research was carried out. The corresponding author, in most cases, is usually the first or the last author of a research article. However, in a recent study by Yu and Yin (2021), the findings revealed that an increase in the number of authors in an article decreases the first or last author's chances of being the corresponding author. From Table 4, Wang J.-B is the most valuable contributor, with 30 articles as the first author and 29 as the corresponding author. Assuming that the contributions of all authors are equal through fractional counting, Wang J.-B has the highest number of articles fractionalized. Yuan J and Zandieh M have 33 and 35 articles as corresponding authors, suggesting that they are senior researchers in this field and supervised most of the research they co-authored. Buyya R is the most productive, with a total of 65 articles. It is essential to point out that the total number of publications count for each author was based on author ID and not the frequency of appearance of names on each document. It is impossible to uniquely identify authors by name as two or more authors could have the same last name and initials and be counted as one author.

In Figure 2, the top ten authors' production over time is shown. The bubble size indicates the number of documents produced per year by the authors. The lines represent the span of production over time (timeline). The number of citations determines the intensity of the colour of the bubble, and deeper colour indicates higher citations. From Figure 2, it

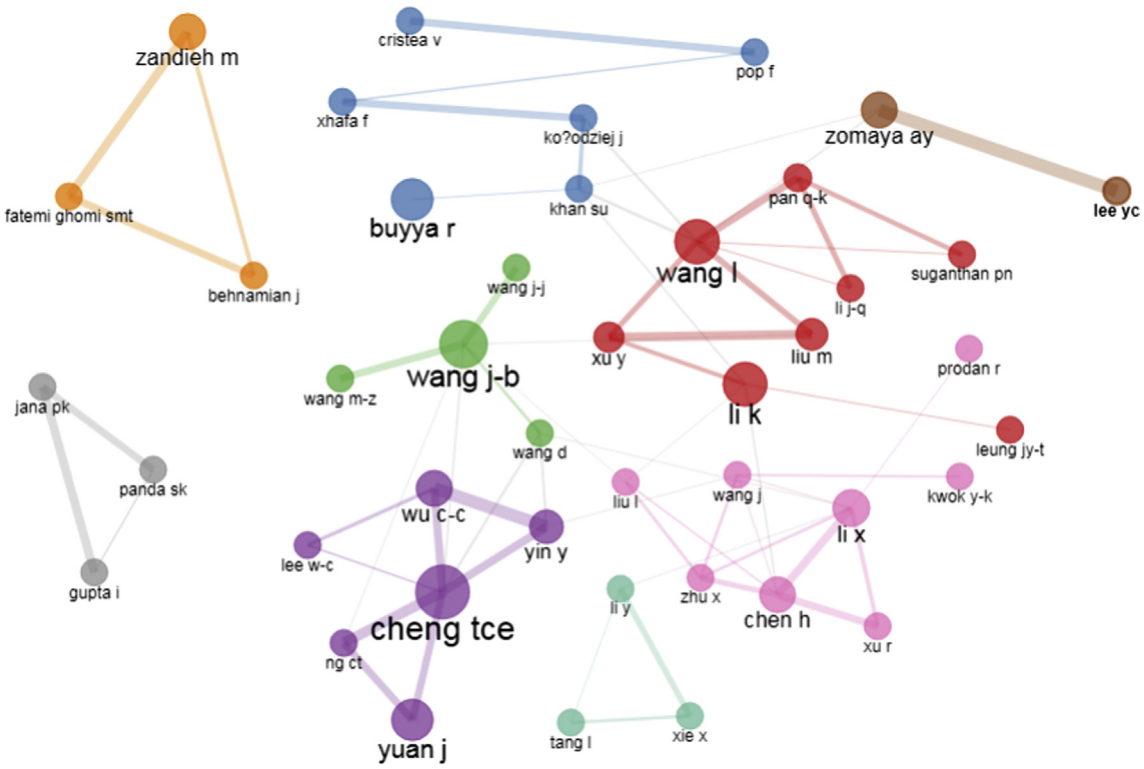

Figure 6. Social structure: Authors' collaboration network in scheduling algorithm research. The edges show that the connected authors have published at least two documents together. The size of the nodes indicates the number of documents published by the author in collaboration, and the thickness of the edges indicates the frequency of collaboration; a thicker edge means more collaborations between the connected authors (nodes).

can be observed that Buyya R has the longest timeline (2001–2021) and has been consistent in scheduling algorithms research. He published three articles and recorded 193.8 total citations per year in 2012. He has an H-index of 30 based on the available data, which makes him the most impactful author in this field. The highest number of publications (13) in a year were recorded by Zandieh M and Wang J.-B in 2009 and 2010. The size of the bubbles indicates this for these years. However, Zandieh has the shortest span from 2008 to 2014.

Li K. has produced 43 documents, and he has an H-index of 26 and one publication in this field in 2021.

Table 5 revealed the top 10 most cited publications locally and globally. In this study, the relevance of a research constituent, such as author, publication, source, institution, and so on, is measured by the frequency of document production and/or citations. The local citation measures the number of times each publication was cited by other publications within the dataset analyzed in this study. The global citations (total citations) measure the number of times each of the publications was cited across the entire Scopus database. The global citation also indicates the degree of relevance of a particular publication to other fields of study. The study by Beloglazov et al. (2012) is the most significant and impactful to other fields as it has the highest number of global citations (1,943) on the top 10 list while the study by Kwok and Ahmad (1999) is the most locally cited by documents within the analyzed dataset.

Interestingly, the most productive author in this field, Buyya Rajkumar from the University of Melbourne, Australia (See Table 3), co-authored three (3) publications in the top 10 list of most cited publications. Also, all publications on the list have more global citations than local citations, which is ideal. This indicates that the publications are not only relevant and impactful to scheduling algorithms research but other fields. Content analysis of the literature presented in Tables 5 and 6 was carried out to determine the proposed, applied, or reviewed scheduling algorithms.

Citation is one of the most popular metrics often used to measure the impact of an article in its field (Aksnes et al., 2019). Therefore, in a bid to examine recent research in this field that has gained momentum and relevance, using citation count as a measure of impact, the top 5 articles in 2021, the top 3 in 2020, and the top 2 in 2019 are presented in Table 6. These articles are (Chen et al., 2021), (Yang et al., 2020a; 2020b), and (Cheng et al., 2019), the top most cited in 2021, 2020, and 2019 respectively. Their broad research areas are Cloud Computing, Distributed machines, Internet of Things, Packet Scheduling, and Edge Computing.

The top 10 most relevant sources based on the number of published documents are presented in Figure 3. Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) published 641 articles, has a total global citation count of 4,607 based on available data, and it has the highest number of publications by any source in this dataset. It has an H-index of 28. The global citation measures the number of citations received by each source in the entire Scopus database. The most cited sources locally (Figure 4) measure the number of citations received by each document within the documents in the dataset used in this research which spans 1992 to 2021.

From Figure 4, the European Journal of Operational Research published by Elsevier is the most cited source locally, with 5,751 citations, an H-index of 31, and a global citation count of 2,967. Future Generation Computer Systems, published by Elsevier, ranked 9th on the most relevant sources and most locally cited list, has an H-index of 40 and a local citation count of 1,508.

3.3. What are the emerging, evolving, developed, and underdeveloped thematic areas in scheduling algorithms research?

The thematic structure of themes in scheduling algorithms research is shown in Figure 5. The co-word analysis network and cluster are based on Cobo et al. (2011) study. The bibliometrix function thematicMap() received the following parameters: Field = "ID", No. of words = 500, No of Labels = 10, Minimum cluster per frequency per thousand documents = 5, Label size = 0.3, Clustering Algorithm = "Louvain", layout = "Auto".

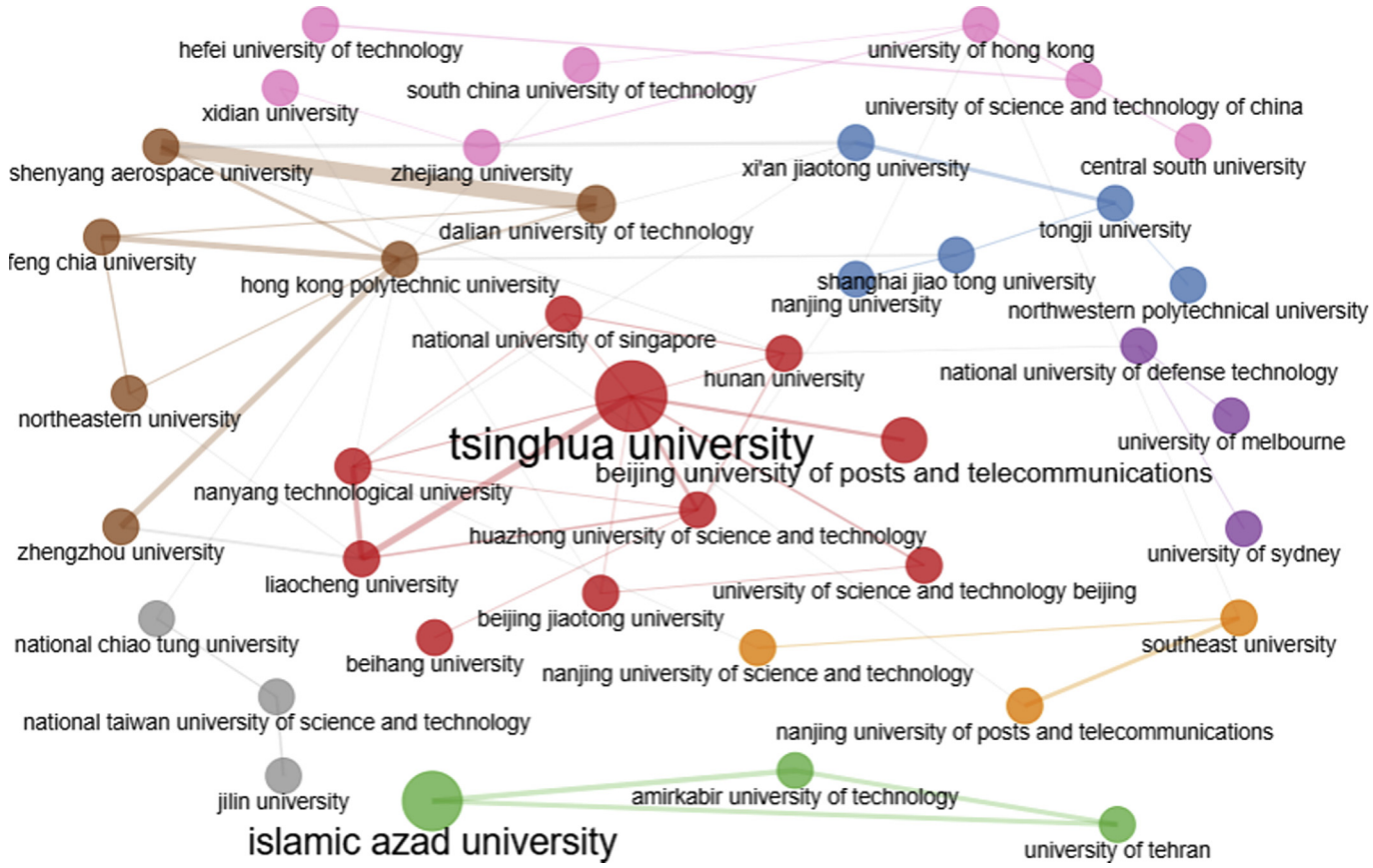

Figure 7. Social structure: Institution collaboration network in scheduling algorithm research. The connection between nodes indicates institutional collaboration. The thickness of the edges indicates the frequency of collaboration, and a thicker edge means more collaborations between the connected institutions.

To avoid bias, the keywords in the search query (*Scheduling Algorithm; Scheduling Algorithms; Multilevel queue; Round Robin; Shortest Job First; First Come First Serve; Shortest Remaining Time; Priority queue; Makespan; average waiting time; turnaround time; Context Switch; Context Switches; Completion time; Resource allocation; Time Quantum; Grid computing; Cloud Computing; Edge Computing; Fuzzy Computing; Evolutionary Computing; Green Computing*) were exempted from the co-word analysis and clustering. The clusters are generated from Keyword Plus (ID); author keywords, keywords in articles, and other important keywords within the abstract of the literature. The thematic map provides a clear interpretation of connections between themes (Grivel et al., 1995). The thematic map presents a visualization of the semantic strength of the themes' internal (correlation between concepts) and external (cohesiveness of nodes) association, which are measured as density and centrality, respectively. A thematic map helps to identify the important concepts within a field. The upper-right quadrant (Q1) shows the driving or motor themes, the lower-right quadrant (Q2) shows the basic themes, the lower-left quadrant (Q3) shows the emerging or declining themes, and the upper-left quadrant (Q4) shows the developed themes less used and possibly understudied in this field. Figure 5 revealed that the themes such as multitasking, task-scheduling and energy utilization in the green cluster are the most important (high centrality) in scheduling algorithm

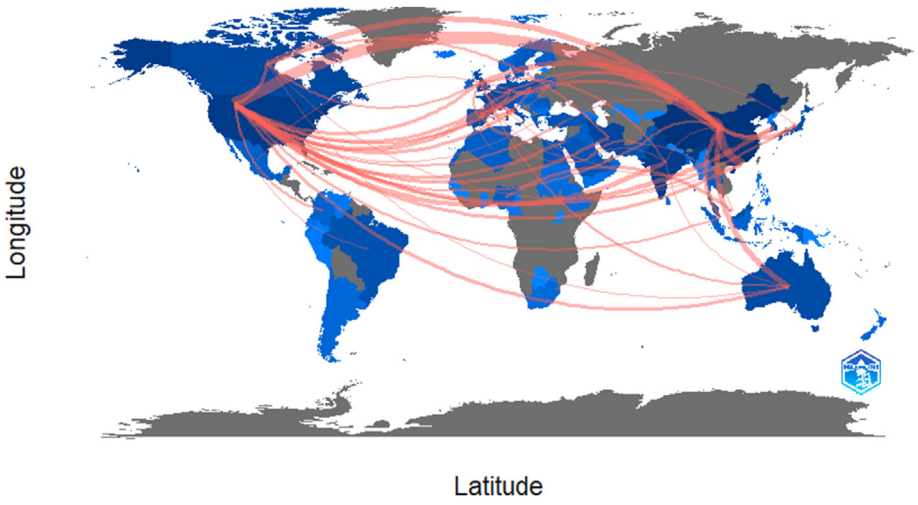

Figure 8. Social structure: Countries collaboration map. The thickness of connecting lines indicates the frequency of collaboration.

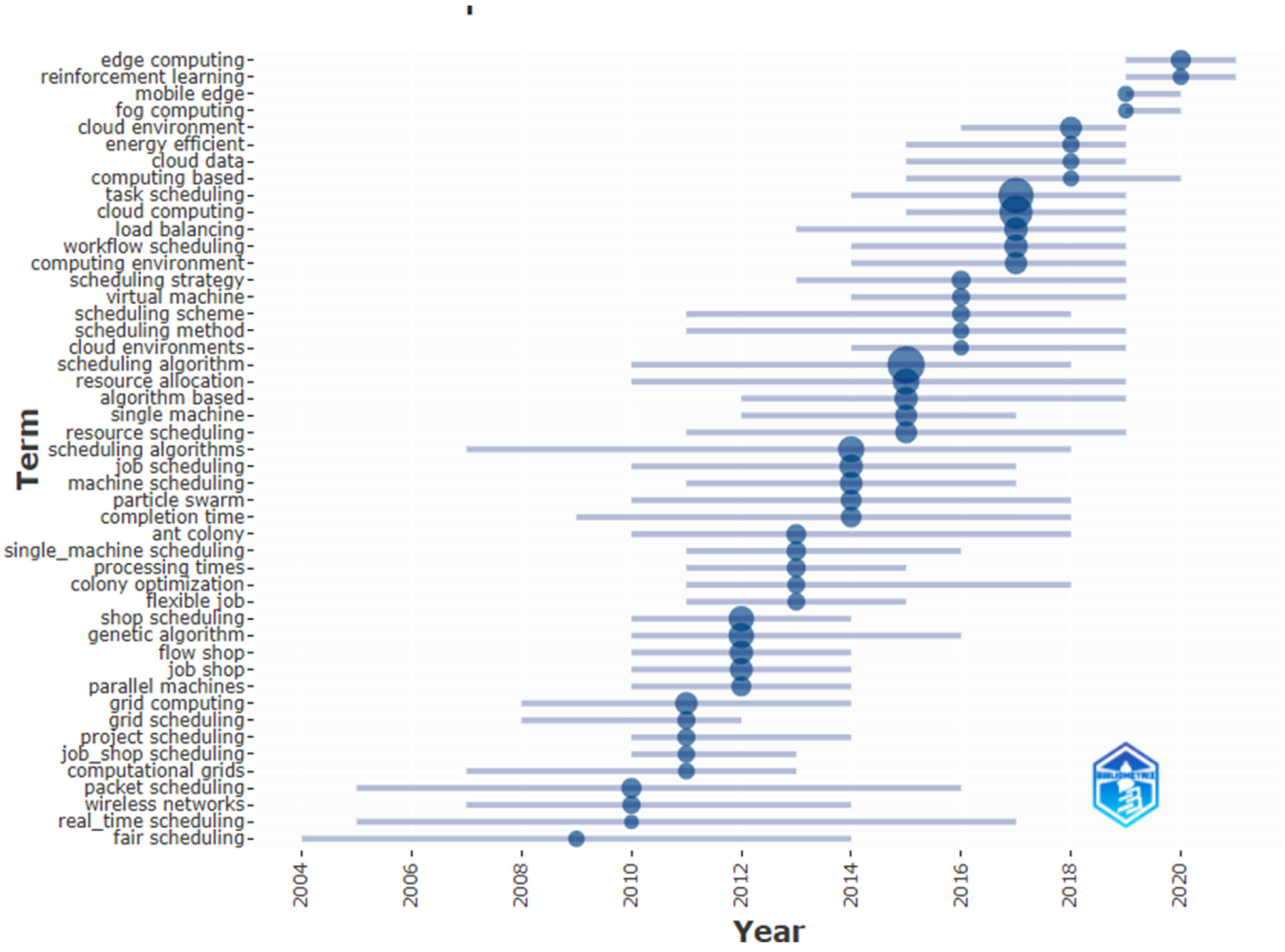

Figure 9. Trends of topics in scheduling algorithms research.

research. The cluster is intercepted by the motor theme (Q1) and Basic theme (Q2), which indicate that they are fairly developed.

The themes in the blue cluster are characterized by low density and centrality, which shows that they are underdeveloped and are fairly important in scheduling algorithm research. The themes are likely to move towards Q3 over time. This means they are likely to keep declining.

The trend analysis in Figure 9 also shows that the themes are not recurring in recent times. The size of the cluster also indicates that there are a few themes in this category. Scheduling is connected to other concepts such as optimization, genetic algorithms, heuristic algorithms, computational complexity, and heuristic methods in Q4. The cluster is characterized by high density and low centrality. Hence, they are well

Figure 10. Most relevant keywords in scheduling algorithms research. The size of a keyword is determined by its frequency of occurrence in the entire dataset.

developed. These concepts are less used and possibly understudied in scheduling algorithms.

3.4. What is the country's scientific production like? How established is the collaboration network of authors, institutions, and countries in scheduling algorithms research?

Table 7 revealed that China is the leading country in scheduling algorithms research, with 14,055 appearances on documents within the analyzed datasets and a total of 44,248 citations. Authors from the United States of America appeared 4,851 times, with a total citation count of 25,807 and an average article citation of 28.71. It is also interesting that three continents (with indigenous human populations), Africa, Oceania, and South America, are not represented in the top 10 countries leading research in scheduling algorithms.

The network diagrams in Figures 6, 7, and 11 were generated based on an unsupervised community detection clustering algorithm called the Louvain algorithm (Blondel et al., 2008). Other parameters set include number of nodes = 50, minimum number of edges = 2, normalization = association, remove isolated nodes = yes, layout = Auto. These parameters could be passed to the network function in bibliometrix through R or biblioshiny interface. In this study, they were passed through the biblioshiny web interface. The authors' collaboration network analysis is presented in the network graph in Figure 6. The network graph comprises nodes that represent the authors and edges that indicate connections (links) between the authors. The edges show that the connected authors have published at least two documents together. The size of the nodes indicates the number of documents published by the author in collaboration, and the thickness of the edges indicates the frequency of collaboration; a thicker edge means more collaborations between the connected authors (nodes). Figure 6 revealed that Zomaya A. Y. from the University of Sydney and Lee Y. C. from Macquarie University, both from Australia, have well-established collaborations. A well-established collaboration can also be seen between Wu C.-C from Feng Chia University, Taiwan, and Yin Y. from Kunming University, China, as indicated by a thicker edge connecting the authors. Wang L. from Tsingua University, China, and Wang J.-B from Shenyang Aerospace University, China, are the biggest facilitators of collaborations in the green and red cluster of nodes with a betweenness centrality of 193.16 and 193.63, respectively. The authors' collaboration is quite sparse, and Table 2 reported a collaboration index of 1.46, which is quite low. The geographical proximity of authors largely facilitates collaborations.

Figure 7 also shows that institutional collaborations are established by the geographical proximity of institutions. Connections are largely between institutions within the same country. All the institutions clustered in green colour are based in Iran, institutions dominate the ones in purple from Australia, the pink clusters are institutions in China, and the red cluster is also dominated by institutions in China save for the collaborations established with the National University of Singapore. Shenyang Aerospace University and the Dalian University of Technology both in China have well-established collaborations. Some of the most relevant institutions in this field in terms of the number of articles published are Tsinghua University, China, Beijing University of Posts and Telecommunications, China, Islamic Azad University, Iran, National

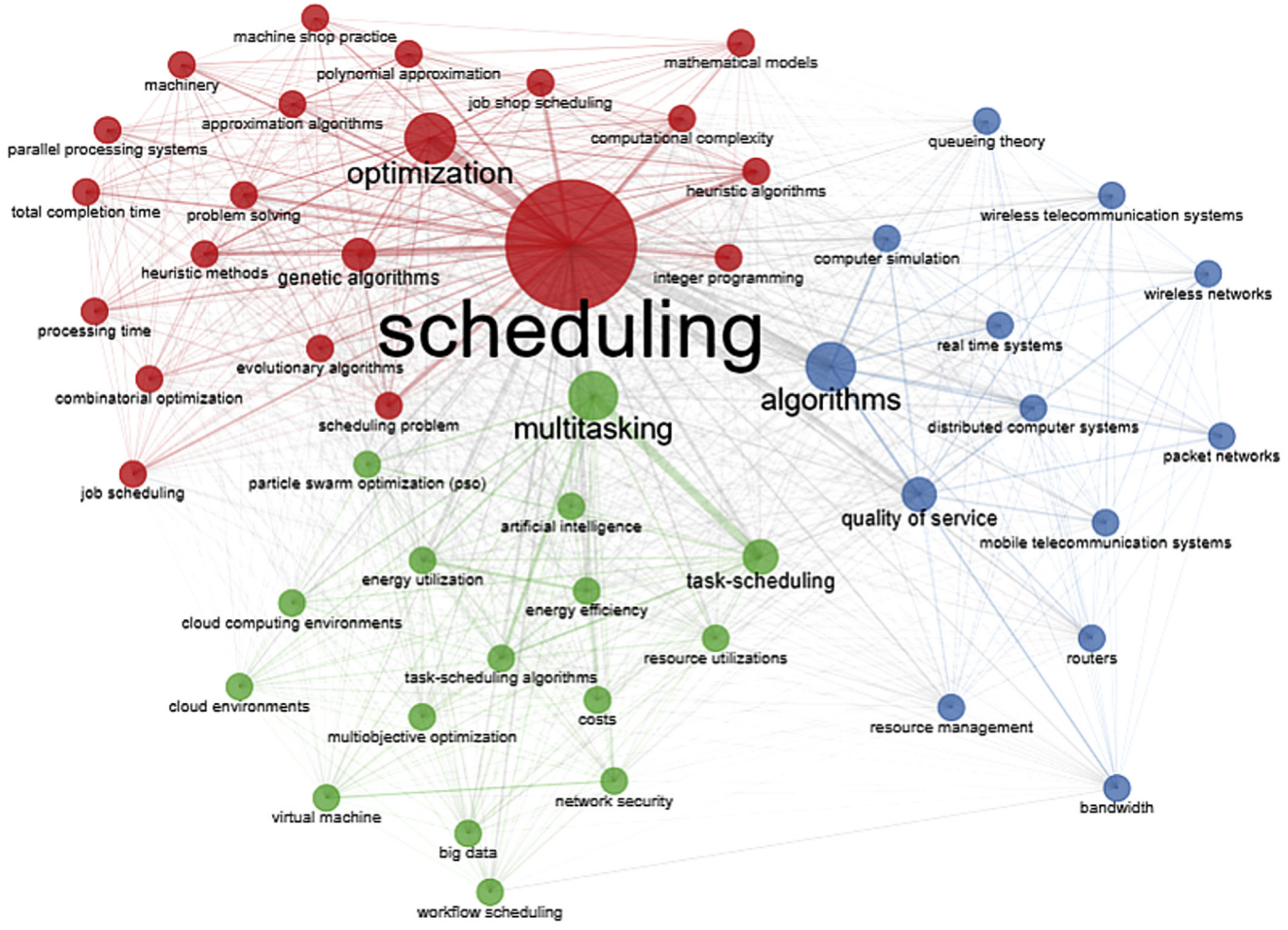

Figure 11. Keywords co-occurrence network in scheduling algorithms research. The edges connecting the keywords (nodes) depict an established relationship between the connected nodes. A thicker edge indicates a high frequency of co-occurrence of the connected keywords in multiple documents.

University of Defense Technology, China, Hunan University, China with a total of 362, 360, 242, 223 and 221 articles published respectively.

In Figure 8, countries' collaboration maps are shown. Only countries with at least five documents are shown on the map. It can be observed that there exists a well-established collaboration between China and the United States of America, as indicated by the thick line connecting the two countries. Australia also has a well-established collaboration with China. The collaboration between Egypt and Saudi Arabia, Australia and Jordan, India and China, Japan and Poland, India and Australia, and the United States of America and Brazil are not expressive, as indicated by the thin lines connecting the countries.

3.5. What are the trends in topics, top keywords, and co-occurrence network of keywords in scheduling algorithms research?

Keywords analysis helps to understand the trends in topics and concepts that are gaining attention in a research field. The results of the keyword analysis are shown in Figures 9 and 10. The trend topic analysis was carried out on the keywords in the titles of articles only. Minimum frequency = 50, No. of words per year = 5, Word Stemming = No; the Bigram frequency measure was used to count how often a pair of keywords co-occur. Figure 9 revealed the trends in topics for each year between 2004 and 2021. The years before 2004 did not have pairs of words with a frequency greater than or equal to 50, so they were not captured in the result. Packet scheduling, fair scheduling, and real-time scheduling were the trending topics between 2004 and 2007, with packet scheduling most discussed. The pair of words with the highest frequency (indicated by the biggest bubble in 2015) in all publication titles are Scheduling Algorithm, with a frequency of 1,560. Figure 9 also revealed that Edge Computing is the most discussed and trend topic concerning scheduling algorithms research in 2020 and 2021. Researchers, especially the young ones interested in scheduling algorithms research, can start looking at edge computing to identify new problems in this area that are gaining the attention of other researchers that could be addressed from the scheduling algorithms perspective. The result also showed that studies on Scheduling Algorithms research covered diverse research areas such as Cloud data, Reinforcement Learning, Ant Colony Optimization, Virtual Machines, Edge Computing, Mobile Edge, and so on. It can be observed (See Figure 9) that there has been a continuous increase in the number of keywords over the years, and it peaked around the year 2017. This implies that there has been a rapid knowledge expansion in this field.

The word cloud shown in Figure 10 further revealed the most frequently used and most relevant keywords in scheduling algorithms research. The size of a keyword is determined by its frequency of occurrence in the entire dataset. The word cloud was generated from Author Keywords (DE), publication titles, and abstracts. This collection is referred to as Keyword Plus (ID) in the Biblioshiny interface. Other parameters are Word occurrence = Frequency, Shape = Circle, Ellipticity = 0.65, Padding = 1, Font size = 1, Font type = Impact. The top three most relevant keywords in scheduling algorithms research are scheduling (Freq = 6,795), resource allocation (Freq = 2,136), and cloud computing (2,135), the reason why these keywords are bigger than others in the word cloud. Other relevant keywords in the scheduling algorithms research include makespan, optimization, algorithms, multitasking, and quality of service.

Keywords Co-occurrence Network (KCN) is essential for gaining new insight into a field based on the patterns and links of co-occurring keywords in analyzed literature (Radhakrishnan et al., 2017). The keywords co-occurrence network was generated based on the Louvain clustering algorithm. The Keyword Plus, which comprises keywords in Titles, Abstract, and Author keywords, were clustered. Other parameters are as stated in Figures 6 and 7. Figure 11 shows the KCN in scheduling algorithms research. The KCN is composed of nodes (Keywords) and edges (links). The edges connecting the nodes (keywords) depict an established relationship between the connected nodes. A thicker edge indicates a stronger association or closer relationship or high frequency of co-occurrence between the connected nodes. The thickness means more shared documents between the connected keywords, that is, the number of times the connected keywords co-occur in multiple documents. The thick edge connection between “scheduling” and “optimization” shows that the two keywords co-occur in more documents compared to other connected pairs of keywords. The importance of a keyword (node) within a network is shown by the number of links (edges) to that keyword. “scheduling” is an essential keyword with the highest betweenness centrality of 101.94. This means that the keyword forms the bridge between major research themes in this field (Painter et al., 2019).

The clusters are characterized by the areas of research in which these keywords are frequently co-occurring. The keywords in the blue cluster are closer to research areas such as packet scheduling and Long-Term Evolution, the green cluster cloud computing, green computing, fog computing, virtual machines, and big data, while the keywords in the red cluster often appear in CPU scheduling, parallel and distributed systems research.

4. Conclusion

This study conducted an exploratory bibliometric analysis of publications in Scheduling Algorithms research. The study results revealed that Scheduling algorithms related to research have an annual scientific production growth rate of 16.62%. The keyword "scheduling" is the most important keyword in scheduling algorithms research, with the highest betweenness centrality of 101.94. It forms the bridge between major research themes in Scheduling Algorithms related research. Edge Computing is the most discussed and trend topic concerning scheduling algorithms research in 2020 and 2021. Institutional collaborations have not been well-established in this field.

The limitation of this study is that the dataset used is from a single source; Scopus. This is because the biblioshiny interface does not have the facility to merge BibTeX files from different sources. Analysis of a combination of data from different sources such as Web of Science, Google Scholar, and Scopus may give better insight into the field. However, studies (Bar-Ilan, 2018; Martín-Martín et al., 2018, 2021) have shown that Scopus and Web of Science have most documents in common, that is, a large intersect of documents. According to Vieira and Gomes (2009), 2/3 of Scopus documents are available on the Web of Science. Ninety-three per cent of the documents found on the Web of Science are also in the Scopus database (Martín-Martín et al., 2021).

Future work may merge documents from different databases and filter out the duplicates. Although this study did not include preprints and articles in the press in its search string, such work may give a more accurate picture of the interests in this field. Also, it would be interesting to see the percentage of preprints in this field compared to refereed works. Future work could include preprints and articles in the press for these insights.

The findings of this study can help both budding and established researchers to find new research focus, relevant sources, and collaboration opportunities and make informed decisions as they research scheduling algorithms and their applications.

Declarations

Author contribution statement

Temidayo Oluwatosin Omotehinwa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

The data that support the findings of this study are openly available in figshare at https://doi.org/10.6084/m9.figshare.19494359.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

I appreciate the efforts of Agbo, Friday Joseph and Dr. Emmanuel Mogaji at the Centre for Multidisciplinary Research and Innovation (CEMRI) for their assistance during the data collection period and proofreading. Also, the immense contributions of the section editor and reviewers to improve the quality of the manuscript are highly appreciated. I am very grateful to the publisher for granting a full waiver of the article processing charge.

References

Agrawal, P., Gupta, A.K., Mathur, P., 2021. CPU scheduling in operating system: a review. Lect. Notes Netw. Syst. 166, 279–289.
Aksnes, D.W., Langfeldt, L., Wouters, P., 2019. Citations, citation indicators, and research quality: an overview of basic concepts and theories. Sage Open 9 (1).
Almansour, N., Allah, N.M., 2019, May 15. A survey of scheduling algorithms in cloud computing. In: 2019 International Conference on Computer and Information Sciences, ICCIS 2019.
An, Y.J., Kim, Y.D., Jeong, B.J., Kim, S.D., 2012. Scheduling healthcare services in a home healthcare system. J. Oper. Res. Soc. 63 (11), 1589–1599.
Aria, M., Cuccurullo, C., 2017. bibliometrix: an R-tool for comprehensive science mapping analysis. J. Informetr. 11 (4), 959–975.
Arora, N., Banyal, R.K., 2022. Hybrid scheduling algorithms in cloud computing: a review. Int. J. Electr. Comput. Eng. 12 (1), 880–895.
Arunarani, A.R., Manjula, D., Sugumaran, V., 2019. Task scheduling techniques in cloud computing: a literature survey. Future Generat. Comput. Syst. 91, 407–415.
Bar-Ilan, J., 2018. Tale of three databases: the implication of coverage demonstrated for a sample query. Front. Res. Metr. Anal. 3 (6), 1–9.
Beloglazov, A., Abawajy, J., Buyya, R., 2012. Energy-aware resource allocation heuristics for efficient management of data centres for Cloud computing. Future Generat. Comput. Syst. 28 (5), 755–768.
Bini, E., Buttazzo, G.C., 2005. Measuring the performance of schedulability tests. R. Time Syst. 30 (1), 129–154.
Blondel, V.D., Guillaume, J.L., Lambiotte, R., Lefebvre, E., 2008. Fast unfolding of communities in large networks. J. Stat. Mech. Theor. Exp. 2008 (10), P10008.
Burdett, R.L., Kozan, E., 2018. An integrated approach for scheduling health care activities in a hospital. Eur. J. Oper. Res. 264 (2), 756–773.
Buyya, R., Murshed, M., 2002. GridSim: a toolkit for the modelling and simulation of distributed resource management and scheduling for Grid computing. Concurrency Comput. Pract. Ex. 14 (13–15), 1175–1220.
Buyya, R., Ranjan, R., Calheiros, R.N., 2009. Modeling and simulation of scalable cloud computing environments and the cloudsim toolkit: challenges and opportunities. In: Proceedings of the 2009 International Conference on High-Performance Computing and Simulation, HPCS 2009, pp. 1–11.
Chandiramani, K., Verma, R., Sivagami, M., 2019. A modified priority preemptive algorithm for CPU scheduling. Procedia Comput. Sci. 165, 363–369.
Chen, H., Zhu, X., Liu, G., Pedrycz, W., 2021. Uncertainty-Aware online scheduling for real-time workflows in cloud service environment. IEEE Transact. Serv. Comput. 14 (4), 1167–1178.
Cheng, X., Lyu, F., Quan, W., Zhou, C., He, H., Shi, W., Shen, X., 2019. Space/aerial-assisted computing offloading for IoT applications: a learning-based approach. IEEE J. Sel. Area. Commun. 37 (5), 1117–1129.
Choudhari, T., Moh, M., Moh, T.S., 2018. Prioritized task scheduling in fog computing. In: Proceedings of the ACMSE 2018 Conference, 2018-January, pp. 1–8.
Cobo, M.J., Lopez-Herrera, A.G., Herrera-Viedma, E., Herrera, F., 2011. An approach for detecting, quantifying, and visualizing the evolution of a research field. J. Infometr. 5 (1), 146–166.
Dao, S.D., Abhary, K., Marian, R., 2017. A bibliometric analysis of Genetic Algorithms throughout the history. Comput. Ind. Eng. 110, 395–403.
Das, N.K.C., George, M.S., Jaya, P., 2017. Incorporating weighted round-robin in honeybee algorithm for enhanced load balancing in cloud environment. In: Proceedings of the 2017 IEEE International Conference on Communication and Signal Processing, ICCSP 2017, pp. 384–389.
Davis, R.I., Burns, A., 2011. A survey of hard real-time scheduling for multiprocessor systems. ACM Comput. Surv. 43 (4).
Dervis, H., 2019. Bibliometric analysis using bibliometrix an R package. J. Sci. Res. 8 (3), 156–160.
Dhinesh Babu, L.D., Venkata Krishna, P., 2013. Honey bee behavior inspired load balancing of tasks in cloud computing environments. Appl. Soft Comput. 13 (5), 2292–2303.
Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., Lim, W.M., 2021. How to conduct a bibliometric analysis: an overview and guidelines. J. Bus. Res. 133, 285–296.
Ellegaard, O., Wallin, J.A., 2015. The bibliometric analysis of scholarly production: how great is the impact? Scientometrics 105 (3), 1809–1831.
Gatti, R., Shivashankar, 2021. Improved resource allocation scheme for optimizing the performance of cell-edge users in LTE-A system. J. Ambient Intell. Hum. Comput. 12 (1), 811–819.
Ghafari, R., Kabutarkhani, F.H., Mansouri, N., 2022. Task scheduling algorithms for energy optimization in cloud environment: a comprehensive review. Cluster Comput. 25 (2), 1035–1093.
Ghosh, S., Banerjee, C., 2018. Dynamic time quantum priority based round robin for load balancing in cloud environment. In: Proceedings - 2018 4th IEEE International Conference on Research in Computational Intelligence and Communication Networks, ICRCICN 2018, pp. 33–37.
Goudarzi, M., Wu, H., Palaniswami, M., Buyya, R., 2021. An application placement technique for concurrent IoT applications in edge and fog computing environments. IEEE Trans. Mobile Comput. 20 (4), 1298–1311.
Grivel, L., Mutschke, P., Polanco, X., 1995. Thematic mapping on bibliographic databases by cluster analysis: a description of the SDOC environment with SOLIS. Knowl. Organ. 22 (2), 70–77.
Kumar, M., Mittal, M.L., Soni, G., Joshi, D., 2018. A hybrid TLBO-TS algorithm for integrated selection and scheduling of projects. Comput. Ind. Eng. 119, 121–130.
Kumar, M., Sharma, S.C., Goel, A., Singh, S.P., 2019. A comprehensive survey for scheduling techniques in cloud computing. In: Journal of Network and Computer Applications, 143. Academic Press, pp. 1–33.
Kwok, Y.K., Ahmad, I., 1999. Static scheduling algorithms for allocating directed task graphs to multiprocessors. ACM Comput. Surv. 31 (4), 406–471.
Leung, J.Y.T., 2004. Handbook of scheduling: algorithms, models, and performance analysis. In: Handbook of Scheduling: Algorithms, Models, and Performance Analysis. CRC Press.
Liu, J., Mao, Y., Zhang, J., Letaief, K.B., 2016. Delay-optimal computation task scheduling for mobile-edge computing systems. In: IEEE International Symposium on Information Theory - Proceedings, 2016-August, pp. 1451–1455.
Liu, S., Wang, Z., Wei, G., Li, M., 2020. Distributed set-membership filtering for multirate systems under the round-robin scheduling over sensor networks. IEEE Trans. Cybern. 50 (5), 1910–1920.
Lv, Z., Chen, D., Lou, R., Wang, Q., 2021. Intelligent edge computing based on machine learning for smart city. Future Generat. Comput. Syst. 115, 90–99.
Mahajan, S, 2021. When to postpone approximating: The Rule of 69.3ish. American Journal of Physics 89 (2), 131–133.
Maipan-uku, J., Rabiu, I., Mishra, A., 2017. Immediate/batch mode scheduling algorithms for grid computing: a review. Int. J. Regul. Govern. 5 (7), 1–13.
Martín-Martín, A., Orduna-Malea, E., Delgado López-Cózar, E., 2018. Coverage of highly-cited documents in Google Scholar, web of science, and Scopus: a multidisciplinary comparison. Scientometrics 116 (3), 2175–2188.
Martín-Martín, A., Thelwall, M., Orduna-Malea, E., Delgado López-Cózar, E., 2021. Google scholar, Microsoft academic, Scopus, dimensions, web of science, and OpenCitations' COCI: a multidisciplinary comparison of coverage via citations. Scientometrics 126 (1), 871–906.
McKeown, N., 1999. The iSLIP scheduling algorithm for input-queued switches. IEEE/ACM Trans. Netw. 7 (2), 188–201.
Moral-Muñoz, J.A., Herrera-Viedma, E., Santisteban-Espejo, A., Cobo, M.J., 2020. Software tools for conducting bibliometric analysis in science: an up-to-date review. Profesional de La Informacion 29 (1), 1699–2407.
Nazar, T., Javaid, N., Waheed, M., Fatima, A., Bano, H., Ahmed, N., 2019. Modified shortest Job first for load balancing in cloud-fog computing. In: Lecture Notes on Data Engineering and Communications Technologies, 25. Springer, Cham, pp. 63–76.
Olofintuyi, S.S., Omotehinwa, T.O., Owotogbe, J.S., 2020. A survey of variants of round robin CPU scheduling algorithms. FUDMA J. Sci. 4 (4), 526–546.
Omotehinwa, T.O., Azeez, S.I., Olofintuyi, S.S., 2019a. A simplified improved dynamic round robin (SIDRR) CPU scheduling algorithm. Int. J. Informat. Proc. Commun. 7 (2), 122–140.
Omotehinwa, T.O., Igbaoreto, A., Oyekanmi, E., 2019b. An improved round robin CPU scheduling algorithm for asymmetrically distributed burst times. Afr. J. MIS 1 (4), 50–68. https://afrjmis.net.
Painter, D.T., Daniels, B.C., Jost, J., 2019. Network analysis for the digital humanities: principles, problems, extensions. Isis 110 (3), 538–554.
Prajapati, H.B., Shah, V.A., 2014. Scheduling in grid computing environment. In: International Conference on Advanced Computing and Communication Technologies, ACCT, pp. 315–324.
Radhakrishnan, S., Erbis, S., Isaacs, J.A., Kamarthi, S., 2017. Novel keyword co-occurrence network-based methods to foster systematic reviews of scientific literature. PLoS One 12 (3), e0172778.

Rahimi, I., Gandomi, A.H., Deb, K., Chen, F., Nikoo, M.R., 2022. Scheduling by NSGA-II: review and bibliometric analysis. Processes 10 (1), 1–31.
Sana, M.U., Li, Z., 2021. Efficiency aware scheduling techniques in cloud computing: a descriptive literature review. PeerJ Comp. Sci. 7, 1–37.
Scopus, 2020. About. Elsevier Scopus Blog, 2020. https://blog.scopus.com//about.
Sharma, D.K., Kwatra, K., Manwani, M., Arora, N., Goel, A., 2021a. Optimized resource allocation technique using self-balancing fast MinMin algorithm. Lecture Notes Data Eng. Commun. Technol. 54, 473–487.
Sharma, R., Nitin, N., AlShehri, M.A.R., Dahiya, D., 2021b. Priority-based joint EDF–RM scheduling algorithm for individual real-time task on distributed systems. J. Supercomput. 77 (1), 890–908.
Shishido, H.Y., Estrella, J.C., 2018. Bibliometric analysis of workflow scheduling in grids and clouds. In: Proceedings - International Conference of the Chilean Computer Science Society, SCCC, 2017-October, pp. 1–9.
Sivertsen, G., Rousseau, R., Zhang, L., 2019. Measuring scientific contributions with modified fractional counting. J. Informetr. 13 (2), 679–694.
Sundararaj, V., 2019. Optimal task assignment in mobile cloud computing by queue based ant-bee algorithm. Wireless Pers. Commun. 104 (1), 173–197.
Tychalas, D., Karatza, H., 2020. A scheduling algorithm for a fog computing system with bag-of-tasks jobs: simulation and performance evaluation. Simulat. Model. Pract. Theor. 98, 101982.
Verbeek, A., Debackere, K., Luwel, M., Zimmermann, E., 2002. Measuring progress and evolution in science and technology - I: the multiple uses of bibliometric indicators. Int. J. Manag. Rev. 4 (2), 179–211.
Vieira, E, Gomes, J, 2009. A comparison of Scopus and Web of Science for a typical university. Scientometrics 81 (2), 587–600.
Yan, P., Cai, X., Ni, D., Chu, F., He, H., 2021. Two-stage matching-and-scheduling algorithm for real-time private parking-sharing programs. Comput. Oper. Res. 125, 105083.
Yang, H.H., Liu, Z., Quek, T.Q.S., Poor, H.V., 2020a. Scheduling policies for federated learning in wireless networks. IEEE Trans. Commun. 68 (1), 317–333.
Yang, L., Yao, H., Wang, J., Jiang, C., Benslimane, A., Liu, Y., 2020b. Multi-UAV-enabled load-balance mobile-edge computing for IoT networks. IEEE Internet Things J. 7 (8), 6898–6908.
Yoo, T., Goldsmith, A., 2006. On the optimality of multiantenna broadcast scheduling using zero-forcing beamforming. IEEE J. Sel. Area. Commun. 24 (3), 528–541.
Yousif, A., Nor, S.M., Abdualla, A.H., Bashir, M.B., 2015. Job scheduling algorithms on grid computing: state-of- the art. Int. J. Grid Distrib. Comput. 8 (6), 125–140.
Yu, J., Yang, Z., Zhu, S., Xu, B., Li, S., Zhang, M., 2018. A bibliometric analysis of cloud computing technology research. In: Proceedings of 2018 IEEE 3rd Advanced Information Technology, Electronic and Automation Control Conference, IAEAC 2018, pp. 2353–2358.
Yu, J., Yin, C., 2021. The relationship between the corresponding author and its byline position: an investigation based on the academic big data. J. Phys. Conf. 1883 (1), 012129.
Yuan, H., Bi, J., Zhou, M., Liu, Q., Ammari, A.C., 2021. Biobjective task scheduling for distributed green data centers. IEEE Trans. Autom. Sci. Eng. 18 (2), 731–742.
Zupic, I., Čater, T., 2015. Bibliometric methods in management and organization. Organ. Res. Methods 18 (3), 429–472.