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Abstract. Wireless Sensor Network is a network of wireless sensor nodes that are capable of sensing information from their surroundings and transmit the sensed information to data collection point known as a base station. Applications of wireless sensor networks are large in number and forest fire detection, landslide monitoring, etc. are few applications to note. The research challenges in wireless sensor networks is the transmission of data from the sensor node to the base station in an energy-efficient manner and network life prolongation. Cluster-based routing techniques are extensively adopted to address this research challenge. Researchers have used different metaheuristic and soft computing techniques for designing such energy-efficient routing techniques. In the literature, a lot of survey article on cluster-based routing methods are available, but there is no bibliometric analysis conducted so far. Hence in this research article, bibliometric study with the focus on the firefly algorithm and its applications in wireless sensor network is undertaken. The purpose of this article is to explore the nature of research conducted

concerning to authors, the connection between keywords, the importance of journals and scope for further research in soft computing based clustered routing methods. A detailed bibliometric analysis is carried out by collecting the details of published articles from the Scopus database. In this article, the collected data is articulated in terms of yearly document statistics, key affiliations of authors, contributing geographical locations, subject area statistics, author-keyword mapping, and many more essential aspects of bibliometric analysis. The conducted study helped in understanding that there is a vast scope for the research community to perform research work concerning firefly algorithm applications in the field of wireless sensor networks.

Keywords: Bibliometric Analysis · Cluster Head · Wireless Sensor Network · Routing Protocol · Energy Efficiency.

1 Introduction

Wireless Sensor Network (WSN) is one of the famous and vast research topics that has attracted a lot of researchers in the field of computer engineering, electronics, telecommunications and mechanical engineering. WSN is a network of wireless sensor nodes where the role of sensor nodes is to sense the physical parameters (examples like temperature, pollution contents in air, water quality parameters such as pH, etc.). The purpose of the sensors and their capability largely depends upon the application type of WSN. Irrespective of the WSN applications, the general operating principle is that there can be several wireless sensor nodes spread across a sensing region. These sensors will sense some physical parameters and transmit sensed information to data collection point know as Base Station (BS). Based on the data collected at BS, meaningful insights can be obtained, or necessary action can be taken to address the needs at sensing region. Since nodes operate wirelessly, a battery needs to be attached on each node for data reception and transmission among the deployed sensors. In critical applications of WSN such as remote health monitoring, volcanic eruption moni-

toring, landslide monitoring, etc. if the battery of sensor nodes dies, it is assumed that associated node is also dead and replacement of the battery is not an option. Hence, most of the research work carried out so far revolves around energy efficiency and network life prolongation. Energy efficiency is vital for all applications of WSNs, and it can be achieved with prudent WSN design techniques at different layers such as physical layer, data link layer, network layer, transport layer [47]. In particular, study related to cluster-based energy-efficient routing methods have been extensively conducted among the WSN research community, and some of the notable survey articles are [19, 28].

Typically, in a cluster-based routing scheme, nodes are categorised as cluster head (CH) nodes and normal nodes (NN). The job of CH is to form a cluster with few NN and collect the data from NN for further transmitting it to BS. Such many CHs are to be elected for data gathering and transmission. As the CHs consume larger energy, the role of CH is shifted to other NNs and hence after some time or based on some conditions, new CHs are to be elected. In the field of computer science, it is proved that CH election for WSNs as NP-Hard problem. Hence a lot of research work is done keeping this as a research problem. Several notable survey articles are also published on the mentioned research problem [1, 23, 43]. Specifically related to energy conservation and network life prolongation, there are lot many routing protocols [1, 14, 19, 23, 32, 37, 43, 49]. Few of the most cited routing methods are LEACH [17], TEEN [25], LEACH-centralized (LEACH-C) [16], PEGASIS [22] and HEED [45]. Also over the period, researchers focused their work on utilising soft computing based techniques such as Firefly Algorithm (FA), Particle Swarm Optimization (PSO), Fuzzy logic, Artificial Bee Colony Optimization (ABC), Genetic Algorithm (GA), etc. for designing energy-efficient routing techniques. [13,14,33,35,49] are some of the published survey articles that are based on the above mentioned soft computing and optimisation techniques.

With the study and brief overview of WSNs and the importance of soft computing techniques in cluster-based routing techniques, it is apparent that WSN

is extensively studied and a lot of survey articles are available. But none of these survey article highlight bibliometric analysis of WSNs and routing protocols. Hence, this article is all about fulfilling such a need for bibliometric research for the domain of WSNs. In this article, bibliometric review of a specific type of nature-inspired optimisation technique, namely the Firefly Algorithm and its applications in the field of WSNs is explored. The reason for writing this article is to understand the correlation of different research work carried out so far in the usage of FA for WSNs contribution of authors, scope and growth of the topic, co-author analysis, network visualisations, etc.

The rest of the article is arranged as follows. Section 2 describes the preliminary data and keyword string used in the Scopus database search engine. Bibliometric information is described in section 3. Network diagrams are created and explained in section 4. Section 5 is about research implications observed in this article. Finally, the article is concluded in section 6.

2 Preliminary Data

This research is carried by querying to Scopus database. The query is made up of components shown in table 1. The references used for formulation of section 2 and 3 are listed at the end of this paper [2–12, 15, 18, 20, 21, 24, 26, 27, 29–31, 34, 36, 38–40, 42, 44, 46, 48].

Table 1. Keywords used for querying to Scopus DB (Source: Scopus DB accessed on 6th November 2020)

Primary Keywords	Wireless Sensor Network
Supporting Keywords	Firefly AND Cluster Head AND Energy Efficiency OR WSN

Using the query string mentioned in table 1, 34 documents are obtained from Scopus DB. All the articles collected from the query string are composed using the English language, as mentioned in table 2.

Table 2. Publication language details (Source: Scopus DB accessed on 6th November 2020)

Publication Language	Count
English	34

3 Bibliometric Information

Bibliometric information presented in this section is articulated using the following details by analysing *.csv* file obtained through Scopus DB. The said information is as follows:

1. Publications by year, prominent authors, source statistics, subject area-specific contribution, document type details, documents by source – yearly details, affiliation statistics and details about funding sponsors
2. Second important aspect is to showcase the information using networked diagrams based on authors, author keywords, source titles, reference scape, Sankey graph showing tri-information like main authors, main keywords and main journals, to name a few.

3.1 Preliminary Bibliometric Information

Fig. 1 shows yearly count of publications. There is a increase in the number of publications for the span from 2017 to 2020. Prior to these years, there was no such a increase observed. So, in a way the consider research area is getting boom since last 3 years.

Fig. 2 shows prominent authors involved in the considered research area. First five authors have two Scopus documents on their name. Remaining are having only one document on their account. This eventually indicated scope of the considered research area.

It is also essential to observe what are the vital source titles where these publications were published. *Journal of Advanced Research in Dynamical and Control Systems*, *International Journal of Intelligent Engineering and Systems*,

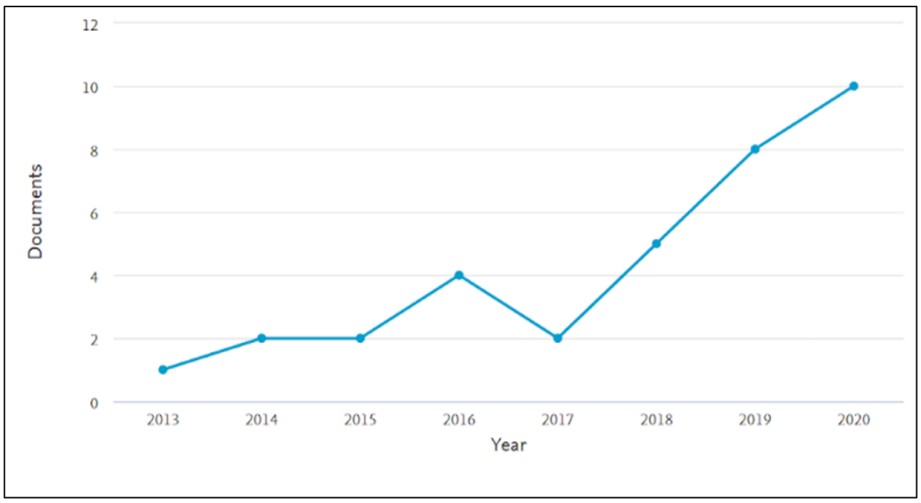

Fig. 1. Yearly publication count (Source: Scopus DB accessed on 6th November 2020)

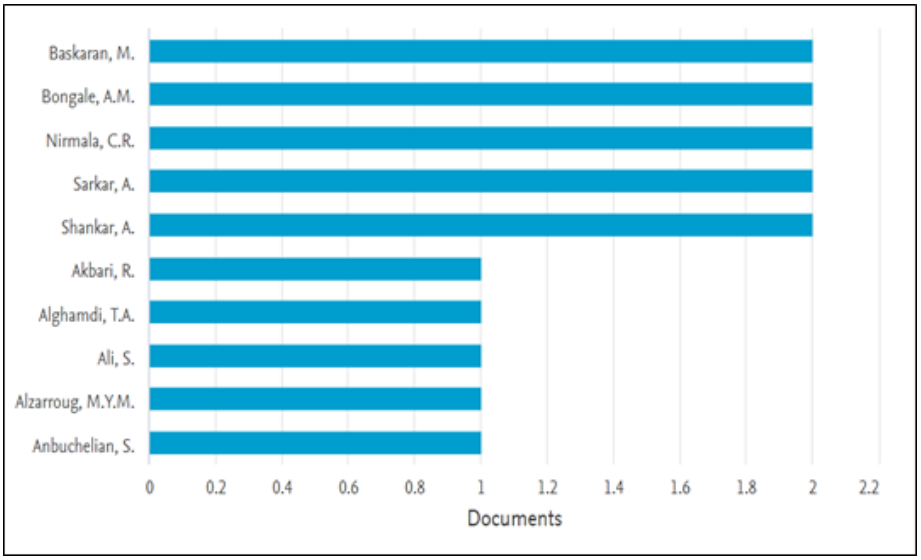

Fig. 2. Prominent authors (Source: Scopus DB accessed on 6th November 2020)

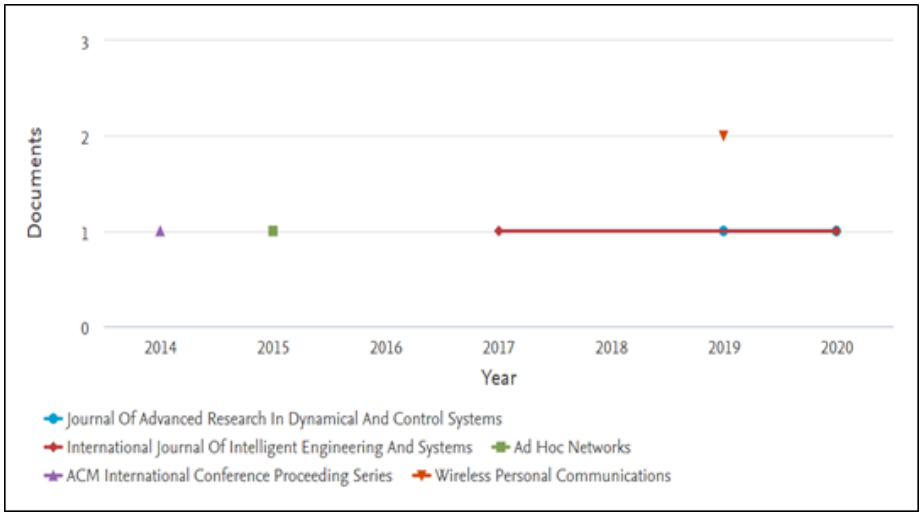

Fig. 3. Yearly document statistics (Source: Scopus DB accessed on 6th November 2020)

Adhoc Networks, *ACM International Conference proceeding series* and *Wireless Personal Communications* are the prominent source titles.

As per fig. 3 it can be observed that from the year 2017 to 2020, one paper is published every year in the *International Journal of Intelligent Engineering and Systems*. It is also indicated from the fig. 3 one article is also published in the *JARDCS* in the year 2019.

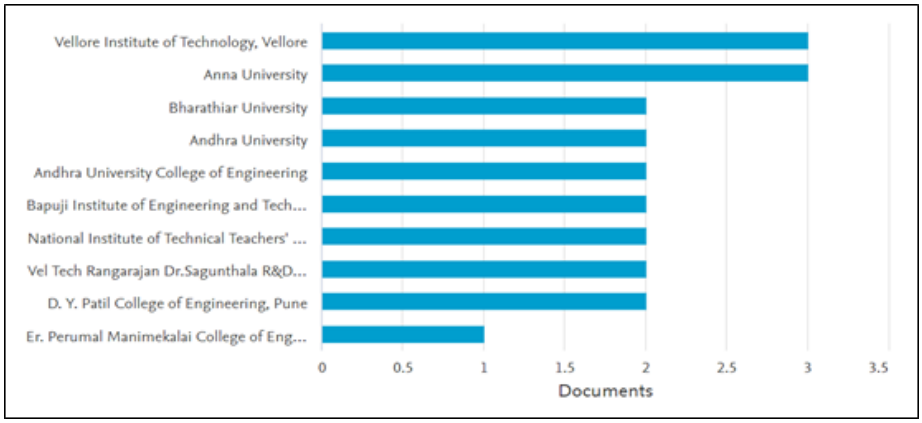

Fig. 4. Key affiliations (Source: Scopus DB accessed on 6th November 2020)

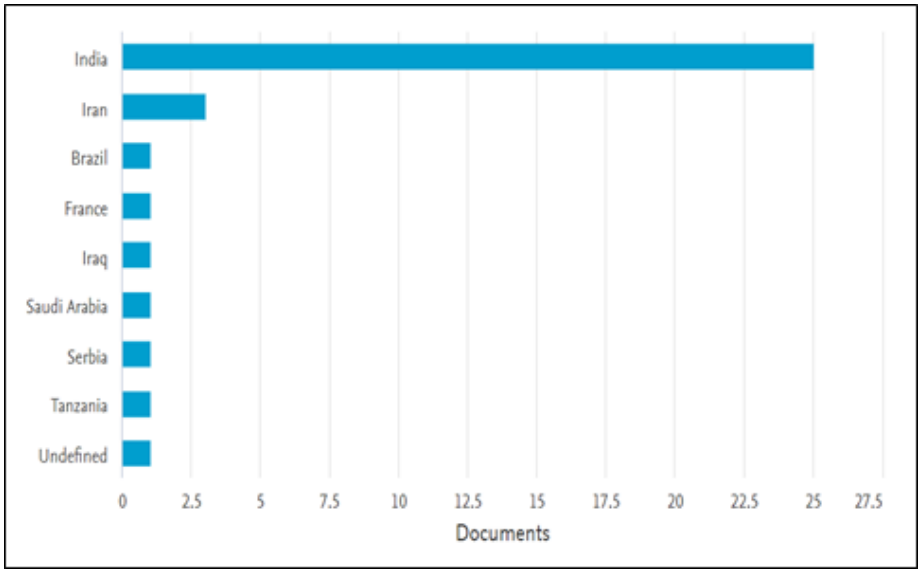

Fig. 5. Key contributing countries (Source: Scopus DB accessed on 6th November 2020)

From fig. 4 it is evident that the majority of the key affiliations are from India. *Vellore Institute of Technology, Vellore* and *Anna University* are the leading ones having three papers against their affiliations. Others have only two documents.

It is clear from fig. 5 that India is leading the said research followed by Iran then Brazil. Out of 34 publications, 25 publications are from India.

Fig. 6 shows the majority of the documents are of article type followed by conference papers. Significantly less contribution in terms of review papers. So, there is a scope of review papers.

The maximum contributing area is computer science followed by engineering as shown in fig. 7. There are other areas too like biochemistry, decision science, energy, environmental science, mathematics, material science, medicine, pharmacology etc.

From the fig. 8 it is clear that only two funding agencies sponsored the research work and they are from Australia mainly. No funding supports for research work emanated from Indian origin. The reason for this could be due to the nature of research work conducted i.e., research is mainly simulation-based.

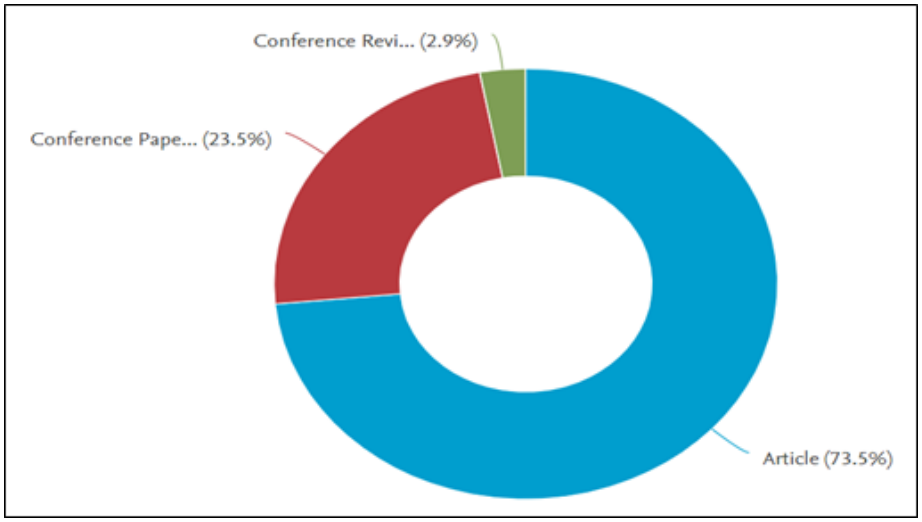

Fig. 6. Document type statistics (Source: Scopus DB accessed on 6th November 2020)

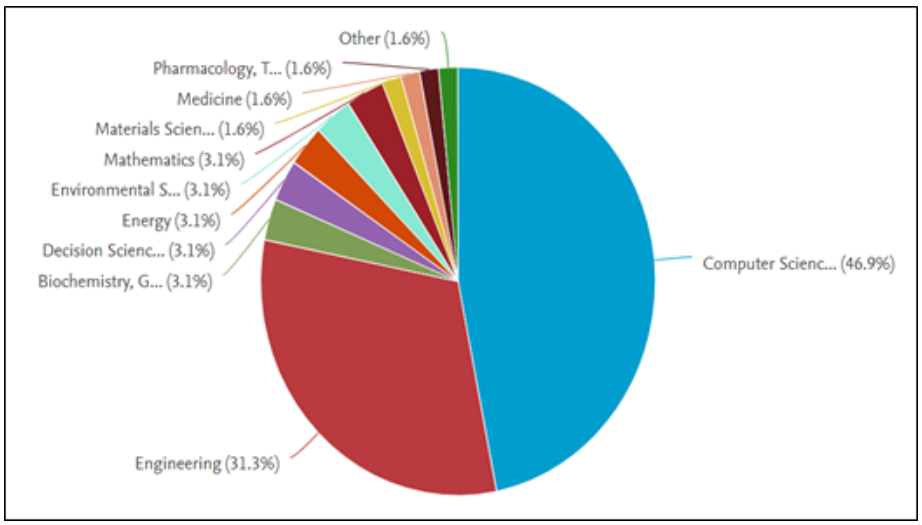

Fig. 7. Subject area statistics (Source: Scopus DB accessed on 6th November 2020)

Hence, for Indian researchers, there is a scope for extending their research work to address the societal problems and approach for financial support from funding agencies.

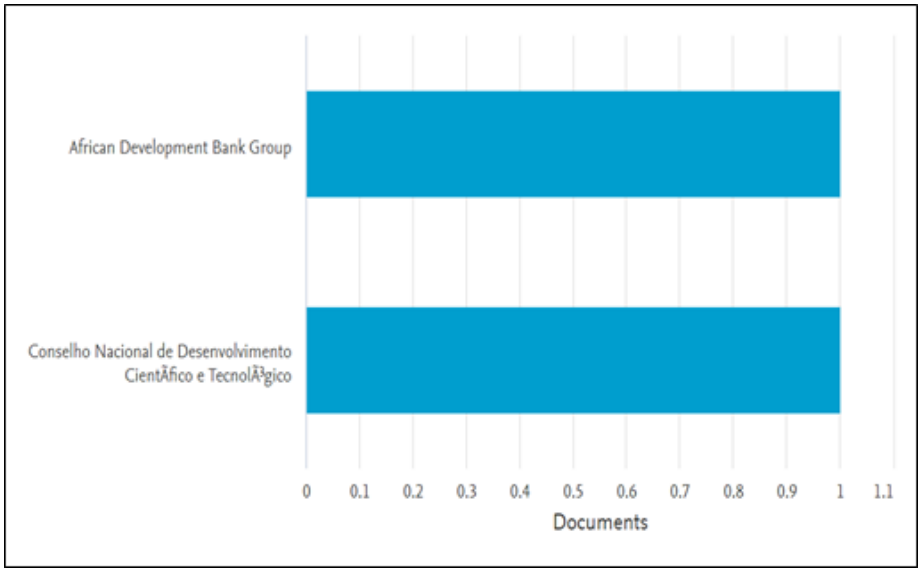

Fig. 8. Funding Sponsors (Source: Scopus DB accessed on 6th November 2020)

4 Networked Diagrams for Bibliometric Information

Fig. 9 denotes a networked diagram with emphasis on authors with their keywords, related co-appearance. Firefly algorithm, clustering, cluster head, energy efficiency are the main keywords found in the articles. *Akbari R*, *Hamid A.A.A.A.*, *Zivkovic M.*, *Bezdan T.* are the co-appearing authors for considered keywords. There is a scope for consideration of other keywords too viz. mobile sink, cluster head selection, energy consumption, chicken swarm optimisation and shuffled frog-leaping algorithm etc.

Fig. 2 and fig. 10 clearly indicate authors viz. *Bongale A. M.*, *Kumar R.*, *Sarkar A.* etc. are the key authors and *Journal of Circuits, Systems and Computers*, *International Wireless Communications and Mobile Computing, 2020* (IWCMC 2020), *International Journal of Intelligent Engineering and Systems* etc. are the prominent source titles.

Source titles, author keywords and their co-appearance in the same papers is shown in fig. 11. In addition to author keywords mentioned for fig. 9 few additional important keywords here are ad hoc networks, open shortest path

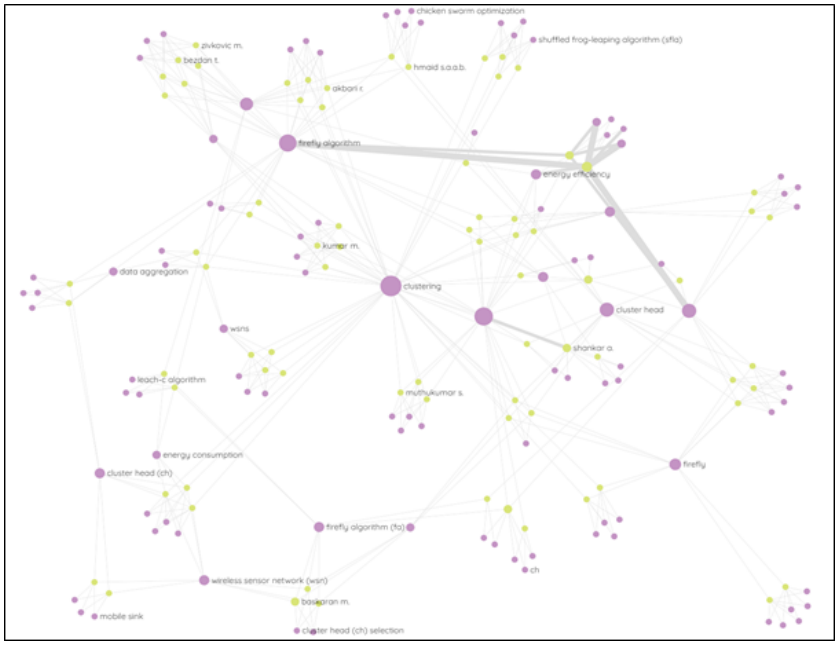

Fig. 9. Authors, author keywords and co-appearing in the same paper (Source: Scopus DB accessed on 6th November 2020)

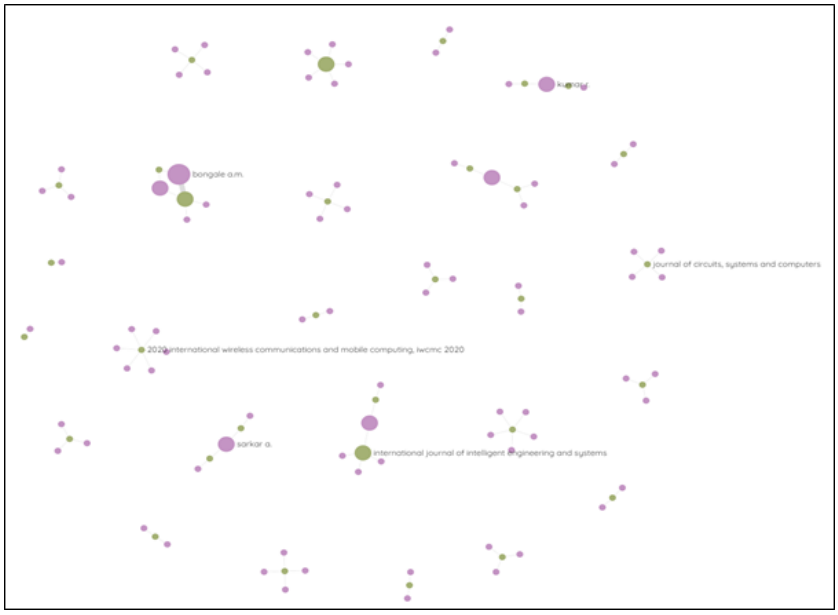

Fig. 10. Authors, source titles and co-appearing in the same paper (Source: Scopus DB accessed on 6th November 2020)

first routing protocol etc. Source titles that need to be considered are *Journal of Critical Reviews*, *International Journal of Wireless and Mobile Computing*, *International Journal of Advanced Technology and Engineering Exploration* and *International Journal of Applied Engineering Research* etc. Networked diagram in fig. 11 in a way clarifies about relationship between journal titles and keywords used by authors

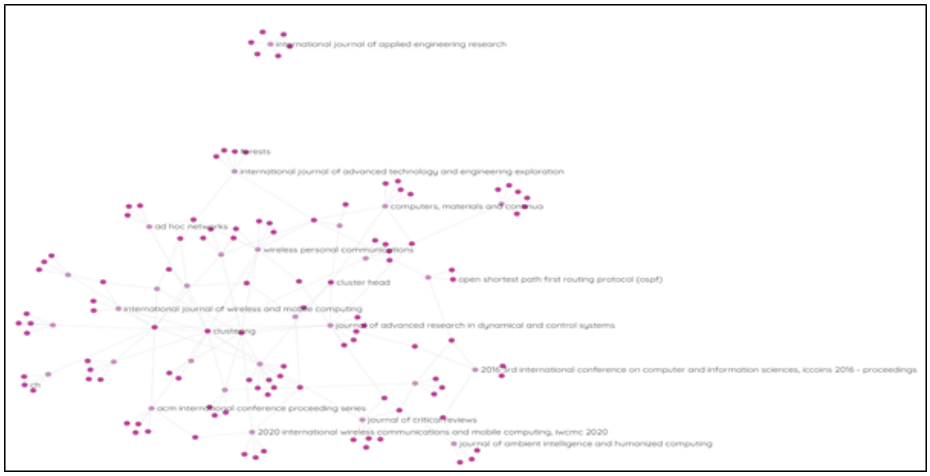

Fig. 11. Source titles, author keywords and co-appearing in the same papers (Source: Scopus DB accessed on 6th November 2020)

This is a disconnected networked diagram. 29 papers are shown in this diagram who are having DOI. Their titles are clearly visible from fig. 13.

Fig. 12 throws light on authors linked through their co-publication. Near about 20 to 22 small clusters are denoting the same. Initially, prominent authors are discussed in this paper. This networked diagram is the next level information related to authors through their collaborative publications. From this networked diagram, author names are visible who did co-publications.

Author keywords co-appearance is shown in fig. 14. Tree, forests, slot allocation, leach-c algorithm, sensor node, adaptive search and firefly with nearest neighbour chain clustering are the co-appearing keywords.

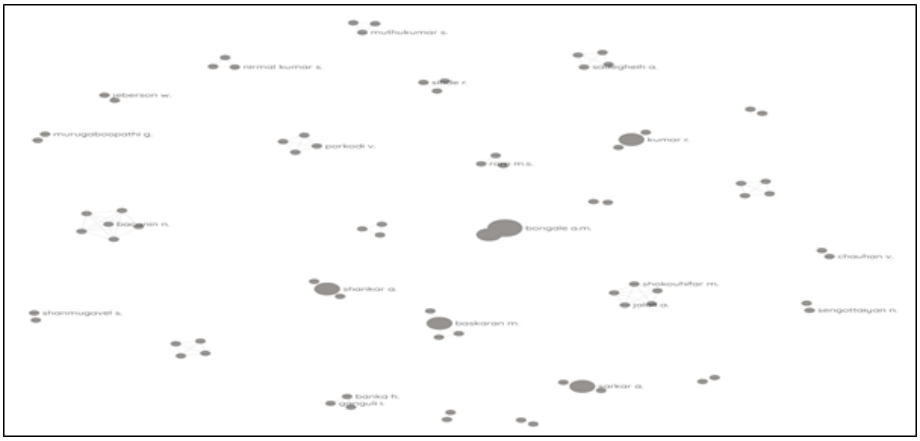

Fig. 12. Authors linked by co-publication (Source: Scopus DB accessed on 6th November 2020)

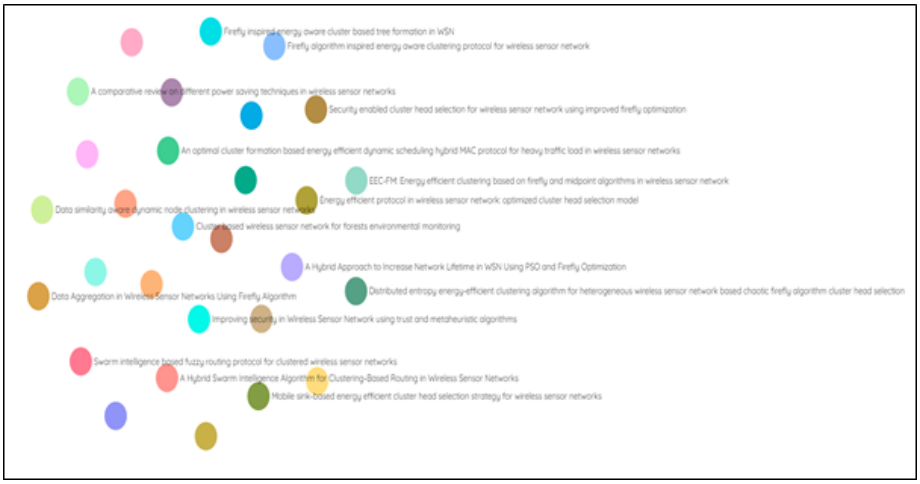

Fig. 13. Papers linked by citation when they have DOI (Source: Scopus DB accessed on 6th November 2020)

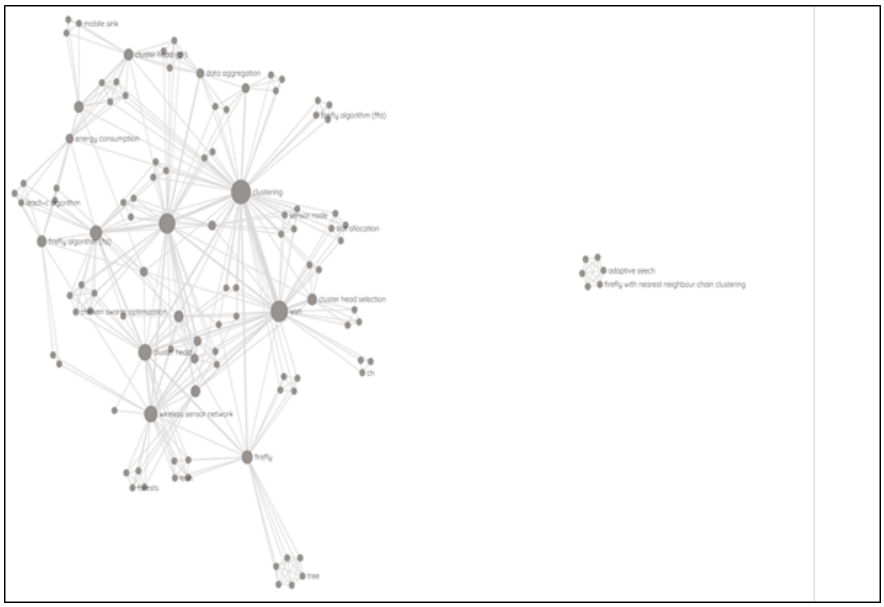

Fig. 14. Author keywords co-appearing in the same papers (Source: Scopus DB accessed on 6th November 2020)

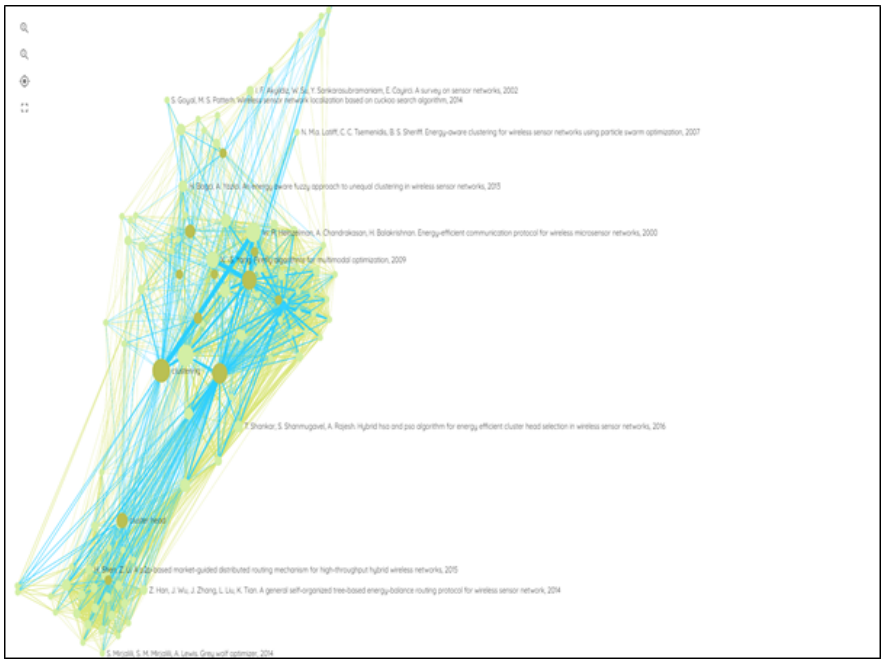

Fig. 15. Reference-scape (Source: Scopus DB accessed on 6th November 2020)

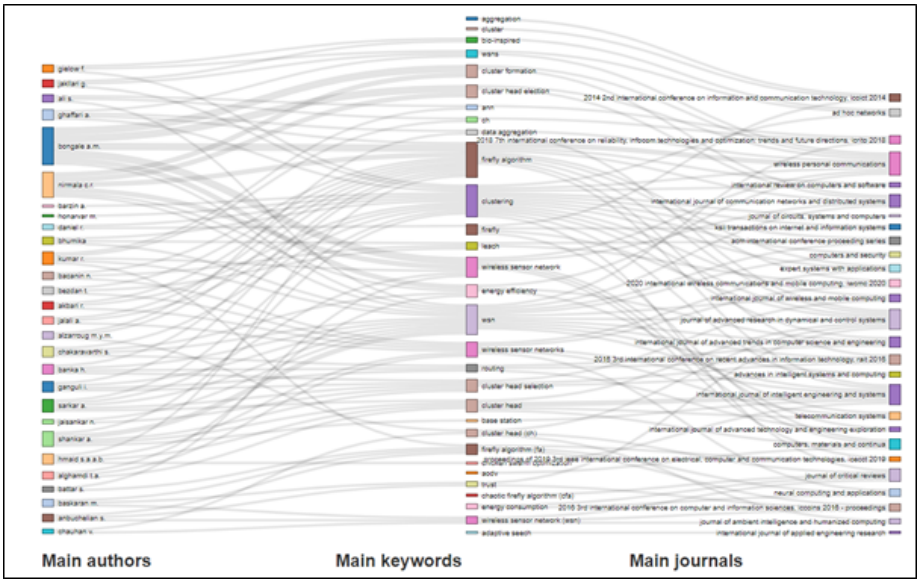

Fig. 16. Sankey Graph – Main Authors, main keywords, and main journals (Source: Scopus DB accessed on 6th November 2020)

Fig. 17. Tabular Information of Sankey Graph in Fig. 15 (Source: Scopus DB accessed on 6th November 2020)

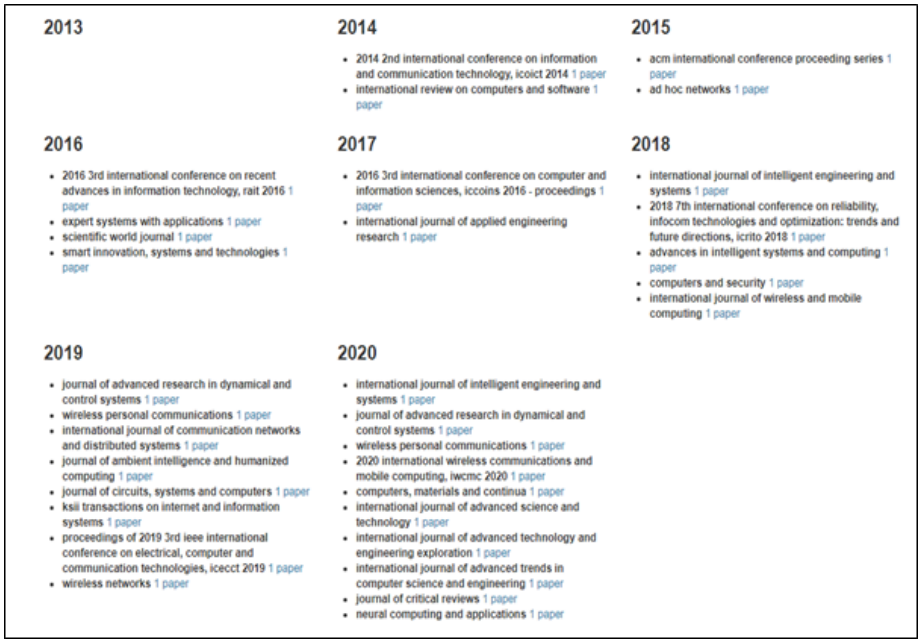

Fig. 18. Journals over the time (Source: Scopus DB accessed on 6th November 2020)

Reference-scape showed in fig. 15 highlights some of the crucial references. This figure is useful for the researchers who want to contribute in the area of firefly algorithm applications for wireless sensor networks as they can be the most valuable references for the formulating their research articles.

Fig. 16, 17 and 18 are related to each other. They show linked tri-information viz. main authors, main keywords, and main journals. These figures are in a way consolidation of preliminary data, and subsequent information discussed through networked diagrams. Fig. 16 is a Sankey graph of the main authors, main keywords, and main journals. Fig. 17 shows the same in tabular format and fig. 18 shows journals over time.

5 Research Implications

There are only 34 publications available on the considered research topic, so this is the research area which has a lot of scope for further research work.

India is a leading country, and only a few countable universities are involved in this research, so other universities in India can also pay attention towards this research area. Contribution in terms of review papers is significantly less. No funding sponsors from India. Chicken swarm optimisation, chaotic firefly algorithm, shuffled frog leaping algorithms are the emerging algorithms in this area. Contribution by key authors is only two papers, so there is a scope for new authors too. 2K7 – 2K20 are the influential years which show linear progression in the paper's count. The formulation of this first-ever bibliometric paper on this research topic will highlight information about attentive keywords, less focused keywords, co-appearance in terms of authors, author keywords and source titles which can be beneficial information for the new researchers. Reference-scape is also throwing light on essential references to paid attention.

6 Conclusion

In this article, a detailed bibliometric study on applications of firefly algorithm in wireless sensor networks is conducted. All the necessary data is collected from the Scopus database search engine. It became possible to identify the authors associated with the studied topic, keywords, and journals liked to the subject of Firefly Algorithm with respect to wireless sensor networks. Though the firefly algorithm is suitable for solving optimisation problems of various disciplines like biochemistry, material science, decision science, etc., nearly 46% of the work is related to the field of computer science. Almost 73% of published work is from journal articles. Scopus database suggested only 34 articles on the topic of firefly algorithm for wireless sensor network, which is an excellent indication for the researchers to research the studied area further.

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