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Bibliometric Analysis of Particle Swarm Optimization Techniques used to enhance Low-Energy Adaptive Clustering Hierarchy Protocol for Wireless Sensor Networks

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Abstract. Wireless Sensor Network (WSN) is a network of tiny wireless sensor nodes. The sensor nodes sense information and transmit the sensed information to a data collection point known as Base Station. WSNs have gained massive popularity due to their incredible benefits, and active research is ongoing for the past two decades. The primary concern with WSN is that the sensor operates on a limited power supply. Due to the nature of applications of WSNs and the hostile environment where the sensors are deployed, providing unlimited power or energy supply is not an option. Hence, the research work mainly focuses on energy efficiency and network life prolongation so that WSN can operate for a longer duration. Design and development of energy-efficient routing protocols is an active research field undertaken in WSNs. Low-Energy Adaptive Clustering Hierarchy Protocol (LEACH) is one of the most cited and referred cluster-based routing protocol in the field of WSN. Many research articles showcase novel methods to improve LEACH protocol's performance, and Particle Swarm Optimization (PSO), a widespread nature-inspired optimization technique, has been extensively applied to improve LEACH. This bibliometric research article aims to know the pattern of PSO techniques used in LEACH improvement and understand the

relationships among researchers, authors, published documents, sources, keywords, funding agencies, etc. This article has projected a detailed bibliometric analysis of PSO techniques for LEACH protocol by querying the Scopus Database. The data collected is articulated in subject areas, top authors and sources of documents, co-citation analysis, keyword co-occurrence analysis, etc. For conducting the bibliometric analysis, some well-known tools such as ScienceScape and VosViewer are utilized. The study revealed that there are opportunities to extend the research work in WSN and cluster-based routing methods.

Keywords: Bibliometric Analysis · Energy Efficiency · Wireless Sensor Network · Particle Swarm Optimization · Network Life.

1 Introduction

Wireless Sensor Networks (WSNs) is a network of wireless sensor nodes connected via a wireless medium of communication. The purpose of a WSN is to collect information from its surrounding environment. The sensors do the job of collecting data. The data can be of any type depending on the application. For example, the sensed information can be the ambient temperature for climate monitoring application, pH value of water in a water quality monitoring application, location of an animal in a habitat monitoring application, etc. Generally, a wireless sensor node's sole purpose is to sense the information and transmit it to a data collection center called a Base station (BS). All the sensor nodes sense information and send the sensed information to BS, and further data collected at the BS can be analyzed to understand the meaningful insights. For the activities of wireless sensor nodes, such as transmission and reception of data over a wireless communication medium, and small amount computation may also need to be performed on the sensor node itself, some energy source is required. Usually, the energy source to a sensor node can be a battery, which eventually will run out of energy. There is active ongoing research for energy efficiency and can be achieved at different layers of WSNs such as physical layer, data link layer,

network layer, transport layer [52]. Hence, the principal research challenge is WSNs is that to prolong the network lifetime of the entire network by incorporating energy-efficient data transmission and routing techniques. There are various routing techniques like proactive routing, reactive routing, hierarchical routing, and cluster-based routing, emphasizing routing techniques. Out of all the mentioned routing techniques, cluster-based routing schemes have gained tremendous popularity in achieving better energy efficiency. A good number of research articles on cluster-based routing techniques were mentioned in the survey articles [22, 35].

One of the most popular and cited cluster-based routing protocols is "Low-Energy Adaptive Clustering Hierarchy (LEACH)" [17] proposed by the authors Wendi Heinzelman et al., in the year 2000. Over the years, the LEACH protocol has become so popular and has been enhanced by several researchers. As per google scholar and Scopus database, the article [17] has got 19866 and 9053 citations, respectively (as of date 17th March 2021). There are several survey articles published purely based on enhancements of LEACH protocol [3, 4, 45]. LEACH protocol is a cluster-based routing protocol, and it operates in rounds. Each round has three crucial phases: the steady-state and cluster formation and data transmission phases. In the steady state phase, few nodes are elected as cluster heads (CHs), and other nodes join any CH as a cluster member. The sensed information from cluster members is transmitted to CHs, and in turn, the CH node will aggregate the data and send it to BS. This process saves the energy of sensor nodes as long-range data transmissions are eliminated. The issues with the LEACH protocol are that CHs with low residual energy in few rounds of operation, CHs may get elected in close proximity, CHs are may not be distributed well enough to cover the entire network, etc. To address these problems, several researchers have proposed quite novel and hybrid approaches to improve the LEACH protocol's performance.

One of the popular methods used by researchers for improving LEACH protocol is via nature-inspired optimization techniques. Ant colony optimization

(ACO) is a pretty popular technique for finding optimal wireless network routes. Particle Swarm Optimization (PSO) is another optimization technique inspired by bird movements to search for food used in CH election. In this bibliometric article, the use of the PSO technique in combination with WSNs, especially for LEACH protocol enhancement, is explored. The significance of some of the key publications that use the PSO technique and LEACH protocol from the year 2019 onwards are listed in Table 1. Bongale et al., is [5] have conducted bibliometric analysis of firefly algorithm applications in WSNs.

Table 1: Key Publications of PSO inspired LEACH protocol for WSNs

Ref. No.	**Year**	**Significant Quality**	**Methodology**
[16]	2021	Network lifetime enhancement	Optimization
[29]	2021	Cluster head selection	Hybrid Optimization
[10]	2021	Energy efficiency	Hybrid PSO
[15]	2021	WSN Link quality	Game based
[44]	2021	Cluster head selection	PSO based
[20]	2021	Routing optimization	Quantum PSO
[41]	2021	Efficient gateway placement	Optimization
[36]	2020	Network lifetime enhancement	ABC based
[34]	2020	Network lifetime enhancement	RPSO
[37]	2020	Load balancing	EC-PSO based
[30]	2020	Optimal minimum coverage	Particle Gene Swarm (PGS)
[19]	2020	Energy Management	Parallel Charged System Search (PCSS)
[27]	2020	Network lifetime enhancement	Fuzzy based
[46]	2020	Cluster head selection	Fuzzy based
[8]	2020	QoS-based clustering	Optimization
[38]	2020	Cluster head selection	Hybri PSO and Firefly

Continued on next page

Table 1 – continued from previous page

Ref. No.	Year	Significant Quality	Methodology
[53]	2020	Network lifetime enhancement	Firefly based
[54]	2020	Energy efficiency	Grey Wolf based
[50]	2020	Energy efficiency	Ensemble algorithm
[32]	2020	Network lifetime enhancement	PSO Based
[39]	2020	Data Dissemination	Harmony Search based
[40]	2020	Cluster head selection	PSO Based
[12]	2020	Comparative study	PSO Based
[28]	2020	Energy efficiency	PSO Based
[9]	2020	Cluster head selection	Bacterial foraging
[43]	2020	Network lifetime enhancement	Discrete PSO based
[25]	2020	Cluster head selection	Elephant Herding Optimization (CSEHO)
[14]	2019	Data transmission	Greedy PSO
[26]	2019	Cluster head selection	Spider monkey optimization
[48]	2019	Optimized routing	Bee Colony based
[23]	2019	Cluster head selection	ACO based
[33]	2019	Cluster head selection	PSO based
[7]	2019	Cluster head selection	PSO based
[24]	2019	Cluster head selection	ACO based
[6]	2019	Cluster head selection	Cat Swarm Optimization
[49]	2019	Cluster head selection	PSO based
[18]	2019	Cluster head selection	PSO based
[51]	2019	Energy balance routing	PSO based
[1]	2019	Network lifetime enhancement	PSO based
[47]	2019	Energy efficiency	PSO based

Continued on next page

Table 1 – continued from previous page

Ref. No.	Year	Significant Quality	Methodology
[13]	2019	Optimal positions	PSO based
[2]	2019	Energy efficiency	PSO based
[21]	2019	Cluster head selection	PSO based
[31]	2019	Cluster head selection	PSO based
[11]	2019	Cluster head selection	PSO based
[42]	2019	Fault tolerant clustering	PSO based

The rest of the paper is organized as mentioned further. Brief information of preliminary and secondary data related to a search query for the Scopus database is described in Section 2. Section 3 is about detailed bibliometric analysis of PSO-based LEACH protocol. Network diagrams explained in section 4. The research implications obtained by the bibliometric study are debated in Section 5. Finally, the article is concluded in Section 6.

2 Preliminary Data

The research work presented in this article is about understanding the importance of PSO for LEACH protocol. The bibliometric analysis is carried out using by setting up a query string in the Scopus database. The components of the query string are specified in Table 2.

Using the search query string mentioned in Table 2, a total of 159 research articles were found. The search results show that documents are located in three languages, namely English, Chinese and Turkish. Only one document was found in the Turkish language, seven documents were of the Chinese language, and the majority of 151 research articles were of the English language. The details are publication language are mentioned in Table 3.

Table 2: Components of the query string used in Scopus Database
(Source: Scopus Database accessed on 17th March 2021)

Primary Search Keywords	Wireless Sensor Network
Supporting Search Keywords	("particle swarm optimization" OR pso) AND ("wireless sensor network" OR wsn) AND (leach OR "Low-energy adaptive clustering hierarchy")

Table 3: Research article language details
(Source: Scopus Database accessed on 17th March 2021)

Publication Language	**Count**
English	151
Chinese	7
Turkish	1

3 Bibliometric Information

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

The term bibliometrics is to understand the quantitative methods of analysis of scientific journals. The bibliometric analysis includes,

1. Various parameters such as author information, publication year, journal in which articles are published, year publication, source of the articles, territory or geographic location of the authors, etc.
2. Understanding meaning insights such as the relationship with the authors and co-authors, frequency of publications, co-occurrences of keywords and articles, top researchers in the field of study, number of citations, etc.

With all the quantitative information obtained from the bibliometric analysis, it is obvious that researchers will benefit from exploring future publication trends, the scope of journals that are focused on a specific domain of interest, etc. In this section, a detailed bibliometric analysis is conducted based on the

".*csv*" file obtained from the Scopus database to understand the essence of PSO techniques in improving the LEACH protocol of WSNs.

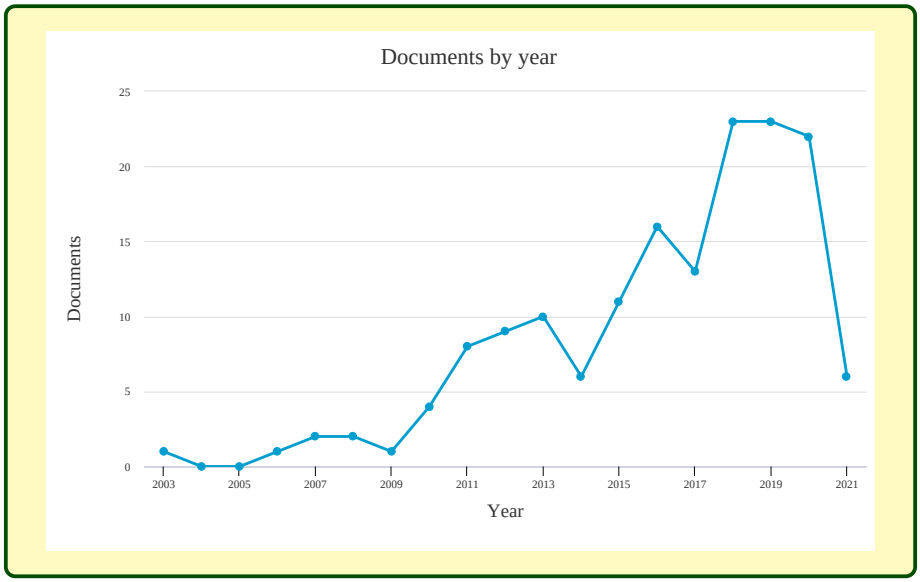

Fig. 1: Research article published per year
(Source: Scopus Database accessed on 17th March 2021)

3.1 Preliminary Data for Bibliometric Analysis

Fig. 1 shows the annual publication count of the research article. It can be observed from the figure that there is a noticeable increase in the number of research article publications from the year 2003 to 2021. A steep rise in publication count can be noticed from the year 2017 onwards. Hence there is great potential in the application of PSO techniques in the improvement of LEACH-based protocol.

Fig. 2 shows research articles published per year by source. The top journals that have published the articles of LEACH enhancements are,

1. *"Chinese Journal of Sensors and Actuators"*
2. *"Wireless Personal Communications"*

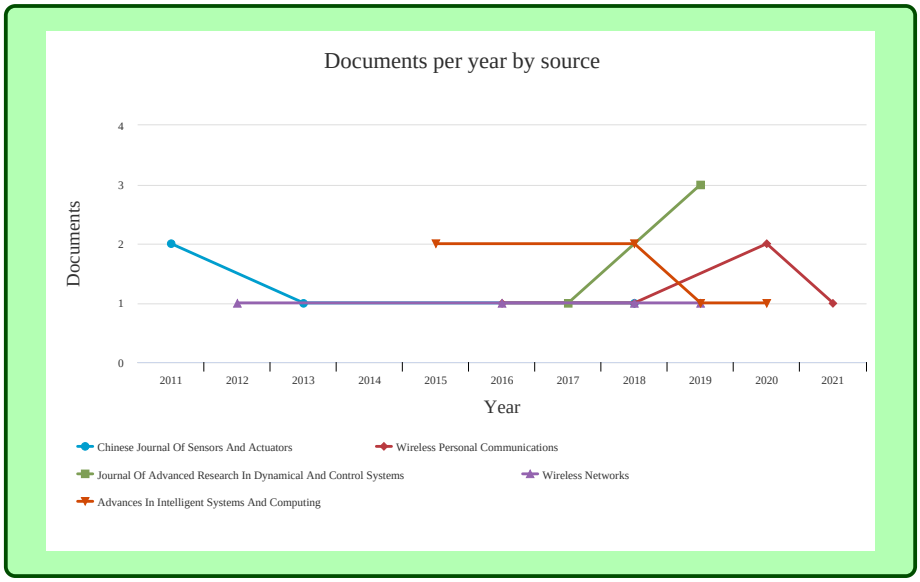

Fig. 2: Research article published per year by source
(Source: Scopus Database accessed on 17th March 2021)

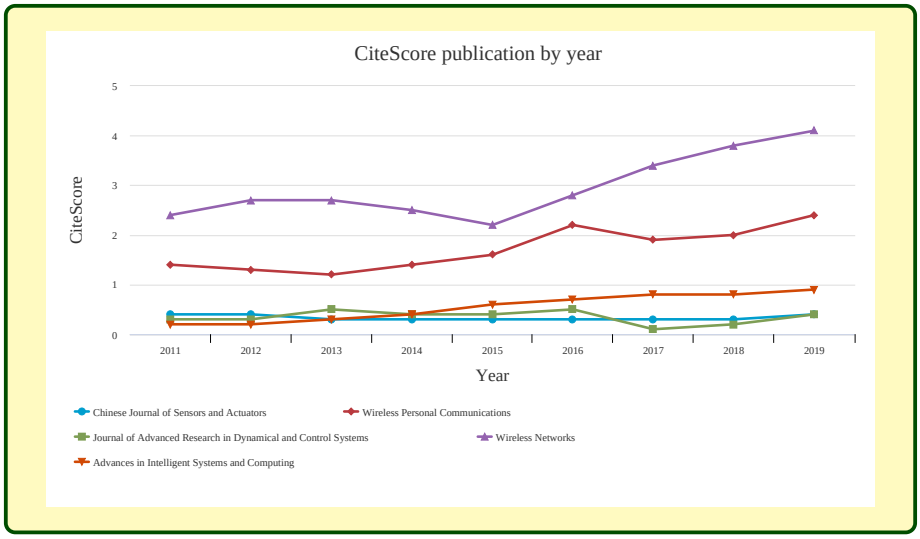

Fig. 3: CiteScore publication by Year
(Source: Scopus Database accessed on 17th March 2021)

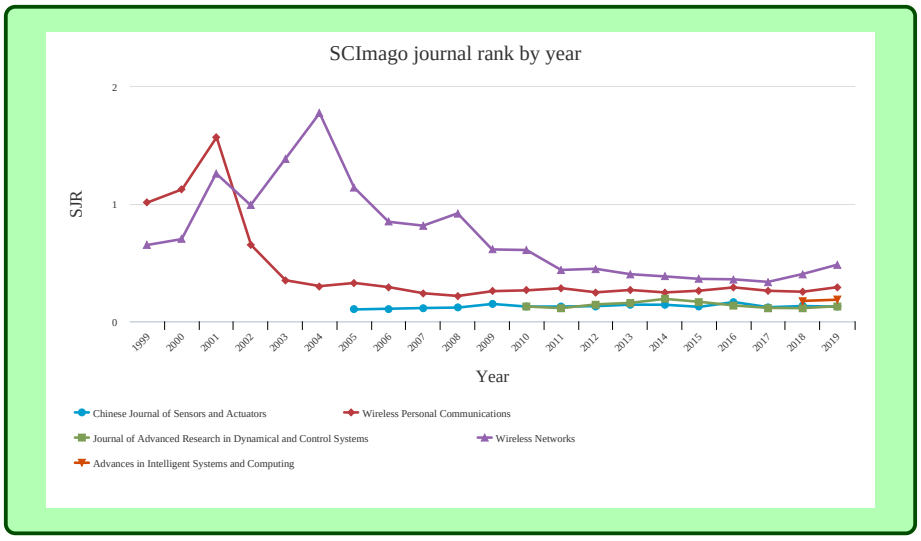

Fig. 4: SCIMago Journal Rank by Year
(Source: Scopus Database accessed on 17th March 2021)

3. *"Journal of Advanced Research in Dynamical and Control Systems"*
4. *"Wireless Networks"*
5. *"Advances in Intelligent Systems and Computing"*

CiteScore is an important parameter that emphasizes citations received by a journal in one year to documents published in the three previous years, divided by the number of documents indexed in Scopus published in those three years. Fig. 3 represents CiteScore of reputed journals.

TThe SCImago Journal Rank (SJR) is another essential indicator and measure of the journal. It represents both the number of citations belonging to the journal based on the published articles and an estimate of the prestige of a particular journal. Generally, SJR is a number. A higher value indicates that better is the journal reputation. Fig. 4 shows comparatively good value to the *"Wireless Networks"* journal.

Fig. 5 shows a plot of SNIP by year. SNIP is one of the journal quality measure metric. SNIP basically shows the impact of citations received for articles that are closely related to domain and subject coverage of the journal. Higher

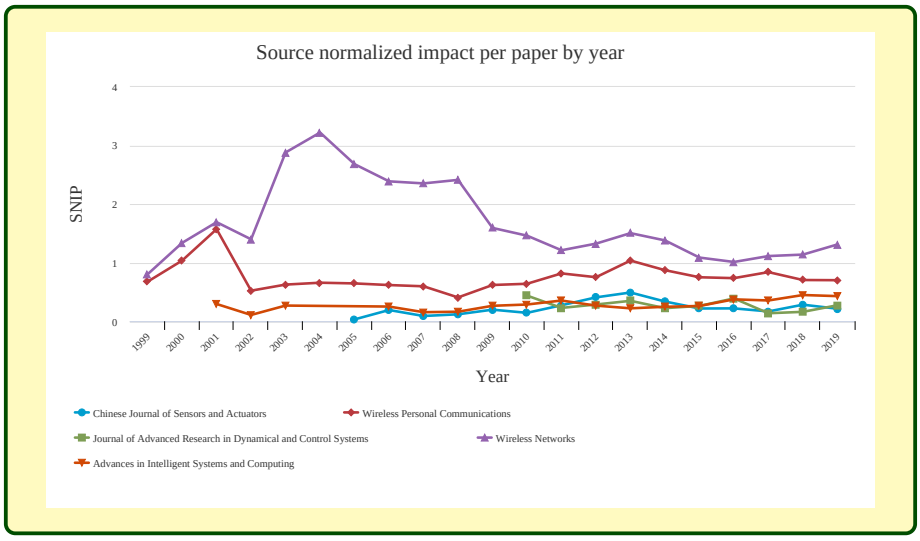

Fig. 5: Source normalized impact per research article by year
(Source: Scopus Database accessed on 17th March 2021)

value indicates that a specific journal publishes the domain specific research articles that are in closely inclined to scope of the journal. In this bibliometric study, it is observed for the Fig. 5 that *"Wireless Networks"* has relatively highest SNIP value for several years.

Fig. 6 shows Source citations of journals per year. With reference source citation metric *"Advances in Intelligent Systems and Computing"* has received a peak value of 30K in the year 2020. Fig. 7 shows the number of research articles published by the journal per year. The notable point from Fig. 7 is that *"Advances in Intelligent Systems and Computing"* has published the highest number of research documents. A steep rise in the number of publications can be noticed from 2017 on-wards. This is the obvious reason that *"Advances in Intelligent Systems and Computing"* has a more significant number of citations as well.

Few published articles may get an extraordinarily massive number of citations, but many documents go unnoticed to the research community and may not get significant citations. Fig. 8 shows the percentage of research documents per

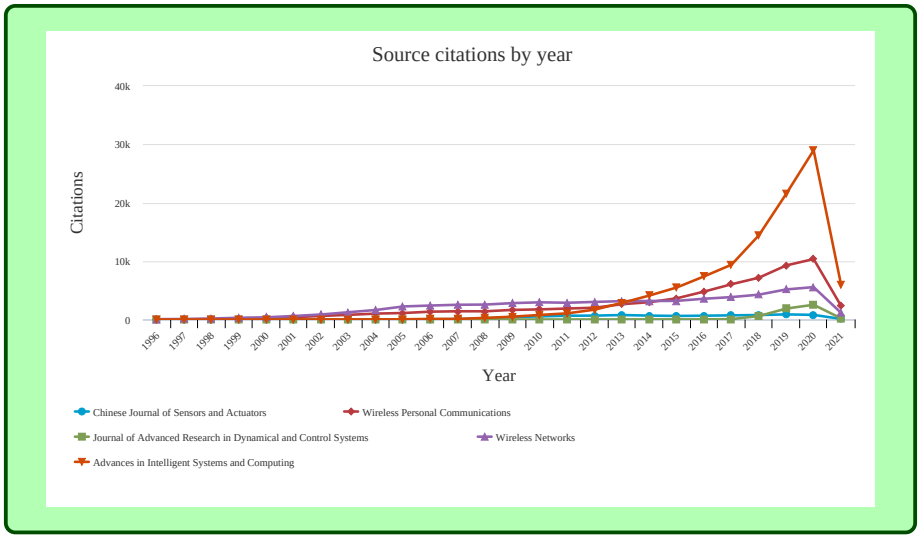

Fig. 6: Source citations of journals per year
(Source: Scopus Database accessed on 17th March 2021)

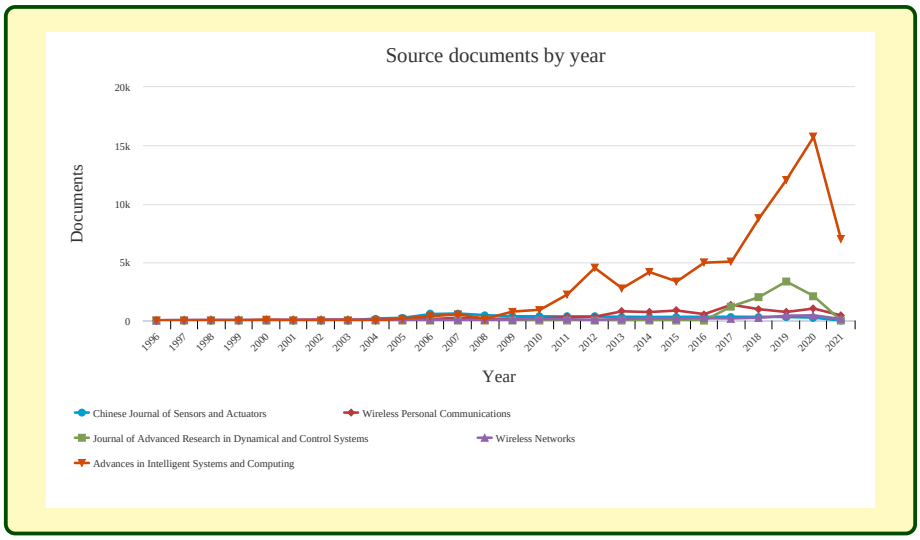

Fig. 7: Source research articles by year
(Source: Scopus Database accessed on 17th March 2021)

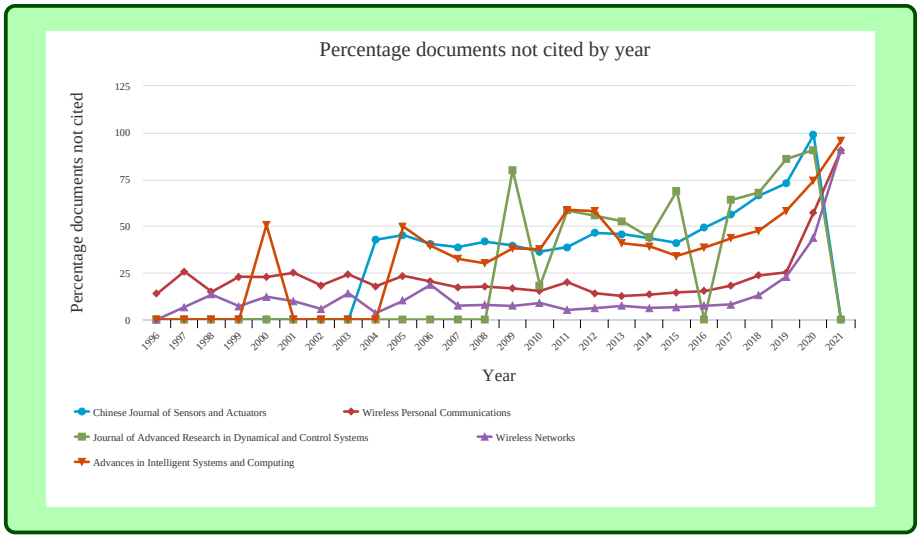

Fig. 8: Percentage of not cited research article per year
(Source: Scopus Database accessed on 17th March 2021)

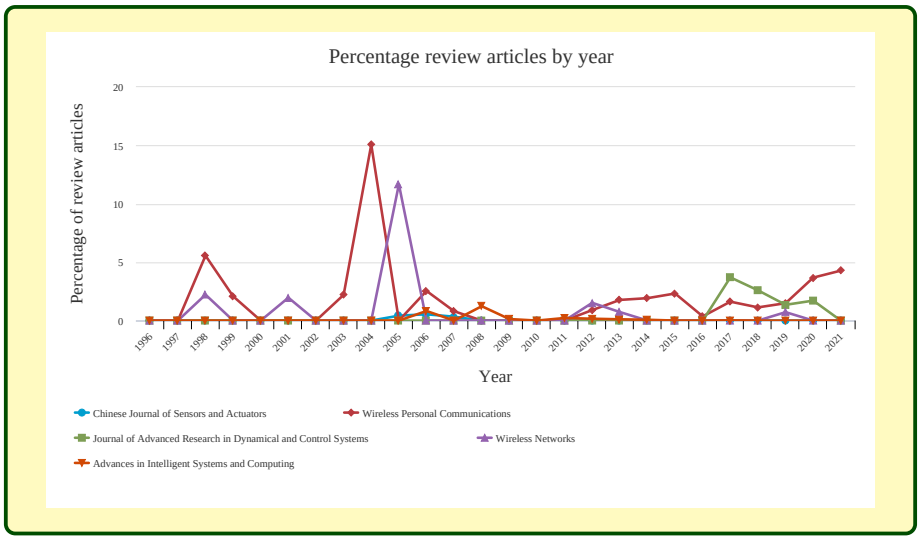

Fig. 9: Percentage of review research articles by year
(Source: Scopus Database accessed on 17th March 2021)

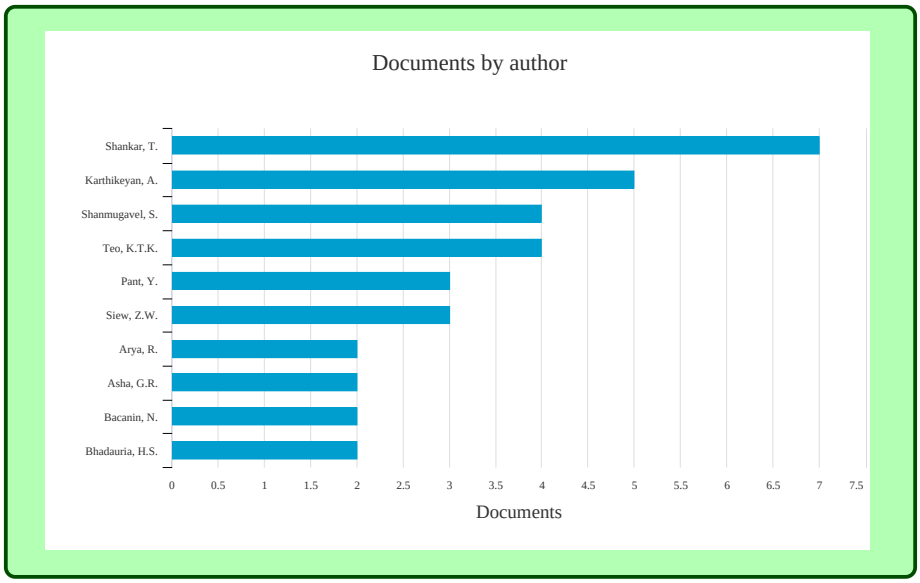

Fig. 10: Research articles published by authors
(Source: Scopus Database accessed on 17th March 2021)

source journal per year that did not receive citations. Most top journals have published articles that do not have any citations seen from the Fig. 8. Fig. 9 shows the percentage of review articles published per year in the journal source.

Fig. 10 show the top authors who are active in publishing the research articles in the chosen field of study. Nearly seven publications are from author *Shankar, T.* as understood from the Scopus database. Along with authors, role of Universities also plays a pivot role in publications. Fig. 11 shows the affiliations of college from which many research articles are published. The name of the universities is *Vellore Institute of Technology, Vellore, Anna University, Universiti Malaysia Sabah, Visvesvaraya Technological University, Zagazig University, Punjab Technical University, B.M.S. College of Engineering, Kalasalingam Academy of Research, Chandigarh University, Scientific Research Group in Egypt SRGE.* Many of these universities/institutes are of Indian origin which have significant research contributions.

Fig.12 shows the geographical spread of the research contributions country/territory wise. Based on the figure, India and China are significant contributors to research work of LEACH protocol enhancement strategies.

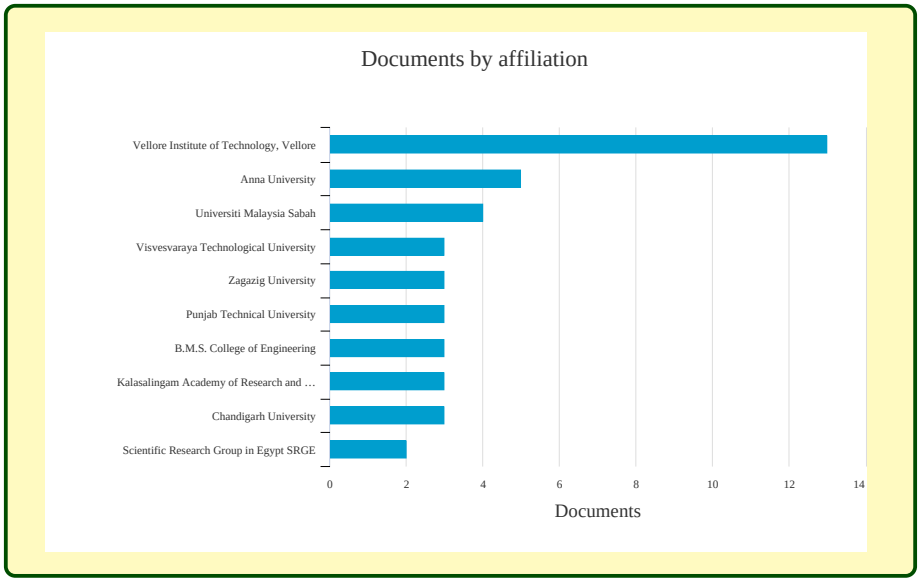

Fig. 11: Research articles published by affiliations
(Source: Scopus Database accessed on 17th March 2021)

Fig. 13 shows the percentage category of documents and Table 4 number of documents belonging to different categories. It can be observed that from the Fig. 13 and Table 4 that 56.3 % of documents are of article types i.e., 90 documents are of article type out of 159 documents.

Fig. 14 shows the percentage documents according to the subject area and Table 5 shows number of documents under particular subject area. It can be observed that from the Fig. 14 and Table 5 that 40.2 % and 30.2 % of documents are published under the computer science area and engineering field, respectively. i.e., 122 documents computer science area and 95 documents are under the engineering area.

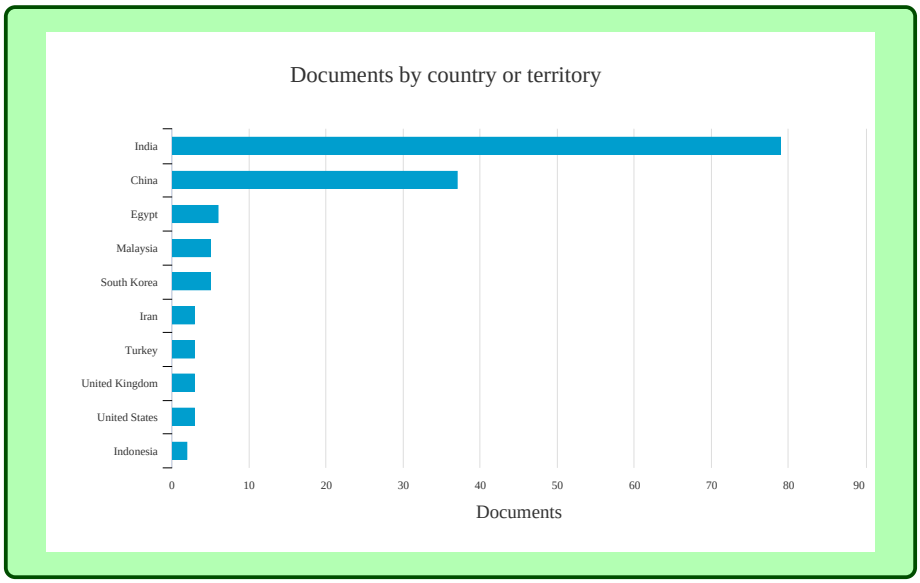

Fig. 12: Research articles published by country
(Source: Scopus Database accessed on 17th March 2021)

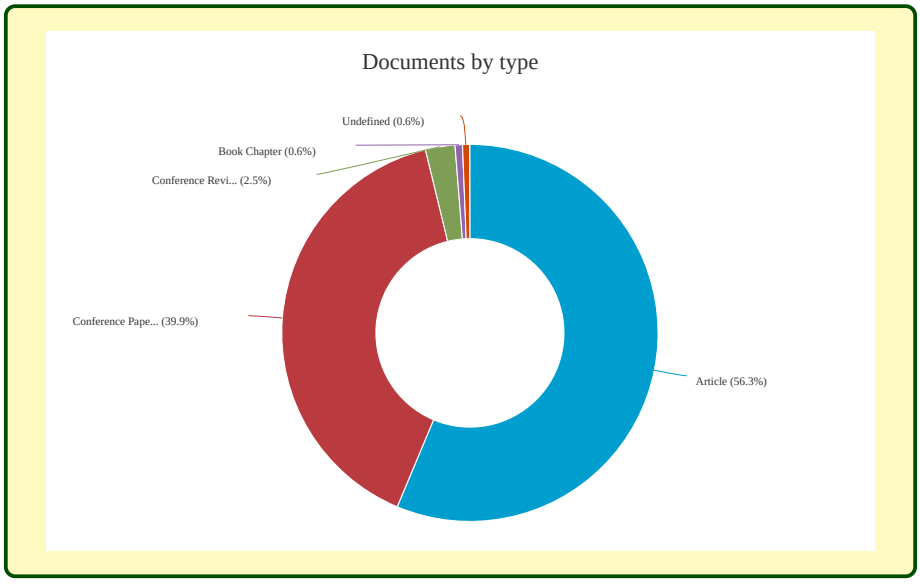

Fig. 13: Different categories of research articles
(Source: Scopus Database accessed on 17th March 2021)

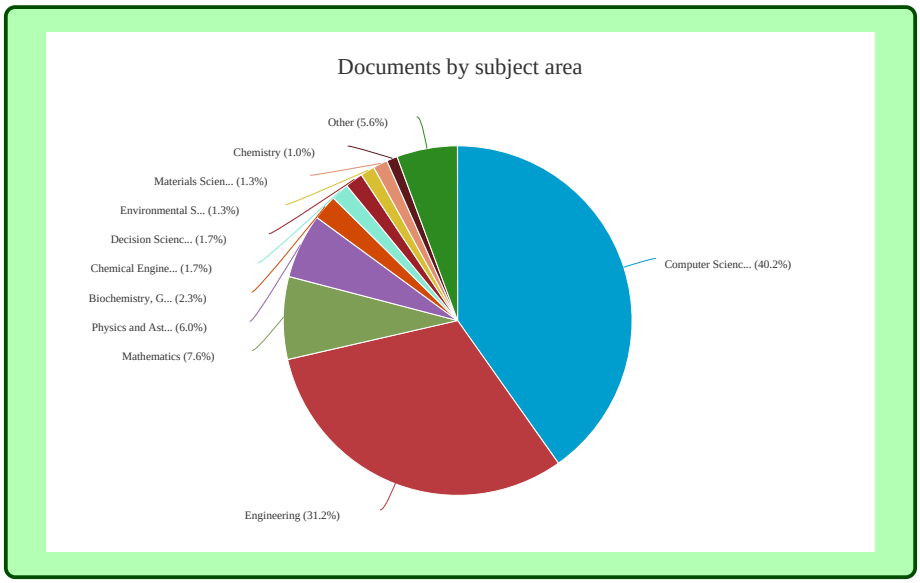

Fig. 14: Research articles in different subject areas
(Source: Scopus Database accessed on 17th March 2021)

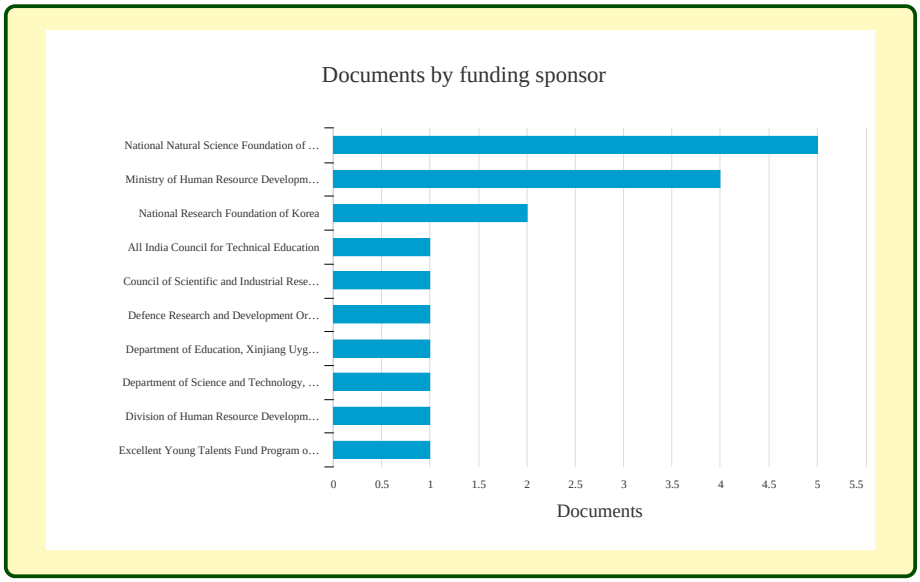

Fig. 15: Funding sponsors or agencies
(Source: Scopus Database accessed on 17th March 2021)

Table 4: Research article type
(Source: Scopus Database accessed on 17th March 2021)

Document type	**Number of Documents**
Article	90
Conference Paper	63
Conference Review	4
Book Chapter	1
Undefined	1

Financial support and funding are the backbones for quality research work. Without funding agencies and sponsors, it would become quite challenging to begin the research work. From the Fig. 15 it can be seen that top sponsors are *National Natural Science Foundation of China* that has funded six documents, *Ministry of Human Resource Development* that has funded four documents, and *National Research Foundation of Korea* that has funded two documents.

4 Networked Diagrams from Bibliometric Information

A network diagram is a graphical representation of nodes and links that is very helpful in checking the relationships and determining the connections between several exciting entities. This research article has used some of the well-known bibliometric network diagram tools, namely, VoSViewer and ScienceScape tool. In this article, the figures are limited to network diagrams and tried to include density graphs generated from VoSViewer tool. The rest of the section explores the different network graphs, density graphs, and Sankey graphs for the Scopus Database query.

Fig. 16 and Fig. 17 are the network and density graphs showing bibliometric coupling with documents on enhancement to LEACH protocol. Bibliometric coupling indicates reference of common documents in the citations. It means that two documents refer to the third common document in their reference, which

Table 5: Number of documents as per subject area
(Source: Scopus Database accessed on 17th March 2021)

Subject area	**Documents**
Computer Science	122
Engineering	95
Mathematics	23
Physics and Astronomy	18
Biochemistry, Genetics and Molecular Biology	7
Chemical Engineering	5
Decision Sciences	5
Environmental Science	4
Materials Science	4
Chemistry	3
Medicine	3

indicates that documents are related based on solving a common or similar research problem.

Fig. 18 and Fig. 19 are the network and density graphs showing citation with documents on enhancement to LEACH protocol. Based on the figures, it can be noted that documents of *karaboga d. (2012)* and *latiff n.m.a. (2017)* have significant better citations. Though Shankar was identified as top publishing author based on Scopus Database, the citations for the documents *shankar t. (2016a), shankar t. (2013a)* and *shankar t. (2013c)* are comparatively less.

Co-citation analysis is another important parameter the helps in understanding the relationship with published documents. Fig. 20 and 21 refer to network and density graphs co-citation with cited source respectively. The figures help in determining the relationship with source journals that are related to one another based on citation. The higher value indicates od co-citation indicates the strong relationship of the document and sources. The co-citations with sources in

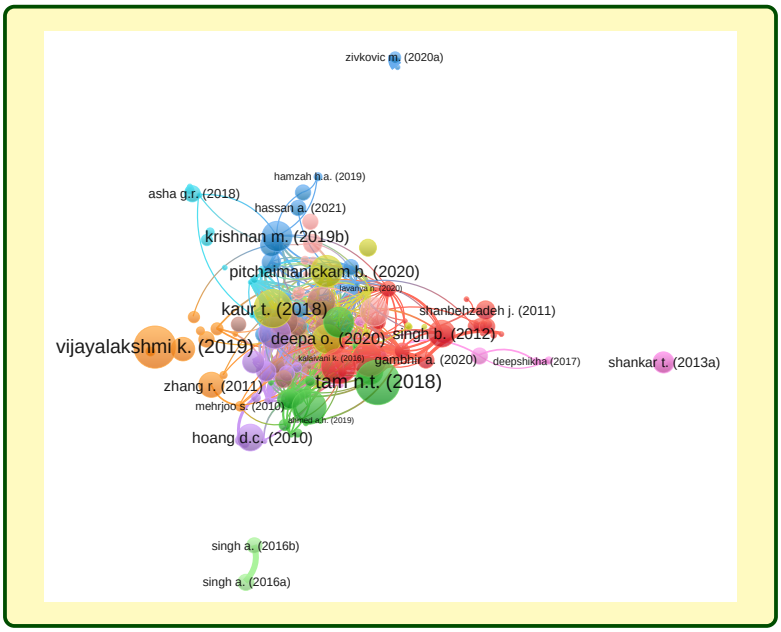

Fig. 16: Network graph of bibliometric coupling with documents (Source: Scopus Database accessed on 17th March 2021)

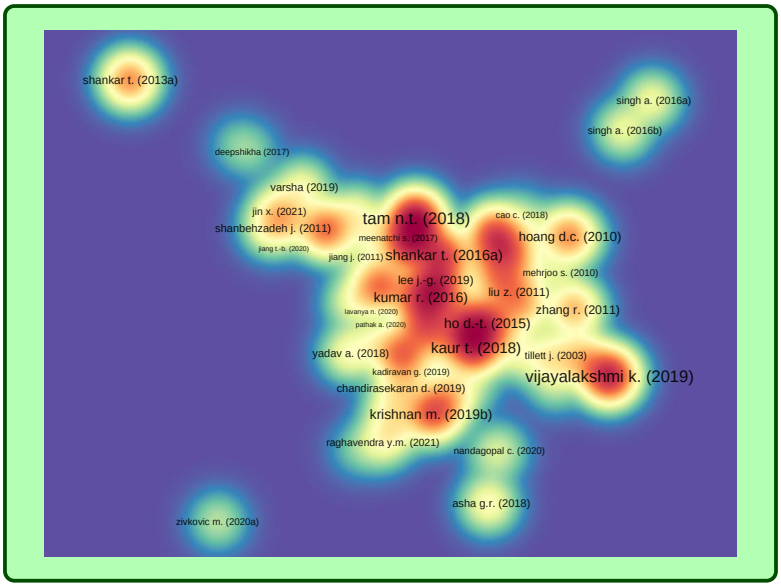

Fig. 17: Density graph of bibliometric coupling with documents (Source: Scopus Database accessed on 17th March 2021)

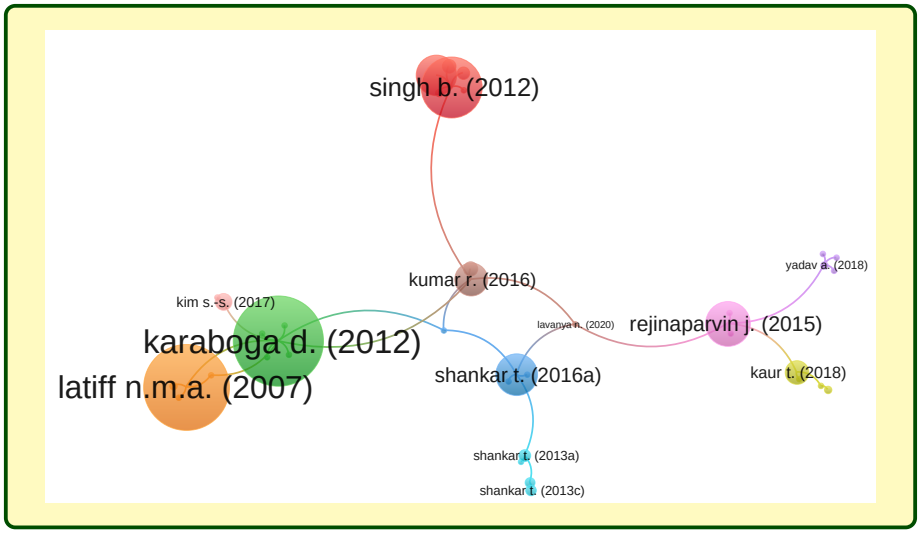

Fig. 18: Network graph of Citation with documents
(Source: Scopus Database accessed on 17th March 2021)

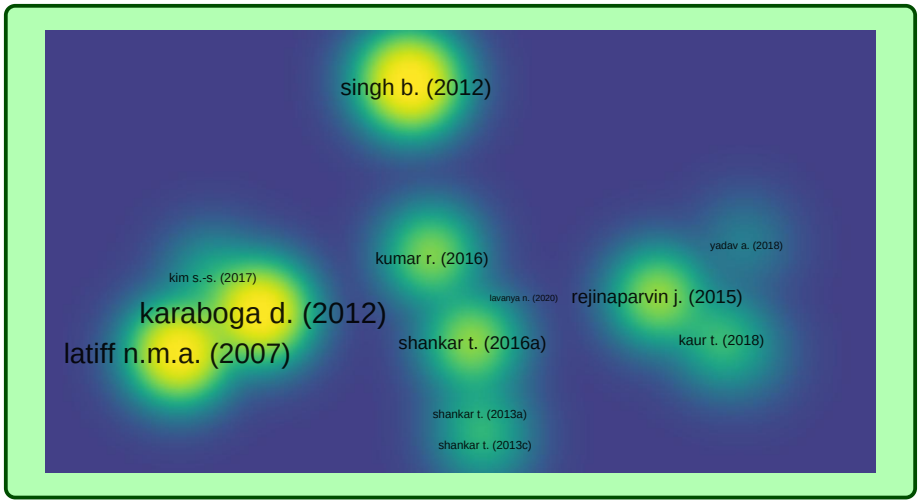

Fig. 19: Density graph of Citation with documents
(Source: Scopus Database accessed on 17th March 2021)

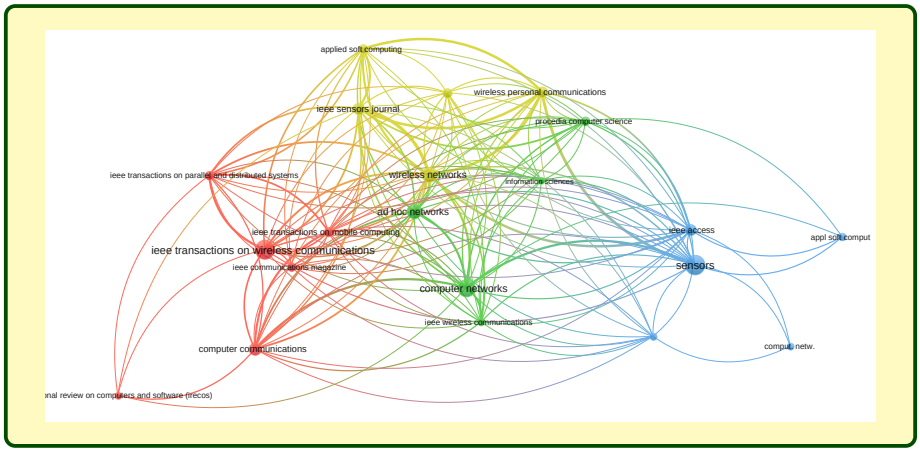

Fig. 20: Network graph of Co-citation with cited source
(Source: Scopus Database accessed on 17th March 2021)

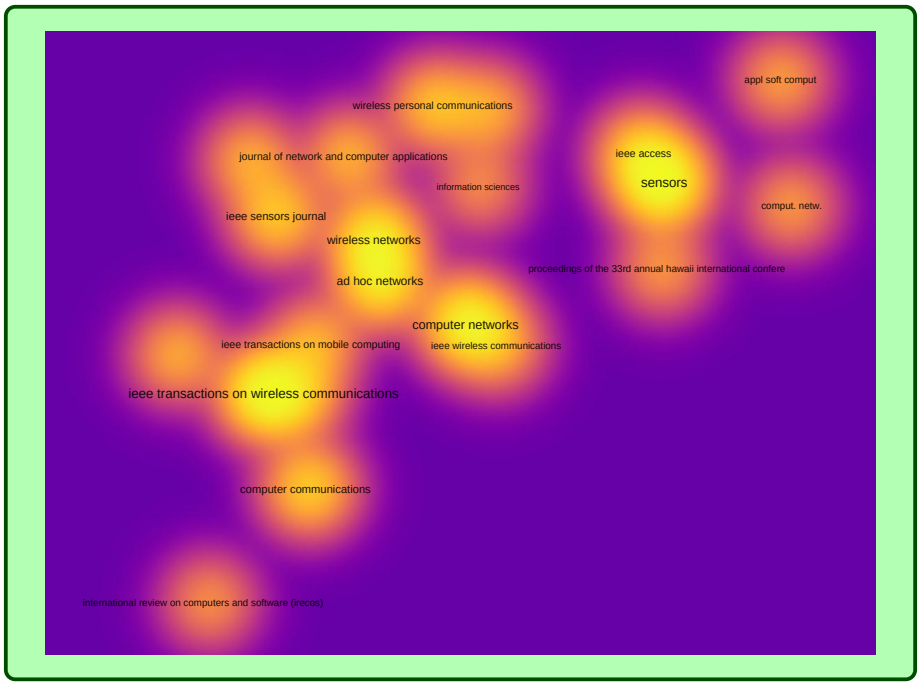

Fig. 21: Density graph of Co-citation with cited source
(Source: Scopus Database accessed on 17th March 2021)

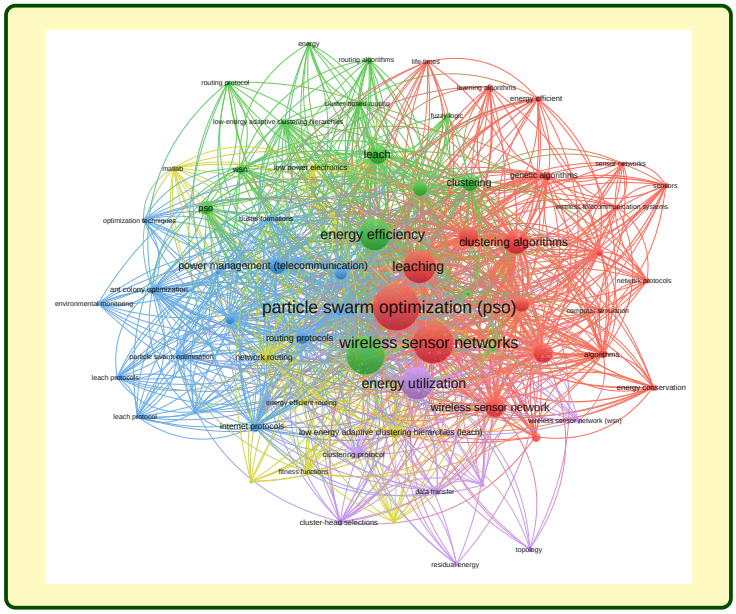

Fig. 22: Network graph of Co-occurrence with all keywords (Source: Scopus Database accessed on 17th March 2021)

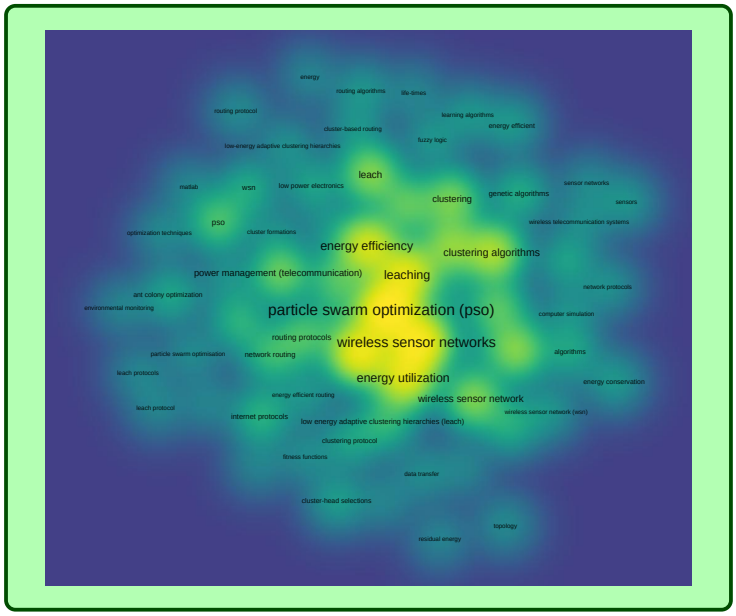

Fig. 23: Density graph of Co-occurrence with all keywords (Source: Scopus Database accessed on 17th March 2021)

shown in the figures for the several journals namely, *information sciences*, *comput. netw.*, *ieee wireless communications*, *appl soft comput*, *procedia computer science*, *ieee transactions on parallel and distributed systems*, *ieee communications magazine*, *applied soft computing*, *ieee transactions on mobile computing*, *wireless personal communications*, *ieee access*, *ieee sensors journal*, *computer communications*, *ad hoc networks*, *wireless networks*, *computer networks*, *ieee transactions on wireless communications*, and *sensors*.

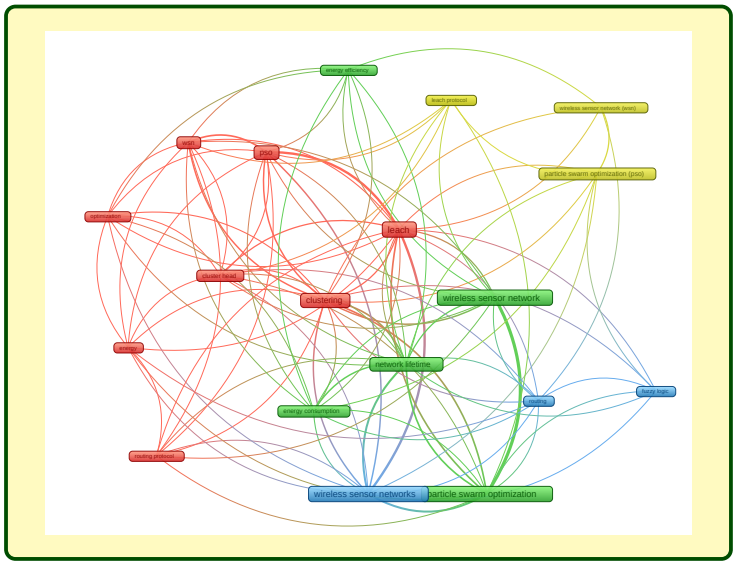

Fig. 24: Network graph of Co-occurrence with author keywords (Source: Scopus Database accessed on 17th March 2021)

Fig. 22, 24, 26 are the network diagrams for Co-occurrence relationship with all the keywords, author keywords and index keywords respectively. Similarly, Fig. 23, 25, 27 are the density diagrams for Co-occurrence relationship with all the keywords, author keywords and index keywords respectively. Author keywords are specified authors of research documents, and index keywords are those that content suppliers finalize. Both these categories of keywords are an important aspect of understanding the relationship and links between the keywords.

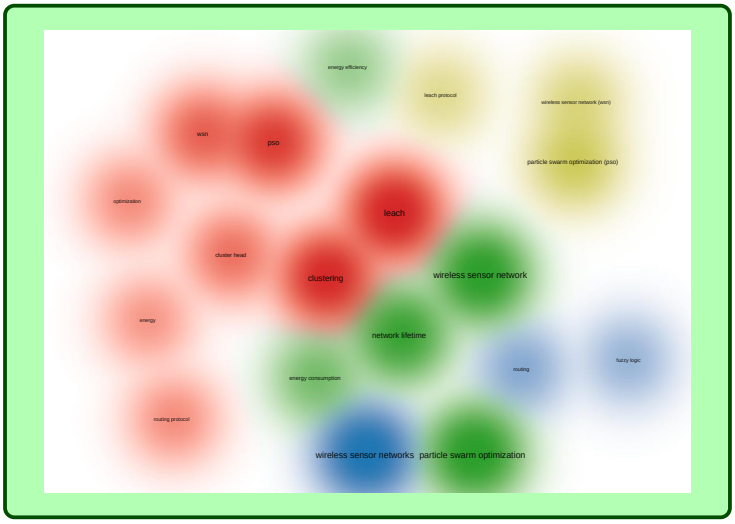

Fig. 25: Density graph of Co-occurrence with author keywords (Source: Scopus Database accessed on 17th March 2021)

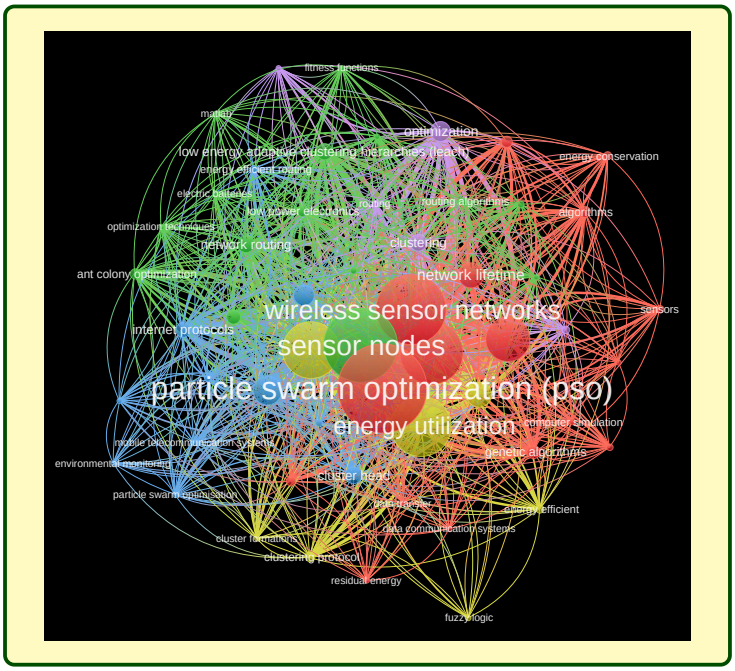

Fig. 26: Network graph of Co-occurrence with index keywords (Source: Scopus Database accessed on 17th March 2021)

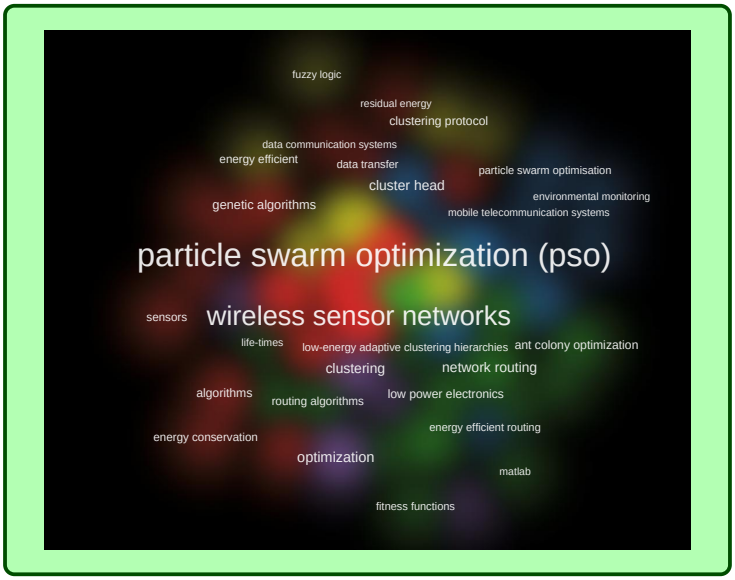

Fig. 27: Density graph of Co-occurrence with index keywords (Source: Scopus Database accessed on 17th March 2021)

Based on the co-occurrence analysis, 68 keywords met the threshold out of 933 all the keywords where a minimum number of occurrences was set to 5 keywords as shown in Fig. 22 and Fig. 23. In-case of co-occurrence analysis of author keywords, 19 keywords met the threshold out of 344 author keywords as shown in Fig. 24 and Fig. 25. In-case of co-occurrence analysis of index keywords, 55 keywords met the threshold out of 713 author keywords as shown in Fig. 26 and Fig. 27.

Fig. 28 presents the Sankey diagram for research in the PSO-based enhancement for LEACH protocol and provides relationship information between the main authors' keywords, authors, and sources. The diagrams indicate which sources authors have published their research work most regularly in PSO-based enhancement for LEACH protocol. From the Fig. 28, it can be observed that there are four authors *(Kakde s., Singh a., Shankar t., and Shanmugavel s)*, five keywords *(particle swarm optimization, wireless sensor network, energy consumption, leach, wireless sensors)* and three sources *(Wireless personal commu-*

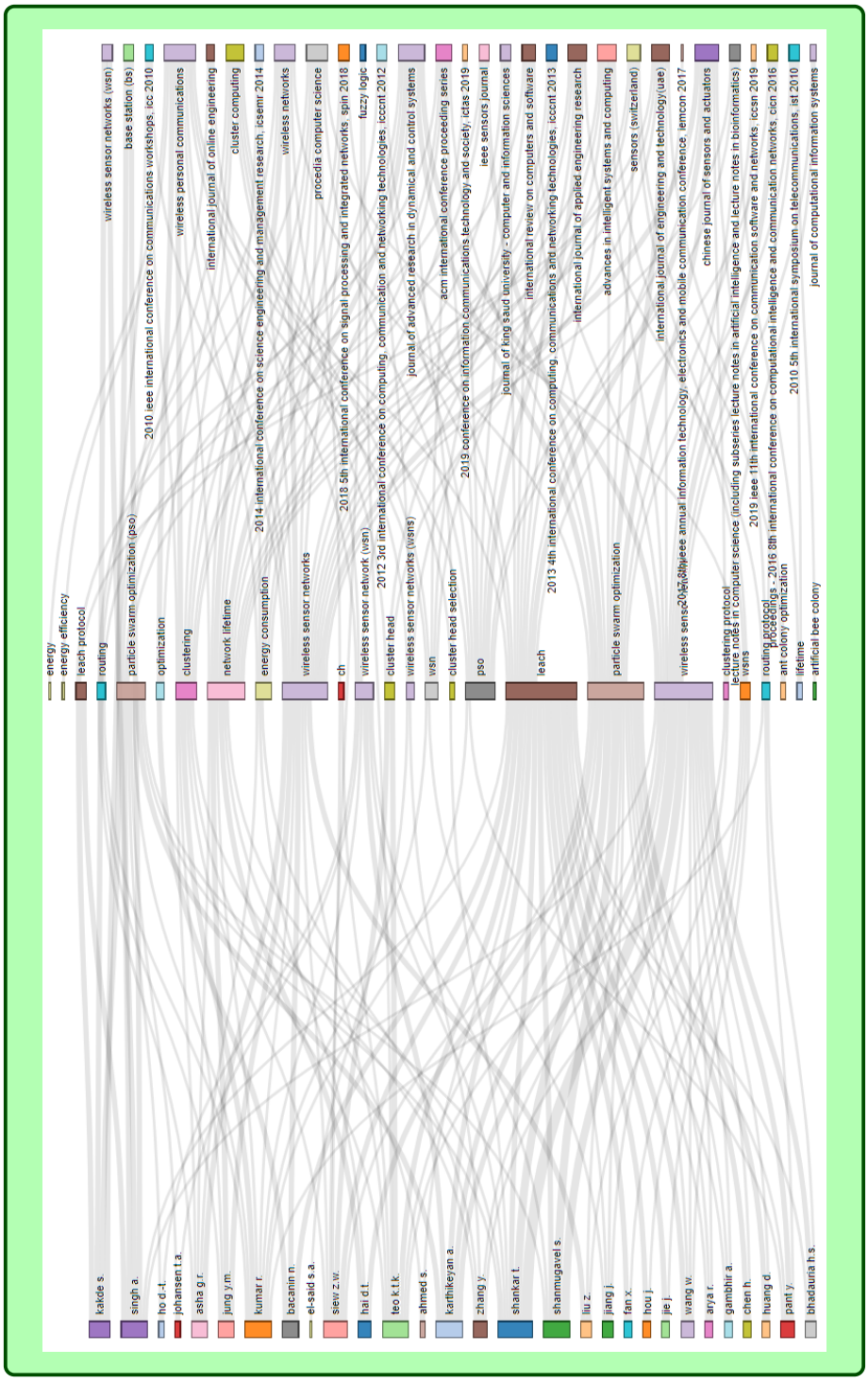

Fig. 28: Sankey graph on Main authors, keywords and journals (Source: Scopus Database accessed on 17th March 2021, drawn using ScienceScape tool)

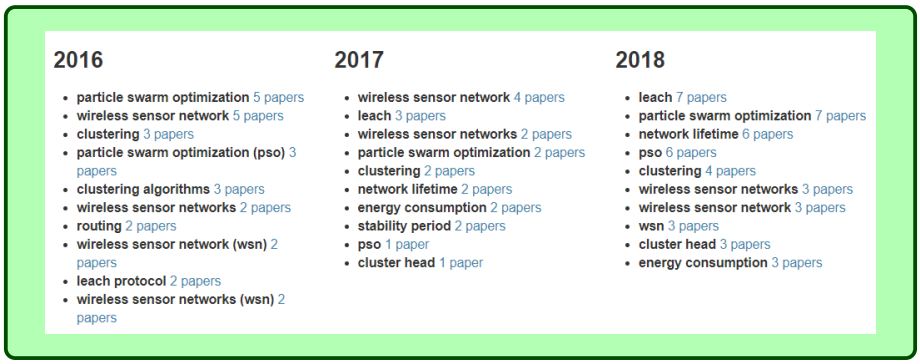

Fig. 29: Top Keywords of year 2016, 2017, 2018
(Source: Scopus Database accessed on 17th March 2021, drawn using ScienceScape tool)

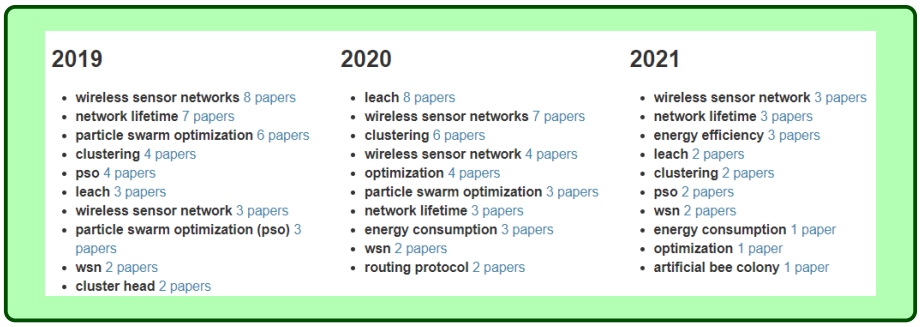

Fig. 30: Top Keywords of year 2019, 2020, 2021
(Source: Scopus Database accessed on 17th March 2021, drawn using ScienceScape tool)

nications, Wireless networks, and Chinese journal of sensor and actuators) have strong bonding and relationship with field of study i.e., PSO based enhancement for LEACH protocol. Fig. 29 and Fig. 30 indicate the top keywords from the year 2016 to 2021.

5 Research Implications

The bibliometric analysis and query string formulation suitable for Scopus Database have resulted in 159 documents spanned across different languages, territories, and the author community. The PSO application for LEACH protocol improvement is found for energy efficiency, network lifetime prolongation, CH election algorithms, etc. This bibliometric analysis's main research implications are that PSO has gained massive popularity in solving several optimization problems of wireless sensor networks. Along with PSO, other nature-inspired optimization techniques such as firefly algorithm, Ant Colony Optimization, Bacterial Foraging, Elephant Herding Optimization, etc., have also found their usefulness in the improvement of LEACH protocol. There is enormous research scope for further exploration in swarm-based optimization techniques in enhancing cluster-based routing schemes for WSNs.

6 Conclusion

A detailed bibliometric analysis related to incorporating the PSO technique for enhancing LEACH-based protocol is done in this article. This analysis has lead to several meaningful insights such as co-citation analysis, keywords co-occurrence, top authors in the field, top journal sources, documents written in English and Chinese languages. Detailed network analysis is also conducted to understand the relationship between main authors, keywords, and sources. Over the years, it is also observed that the basic PSO technique has been modified to make it suitable to apply in WSNs and cluster-based routing scheme enhancements. Based on the query string, the Scopus database has suggested around 159 documents linked to

PSO techniques. Since active research is ongoing, further bibliometric analysis and study is needed in the future. This bibliometric study and analysis can also be extended with the incorporation of other swarm intelligent techniques.

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