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Unveiling Trends and Trajectories: An In-Depth Bibliometric Study of Unequal Clustering in Wireless Sensor Networks

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Keywords:

Wireless sensor networks; unequal clustering; energy efficiency; metaheuristic algorithms; bibliometric analysis

ABSTRACT

In the Wireless Sensor Networks (WSNs) environment, the optimization of the unequal clustering algorithm has been identified as an important factor affecting the efficiency and sustainability of the network. This research aims to analyse the development and impact of the unequal clustering algorithm through bibliometric analysis. Using bibliometric tools, this study catalogues and analyses data from high-impact journals in the Scopus database, tracing development trajectories from the last decade and assessing the influence of unequal clustering. The analysis shows an increasing trend in unequal clustering publications, with significant contributions from prominent researchers whose works receive many citations, indicating their strong influence in the field. Major journals such as "IEEE Transactions on Mobile Computing" and "Sensors" stand out as centres of innovation and knowledge publications in unequal clustering. Findings emphasize the tendency to integrate metaheuristic techniques and machine learning in developing unequal clustering. This hints at a future direction where generative AI can play an important role in WSN research, with the potential to explore new unexplored areas and strengthen the effectiveness of WSNs.

1. Introduction

In the rapidly evolving domain of Wireless Sensor Networks (WSNs), the optimization of clustering algorithms has emerged as a crucial area of research, critical for enhancing network efficiency and longevity [1-4]. Despite the growing interest and substantial advancements in WSN technologies, a distinct gap still exists in studying the development and impact of unequal clustering algorithms. This study leverages bibliometric methods to map the landscape, identifying key research clusters, influential publications and emerging themes in unequal clustering algorithms. Utilizing bibliometric tools and techniques, this study precisely catalogues and analyses data from a multitude of high-

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impact journals from the Scopus database. Traces the trajectory of development from the last decade to the present day and assesses the impact and growth of unequal clustering.

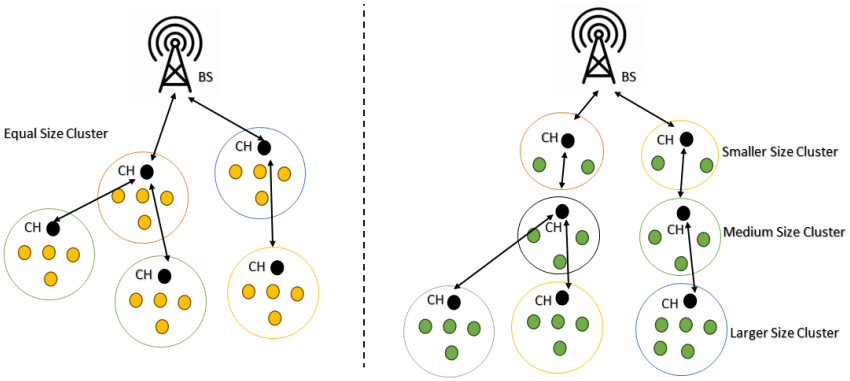
This study maps the publication trends, key contributors, research keywords, institutions and geographic distribution of research to provide an in-depth view of the global research landscape. It highlights important work and developments in the field and reveals the interconnections and thematic trajectories that have shaped the development of non-uniform clustering algorithms in WSNs. The findings of this study are expected to accelerate further innovation and foster a deeper understanding of the importance of unequal clustering in WSNs. Recent studies by Ahmed *et al.,* [5] focus on improving energy consumption in unequal clustering by considering residual energy and distance to the Base Station (BS). Gunjan *et al.,* [6] mentioned that unequal clustering is the best method of data transmission, thus focusing on improving energy consumption to extend the network lifetime. Energy optimization remains an important problem in unequal clustering. Therefore, Maleki and Bidgoli [7] focuses on optimization methods to improve energy consumption with prolonging network lifetime as the primary objective. Considering the growth of new technologies and applications in WSNs, unequal clustering research remains an area worth exploring. This study aims to provide an in-depth review of this field's current state, trends and future directions. Hence, the study not only provides the field's progression but also forecasts emerging trends and potential future research pathways.

1.1 Unequal Clustering

Clustering is a significant approach to managing and optimizing sensor nodes in WSNs. It is used to group these sensor nodes into several clusters [8-10]. Each cluster will be led by a node called the Cluster Head (CH), which is responsible for collecting data from the nodes in its cluster and sending them to other clusters or BS. Clustering is generally categorized into two types:

i. equal clustering
ii. unequal clustering, as illustrated in Figure 1.

In equal clustering, each cluster is grouped into the same size with an equal number of nodes. This helps reduce overhead on the CH, especially near the BH. It also ensures a more balanced energy consumption between all nodes. However, in unequal clustering, the size of each cluster is not the same. This is usually done in an area where the data is more critical and energy consumption is a concern. Nodes are grouped unequally to reduce the energy consumption near the BS. This improves energy consumption and data management efficiency, enabling resource allocation to areas with higher demand [11-13].



(a) (b)

Fig. 1. Clustering (a) equal clustering (b) unequal clustering

One of the biggest advantages of unequal clustering is its ability to overcome the hot spot problem. A hot spot is an area in a WSN where there is little or no coverage at all, usually due to running out of energy or damage to sensor nodes. In clustering, clusters far from the BS will communicate via inter-cluster communication to reduce energy consumption. Sensor nodes within the cluster will send the data via its CH through intra-cluster communications. The CH will then send the data to the next cluster via inter-cluster communications. The operation between the CHs sending data between the clusters will cause high energy consumption near the BS due to the frequency of data reception and transmission [14]. This contrasts with equal clustering, where resources and nodes are distributed equally. However, this approach does not consider the effect of hot spots near the BS, where nodes consume their energy faster due to heavier relay traffic [15]. The design of energy-efficient clustering algorithms is essential to prolong the network lifetime of WSNs [16]. Therefore, unequal clustering algorithms have been proposed to address this issue, where clusters closer to the BS are smaller, thereby balancing the energy load among CHs.

In the unequal clustering algorithm approach, four objectives are always studied in unequal clustering, as shown in Figure 2. However, the main purpose of load balancing is to save energy consumption while maximizing the network's lifespan. Additionally, scalability and availability can only be achieved when the available energy can extend the life of the network. Thus, energy consumption becomes the main objective of the approach of unequal clustering algorithms [17]. The algorithm is designed to ensure resource efficiency through load balancing between sensor nodes. This will directly extend the network's operational period. Therefore, the use of unequal clustering in WSNs not only extends the network lifetime but also strengthens and extends the connections between sensor nodes. This leads to more optimal energy management and reduction of overall energy consumption, which is the key to creating reliable and sustainable WSNs.

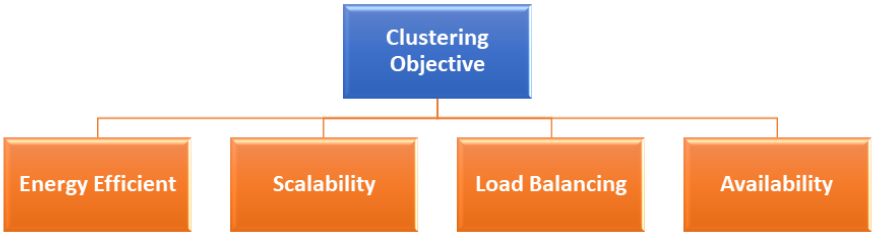


Fig. 2. Clustering objectives

Unequal clustering algorithms are techniques used to group sensor nodes into clusters of different sizes. The algorithms can be categorized into three main categories: hierarchical, partitional

and machine learning [18-20]. Hierarchical clustering is a method to build a hierarchy of groups. This is done with a bottom-up strategy where each node starts as its own cluster and the closest pairs of clusters are gradually combined. It can also be created as a top-down strategy where all nodes start in one cluster and then are divided. The advantages of this method include not having to determine the number of clusters in advance. Partitional clustering divides the data into several groups that are almost similar but not equal group members. Partitional clustering is effective for large-scale networks but requires a predetermined number of clusters and is sensitive to the initial selection of the CH. Finally, Machine Learning uses algorithms to enable machines to learn from data and make decisions or predictions. Machine Learning can be divided into three subcategories: supervised, unsupervised and reinforcement. Figure 3. Illustrates the clustering algorithm categories.

Fig. 3. Clustering algorithms categories

Interestingly, recent literature has seen the application of various metaheuristic optimization algorithms to formulate unequal clustering as an NP-hard problem [21]. For instance, the Seagull Optimization-Based Unequal Clustering (SGOBUC) technique is inspired by the migrating and attacking behaviour of seagulls, aiming to achieve energy efficiency in WSNs [22]. This algorithm will

find 'food' or, in this case, the best configuration for clusters that will reduce energy consumption and maximize network lifetime. The Competitive Swarm Optimization Unequal Clustering and Routing Algorithm (CSO-UCRA) is another algorithm that reviews several uneven clustering methods and compares them based on clustering properties, CH properties and the type of clustering process [23]. This algorithm encourages 'particles' in the swarm to compete, where only the best 'particles' survive and others will adapt or die. Lastly, the Quantum Inspired Genetic Algorithm (GA) is another metaheuristics approach that deals with the problem of multi-hop energy-balanced unequal clustering and prolongs the network lifetime. This algorithm combines the concepts of the evolutionary computation process in GA that involves natural selection, crossover and mutation to produce better new generations with the principles of quantum computing, which allows qubits (quantum bits) to represent many states simultaneously, as opposed to only one state at a time (0 or 1) in classical bits, providing better quality solutions in less time [24]. In summary, unequal clustering algorithms in WSNs aim mainly to improve energy consumption. Energy consumption has become an important factor in extending the lifespan of the network and maintaining node connectivity. The literature highlights a trend towards using metaheuristic techniques to develop novel clustering algorithms that are energy-aware and can handle the crucial challenges of WSNs, such as the hot spot problem. These advancements contribute significantly to the field of WSNs, offering a pathway to more sustainable and efficient network designs.

2. Methodology

Bibliometrics refers to the combination, management and investigation of bibliographic information acquired from scientific publications [25-27]. It includes basic descriptive statistics such as publishing journals, publication year and main author classification [28] and it also encompasses complex techniques like document co-citation analysis. The process involves a series of keyword searches, literature searches and analysis in constructing a bibliography and achieving reliable results in developing effective analysis [29]. Considering this, the study aimed to focus on high-quality publications as they can aid in understanding the theoretical perspective on the evolution of the research domain. Considering that Scopus stands as the most extensive repository of scholarly publications compared to both Web of Science and PubMed [30-32], the study relied on the Scopus database for data collection. Moreover, to ensure the inclusion of top-tier publications, only articles published in peer-reviewed and distinguished academic journals were considered, while books and conference proceedings were excluded [33,34].

2.1 Data Search Strategy

The study commenced a precise exploration approach employing the Scopus database. An extensive search string titled TITLE-ABS-KEY, which encompassed terms like 'unequal,' 'dynamic,' 'cluster*,' as well as 'algorithm*' or 'mechanism*,' with a specific focus on 'wireless sensor networks' was utilized. The search was confined to articles published between 2014 and 2023, concentrating on the pattern during this timeframe. The search was limited to the document type 'article' and required English texts. This preliminary query resulted in a significant compilation of 2,011 articles. The search terms were refined to further narrow the focus specifically on clustering algorithms, resulting in 725 pertinent articles. These articles were subsequently filtered to include solely research articles, excluding reviews and non-English papers, leading to a strong selection for bibliometric analysis. Articles until December 2023 were integrated into the study from the Scopus database,

specifically emphasizing unequal clusters and ensuring a comprehensive and pertinent dataset for analysing trends over the past decade. Details of the search are described in Table 1 and Table 2.

Table 1
The search strings

SCOPUS	TITLE-ABS-KEY ((unequal OR dynamic) AND cluster* AND (algorithm* OR mechanism*) AND "wireless sensor network*")

Table 2
The selection criteria for searching

Criterion	Inclusion	Exclusion
Language	English	Non – English
Timeline	2014 – 2023	< 2014
Literature Type	Journal (Article)	Conference, Book, Review

2.1 Data Search Strategy

Data sets containing the study publication year, publication title, author name, journal, citation and keyword in PlainText format were analysed using Scopus Analyzer and VOSviewer software version 1.6.20. The application of the software was employed to carry out analysis and produce maps by utilizing the Scopus Analyzer and VOS clustering and mapping methods. VOSviewer is an applicable alternative to the Multidimensional Scaling (MDS) approach, where this approach visualizes the similarity level between datasets, as highlighted by Van Eck and Waltman [35]. However, unlike MDS, which focuses on computing similarity measures such as Jaccard indexes and cosine, VOS employs a more suitable technique for normalizing co-occurrence frequencies, as discussed by Van Eck and Waltman [36]. One such technique is the calculation of Association Strength (AS_{ij}), which is calculated as follows:

$$AS_{ij} = \frac{c_{ij}}{w_i w_j}. \quad (1)$$

In the context of Eq. (1), c_{ij} is the total observation of the occurrence of *i* and *j* while w_i and w_j are the total occurrence of each item individually [35]. Hence, Association Strength (AS) measures the strength of the relationship between two items by comparing the actual amount of co-occurrence with the expected amount if the two items are independent and unrelated. VOSviewer uses an index like AS to determine how items should be displayed in the visual space based on the frequency and strength of the relationship between them. Furthermore, applying visualization techniques through VOSviewer to the data set uncovered patterns built on mathematical relationships and analyses such as keyword co-occurrence, citation analysis and co-citation analysis were performed. Table 3 and Table 4 show the type of analysis used in this paper. These analyses are chosen to identify the current subject area, emerging topics and top journals to search for and publish in the research area. This will be useful to set targets and priorities in the research area.

Table 3
Types of analysis used in Scopus analyser

Analysis	Unit of Analysis	Purpose
Publication Growth	Number of Publications	Publication trends
Authors Publication	Number of Publications	Authors with high publications in research area
Journal	Number of Publications	Top journal where research area is published
Cited Articles	Number of Citations	Most cited articles in the research area

Table 4
Types of analysis used in VOSviewer

Analysis	Unit of Analysis	Purpose
Co-authorship	Countries organisation	Organizations and countries in the research area
Co-occurrence	Keywords	Keywords used in the research area
Co-citation	Sources (Journal)	A similar research area in the journal

3. Results

3.1 Unequal Clustering Publications' Growth

Firstly, there has been an upward trend in the publications of unequal clustering since the last decade. This trend can be observed at a count of 38 works in 2014, reaching its peak at a remarkable count of 101 in 2022. This notable increase in publication trends indicates a high interest in unequal clustering. The annual percentages show a little fluctuation, although they do not necessarily correlate directly with the surge in the number of publications. For instance, even though there was a greater number of publications released in 2022 in comparison to 2023, the percentage is only marginally lower, specifically standing at 13.10% as compared to 13.93%, as illustrated in Table 5 and Figure 4. Moreover, the publications trends can be observed through the keyword index shown in Figure 8. The keywords can be related to different fields in the same WSN domain.

Table 5
Publication growth by year

Year	Number of Publications	Percentage (%)
2023	95	13.10
2022	101	13.93
2021	85	11.72
2020	80	11.03
2019	86	11.86
2018	59	8.14
2017	60	8.28
2016	70	9.66
2015	51	7.03
2014	38	5.24

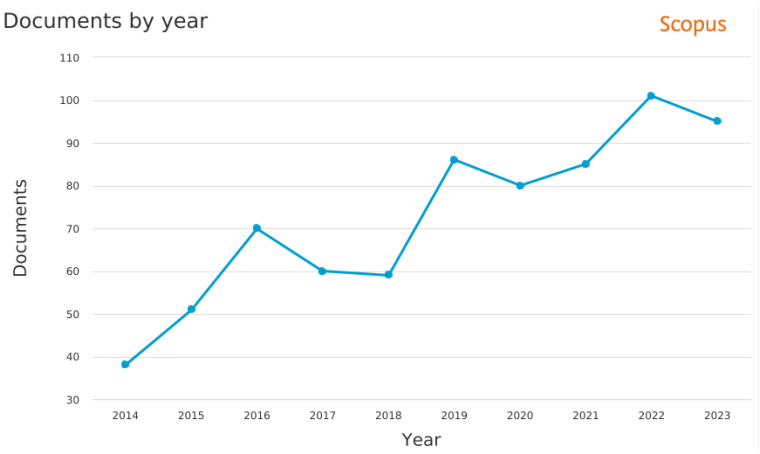


Fig. 4. Publication trends

3.2 Most Productive Authors in the Research Area

The bar chart in Figure 5 obtained from Scopus presents the number of documents produced by the authors since 2014. This graphical representation serves as an instrument for examining the research output of these individuals to determine whether these authors' research fields are in sync with our focus area in unequal clustering.

Analysis of authors to gain insight into their publication trends and impact based on the documents published are shown in Table 4. Sangaiah [77] from the National Yunlin University of Science and Technology, Taiwan, has a very high number of citations, with 399 from 6 documents, indicating that his work may be very influential in unequal clustering.

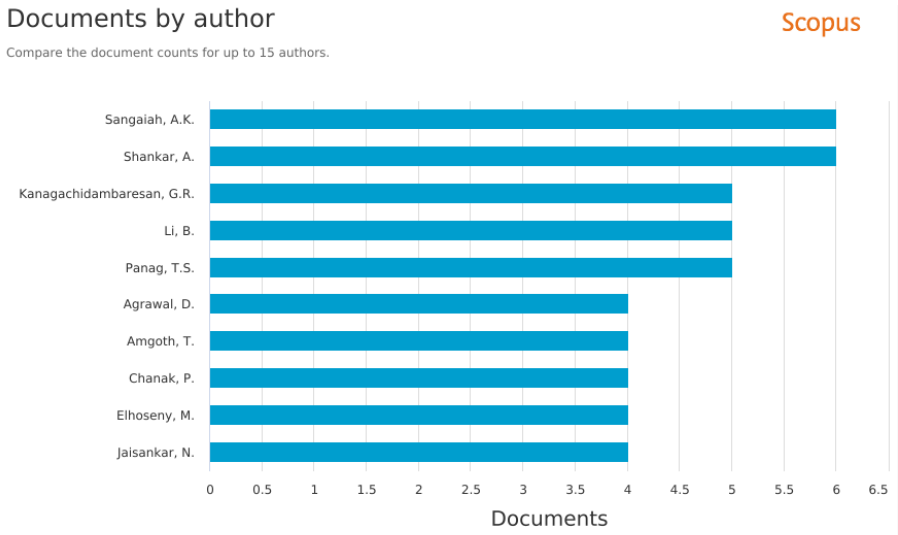


Fig. 5. Topmost productive authors

This is further supported by his latest article in 2023 titled "Hierarchical Clustering Based on Dendrogram in Sustainable Transportation Systems," with 18 citations [37]. Elhoseny [45] from the UAE also shows a strong influence in the field of research with 476 citations for 4 documents, with his latest article in clustering titled "Swarm intelligence–based energy efficient clustering with multi-hop routing protocol for sustainable wireless sensor networks" having 42 citations.

Furthermore, Table 6 shows that these authors come from various countries, reflecting the global diversity in academic research, especially in unequal clustering, which attracts researchers worldwide.

Table 6
Productive authors and their organization

Authors	Documents	Citations	Country	Organization	Latest Related Publications & Citations
Sangaiah [37]	6	399	Taiwan	National Yunlin University of Science and Technology, Taiwan.	18 citations
Shankar [38]	6	55	UK	University of Warwick, United Kingdom	2 citations
Kanagachidambaresan [39]	5	118	India	Veltech Rangarajan Dr Sagunthala R&D Institute of Science	2 citations
Li, Baoqing [40]	5	59	China	Shanghai Institute of microsystem and information technology	0 citations
Panag [41]	5	52	India	Baba Banda Singh Bahadur Engineering College	5 citations
Agrawal [42]	4	86	USA	University of California, Santa Barbara	62 citations
Amgoth [43]	4	45	India	Siliguri Institute of Technology	2 citations
Chanak [44]	4	124	India	Indian Institute of Technology	5 citations
Elhoseny [45]	4	476	UAE	University of Sharjah, UAE	42 citations
Jaisankar [46]	4	21	India	Vellore Institute of Technology	2 citations

Authors from Asia, especially India, as illustrated in Figure 6, dominate this table with a strong presence in the field. Several leading institutions from India are represented here, such as the Indian Institute of Technology, Veltech Rangarajan Dr Sagunthala R&D Institute of Science and Vellore Institute of Technology. Several renowned institutions, such as the University of California, Santa Barbara from the USA and the University of Warwick from the UK, are also on the list.

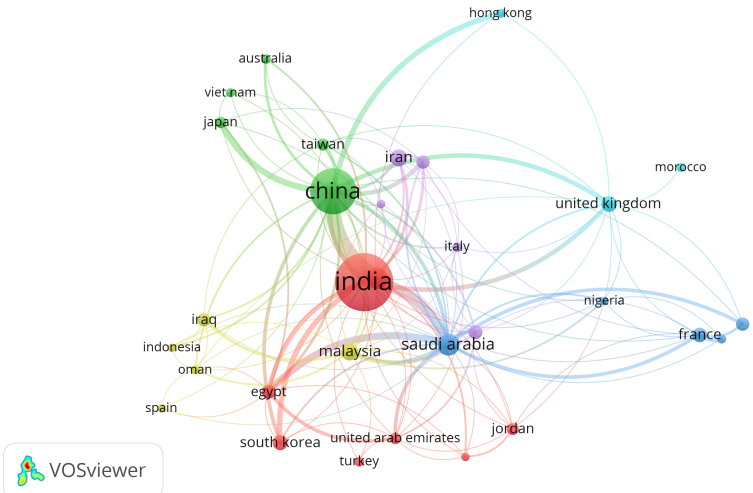


Fig. 6. Network visualization map of co-authorship country

3.3 Popular Journal in the Research Area

Journals with a high impact factor and a good ranking in quartiles (Q1, Q2, etc.) are credible and recognized by the academic community. Figure 7 shows a comparison of the number of documents published annually. The publication activities are usually influenced by various factors such as changes in research interests, editorial policies, time of publication or even processing fees.

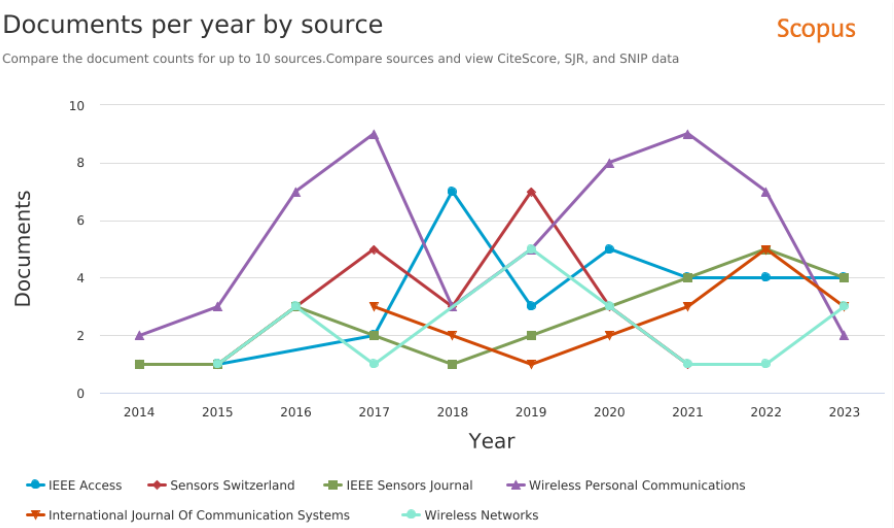


Fig. 7. Top journal in the last decade

Therefore, to further investigate the trend of publications of the sources, journal impact factor, journal ranking, H-Index, publishing time and processing fees, some additional research is done to formulate Table 7.

Table 7
Journal ranking and publishing time

Journal	Impact Factor (SJR)	Publisher	Ranking	H-Index	Publishing Time	Processing Fees
IEEE Access	0.93	IEEE	Q1	204	30 – 50 days	USD 1995.00
Sensors	0.76	MDPI	Q1	219	17 days	USD 2936.00
IEEE Sensors Journal	0.99	IEEE	Q1	145	70 days	USD 2345.00
Wireless Personal Communication	0.55	Springer	Q2	75	90 – 120 days	USD 3290.00
International Journal of Communications Systems	0.52	Wiley	Q2	56	194 days	USD 3450.00
Wireless Networks	0.71	Springer	Q2	98	351 days	USD 3190.00

Hence, it can be seen from the top journals listed in the graph that all the journals are high-impact journals from renowned publishers based on their rankings. Journals with Q1 ranking, such as IEEE Access, Sensors and IEEE Sensors Journal, have a high impact factor and a large H-Index, indicating a strong influence in the research community. This attracts researchers who want their work to be recognized and cited widely to publish in those journals. IEEE Access Journal and IEEE Sensors Journal, both published by IEEE, have almost the same impact factor and publication costs, but the IEEE Sensors Journal has a longer publication time. Sensors from MDPI, even with the highest publishing costs on this list, offer very fast publishing times. This can be the main attraction for researchers who want their work published immediately. Publication costs can vary significantly, which is an important

consideration for researchers, especially those who do not have large publication funds or work in institutions with limited budgets. IEEE journals tend to have lower costs than MDPI and Springer, which can be a deciding factor for some researchers when choosing where to submit their work. In choosing a journal for publication, researchers need to weigh the reputation of the journal, speed of publication, cost of publication and compatibility with their field of study. Journals with a Q1 ranking may be the main target because of their reputation, but the cost and time of publication should also be considered. The choice of the journal will greatly depend on the individual researcher's priorities, whether they need quick publication, are under budget constraints or pursue academic performance through publication in a journal with a high reputation [47].

3.4 Top 10 Numbers of Citations by Researchers

The number of citations of a research article is an important indicator of the impact and importance of the study. Articles with a high number of citations indicate that they have contributed to a better understanding of a topic or have introduced new techniques considered useful by other researchers. Therefore, when examining the 'top 10 citations' in the field of unequal clustering, this refers to works that have made a significant impact in the field. Table 8 mapped the top 10 most cited articles in the Scopus database as evaluated by the Scopus Analyzer.

Table 8
Top 10 most cited articles in unequal clustering

No	Authors	Title	Year	Source Title	Cited By	Latest Cited Publications
1	Alsheikh *et al.,* [18]	Machine learning in wireless sensor networks: Algorithms, strategies and applications	2014	IEEE Communications Surveys and Tutorials	671 (389 from 2020-2023)	[48-50]
2	Sundararaj *et al.,* [51]	An optimal cluster formation-based energy efficient dynamic scheduling hybrid MAC protocol for heavy traffic load in wireless sensor networks	2018	Computers and Security	289 (272 from 2020-2023)	[52-54]
3	Sert *et al.,* [55]	MOFCA: Multi-objective fuzzy clustering algorithm for wireless sensor networks	2015	Applied Soft Computing	232 (136 from 2020-2023)	[56-58]
4	Zhang *et al.,* [59]	Novel unequal clustering routing protocol considering energy balancing based on network partition & distance for mobile education	2017	Journal of Network and Computer Applications	213 (149 from 2020-2023)	[60-62]

5	Baranidharan *et al.,* [63]	DUCF: Distributed load balancing Unequal Clustering in wireless sensor networks using Fuzzy approach	2016	Applied Soft Computing Journal	203 (125 from 2020-2023)	[64-66]
6	Logambigai *et al.,* [3]	Fuzzy logic-based unequal clustering for wireless sensor networks	2016	Wireless Networks	196 (111 from 2020-2023)	[65,67,68]
7	Jia *et al.,* [69]	Dynamic cluster head selection method for wireless sensor network	2016	IEEE Sensors Journal	176 (100 from 2020-2023)	[70-72]
8	Yuan *et al.,* [73]	A Genetic Algorithm-Based, Dynamic Clustering Method Towards Improved WSN Longevity	2017	Journal of Network and Systems Management	171 (100 from 2020-2023)	[74-76]
9	Wang *et al.,* [77]	Energy efficient routing algorithm with mobile sink support for wireless sensor networks	2019	Sensors (Switzerland)	165 (148 from 2020-2023)	[74,78,79]
10	Shankar *et al.,* [80]	Hybrid HSA and PSO algorithm for energy efficient cluster head selection in wireless sensor networks	2016	Swarm and Evolutionary Computation	158 (117 from 2020-2023)	[81-83]

Notably, 90% of the articles listed emphasize energy efficiency in WSNs, which is a key issue in this field of research. This includes the development of protocols, algorithms and strategies to optimize energy use. Some articles also use approaches based on artificial intelligence, such as fuzzy logic and GA, to make better clustering and load-balancing decisions. The article titled "Machine Learning in Wireless Sensor Networks: Algorithms, Strategies and Applications" by Alsheikh *et al.,* [18] has been cited since 2014 with 671 citations. The citation data supporting this is filtered from 2020-2023. The number of citations in the article is still high, with a total of 389 citations. This shows that the machine learning approach is getting more and more attention from researchers in developing protocols, algorithms and strategies for optimizing the use of energy in WSNs. Apart from that, it can also be seen that metaheuristics clustering algorithm approaches are a technique that is widely studied and cited by researchers. Methods such as Harmony Search Algorithms (HSA), Particle Swarm Optimization (PSO), Genetic Algorithms (GA) and Load Balanced Clustering Algorithms (LBCA) topped the top 10 cited article list. This shows that the metaheuristics approach is still used in the research of clustering algorithms, although there is an increasing trend (shown by the high citations of machine learning) in machine learning. Hence, research in unequal clustering using metaheuristics or machine learning approaches is still applicable in the context of the research. Based on the

previous data, it can be forecasted that machine learning is the future research trend in unequal clustering due to the popularity of generative AI, such as GPT, one of the fields in machine learning. This shows that this field of study still has many research areas that can be improved using the upcoming technology.

3.5 Focus Keywords in the Research Area

The network visualization map in Figure 8 shows several clusters of keywords that are related to unequal clustering algorithms. The largest cluster (group) in the centre of the map includes keywords such as "energy-efficient," "hot spot," "sensor nodes," and "data acquisition." This group suggests that one of the main areas of research in unequal clustering algorithms is improving energy efficiency. 'Energy-efficiency', 'energy-aware' and 'energy adaptive' are top keywords and much research is focused on developing adaptive algorithms, such as heuristics, to optimize energy consumption. CH plays an important role in regulating energy and data traffic. If it is not handled well, this can create hot spots and shorten the life of the network. The solutions proposed by the related literature aim to achieve more efficient unequal clustering operations in terms of energy by considering factors such as network topology, network dynamics and network security [84].

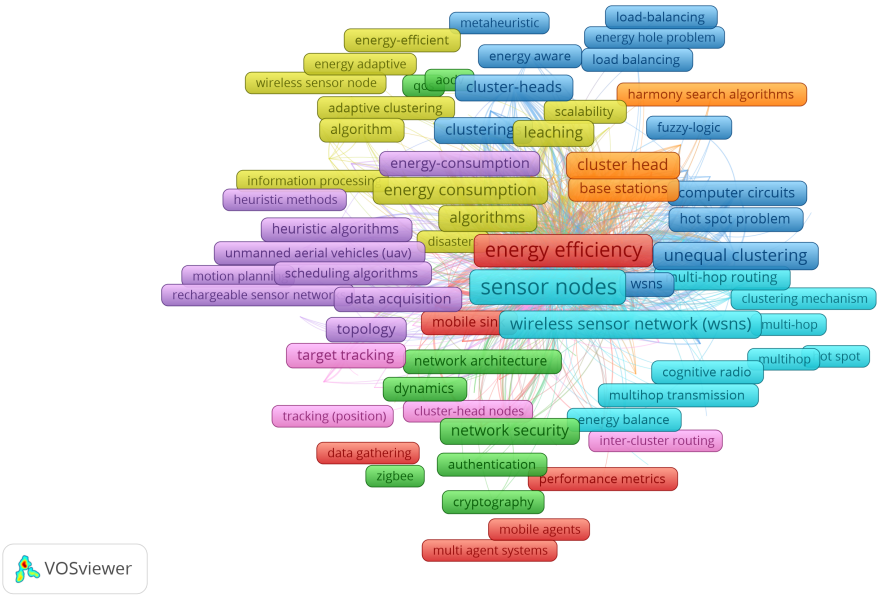


Fig. 8. Network visualization map of keywords' co-occurrence

This shows the importance of a clustering that is efficient in energy use and able to manage resources intelligently to strengthen the network's sustainability, connectivity and reliability. The solution that must be proposed throughout the research will aim to achieve a balance between system longevity, reliability and security, all while maintaining the required level of performance.

3.6 Journal Cluster in the Research Area

Figure 9 illustrates a network visualization map of co-citation by sources for unequal clustering algorithms created using VOSviewer. Co-citation is a method used to establish subject similarity between two sources. Co-citation occurs when two or more documents are cited together in one or more publications [85].

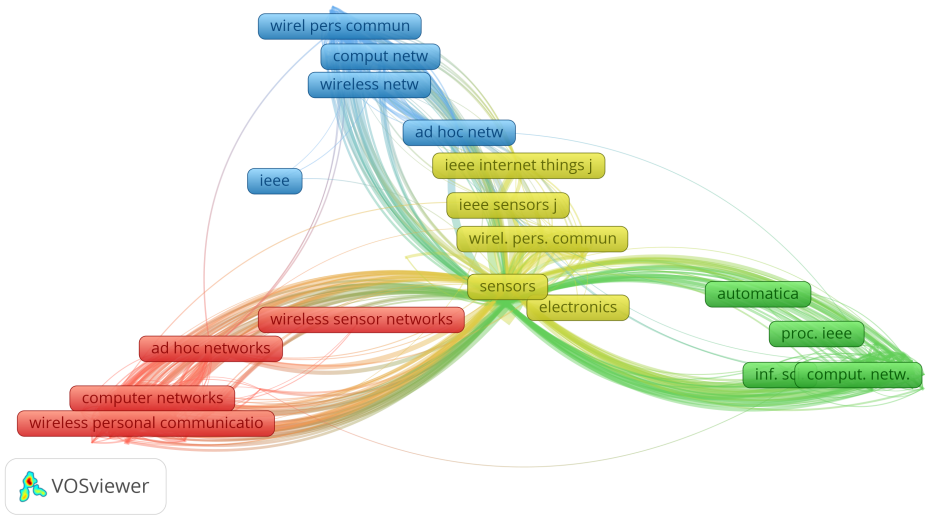


Fig. 9. Network visualization map of co-citation by sources

This indicates that the documents are related or relevant to the same research topic. Therefore, to investigate the trend of co-cited sources further, additional research was done to formulate Table 9.

Table 9
Journal citations

Journal	Impact Factor (SJR)	Publisher	Ranking	Citations
Sensors	0.76	MDPI	Q1	545
IEEE Access	0.93	IEEE	Q1	474
Wireless Personal Communication	0.55	Springer	Q2	218
Wireless Networks	0.71	Springer	Q2	193
IEEE Sensors Journal	0.99	IEEE	Q1	140
Ad hoc networks	1.3	Elsevier	Q1	152
IEEE Transactions on Mobile Computing	2.54	IEEE	Q1	134
Computer Communications	1.4	Elsevier	Q1	142
Journal Of Network and Computer Applications	2.38	API	Q1	111
Computer Networks	1.63	Elsevier	Q1	97

A high "impact factor" in the context of an academic journal usually refers to the frequency in which articles in the journal are cited in a certain period [86]. This is often considered an indication of the influence or quality of the journal in its academic field. Eq. (2) and Eq. (3) illustrate how the impact factor is calculated.

$$Impact\ Factor_X = \frac{Total\ Citation\ in\ Year\ \ X\ to\ Article\ Published\ in\ Year\ (X-1)\ and\ (X-2)}{Total\ Articles\ Published\ in\ the\ Journal\ Years\ (X-1) and\ (X-2)} \quad (2)$$

$$Impact\ Factor_{2024} = \frac{Total\ Citation\ in\ Year\ 2024\ to\ Article\ Published\ in\ 2022\ and\ 2021}{Total\ Articles\ Published\ in\ the\ Journal\ Years\ 2022\ and\ 2021} \quad (3)$$

From the table above, almost all journals in the list are in the first quartile (Q1), with "IEEE Transactions on Mobile Computing" and "Journal of Network and Computer Applications" having the highest impact factor, which indicates great influence in the research community. Although "Wireless Personal Communication" and "Wireless Networks" are Q2, they are still quite significant in this field. "Sensors" and "IEEE Access" lead in terms of the number of citations, which shows that the works

published in this journal significantly influence the field of 'unequal clustering'. This scenario could also imply a lesser processing time in the "Sensors" journal and a lesser processing fee in "IEEE Access" compared to other high-impact journals. Therefore, the journals that are referred to together have made a significant contribution to research in unequal clustering.

This co-citation analysis suggests that unequal clustering algorithms are a widely studied topic in various journals and fields. These fields are all areas where unequal clustering algorithms can be used to improve the performance of network protocols. Overall, the Figure 9 provides a valuable overview of the research landscape for unequal clustering algorithms. It shows the most important journals in the field and the key areas of research. This information can be helpful for researchers who are interested in learning more about unequal clustering algorithms, as well as for those who are looking for potential publication venues for their research.

4. Conclusions

Firstly, the research trends in unequal clustering demonstrate consistent growth, which shows continued interest in this field. The findings show that unequal clustering plays a significant role in energy efficiency. This reflects the growing importance of developing more energy-efficient WSN networks. Influential articles with a high number of citations indicate a significant contribution to this field, with researchers such as Sangaiah and Elhoseny being top authors in the field. Recent publications emphasize increasing energy consumption and overcoming the hot spot problem. Metaheuristics and machine learning algorithms are getting more and more attention in developing unequal clustering protocols and strategies. Journals with a high impact factor, such as "IEEE Transactions on Mobile Computing" and "Journal of Network and Computer Applications", as well as "Sensors" and "IEEE Access", dominate in terms of the number of citations, showing that these journals are important publication centres in this field.

Considering the development of generative AI, there is expected to be an increase in the application of machine learning methods to overcome challenges in unequal clustering in the future. Future research may also continue exploring areas such as load balancing optimization, network scale and availability to extend the network's life and improve connections between sensor nodes. The key to achieving this is optimal energy management and reduced overall energy consumption.

Additionally, co-citation analysis shows potential for further collaboration between researchers in various fields and journals, which can lead to innovations and improvements in network protocols. This shows that research in this field does not only focus on one aspect but crosses various scientific disciplines. The journals often collected show the consensus in the research community about the importance of this topic, as well as the interrelation and thematic direction that has shaped the development of the unequal clustering algorithm.

Overall, research in unequal clustering in WSNs is still dynamic, with much room for innovation. With the advancement of technology and the need for more resilient and efficient WSNs, more research will be directed at optimizing network protocols and clustering mechanisms. Researchers need to be at the forefront of the latest technology trends and integrate approaches from various fields to develop innovative and sustainable solutions.

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