Clustering algorithms for Wireless Sensor Networks based on Fuzzy logic: A literature survey

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Abstract : The challenge of extending lifespan of the wireless sensor networks has led to enlarged research awareness from the researchers. Cluster-based routing methods are most suitable for extending their lifespan. Several fuzzy logic based solutions have been gained a great success for implementing the clustering algorithms in sensor networks. We present a taxonomy and general classification of published clustering algorithms for wireless sensor networks based on fuzzy logic. We survey diverse clustering algorithms based on fuzzy logic; focusing their purposes, characteristics, complexity, etc. We also evaluate of these algorithms based on metrics such as network type, input variables, clustering method, mobility inter and intra communication methods and base station position.

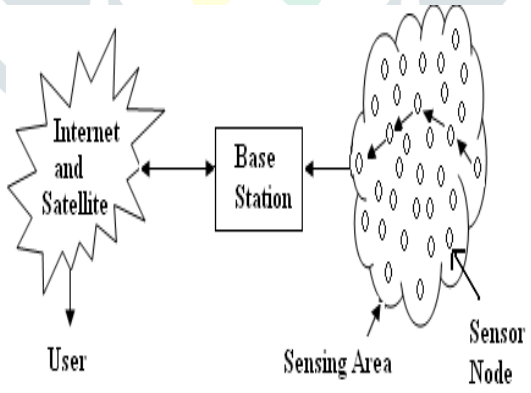
Index Terms **- wireless sensor networks; lifespan; clustering algorithms; fuzzy logic.**

I. INTRODUCTION

Wireless Sensor Network (WSN) is made up of several hundred or thousands of small nodes. Constituent small nodes are entitled with sensing, computation, and wireless communications capabilities [1]. Basic schematic of WSN model is as shown in Fig.1.Area where sensor node are deployed is called sensing area. Nodes may be deployed in either of two ways i.e. Randomly or installed manually. Sensor nodes performs the accumulation of data from the sensing area, process it, and revert the same wirelessly in either directions i.e other nodes or to an external base station. Base station is a central point of control the network. It can be fixed or mobile and connected to the accessible communication infrastructure or to the internet as to enable to access the available data

WSNs have found for a variety of application areas including health, military, home etc. They are as well employed in monitoring of inaccessible environment applications [2, 3]. In that application, changing or yet refilling the attached battery with the node is not feasible Cluster-based routing techniques are most suitable for lengthening the lifespan of these networks [4-6].

The challenge of prolonging the lifespan of WSNs has led to enlarged research awareness from the researchers. Accordingly researchers have recommended various schemes such as duty cycling [7-9], data diminution [10-12], and topology management [13-15] etc for increasing the lifespan of the network.



II.

Fig. 1**:** WSN model

In Fig. 2, we can see the architecture of a clustering [16-17].

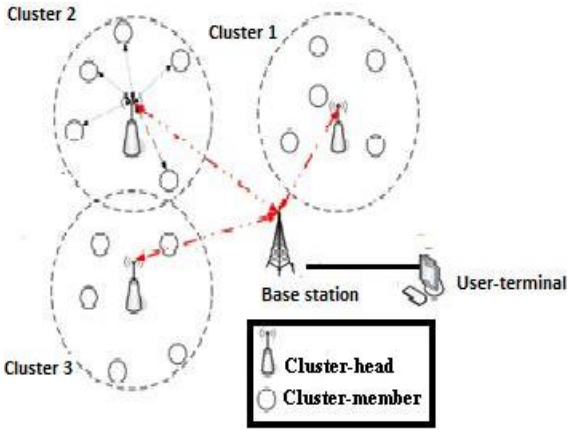


Fig. 2: General architecture of clustering

Cluster-head: It assembles and combined data from its members and transmits or receives data from nearby cluster-head or base station.
Cluster Member: It is a member that associates to a specific cluster. It sends its gathered information to its head.
Base Station: It makes available communication link between network and the user.
User: The information obtained from the networks is very useful for various applications. Hence, a specific application may make use of the network data over the internet or even a desktop computer.
Low Energy Adaptive Clustering Hierarchy (LEACH) is a renowned clustering scheme in WSN [18]. Here, heads of clusters are selected with random probability. This protocol could gain partial success because it is entirely distributed protocol. In distributed protocol, more energy is required to transmit the packet. The paper presented in [19] attempted to resolve the problem of non-uniform load allocation of heads. But the [19] requires node positioning system like GPS that causes the system to be more expensive. Authors in paper [20] presented a novel thought that depends on thresholds for transmitting node's data. Nevertheless, to analyse the accurate value of these thresholds is very tough in view of the fact that this method is not suitable for supervising applications wherever information is regularly communicated to the base station.
Artificial neural networks, genetic algorithm, fuzzy logic, ant colony optimization, and swarm intelligence has been recommended for clustering in WSNs [21-22]. Fuzzy logic is one of the most appropriate problem-solving methodologies among these methods. Fuzzy logic handles with unexpected circumstances and incomplete data like human intelligence. This manuscript is an effort to comprehensively literature survey and significantly discusses the major well-known published fuzzy based clustering methods that have been implemented for WSNs. The motives of this review can be encapsulated as follows: (1) Aware to the researchers of the existence and of the typically excellent performance of ample fuzzy based clustering algorithms in WSNs; (2) To assist the audience as well as to make available a sound framework by a detailed taxonomy of fuzzy based clustering algorithms; (3) To emphasize the strong points and weak pointes of the published algorithms; (4) To facilitate application designers recognize substitute solutions and decide on suitable methods by assessment of diverse clustering algorithms.
The remainder of this paper is as follows: basics of fuzzy logic are discussed in Section 2. Related works are explained in Section 3. Fuzzy based clustering algorithms are reviewed in Section 4. A comprehensive comparison of the schemes is carried out in Section 5. Conclusion is given in last section.

III. FUZZY LOGIC

The term *fuzzy logic* was foremost introduced by Lotfi Zadeh in the 1960s at university of California, Berkeley [23]. He was struggling with the problem of computer recognizing of natural language. Fuzzy Logic is a technique of reasoning that is similar to human reasoning. The approach emulates the mode of decision making in human brains that involves all transitional possibilities between digital values YES and NO.

It is a suitable resolution for the complex procedure of cluster-head selection phase in WSNs [24-26]. Structure of a fuzzy system is shown in Fig. 3. The system consists of four fundamental elements; fuzzifier, inference engine, rule base, and defuzzifier. Initially crisp data is given to fuzzfier where it converts input data into a suitable set of linguistic values. Then the converted data is given to inference engine. The rule base of a fuzzy logic includes a set of fuzzy rules. The inference engine is employed in order to form inferences and build conclusions from the fuzzy rules. Then, the output of inference engine is sent to the defuzzication unit. During the defuzzification process, a space of fuzzy actions is mapped into a space of crisp actions.

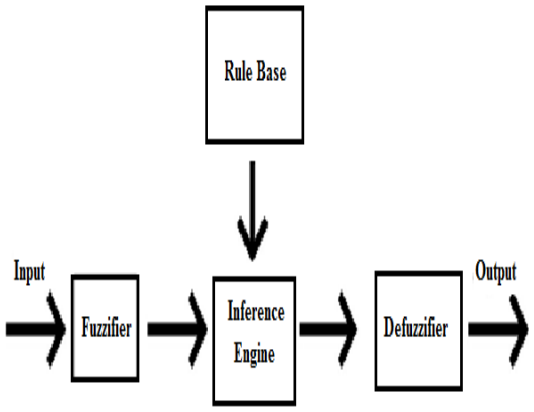


Fig. 3: Structure of a fuzzy system

IV. Related Work

We analysis various review credentials in the area of fuzzy based clustering algorithms for WSNs. These surveys are typically outdated or have some weakness. We refer to a manuscript as 'outdated' if it surveyed published papers before 2012 only. We summarize the earlier reviews in Table 1 that shows their major contributions and weakness. A survey of fuzzy based clustering algorithms for WSNs was presented by Singh et al. [27].

Table 1. Summary of earlier reviews on Fuzzy based clustering algorithms in WSNs

Year	Reference	Main contributions	Weakness
2013	Singh et al. [27]	Categorized all algorithms into two major groupings; type-1 fuzzy set and type-2 fuzzy set	• Outdated Survey
2013	Kumari et al. [28]	Describes only fuzzy variables for cluster-head selection for each surveyed paper	• Outdated Survey
2014	Nejad et al. [29]	Summaries only two papers of fuzzy logic based clustering	• Outdated Surveyed
2014	Chandra et al. [30]	Short survey on Ant and Fuzzy Clustering	• Emphasizing more on Ant clustering
2015	Kaur et al. [31]	Short survey on fuzzy based clustering	• Only definitions are given • Not presented the merits and demerits
2015	Mishra et al. [32]	Short survey on fuzzy based clustering	• Only definitions are given • Not presented the merits and demerits

The authors of that survey described some important fuzzy based clustering algorithms for WSNs. The paper categorized all algorithms into two major groups; type-1 fuzzy set and type-2 fuzzy set. Fuzzy rules are also described for the surveyed papers. Kumari et al. [28] surveyed fuzzy logic based clustering in 2013. Paper describes only fuzzy variables for cluster-head selection for each surveyed paper. Nejad ae al. [29] summaries only two papers of fuzzy logic based clustering. A short survey in this area is done by Chandra et al. [30] where the focus is given on Ant clustering. Another survey is given by Kaur et al. [31] and Mishra et al. [32], however only definitions are provided in the survey.

V. Fuzzy based clustering algorithms

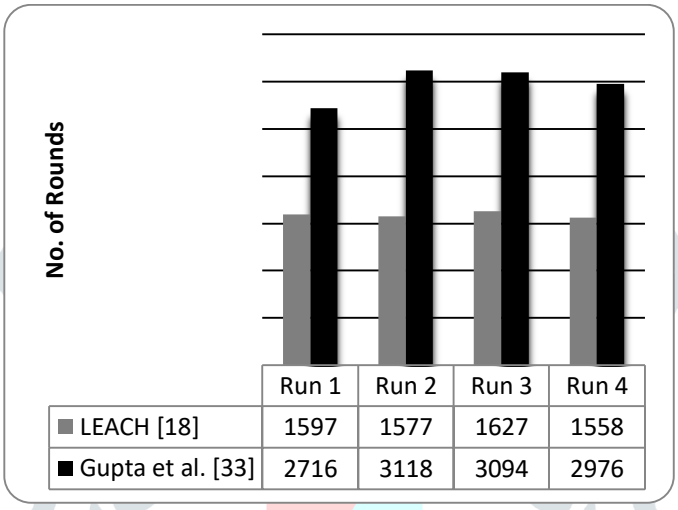
In this segment we present a literature survey of state-of-the-art of Fuzzy based clustering algorithms for WSNs.

2.1 Novel approach for Cluster Head election

First fuzzy logic based clustering is described by Gupta et al. [33]. It is a centralized clustering algorithm. Base station computes chance value for all sensor nodes with the help of three fuzzy input variables: node energy, node concentration, and node centrality. The algorithm is divided into two phases. In the first phase, base station collects information of the sensor nodes and selects suitable cluster head candidates according to their chance values.

The algorithm compares the result with LEACH for first node dead metric for four runs. With simulations it is observed that in case of LEACH, first node is dead in 1597 rounds in Run1, 1577 rounds in Run2, 1627 rounds in Run3, 1558

rounds in Run 4 respectively. In case of [33], first node is dead in 2716 rounds in Run1, 3118 rounds in Run2, 3094 rounds in Run3, 2976 rounds in Run4 respectively. Fig. 4 shows the metric first node dead for each Run. However limitations of this algorithm are many such as 1) this algorithm is for small scale networks. 2) All nodes should be equipped with GPS 3) Overhead is produced due to periodical collection of information by the base station. 4) An optimal number of cluster heads needed in the network is not mentioned. 5) Cluster heads failure issue is not addressed.



	Run 1	Run 2	Run 3	Run 4
LEACH [18]	1597	1577	1627	1558
Gupta et al. [33]	2716	3118	3094	2976

Fig. 4 Metric first node dead for each Run

2.2 Cluster Head Election Mechanism Using Fuzzy Logic (CHEF)

Kim et al. [34] presented distributed approach to select the cluster-heads; selection of cluster-heads is carrying out in the vicinity at the node level. The fuzzy output is estimated by means of two input parameters: node energy and local distance. The algorithm compares the result with LEACH for first node dead metric and simulation results show that CHEF is about 22.7% more competent than LEACH.

However, algorithm does not consider energy consumption in information exchange between nodes. Cluster heads are not evenly distributes in the network; if cluster heads are concentrated on one side of a network, then that side's cluster heads have to serve more members than low concentrated region's heads. Thus the probability of cluster heads failure increases.

2.3 Cluster Head Selection using a Two-Level Fuzzy Logic

Torghabeh et al. [35] utilized two-level fuzzy logic to assess the criterion of sensors to become a cluster head. First level is known as local level where cluster heads are selected on the basis of their energy and number of neighbours. In second level also known as global level, nodes' overall cooperation is considered in the whole network with three fuzzy parameters. These parameters are centrality, proximity to base station and distance between cluster heads.

The algorithm compares results with LEACH [18], Gupta et al. [33] , Kim et al. [34] and demonstrate that the proposed approach consumes fewer energy and enlarges the network lifespan about 54% compared with other algorithms. The algorithm does a fair load distribution throughout the network, however overhead for calculating the chance to become cluster head enhances due to two-level computation.

TABLE II. Comparative Analysis of Different Fuzzy Based Clustering Methods in WSN

Algorithm	Clustering method	Network Type	Input Variables	Inter-cluster Comm	Intra-cluster Comm.	Mobility	Node deployment	Base station location
Gupta et al. [33]	Centralized	Homogenous	• energy • concentration • centrality	Direct	Direct	Stationary	Random	Inside deployment area.
Kim et al. [34]	Distributed	Homogenous	• Energy • Local distance	Direct	Direct	Stationary	Random	Inside deployment area.
Torghabeh et al. [35]	Centralized	Homogenous	• energy • number of neighbours • centrality • distance between heads	Direct	Direct	Stationary	Random	Outside deployment area.
H. Bagci et al. [36]	Distributed	Homogenous	• Distance to Base • Residual Energy • Competition Radius	Direct	Direct	Stationary	Random	Inside deployment area.
G. Ran et al. [37]	Centralized	Homogenous	• Battery • distance • node density	Direct	Direct	Stationary	Random	Inside deployment area.
H. Taheri et al. [38]	Distributed	Homogenous	• node degree • centrality	Multi-hop	Multi-hop	Quasi-Stationary	Random	Inside deployment area.
Energy Aware Distributed Clustering using Fuzzy Logic	Centralized	Homogenous	• node degree • centrality	Multi-hop	Multi-hop	Stationary	Random	Outside deployment area.
Fuzzy power-optimised clustering routing algorithm	Centralized	Homogenous	• degree of centralisation • between node and base station	Direct	Direct	Stationary	Random	Inside deployment area.
Fuzzy Logic Based Clustering Combined With Mobile Sink	Centralized	Homogenous	• Residual Energy • Local Distance	Multi-hop	Multi-hop	Quasi-Stationary	Random	Inside deployment area.
Energy based Clustering Heterogeneous WSN	Centralized	Heterogeneous	• Energy • distance	Multi-hop	Multi-hop	Mobile	Random	Inside deployment area.
Two-tier distributed fuzzy logic based protocol	Distributed	Homogenous	• relative node connectivity • distance to the base station, • Remaining node energy.	Multi-hop	Multi-hop	Quasi-Stationary	Random	Outside and Inside deployment area.

4.4 Energy-Aware Unequal Clustering with Fuzzy

Proposed algorithm [36] intends to diminish the intra-cluster effort of the heads especially whichever near to the base station or contain little residual battery power. The algorithm does not equal distribute the clusters. The algorithm gets three input fuzzy parameters; distance to base station, residual energy, and competition radius. The algorithm does not equal distribute the clusters.

Results are compared for metrics; first node dies, and half of the nodes alive with LEACH [18], and, Kim et al. [34]. With the results for first node dies metric [36] is more competent than [18] by 129.5%, [34] by 154.5%. For half of the nodes alive metric [36] is more competent than [18] by 31.3%, [34] by 6.0%.

4.5LEACH-Fuzzy Logic

LEACH-Fuzzy Logic [37] is a centralized algorithm which works out the possibility for selecting the heads on the basis of battery level, distance and node density. The node that obtains high chance is selected as head. The algorithm gets better results than LEACH for metric energy consumption and number of living rounds.

4.6Clustering Protocol using Fuzzy logic (ECPF)

ECPF [38] have taken node degree and node centrality as input variables. Firstly, every node computes its cost. Then a delay timer is set by every node that is relative to its inversed residual energy. Consequently, node that has superior residual energy must wait a lesser time than the nodes that has lesser energy. Node broadcasts a provisional head proclamation inside its range. If this particular node has the least cost among the provisional heads in its propinquity, it will turn out to be an ultimate head.

Simulations result is compared with LEACH [18], and, Kim et al. [34] for metric; first node dies, half nodes alive, last node alive, and dissipated energy. ECPF outperforms than other compared algorithms. ECPF is a scalable clustering protocol in terms of the number of nodes and the network size.

4.7 Energy Aware Distributed Clustering using Fuzzy Logic (EADC-FL)

Algorithm [39] selects head of cluster two-folds. Firstly energy of the nodes is taken into concern for heads selection. Afterward, node degree and node centrality is utilizes by using Fuzzy Logic to spot the ultimate heads. Presented approach solves clustering problem in distributed way.

Algorithm [39] executes clustering on demand for decreasing the energy dissipation due to the overhead of repeated clustering phases. The results reveal that [39] considerably diminishes the consumption of energy and lengthen the lifespan of network with non-uniform node distribution.

4.8 Fuzzy power-optimised clustering routing algorithm

The algorithm [40] select the head by various parameter iteration amongst the similar grouping, and optimise the cluster composition with a deliberation of factors such as degree of centralisation, distance between node and base station. At last, fuzzy logic is used to regulate the transmission power of cluster nodes animatedly to minimise the energy consumption.

Simulations results demonstrate for metrics average number of surviving nodes, average number of data received at the sink node, average total energy consumption. Compared with LEACH, the time that the first node dies is prolonged by about 160 rounds, The algorithm [40] is improved by about 183.9 % than LEACH for metric average number of data received at the sink node. The total energy consumption rate of [40] is less than that of LEACH by about 46.5 %.

4.9 Fuzzy Logic Based Clustering Combined With Mobile Sink

The algorithm [41] unites mobile sinks by fixed-path sink with fuzzy clustering algorithm. Algorithm provides two proposals. Suggestion 1 offers a resolution to the problem of movable sink in hierarchical sensor networks. The movable sink begins at a preset position and follows a pre-planned moving path. Suggestion 2 offers a resolution to advance the proposed Suggestion 1 in improved clustering selection. The cluster head corresponds with the sink. Selection of heads was executed by using a fuzzy logic-based approach. The heads were selected on the basis of two input Fuzzy Inference System parameters: residual energy, the local distance of each node.

Simulation results are compared with LEACH [18], and Kim et al. [34] for number of alive nodes and found better results. It is found that for homogenous environment, [41] is more efficient.

4.10Energy based Clustering Heterogeneous WSN

The algorithm [42] has taken heterogeneous network. It is centralized algorithm where base station selects the heads of all clusters. Algorithm works on mobile network where nodes are randomly distributed. Algorithm proves to be more efficient than static homogenous environment. However the cost of mobile nodes and base station enhances the cost of hardware. Algorithm compares its simulation results for throughput and average residual energy.

4.11Two-tier distributed fuzzy logic based protocol

S. Sert et. al. [43] proposes a protocol to advance the effectiveness of data fusion operations in multi-hop sensor networks. Algorithm takes relative node connectivity, distance to the base station, and remaining node energy parameters in the election of heads. It divides clusters with unequal size. Algorithm also finds the energy-efficient path for data transmission. It takes average link remaining energy as important factors for the selection of a path.

S. Sert et. al. [43] compares three metrics: first node dead, half node dead and total remaining energy with state of art algorithms. Performance of [43] much better than the compared protocols and conserve its scalability when quantity of nodes augments.

VI . COMPARATIVE ANALYSIS OF SOFT COMPUTING BASED CLUSTERING

This literature investigation illustrates that all of the various fuzzy based clustering techniques has its individual assumptions, head selection criteria, benefits and shortcomings. We recapitulate them in Table II. In the former column, we indicate the section number in which each protocol is explained. Type of clustering (centralised or distributed) is mentioned in second column. Third column is for Network type. Fifth column defines the input fuzzy variables. Sixth column mentioned the Inter-cluster communication method. Seventh column mentioned the cluster-head to base station routing approach. Seventh column explain the all sensor nodes are stationary, quasi-stationary or mobile after deployment. Next column defines about the deployment of nodes in the targeted region. Last column tell about base station location in the network.

VII. CONCLUSION

Clustering in WSNs is a burning research issue. It has growing outcomes within recent years. In this paper, we have carried out a comprehensive literature survey of fuzzy based clustering methods for WSN. In this review work we made an effort to compare the above mentioned algorithms on different parameters. Moreover fuzzy logic along with other computational methods could be combined to form hybrid techniques for energy efficient clustering protocols.

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