A Comparative Study on Fuzzy and Neuro-Fuzzy Enabled Cluster Based Routing Protocols for Wireless Sensor Networks

Y. Harold Robinson, E. Golden Julie

Abstract**—**Dynamic Routing in Wireless Sensor Networks (WSNs) has played a significant task in research for the recent years. Energy consumption and data delivery in time are the major parameters with the usage of sensor nodes that are significant criteria for these networks. The location of sensor nodes must not be prearranged. Clustering in WSN is a key methodology which is used to enlarge the life-time of a sensor network. It consists of numerous real-time applications. The features of WSNs are minimized the consumption of energy. Soft computing techniques can be included to accomplish improved performance. This paper surveys the modern trends in routing enclose fuzzy logic and Neuro-fuzzy logic based on the clustering techniques and implements a comparative study of the numerous related methodologies.

Keywords**—**Wireless sensor networks, clustering, fuzzy logic, neuro-fuzzy logic, energy efficiency.

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I. INTRODUCTION

IN WSNs, routing consists of both heterogeneous and homogeneous systems with a huge number of tiny devices called sensor node. Each device will have the responsibility of sensing, computation and secure communication [1], [85]. Devices are cooperating to each other and the sensor will autonomously sense the data. Two components are used in the wireless network aggregation; point and base station [3]. Further, nodes have rigorously limited computation, storage and power capabilities. However, they will tolerate numerous challenges [6]. The position of sensor nodes cannot be pre-determined because they are deployed randomly. The sensors are battery driven and deployed in unmanned environments, requiring energy conservation. The sensors are mostly mobile [2]. Static routing algorithms fail in WSNs. Random deployment may result in holes which are regions without enough working sensors. Clustering is one of the techniques to extend the network lifetime. In a clustering protocol, the geologically neighboring nodes are gathered into virtual groups called "clusters" [9], [65].

Each cluster has one Cluster Head (CH) and other nodes are called cluster nodes. Instead of direct communication with the destination, all the cluster nodes send data to the CH [88]. Clustering algorithms can be based on some criteria like battery nodes power, mobility, network size, speed, distance and direction [4], [5].

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Low Energy Adaptive Clustering Hierarchy (LEACH) is one of the most well-known energy efficient clustering algorithms for WSNs [7], [66]. The operation of LEACH has two stages; setup phase and steady phase. To minimize the packet overhead, the steady-state segment considers data aggregation [12] for secure transmission. Besides LEACH, various clustering algorithms have been proposed for homogeneous WSNs [8], [86]. Fig. 1 illustrates the architecture for the WSNs.

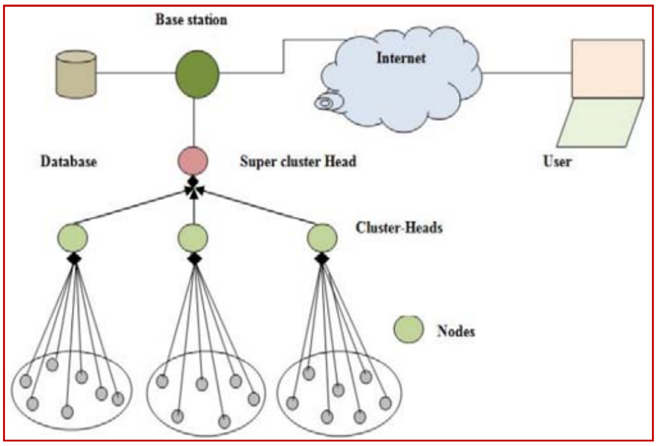

Fig. 1 Architecture of WSNs

II. ROUTING PROTOCOLS

Routing is the process of forwarding data from source to destination. Routing occurs in network layer. Routing involves two activities. One is identifying the path for forwarding the data; second is transferring the packet without error [10], [11], [87]. A lot of attributes to the sink will select the best path for transfer the packet using packet control messages [15], [76]. Subsequently, transferring packet from the source to the destination also hold various attributes for forwarding data successfully. Each packet should deliver the data without any error or security issues to the destination for finding optimal path [18], [77].

The delivered packet uses some standard metric to evaluate the correct and efficient path [89]. They are, Flat network routing, Hierarchical routing, and Location based routing as shown in Fig. 2.

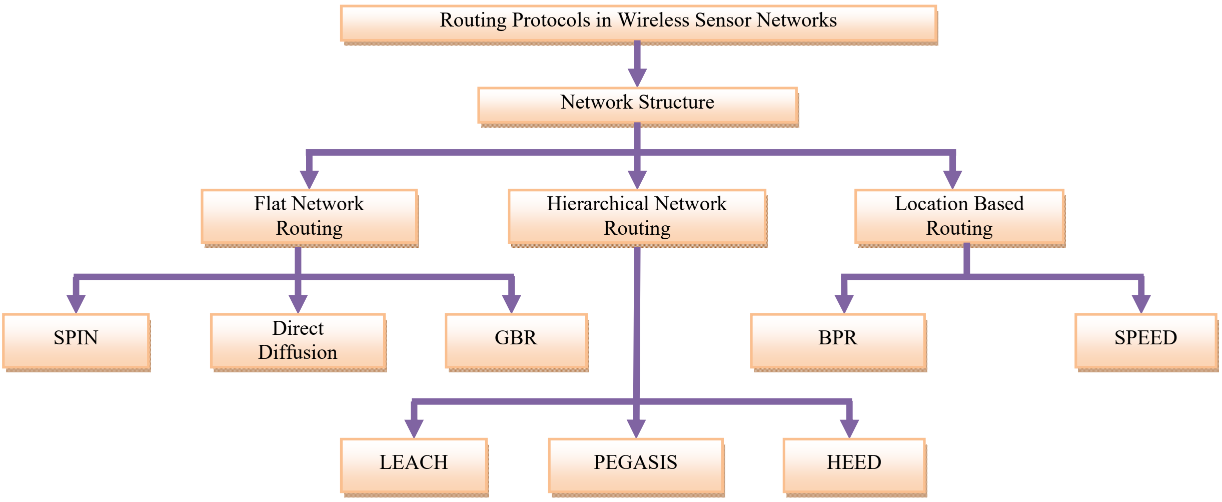

Fig. 2 Taxonomy of routing protocol in WSN

A. Flat Network Routing

Flat network routing consists of larger number of nodes in a network. Due to larger network size the node will not have general identifier. Some of the Flat network routing algorithms are SPIN [40], Directed diffusion [41], GBR [43].

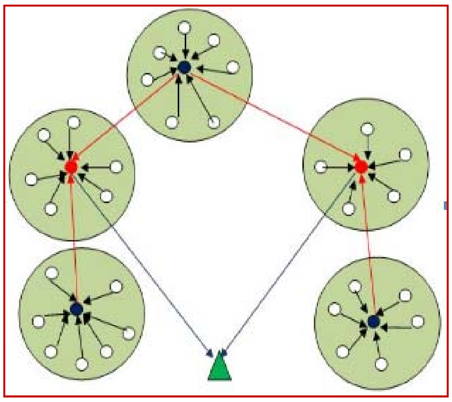

Fig. 3 Cluster Formation in WSN

B. Hierarchical Network Routing

Hierarchical routing or cluster based routing is a layer routing protocol. It utilizes energy in an efficient manner, it improves overall system scalability. It consists of two layers in formal model, in which one layer is responsible for selecting the CH and the other layer is responsible for routing. This is used for lower energy consumption. Examples are LEACH [46], HEED [44].

C. Location Based Routing

In location based routing, sensor nodes are addressed by means of their location, the location may be available from GPS. Sensor node consists of small GPS receiver for communicate [67]. It is equipped with scheduling the node for sleep (ideal) to improve energy. Node distances are calculated by their signal strength. Example: GRF [42].

III. Cluster Based Routing Protocol

Traditional routing protocols for WSN are used for energy efficiency and load balancing. Clustering is used for energy efficiency and reducing overhead [25], [28].

A. LEACH

LEACH has two phases. The first one is setup phase and the other is steady state phase. In the setup phase, LEACH selects randomly some nodes as a CH without any predetermined fraction of nodes. The threshold T(n) is computed based on an equation that integrates the valuable percentage to suit a CH, the set of nodes, and the current nodes that have not been selected as a CH in the last (1/P) rounds, it is denoted by G. It is given by,

$$T(n) = \frac{p}{1-p(r \bmod (1/p))} \text{ if } n \in G \quad (1)$$

where, G is the set of nodes that are involved in the CH election [26], [29]. During the steady phase, each CH collects the sensed data from the member node and aggregates them [90].

B. PEGASIS

The enhancement of LEACH protocol is called as Power Efficient Gathering in Sensor Information System (PEGASIS). It consists of chain based clusters. All the nodes can communicate with its neighbor nodes in the chain. The chain construction is based on greedy fashion. Other nodes in the chain start receiving data and send the data to its next neighbor after aggregating the data. Sink node will receive data from the leader. Multi-hop routing is done in PEGASIS. There is delay in the chain for the nodes which are far away from the leader node [32].

C. Threshold Sensitive Energy-Efficient Sensor Network Protocol (TEEN)

TEEN protocol is used for time critical applications. It uses a data centric mechanism [63]. Sensor node senses the medium continuously. The minimum possible value of an

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attribute is known as hard threshold. Message transmission consumes less energy. This process will remove burden from the CH [34].

D. Geographic Adaptive Fidelity (GAF)

GAF [22] has three states; (i) detection, (ii) active and (iii) sleeping. Every node starts with the detection state [35].

TABLE I
CLUSTER ROUTING PROTOCOLS IN WSNS

Protocol Name	Cluster Stability	Delivery Delay	Scalability	Algorithm Complexity	Energy Efficiency
LEACH	Medium	Very Small	Very Low	Low	Very Poor
HEED	High	Medium	Medium	Medium	Medium
PEGASIS	Low	Very Large	Very Low	High	Poor
TEEN	High	Small	Low	High	Very High
GAF	Medium	Poor	High	Medium	Medium

IV. SOFT COMPUTING TECHNIQUES

Soft computing could be a branch of engineering that has its inspiration from nature. In control system engineering, formal logic primarily based controller provides higher performance than standard controllers. Recently, several fuzzy based clustering algorithms [21], [10] have been proposed which ensure lower energy consumption.

A. Fuzzy Logic

A fuzzy inference system is based on fuzzy set theory for computing framework. The basic structure of fuzzy rule base system consists of three parts [60], [69]. They are rule based, database and reasoning mechanism [57], [70]. Fig. 2 illustrates the procedure.

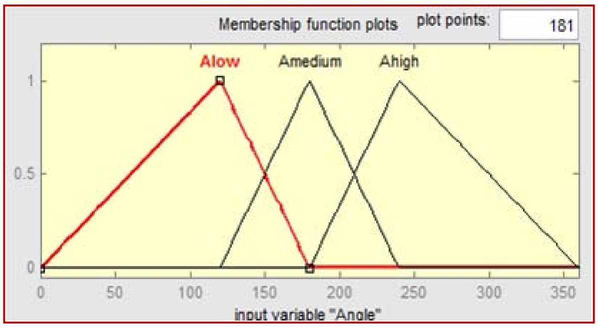

Fig. 4 Membership function for Angle

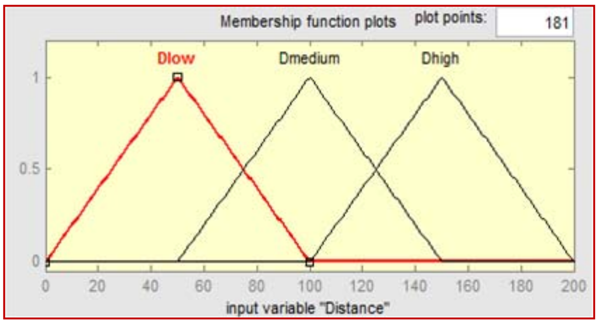

Fig. 5 Membership function for Distance

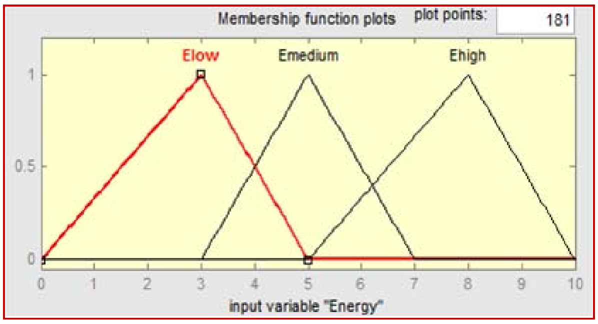

Fig. 6 Membership function for Energy

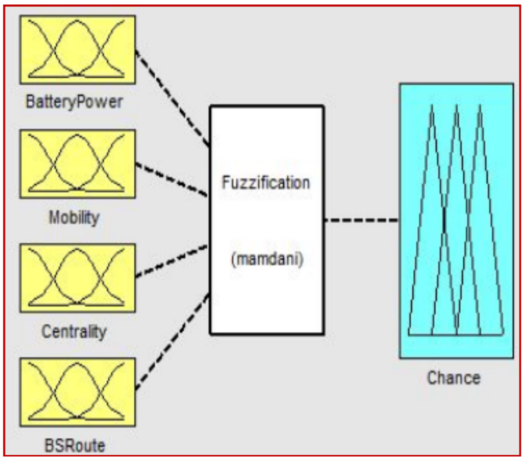

Fig. 7 Membership function for Fuzzification using Mamdani

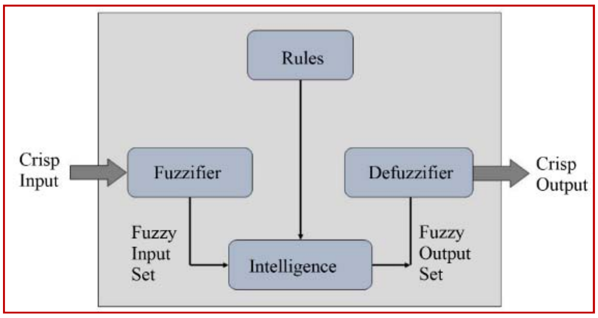

Fig. 8 Architecture for Fuzzy Logic

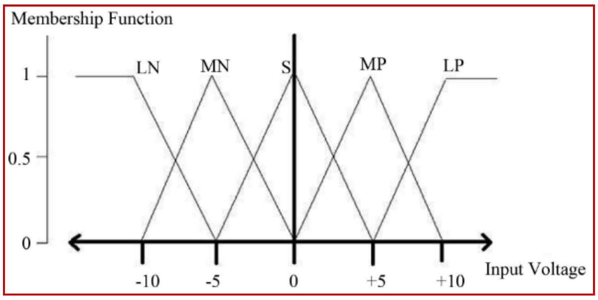

Fig. 9 Membership Function

Fuzzy logic consists of a decision making approach which works similarly to human control logic, which provides a simple method to reach a conclusion from imprecise, vague, or ambiguous input information [13], [17], [71]. The

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execution of a fuzzy logic system will reduce the computation problem compared to the conventional mathematical methods [14], [19].

The fuzzy rules and fuzzy reasoning are the backbone of fuzzy inference system [23]. It consists of a series of IF-THEN rules that relate the input fuzzy variables with the output fuzzy variables using linguistic variables (modeling human thinking) [16], [20].

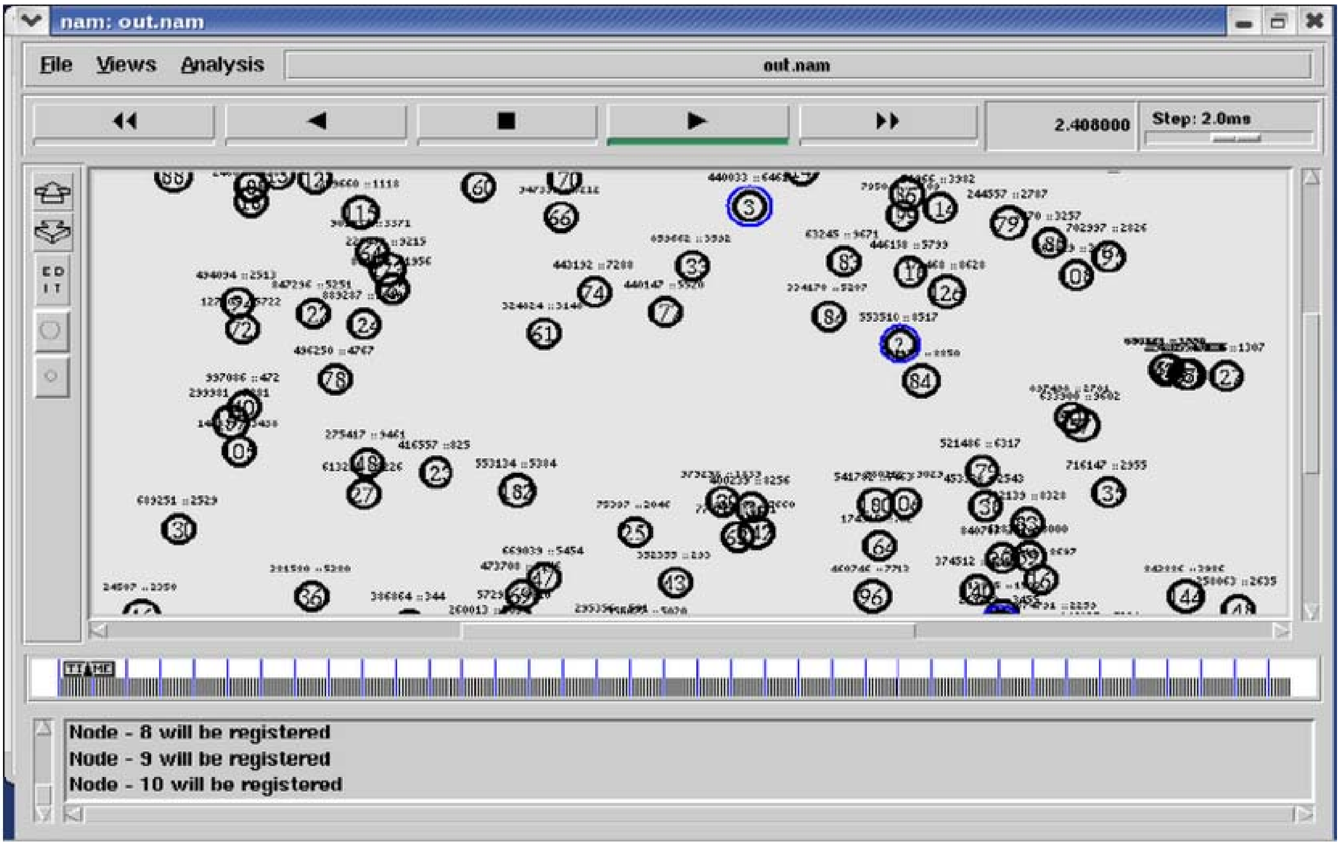

Fig. 10 Output File

V. Cluster Based Protocol Using Fuzzy Logic

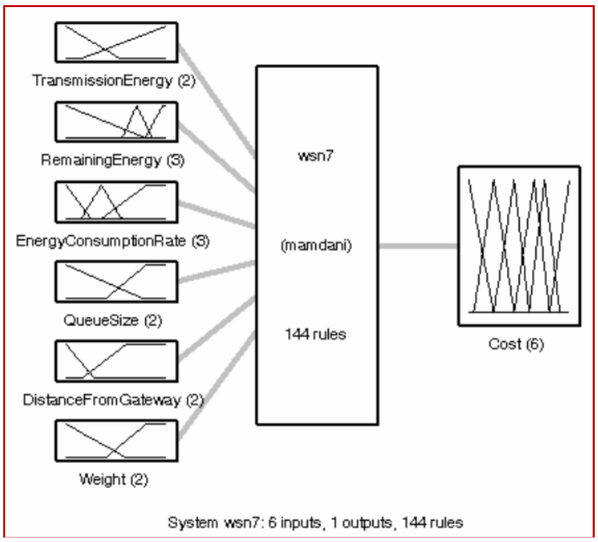

Fig. 11 Fuzzy System Model

In general, fuzzy logic is a multi valued logic, by which intermediate values can be defined using expressions such as true/false, high/low, below/above, etc. [37], [72], [73]. The most common fuzzy logic inferences are the Mamdani and Tsukamoto-Sugeno methods [38].

The input of a Mamdani fuzzy logic system is usually a crisp value. Mamdani uses the centroid technique which tries to determine the point where a vertical line divides the combined set into two equal parts [24]. Fig. 5 displays our fuzzy model.

VI. CH Selection Based Protocol Using Fuzzy Logic

In Cluster Head Election using Fuzzy (CHEF) logic approach [47], the CH selection is based on two parameters: One is energy remain of the node (initial all nodes having same energy), second parameter is local distance (it is based on the signal receiving strength) and output parameter is chance (tentative CH) using fuzzy if then rule. CH election is based on fuzzy rule among all sensor nodes in the network. By using fuzzy logic, the computational overhead is reduced and prolongs the network lifetime [75].

A. Fuzzy Multi Constraint Routing

The fuzzy multi constraint routing protocol [59] consists of many constraints like collision, traffic level, buffer occupancy, battery power etc. Only one constraint is not enough for selecting CH.

TABLE II
RULE-BASE FUZZY INFERENCE SYSTEM

RULE NO.	INPUT PARAMETERS			OUTPUT
	ANGLE	DISTANCE	ENERGY	CHANCE
1	Low	Low	Low	Medium
2	Low	Low	Medium	Medium
3	Low	Low	High	High
4	Low	Medium	Low	Low
5	Low	Medium	Medium	Medium
6	Low	Medium	High	Medium
7	Low	High	Low	Low
8	Low	High	Medium	Low
9	Low	High	High	Medium
10	Medium	Low	Low	Low
11	Medium	Low	Medium	Medium
12	Medium	Low	High	Medium
13	Medium	Medium	Low	Low
14	Medium	Medium	Medium	Medium
15	Medium	Medium	High	Low
16	Medium	High	Low	Low
17	Medium	High	Medium	Low
18	Medium	High	High	Medium
19	High	Low	Low	Low
20	High	Low	Medium	Low
21	High	Low	High	Low
22	High	Medium	Low	Low
23	High	Medium	Medium	Medium
24	High	Medium	High	Low
25	High	High	hLow	Low
26	High	High	Medium	Low
27	High	High	High	Medium

B. Improved Fuzzy Unequal Clustering

Improved fuzzy unequal clustering [58] approach contains three parameters, energy, distance and density, as input variables and output variables are chance and radius as shown in Table V. A simulation result shows better improvement in the network life time.

C. FRCA

Fuzzy Relevance–Based CH selection algorithm [61] is developed for wireless mobile ad-hoc sensor networks. It consists of three parameters Energy, Mobility, and Distance. Based on the degree, the node will select tentative CH. It reduces overhead due to flat structure by easy resource management and bandwidth allocation, efficient management of node positions and energy. FRCA improve routing performance.

D. Fuzzy C Means Algorithm (FCM)

It is a centralized clustering algorithm [50]. It uses the highest residual energy and the location information of nodes for selecting CHs. In this one, every point has a degree of belonging to some clusters rather than specifically belonging to single cluster [54]. The fuzzy logic principle is used for computing the degree of belonging to each cluster. This algorithm minimizes the inter-cluster distance. It is a very important tool used for image processing systems. There is better formation of clusters when compared to other approaches because the mean distance of each node to CH is minimized which optimizes the transmission power of non-CH nodes [74]. Fuzzy C-means approach is more useful to distribute the nodes among the clusters and to distribute the loads of the networks [51].

E. Energy-Efficient CH Selection

The energy-efficient cluster head selection (NECHS) mechanism is using fuzzy logic [56]. Table VI demonstrates Rule-Base Fuzzy Inference System for Energy-Efficient CH selection. For defuzzification, centre of gravity method has been used [48].

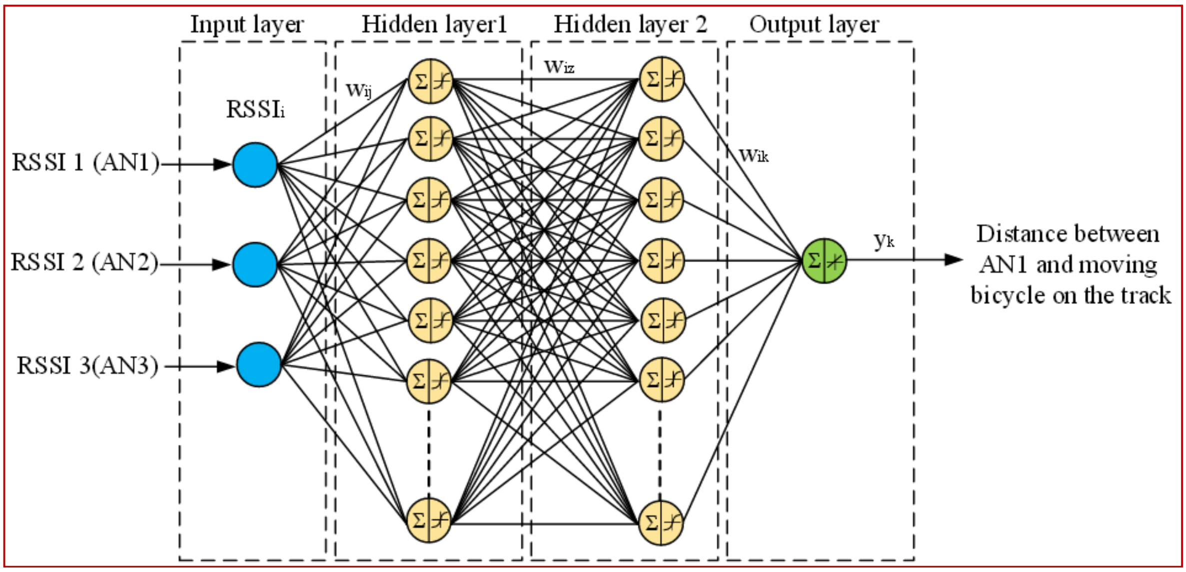

Fig. 12 Artificial Neural Network Model

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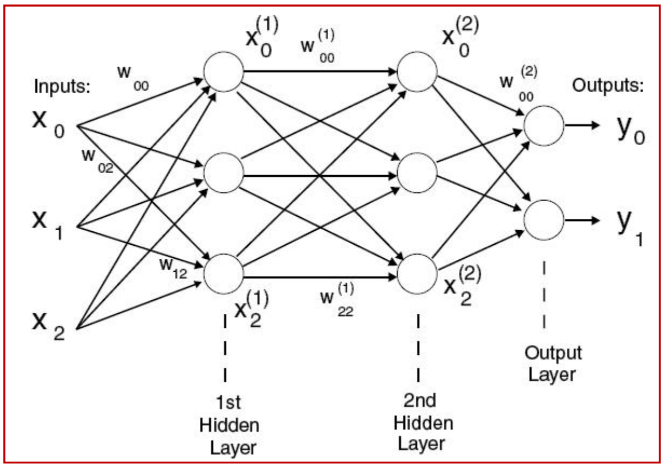

Fig. 13 Feed Forward Neural Network Model

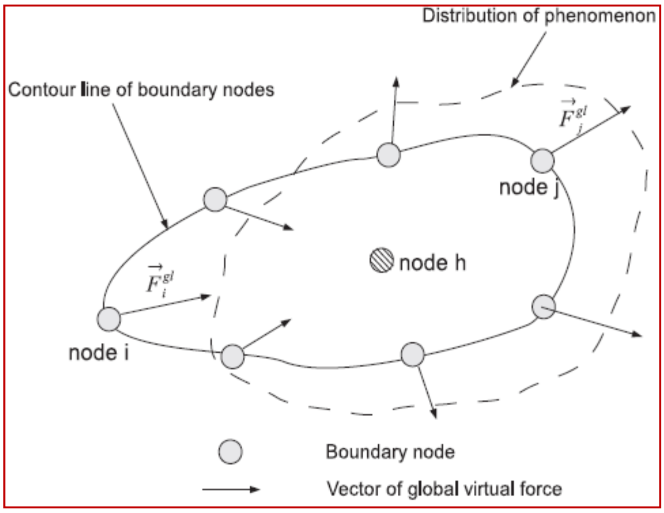

Fig. 14 Routing Model

F. Fuzzy Self Clustering Algorithm (FSCA)

It improves the performance of ACE [52] (an emergent algorithm for highly uniform cluster formation), clustering technique by fuzzy logic based system in each node. FSCA [36] ensures to become a CH by specifying the nodes eligibility (Tables VII and VIII). It is useful when all the nodes within a cluster possess low energy [39]. The clusters are formed with size equal to or greater than the network density then after these clusters migrate away from each other such that the overlap between them is reduced to zero. New clusters might be formed in this process [45], [81], [84].

G. Energy Aware Unequal Clustering Fuzzy Algorithm

The algorithm [49] proposes unequal clustering to overcome the clustering problem. In the first round, CHs are selected based on probabilistic models. In subsequent rounds, heads are selected based on their energy levels. Fuzzy parameters used are residual energy and distance of the nodes as shown in Table IX. Mamdani method is used as the fuzzy inference technique. Linguistic variables for the fuzzy set are close, medium and far for distance to base station whereas for residual energy, the variables are low, medium and high [30]. Nodes can adjust their transmission range. Distance of next node is calculated based on Received Signal Strength. Nodes are all stationary. All the nodes are homogeneous. Node density is not considered [33].

TABLE III
RULE-BASE FUZZY INFERENCE SYSTEM FOR CHEF

Energy	Local distance	Chance
Low	Far	Very Low
Low	Medium	Low
Low	Close	Rather Low
Medium	Far	Medium Low
Medium	Medium	Medium
Medium	Close	Medium High
High	Far	Rather High
High	Medium	High
High	Close	Very High

TABLE IV
RULE-BASE FUZZY INFERENCE SYSTEM FOR FUZZY CONSTRAINT ROUTING

Buffer occupancy	Battery power	Hop count	Grade
Low	Low	Low	0
Medium	Medium	Medium	0
Medium	High	Medium	0
Medium	Medium	High	0
Medium	High	High	0
High	High	Medium	1
High	Medium	High	1
High	High	High	1

TABLE V
RULE-BASE FUZZY INFERENCE SYSTEM FOR IMPROVED FUZZY UNEQUAL CLUSTERING

Input variables			Output variables	
Energy	Distance	Density	Chance	Radius
High	Far	High	High	Little Large
High	Far	Medium	Little High	Large
High	Far	Low	Medium	Large
High	Moderate	High	High	Little Large
High	Moderate	Medium	Medium	Medium
…	……	…	…	…
Low	Near	Low	Low	Small

TABLE VI
RULE-BASE FUZZY INFERENCE SYSTEM FOR ENERGY-EFFICIENT CH SELECTION

Set of node number	Set of remaining energy	Probability of CH selection
Few	Very low	Very low
Few	Low	Very low
Few	Medium	Low
Few	High	Medium
Medium	Very low	Very low
Medium	Low	Low
Medium	Medium	Medium
Medium	High	High
Many	Very low	Low
Many	Low	Medium
Many	Medium	High
Many	High	Very high

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TABLE VII
RULE-BASE FUZZY INFERENCE SYSTEM FOR FSCA INITIAL RULES

Node's Time (T)	Node's Loyal Follower	Initiation Chance
Low	Low, Medium	0
Low	High	1
Medium	Low	0
Medium	Medium, High	1
High	Low, Medium, High	1

TABLE VIII
RULE-BASE FUZZY INFERENCE SYSTEM FOR FSCA MITIGATION RULES

Node's loyal followers	Node's energy	Migration chance
Low	Low, Medium, High	1 ,2, 3
Medium	Low, Medium, High	4 ,5, 6
High	Low, Medium, High	7 ,8, 9

TABLE IX
RULE-BASE FUZZY INFERENCE SYSTEM FOR ENERGY AWARE UNEQUAL CLUSTERING FUZZY ALGORITHM

Distance to base	Residual energy	Competition radius
Close	Low	Very small
Close	Medium	Small
Close	High	Rather Small
Medium	Low	Medium Small
Medium	Medium	Medium
Medium	High	Medium large
Far	Low	Rather large
Far	Medium	Large
Far	High	Very large

VII. CLUSTER BASED PROTOCOL USING NEURO-FUZZY TECHNIQUE

Neuro-fuzzy [55], [79], [80], [82], [83] means combination of neural network and fuzzy logic. The memory, available power, processing speed is the linguistic input variables. The output variable is monitoring coefficient. It works in dense environment. It uses fuzzy logic for increasing the network lifetime as shown in Table X.

A. Cluster Adaptation Method

It gives better performance than statistical en-route filtering. It has been reported by developing fuzzy based system [53], [78]. It gives better routing in sensor networks. The input parameters are Partition Information of Cluster Region (PICR) [62], the Number of Sensors in the Cluster Region (NSCR) [64], Energy of Cluster Head (EOC) [11] and Distance from Cluster to base station (DFC) [31]. The output Fitness of the Cluster with Cluster head (CFWC) [27] is derived using Fuzzy rules. The fuzzy set for CFWC is Stop, Consider and Move.

TABLE X
RULE-BASE FUZZY INFERENCE SYSTEM FOR NEURO-FUZZY

Power	Memory	Processing speed	Monitoring coefficient
Low	Low	Low	Not used
Medium	Medium	Medium	Critical
Medium	High	Medium	Event
Medium	Medium	High	Event
Medium	High	High	Event
High	High	Medium	Continuous
High	Medium	High	Continuous
High	High	High	Continuous

VIII. CONCLUSION

Clustering is an important operation in WSN. In this paper, several fuzzy clustering techniques are analyzed. Comparative table is drawn for those fuzzy clustering techniques. Each has its own merits and demerits. No algorithm is perfectly suitable for commercial purposes. So it is still an open challenge for future research and development.

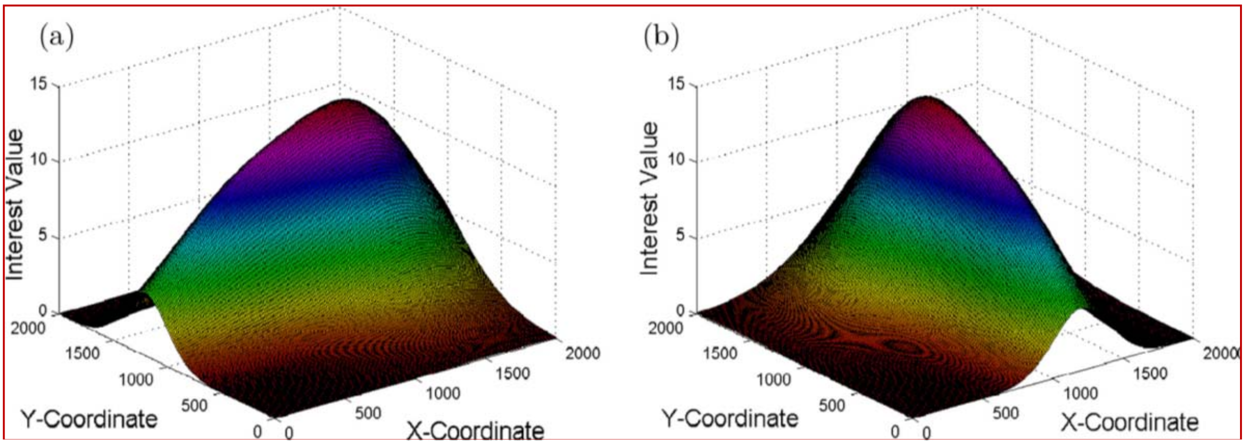

Fig. 15 Interest value

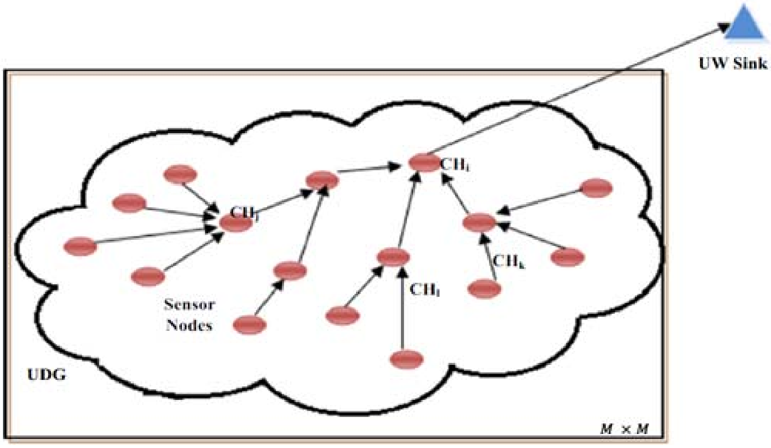

Fig. 16 CH formation

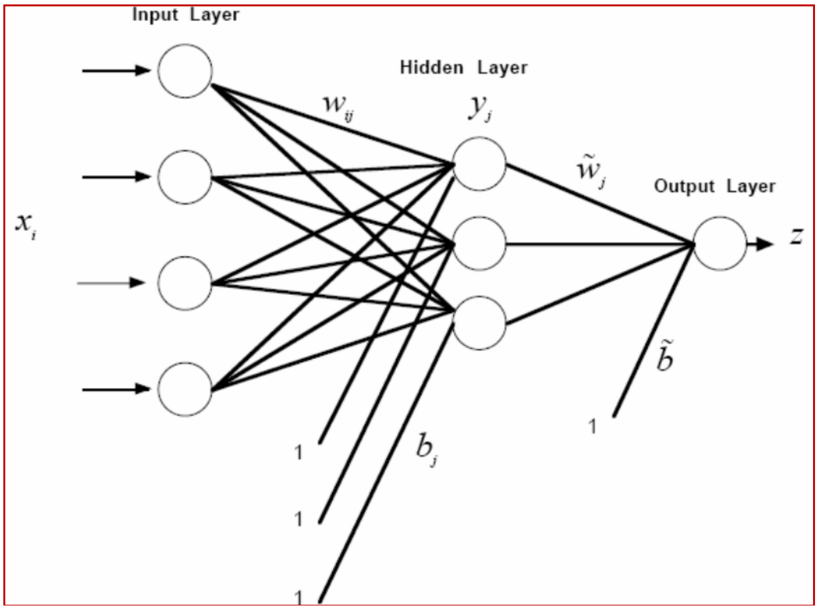

Fig. 17 Non-Linear Regressive Neural Network

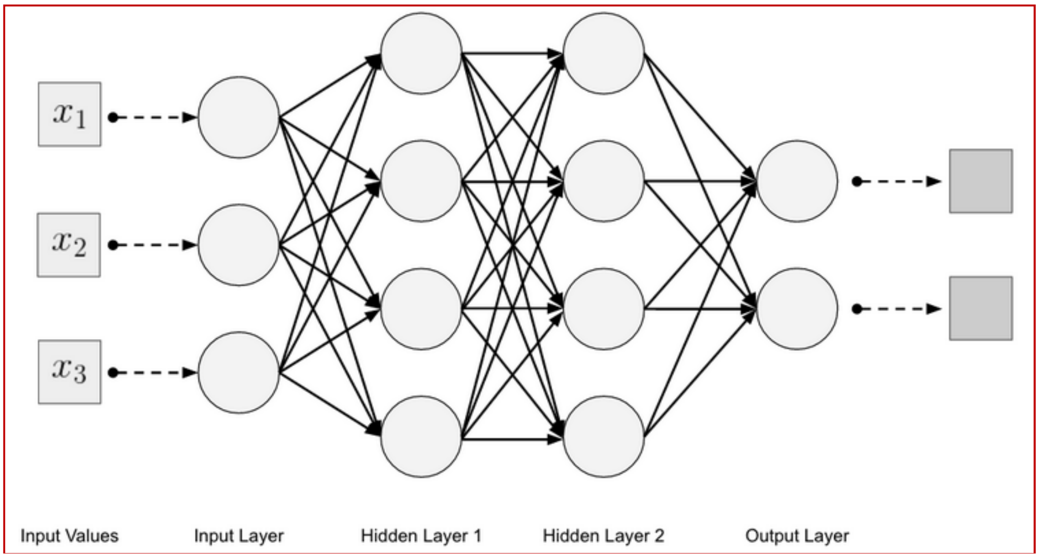

Fig. 18 Linear Regressive Neural Network

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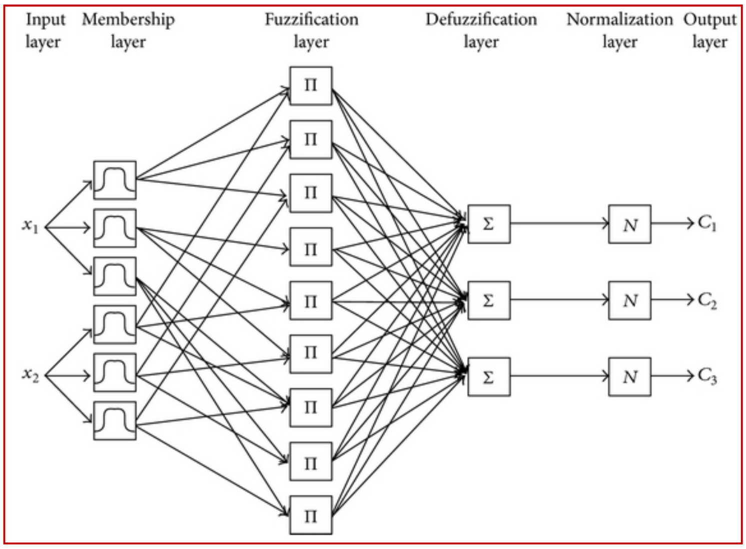

Fig. 19 Neuro-Fuzzy Layers

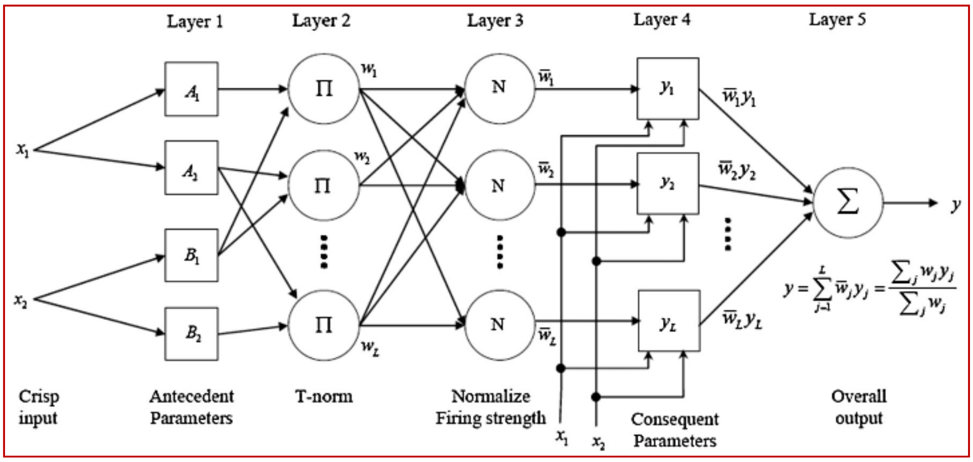

Fig. 20 Architecture of ANFIS

TABLE XI
INPUT AND OUTPUT PARAMETERS OF FUZZY LOGIC BASED CH SELECTION

Algorithm	Fuzzy Logic Type	Input Parameter	Output Parameter	Membership Function for Output Parameter	Features
CHEF [47]	Type 1 fuzzy set	Energy, Local Distance	Chance	Triangular	Reduce overhead, Prolong the lifetime
Fuzzy Multi constraint Routing [59]	Type 1 fuzzy set	Buffer occupancy, Energy, Hop count	Grade	Triangular	Reduce overhead, Maximizes throughput
Improved Fuzzy Unequal Clustering [58]	Type 1 fuzzy set	Energy, Distance, Density	Chance, Radius	Triangular	Prolong the lifetime of WSN
FCM [50]	Type 1 fuzzy set	Mean distance	-	-	Uniform distribution of clusters
NECHS [56]	Type 1 fuzzy set	Neighbor nodes, residual energy	Probability	Trapezoidal-very low, very high; Triangular-low, little low, medium; little high, high	Efficient than LEACH
FSCA [52]	Type 1 fuzzy set	Node lifetime, total number of loyal follower	Chance to being CH	Triangular	Efficient coverage, reduce amount of redundant messages
EEUCF [49]	Type 1 fuzzy set	Distance to base, Residual energy	Competition radius	Triangular	Prolong the lifetime of WSN by distributing the workload
Neuro-fuzzy technique [55]	Type 1 fuzzy set	Memory, Available power, Processing speed	Monitoring coefficients	Trapezoidal-not used, continuous triangular-critical, event	Used in monitoring systems
Cluster adaptation method [53]	Type 1 fuzzy set	EOC, PICR, DFC, NSCR	CFWC	Triangular	To evaluate the fitness of clustering

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TABLE XII
INPUT AND OUTPUT PARAMETER OF FUZZY LOGIC BASED CH SELECTION

Protocol Name	CH Stability	Delivery Delay	Scalability	Algorithm Complexity	Energy Efficiency
CHEF	Medium	Very Small	Very Low	Medium	Very Poor
Fuzzy Multi constraint Routing	High	Medium	Medium	Medium	Medium
Improved Fuzzy Unequal Clustering	Medium	Large	Very Low	High	Medium
FCM	High	Small	Low	High	Medium
NECHS	Medium	small	High	Medium	Medium
FSCA	Medium	small	Medium	Medium	High
EEUCF	High	Medium	Medium	Low	Very High
Neuro-fuzzy technique	High	Medium	High	Low	High
Cluster adaptation method	Medium	Large	Medium	Medium	High

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