Journal of King Saud University – Science 32 (2020) 390–401

Contents lists available at ScienceDirect

Journal of King Saud University – Science

journal homepage: www.sciencedirect.com

Original article

Fuzzy based enhanced cluster head selection (FBECS) for WSN

Pawan Singh Mehra *, Mohammad Najmud Doja, Bashir Alam

Department of Computer Engineering, Faculty of Engineering & Technology, Jamia Millia Islamia, Jamia Nagar, New Delhi 110025, India

ARTICLE INFO

Article history:
Received 4 March 2018
Accepted 25 April 2018
Available online 27 April 2018

Keywords:
Clustering
CH
Energy efficiency
Fuzzy logic
WSN

ABSTRACT

For efficient data gathering in context to energy dissipation, WSN is divided into clusters. Clustering not only organizes a deployed network into connected hierarchy but also balances the network load thereby dragging out the lifetime of the system. In cluster based WSN, every sensor node sends the gathered information to the coordinator of their respective cluster. The cluster coordinator holds the responsibility of aggregation of the collected information & route it to the sink of the deployed network. In this paper, a fuzzy based balanced cost CH selection algorithm (FBECS) is proposed which contemplates the remnant energy, farness from sink and the density of the node in its vicinity as input to Fuzzy Inference System. Eligibility index is calculated for each node for the selection of CH role. This protocol ensures load balancing by choosing the best candidate for the role of the coordinator of the cluster by considering the probability assigned to each sensor node. The experimental results validates the performance of FBECS to its counterparts BCSA and LEACH on the basis of better stability period, prolong lifetime with load balancing and large information forwarding to sink.

1. Introduction

WSN is playing a key role in remote or unattended real time applications such as monitoring the environmental conditions, monitoring the traffic, surveillance in battle field, natural disaster prevention, health monitoring, medical monitoring, climatic and weather monitoring, Industrial monitoring etc. (Akyildiz et al., 2002). Such network gathers highly correlated data where the end user requires high level information sensed by the deployed sensor nodes (SN). Major activities which are carried out by SN are gathering information about physical phenomena from the surrounding, computing the information and communicating with rest of the SN. WSN has limited power with limited capacity for processing. In some application, the energy can be replenished by external source such as solar cells (Want et al., 2005) but it portrays non continuous supply which hinders the smooth functioning. Topology of the network and consumption of energy are key addressing issues in WSN for better performance of network in various applications. Clustering schemes which partitions the network by grouping the nodes, play a vital role in maintaining the network topology in effective manner. It is inevitable to develop clustering protocol which is efficient in conserving energy for dragging out the span of the network. Data is communicated from SN (i.e. its origin) to the base station (BS) or sink by single hop or multi hop paradigm. Experimental results exhibit that communication is expensive while computation and processing dissipates very less energy comparatively (Raghunathan et al., 2002). The amount of energy required for transferring a bit is equivalent to thousand processing operations in each sensor node (Pottie and Kaiser, 2000). The energy expenditure by the sensor's sensing subsystem is dependent on the type of sensor. In many cases, it is very less in terms of energy exhaustion by processor and transceiver subsystem. In some cases, sensing consumes comparable or even more than energy required for data communication. Energy conservation methods emphasizes on two components: operation of sensor node and the communication protocol implemented. Amalgam of different techniques can be applied for extensibility of the system lifetime (Anastasi et al., 2009).

Due to fixed energy of SN in WSN (i.e. battery source) which cannot be replenished through external resource, the routing of information need to be non-complex in order to preserve computational energy. The routing protocol is dependent on the procedure to gather information, computation of path and maintenance of information from source to sink (Akyildiz et al., 2002). Routing in WSN can be reactive, proactive and hybrid

* Corresponding author.
E-mail address: pawansinghmehra@gmail.com (P.S. Mehra).

Peer review under responsibility of King Saud University.

ELSEVIER Production and hosting by Elsevier

https://doi.org/10.1016/j.jksus.2018.04.031
1018-3647/

(Singh et al., 2016). Proactive protocols maintain a precise routing table of all nodes globally for transfer of information. The reactive protocols establish path between sources and sink as per the need of the hour. Hybrid protocol amalgams the characteristics of both reactive and proactive protocols by making the use of clustering for stable and scalable network. Generally, reactive protocols are employed for inter-cluster routing and proactive protocols are used in intra-cluster communication.

This literature proposes an energy aware fuzzy clustering protocol called fuzzy based enhanced Cluster Head selection (FBECS) for expansion of network span. It is a distributive algorithm which elects cluster head (CH) using a probabilistic method. FBECS is an enhancement of balanced cost CH selection algorithm (BCSA) (Zytoune et al., 2009). In BCSA, the network is divided into 4 equal-size sub networks (regions) considering the separation distance from the BS. The SN which are in the regions nearer to the BS have higher associated probability value in comparison to the SN at region farthest from the BS. BCSA protocol is developed on the basis of LEACH (Heinzelman et al., 2000) which is randomized protocol giving equal chance to all the SN deployed in the region. In the proposed work, improvement over BCSA is shown by using Fuzzy Logic (FL) which computes the eligibility index of the SN for the role of CH. Fuzzy logic is one of the Computational Intelligence technique which can be used in applications where there are uncertainties. The formation of clusters in WSN may not be suitable if it is based on fixed rules because the efficiency is based on several overlapping metrics like energy, density of nodes, distance between nodes and BS etc. Thus, FL is suitable in CH election solving the uncertainties. The input parameters supplied to fuzzy inference system are remnant power of the SN, node separation from BS and node density around each sensor node. In FL, Mamdani method (Mamdani, 1977) is used for the fuzzification which is frequently used (El Alami and Najid, 2017; Logambigai and Kannan, 2016; Nayak and Devulapalli, 2016) in past literatures and centre of area (COA) is used in the proposed work for defuzzification, For performance assessment, FBECS is compared with CAFL, BCSA & LEACH which are popular clustering algorithm in literature. The simulation experiments are performed on two scenarios with varying initial energy.

This literature is prepared as follows. Section 2 reviews the literature pertinent to our work. System model is discussed in Section 3. FBECS is discussed in Section 4. Evaluation of FBECS with CAFL, BCSA and LEACH is done in Section 5. Finally our contribution is summarized and concluded in Section 6.

2. Pertinent work and motivation

In this literature, important characteristics of efficient clustering algorithm are discussed. LEACH algorithm is a distributive approach which elects the CH primarily based on local choices. The rotation of the CH responsibility in static network prevents the premature death of the sensor node. LEACH incorporates rotation of CH randomly for even distribution of energy dissipation. LEACH protocol also includes fusion of the collected data to lessen the information to be directed towards BS.

In LEACH-C (Heinzelman et al., 2002), enhancement over the LEACH algorithm is discussed where the CH are diffused all over the network resulting in better performance. PEGASIS (Lindsey and Raghavendra, 2002) which is another cluster-based routing protocol, enhances the lifespan of the network with increased local collaboration among the deployed SN. In PEGASIS protocol, by incorporating greedy algorithm, chain is formed with the deployed nodes so that each sensor node has only one neighbor either for transmission or reception. For a round, a SN is indiscriminately chosen from the chain which transmits the melded information to the BS, thereby reducing each round expenditure of energy as contrasted to LEACH. SEP (Smaragdakis et al., 2004)) protocol, which is an extension of LEACH protocol, considers two level energy heterogeneity in WSN. It is capable of longevity of stable region due to extraneous energy provided to some of the SN. A distributed algorithm HEED (Younis and Fahmy, 2004) is proposed which forms the clusters uniformly across the target area. This algorithm embodies the remnant energy and propinquity of deployed SN during the periodical formation of clusters. This algorithm is capable of achieving uniform cluster formation around the network with low messaging overhead. However, random selection of CH is the limitation of this proposed work. Chan et al. proposed a distributed clustering algorithm, ACE (Chan and Perrig, 2004) which forms clusters in two phases: spawning and migration. Several repetitions are done in every phase. Two successive repetitions have a span which follows uniform distribution. In spawning phase, cluster formation occurs in self-elective manner. Each node decides itself as CH and broadcast join message to the neighbor nodes to become the follower. In migration phase, rearrangement and maintenance of existing cluster takes place if needed. Periodically, every CH polls among its followers for the best candidature for the leadership of the cluster. Once determined, the current CH renounce itself from the role of the leader and promotes the best candidate for its role. Limitation of ACE is non consideration of remnant energy during CH selection and node density.

DEEC (Qing et al., 2006) protocol incorporate bi-level and multilevel energy based heterogeneity in WSN where election probability of CH is computed by the proportion of remnant power to average power of network. Paper (LI et al., 2006) proposed a routing algorithm, which makes the combination of geographical and hierarchical routing that exhibits good performance in greedy environments. Packet forwarding process initiating from the SN to the BS comprises of two phases: Intra cluster and Inter cluster routing. In intra cluster based routing, flooding of packets in the cluster is done when the cluster member's count is below than a predetermined threshold. In inter cluster based routing, packet forwarding from CH to the BS is done by applying greedy algorithm. Otherwise, the packet is disseminated inside the target cluster by applying recursive geographic forwarding approach. PEACH (Yi et al., 2007) is an adaptive approach which uses multi hop communication between clusters. Clustering technique in this algorithm is based on overhearing information accumulated from the deployed SN. In this proposed work, CH can also play the role of intermediate node and fix the base station as its next hop. Consequently, a timer is set to collect and fuse packets from the SN for a specific time period. However, PEACH algorithm also suffers with the same limitations as those of PEGASIS. CHEF (Kim et al., 2008) which is distributive clustering protocol based on FL. In this protocol the chance to elect CH is calculated using FL if-then rules. The input variables to the FIS is the remnant energy and proximity distance in computing the chance for becoming the CH. This algorithm gives chance to sensor node possessing higher energy level and locally optimal to play the role of CH and achieves 22.7% more efficiency than LEACH. LEACH-FL (Ran et al., 2010) which is enhancement over LEACH by incorporating FL. The input parameters to FIS is density, remnant power and distance from CH to BS. This protocol has two stages: setup stage and steady state stage and is capable of prolonging lifetime.

In paper (Elbhiri et al., 2011), author discusses stochastic and equitable cluster based energy efficient protocol for bi-level heterogeneity. The CH election is established on dynamic probability computed by dispensing the uniform power consumption. Chand et al. proposed Heterogeneous HEED which incorporated FL and considers node density and remnant energy for cluster head election (Chand et al., 2014). In CFFL(El Alami and Najid, 2015), the author has focused on cluster formation for better network lifetime and uses FL with two parameter remnant energy and Closeness to BS reducing the energy consumption. In paper (Nayak and Devulapalli, 2016),issue of appropriate CH selection is addressed. It extends LEACH by implementing FL. Inputs to FIS are remnant battery level, BS mobility and cluster's centrality. Mamdani's rule is used to select super CH. The performance of this protocol is better in lifetime and stability. Singh et al. proposed HEED with different level heterogeneity (Singh et al., 2016) which is based on model parameters and exhibit energy efficiency with better throughput and packet delivery to BS. In EEFL-CH, (Alami and Najid, 2016) the author has improved the LEACH protocol by decreasing the energy consumption by using Fuzzy based approach. This protocol uses three parameters namely expected efficiency, closeness to BS and remnant energy for cluster formation. Doja et al. proposed a primarily zonal based cluster formation in which the field is partitioned into three equi-sized zones (Mehra et al., 2017). The appointment of CH is dynamic in order to balance the load with uniform frittering of energy by the deployed SN. The proposed work is contrasted with Z-SEP, SEP, DEEC & LEACH and simulation exhibit the extended stable period and prolonged span with larger number of packet delivery to BS. FZSEP-E (Sahaaya Arul Mary and Gnanadurai, 2017) has incorporated Fuzzy logic in cluster formation. Factors like distance to BS, node density and residual energy of SN are taken into account and significantly increases the effectiveness in energy consumption and network life time. In (Tamandani et al., 2017), author proposed a fuzzy based routing protocol for balancing the load and minimizing the energy depletion. The CH selection considers 6 parameters viz. distance to BS, density, remnant energy, vulnerability index, distance between CH and Centrality. Alami et al. proposed CAFL (El Alami and Najid, 2017) which is an enhancement of CFFL. In this approach, the author has chosen remnant energy and Closeness to BS for CH selection and for cluster formation, Closeness to CH and remnant energy of tentative CH are considered for efficiency. In (Mehra et al., 2018), author proposed energy conscious protocol in which two BS are positioned on either side of the target area. In this protocol, two level energy heterogeneity is used for maximizing the network life time.

In BCSA, a decentralized algorithm is proposed for the election of CH on the basis of energy required to communicate the information to the BS. The network is divided into 4 sub networks. This algorithm doesn't consider the remnant energy and node density of the node. To overcome this, we have proposed FBECS which uses FL for the sensor nodes and considers the node density, separation distance from the BS along with the remnant energy of the node while selecting the CH for a round to provide better lifetime by conserving the energy of the SN.

3. Preliminaries and system model

The SN form clusters in WSN to conserve energy. Every cluster has a coordinator known as CH. The SN gather information from target area and communicate it to BS. Every SN can act as a sensing node as well as CH. The CH fuses the information amassed from its members and route it to the BS. As huge amount of energy of the deployed SN is depleted during transmission of information, thus the focus is on energy optimization of the deployed SN.

3.1. Assumptions

The system architecture of the proposed work is intended to monitor the environment by deploying SN in the target area. Some assumptions which are made in this proposed work are as follows:

1. The network consist of homogeneous SN with energy level at par.
2. The deployed SN in the network are randomly scattered.
3. The BS and the SN are static i.e. they are immobile once they are deployed.
4. The SN are unattended after the deployment and are energy constrained i.e. the power supply is irreplaceable.
5. The distance between the SN as well as the base station is computed by RSSI (received signal strength index).
6. The position of the BS is presumed at far off place from target area.
7. The BS has limitless energy.
8. The transmission power can be adjusted in line with the separation distance.
9. Radio communication is symmetric.
10. Failure of SN occur due to power exhaustion.
11. The network generates report continuously.

3.2. Network model

The SN in the network are deployed indiscriminately over the target field. The target field is distributed into four regions as done in BCSA for proficient energy utilization. The target area in the proposed work is considered to be 100∗100 and the division of regions is based on farness from BS as shown in Fig. 1.

The BS is positioned at (175, 50). The regions can be located as

Region 1: 0<=X<=25 and 0<=Y<=100
Region 2: 26<=X<=50 and 0<=Y<=100
Region 3: 51<=X<=75 and 0<=Y<=100
Region 4: 76<=X<=100 and 0<=Y<=100

In BCSA, the nodes deployed in each region are assigned some probability on the basis of the distance from BS as shown in Table 1.

It helps in extending the life of SN which are distant from BS. This associated probability of SN is considered while selection of CH for each round.

3.3. Radio model

The energy expenditure model which is applied in our proposed work is like the work shown in (Zytoune et al., 2009). However, the behavior is based on Eqs. (1) and (2). The ε_{mp}, ε_{fs} and E_{elec} are the amplifier energy in multipath, free space and electronics energy respectively.

$$E_{Tx}(m,d) = \begin{cases} mE_{elec} + m\varepsilon_{fs}d^2 & d < d_o \\ mE_{elec} + m\varepsilon_{mp}d^4, & d \geqslant d_o \end{cases} \quad (1)$$

where $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$ and d is the separation distance.

The energy required for reception of m-bits message is as follows:

$$E_{Rx}(m) = E_{Rx-elec}(m) = m.E_{elec} \quad (2)$$

We have assumed the size of the network S = a∗b square meter with n number of SN which are scattered over the given area S. The BS is positioned at distant place far away from network S. For each round, the energy exhausted by each CH can be computed by the Eq. (3)

$$E_{CH} = nm(E_{elec} + \varepsilon_{fs}d_{BS} + E_{DA}) \quad (3)$$

where d is the distance from CH to BS. Likewise, the energy exhausted by cluster member is computed by Eq. (4)

$$E_{CM} = m(E_{elec} + \varepsilon_{fs}d_{CH}) \quad (4)$$

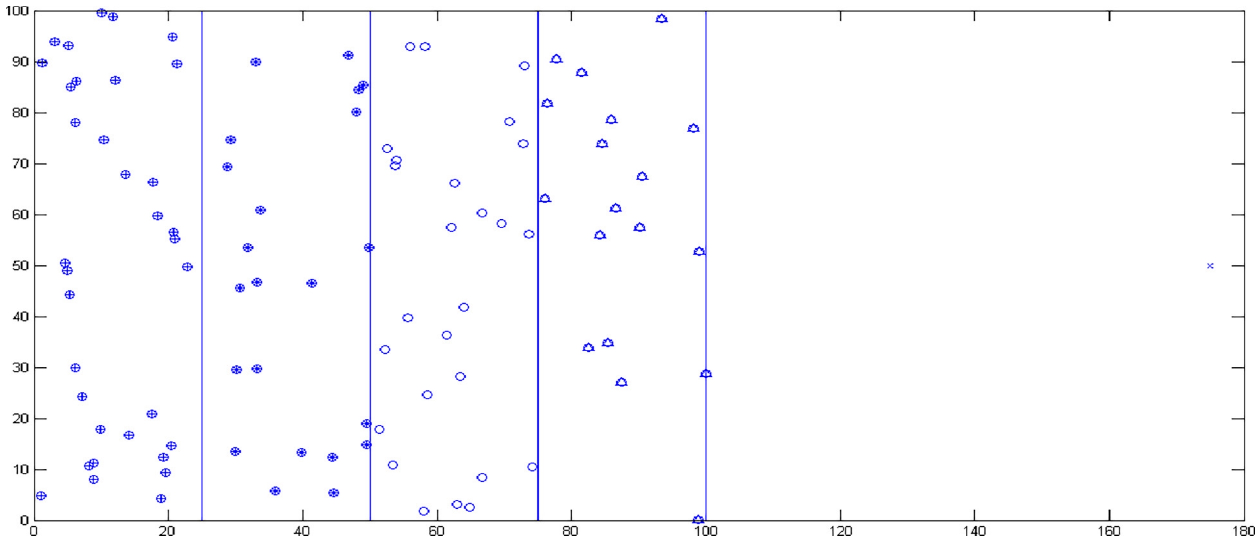

Fig. 1. Network structure.

Table 1
Probability associated with SN (Zytoune et al., 2009).

Description	Values
Probability of SN associated with Region 1	0.036
Probability of SN associated with Region 2	0.039
Probability of SN associated with Region 3	0.039
Probability of SN associated with Region 4	0.0648

The mean distance from a CH to its members i.e. d_{CH} can be estimated by Eq. (5). This mean distance can be used to estimate the transmission radius of each SN.

$$d_{CH} = \frac{1}{(n \setminus k)} \sum_{1}^{n/k} di \tag{5}$$

where n is the total SN, k is the cluster count and d_i is the distance between a cluster member i and CH.

4. FBECS

In this section, Fuzzy Logic based enhanced clustering scheme is discussed. It is an enhanced version of BCSA. The enhancement is done in three ways. First, the CH selection employs fuzzy logic for best candidate selection from the available nodes in the network. Second, the remnant power level of the SN is considered. Third, the node density around the sensor node is taken into account to calculate the energy expenditure if the node is chosen as CH. FBECS is a distributive protocol which is based on rounds like LEACH. The operation of FBECS in one round can be classified into two phases: *Topology building phase* and *Forwarding phase*.

4.1. Topology building phase

The SN are indiscriminately scattered over target area. Once the SN are deployed in target area, proposed protocol comes into play. After initiation of each round, formation of clusters takes place before collecting the data from target area. In each round, maximum p% CH are chosen from the deployed alive SN. After the deployment, BS broadcast a packet (LOC_BS) into the target area. This packet contains some crucial information like location of BS, coordinates of the regions classified, time slot for SN to evade collision. The SN now broadcast a message (Hello_pkt) around the network in accordance with the time slot provided by BS to evade collision. Once all the broadcasts are completed, the SN calculate the local parameter like node density, its remnant energy and distance to BS. The algorithm for the cluster formation of proposed protocol is explained in Algorithm 1.

Algorithm1: Cluster formation in FBECS

```
Begin:
N ← Total SN in network
I ← Unique ID of SN
Node(i).E ← Eo
Node(i).State ← member
CH_list ← 0
CH_count ← 1
Node(i).P ← Assign region based probability
Node(i).D ← Total nodes within Transmission Range (Rc)
Node(i).DTBS ← Distance between Node(i) to BS
While (CH_count<=p%)
{
Calculate eligibility index for each Node (i).
Calculate mean[EI]
Compute Threshold(TH) for Node(i)
Generate random number (RN) for each Node (i).
If RN < Node(i).TH and CH_count<P% then
Node(i).State ← Cluster_head
CH_count++
Add Node(i) to CH_list
End If
}
Every CH sends CH_Msg(i,Res_Energy) to each node
Node(i) joins closest CH to form cluster
Terminate
```

4.2. Fuzzy based model

In this proposed work, FL approach is incorporated for best candidate selection to play the role of CH. FL is efficient in modelling experience and decision making behaviour of human being. The basic structure of Fuzzy System incorporated in proposed work is shown in Fig. 2.

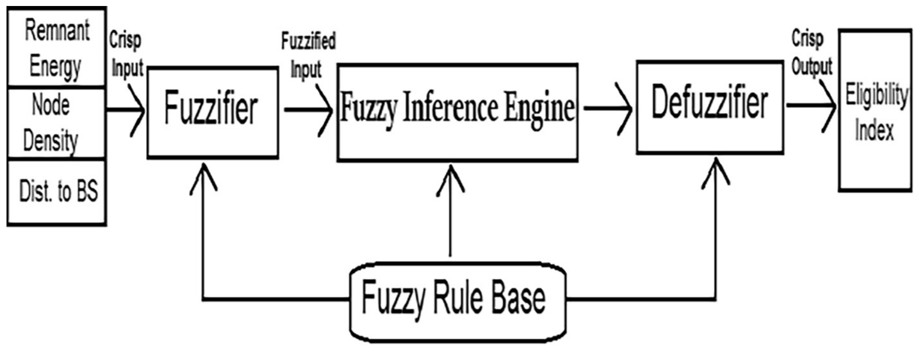

Fig. 2. Building blocks of fuzzy system.

It has four building blocks:

Fuzzifier: In Fuzzy based applications, the system inputs are crisp set which need to be transformed into fuzzy sets. Each fuzzy set is assigned a degree of membership. Thus, conversion of crisp set into suitable linguistic value is done with fuzzifier.
Fuzzy Rule Base: It consists of IF-THEN rules decided by the user. Rule base with if-then defines the dynamic behaviour of the fuzzy system. The fuzzy rule base is also referred to as knowledge base.
Inference Engine: Fuzzy inference engine with inputs and IF-THEN rules tries to simulate the inference system of human being. Fuzzy Inference Engine plays a vital role in inferring and drawing conclusion from the conditions in rule base.
Defuzzification: Defuzzification process carry out the mapping of the fuzzy set acquired from the inference engine into a crisp output value which can be used for drawing some conclusion. Centroid is calculated by the defuzzifier for computing the probability.

4.2.1. Fuzzification

We used three variables as input for FL. The fuzzifier crisp input variable with their maximum and minimum values for calculating eligibility index are shown in Table 2. *Distance to BS* is the Euclidean distance of each SN from the BS. *Remnant Energy* is the total power available with the SN at that instant of time. *Node Density* is the count of the neighboring nodes in the surrounding of the node under consideration for CH candidature.

These crisp values (discrete values) are fed to the FIS. With these three variables, arbitration of membership function's (MF) values and the intersection point of input variable is done as depicted in Figs. 3-5.

4.2.2. Fuzzy rule base

Membership values obtained after fuzzification are fed to the rule base for IF-THEN conditions. Using the Fuzzy AND and OR operators on the inputs, a value is obtained. After the application of the 27 rules as depicted in Table 3, Aggregation method union all the output and a maximum value is chosen from the aggregated fuzzy set. To obtain the eligibility index by the Fuzzy Logic, we have used Mamdani inference system which is most commonly used because of its characteristics.

Table 2
Fuzzifier input function.

Input	Linguistic Variables		
Remnant energy	Low	Medium	High
Distance to BS	Close	Medium	Far
Node Density	Sparse	Medium	Dense

4.2.3. Defuzzification

The fuzzy variables which are used for the crisp value output is depicted in Table 4.

For defuzzification, the center of area ($Z*$) method is used as given in Eq. (6)

$$Z* = \frac{\int \mu_A(x)xdx}{\int \mu_A(x)dx} \tag{6}$$

There are different shapes for membership functions like Triangular, Trapezoidal, Sigmoid, Gaussian etc. The one and only condition which an MF needs to satisfy is that it must range from 0 to 1. In this proposed work as shown in Fig. 6, we have used Gaussian MF for the intermediate values as it is popular while specifying fuzzy sets because of its smoothness and non-zero values at all point and Trapezoidal MF is used for boundary variables because of its simplicity and faster computation (Singh et al., 2017). We can also use other membership function but we have obtained better results using Gaussian and Trapezoidal MFs. The Gaussian and trapezoidal MF which are incorporated in our FIS are given in Eqs. (7) and (8) respectively.

$$\mu_{gaus}(x) = e^{\frac{-(x-c)^2}{2\sigma^2}} \tag{7}$$

$$f(x;a,b,c,d) = \max\left(\min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right), 0\right) \tag{8}$$

The feet & the shoulders of the trapezoid are located by a, d and b, c respectively.
Defuzzifier converts the received input into crisp set and eligibility index for each node is obtained.
Once the eligibility index for all the nodes is computed, threshold (TH) is calculated as from the Eq. (9).

$$TH = \frac{Node(i).P \times mean[EI]}{1 - Node(i).P \times mod(r, \frac{1}{Node(i).P})} \tag{9}$$

During the computation of TH, mean of eligibility index of all the nodes and probability assigned to each node as per their existence in corresponding region is considered. Each node alive in the network generates a randomized number for indiscrimination in CH selection. If that number is smaller than the calculated TH then the node is chosen to play the CH role. The role of CH is vital in energy efficiency of the network and it is rotated after every round for balancing the load among the deployed SN. After the selection of candidates for the role of CH in topology building phase, the nodes in CH list broadcast (CH_Head) their selection within the transmission range (Rc). The SN which did not get elected for CH role join one of the nearest cluster by transmitting (CM_Join) to

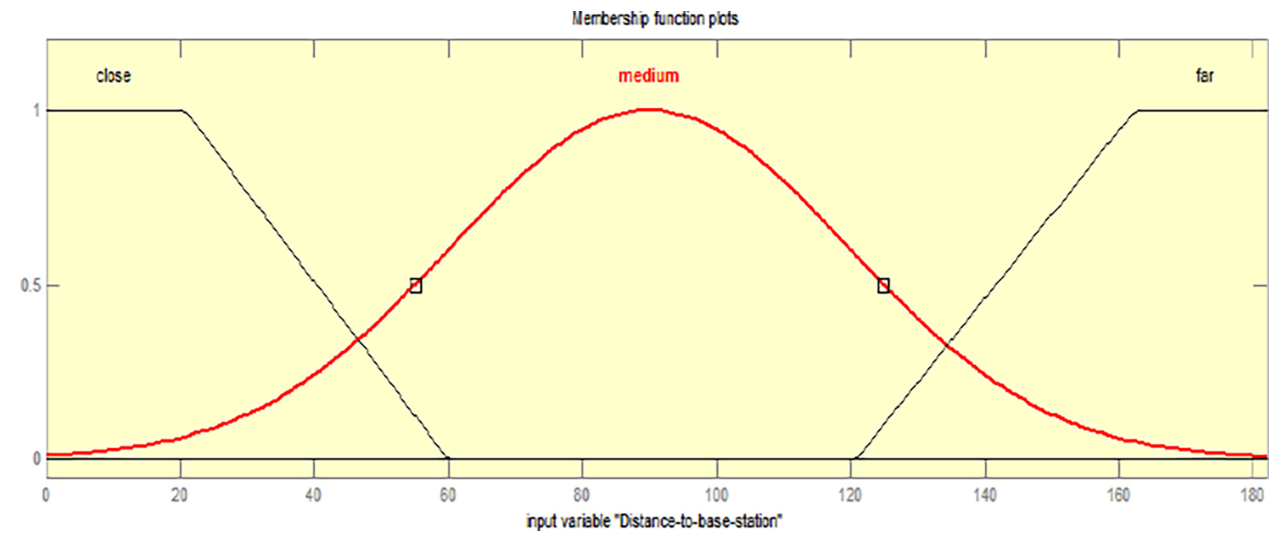

Fig. 3. Input-Var: DTBS.

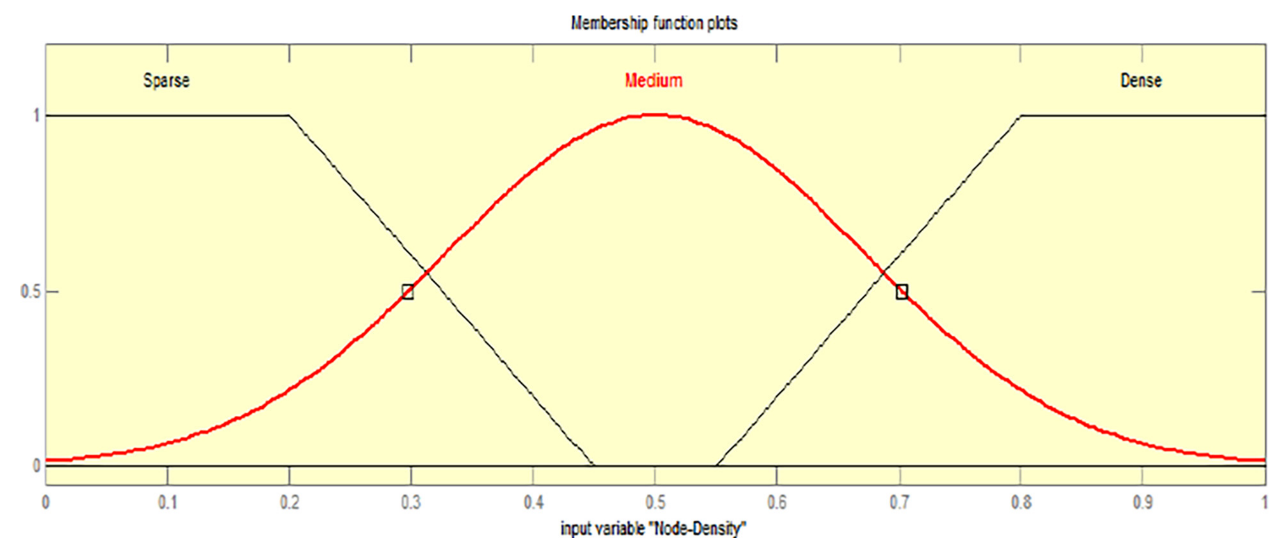

Fig. 4. Input-Var: node density.

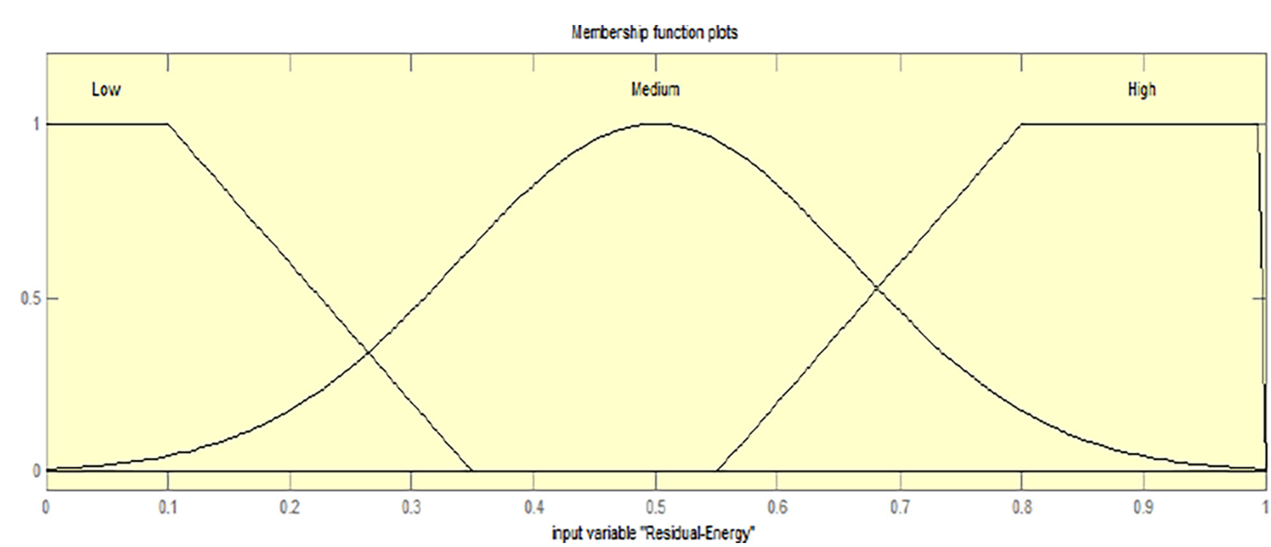

Fig. 5. Input-Var: res-energy.

Table 3
Fuzzy Rules established for FBECS.

Rule	R_Energy	DTBS	Density	Eligibility Index
1	Low	Close	Dense	Good
2	Medium	Close	Dense	Better
3	High	Close	Dense	Far Better
4	Low	Close	Sparse	Far Better
5	Medium	Medium	Medium	Good
6	High	Close	Medium	Best
7	Low	Close	Medium	Better
8	Medium	Close	Medium	Far Better
9	High	Close	Sparse	Very Best
10	Low	Medium	Dense	Bad
11	Medium	Close	Sparse	Best
12	High	Medium	Dense	Good
13	Low	Medium	Sparse	Good
14	Medium	Medium	Dense	Fair
15	High	Medium	Medium	Better
16	Low	Medium	Medium	Fair
17	Medium	Medium	Sparse	Better
18	High	Medium	Sparse	Far Better
19	Low	Far	Dense	Worst
20	Medium	Far	Dense	Worst
21	High	Far	Dense	Bad
22	Low	Far	Medium	Worse
23	Medium	Far	Medium	Bad
24	High	Far	Medium	Fair
25	Low	Far	Sparse	Bad
26	Medium	Far	Sparse	Fair
27	High	Far	Sparse	Good

Table 4
Defuzzifier output function.

Output	Linguistic variables
Eligibility Index	Very Best, Best, Far Better, Better, Good, Fair, Bad, Worse, Worst

the closest CH. In this way p_{opt} clusters are formed. If some nodes are left after the cluster formation, then these nodes join the cluster nearest to them after CH acknowledgement. Topology setup phase gets accomplished once all the SN get bind to clusters.

4.3. Forwarding phase

After successful cluster formation in topology setup phase, now CH is supposed to collect data from its members as per the TDMA slot allotted to each member for collision free communication. The CH provides a TDMA slot to all its members during the cluster formation. The CH after gathering information from each SN, melds the information in order to limit the repetitive information and thereby diminishing the cost of communication. The melded information from each CH is collected by the BS as per the TDMA schedule with the goal that collision free communication takes place. Along these lines, the proposed algorithm successfully completes one round.

5. Performance evaluation and discussion

FBECS is simulated to validate its performance and comparison is made with CAFL, BCSA and LEACH. The simulation work is carried out in MATLAB as all types of fuzzy MFs are available and it is easier for implementation. SN are indiscriminately positioned in a field of (100×100) m^2. The optimum percentage of CH is taken as 10% (Alami and Najid, 2016).The position of the BS is kept at far off place from the target area so as to generalise the protocol for maximum application. The position of base station is considered at (50,175).Two scenarios have been considered N#1 and N#2 for the proposed work. In Scenario 1 (N#1), the nodes are bundled with 0.5 J energy and the total count of nodes in this scenario is kept 100. In Scenario 2 (N#2), the nodes are equipped with 1 J of energy and the total nodes in this scenario is kept 200.For the sake of fair comparison, the values of simulation parameters for CAFL, BCSA and LEACH are kept like FBECS. We have executed the proposed protocol extensively for normalised results.

Performance evaluation and validation of FBECS is done on the basis of FND (First Node Dead), QND (Quarter Node Dead), HND (Half Node Dead), Total alive nodes in each round, successful packet delivery to the BS and average remnant power of the network during each round. The parameters for the simulation are given in Table 5 and are kept same as used in (Zytoune et al., 2009).

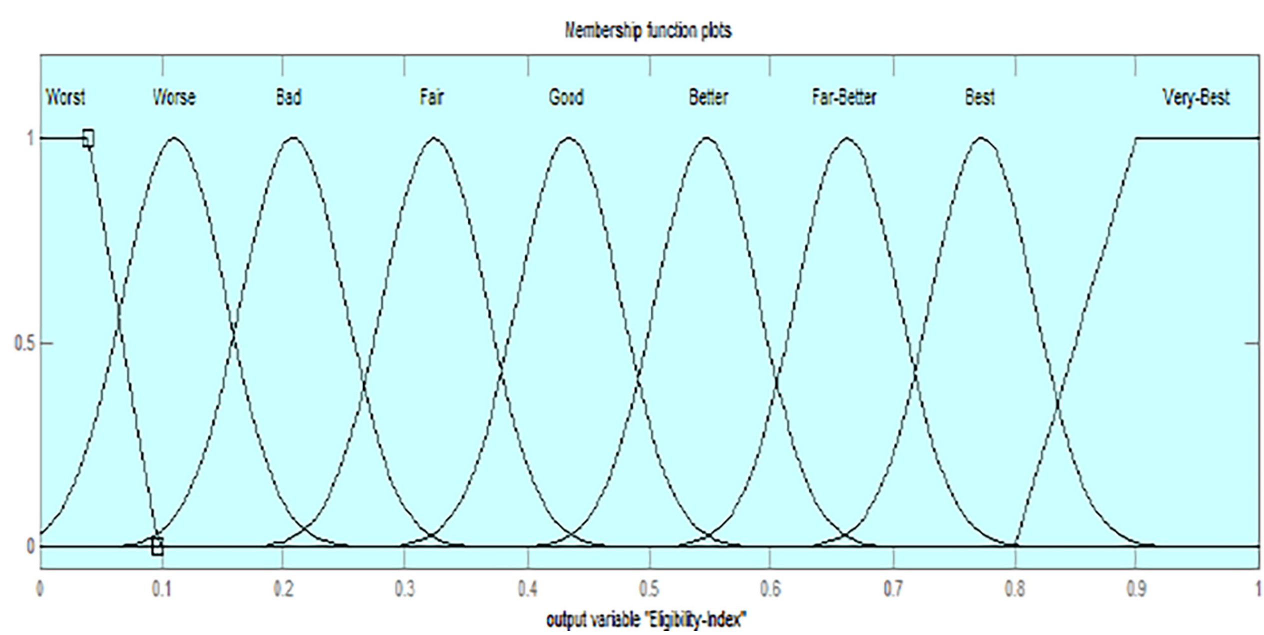

Fig. 6. Output-Var: eligibility index.

Table 5
Simulation configuration of FBECS.

Parameter description	Symbol	Values
Node Count	N	100/200
Energy level during deployment	Eo	0.5 J/1.0 J
Energy dissipated by amplifier for free space	ε_{fs}	10pJ/bit/m^2
Energy dissipated by amplifier for multipath	ε_{mp}	0.0013pJ/bit/m^4
Energy exhausted in electronic circuitry	Eelec	50nJ/bit
Energy exhausted in data fusion	E_{DA}	5nJ/bit/report
Data packet size	M	4000bits

5.1. Alive nodes per round

If more number of SN are alive and are available in the sensor network, then large amount of information can be collected from the target area. In Figs. 7 and 8, the graph is plotted for the total alive nodes per round for N#1 and N#2 respectively. In N#1, first node dies at 580 round in LEACH, 630 for BCSA and 680 for CAFL where as in FBECS no SN death occur till 800 rounds. For N#2, cent percent SN are alive up to 1500 rounds where as in case of LEACH, BCSA and CAFL, it is only 1120, 1260, 1320 respectively. It is clearly visible that the SN in FBECS have dissipated the power in equalised manner and all the nodes are alive for more rounds in contrast to CAFL, BCSA and LEACH making the proposed algorithm more stable. In both the scenarios i.e. N#1 and N#2, LEACH protocol has poorly performed whereas the BCSA has performed better than LEACH because the former considers the distance of SN from base station but later does not consider remnant energy. CAFL has performed better than LEACH and BCSA as it has incorporated FL by removing uncertainties in CH selection and cluster formation but do not consider node density which is covered in FBECS. FBECS has performed better than its comparatives as the expiration of nodes begin at later rounds as compared to LEACH, BCSA and CAFL. With the premature expiration of nodes round by round, the network becomes unstable and unreliable as incomplete monitoring/surveillance of the field will be reported. For longer stability and reliability, the nodes should perish after long interval from the deployment of nodes.

5.2. Network's average remnant energy

A huge amount of energy is frittered from SN in wireless communication. As soon as the count of round increases, the average remnant energy of the network tends to decrease which result in

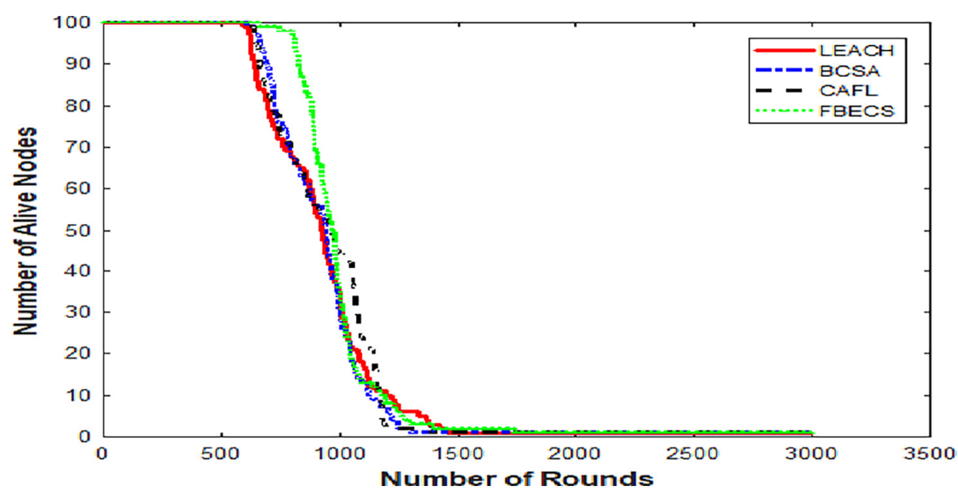

Fig. 7. Round vs. alive nodes N#1.

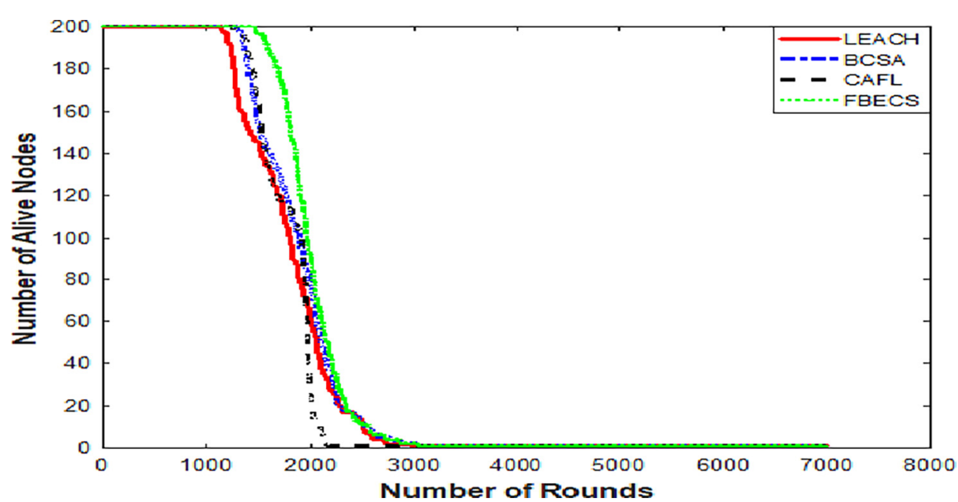

Fig. 8. Round vs. alive nodes N#2.

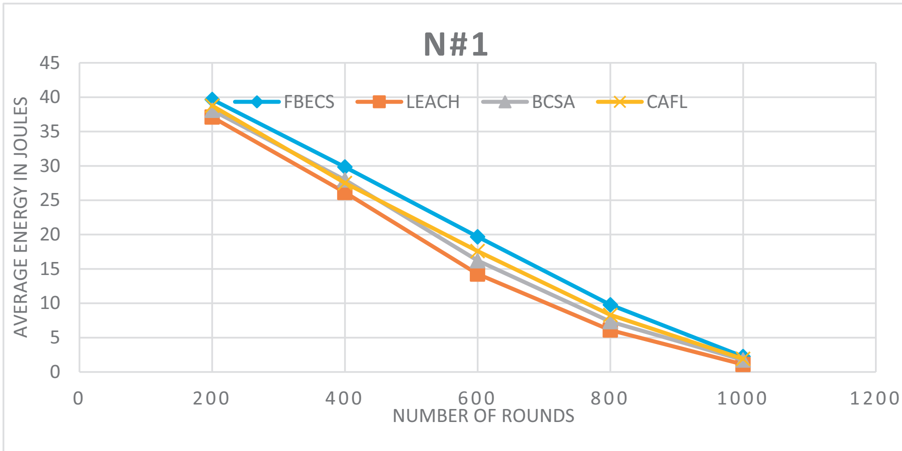

Fig. 9. Round vs. average energy for N#1.

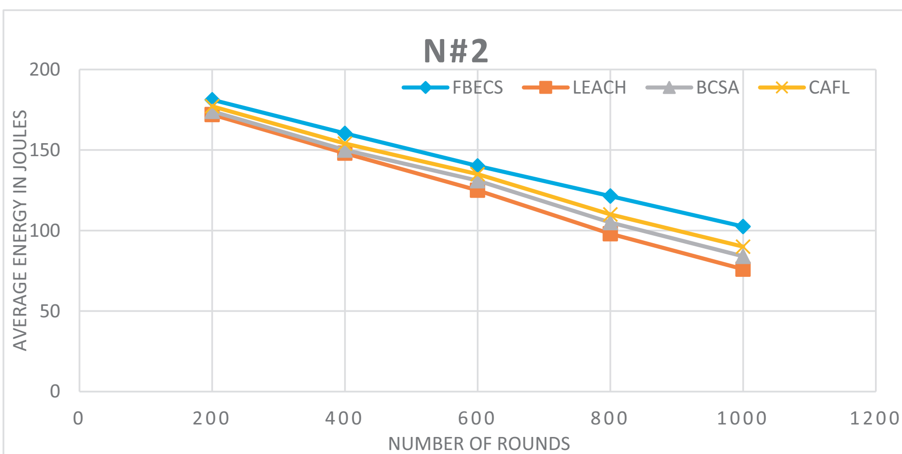

Fig. 10. Round vs. average energy for N#2.

death of nodes. Fig. 9 and Fig. 10 depicts the average network energy for Scenario 1(N#1) and Scenario 2(N#2) respectively. Considering both the scenarios, we can observe that the average remnant energy of FBECS is always higher than CAFL, LEACH and BCSA for round interval 200, 400, 600, 800 and 1000. It reveals that the proposed algorithm successfully distributes the load of the WSN resulting in more stable region.

5.3. FND, QND and HND

Once the network is setup, the objective is to collect maximum information from the target area where the life of the node plays a vital role. It is because death of each nodes makes the network susceptible to non-coverage of some parts of target area. This will result in poor performance of the actual system requirements. Figs. 11 and 12 depicts FND, QND and HND metrics obtained from the simulation results for both the scenarios. For scenario N#1, FND (it justifies the span for which the network was stable) of FBECS protocol is protracted by 27.40%, 22.83 % and 16.04% as compared to LEACH, BCSA & CAFL protocol respectively. Likewise, QND is extended by 32.04%, 22.51%, 17.27% in comparison to LEACH, BCSA and CAFL respectively. Finally, HND is prolonged by 18.17%, 11.53% and 6.73% in contrast to LEACH, BCSA and CAFL respectively.

Similarly for scenario N#2, FBECS achieves 24.56%, 15.44 % and 12.11% better stability region as compared to LEACH, BCSA and CAFL protocol respectively. In Quarter Node Death, FBECS has 28.03%, 17.35% and 11.62% better result than LEACH, BCSA and CAFL respectively. Half Node deaths in FBECS is delayed by 13.47%, 11.38% and 8.1% against LEACH, BCSA and CAFL respectively. Simulation results illustrate that the FBECS is proficient in meeting the requirements of the application with better lifetime and stability period.

5.4. Network's throughput

Throughput can be measured with more packet delivery to the BS over the rounds which means more information is collected from the target area. It can be clearly observed in Fig. 13, FBECS has delivered 42.02%, 55.6% and 36.61% more packets to BS in comparison with LEACH, BCSA and CAFL for scenario N#1. Similarly, for scenario N#2, FBECS has higher throughput of 24..02%, 37.14% and 24.71% against its comparatives as depicted in Fig. 14.

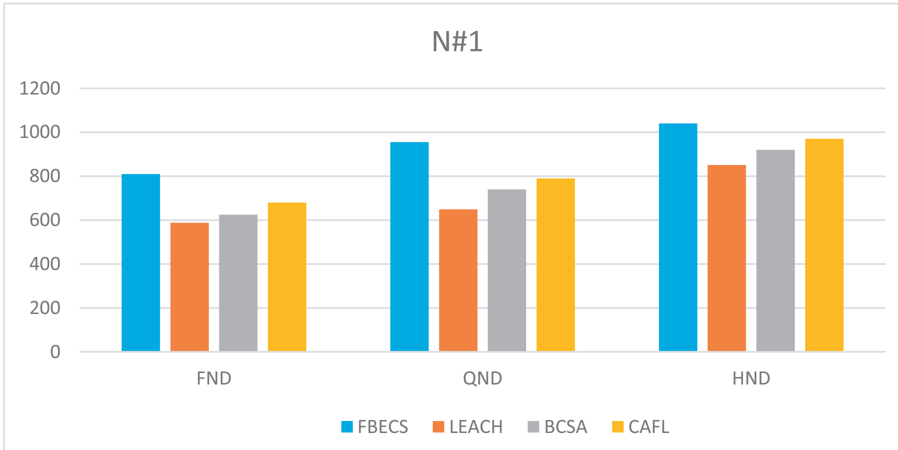

Fig. 11. FND, QND and HND for N#1.

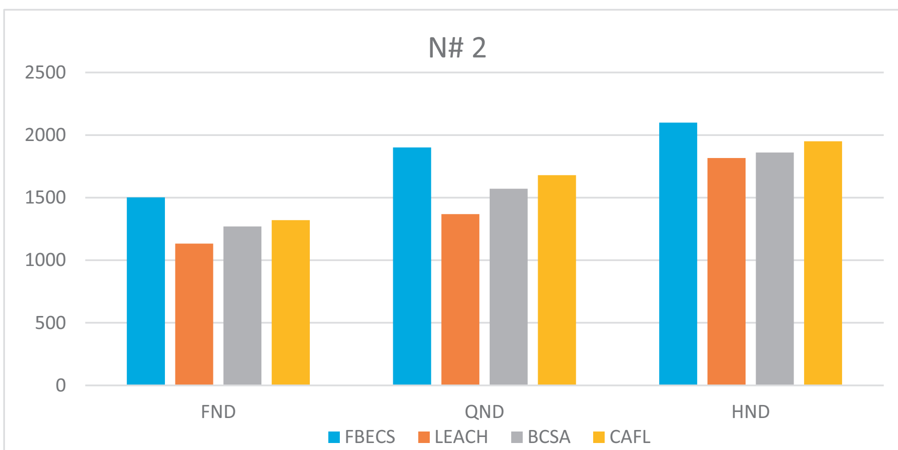

Fig. 12. FND, QND and HND for N#2.

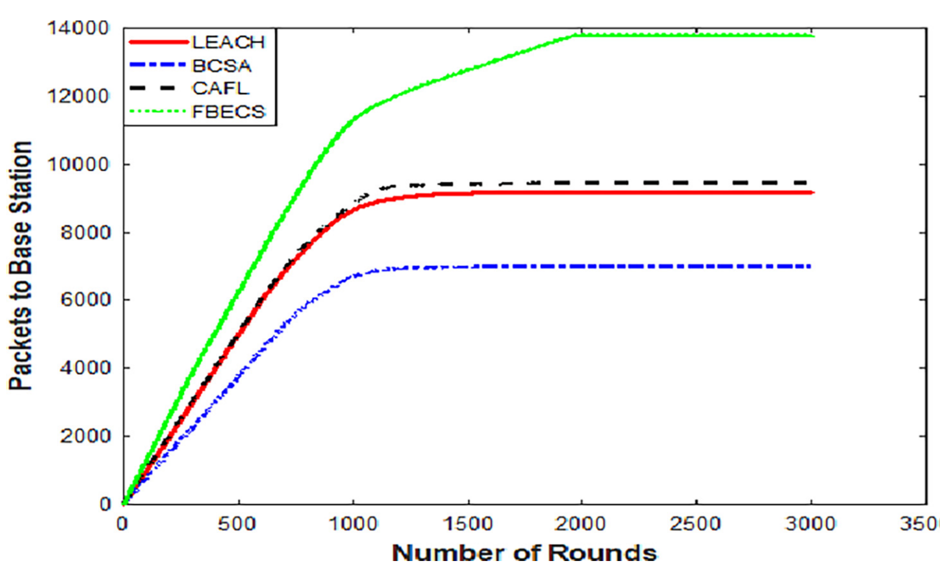

Fig. 13. Round vs. Packet to BS for N#1.

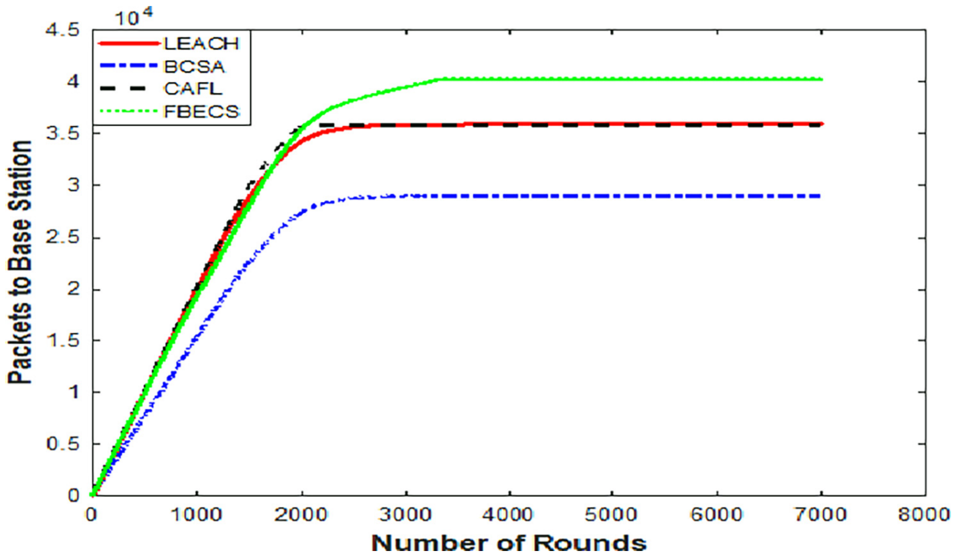

Fig. 14. Round vs. Packet to BS for N#2.

6. Conclusion

With the proliferation in separation distance of sensor node from the BS, the required transmission power rises exponentially and if a sensor node which is located at a distant place from Base station is chosen to play the role of CH, then it will lead to premature death of that sensor node. Thus, the separation distance has a vital role in CH selection. In FBECS, the network is divided into sub-network and the probability is allocated to every node as per the separation distance. With the integration of FL in clustering process, the proposed work has exhibit better performance in comparison with BCSA and LEACH. The stability period along with the QND and HND have significantly increased. The amount of information forwarded to BS in FBECS is far better than its comparatives with more average remnant energy per round.

7. Declaration of interest

None.

Acknowledgement

The authors would like to thank the editor and anonymous reviewers for their constructive and valuable comments along with generous feedback for improving the quality of the paper.

References

Akyildiz, I.F., Su, W., Sankarasubramaniam, Y., Cayirci, E., 2002. Wireless sensor networks: a survey. Comput. Networks 38, 393–422. https://doi.org/10.1016/S1389-1286(01)00302-4.

Alami, H El, Najid, A., 2016. Energy-efficient fuzzy logic cluster head selection in wireless sensor networks, in: 2016 International Conference on Information Technology for Organizations Development (IT4OD). IEEE. https://doi.org/10.1109/IT4OD.2016.7479300.

Anastasi, G., Conti, M., Di Francesco, M., Passarella, A., 2009. Energy conservation in wireless sensor networks: a survey. Ad. Hoc. Networks 7, 537–568. https://doi.org/10.1016/J.ADHOC.2008.06.003.

Chan, H., Perrig, A., 2004. ACE: an emergent algorithm for highly uniform cluster formation. In: Lecture Notes on Computer Science. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-24606-0_11.

Chand, S., Singh, S., Kumar, B., 2014. Heterogeneous HEED protocol for wireless sensor networks. Wirel. Pers. Commun. 77, 2117–2139. https://doi.org/10.1007/s11277-014-1629-y.

El Alami, H., Najid, A., 2017. Fuzzy logic based clustering algorithm for wireless sensor networks. Int. J. Fuzzy Syst. Appl. 6, 63–82. https://doi.org/10.4018/IJFSA.2017100105.

El Alami, H., Najid, A., 2015. CFFL: Cluster formation using fuzzy logic for wireless sensor networks, in: 2015 IEEE/ACS 12th International Conference of Computer Systems and Applications (AICCSA). IEEE. https://doi.org/10.1109/AICCSA.2015.7507248.

Elbhiri, B., Saadane, R., Aboutajdine, D., 2011. Stochastic and Equitable Distributed Energy-Efficient Clustering (SEDEEC) for heterogeneous wireless sensor networks. Int. J. Ad Hoc Ubiquitous Comput. 7, 4. https://doi.org/10.1504/IJAHUC.2011.037849.

Heinzelman, W.B., Chandrakasan, A.P., Balakrishnan, H., 2002. An application-specific protocol architecture for wireless microsensor networks. IEEE Trans. Wirel. Commun. 1, 660–670. https://doi.org/10.1109/TWC.2002.804190.

Heinzelman, W.R., Chandrakasan, A., Balakrishnan, H., 2000. Energy-efficient communication protocol for wireless microsensor networks, in: Proceedings of the 33rd Annual Hawaii International Conference on System Sciences. IEEE Comput. Soc. https://doi.org/10.1109/HICSS.2000.926982.

Kim, J., Park, S., Han, Y., Chung, T., 2008. CHEF: Cluster Head Election mechanism using Fuzzy logic in Wireless Sensor Networks, in: Proceedings of 10th International Conference on Advanced Communication Technology. pp. 654–659. doi: 10.1109/ICACT.2008.4493846.

Li, L., Dong, S., Wen, X., 2006. An energy efficient clustering routing algorithm for wireless sensor networks. J. China Univ. Posts Telecommun. 13, 71–75. https://doi.org/10.1016/S1005-8885(07)60015-6.

Lindsey, S., Raghavendra, C.S., 2002. PEGASIS: Power-efficient gathering in sensor information systems, in: Proceedings, IEEE Aerospace Conference. IEEE. https://doi.org/10.1109/AERO.2002.1035242.

Logambigai, R., Kannan, A., 2016. Fuzzy logic based unequal clustering for wireless sensor networks. Wirel. Networks 22, 945–957. https://doi.org/10.1007/s11276-015-1013-1.

Mamdani, H.E., 1977. Application of fuzzy logic to approximate reasoning using linguistic synthesis. IEEE Trans. Comput. C 26, 1182–1191. https://doi.org/10.1109/TC.1977.1674779.

Mehra, P.S., Doja, M.N., Alam, B., 2018. Stable Period Extension for Heterogeneous Model in Wireless Sensor Network. Springer, Singapore. 10.1007/978-981-10-6005-2_48.

Mehra, P.S., Doja, M.N., Alam, B., 2017. Zonal based approach for clustering in heterogeneous WSN. Int. J. Inf. Technol. 1–9. https://doi.org/10.1007/s41870-017-0071-2.

Nayak, P., Devulapalli, A., 2016. A fuzzy logic-based clustering algorithm for WSN to extend the network lifetime. IEEE Sens. J. 16, 137–144. https://doi.org/10.1109/JSEN.2015.2472970.

Pottie, G.J., Kaiser, W.J., 2000. Wireless integrated network sensors. Commun. ACM 43, 51–58. https://doi.org/10.1145/332833.332838.

Qing, L., Zhu, Q., Wang, M., 2006. Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks. Comput. Commun. 29, 2230–2237. https://doi.org/10.1016/J.COMCOM.2006.02.017.

Raghunathan, V., Schurgers, C., Park, Sung, Srivastava, M.B., 2002. Energy-aware wireless microsensor networks. IEEE Signal Process. Mag. 19, 40–50. https://doi.org/10.1109/79.985679.

Ran, G., Zhang, H., Gong, S., 2010. Improving on LEACH protocol of wireless sensor networks using fuzzy logic. J. Inf. Comput. Sci. https://doi.org/10.1109/SENSORCOMM.2007.21.

Sahaaya Arul Mary, S.A., Gnanadurai, J.B., 2017. Enhanced zone stable election protocol based on fuzzy logic for cluster head election in wireless sensor networks. J. Fuzzy Syst. Int. https://doi.org/10.1007/s40815-016-0181-1.

Singh, S., Chand, S., Kumar, B., 2017. Multilevel heterogeneous network model for wireless sensor networks. Syst Telecommun. 10.1007/s11235-016-0174-2.
Singh, S., Chand, S., Kumar, B., 2016. Energy efficient clustering protocol using fuzzy logic for heterogeneous WSNs. Wirel. Pers. Commun. 86, 451–475. https://doi.org/10.1007/s11277-015-2939-4.
Smaragdakis, G., Matta, I., Bestavros, a., 2004. SEP: A stable election protocol for clustered heterogeneous wireless sensor networks. Second Int. Work. Sens. Actor Netw. Protoc. Appl. https://doi.org/10.3923/jmcomm.2010.38.42 (SANPA 2004).
Tamandani, Y.K., Bokhari, M.U., Shallal, Q.M., 2017. Two-step fuzzy logic system to achieve energy efficiency and prolonging the lifetime of WSNs. Wirel. Networks 23, 1889–1899. https://doi.org/10.1007/s11276-016-1266-3.
Want, R., Farkas, K.I., Narayanaswami, C., 2005. Guest Editors' Introduction: energy Harvesting and Conservation. IEEE Pervasive Comput. 4, 14–17. https://doi.org/10.1109/MPRV.2005.12.
Yi, S., Heo, J., Cho, Y., Hong, J., 2007. PEACH: power-efficient and adaptive clustering hierarchy protocol for wireless sensor networks. Comput. Commun. 30, 2842–2852. https://doi.org/10.1016/J.COMCOM.2007.05.034.
Younis, O., Fahmy, S., 2004. HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. Comput. IEEE Trans. Mob. https://doi.org/10.1109/TMC.2004.41.
Zytoune, O., Fakhri, Y., Aboutajdine, D., 2009. A balanced cost cluster-heads selection algorithm for wireless sensor networks. Int. J. Electron. Commun. Eng. 3, 761–764. http://scholar.waset.org/1307-6892/8896.