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# Energy Efficient Fuzzy Routing Protocol for Wireless Sensor Networks

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**Abstract**
Energy efficiency to route data in wireless sensor networks is key concern to enhance network lifetime. In this paper, an energy efficient routing protocol has been proposed using fuzzy logic tools. Fuzzy sets and fuzzy decision rules have been introduced for intelligent selection of CHs and to establish multi-hop routes to base station. The performance of the proposed protocol is compared with FD-LEACH, OCM-FCM and MH-EEBCDA. Simulation results confirm that the proposed protocol is far better than these protocols in terms network lifetime and throughput. The performance of proposed protocol improves further for networks with higher node density.

**Keywords** Clustering · Fuzzy logic · Fuzzy sets · FCM · Routing · WSN

## 1 Introduction

Wireless Sensor Networks (WSNs) are turned out to be a foremost research area from last few years due to its fast-growing applications. WSNs incorporate thousands of minute sensor nodes to process and monitor various ambient conditions such as temperature, humidity and pressure [1]. Sensor nodes in the network are linked to each other to gather information from surrounding and transmit it to a dedicated node known as Base Station (BS). These nodes have restricted power source batteries and processing capabilities. In hostile application areas, it is impossible to recharge or replace these batteries. Each sensor node consumes its battery power for data communication, processing and sensing. As battery is the only power source in the nodes so it is important to enhance its life and optimizes the energy consumed by the sensors while performing various tasks of the network. Most of the energy is consumed by sensors for data communication. Therefore, energy efficient routing in WSNs is important to enhance the network lifetime.

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A multi-hop energy efficient routing protocol has been proposed in this paper in order to enhance the network lifetime. Soft computing techniques are used in this protocol in order to deal with various uncertainties in WSNs and provide with more flexible and adaptive routes for data transmissions. The whole network is initially divided into optimal number of static clusters using Fuzzy C Means (FCM) clustering. Fuzzy sets and fuzzy decision rules are used for CH selections and multi-hop route establishment.

The remnant of the paper is systematized as follows: An epitome of related work is presented in Sect. 2. An energy model and network model used for the proposed work described in Sects. 3 and 4 respectively. An energy efficient multi-hop routing algorithm using fuzzy sets and fuzzy rules is proposed in Sect. 5. The comparative account of proposed algorithm with other existing algorithms has examined in Sect. 6. Lastly concluding remarks and future directions are given in Sect. 7.

## 2 Related Work

The routing protocols in WSN are categorized as flat, hierarchical and location-based routing protocols [2]. However, hierarchical routing protocols are found more promising to conserve the network energy [3]. LEACH (Low-Energy Adaptive Clustering Hierarchy) is a first clustering protocol proposed to enhance network lifetime [4]. CHs in the network are responsible to transmit the cluster data directly to BS. CHs which are distant from BS consume remarkably higher energy as compared to other nodes in the network and will die soon. The protocol has limited control over the number of clusters formed and their size. Therefore, it agonizes from poor cluster formation and CH selection. In order to overcome these short comings, many researchers have proposed many variants of LEACH such as LEACH-C, V-LEACH, IB-LEACH, MR-LEACH, MH-LEACH, EE-LEACH, DB-LEACH and DBEA-LEACH, DK-LEACH and so on [3, 5–11]. LEACH-C is a centralized clustering protocol where BS elects CHs from nodes with residual energy higher than average energy of network. CH distribution over the network is controlled [5]. IB-LEACH introduced aggregator nodes in order to share work load of CH [7]. MR-LEACH and MH-LEACH uses multi-hop routing in order to reduce long distance transmissions and thereby saving energy [8, 9]. EE-LEACH elects CH with higher residual energy and prolongs the network lifetime [10]. DB-LEACH selects CHs by considering their distance to BS. DB-LEACH is further improved in DBEA-LEACH which selects a CH by considering two factors: distance to BS and residual energy of the node greater than the average residual energy in the network [11]. DK-LEACH proposed an optimized cluster structure routing method depending upon the energy distribution in the network [3]. LEACH variants [3, 5–11] use probabilistic method to choose CHs in the network. Therefore, these protocols suffer from unequal load distribution in the network which affects the performance of the network largely. EEBCDA addressed the problem and divides the whole network into uneven grids in order to enhance network lifetime. Multi-hop EEBCDA used the inter-cluster multi-hop routing method to further enhance the lifetime of network [11].

All the protocols [3–11] discussed waste undue amount of network energy in densely deployed application areas. The nodes which are positioned closely tend to produce redundant information. A large amount of network energy is squandered in transferring this redundant information to the sink which affects the whole network performance. Protocols like LEACH-SM and GBRR keep small subset of sensor nodes active in such a way to ensure full coverage of monitoring area [12, 13]. Consequently, overall energy consumption of network is reduced and enhances the lifetime of WSN.

The most affecting parameters for CH selection and multi-hop route establishment are residual energy, distance to BS, node proximity, intra-cluster distance and for inter-cluster distance. As network operates, nodes consume different amount of energies in data communications and may die at any movement. Therefore, energy consumption in nodes is not fixed and cannot be exactly predicted. Similarly, variations in other parameter are non-uniform and cannot be predicted. Therefore, the exact boundaries and importance given to these parameters are not practical. Soft Computing methods can beneficially be applied to process these uncertainties and to improve the flexibility and adaptability of routing protocols. In [14], fuzzy logic and fuzzy rules are used to establish the multi-hop routes in the network. The drawback of this technique is cluster head are chosen randomly which results into poor CH selection and cluster formation and degrades the overall performance of the network. A multi-hop clustering technique using swarm intelligence has been proposed in paper [15]. This protocol bears lot of communication overhead. Su and Zhao [16] proposed a Fuzzy C Means (FCM) clustering method to search out the appropriate locations of CHs to enhance the life time of the network. This method assists the network to sustain the lifetime. OCM-FCM runs at BS and organises the whole network into K optimal number of clusters. The CH for each cluster is elected by BS centrally. After completing the first round, the present CH choses a new CH for next round and allocate the TDMA schedule to all CMs in the cluster. Multi hop method is being used in this framework if BS is far away from the MA. The route to BS is established by choosing the secondary cluster heads and thereby, reducing inter and intra cluster distances. Therefore, number of long range transmissions are reduced in the network and saves energy. The BS helps to cut down the overhead in cluster formation of SNs. The drawback of this algorithm is that CH selection and route establishment is still deterministic and not coping with uncertainty of actual network.

The main contributions of paper are as follows:

1. A concept of coherence is used to identify nodes that are generating redundant data. The whole network is divided into small sized granules depending upon the degree of coherence in the sensed data. Keep only one node active in each granule in order to eliminate data redundancy and thereby saving energy.
2. Soft computing methods are used for cluster formation, CH selection and multi-hop route establishment in order to deal with uncertainties occur in actual WSNs.

## 3 Energy Consumption Model

Energy consumption in transmissions and receptions of data packets carried out in network is calculated by first order radio model proposed in [3]. Energy Consumed to transmit a *k*-bit data packet over a distance *d* by a sensor node is given as under:

$$E_{TX}(k,d) = \begin{cases} k \times E_{elec} + k \times \zeta_{fs} \times d^2 & if \;\; d \le d_o \\ k \times E_{elec} + k \times \zeta_{mp} \times d^4 & if \;\; d > d_o \end{cases} \tag{1}$$

where $E_{elec}$ is energy dissipated per bit to run transmitter or receiver circuit. $\zeta_{fs}$ and $\zeta_{mp}$ are energy used in free space model and energy used in multipath fading model respectively. $d_o$ is the threshold distance given by Eq. 2.

$$d_o = \sqrt{\frac{\zeta_{fs}}{\zeta_{mp}}} \tag{2}$$

It is clear from Eq. (1) that energy consumption in transmitting data is directly proportional to power of the distance between the transmitting and the receiving node. For the distance greater than do, energy is consumed with power 4 of distance. Therefore, long range transmission need to be reduced in order to enhance the lifetime of network.

To receive and aggregate the packet of length $k$ bits with its own data packet, the energy consumed by the sensor node is shown as follows:

$$E_{RA} = k \times (E_{elec} + E_{DA}) \tag{3}$$

where $E_{DA}$ is energy consumed in aggregating one bit data packets.

## 4 Network Model

Total N sensor nodes are randomly positioned in monitoring area of size X meter by Y meter. It is assumed that SNs once deployed in monitoring area remained static i.e. their positions in the field continued to be same throughout the network life time. All SNs are equipped with GPS systems and able to find the positions in the field. Sink is placed outside monitoring area and remained fixed. Sink has no constraint on power consumption as equipped with unlimited power device while SNs are powered by embedded batteries. Initial battery power given to all SNs is same $E_o$. The whole monitoring area is divided into small equal sized granules. All SNs in a granule assumed to generate redundant data. Therefore, only one SN is kept active in each granule and keeping other nodes in sleep mode. Two types of nodes are introduced: Intra-Gateway and Inter-Gateway for establishing multi-hop routes.

## 5 Proposed Energy Efficient Fuzzy Routing Protocol

The proposed protocol initially runs at BS to divide the whole network into K optimal number of static clusters using FCM technique. Initially, BS elects CH for each cluster using type1 fuzzy logic. Thereafter, it runs the network operation into a series of rounds. In each round, new CHs are elected in static clusters if required and energy efficient multi-hop paths are established from each SN to the sink using fuzzy sets and fuzzy rule. Data sensed at each SN is communicated to the BS through the established path.

### 5.1 Formation of Static Clusters

Initially all active SNs transmit their location coordinates and IDs to BS. BS will divide whole WSN into K clusters using FCM clustering algorithm. Each node in the network can belong to all clusters with some membership value less than one such that the sum of its membership values in all clusters is equal to 1. The membership value of a node in cluster is assigned on the basis of distance between cluster centroid and data point. More the distance less will be the membership and vice versa.

Let $C = \{c_1, c_2, \dots, c_K\}$ is the vector of centroid points of $K$ clusters, $U = \{\mu_{ij}\}_{n\times K}$ is the fuzzy membership matrix and $\mu_{ij}$ is the degree of membership $i$th node $(p_i)$ in a cluster with centroid $c_j$. The objective function of FCM technique is presented in Eq. 4 that need to be minimized.

$$J(U, C) = \sum_{j=1}^{K} \sum_{i=1}^{n} \mu_{ij}^{m} \left\| p_i - c_j \right\|^2 \tag{4}$$

Subject to constraint $\sum_{j=1}^{K} \mu_{ij} = 1 \; \forall i$ where $m$ is constant exponent to control the degree of fuzziness in classification and $m$ is always greater than 1 and reaches up to $\infty$. For implementation of our research work $m$ is taken as 2. The degree of membership of $i$th node in $j$th cluster is calculated as under:

$$\mu_{ij} = \left[ \sum_{q=1}^{K} \left( \frac{\left\| p_i - c_j \right\|}{\left\| p_i - c_q \right\|} \right)^{\frac{2}{m-1}} \right]^{-1} \tag{5}$$

Centroid point of each cluster is updated for next iteration and is calculated as under:

$$c_k = \left[ \frac{\sum_{i=1}^{n} \mu_{ik}^{m} p_k}{\sum_{i=1}^{n} \mu_{ik}^{m}} \right] \tag{6}$$

### 5.2 Cluster Head Selection

Once the clusters are formed remains fixed throughout the whole network operation and only topology of cluster keeps on changing in each round if required. The possibility of each active SN in cluster to become a CH is calculated using fuzzy sets and fuzzy rule base. The node with highest possibility value is elected as new CH for next rounds. Two fuzzy input variables, residual energy of SN and intra cluster communication cost are taken to select a CH in each cluster. The discrete values for each input variable are taken in their normalized form with respect to its cluster members. The formula to calculate normalized residual energy for $i$th SN in the cluster is given as under:

$$NorE(i) = \frac{E(i) - E_{\text{min}}}{E_{\text{max}} - E_{\text{min}}} \tag{7}$$

where $E(i)$ is the residual energy of $i$th SN in the cluster. $E_{\text{min}}$ and $E_{\text{max}}$ are the minimum and maximum residual energies in the current cluster respectively. The linguistic values for residual energy and their fuzzy membership function are presented in Fig. 1.

Intra cluster communication cost is sum of cost involved in transmission of data to CH by all other active members of the cluster. It is directly proportional to the $\beta$ power to distance between member and CH nodes. The normalized value of intra cluster communication cost for $i$th SN in the cluster is given by (10).

$$Distance(i, j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{8}$$

$$Cost(i) = \sum_{j=1}^{n} Distance(i, j)^{\beta} \tag{9}$$

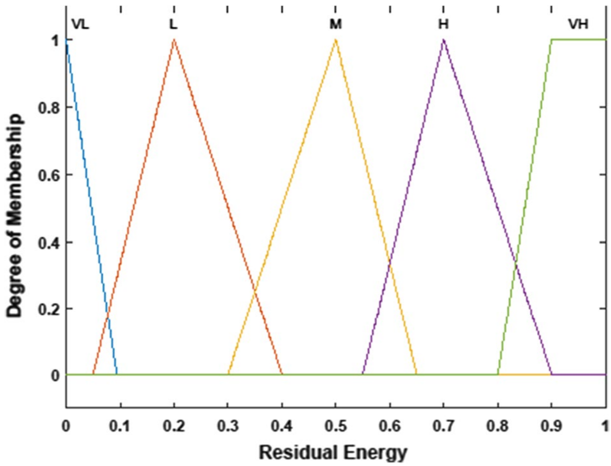



**Fig. 1** Membership function plot for 'residual energy

$$NorCost(i) = \frac{Cost(i) - \min Cost}{\max Cost - \min Cost} \tag{10}$$

where $Distance(i,j)$ in Eq. (8) is the Euclidean distance between the $i$th and $j$th SNs in the cluster with $(x_i, y_i)$ and $(x_j, y_j)$ coordinates respectively. $Cost(i)$ in Eq. (9) is the intra cluster communication cost $i$th SN which is calculated as the sum of distance between $i$th SN and other member nodes of the cluster raise to power $\beta$. The value of $\beta$ is taken as 2 for $Distance(i,j)$ less than $d_o$ otherwise 4. $n$ is the total number of member nodes in the cluster. $NorCost$(i) in Eq. (10) is the normalized cost of $i$th SN, $\min Cost$ and $\max Cost$ is the minimum and maximum intra cluster communication cost of the cluster respectively. The linguistic values for Intra Cluster Communication Cost and their fuzzy membership function are presented in Fig. 2.

The linguistic values of variable chance and their fuzzy set are shown in Fig. 3. The chance value of $i$th SN to become CH is obtained using the fuzzy rules tabulated

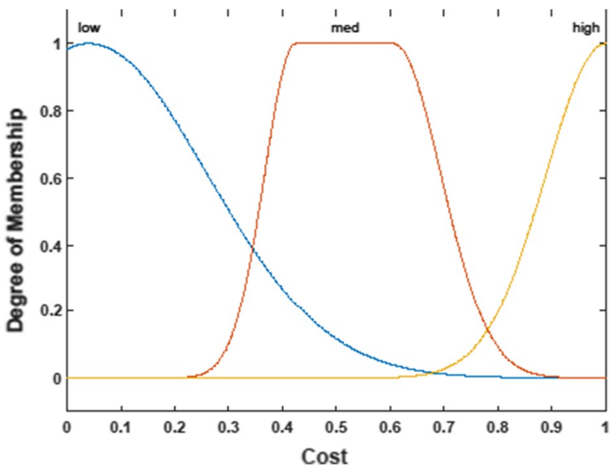



**Fig. 2** Membership function plot for 'intra cluster communication cost'

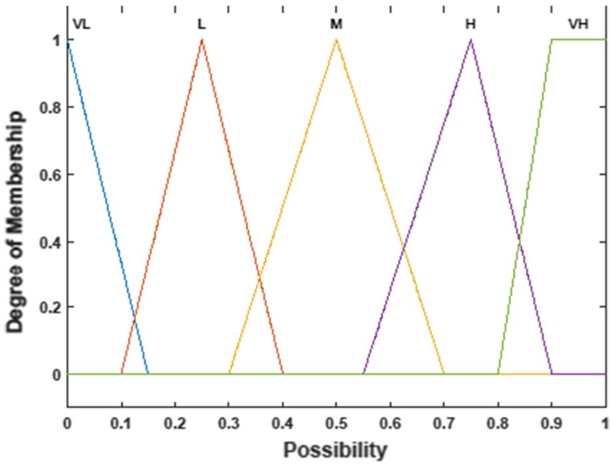



**Fig. 3** Membership function plot for 'possibility'

**Table 1** Fuzzy rules for CH selection

| S. nos. | Residual energy | Cost | Possibility |
|---|---|---|---|
| 1 | Very low (VL) | Low | Very low (VL) |
| 2 | Very low (VL) | Medium | Very low (VL) |
| 3 | Very low (VL) | High | Very low (VL) |
| 4 | Low (L) | Low | Low (L) |
| 5 | Low (L) | Medium | Low (L) |
| 6 | Low (L) | High | Very low (L) |
| 7 | Medium (M) | Low | High (H) |
| 8 | Medium (M) | Medium | Medium (M) |
| 9 | Medium (M) | High | Low (L) |
| 10 | High (H) | Low | Very high (VH) |
| 11 | High (H) | Medium | High (H) |
| 12 | High (H) | High | Low (L) |
| 13 | Very high (VH) | Low | Very high (VH) |
| 14 | Very high (VH) | Medium | High (H) |
| 15 | Very high (VH) | High | Medium (M) |

in Table 1. To get crisp value for Possibility, a Centre of Area (COA) defuzzification method is used.

### 5.3 Communication Strategy

In the first round, the CH nodes in each cluster are identified by the BS. A CH of a cluster remains to be CH for the next rounds until its residual energy is greater than threshold energy of its cluster. The technique eliminates the overhead of forming CHs in each round and saves energy. To trigger a new CH election procedure, threshold energy of the cluster is changing dynamically. It starts with 60% of $E_o$ and decreased by 20% when energy of all nodes in the cluster falls below the threshold level. When residual energy of current CH goes below cluster threshold, it impels new CH election process and evokes the active-sleep process in the cluster. Each active SN in the cluster examines all SNs (in sleep mode) in its granule and activates SN with highest residual energy. Then current CH choses new CH from the newly active nodes of the cluster using proposed fuzzy inference system. It broadcast the information to all active CMs in the cluster.

#### 5.3.1 Intra-cluster Communication

A CH in a cluster collects data from its CMs, aggregate and send it to BS in single hop or in multi-hop whereas CM transmit it sensed data to CH in single hop. Consequently, CH does more labour than CM nodes. In order to cut down its work done, the responsibility to forward aggregated cluster data is shifted to another node called as intra cluster GW node. CH chooses it in the direction of BS with highest residual energy. CH of cluster allocates a TDMA schedule to all its CMs. The CM in its allotted slot transmits its sensed information to CH. CH in turn, aggregates the received data and forwards it to the selected GW node using CDMA protocol. If selected GW node lies in the announced virtual region, it establishes a direct link to the BS otherwise inter cluster communication take place.

#### 5.3.2 Inter Cluster Communication

When BS lies outside the monitoring area, many long-distance communications take place between GW nodes and the BS which results in large energy consumption of GW nodes. In order to avoid it, fuzzy sets and fuzzy rules based multi-hop communication has been proposed in this paper. To establish multi-hop routes a fuzzy inference system has also been proposed in this paper. Intra-cluster GW node finds sensor node in other cluster which is presently not connected to its cluster using a fuzzy inference system. The selected inter cluster node called inter cluster GW node.

Firstly, each active sensor node calculates its possibility to become an inter-cluster gateway node using fuzzy parameters: Distance to BS and residual energy. The linguistic values for ‘Distance to BS’ are taken as ‘Low’, ‘Medium’ and ‘High’ and that of ‘residual energy’ are ‘Low’, ‘Medium’ and ‘High’. The linguistic values for fuzzy output variable ‘possibility’ are taken as ‘Very Low’, ‘Low’, ‘Medium’, ‘High’ and ‘Very High’. Triangular fuzzy membership functions are used for all linguistic variables. There are 9 rules in proposed multi-hop FIS and are tabulated in Table 2. The crisp values for input parameters

**Table 2** Rule table for multi-hop route establishment

| S. nos. | Residual energy | Distance to BS | Possibility |
|---|---|---|---|
| 1 | Low | Low | Medium |
| 2 | Medium | Low | High |
| 3 | High | Low | Very high |
| 4 | Low | Medium | Low |
| 5 | Medium | Medium | Medium |
| 6 | High | Medium | High |
| 7 | Low | High | Very low |
| 8 | Medium | High | Low |
| 9 | High | High | Medium |

have been taken in their normalized form. A COG defuzzification method is used to get crisp output.

Secondly, the selected Intra-cluster Gateway choses candidate Inter-Cluster Gateways with higher possibility value than it. From the set of candidate gateway nodes, a nearest gateway node to the Intra-Cluster Gateway is finally selected as Inter-Cluster Gateway node. A link is established between Intra-cluster and selected inter-cluster gateway nodes.

Inter cluster GW node receives other cluster's data through GW nodes of their cluster. It aggregates its own sensed data with the received data and forwards to CH of its cluster. If a intra cluster GW node unable to find nearest SN from other non-connected clusters, then it establishes direct link to BS.

## 6 Simulation Setup

For a WSN simulation setup, 100 static sensor nodes are randomly positioned in the monitoring area of 200 m by 200 m. The BS is kept away from the monitoring area at position (100, 250). Initial Energy given to all sensor nodes is 0.5 J. Therefore, total initial energy of network is 50 J. Data packet size to communicate sensed information is taken as 4000 bits. The monitoring area is divided into equal sized granules of 10 m × 10 m. For simplicity, control packet overhead occurred while establishing a path in the network is ignored. Energy model described in Sect. 3 has been used to evaluate energy consumption in the network. The values for energy parameters $\zeta_{fs}$ and $\zeta_{mp}$ are taken as 10 pJ/bit/m$^2$ and 0.0013 pJ/bit/m$^4$ respectively. The parameter values for $E_{elec}$ and $E_{DA}$ are set to 50 nJ/bit and 5nJ/bit/signal respectively. To ensure fairness and correctness of the results, the simulation experiments were conducted for 100 WSN deployments and average results obtained from them have been used to present the comparative account of the protocols.

The value of $K_{opt}$ is determined experimentally by varying number of clusters $K$ from one to twenty. The average energy consumption per round for each value of $K$ is calculated. The average energy consumption per round is found minimum at $K = 10$. Thence, $K_{opt} = 10$ is taken.

FD-LEACH, OCM-FCM, MH-EEBCDA and the proposed protocol are implemented in MATLAB. The performance of the proposed protocol has been compared with three existing protocols: and EEFRP.

### 6.1 Simulation Results and Analysis

The total energy consumption is calculated as the sum of energy consumed in data transmission, reception and aggregation by each node as the network runs normally. The comparative graph of total energy consumed in percentage verses rounds for all protocols under test and proposed protocol is shown in Fig. 4. It can be observed from the figure that the total energy consumed is much less in proposed protocol as compared to FD-LEACH, OCM-FCM and MH-EEBCDA. Further, it is seen from figure that when proposed protocol consumed its 50% of network energy, OCM-FCM and MH-EEBCDA consumed 65% while the network in FD-LEACH become completely un-operational. FD-LEACH selects CHs using probabilistic methods which results into non-uniform dispersion of CHs in WSN and intra-cluster distances got increased. Therefore, it consumed higher network energy despite of using fuzzy sets and decisions while multi-hop route establishment. Further, OCM-FCM

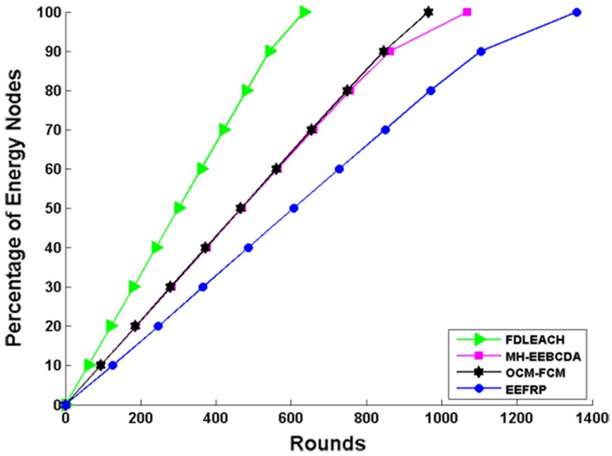



**Fig. 4** Percentage of energy consumed versus rounds for WSN with N = 100

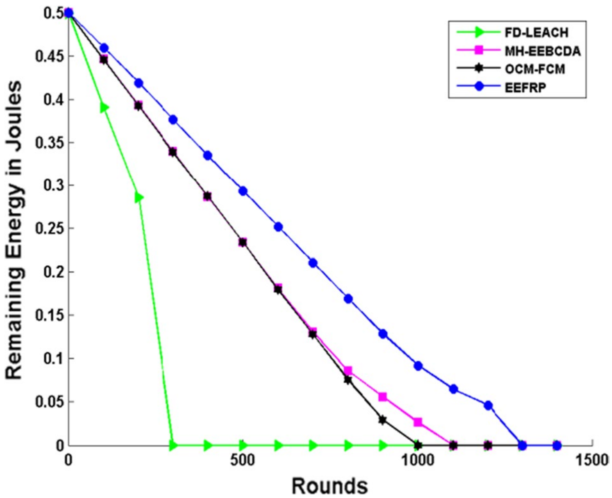



**Fig. 5** Average energy consumption per SN for WSN with N = 100

and MH-EEBCDA consume almost same amount of energy in each round. Owing to optimal clusters formation using FCM, fuzzy CH selection and multi-hopping with gateway nodes, long distance transmissions are reduced to larger extent in the network which results into low energy consumption per sensor node as shown in Fig. 5. Therefore, the proposed algorithm balance energy load and consumes much less energy as compared to the other protocols under test.

A sensor node in the network is considered as dead when its residual energy reaches to zero. The operational ability of the network decreases with the increase in number of dead nodes in the network. Therefore, the rate of death in sensor nodes directly affects the network performance. The network operational ability for all the four protocols is plotted in Fig. 6. From the figure, it is apparent that the rate of decay of sensor nodes in the proposed protocol is much less as compared to other three protocols under test. It is observed from the figure that FD-LEACH, OCM-FCM and MH-EEBCDA almost ceased to exist when only 10% nodes of the network become dead in the proposed protocol. Therefore, it can

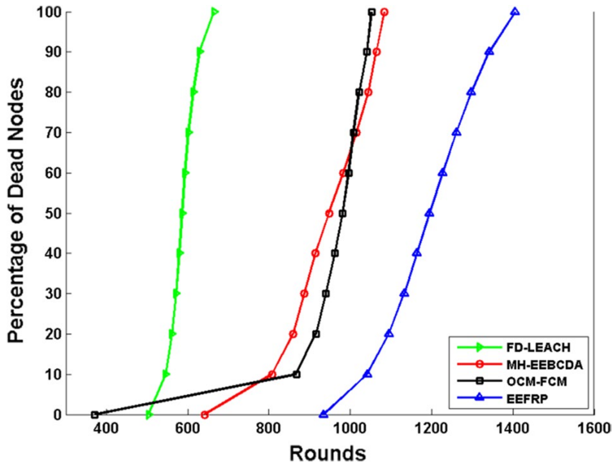



**Fig. 6** Percentage of dead nodes versus rounds for WSN with N = 100

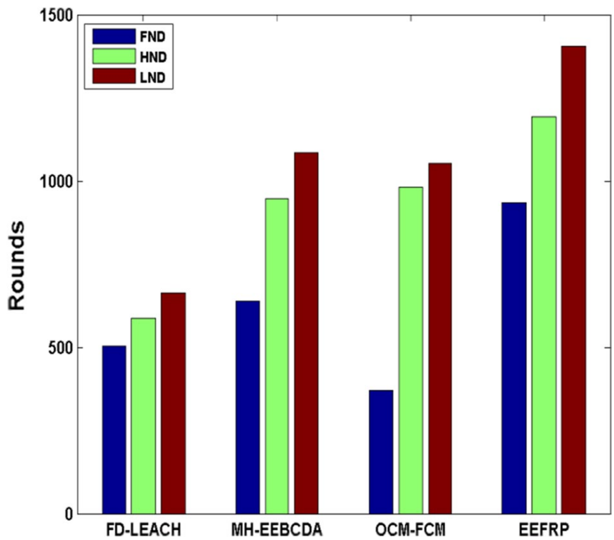
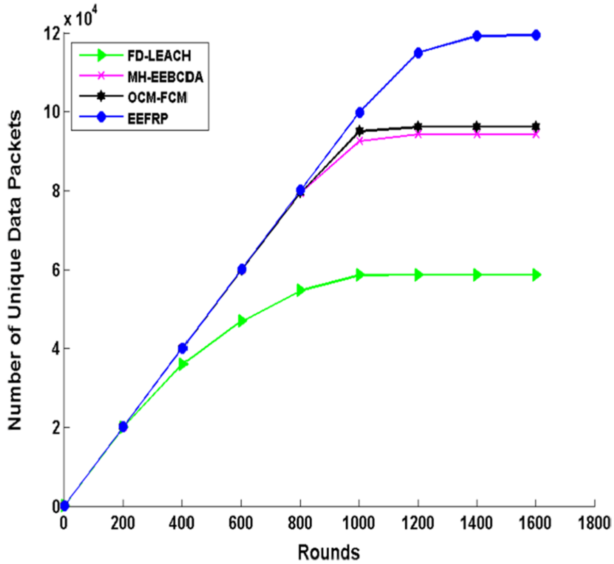



**Fig. 7** FND, HND and LND plots for WSN N = 100

be concluded that the proposed protocol performs far better than FD-LEACH, OCM-FCM and MH-EEBCDA throughout the lifetime of the network.

A comparative graph for round for First Node become Dead (FND), Half Nodes become Dead (HND) and Last Node become Dead (LND) for all protocols is shown in Fig. 7. The round for FND indicates the time for which the network remains completely operational and reliable. The round number for HND specifies the time duration in which the network decay its 50% operational ability. The round number for LND specifies the total lifetime of the network. Figure 7 presents the comparative plot of FND, HND, and LND round numbers for proposed protocol, MH-EEBCDA, FD-LEACH and OCM-FCM. From the figure it is observed that round number of FND in the proposed protocol is delayed by 563 rounds, 431 rounds and 293 with respect to FND round of OCM-FCM, FD-LEACH and MH-EEBCDA. Further, round number for HND in the proposed protocol is 22% and 26% better than OCM-FCM and MH-EEBCDA respectively. It shows that the proposed

**Fig. 8** Throughput of the network with N = 100




protocol takes longer time for being completely dead. In EEA-FCM the tasks such as data collection, aggregation and information forwarding are divided amongst CH and GW nodes of the cluster which results into healthier CH for longer period. Therefore, overall energy usage of the whole network is deduced and reliability is plunged.

Throughput of the network is calculated as the sum of unique data packets generated for each round. Throughput for all the four protocols is presented in Fig. 8. It can be perceived from Fig. 8 that data packet generations in OCM-FCM and MH-EEBCDA get saturated at about 1050 and 1084 round respectively. Total 94,293 and 96,135 number of data packets are generated in MH-EEBCDA and OCM-FCM respectively. The total amount of data packets generated in the proposed protocol is increased by 24% and 27% as compared to OCM-FCM and MH-EEBCDA. FD-LEACH, OCM-FCM and MH-EEBCDA generate less amount data from the monitoring area as their nodes survive for lesser time as compared to proposed protocol. Thence, the proposed algorithm shows a significant improvement in throughput.

Node density has great impact on network coverage, connectivity and its operational time. To analyse the impact of node density on the behaviour of network, another set of 100 WSN deployments has been taken by increasing number of nodes from 100 to 400. Figures 9, 10 and 11 compare the performance metrics for FD-LEACH, MH-EEMRP, OCM-FCM and the proposed protocols by increasing number nodes to N = 400. From Fig. 9, it is observed that FD-LEACH, MH-EEMRP, OCM-FCM are become completely dead till round 1100 whereas the network in the proposed protocol is completely operational even after 125 rounds. The lifetime of network for the proposed protocol is extended by 983 rounds and 1288 rounds as compared to OCM-FCM and FD-LEACH respectively. However, the lifetime of network for the proposed protocol in WSN with 100 nodes is extended only by 354 rounds and 740 rounds as compared to OCM-FCM and FD-LEACH respectiv ely.

The value of rounds for First Node Dead (FND), Half Node Dead (HND) and Last Node Dead (LND) for all the four protocols N = 100 and 400 are presented in Figs. 7 and 10. The

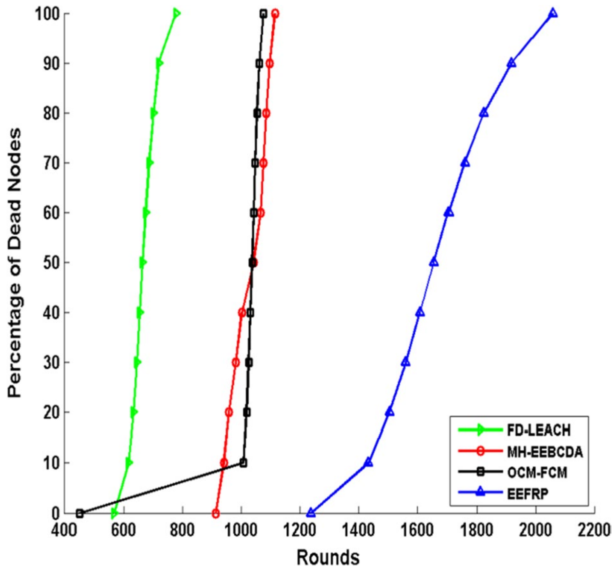



**Fig. 9** Percentage of dead nodes versus rounds for WSN with N = 400

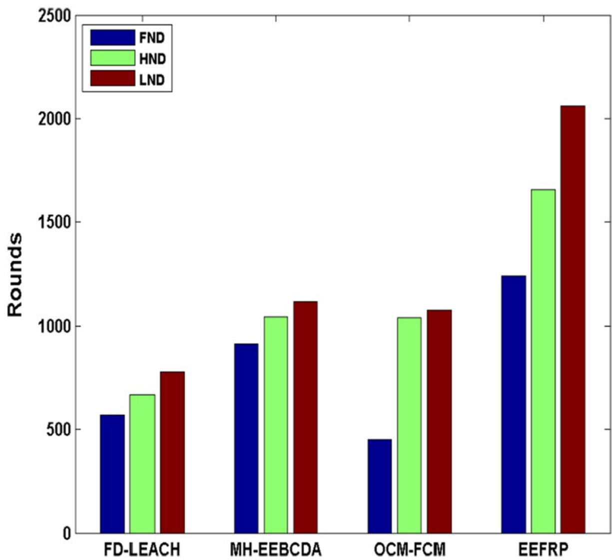



**Fig. 10** FND, HND and LND plots for WSN for N = 400

round number for FND in WSN with 400 nodes for the proposed protocol is delayed by 303 rounds in as compared to FND round number in WSN with 100 nodes. However, FND round number in FD-LEACH, MH-EEBCD and OCM-FCM are not improved significantly by changing node density. HND and LND in the proposed protocol is extended by 39% and 47% respectively as compared to their values at N = 100.

Comparative throughput of network for FD-LEACH, MH-EEBCDA, OCM-FCM and proposed protocol obtained with N = 400 is plotted in Fig. 11. It is observed from the figure that the proposed protocol generates 256,000 and 403,000 more data packets

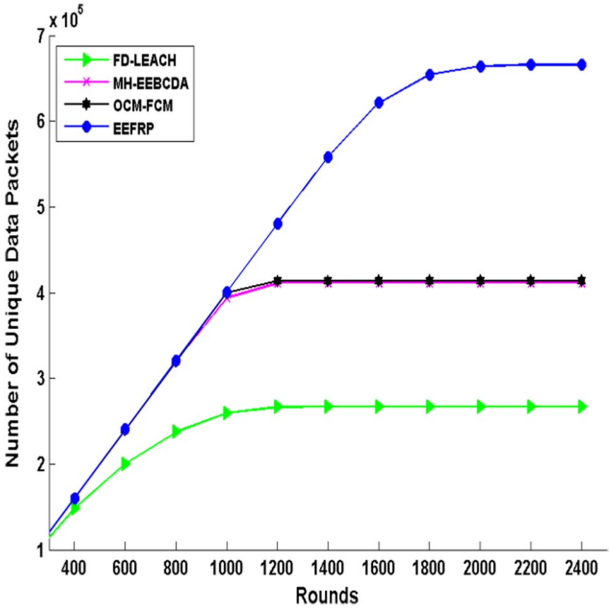



**Fig. 11** Throughput of network with N = 400

as compared to OCM-FCM and FD-LEACH respectively whereas this increases is only by 23,400 and 60,800 data packets for WSN with N = 100. Thence, it can be concluded that the proposed protocols performs much better than other protocols under examination with the increase in node density.

## 7 Conclusion

In this paper, an energy efficient routing protocol for WSN using fuzzy set and fuzzy rules is presented. The proposed protocol has been compared with FD-LEACH, MH-EEBCDA, and OCM-FCM for throughput, energy efficiency and network lifetime. EEFRP improved network lifetime by 30% and 34% as compared to MH-EEBCDA, OCM-FCM respectively. It is almost double as compared to FD-LEACH. There is a 24% improvement in throughput of EEFRP compared to OCM-FCM. From the results, it is concluded that energy load distribution in EEFRP amongst all sensor nodes is balanced more effectively as compared to other three protocols. The performance of the proposed protocol is further enhanced for higher network node densities. Therefore, it is confirmed that the proposed protocol is pertinent for WSN applications. This work can further be extended by adding trust value as fuzzy parameter while CH selection and establishing multi-hop links to make protocol suitable for secure networks.

## References

1. Mann, P. S., & Singh, S. (2017). Energy-efficient hierarchical routing for wireless sensor networks: A swarm intelligence approach. *Wireless Personal Communications, 92*(2), 785–805.

2. Aetesam, H., & Snigdh, I. (2017). A comparative analysis of flat, hierarchical and location-based routing in wireless sensor networks. *Wireless Personal Communications, 97*(4), 5201–5211.
3. Ding, X. X., Ling, M., Wang, Z. J., & Lou Song, F. (2017). DK-LEACH: An optimized cluster structure routing method based on LEACH in Wireless Sensor Networks. *Wireless Personal Communications, 96*(4), 6369–6379.
4. Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000). Energy efficient communication protocol for wireless microsensor networks. In *Proceedings of 33rd annual Hawaii international conference on system sciences*. IEEE. http://doi.org/10.1109/HICSS.2000.926982.
5. Heinzelman, W. B., Chandrakasan, A. P., & Balakrishnan, H. (2002). An application-specific protocol architecture for wireless microsensor networks. *IEEE Transactions on Wireless Communications, 1*(4), 660–670.
6. Ahlawat, A., & Malik, V. (2013). An extended vice-cluster selection approach to improve v-leach protocol in WSN. In *IEEE third international conference on advanced computing and communication technologies* (*ACCT*) (pp. 236–240).
7. Hssane, A. B., & Lahcen, M. (2010). Improved and Balanced LEACH for heterogeneous wireless sensor networks. *IJCSE International Journal on Computer Science and Engineering, 2*(08), 2633–2640.
8. Farooq, M. O., Dogar, A. B., & Shah, G. A. (2010). MR-LEACH: Multi-hop routing with low energy adaptive clustering hierarchy. In *2010 Fourth international conference on sensor technologies and applications* (*SENSORCOMM*) (pp. 262–268).
9. Neto, J. H. B., Rego, A., Cardoso, A., & Celestino, J. (2014). MH-LEACH: A distributed algorithm for multi-hop communication in wireless sensor networks. *ICN, 2014,* 55–61.
10. Arumugam, G. S., & Ponnuchamy, T. (2015). EE-LEACH: development of energy-efficient LEACH Protocol for data gathering in WSN. *EURASIP Journal on Wireless Communications and Networking, 76*(1), 2–9.
11. Nguyen, T. G., So-In, C., & Nguyen, N. G. (2014). Two energy-efficient cluster head selection techniques based on distance for wireless sensor networks. In *proceeding of IEEE international conference on computer science and engineering conference* (*ICSEC*) (pp. 33–38).
12. Bakr, B. A., & Lilien, L. T. (2014). Extending lifetime of wireless sensor networks by management of spare nodes. In *2nd international workshop on communications and sensor networks procedia computer science ComSense-2014*, vol. 34 (pp. 493–498).
13. Meng, X., Shi, X., Wang, Z., Wu, S., & Li, C. (2016). A grid-based reliable routing protocol for wireless sensor networks with randomly distributed clusters. *Ad Hoc Networks, 51,* 47–61.
14. Xu, F., Zhu, W., Xu, J., Lai, H., & Zheng, C. (2015). A low energy adaptive clustering multi-hop routing protocol based on fuzzy decision. *Journal of Intelligent & Fuzzy Systems, 29*(6), 2547–2554.
15. Taheri, M., & Kavian, Y. S. (2014). Energy efficient clustering algorithm for wireless sensor networks using fuzzy logic. *International Journal of Computer Applications, 89*(14), 1–5.
16. Su, S., & Zhao, S. (2018). An optimal clustering mechanism based on Fuzzy-C means for wireless sensor networks. *Sustainable Computing Informatics & Systems*, *18*, 127–134.



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