Advances and Applications in Mathematical Sciences
Volume 18, Issue 8, 2019, June Pages 587-604

AN IMPROVED HIERARCHICAL CLUSTERING APPROACH FOR MOBILE SENSOR NETWORKS USING TYPE-2 FUZZY LOGIC

ASRA KOUSAR, NITIN MITTAL and PRABHJOT SINGH

Department of Electronics and Communication Engineering
Chandigarh University, Mohali, Punjab
E-mail: asrashah80@gmail.com

Department of Electronics and Communication Engineering
Chandigarh University, Mohali, Punjab
E-mail: mittal.nitin84@gmail.com

Department of Electronics and Communication Engineering
Chandigarh University, Mohali, Punjab
E-mail: psprabh882@gmail.com

Abstract

Fuzzy logic (FL) in wireless sensor network (WSNs) is being used for the election of cluster head (CH) as it has ability to handle the imperfections accurately than the probability one. In mobile wireless sensor networks (MWSNs) due to the mobility factor in nodes high packet loss occurs and is a major issue for mobile applications. To overcome this problem, FL is used. Further, type-2 fuzzy logic (T2FL) has the capability to manage the uncertainties level efficiently than type-1 fuzzy logic (T1FL) as the fuzzy set of T2FL are membership function themselves. This paper presents how the T2FL and its membership functions elect the appropriate CH for mobile wireless sensor networks. In this paper, an improved hierarchical clustering approach using T2FL is proposed. Simulation results show that proposed method is better than the traditional ones in terms of network lifespan, energy consumption, and packet delivery ratio.

I. Introduction

Wireless Sensor Network (WSN) is an embedded system used in specific area for sensing the surrounding environmental factors like temperature, pressure, gas, humidity. Usually, WSNs are implemented in regions where probability of hazardous action is greater such as the areas where recharging

2010 Mathematics Subject Classification: 03B52.

Keywords: Fuzzy logic, type-1 fuzzy logic, type-2 fuzzy logic, cluster head election, mobility, sensor network CH, MSN, energy.

Received February 19, 2019; Accepted March 22, 2019

of battery is not easy and regions where it is impossible for humans to do the monitoring task. Generally, sensor nodes (SNs) are stationary and are fixed in their location once they are deployed. However, in various different applications of WSNs such as observing the habitant, surveillances, monitoring the transport activities and tracking of animals, mobile sensor nodes (MSNs) are used. But due to the rapid topology changes in the network high packet loss occurs. Therefore, for such networks, mobility is a problem during network designing [1]-[2]. There are various problems like limited power, low computing ability, open surrounding, and radio connectivity makes the SNs defected for many times. To overcome these problems, various routing algorithms have been introduced by different researchers to make the system more efficient in terms of operation [3].The Hierarchical cluster based routing algorithms is one of the method in which the groups of SNs are created and these groups are known as cluster. In each formed group, it is required to choose the group head called as Cluster Head (CH). Final collection of information is done at the CH. CH transmits the gathered data to Base station (BS). A well-known approach is the low-energy adaptive clustering hierarchy (LEACH) protocol [4]-[5], which is a probabilistic based approach to elect the CH in order to balance the energy consumption. But this approach is unable to support the mobile applications as SNs deployed in this approach are fixed and hence can cause more packet loss.

We can enumerate the contributions of our paper as follows:

i. Energy efficient CH election which maximizes the lifespan of the whole network.

ii. Electing stable CH in cluster that overcomes frequency of CH role of change.

iii. Reduces packet loss by electing appropriate CH using T2FL.

The remainder of the paper organization is as follows: in section II, literature review is discussed, section III describes the energy model, section IV presents the mobility model, and section V describes the detail of the proposed LEACH-MT2FL and proposed algorithm. Section VI describes the simulation results. Finally, VII present the concluded remarks.

II. Literature Review

Many mobility based clustering protocols were proposed on the basis of LEACH method [6]. The LEACH-mobile (LEACH-M) protocol presented in [7] is able to support the mobility of a SN. The logic behind LEACH-M is to confirm whether MSNs are able to transmit their data to CH in the steady-state phase. In LEACH-M, CH selection is same as that in LEACH protocol. Santhosh et al. [8] presented the LEACH-mobile enhanced (LEACH-ME) for CH election in mobile sensor networks. In this protocol, the SN with less mobility, more residual energy will be elected as CH in the set-up phase. Rest of the algorithm is same as that of LEACH. Data transmission between CH and SNs is high though nodes are moving. However, it causes more energy consumption and large amount of overhead as extra time is required to calculate the mobility factor. Samer et al. [9] Proposed cluster-based routing (CBR-MOBILE) protocol for MSNs based on adaptive scheduling. In this protocol, the nodes that enter the cluster during their free timeslot transmit their information to the CH and CH also collects the information from its member and then sends the aggregated data to the BS. The CBR protocol in steady-state phasechanges the TDMA scheduling adaptively when SNs move out of the cluster or join the new cluster. But, in CBR-mobile protocol CH election is the same as that of LEACH protocol which does not consider the movement of SNs. Also, in this algorithm, all CHs taken are static throughout the steady-state phase. Hence, the CBR protocol reduces the packet loss significantly compared to the LEACH-M protocol. Deng et al. [10] proposed a mobility-based clustering (MBC) algorithm for WSNs with MSNs. In the set-up phase, CH is elected by taking the remaining battery power and moving speed of every node. Every member of cluster joins the CH as per its approximate connection time, range to the CH, remaining battery power, and members of the CH. Therefore, MBC assures a strong link between a SN and the CH and hence, enhanced the packet received ratio successfully and reduces the energy dissipation.

Considering the LEACH protocol as a base, most of the upgraded protocols are used for mobile sensing environment to improve the Packet Delivery Ratio (PDR). But this leads to more energy dissipation due to the increased amount of control overhead and thus may result in shorter network lifespan. So, appropriate selection of the CH can reduce energy dissipation and hence can enhance the network lifetime. To deal with uncertainties in WSNs some of the fuzzy logic-based clustering algorithms are proposed. CHEF [11] takes two fuzzy descriptors such as minimum distance to BS and maximum residual energy for the election of CH. Alkesh et al. [12] and

Taheri et al. [13] consider three fuzzy descriptors for the election of CH and those fuzzy descriptors are remaining energy, concentration and centrality to enhance the network lifetime. F-MCHEL [14] is the improvement of the CHEF. In this algorithm, CH is elected on the basis of proximity distance to BS and energy. The CH having more energy is elected as Master CH (MCH) among the CH and MCH transmit the aggregated data to the BS. Nayak et al. [15] proposed the Energy Efficient Clustering Algorithm for Multi-Hop WSN using T2FL. In this algorithm, three fuzzy parameters were considered for the selection of CH such as minimum distance to BS, maximum residual energy, and concentration using T2FL. Many algorithms have been discussed based on the fuzzy inference system [16-19]. Above discussed, fuzzy based protocols were designed for stationary SNs and are unable to support mobile sensing applications. Lee [20] proposed Enhanced LEACH-M using Fuzzy Inference System (FIS) to enhance the network lifetime of MSNs in MWSNs and reduce the packet loss. In this protocol, three fuzzy parameters were taken into account for the selection of CH and these fuzzy parameters are remaining battery power, the mobility of nodes and pause time. The SN having more remaining battery power, slow moving speed, and larger pause time has a chance to be elected as a CH.

III. Energy Dissipation Model

The energy model [21] is applied in this paper to compute the power dissipation between transmitting and receiving device. A free space energy model (d2 power loss) is used when the range between transmitting node and receiving node is less than a threshold value do. Otherwise, the multipath fading energy model (d4 power loss) is employed. Energy consumption required for sending l bits of information to distance 'd' and taking l bits of information are given in equation 1and 2.

$$E_{TX}(l, d) = \begin{cases} lE_{elec} + l\varepsilon_{fs}d^2, & if\ d < d_0 \\ lE_{elec} + l\varepsilon_{mp}d^4, & if\ d \geq d_0 \end{cases} \tag{1}$$

$$E_{RX}(l) = lE_{elec}, \tag{2}$$

where E_{elec} means energy consumed per bit to function the transmitting or receiving module.

ε_{fs} is used for free space energy model and

ε_{mp} is used for multipath fading energy model.

IV. Mobility Model

The Random Waypoint Model (RWP) model is implemented for the management of mobility, location, velocity and acceleration change over time of mobile users. RWP is simplest and is widely used for the evaluation of mobile ad hoc network (MANET) routing protocols [22]. From the survey it has been revealed that widely used mobility model in Ad-hoc networks is RWP. In this paper, RWP model is applied as it is simplest one and is widely used for the evaluation of clustering routing protocols such as CBR-Mobile [9] and MBC [10], in mobile sensor networks. The mobility model applied here is same as used in [9] [10]. In this model, each SN chooses its direction randomly from $[0, 2\pi]$ and go towards a new waypoint from its current position for a distance with constant velocity generated randomly. In this model, if SN reaches a boundary it will reflect back from the boundary. Before moving to the next point, SN waits for the pause time.

In addition to the residual energy, the given proposed model considers the moving speed and pause time, which are available in the RWP model for the election of CH using fuzzy rules.

V. Proposed Model

In this paper, hierarchical clustering approach is modified for mobile sensor network by using type-2 fuzzy logic as T2FL model has the ability to handle the measured level of uncertainties exactly comparative to the T1FL model since its membership functions themselves are fuzzy sets.

In this paper, LEACH-MT2F is proposed to deal with uncertainties during CH selection in MWSNs in order to reduce the packet loss and extend the network lifetime.

A. System Assumption

The proposed network is developed on the basis of following assumptions:

- All the deployed SN in the proposed network along with the BS is mobile in nature.

- Initially, an equal amount of energy is given to the SNs in the network.

- The distance among SNs and BS in the network is computed by the received signal strength (RSSI).

B. Proposed LEACH-MT2FL Algorithm

The working of proposed LEACH-MT2FL algorithm is as follows:

1. The network is composed of N number of SNs that are distributed equally in the given network area.

2. The deployed network is comprised of k clusters.

3. The deployed SNs are divided into various levels on the basis of the distance of the nodes with BS.

4. In this step, the proposed T2FL is applied for the CH selection process.

5. Apply fuzzy if-then-rule else to select the CH for mobile sensor network.

6. In each round, select k number of CHs.

7. Transfer the information from SNs to CH till it reaches the BS.

8. The aggregated information is collected by BS.

C. Type-2 FL Model

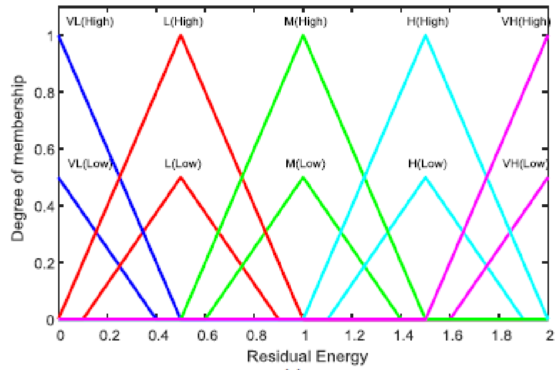
In proposed work, the T2FL is applied for creating the optimal CH in the mobile wireless sensor network. For this process, FL requires some kind of crisp input sets. The T2FL is applied as it produces the more smooth and reliable output and outperforms the generalized T1FL system. In this model, three fuzzy descriptors are used to elect the CH such as residual energy, moving speed and pause time and one output parameter namely chance. The higher the value of output more will be the probability of SN to become CH in mobile sensor network. The fuzzy set of residual energy is presented in Figure 1(a) and its linguistic variables are very low, low, medium, high and very high (abbreviated as VL, L, M, H, and VH, respectively). Second fuzzy set variable is the moving speed and is depicted in Figure 1(b) and its linguistic variables are very slow, slow, medium, fast, and very fast (as VS, S M, F, and VF, respectively). The last input variable is the pause time and its linguistic variables are very small, small, moderate, large, and very large (as VS, S, M, L, and VL, respectively) and are depicted in Figure 1(c). In Table I fuzzy set for input variables is shown. The fuzzy set for output variable chance is shown in Figure 1(d) and its linguistic variables are very poor, poor, rather poor, medium poor, moderate, moderate large, rather large, large, and very large (as VP, P, RP, MP, M, ML, RL, L , and VL, respectively). In Table II fuzzy set for output variable is shown. In this paper, triangular membership function is used to avoid computational burden.

Table I. Membership Function of I/P Variables.

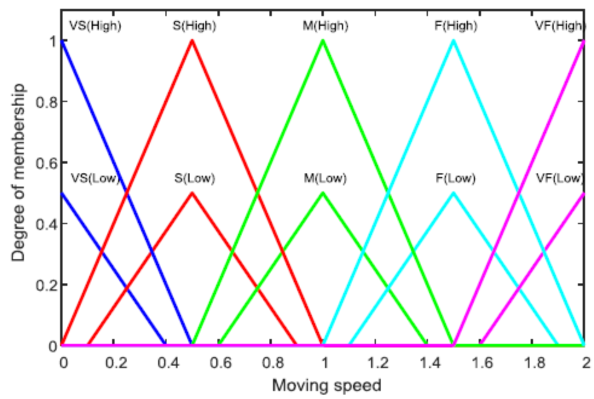
Residual	**energy**	**Moving**
very low	very slow	very small
low	slow	small
medium	medium	moderate
high	fast	large
very high	very fast	very large

Table II. Membership Function of O/P Variable.

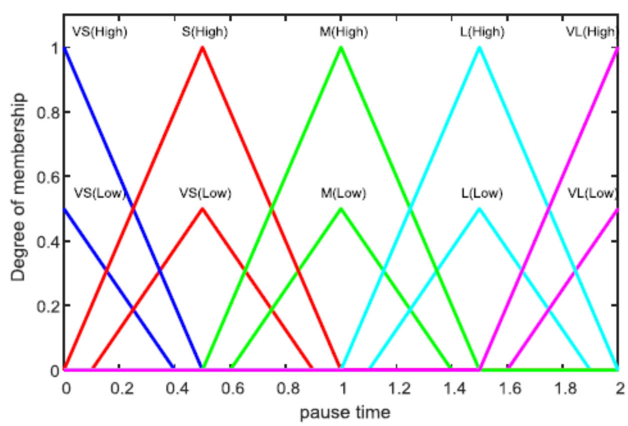
Chance
very poor, poor, rather poor, medium poor, moderate, moderate, large, rather large, large, and very large


VL(High)
L(High)
M(High)
H(High)
VH(High)
VL(Low)
L(Low)
M(Low)
H(Low)
VH(Low)
Degree of membership
Residual Energy

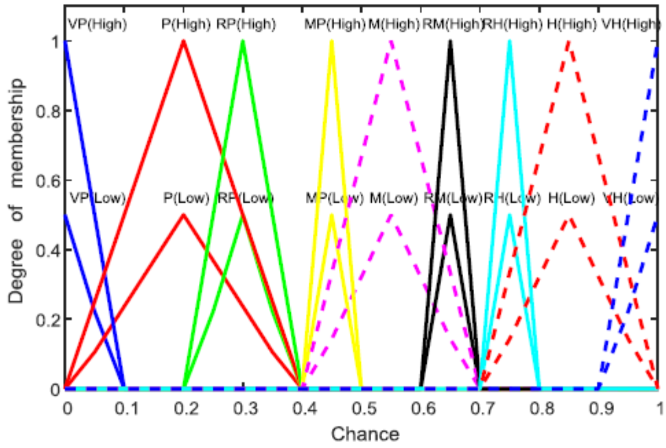
(a)


VS(High)
S(High)
M(High)
F(High)
VF(High)
VS(Low)
S(Low)
M(Low)
F(Low)
VF(Low)
Degree of membership
Moving speed

(b)


VS(High)
S(High)
M(High)
L(High)
VL(High
VS(Low)
VS(Low)
M(Low)
L(Low)
VL(Low)
Degree of membership
pause time

(c)



(d)

Figure 1. Fuzzy sets for I/P variables (a) residual energy, (b) moving speed, and (c) pause time, and for O/P variable (d) chance.

D. Rule Base LEACH-MT2FL

Chance is computed by using predefined fuzzy if-then else rules according to the three fuzzy input descriptors. Generally, fuzzy rules are established from experimental data or human heuristics. In this paper, we have used 53 (125) fuzzy rules for the election of appropriate CH. The structure of rule is like if *U*, *V*, *W*, and then *Z*. Here *U* means the residual energy, *V* means moving speed, *W* means pause time, and *Z* means selection of CH namely, chance. In this paper, a node which holds greater residual energy, slow moving speed and larger pause time has an opportunity to be elected as a CH on the basis of Mamdani's Fuzzy rule. In Table III, fuzzy rules and value of chance are described. Rule number 108 is the favorable example of this proposed algorithm.

The difference between T1FL and T2FL is that T1FL model is composed of four components i.e. a fuzzifier, fuzzy inference engine, fuzzy rules, and a defuzzifier. The framework of T1FL is illustrated in Figure 2. To complete the process in T1FL only four steps are required. It is employed to manage the uncertainty level to some level but not accurately since fuzzy sets used in T1FL are certain, whereas T2FL model is applied in a situation where it is difficult to find definite numeric membership functions and their uncertainties levels [23]. The concept behind T2FL on MWSNs is to enhance the network lifetime, reduce packet loss and increase the PDR as it can circulate the load equally among SNs and can efficiently elect the appropriate CH. In [24], T2FL is distinguished by superior membership function and an inferior membership function. The interval between these two functions describes the footprint of uncertainty (FOU) and is used to distinguish a T2FL set. It can be varied from 0 to1.

T2FL model is consists of five modules shown in Figure 3 below.

(1) Fuzzifier: To convert crisp values to fuzzy values a fuzzifier is used.

(2) Fuzzification Module: In this module, mapping is done from an inputT2F set to output T2F set by combining the fuzzy rules with the help of fuzzy inference engine.

(3) Type Reducer/Defuzzifier: In reducer module, T1FL is generated as output, then is converted to a numeric value with the help of running defuzzifier [25].

(4) Knowledge Base: Set of fuzzy rules and membership functions are contained in this unit.

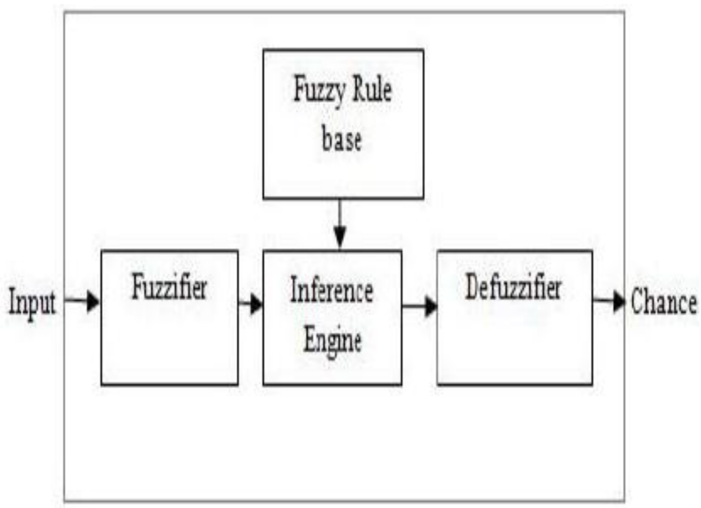


Figure 2. Framework for T1FL.

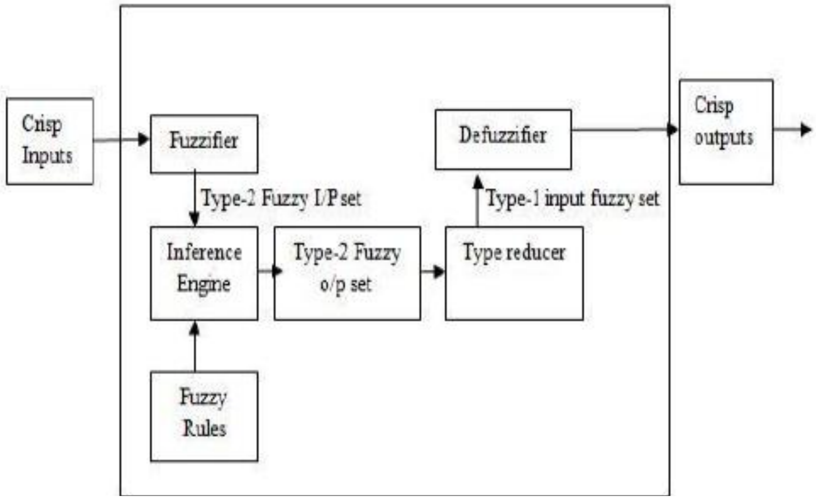


Figure 3. Framework for T2FL.

Table III. LEACH-MT2FL Rules.

Rule	Residual energy	Moving Speed	Pause Time	Chance
1.	VL	VS	VS	RP
2.	VL	VS	S	RP
3.	VL	VS	M	MP
…				
21.	VL	VF	VS	VP
22.	VL	VF	S	VP
…				
108.	VH	VS	VL	VH
109	VH	S	VS	M
…				
122.	VH	VF	S	RP
123.	VH	VF	M	MP
124.	VH	VF	L	MP
125.	VH	VF	VL	M

VI. Results and Discussion

The proposed work is implemented for network size of 100 nodes and on the basis of T2FL the CHs are elected using three fuzzy descriptors such as residual energy, moving speed and pause time for the mobile sensor network and then is simulated on MATLAB. The Mamdani's if then-else rules have been used to compute the chance to be the CH. Simulation parameters are given in Table IV.

This section gives an overview to the results and outcomes that are obtained after implementation of theproposal. The performance of the proposed work is measured in the terms of PDR, number of dead nodes, total energy consumption etc. To prove the efficiency of proposed work, a comparison analysis is done with LEACH-M, MBC and LEACH-MF. The graph in figure 4 represents the comparison analysis of proposed and traditional techniques on the basis of PDR with respect to the percentage of mobile sensor nodes. PDR means ratio of packets delivered to the BS successfully. From the observations of graph, it can be said that the PDR of LEACH-M is the lowest in contrast to the MBC, LEACH-MF, LEACH-MT2F.

Table IV. Experimental setup of the proposed work.

Parameters	Value
Network Area	100*100m
Number of Nodes	100
Base Station Location	50*50
Node Distribution	Random
Base Mobility	Random
Moving speed	1-20m/s
Pause Time	0-5 sec
Round Time	20s

The graph in Figure 5, shows the number of dead nodes found in proposed and traditional approaches with respect to the various rounds of communication performed in network for data transmission. The x axis calibrates the data for number of communication rounds, it ranges from 0 to 900. The *y* axis, shows the data for number of dead nodes and it lies within 0 and 100. The graph explains that in LEACH-M, the nodes started running out of energy earlier i.e. nearby 200 rounds, in MBC, the nodes started dying at 300 rounds, in LEACH-MF, and this reaches to the approximately 360 rounds. In LEACH-MT2F the nodes started dying after 400 rounds of communication. Hence, it can be said that the network operated by using the proposed work has the highest possibility of longer lifetime. The graph in Figure 6 elaborates the total energy consumption of proposed modified LEACH-MT2F and other traditional techniques. The energy consumption of traditional LEACH-M is higher as this network runs out of energy after the completion of 300 rounds, similarly, the MBC network dies after the completion of 500 rounds, the LEACH-MF exists till 550 rounds, LEACH-MT2F remains active till 880 rounds approximately. On the basis of these observations, it is concluded that the energy consumption of traditional work is higher than LEACH-MT2F.

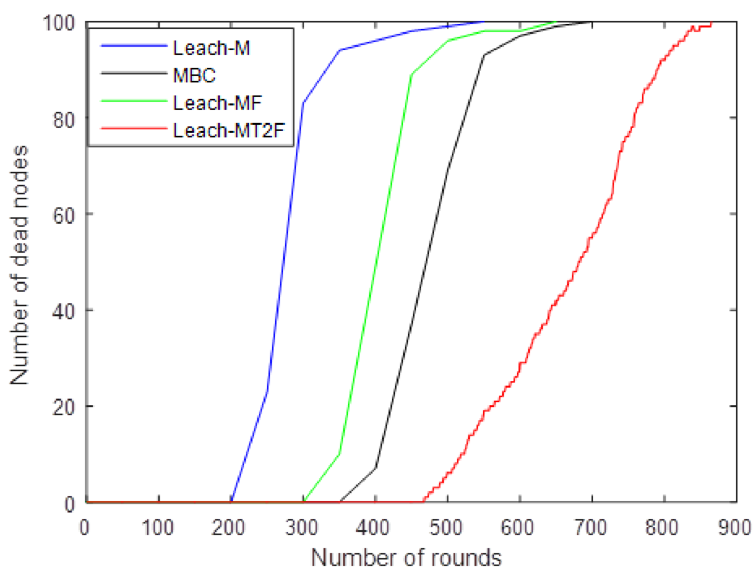


Figure 5. Comparison Analysis of Number of Dead Nodes.

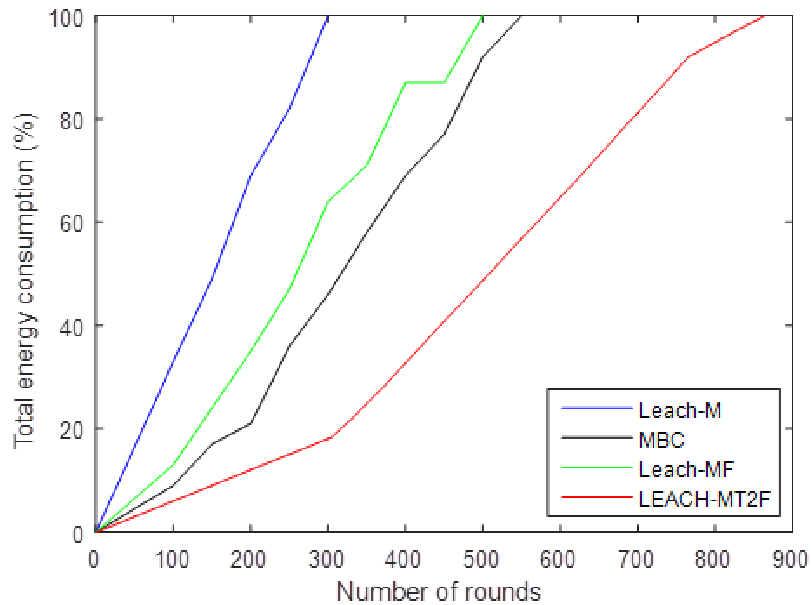
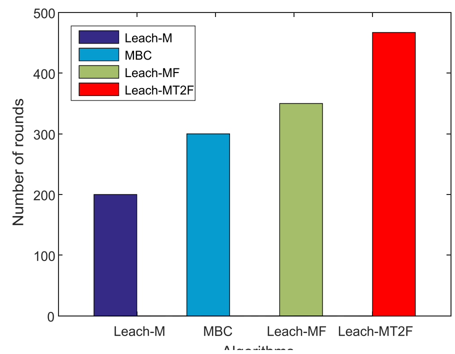
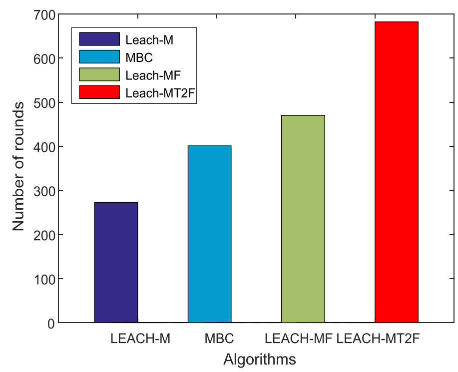


Figure 6. Comparison analysis of total energy consumption.

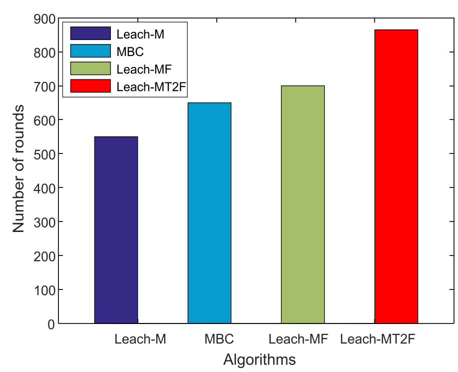
The graphs given in Figure 7 show the First Node Dead, Half Node Dead and Last Node Dead in proposed work and traditional work. The graph (a) delineates the comparison analysis for FND on the basis of the communication rounds shown on y axis among LEACH-M, MBC, LEACH-MF and LEACH-MT2F Similarly, the graph in figure (b) and (c) shows the comparison analysis for HND and LND. The observations of the graphical facts are shown in Table V below. On the basis of the facts shown in table, it is concluded that the FND in LEACH-M at 200 rounds, in MBC at 300, in LEACH-MF at 350 and in LEACH-MFT2 at 467 rounds respectively. The HND in LEACH-M at 273 rounds, in MBC at 401, and LEACH-MF at 470 rounds whereas for LEACH-MF T2 it is located at 682 respectively. Similarly, the last node dead in LEACH-M is at 550 rounds, in MBC at 650, in LEACH-MF is at 700 rounds and in LEACH-MT2F is at 865 rounds.



(a) First Node Dead



(b)Half Node Dead



(c)Last Node Dead

Figure 7. Comparison Analysis of Dead Nodes (a) FND (b) HND and (c) LND.

Table V. FND, HND and LND in Proposed and Traditional Approaches.

Techniques	LEACH-M	MBC	LEACH-MF	LEACH-MT2F
FND	200	300	350	467
HND	273	401	470	682
LND	550	650	700	865

VII. Conclusion

The main issue in mobile sensor networks is the mobility. So, protocol must be able to handle node movement and frequent topology changes. In this paper, an enhanced LEACH-MT2F has been developed to enhance the network lifespan and minimize the packet loss for mobile sensing surroundings. In the proposed method, type-2 fuzzy logic has been proposed for CH selection in mobile sensor networks. In this approach, a node having more residual energy, smaller speed, and larger pause time would have the opportunity to be elected as CHs. The simulated results conclude that the performance of the proposed work is efficient over traditional work i.e. LEACH-M, MBC and LEACH-MF respectively in the terms of PDR, total energy consumption and dead nodes in the network.

The aim of this paper is not only to improve the lifetime of mobile sensor networks, but also to minimize the packet loss in mobile sensing surroundings. It may include the evaluation with many multiple mobility models in future also ,the improvement of the proposed scheme in terms of optimality and efficiency, and the comparison of other performance metrics, such as the achieved throughput, end-to-end delay, and packet jitter.

References

[1] R. Velmani and B. Kaarthick, An efficient cluster-tree based data collection scheme for large mobile wireless sensor networks, IEEE Sensors Journal vol. 15, pp. 2377-2390, 2015.

[2] M. Al-Jemeli and F. A. Hussin, An energy efficient cross-layer network operation model for IEEE 802.15. 4-based mobile wireless sensor networks, IEEE Sensors Journal, vol. 15, pp. 684-692, 2015.

[3] S. Kamble and T. Dhope, Reliable routing data aggregation using efficient clustering in WSN, in 2016 International Conference on Advanced Communication Control and Computing Technologies (ICACCCT), 2016, pp. 246-250.

[4] W. B. Heinzelman, A. P. Chandrakasan and H. Balakrishnan, An application-specific protocol architecture for wireless microsensor networks, IEEE Transactions on wireless communications, vol. 1, pp. 660-670, 2002.

[5] W. R. Heinzelman, A. Chandrakasan and H. Balakrishnan, Energy-efficient communication protocol for wireless microsensor networks, in System sciences, 2000. Proceedings of the 33rd annual Hawaii international conference on, 2000, p. 10 pp. vol. 2.

[6] S. Tyagi and N. Kumar, A systematic review on clustering and routing techniques based upon LEACH protocol for wireless sensor networks, Journal of Network and Computer Applications, vol. 36, pp. 623-645, 2013.

[7] D.S. Kim and Y.-J. Chung, Self-organization routing protocol supporting mobile nodes for wireless sensor network, in Computer and Computational Sciences, 2006.IMSCCS'06. First International Multi-Symposiums on, 2006, pp. 622-626.

[8] G. S. Kumar, P. M. Vinu and K. P. Jacob, Mobility metric based leach-mobile protocol, in Advanced Computing and Communications, 2008. ADCOM 2008. 16th International Conference on, 2008, pp. 248-253.

[9] S. A. Awwad, C. K. Ng, N. K. Noordin and M. F. A. Rasid, Cluster based routing protocol for mobile nodes in wireless sensor network, Wireless Personal Communications vol. 61, pp. 251-281, 2011.

[10] S. Deng, J. Li and L. Shen, Mobility-based clustering protocol for wireless sensor networks with mobile nodes, IET Wireless Sensor Systems, vol. 1, pp. 39-47, 2011.

[11] J.M. Kim, S.-H. Park, Y.-J.Han, and T.-M. Chung, CHEF: cluster head election mechanism using fuzzy logic in wireless sensor networks, in Advanced Communication Technology, 2008. ICACT 2008. 10th International Conference on, 2008, pp. 654-659.

[12] A. Alkesh, A. K. Singh and N. Purohit, A moving base station strategy using fuzzy logic for lifetime enhancement in wireless sensor network, in 2011 International Conference on Communication Systems and Network Technologies, 2011, pp. 198-202.

[13] H. Taheri, P. Neamatollahi, O. M. Younis, S. Naghibzadeh and M. H. Yaghmaee, An energy-aware distributed clustering protocol in wireless sensor networks using fuzzy logic, Ad Hoc Networks, vol. 10, pp. 1469-1481, 2012.

[14] T. Sharma and B. Kumar, F-MCHEL: Fuzzy based master cluster head election leach protocol in wireless sensor network, International Journal of Computer Science and Telecommunications, vol. 3, pp. 8-13, 2012.

[15] P. Nayak and B. Vathasavai, Energy efficient clustering algorithm for multi-hop wireless sensor network using type-2 fuzzy logic, IEEE Sensors Journal, vol. 17, pp. 4492-4499, 2017.

[16] Z. Siew, C. F. Liau, A. Kiring, M. Arifianto and K. T. K. Teo, Fuzzy logic based cluster head election for wireless sensor network, in Proc. 3rd CUTSE Int. Conf., 2011, pp. 301-306.

[17] V. Nehra, R. Pal and A. K. Sharma, Fuzzy-based leader selection for topology controlled PEGASIS protocol for lifetime enhancement in wireless sensor network, International Journal of Computers & Technology, vol. 4, pp. 755-764, 2013.

[18] G. Ran, H. Zhang and S. Gong, Improving on LEACH protocol of wireless sensor networks using fuzzy logic, Journal of Information &Computational Science, vol. 7, pp. 767-775, 2010.

[19] H. Ando, L. Barolli, A. Durresi, F. Xhafa and A. Koyama, An intelligent fuzzy-based cluster head selection system for WSNs and its performance evaluation for D3N parameter, in 2010 International Conference on Broadband, Wireless Computing, Communication and Applications, 2010, pp. 648-653.

[20] J.S. Lee and C.-L. Teng, An enhanced hierarchical clustering approach for mobile sensor networks using fuzzy inference systems, IEEE Internet of Things Journal, vol. 4, pp. 1095-1103, 2017.

[21] M. Mirsadeghi, A. Mahani and M. Shojaee, A novel distributed clustering protocol using fuzzy logic, Procedia Technology, vol. 17, pp. 742-748, 2014.

[22] T. Camp, J. Boleng and V. Davies, A survey of mobility models for ad hoc network research, Wireless Communications and Mobile Computing, vol. 2, pp. 483-502, 2002.

[23] P. Nayak and A. Devulapalli, A fuzzy logic-based clustering algorithm for WSN to extend the network lifetime, IEEE Sensors Journal, vol. 16, pp. 137-144, 2016.

[24] N. N. Karnik and J. M. Mendel, Introduction to type-2 fuzzy logic systems, in 1998 IEEE International Conference on Fuzzy Systems Proceedings. IEEE World Congress on Computational Intelligence (Cat. No. 98CH36228), 1998, pp. 915-920.

[25] D. Pushpalatha and P. Nayak, A clustering algorithm for WSN to optimize the network lifetime using type-2 fuzzy logic model, in 2015 3rd International Conference on Artificial Intelligence, Modelling and Simulation (AIMS), 2015, pp. 53-58.