January - February 2020
ISSN: 0193 - 4120 Page No. 402 - 412

Traffic Heterogeneity Aware Fuzzy Logic Based Clustering Protocol to Maximize the Lifetime of Wireless Sensor Networks

Harmeet Singh[1], Manju Bala[2], Sukhvinder S Bamber[3]

[1]Research Scholar, Department of Applied Sciences – Computer Applications, I. K. Gujral Punjab Technical University, Kapurthala 144603,, INDIA. ap.singh.harmeet@gmail.com.

[2]Professor, Department of Computer Science and Engineering, Khalsa College of Engineering & Technology, Amritsar 143001, India. drmanju571@gmail.com.

[3]Assistant Professor, Department of Computer Science and Engineering, P.U. Swami Sarvanand Giri Regional Centre, Hoshiarpur 146021, India. bambery2k@yahoo.com.

(Corresponding author: Harmeet Singh, Email Id: ap.singh.harmeet@gmail.com)

Article Info
Volume 82
Page Number: 402 - 412
Publication Issue:
January-February 2020

Article History

Article Received: *14 March 2019*
Revised: *27 May 2019*
Accepted: *16 October 2019*
Publication: *02 January 2020*

Abstract

Wireless sensor networks (WSNs) have been of importance since they came into existence because of their numerous uses and low cost of electronics involved in sensor nodes. The nodes are powered by smaller batteries and energy conservation has remained important area of research of WSN because replacement of the batteries is costly affair. Clustering is the most famous approach followed by researchers to maximize the network lifespan. These nodes do have heterogeneity levels in terms of energy and traffic sensor by them. Selection of the optimal cluster head considering the node's characteristics is important task in clustering as it impacts the performance of the network. This paper proposed a clustering protocol named as Traffic Heterogeneity aware Fuzzy logic based Clustering Protocol (THFLCB). This protocol uses the fuzzy rules to find the aptness value of a node to become cluster head. The parameters considered for cluster head election are traffic sensed by a node (traffic heterogeneity), remaining energy of the node (energy heterogeneity), energy cost of communication with the base station and distance to the base station. The proposed protocol was evaluated in terms of number of alive nodes in the network. The protocol has outperformed other state of the art protocols.

Keywords: *Keywords: WSN, Traffic heterogeneity, Energy heterogeneity, network lifespan*

1. Introduction

Recent times have seen many improvements in wireless communications, micro- electromechanical systems (MEMS) technology in addition to low-power electronics. Wireless sensor networks (WSNs) are evolving as indispensableas they offer widespreadmethods of assistingprevalent computing environments for numeroususesowing to characteristics like lesser size, less-cost, low-power, in addition tobeing their use in multiple purposes (Jiang et. al 2009). In theseuses, huge number of less-cost sensor nodes are distributedin the observingregion and thesensorswiselystructured in a wireless network. WSNs are extensively used to accomplish army tracking and investigation, natural calamity respite, dangerous atmosphere survey in addition to health observing etc (J. Yick et. al 2008). In this networkindividual sensor node intermittentlyforwards its observedinformation to the central server known as base station. The sensor networks are further classified into homogeneous and heterogeneous networks in context of node characteristics. In former type of networks, every sensor node is equal in context of battery size as well as hardware complication whereas in the latter type, the sensor nodes have different characteristics such as different energy levels, different transmission range etc. The situation is problematicwhen the nodes have to besubstituted or to revitalize batteries of the nodes while they function in unfriendlyatmospheres/surroundings. Energy preserving is an imperativequestion for such network.

January - February 2020
ISSN: 0193 - 4120 Page No. 402 - 412

Countlessmethods for energy preserving are established, comprisingof sleep-wake mechanism, media access control (MAC) procedures, routing procedures, clustering techniques, topological control, etc (Thakkar A et. al 2014). Amongst these schemes, designing optimal routing protocol is an imperativequestion for sensor networks. Routingiscategorized in planar routing plus hierarchical routing. The latterdivides the network inmultiple clusters in which cluster head aggregates data from the cluster members.The aggregated data is forwarded to the base station (BS). The benefit of less energy depletion, simple routing tables as well asdecent scalability, makes such approaches to be constant research field of sensor networks (Zhu K. et. al 2013). Clustering is method in which the network is divided into number of clusters. Various research works have been done that decides the optimal number of clusters for a network. This is done because large sized clusters increase load over a cluster head and multiple small sized clusters increases the clustering cost. Each cluster is headed by a cluster head and other sensors in its range are cluster members. The whole clustering process follows traditional clustering protocol named Low Energy Adaptive clustering hierarchical (LEACH) protocol which randomly selects the cluster heads among sensor nodes (M. Zeng et. al 2019). For heterogeneous networks in terms of different energy levels of the nodes, the Stable Election Protocol comes into play which gives more priority to the high-energy nodes to become cluster heads. However, heterogeneity is also observed in terms of traffic generated by the nodes. The protocol that decides the optimal cluster head considering the traffic generated by a node has been explained in Traffic and Energy Aware Routing (TEAR) (D. Sharma et. al 2018).

This paper describes a routing protocol that considers the traffic as well as energy heterogeneity of the sensor nodes and uses the fuzzy rules to further optimize the performance of the network. The proposed protocol is an extension to TEAR and is termed as Traffic Heterogeneity aware Fuzzy logic based Clustering Protocol (THFLCB). The section 2 of this paper describes the previous research techniques related to clustering of sensor networks. Furthermore it also describes the motivation to design the proposed protocol. Section 3 explain the system model and assumptions undertaken in this work. The detailed proposed protocol has been explain in Section 4. Results and discussion is described in Section 5 and paper has been concluded in last section.

2. Related Work and Motivation

T.M. Behera et. al (2019) have presented a clustering protocol where they have modified only cluster head rotation phase. In this, the cluster heads are rotated among the high-energy nodes only and cluster heads are elected according to remaining energy of the nodes as well as optimum number of clusters. H.E. Alami et. al (2019) have focused on improving the network lifetime in clustered wireless sensor network. They have grouped the nodes whose the sensing ranges are found partially or fully overlapping with each other. Then these nodes are undergo sleep and wake mechanism to preserve the energy which consequently increases the network lifespan. O.O. Ogundileet. al (2019) proposes the use of mobile sink to increase lifetime of wireless sensor networks. It formulates two shortest routes to the cluster head or the mobile sink based on the transmission power as well as residual energy of the sensor nodes. While many of the clustering protocols focus on formation of equal sized clusters, F. Liu et. al (2019) focuses on unequal clustering that occurs because the nodes are randomly positioned in the sensor field. They propose unequal clustering protocol that selects the cluster heads based on the priorities of the nodes computed with the help of fuzzy rules and furthermore during the cluster formation different size of cluster radius is assigned to the selected cluster heads. The algorithm used in the cluster formation phase is adaptive kernel density estimation algorithm and the protocol proves to outperform the other works in terms of stability of the network as well as its lifespan. D. Lin et. al (2019) focuses on the reduction of energy consumption during the process of cluster head rotation. For this, they proposed the selection of dual cluster heads where the rotation of the role of cluster head occurs between the current cluster head and the second back up cluster head. Furthermore, to balance the energy consumption between the cluster heads Nash equilibrium point for non-cooperative game theory was proposed. It is seen that majority of energy conservation issues are address

January - February 2020
ISSN: 0193 - 4120 Page No. 402 - 412

in 2D wireless sensor networks, on the other hand, Z. Zhao et. al (2019) have worked in 3D sensor networks in which network was modelled in spherical structure. In this work, the authors have used distance similarity index method to optimize the clustering process. Clusters head are elected according to their position in 3D model and their remaining energies. If size of clusters formed is large, then dual cluster head selection mechanism is proposed for those clusters. Furthermore, to balance the consumption of energy after the death of first node, the network uses node dormancy mechanism. Z. Wei et. al (2018) uses the concept of rechargeable sensor nodes and mobile charging device. The mobile sink is used in this protocol to collect data from the sensor nodes and mobile charging device is used to recharge the sensor nodes. E.F.A. Elsmany et. al (2019) focuses on the scalability issue of the sensor networks and uses three layers of hierarchy to extend the network's lifespan. The proposed clustering protocol uses multi hop transmission method to minimize the load among the cluster heads. R. Sharma et. al (2019) uses the differential evolutionary technique along fuzzy C to compute the fitness of eligible nodes and optimize the cluster head selection process. Majority of the clustering protocols discussed above consider the homogeneous traffic generation at the nodes, D. Sharma et. al (2018) considers the traffic heterogeneous scenarios. The threshold value of the node considered during selection of cluster head is adjusted according to the traffic generated at each node.

The related works show that clustering protocols designed lately do focus on the energy heterogeneity and the use of various cluster head selection techniques to optimize the performance of the network. One of the above mentioned technique also takes into account traffic heterogeneity as well. This scheme lacks the use of optimal cluster head election methods that consider various parameters of the node as well. This paper proposes a modification to traffic heterogeneous sensor network clustering technique to optimally select the cluster head by using the fuzzy rules. This is expected to further improve the performance of the network in terms of its lifetime and stability.

3. System Model and Assumptions:

- The 'N' nodes are randomly distributed in the region of interest (X*X) with the base station positioned in the center.
- Every node is aware of its own location coordinates as well as coordinates of the base station.
- Nodes are heterogeneous in terms of initial energy. If the energy heterogeneity factor is λ, then the range of initial energies of the nodes is $[E_0, E_0(1+\lambda)]$ where E_0 is the energy's lower bound.
- Nodes generate unequal amount of data i.e. nodes are heterogeneous in terms of traffic generation. Assume that traffic heterogeneity factor is β. In such scenario, the length of data sensed and transmitted by any node having the traffic heterogeneity factor 'β' is given by $b_i = b_0(1+\beta)$; where b_0 is the lower bound and upper bound is controlled by traffic heterogeneity factor. The traffic length is randomly distributed over the range $[b_0, b_0(1+\beta)]$.
- Network has sufficient bandwidth to meet the support upper bounds of traffic.

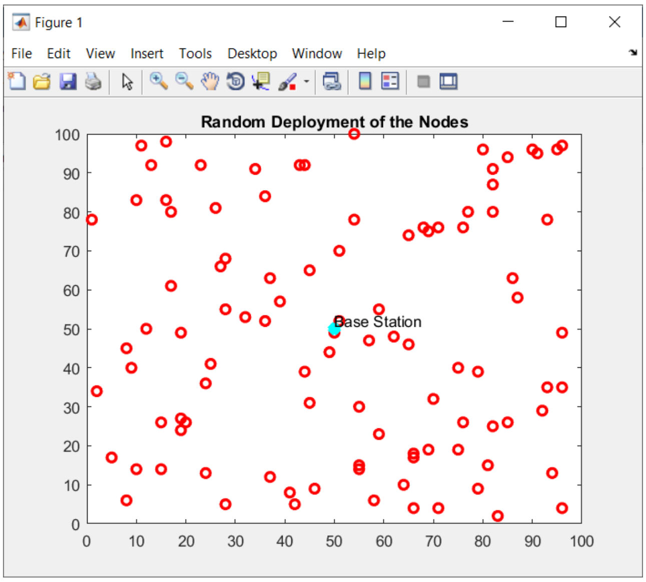

Figure 3.1: Network Model

4. Proposed Clustering Protocol:

This section describes the clustering protocol that selects the cluster heads considering the traffic associated with each node as well as other node parameters. The other parameters include the residual energy of the node, the distance of the node from the

January - February 2020
ISSN: 0193 - 4120 Page No. 402 - 412

base station and energy cost of communication with the base station. This protocol is enhanced version of TEAR. The enhancement is done by introducing the Fuzzy Rules to TEAR and considering different parameters to the cluster head selection. Here, we first discuss the impact of these parameters on the network's performance and their computations such that cluster heads can be selected optimally in the network. After this, the details of the THFLCB has been presented.

4.1 Impact of the selected parameters over the network's performance:

The parameters namely traffic forwarded by a node, its remaining energy, its distance to base station and energy cost of communication with the base station are all inter-related. The energy consumption by the cluster head in any clustering protocol happens when the cluster head receives the data from the cluster members and aggregates it and when it forwards the aggregated data to the base station.

The energy involved in the receiving of the data from its cluster members depends on number of cluster members as well as number of bits received. The energy consumed in receiving the data is given by basic Radio model (W.B. Heinzelman et. al 2002)

$$E(Rx) = \sum_{i=1}^{k} b_i * E_{elec} \quad (1)$$

Where 'b_i' is the number of bits received from i^{th} cluster member and 'k' is the number of members in the cluster.

After receiving this data, the cluster head needs to forward the same to the base station. The energy involved in data forwarding according to basic radio model will be:

$$E(Tx) = b * E_{elec} + b * E_{fs} * {d_{CH,BS}}^2 \quad \text{if } d_{CH,BS} < d_0 \quad (2)$$

$$E(Tx) = b * E_{elec} + b * E_{amp} * {d_{CH,BS}}^4 \quad \text{if } d_{CH,BS} > d_0$$

Where $d_{CH,BS}$ is the distance between cluster head and base station; d_0 is the threshold value of distance.

The energy cost of communication of single cluster head with the base station will be:

$$E_{cost} = E(Tx) + E(Rx) \quad (3)$$

This cost of communication is directly proportional to traffic received i.e. number of bits and β, number of cluster members 'k' and distance to the base station. If the size of cluster is large, i.e. it has more number of cluster members, then energy of receiving the data will be very high and vice-versa. Furthermore, this energy consumption will also have an upper bound of β. This energy consumption will vary from [E(Rx), (1+β)E(Rx)]. If the value of β increases, then energy consumption will move towards its higher limits and it will negatively impact the network lifetime. Also, the energy consumed in transmission is directly proportional to distance and it varies as square or fourth power of it. The more the distance, the more will be the energy consumed in transmission and vice-versa.

Therefore, if a cluster head islocated at farther distance from the base station and has lesser energy makes a larger cluster and in which the traffic generated by the cluster members is closer to the upper limits, the cluster head will experience high load and will drain its energy quickly. This will degrade the performance of the network.

4.2Traffic Heterogeneity aware Fuzzy logic based Clustering Protocol (THFLCB)

In this protocol, there are three stages. In first stage, each node computes its aptness value (A.V.) using the fuzzy logic. Using the computed A.V., the node computes the threshold value to decide if it becomes cluster head or not. The second stage deals with the formation of the clusters where each node joins the cluster head having highest remaining energy. The third stage is focused on aggregating the data by cluster head from the cluster members, which is then sent to the base station for processing. Just like LEACH, the proposed THFLCB is also distributed protocol and operates in rounds where each round consists of the stages described above.

4.2.1 Cluster head election stage:

Initially all the nodes are randomly deployed in the region of interest. To make sure that the network

January - February 2020
ISSN: 0193 - 4120 Page No. 402 - 412

provides adequate quality of service, the nodes execute the proposed protocol. Therefore, all the nodes will carry out the cluster head election process first before they start sensing the data from the environment. Similar to LEACH, in each round maximum of 'p' percentage of the nodes that are still alive in current round, will be chosen as cluster heads. A node becomes cluster head if random number generated by it is less than respective threshold value.

$$Th(i) = \begin{cases} \frac{p_i(r)}{1-p_i(r)(r \bmod \frac{1}{p_i(r)})} & \text{if node(i)} \in G(r) \\ 0 & \end{cases} \quad (4)$$

otherwise

where $p_i(r)$ is the probability of the node(i) to become cluster head, 'r' is the current round number and G(r) represents the set of eligible nodes. Other protocols, such as SEP or DEEC which work in energy heterogeneous environment, adjust probability of the node to become cluster head in a way that the node having higher residual energy has higher probability. TEAR on the other hand is a protocol that operates in environment where traffic sensing is different at different nodes. This protocol adjusts probability in a way that the node which has higher traffic load has less chances of becoming cluster head as more load drains out more energy of the node. Section 4.1 describes the impact of other parameters as well on the selection of optimal cluster head. Therefore, considering those parameters that proposed THFLCB defines the probability of a node to become cluster head in round 'r' as:

$$p_i(r) = \frac{p_{opt}\,.N(1+\lambda_i)N(1+\beta_i-\lambda_i)}{(N+\sum_{i=1}^{N}\lambda_i)(N+N\beta_i-\beta_{Tot})} * A.V. \quad (5)$$

Where $p_{opt} = \frac{m_{opt}}{N}$ is the optimal probability, $\beta_{Tot} = \sum_{i=1}^{N}\beta_i$ and m_{opt} is optimum number of clusters.

$$m_{opt} = \sqrt{\frac{N(N+\beta_{Tot})E_{fs}.X^2}{2\pi((N.\beta \quad -\beta_{Tot})E_{elec} \quad +N(1+\beta \quad)E_{fs}.d_C}} \quad (6)$$

To compute A.V each node uses the fuzzy rules described in the next section.

4.2.1.1 Fuzzy Model

This model is used for the nodes to compute their A.V. Fuzzy solution will help to provide optimal selection of the node as cluster head using the multiple parameters described in Section 4.1. The figure below shows the fuzzy system.Initially all the three parameters are fed as input to the fuzzy system. This systems consists of fuzzification, fuzzy interference system, rules evaluation and de-fuzzification.

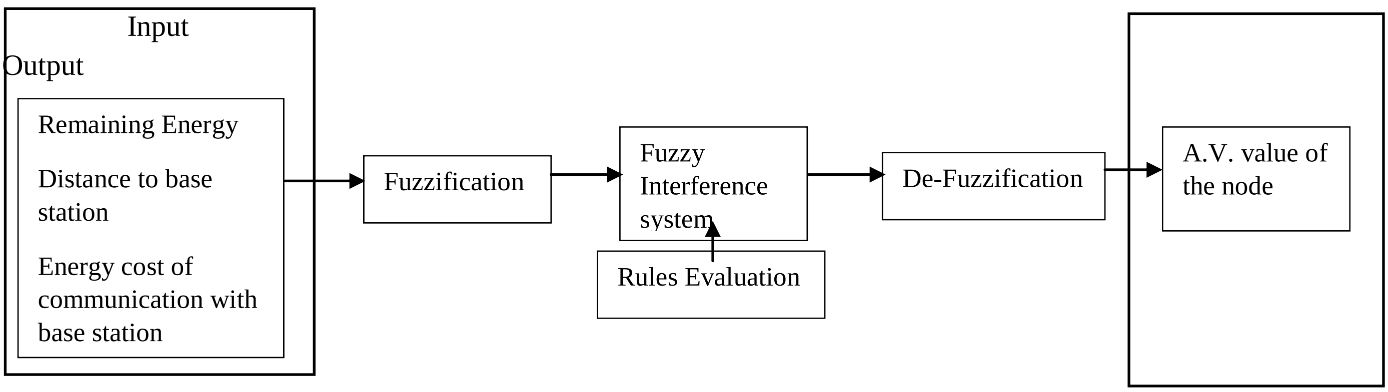

Figure 4.1 Fuzzy System

These four parts work in the following way:

- Fuzzification: The three parameters for each sensor node are fed as input to this phase. These parameters have crisp values which are converted into appropriate linguistic values with the help of this fuzzification phase. The

January - February 2020
ISSN: 0193 - 4120 Page No. 402 - 412

values are converted by mapping them into the value in the range of [0, 1]. The maximum and minimum values corresponding to the three crisp input variables are:

Table 4.1: Fuzzification Phase

Input	Linguistic values		
Remaining Energy	Low	Medium	High
Distance to base station	Near	Moderate	Far
Energy cost of communication with base station	Less	Average	High

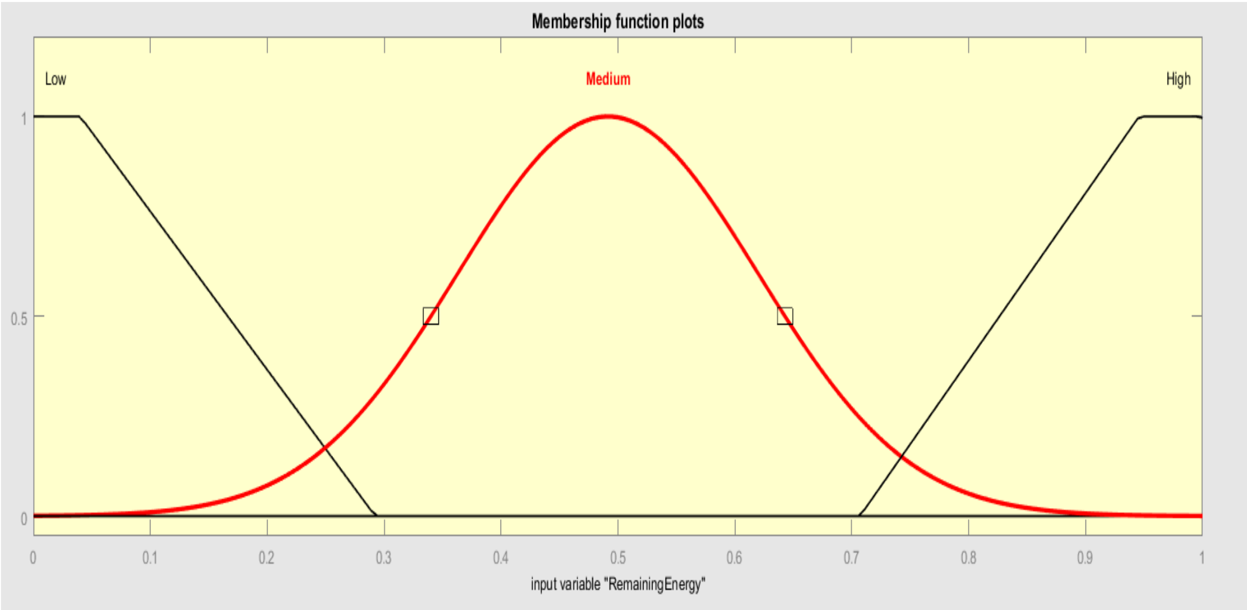

Figure 4.2 Input variable: Remaining Energy

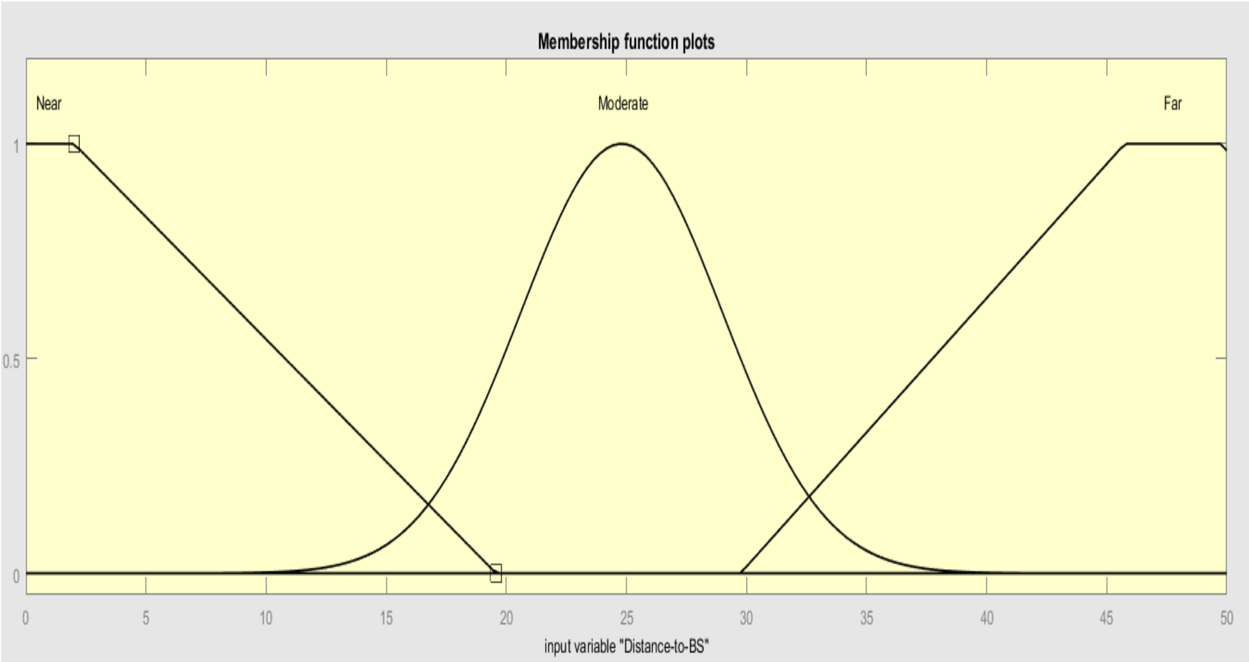

Figure 4.3 Input variable: Distance to Base station

January - February 2020
ISSN: 0193 - 4120 Page No. 402 - 412

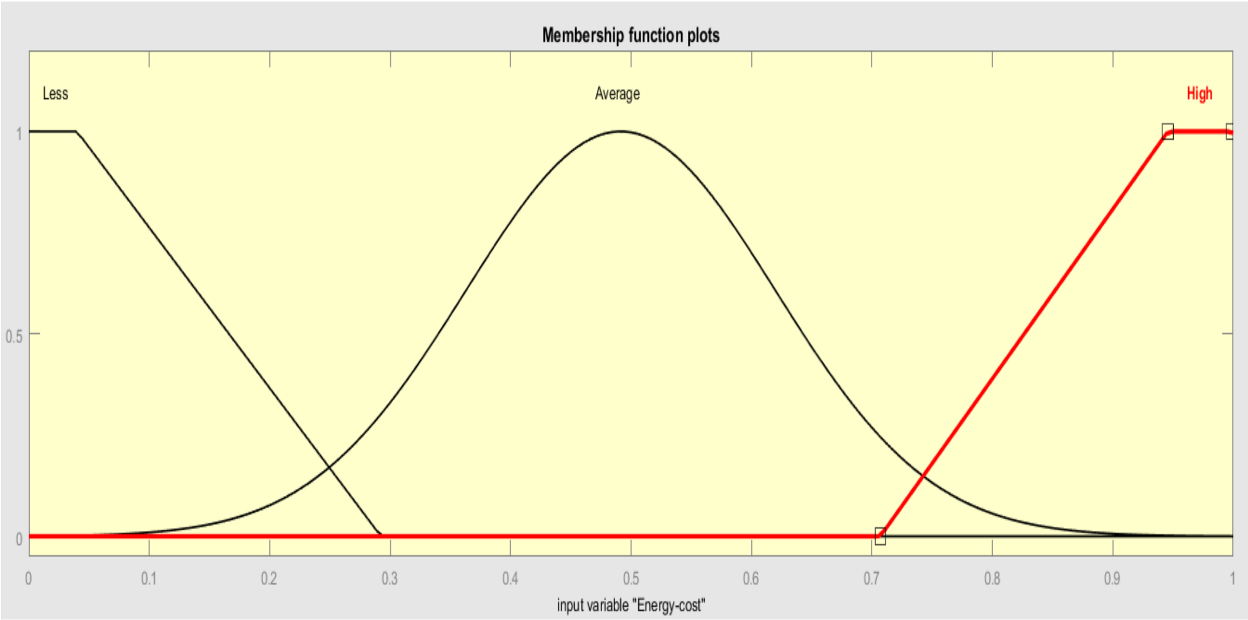

Figure 4.4 Input variable: Energy cost of communication with Base station

Rules evaluation: In this phase, we make the If-THEN rules to evaluate the parameters of the node. The previous phase provides with the membership values. These values are fed to the knowledge base for IF-THEN conditions laid out by the user. This will help to determine the A.V. value in the output. In this paper, we are using three parameters having three linguistic values, so the number of IF-THEN conditions become 3^3=27. The table below shows the IF-THEN rules which are used in this study.Mamdani interface system has been used to obtain the aptness value of a node which will show its probability to become cluster head.

Remaining Energy	Distance to base station	Energy cost of communication with base station	Aptness Value
Low	Far	High	Very Poor
Low	Far	Average	Poor
Low	Far	Less	Bad
Low	Moderate	High	Poor
Low	Moderate	Average	Bad
Low	Moderate	Less	Fair
Low	Near	High	Bad
Low	Near	Average	Fair
Low	Near	Less	Good
Medium	Far	High	Bad
Medium	Far	Average	Fair
Medium	Far	Less	Good
Medium	Moderate	High	Fair
Medium	Moderate	Average	Good
Medium	Moderate	Less	Better
Medium	Near	High	Good
Medium	Near	Average	Better

Medium	Near	Less	Far Better
High	Far	High	Better
High	Far	Average	Far Better
High	Far	Less	Best
High	Moderate	High	Better
High	Moderate	Average	Far Better
High	Moderate	Less	Best
High	Near	High	Far Better
High	Near	Average	Best
High	Near	Less	Very Best

Table 4.2: Fuzzy rules for THFLCB protocol

- Fuzzy interference System: This system deals with generating some inferences using the IF-THEN conditions along with the Linguistic values of the input variables.
- De-fuzzification: The fuzzy interference system gives the fuzzy set and this phase de-fuzzification converts the fuzzy set into crisp output values. These values can be further used to draw meaningful conclusions. This work uses the center for area method for de-fuzzification:

$$Output = \frac{\int \mu(x) * x dx}{\int \mu(x) dx} \quad (7)$$

Where $\mu(x)$ represents the aggregated membership function of fuzzy set and 'x' represents the output variable. In this work, Guassian membership function has been used for intermediate values and for boundary variables we have used Trapezoidal membership function. The output of the de-fuzzification will give the aptness value for each node. The high value will show that the node has higher probability to become cluster head.

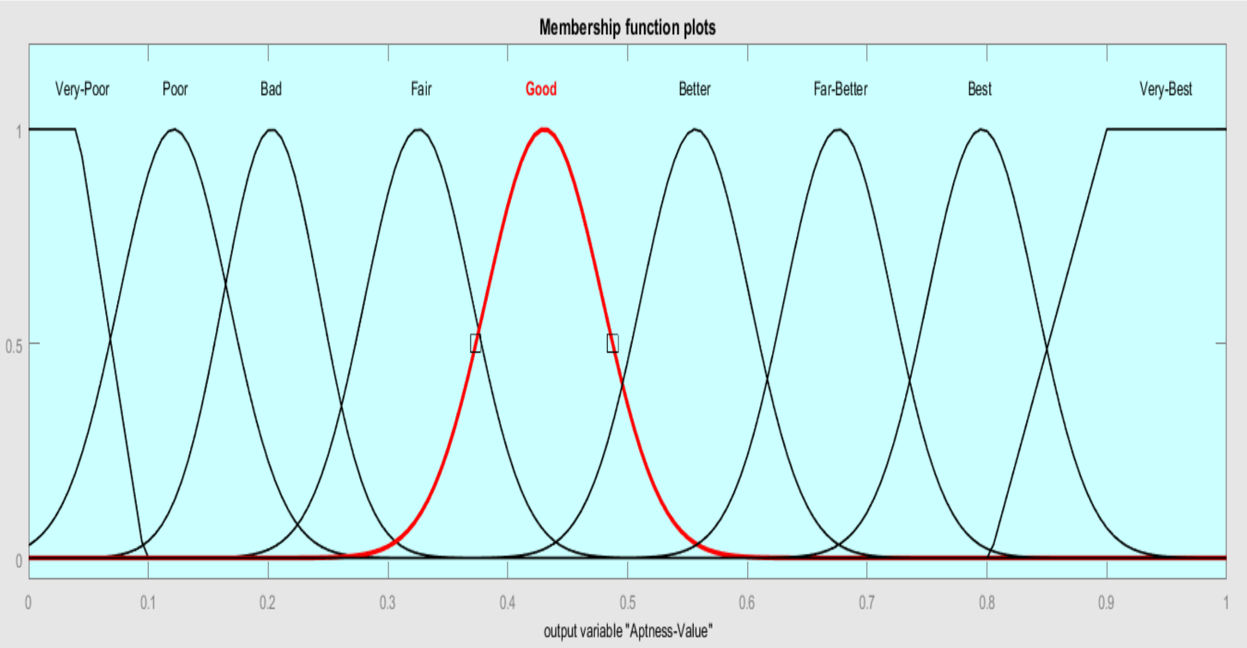

Figure 4.5 Output variable: Aptness Value

4.2.2 Cluster formation stage:

Once the cluster heads are selected, cluster formation phase begins where each selected cluster head broadcasts an advertisement packet in its communication range to the other sensor nodes. The cluster head will send its residual energy along with the advertisement packet. There is very high

January - February 2020
ISSN: 0193 - 4120 Page No. 402 - 412

probability that a sensor node receives the advertisement packet from more than one cluster head. Let us suppose that CH = {CH_1, CH_2,....,CH_z} denotes the set of cluster heads from which sensor node receives the advert message and ECH = {ECH_1, ECH_2,....,ECH_z} be the set of remaining energy of the cluster heads in set CH. Sensor node will choose the cluster head for which the remaining energy is maximum., i.e. Parent cluster head (PCH) = CH(max{ECH}). Once the sensor nodes choose their high-energy cluster head, each sensor node sends a JOIN packet to the cluster head. In this way, the cluster head forms the clusters with the member nodes. Cluster heads are rotated every round to balance the load among them.

4.2.3 Data transmission stage:

This is the last stage in every round of the protocol. In this stage, each cluster head distributes the TDMA schedule to all the cluster member nodes. Each sensor node forwards the sensed data to the respective cluster head which aggregates the data and forwards it to the base station. This marks the end of the current round and then all the steps are repeated in every round.

5. Results and Discussion

The simulation scenario considers 100 nodes randomly deployed in the region having dimensions 100m*100m. All the nodes are heterogeneous in terms of initial energy and traffic sensing capability. The base station is position in the center of the network. Simulation was done in MATLAB 2016 and the parameters used for simulation are described in the table 5.1.

Parameter	**Value**
Network area	100m*100m
Energy model	First order Radio Energy model
E_{elec}	50 nJ/bit
E_{fs}	10 pJ/bit/m^2
E_{amp}	0.0013 pJ/bit/m^4
Packet Length	4000 bits
Base station position	Center of the network 50,50
Initial Energy lower bound	0.5 J

Table 5.1 Simulation Parameters

Figure 5.1 shows the performance of the proposed THFLCB protocol when the values of traffic heterogeneity factor β=4 and energy heterogeneity factor λ=1.The results were plotted every 100th round. The round at which first node goes dead (also known as stability period of protocol) was 285, 280, 291, 379, 402 for LEACH, SEP, DEEC, TEAR and THFLCB respectively. Another scenario for different values of heterogeneity factors β=2 and λ=1 has been shown in figure 5.2. The stability periods in this case are 521, 448, 567, 614, 643 for LEACH, SEP, DEEC, TEAR and THFLCB respectively.

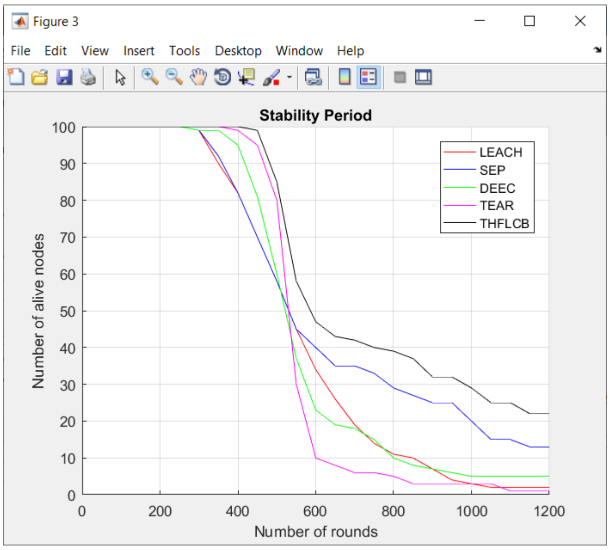

Figure 5.1: Stability Period (β=4 and λ=1)

The proposed protocol has shown improved stability period under different scenarios as compared to other protocols. LEACH selects cluster heads randomly without considering any heterogeneity for energy or traffic. It leads to its worst performance among all the protocols. SEP and DEEC on the other hand do consider energy heterogeneity but does not focus on traffic heterogeneity, so their results are better than LEACH and less than TEAR. TEAR on the other hand does considers both energy as well as traffic heterogeneity but other parameters such as distance to the base station, cost of communication with the base station is ignored in it. The proposed protocol however selects the optimal cluster head by considering all these parameters which leads to better network stability.

January - February 2020
ISSN: 0193 - 4120 Page No. 402 - 412

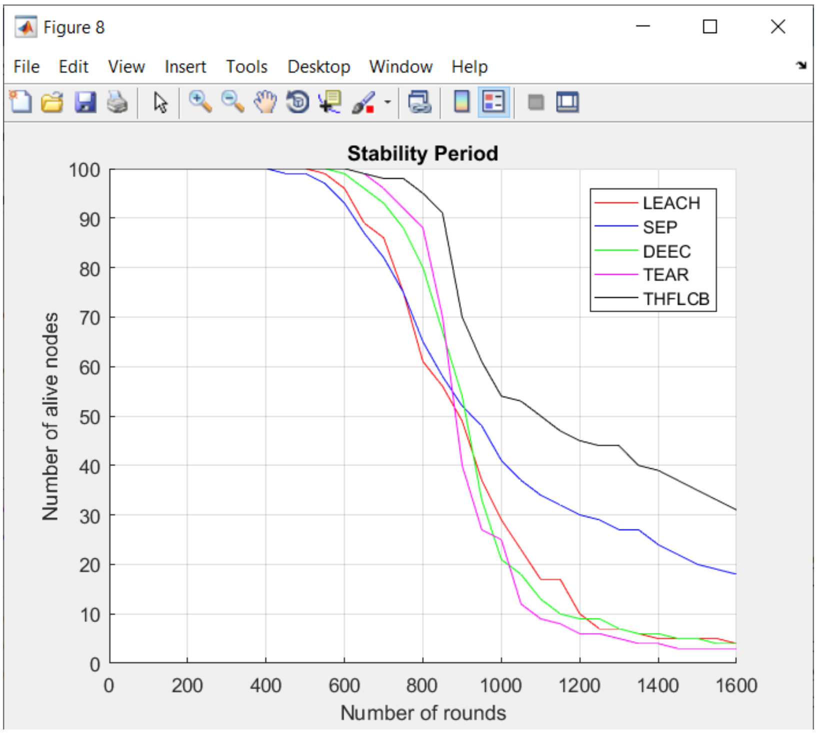

Figure 5.1: Stability Period (β=2 and λ=1)

Also the analysis was done by randomly deploying the nodes ten times. The table 5.2 shows the results obtained for each protocol.

Stability Period:Mean (Standard Deviation) β,λ	LEACH	SEP	DEEC	TEAR	THFLCB
3, 0	1131	1352	1870	1870	1901
2, 2	486	513	658	708	745
2, 3	376	386	507	538	567
1, 2	475	450	579	632	651
1, 3	367	339	438	489	512
1, 4	295	284	344	392	403

Table 5.2 Mean Results for 10 deployments

6. Conclusion

This protocol proposed an enhancement to traffic and energy heterogeneous protocol by using the fuzzy logic to optimally select the cluster heads. The proposed THFLCB has performed better than other protocols (TEAR, DEEC, SEP, LEACH) in different scenarios of energy and traffic heterogeneity. The fuzzy rules have helped considering different parameters to optimally select the cluster head in the network. Sensor networks are these days used as backbone for Internet of Things where the nodes are normally heterogeneous in terms of traffic generation. This paper is expected to provide a base of developing more effective protocols for such scenarios.

References:

[1] Jiang C F; Yuan D M; Zhao Y H; "Towards clustering algorithms in wireless sensor networks: a survey", Proceedings of the 2009 IEEE Wireless Communications and Networking Conference (WCNC'09), Apr 5−8,

2009, Budapest, Hungary. Piscataway, NJ, USA: IEEE, 2009: 6p

[2] J. Yick; B. Mukherjee; D. Ghosal; "Wireless sensor network survey, Computer Networks the International Journal of Computer & Telecommunications Networking", 52(12) (2008) 2292-2330.

[3] Thakkar A; Kotecha K; "Cluster head election for energy and delay constraint applications of wireless sensor network", IEEE Sensors Journal, 2014, 14(8), 2658−2664

[4] Zhu K; Dou Q; Shao A H; et al. "An energy-efficient routing protocol based on hotspot-aware uneven clustering and dynamic path selection", Proceedings of the 22nd Wireless and Optical Communication Conference (WOCC'13), May 16−18, 2013, Chongqing, China. Piscataway, NJ, USA: IEEE, 2013: 315−320

[5] Mengjia Zeng; Xu Huang; Bo Zheng; Xiangxiang Fan, "A Heterogeneous Energy Wireless Sensor Network Clustering Protocol", Wireless Communications and Mobile Computing, Volume 2019, Article ID 7367281, 11 pages.

[6] W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, "An application on specific protocol architecture for wireless micro sensor networks," IEEE Trans on Wireless Communications, vol. 1, no. 4, pp. 660–670, 2002.

[7] TruptiMayeeBehera; Sushanta Kumar Mohapatra; Umesh Chandra Samal; Mohammad S. Khan, "Residual Energy-Based Cluster-Head Selection in WSNs for IoT Application", IEEE Internet of Things Journal, Volume: 6, Issue: 3, June 2019.

[8] Hassan El Alami; AbdellahNajid, "ECH: An Enhanced Clustering Hierarchy Approach to Maximize Lifetime of Wireless Sensor Networks", IEEE Access, Volume: 7, August 2019.

[9] Olayinka O. Ogundile; Muyiwa B. Balogun; Owoicho E. Ijiga; Elijah O. Falayi, "Energy-balanced and energy-efficient clustering routing protocol for wireless sensor networks", IET Communications, Volume: 13, Issue: 10, June 2019.

[10] Fagui Liu; Yufei Chang, "An Energy Aware Adaptive Kernel Density Estimation Approach to Unequal Clustering in Wireless Sensor Networks", IEEE Access, Volume: 7, February 2019.

[11] Deyu Lin; Quan Wang, "An Energy-Efficient Clustering Algorithm Combined Game Theory and Dual-Cluster-Head Mechanism for WSNs", IEEE Access, Volume: 7, April 2019.

[12] Zhidong Zhao; Duoshui Shi; Guohua Hui; Xiaohong Zhang, "An Energy-Optimization Clustering Routing Protocol Based on Dynamic Hierarchical Clustering in 3D WSNs", IEEE Access, Volume: 7, June 2019.

[13] Zhenchun Wei; Fei Liu; Xu Ding; Lin Feng; ZengweiLyu; Lei Shi; Jianjun Ji, "K-CHRA: A Clustering Hierarchical Routing Algorithm for Wireless Rechargeable Sensor Networks", IEEE Access, Volume: 7, December 2018.

[14] EymanFathelrhman Ahmed Elsmany; MohdAdib Omar; Tat-Chee Wan; AltahirAbdallaAltahir, "EESRA: Energy Efficient Scalable Routing Algorithm for Wireless Sensor Networks", IEEE Access, Volume: 7, July 2019.

[15] Richa Sharma; VasudhaVashisht; Umang Singh, "EEFCM-DE: energy-efficient clustering based on fuzzy C means and differential evolution algorithm in WSNs", IET Communications, Volume: 13, Issue: 8, May 2019.

[16] Deepak Sharma; Amol P. Bhondekar, "Traffic and Energy Aware Routing for Heterogeneous Wireless Sensor Networks", IEEE Communications Letters, Volume: 22, Issue: 8, Aug. 2018.