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Network Lifetime Enhancement in WSN using Fuzzy Based Clustering Algorithm

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Abstract: ***These-days Wireless Sensor Networks (WSNs) has become integral part of many applications include tracking, monitoring and so on. Nodes are limited in battery, memory and processing capacity. Tracking and monitoring applications continue to work for longer hours; energy is the major constraint for network to transmit sensed data. State of the art specifies that by using clustering method energy-efficiency, scalability, and efficient-data-communication is achieved. Sensors deployed in the network be partitioned to clusters then one of the nodes is designated to become a Cluster Head (CH) that accumulate sensed information and sends to Sink/Base Station (BS). Normally CH is elected by considering nodes remaining energy and topological attributes related to the node in network. In this projected clustering method a centrality-metric "Cluster-Optimal-Degree-Centrality (CODC)", is defined and also considered other parameters residual energy, distance between CHs, plus number of nodes belonging to a cluster guarantees better cluster configuration and CH selection. Fuzzy-Inference-System takes Expected-Residual-Energy (ERE) and CODC as inputs. Experiments are carried using ns-2; the proposed clustering method improves QoS, and efficiently prolongs network lifetime.***

Keywords: ***Cluster Head Election, Energy Efficiency, Cluster Optimal Degree Centrality, Fuzzy Inference System, Fuzzy Parameter.***

I. INTRODUCTION

The phenomenal advancement of VLSI technology, microelectromechanical systems and wireless communication has paved a way for a new generation of inexpensive sensors and actuators. A network is built using small low power sensor nodes having sensing, processing and communication capability. Sensors are distributed arbitrarily or deterministically in a region of interest to collect the data. Nodes are battery-powered and are placed in remote-areas where replacing dead nodes is almost impossible. Transmission of data consumes more energy that creates network-partition, and a hotspot problem.

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The nodes near the base station may drain faster as these nodes transmitting more data from many nodes far away or some nodes may go down creating network partition. Energy is the major constrain for prolonging the network lifetime. So Energy conservation and network scalability are the two important factors to be considered while designing a WSN application.

Literature evidences that hierarchical routing procedures load balance across network nodes, so lifetime of network can be improved. Nodes in network are partitioned to small groups called Clusters. This process of cluster formation lead to two-level hierarchy, Cluster-heads (CHs) at upper level and the cluster-member at next level shown in fig1. Member nodes of the cluster send the sensor data to related CHs; Cluster Head communicates aggregated data to BS, if node is located at one-hop distance or all the way through multi-hop communication (this reduces the total number of relays required). Additional work associated with CHs leads to extra energy depletion. To balance energy expenditure and to distribute load uniformly clustering process is repeated periodically. More commonly nodes having high residual energy are picked as CHs or rotate CHs periodically with some probability [1,2,3,4]. Also other computing intelligence techniques exist for clustering. These schemes use residual energy, distance between nodes and other local parameters for electing CH.

Essential issues to be addressed to prolong network lifetime are topology and energy-efficient routing. In fact cluster based solutions preserve network-topology and scalable for various applications.

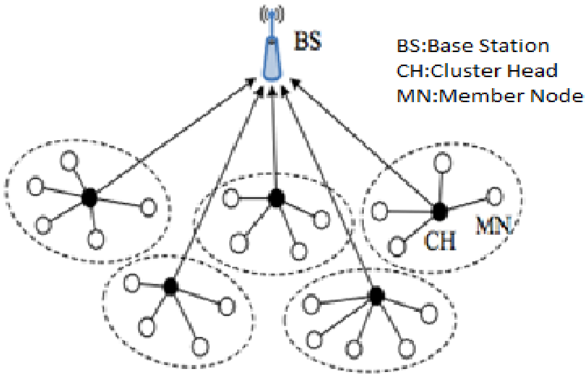

Fig1. Cluster Based Architecture in WSN

In this proposed work to select CH, we have considered a predicted residual energy (ERE) and (CODC) cluster-optimal-degree centrality as inputs to Fuzzy Inference system (FIS).

Here ERE is calculated by using WSN energy model discussed in the following section, CODC metric is calculated in terms of closeness-centrality and degree-centrality these are based on number of nodes within the cluster, distance measured from member nodes to CH. (FIS) based solution provides more promising results [5]. The experimental result shows that proposed approach improves network lifetime and cluster quality.

A. Fuzzy Logic in WSN:

Many of real time needs make us to use lot of imprecise or incomplete information, in various conditions we use several logical linguistic labels to communicate abstract concepts [5,6]. Use of various appropriate computationally intelligent tools in different context of WSNs applications has been detailed [7]. Even sensor reading can be inaccurate, imprecise and unreliable. Fuzzy logic a soft computing and intelligence technique was initiated by L. Zadeh in 1965 [6,7]. From then, various domains like control system engineering, electrical engineering, etc have explored new dimensions. Most of the real time parameters related to varied domains is fuzzy in nature, these kind of data can be more optimally can be illustrated using fuzzy-logic. It is very is similar to general logical form of thinking rather crisp logic and other algorithms. Fuzzy-systems are regarded as knowledge based systems where understanding of the system is presented using set of "if-then" rules for given Fuzzy-variables and the output is composed as fuzzy-logic statements. Most important aspect of fuzzy system is its capability to fit general human-understanding into a system in spite of inaccurate, imprecise, and uncertainty in information. Fuzzy models are multi-valued they have potential to recognise, represent, manipulate these fuzzy data and can provide conventional evaluation. General organization of a Fuzzy Logic System depicted in Fig2. Basically a Fuzzy system includes 3 elements: Fuzzification, Inference-Engine, Defuzzification. Fuzzification is the method to convert crisp-set to a fuzzy-set, whereas defuzzification is the method to produce results in measurable values in crisp-logic. Provided a fuzzy-rule set and a membership degree Inference-Engine maps a fuzzy input to a crisp output. That is Inference-engine of the system apply logical-rules to the knowledge-base to infer latest information.

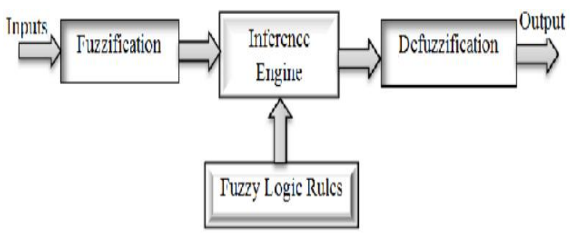

Fig2. General architecture of Fuzzy Logic System

The remain part is work prepared as: Literature in section-II. Details about assumptions made for system in section-III. Section-IV gives implementation details. Section-V includes WSN applications. Simulation results are compared with LEACH are given away in section VI and VII. Conclusions of the work in Section VIII.

II. LITERATURE

Clustering is the most widely used method for building WSN applications. Though clustering is very good for bringing scalability, improved QoS in WSN, but there are some intrinsic problems. Clustering creates hierarchy, member nodes generate data by sensing the phenomena, then the comprehensive data collected by CH is communicated to BS. So CHs are having additional responsibilities by which more energy is consumed. The nodes near the BS may need to do more relaying compared to other nodes this creates irregular energy consumption. But it is also required to conserve the number of messages transmitted and time complexity remains stable even if the network grows. To mitigate uneven energy consumption problem, researchers' focus largely on rotation of CHs. Very first well know approach in this direction was LEACH[3] (Low Energy Adaptive Clustering Hierarchy) proposed. LEACH is a distributed clustering technique runs in 2-phases; first in setup phase clusters are configured and CHs are selected probabilistically on periodic rotation basis. In second steady state phase actual data transmission takes place. LEAH being a distributed algorithm nodes are free to elect CH locally, all nodes may have equal chance to become CHs. Probabilistic selection of CHs may lead overlapping of communication range between CHs. This may lead to inefficient cluster formation. In this protocol node energy is not considered for CH election this may result into a node having less energy to become CH. In turn CH may fail very soon by creating network partition.

Low computational complexity and less processing cost of using fuzzy-logic suggested its use in different areas; similarly fuzzy-logic also has its significance in WSN for clustering. Fuzzy clustering algorithms combine different clustering parameters to select CH. An enhanced LEACH is designed to reduce energy consumption with modified threshold while selecting best CH candidate. And also for better transmission a customized TDMA scheduling mechanism is used [8]. [9]Proposed a centralized Fuzzy based clustering method is an improvement of LEACH, results proved an improvement in network lifetime by means of 3 fuzzy-parameters: nodes centrality, nodes concentration and its remaining energy by applying Fuzzy Inference System (FIS[10]). The main drawback is control overhead involved due to centralized decision and this method is not appropriate for networks having more energy limitation.

In [11] CHEF: Cluster-head Election mechanism using Fuzzy logic, a distributed mechanism is discussed. It makes use of 2 fuzzy input variables: nodes' remaining energy and its local distance. An important parameter degree of the node is not considered for CH election. Therefore it is more probable that nodes having the same residual energy or nodes with less number of neighbors might happen to CH, this might results into inefficient cluster formation. Due to huge intra-cluster communication performance is deteriorated. A CHEATS approach is proposed [12], here remaining energy in the nodes and distance between nodes and the BS are used in electing CH.

In [13] authors have proposed a protocol LEACH-ERE (LEACH Expected Residual Energy) uses remaining energy and expected remaining energy as fuzzy-parameters to select CH. ERE is calculated using (EEC) Expected Energy Consumption, at the stage of cluster head selection some number of nodes are nominated as candidates based on nodes remaining energy. The candidate nodes broadcast its remaining energy to other nodes in its communication range. Nodes compete with each other to become CH; a node with additional energy is designated to become CH. The protocol is applicable to homogeneous networks.

In [14] authors have proposed FL-EEC/D approach, here fuzzy logic model is designed that uses nodes remaining energy, compacting, position, fitness, density (concentration of cluster), and separation from BS. Energy efficiency of suggested approach is measured using Gini-index in the form of energy distribution across WSN. A total of seventy two fuzzy- rules are framed and on an average 4.48 times of lifetime improvement is achieved compared to LEACH. Also ensures even distribution of CHs in WSN by setting adaptive minimum separation distance.

In [15] authors devised a protocol RE-TOPSIS, this method reduces the need of CH election in every round during setup phase. Effective and reliable CH selection through fuzzy-logic is combined with Multi-Criteria-Decision-Making (MCDM) method. Here conventional LEACH is used to select one-time CH, and then a RE-TOPSIS rank index value is scheduled in each cluster. Fussy-parameters considered to devise new scheme include: separation between of adjacent nodes; left over energy; accessibility of neighbor nodes; energy utilization rates; distances from sink to CHs as well as distances from CHs to cluster members and reliability-index. Compare to LEACH, proposed algorithm improves network lifetime, saves energy, also about 20% to 25% CH selection frequency per round is reduced.

A fuzzy-logic based method for clustering to improve the performance of WSN is given in [16] Fuzzy-variables considered are nodes remaining energy, local node density, and measured distance from the sink. CH selection decisions are made by calculating the rank of all nodes. Along with other regular fuzzy-variables overhead of the CH is also considered for selecting CH. An energy-efficient stable clustering approach using fuzzy EGWO:extended grey-wolf optimization technique is discussed in [17] to extend network lifetime. Optimized energy conservation is achieved using EGWO for CH election. The parameters considered here are nodes remaining energy, nodes centrality and distance to base station. Energy is conserved by applying a threshold on Inter-cluster data transmission. An improved load balancing is attained through dual-hop communication.

A (FBCFP) neuro-fuzzy based cluster formation protocol [18] is proposed, network learning is carried by taking CH current energy level, changes to the location of cluster members and CH because of mobility, distance between sink node and CH, degree of CH. Convolution neural network is used to train the network and weights are maintained using fuzzy-rules. A promising cluster configuration also better cluster based routing is achieved using Fuzzy reasoning approach. A FBECS fuzzy base balanced cost cluster head selection algorithm is presented in [19]. Parameters considered are node left over energy, node density and distance to the sink as input to FIS. Basically network is subdivided into subnetwork and for each node a probability is assigned depending on the separating distance. For every node an eligibility index is calculated based on this CH selection takes place. A good load balancing is guaranteed by choosing best candidate for the CH to coordinate the cluster. In [20] authors considered a scheme based on (PSO) Particle Swarm Optimization for CH selection. Initially fuzzy clustering is applied for initial clustering then extended PSO is applied. This method increases network lifetime by reducing casualty rate of sensor nodes. Main disadvantage is that it needs more computation time for clustering at initial stage. A consistent spatial CHs distribution and energy balance across the network is attained [21,25] using an energy efficient Fuzzy C means clustering. Nodes of the network are separated to specific set of clusters using fuzzy-C means algorithm. Overall energy loss from entire network and node density is considered to predict the optimal CHs to enhance the network lifetime.

An ECFU in [22] proposed a clustering technique, efficient network operations are attained using fuzzy-updates along with machine learning techniques. For every cycle a cluster update is calculated considering node to the sink node distance, nodes' left over energy, and average data rate. Message overhead is addressed here, when there are no remarkable changes in sensor values the messages are not transmitted so the energy is retained in the node. This will improve network lifetime significantly. The updates are increased as the network increases this might require more computation time. In [23] authors have designed MACHFL-FT to cluster heterogeneous nodes in WSN and it uses three clustering algorithms in different rounds. In order to reduce number of message transmissions it postpones frequent CHs selection in some rounds by fixing threshold value, this leads to better network energy management. An extension of CFFL approach termed as (Fuzzy Logic based Clustering Algorithm) CAFL discussed in [24]. Both cluster configuration and CH election uses FIS, an improvement in throughput and lifetime is attained. For each node a chance value is calculated using two fuzzy values: nodes closeness to sink and residual energy during CH selection. The node having highest value is selected as CH, and then cluster formation takes place. Every non-CH node in the each cluster calculates a probability of becoming CH using (Barnabas Bede, 2013) FIS. Here two fuzzy-parameters are considered: nodes' residual energy and distance between node to CHs, node having maximum chance value will join CH.

Literature discussed so far include clustering algorithms more commonly based on LEACH; residual energy and other local parameters are considered for CH selection. In our proposed work along with energy and local parameters, degree centrality and closeness centrality are also considered for fitness calculation for each node in order to select better CH. The proposed method reduces unnecessary load management of CH through intra-cluster communication.

III. SYSTEM ASSUMPTIONS

Simulations are carried using ns-2, a network of 30 sensor nodes randomly deployed in area 100x100 Sq units. Nodes are homogeneous means all sensors having equal computational capability, 2 joules of initial battery power. The traffic generated at constant bit rate with both sink and source for UDP setup. Short-range radio capacity is used to communicate the data across the configured network and the nodes.

Depending on the arriving signal strength nodes adjust their transmission range. Omni-directional antennas support packet transmissions and reception/Communication among the nodes. In addition the following assumptions have been made for the proposed method and the results are compared with LEACH:

1. A homogeneous network, all nodes having equal initial energy and computation capability.
2. Nodes of WSN are static (sensors and base station)
3. Every node is battery powered; recharging or replacing of nodes is unlikely.
4. Sensor nodes within the cluster can transmit/receive data with CH directly.
5. BS has unlimited energy.
6. Links are symmetric. Both transmission and reception takes place on the same link.

IV. IMPLEMENTATION

A. Network Communication Model

Energy dissipated to communicate the sensed data in the network is given by network communication model discussed [26].

$$E_{TX}(k,d) = \begin{cases} kE_{elec} + k\varepsilon_{fs}d^2 & d < d_0 \\ kE_{elec} + k\varepsilon_{amp}d^4 & d \geq d_0 \end{cases} \tag{1}$$

Energy spent to transmit (ETX) k bit of information under free space and multi-path fading channel at distance d given Eelec. ε_{fs} and ε_{amp} are power amplification systems for both channels; d0 is the distance threshold value estimated by equation (2).

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}} \tag{2}$$

The energy required to receive k bit of data is given in equation (3):

$$E_{RX}(k) = E_{elec}(k) \tag{3}$$

The energy dissipated by CH for every round is derived in (4):

$$E_{CH} = nk(E_{elec} + \varepsilon_{fs}d_{BS}) + E_{DA} \tag{4}$$

dBS : distance between CH and BS ; n number of nodes within cluster, Amount of energy spent in data aggregation is EDA. Energy spent by cluster- member can be calculated as follows in equation (5):

$$E_{CM} = k\left(E_{elec} + \varepsilon_{fs}d_{CM}\right) \tag{5}$$

Where dCM is the distance from cluster member to its CH. Energy consumed to communicate one bit of data is given in equation(6):

$$E_{total} = E_{RX} + E_{TX} + E_o \tag{6}$$

Where Eo is the overhead involved to communicate CH information

B. Expected Residual Energy (ERE):

ERE is the residual energy of candidate node at steady state stage [13]. ERE is calculated using residual energy (REnew -calculated in equation (8)) for every t seconds on combined timestamp of both setup phase and steady state phase. ERE can be calculated as in equation (7):

$$ERE(l, d_{BS}n) = RE_{new} - E_{exp-consume} \tag{7}$$

Packet size in bits represented by l, distance to base station - dBS, number of nodes-n.

$$RE_{new} = RE_{old} - E_{total} \tag{8}$$

RE_{old} - the remaining energy of previous round/iteration

$E_{exp-consume}$: Energy consumed to send 1-packet from cluster member to CH and is measured by time required to send data from cluster-member to CH, overhead involved to aggregate data in CH and to send this cumulative information from CH to BS at distance dBS.

C. Cluster- Optimal- Degree- Closeness-Centrality:

To calculate CODC both degree centrality and closeness centrality of a node are considered for a given network graph. Closeness centrality of a node is computed by taking average shortest-path of a node to other nodes in the graph based on the closeness-weight. Degree centrality of a node defines the number of directly related nodes. Degree centrality confines the importance of a node in its locality. To calculate centrality consider (N,R) a weighted graph representing the topology of network having N number of nodes over R relation correspond to the distance space between two nodes within the cluster.

The CODC can be computed by equation (9):

$$C^k(X_i) = DEG[X_i]/n_\alpha \tag{9}$$

Where C^k - Closeness Centrality measure up to k nodes

n_α – Member nodes distance

D. Distance Between Neighbor Nodes:

Neighbour nodes in the cluster can be calculated based on the radio signal strength available for transmission or the distance between the nodes, is calculated as equation (10):

$$d = \sqrt{((x2 - x1)^2 + (y2 - y1)^2)} \tag{10}$$

E. Fuzzy Inference System:

The fuzzy-inference method specified here is Mamdani [10] is the most widely used technique. Changes in fitness values are computed based on the values of ERE and CODC. Basically FIS brings together various clustering-parameters for selecting CH. Fitness computations and mappings are performed using simple fuzzy “if-then” rules.

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Table1. Fuzzy Inference Rules framed

Sl.no.	Energy-ERE	CODC-Weight	Fitness
1.	L	L	L
2.	L	O	L
3.	L	VH	L
4.	M	L	L
5.	M	O	M
6.	M	VH	M
7.	H	L	M
8.	H	O	VH
9.	H	VH	M
10.	VH	L	H
11.	VH	O	VH
12.	VH	VH	H

Fuzzy values defined for input variable Energy-ERE included as L-low, M-medium, H-high, and VH-very-high, and the second fuzzy-variable is CODC-weight the values set as L-low, O-Optimal, VH-very high. The membership-function or a fitness of a node as mapping fuzzy set are L-low, M-medium, H-high, VH-very high. Implementation is carried using ns-2 simulator for thirty nodes, and results comparisons with LEACH are noted in graph.

F. Proposed Fuzzy-Centrality Algorithm

INPUT:

A WSN of N number of nodes at a time instance t
A sink node -S
Number of neighbor nodes -n
Cost value of node-cv
ith Cluster- c(i)
Distance of neighbor node- nα
Base Station-BS

OUTPUT:

Node fitness-F
Cluster Head for each cluster –CH

Algorithm:

//number of nodes in network
1. *N ⟵ 30*
//to distribute nodes to clusters
2. *N is divided to 5 clusters, N/5;*
//broadcast energy and cost value
3. *Broadcast (Energy, cv);*
// The node which has high energy and cost value in c(0)
4. *S ⟵ (ERE, cv);*
// The distance from node s[0] to i
5. *CODC ⟵ (DEG(X[i])/nα);*
6. *high-cluster energy (comparing CODC)*
7. *if(ERE,CODC= F)*
8. *the nodes will become CH*
9. *else*
10. *the nodes will become member-nodes*
11. *end if*
12. *if(CH=true)*
13. *broadcast(CH message, n)*
14. *Cluster members send data aggregation message to CH;*
15. *CH passes aggregation message to the BS;*
16. *end if*

V. APPLICATIONS

Presently wireless sensors networks have been incorporated to many inter-disciplinary applications includes various domains related to industry, electrical engineering, machinery, and the environment etc for well-organized transmission of data. The applications of WSNs are varied, typically target tracking, mission controlling, or monitoring. Well-known sample applications of wireless sensor network are listed:

Disaster Prevention: various disaster prevention applications have been built using different types of sensors to prevent hazards. To create alert systems, WSNs be utilized for hazardous areas such as steelworks, refineries and underground mining. WSNs can be installed in underground mining to detect harmful gas leakages, fire etc. Any refinery might be well built with required safety measures to prevent dangerous accidents; sensor nodes can be deployed to track workers and to be vigilant if some accidental event or entry to a risky region or to guide fire fighters to help people under threat.

Smart Bridges: To monitor structure conditions, balance the load, pressure and stress conditions. And also creating alert systems based on other external parameters, to improve the efficiency of rescue.

Intelligent Buildings: The sensors are used as an effective means to save resource wastage and to provide automated systems to monitor environment and to provide required alternatives. Minimize power waste through proper control of (HVAC) humidity, ventilation, air conditioning.

Surveillance: VigilNet a military wireless sensor network that obtains details about enemy potential and positions of hostile targets. It has been successfully designed, built, demonstrated, and delivered to the Defence Intelligence Agency for realistic deployment.

Green House Monitoring: monitoring of various parameters required for plants growth are assisted by installing sensors in suitable locations in the green house. Plantation is monitored with precise measurement of temperature under high spatial resolution, so that reliable and consistent results are obtained.

Agriculture: Smart agriculture [27] is among the potential application domains; WSNs are deployed to reduce overall effort required by farmers to irrigate the field. WSN integrated with other technology such as machine learning to provide decision making by systems to deliver feasible/optimal solution. To monitor the risk of diseases developing in field and also to maintain other information the area can be instrumented with Fraunhofer IMS.

Animal Rearing: By installing sensors in suitable parts of the area near animals the conditions needed for animal rearing are optimized.

VI. SIMULATIONS

Proposed work is implemented using ns-2.35, an open source discrete event driven simulator popular at UC-BERKELEY developments. It supports academic, teaching and learning purpose as well as to explore new research ideas before actual deployment of network. Suitable for designing new network protocols, or to integrate more than one protocol. Compare different protocols and evaluate network traffic engineering.

Simulation Tool:

The ns-2 is built with C++ methods and Object oriented Tool Command Language (OTcl). Set of OTCL scripts are built with other network components to simulate different network scenarios. Under ns-2 it is easy to set up and implement new network components. Different events are carried by the event scheduler, responsible for event triggering, tracing and simulation event time management also. Protocol implementations and backend mechanism are maintained using C++, while OTcl is used to assemble, configure and schedule the events. User writes OTcl scripts to simulate various network topologies, with different traffic configurations etc.

VII. RESULTS

Here simulation result illustrates the performance of the proposed method compared with LEACH. WSN is built by deploying sensors in the area of 900 x 800 m2. The graphs plotted show suggested method performs better than LEACH.

A. Number of Alive Nodes

Energy in the network is evaluated by counting the number of alive nodes capable of performing network operations or nodes radio signal strength is able to transmit and receive the data. The graph plotted shows after simulation time the energy remaining is much greater than LEACH. Fig3 the network lifetime plotting time versus energy.

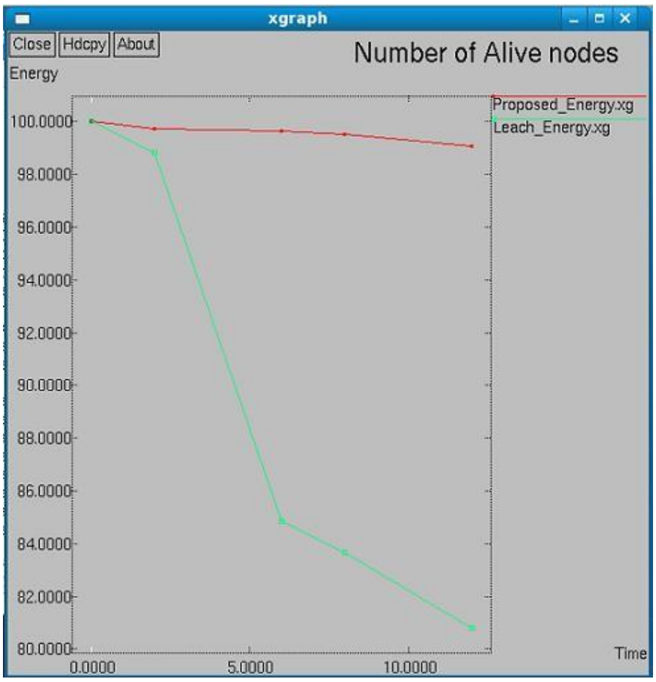

Fig3. Number of Alive Nodes

B. Throughput

Throughput is the measure of successful transmission that the number of packets received/unit time. Fig4 the graph plotted explains better results. It is calculated by using equation(11):

Throughput=(Number of bits received) / (Simulation time*millisecond) (11)

C. Packet Delivery Ratio

Packet delivery ratio is defined as the number of packets delivered successfully to the destination out of total number of packets transmitted. Fig5 gives graph plot packet delivery ratio.

VIII. CONCLUSIONS

In WSN energy defines the network lifetime, in our proposed work we have implemented a fuzzy-based clustering algorithm base on CODC and ERE. Outcome of the work is compared with LEACH, the projected method achieve better results, improves network lifetime, intra-cluster communication and individual cluster QoS. Further the method can be improved with other parameters and optimization can be applied to place sink and nodes as well as relay nodes.

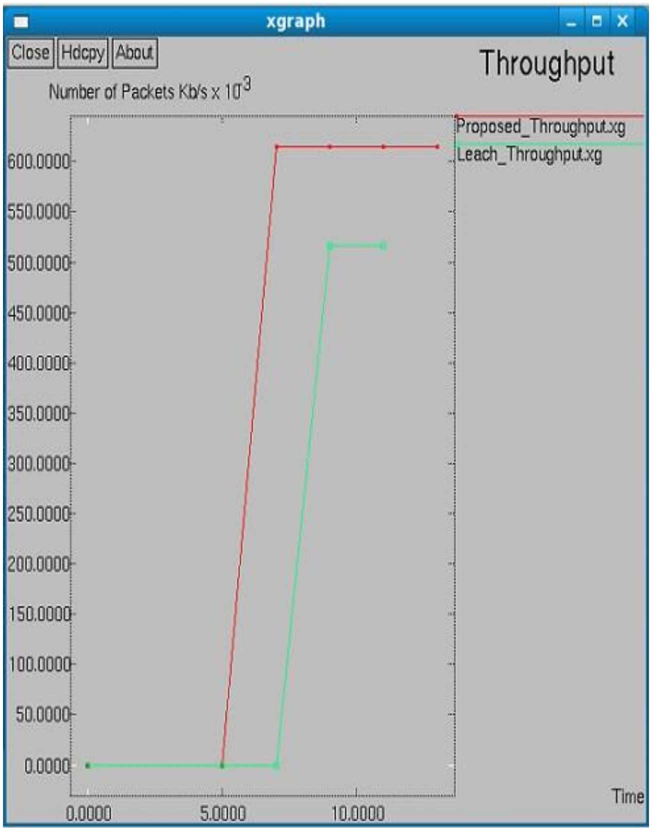

Fig4. Network Throughput

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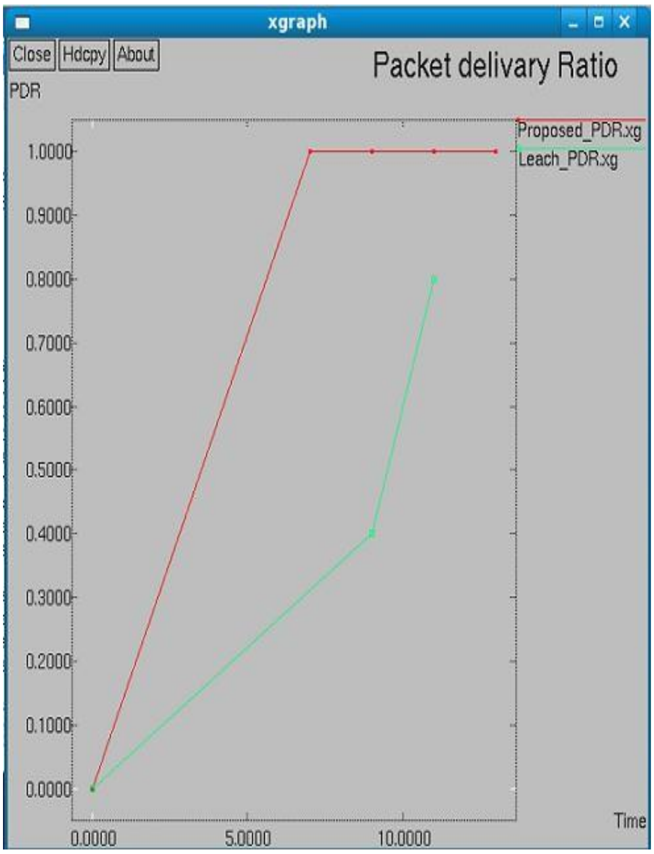

Fig5. Packet Delivery Ratio

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