FAICP: Fuzzy Logic based Adaptive Intra Clustering Protocol for Wireless Sensor Networks

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Abstract –Today's the most interesting and emerging technology which are made up of large number of inexpensive devices that often have a limited resources like battery-power is wireless sensor networks (WSNs). These networks has several key issues, one such issue is energy consumption while routing the packets from source node to sink node. Many routing protocols have been proposed to improve the energy efficiency based on clustering algorithms by increasing the lifetime of the network. These cluster- based routing protocols are not achieved the desired energy efficiency effectively duo to selection of number of parameters and its weights. In this paper, a fuzzy logic based adaptive intra clustering protocol is proposed to increase the throughput and network lifetime in wireless sensor network. The simulated results of proposed fuzzy logic based adaptive intra clustering protocol (FAICP) is better than LEACH, TEEN, and CHEF.

Index Terms — Adaptive, fuzzy logic, clustering, intra routing.

1. INTRODUCTION

The radical advances in the fields of MEMS [1](Micro Electro Mechanical Systems) technology development of high speed broadband wireless technologies and low power Radio Frequency (RF) design have lead to the birth of WSN. Wireless Sensor Networks can be safely identified as one of the most important technologies of recent times. A Wireless Sensor Network consists of a large number of unattended, usually self-organized micro sensors. The sensor nodes have very limited energy, processing power and storage. Thus, energy is a scarce resource in a wireless sensor network and hence its efficient usage is crucial for extending the life of the whole sensor network. Routing is one of these areas in which attempts for efficient utilization of energy have been made. Because the energy consumption of sensor node mainly originates from the long distance transmission of data along the routing path, an efficient routing path formed by the routing protocol will have a great impact on the energy consumption. To route a packet, the nodes may follow either single-hop/multi-hop fashion. If wireless network uses single-hop, data packets find their paths through gateways. Each time a packet is passed to the next hop occurs. The function of intermediate hops is to relay data from one hop to the next one. Multi-hop routing involves sending signals through multiple stops instead of one long pathway.

In recent years, many approaches and techniques have been explored for the optimization of energy usage. Energy-efficient routes can be computed using either the minimum energy path, maximum residual energy path, path with minimum number of hops to sink. Existing proposed routing protocols for WSNs use fixed metrics for making energy-aware routing decisions. This has the disadvantage of not being easily adaptive to changes in sensor types because energy metrics vary widely with the type of sensor node implementation platform.

In this paper, a new algorithm is proposed to increase network lifetime, throughput and minimize energy consumption. For this purpose, sensor nodes in WSN are deployed to form clusters followed by cluster-head selection. Cluster-based routing has been shown to be an effective in wireless sensor networks [2]. The main advantage of using this approach is that as the data gathered by sensors in the close vicinity is usually redundant, the gateway can perform the task of data aggregation before sending it to the remote command node called sink node. Various criteria for cluster-formulation have been proposed, but our focus is on routing within a cluster to reduce overhead messages. Within each cluster, nodes with higher energy are identified. Thereafter, residual energy and distance are considered as the main parameters and a decision is made whether routing should be done either in single-hop or in multi-hop fashion or both if possible using fuzzy logic for energy aware routing in wireless sensor networks. The traditional system has the disadvantages of not being easily adaptive to changes in sensor types because energy metrics vary widely with the type of sensor node implementation platform. Moreover, some of the factors for calculating routing metric are conflicting. Fuzzy logic has potential for dealing with conflicting situations and imprecision in data without needing complex mathematical modeling.

In section I, introduction and importance of routing of Wireless Sensor Networks discussed. Section II will discuss about description and limitations of existing protocols. Section III will discuss proposed architecture. Proposed algorithm explained in section IV. Implementation of proposed explained in section V. Results obtained are presented in section VI. Section VII concludes the paper.

2. RELATED WORK

A. LEACH protocol

Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol [2], a distributed clustering algorithm provides a balancing of energy usage by random rotation of cluster heads meanwhile assuring uniform load balancing in single-hop sensor networks. This protocol adopts the Time-driven model. This LEACH protocol assumes that the nodes are homogeneous and the routing of packets to the base station is done in a single hop via the cluster-heads. The main idea of LEACH protocol is that all nodes are chosen to be the cluster heads periodically. The processes of cluster formation of LEACH is shown in Fig.1.

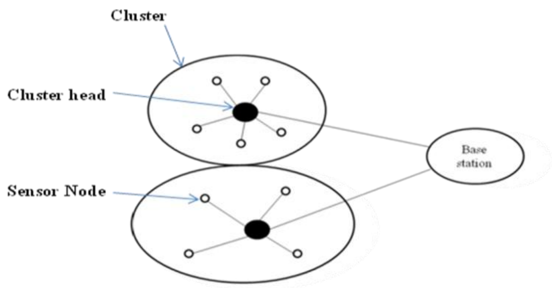

Fig 1: Cluster formation in LEACH

Disadvantages:

Although LEACH protocol prolongs the network lifetime in contrast to plane multi-hop routing and static routing, it still has problems.

1. The cluster heads are elected randomly, so the optimal number and distribution of cluster heads cannot be ensured. The nodes with low residual energy have the same priority to be a cluster head as the node with high residual energy. Therefore, those nodes with less remaining energy may be chosen as the cluster heads which will result that these nodes may die first. If 50% of nodes die, the sensor network will die.
2. The cluster heads communicate with the base station in single-hop mode which makes LEACH cannot be used in large-scale wireless sensor networks for the limited effective communication range of the sensor nodes.
3. In LEACH protocol the information is transmitted from cluster head (CH) to base station (BS) node through single hop communication no matter the distance between BS and CH. Hence, energy consumption will be more if distance is far.
4. Also, LEACH protocol is unsuitable for event-driven applications where a reactive behavior is necessary for the proper functioning of the system.
5. Any node can choose itself as a cluster head independent of other nodes. Set up phase consists of choosing cluster heads randomly, such that every node becomes cluster head at least once.

B. TEEN Protocol

Threshold-sensitive Energy Efficient Network (TEEN) [3] is a reactive protocol for time critical applications. It is a technique of clustering proposed by Manjeshwar and Agarwal for applications where the architecture of the network is based on hierarchical grouping at several levels where the closest nodes form clusters. Then the processing of clustering goes to the second level until the base station is reachable. After the formation of clusters, each cluster head transmits, to its members, two thresholds: Hard Threshold (HT), which is the threshold value of the monitored parameter and a Soft Threshold (ST) representing a small change in the value of the monitored parameter. The occurrence of this small variation ST detected by the node, transmits an alert message to the base station since it does not allow the transmission if there is a little or no change in the value of the monitored control parameter [10]. At the beginning, the nodes listen to the medium continuously and when the value captured from the monitored parameter exceeds the hard threshold, the node transmits the information. The value captured is stored in an internal variable. Then, nodes have no longer to transmit data unless the current value of the controlled parameter becomes greater than the hard threshold or differs from the internal variable value by a quantity greater or equal to the soft threshold value.

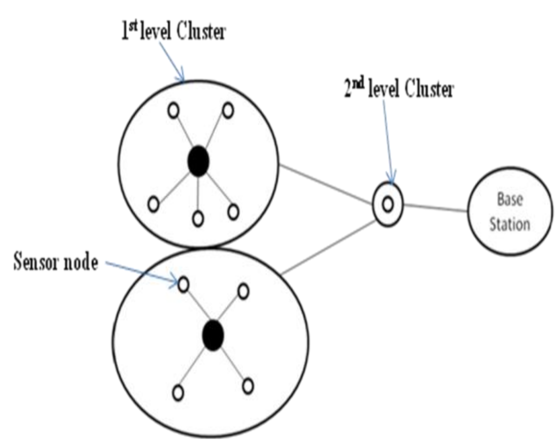

Fig.2: Cluster formation in TEEN

Since the transmission of the message consumes more energy than data sensing, energy consumption by TEEN protocol is then less important than in proactive routing protocols or protocols that transmits data periodically such as LEACH. The algorithm works in rounds. Each round is made up of an initialization phase, a search phase and a transmission phase. The initialization phase is composed of two sub phases: an announcement phase and group's organization phase. The formation of clusters in TEEN is shown in Fig.2.

Disadvantages:

- If the thresholds HT and ST are not received, then the nodes never communicate.
- Random selection of cluster head in TEEN allows nodes to be self-organized into clusters without spending a lot of energy, which causes great energy dissipation.

C. CHEF Protocol

Fuzzy logic selects best cluster head in terms of node's energy and intra-cluster transmission cost. However, each node has to send information about its current location and energy level to BS in each round which is a transmission overhead. Cluster Head Election mechanism using Fuzzy Logic (CHEF) [5] protocol overcomes this overhead by running fuzzy logic with residual energy of node and local distance (sum of distances between particular node and its neighbors within a specified radius) as fuzzy descriptors for cluster head selection at the node. On the downside, CHEF doesn't consider inter-cluster communication cost for cluster head selection. Cluster Head Election protocol by Junpei Anno et. al. uses fuzzy logic with distance of cluster centroid from BS, residual energy of node and network traffic as inputs for cluster head selection [6]. The probability of the node to become cluster head is zero if its residual energy is less than a predefined value. The work does not suggests as to where the fuzzy logic will run and how the input fuzzy descriptors will be collected.

To overcome disadvantages in existing protocols, proposed a new algorithm for WSNs, which increases their lifetime and throughput and thereby reduces energy consumption, in which a decision is made whether to route the packets either through single-hop/multi-hop fashion by using fuzzy logic within a cluster through higher energy nodes or medium energy nodes or low energy nodes . The advantages of proposed system are:

- Increase in the lifetime of wireless sensor network
- Increase in throughput.
- Minimized energy consumption.
- Decrease in Delay of packet routing.
- Routing through higher energy nodes within a cluster.
- Cost effective duo to determine single-hop/multi-hop routing using Fuzzy logic.

D. Energy Dissipation Model

The first-order radio model as in [5], is used as the radio energy model in our simulation. The following equation (2) represents the amount of the energy consumed for transmitting the *l* bits of the data to distance *d*. And equation (3) represents the amount of the energy consumed for receiving *l* bits of the data.

$$E_{TX}(l,d) = \begin{cases} l\mathrm{E}_{elec} + l\varepsilon_{fs}\mathrm{d}^2 & \text{if } \mathrm{d} < \mathrm{d}_0 \\ l\mathrm{E}_{elec} + l\varepsilon_{amp}\mathrm{d}^4 & \text{if } \mathrm{d} > \mathrm{d}_0 \end{cases} \qquad (2)$$

$$E_{RX}(l) = E_{elec}\, l \qquad (3)$$

Where, E_{elec} represents the energy using per bit in the receiver and transmitter circuits. ε_{amp} and ε_{fs} are the energy indulgence factors of strengthening for the corresponding channel models. The threshold value d_0 is obtained as equation (4).

$$\mathrm{d}_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}} \qquad (4)$$

The number of the Cluster Members(CMs) are not known before the formation of the clusters. During the CH selection, the number of neighbor nodes can be used to obtain the EEC.

3. PROPOSED ROUTING ARCHITECTURE

The routing architecture of WSN consists of sensor nodes which are battery powered. The routing of data packets is done through the higher energy nodes and is send to the base station. The routing process of proposed model using fuzzy logic is as show in Fig.3.

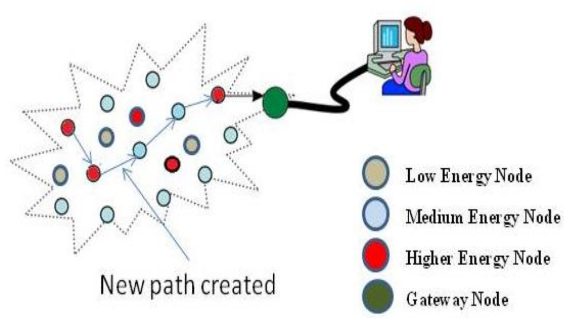

Fig. 3: Routing process of proposed model using Fuzzy Logic.

Architecture of Sensor Node

The main components of a sensor node is shown in Fig. 4.

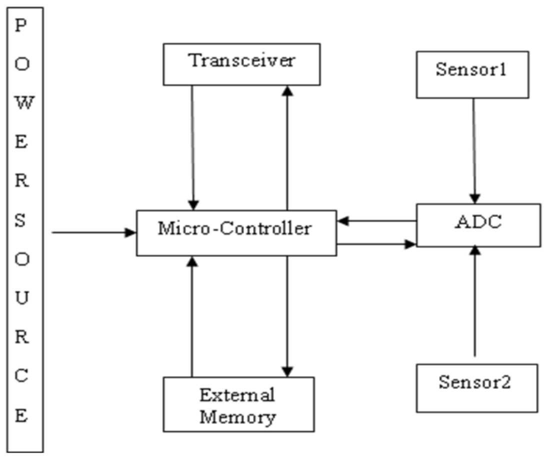

Fig.4 : Architecture of Sensor node

i. Microcontroller

The controller performs tasks, processes data and controls the functionality of other components in the sensor node

ii. Transceiver

The functionality of both transmitter and receiver are combined into a single device known as transceiver. Transceivers often lack unique identifiers. The operational states are transmit, receive, idle, and sleep.

iii. External memory

From an energy perspective, the most relevant kinds of memory are the on-chip memory of a microcontroller and Flash memory—off-chip RAM is rarely, if ever, used. Flash memories are used due to their cost and storage capacity. Memory requirements are very much application dependent.

iv. Power source

A wireless sensor node is a popular solution when it is difficult or impossible to run a mains supply to the sensor node. However, since the wireless sensor node is often placed in a hard-to-reach location, changing the battery regularly can be costly and inconvenient. An important aspect in the development of a wireless sensor node is ensuring that there is always adequate energy available to power the system. The sensor node consumes power for sensing, communicating and data processing. More energy is required for data communication than any other process.

v. Sensors

They are hardware devices that produce a measurable response to a change in a physical condition like temperature or pressure. Sensors measure physical data of the parameter to be monitored. Sensors are classified into three categories:

- passive, Omni-directional sensors;
- passive, narrow-beam sensors;
- active sensors.

Passive sensors sense the data without actually manipulating the environment by active probing. They are self powered; that is, energy is needed only to amplify their analog signal. Active sensors actively probe the environment, for example, a sonar or radar sensor, and they require continuous energy from a power source.

4. METHODOLOGY

FAICP: The proposed methodology is called Fuzzy logic based adaptive intra clustering protocol (FAICP) algorithm using Fuzzy logic is based on routing of packets within a cluster in wireless sensor networks. In this:

1. First, the sensor nodes are deployed in the given geographical area and the base station selects the cluster-head for each cluster. The clusters are formed based on the following parameters by base node:
   - Residual Energy of the node.
   - Distance between sensor node and cluster head.
2. After the formation of clusters, the energy of each and every node within the cluster is calculated.
3. The cluster-head selects nodes with higher energy to route the packet. Each sensor node within the cluster updates its energy level periodically.
4. Based on the distance between the higher energy node and the cluster-head, a decision is taken whether to route the packets through single-hop/multi-hop by using fuzzy logic.

Hence, the energy consumption is minimized since, if the distance is high, we choose multi-hop routing or we choose single-hop routing and sometimes both. This results in increase in the lifetime and throughput of the network.

The following are the parameters used for computation:

Input

1. Residual Energy of the node : This refers to the Battery backup of the sensor node, which is considered as the main parameter to perform energy efficient adaptive intra-clustering hierarchy.
2. Distance: The distance between the sensor node and the cluster head and other sensor nodes is taken as input. It is calculated based on the reflected time, which is the

time taken for the packet to be transmitted to the source from the destination.

Output

1. Increased Lifetime: By reducing the number of dead cells in the network, the lifetime of the WSN can be increased.
2. Increase in Throughput: By reducing cluster overhead and control message overhead in the network, throughput can be increased.
3. Delay: A decision is taken whether to follow multi-hop/single-hop routing, based on the distance between the cluster-head and the sensor node.

Algorithm:

Input:

A set of sensor nodes S= {S_1, S2 …Sn}

A set of cluster heads H= {H_1, H2 ….H_n}

A set of energy levels E= {E_1, E2 ………E_n}

1. Cluster Formation

Step1: Deploy all the set of sensor nodes in the area of application.

Step2: After the nodes are deployed, the base station sends the start packet to all the deployed sensor nodes.

/*start packet is denoted by s_j*/

Step3: The total number of clusters to be formed in the area is determined by the formula:

Number of Clusters= ln N

Where, N is the number of nodes

Step4: The base station selects the cluster head for each cluster depending on the energy level of the node, E_i.

Step5: Each node in the respective cluster sends the join details to the CH for the formation of clusters. This is done based on the following parameters:

i. Signal strength between the sensor node and the cluster head(CH)(S_i)

ii. The relative distance of a sensor node to the cluster head(d_{ij})

iii. The factor of load-balance for a cluster

Step6: After the formation of clusters, the cluster-head maintains a record of all the nodes in the cluster.

2.Intra-Cluster Routing Approach

Step7: while (E_e of CH>0)

Step7.1: Enduring energy of all the nodes in a cluster will be calculated using:

E_e= E-mE_t-nE_r

Where, E_e is enduring energy

E_t is transmitting energ

E_r is receiving energy m is number of times data has been transmitted n is number of times data has been received

Step7.2: All the nodes send their E_e to the cluster-head (CH).

Step7.3: Using fuzzy logic, the nodes will decide whether to follow single-hop/multi- hop fashion to transfer the data. The decision will be taken depending on the following parameters:

i. Energy level of the node, E_i

ii. Distance between the sensor node and the cluster-head(d_{ij})

The rules to be followed for deciding whether the nodes should follow either single-hop/multi-hop are:

Rule1: if(E_i is high && d_{ij} is high) {
Multi-hop
}

Rule2: if(E_i is high && d_{ij} is low)
{
Single-hop
}

Rule3: if(E_i is low && d_{ij} is high)
{
Multi-hop
}

Rule4: if(E_i is low && d_{ij} is low)
{
Single-hop
}

Rule5: if(E_i is high && d_{ij} is medium)
{
Single-hop
}

Rule6: if(E_i is medium && d_{ij} is high)

{

Single/Multi-hop

}

5. IMPLEMENTATION OF PROPOSED METHOD

The objective of fuzzy logic is used here to determine the route value of a link between sensor nodes such that the life of a sensor network is maximized. The lifetime of wireless sensor networks is generally defined as the time when the energy level of the first sensor node becomes zero. The fuzzy rule base has been tuned so as to not only extend the life time of the sensor network but also to balance the routing load among sensor nodes effectively so that a maximum number of nodes have sufficient energy to continue performing their own sensing tasks. Fig.5 displays our fuzzy system model. The input fuzzy variables are: energy level and distance from cluster head. There is a single output fuzzy variable, Single/Multi hop selection, the defuzzified value of which determines the routing path of link between sensor nodes.

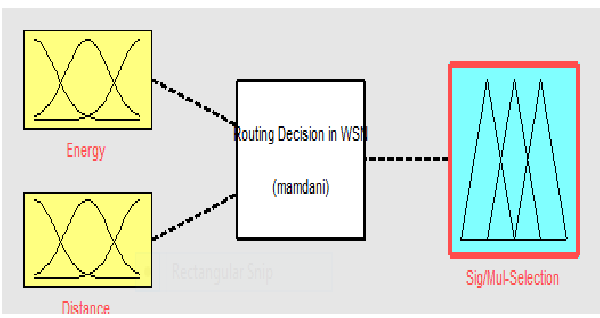

Fig. 5 Fuzzy System Model

Fig.6 and 7 gives details of the input fuzzy variables. In determining the cost of link from node i to node j, " energy" represents the energy needed to transmit a data packet from node i to j. The Lower value of energy level and lower distance leads to select single hop routing. The higher level of energy node and higher distance from cluster header leads to multi- hop routing.

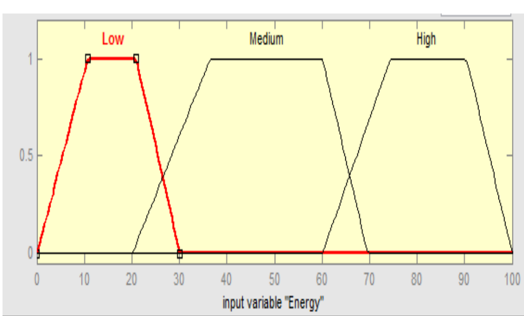

Fig.5 Member function for input varialble Energy

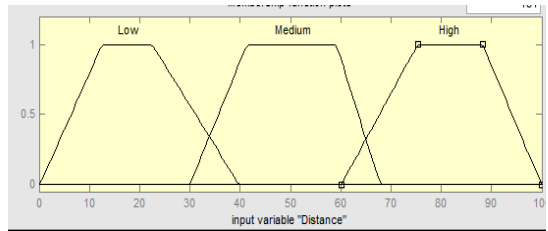

Fig.6 Member function for input varialble Distance

The output fuzzy variable, as shown in Fig. 7, consists of two membership functions. A value between 0 and 100 is assigned.

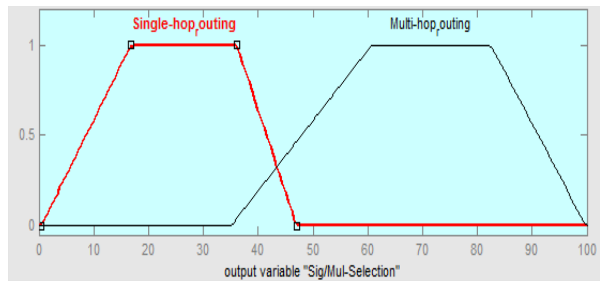

Fig. 7. Member function for output variable fuzzy variable Single/Multi hop routing

The proposed system has used Mamdani Fuzzy Inference system. Any rule that applies contributes to the final Fuzzy solution space. In Fuzzy logic world, user expresses numeric data into word language known as linguistic variable. The rules used in this system is shown in Fig.8

By considering MATLAB fuzzy tool box provides the rules for Fuzzy inference system and surface viewer are shown in Fig.9 and 10 respectively.

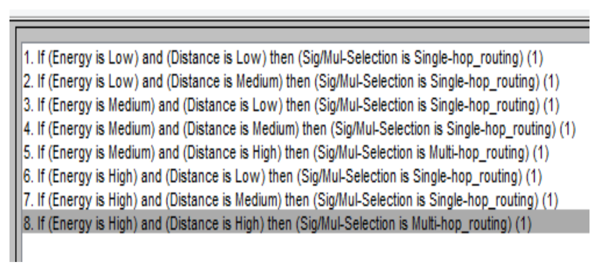
1. If (Energy is Low) and (Distance is Low) then (Sig/Mul-Selection is Single-hop_routing) (1)
2. If (Energy is Low) and (Distance is Medium) then (Sig/Mul-Selection is Single-hop_routing) (1)
3. If (Energy is Medium) and (Distance is Low) then (Sig/Mul-Selection is Single-hop_routing) (1)
4. If (Energy is Medium) and (Distance is Medium) then (Sig/Mul-Selection is Single-hop_routing) (1)
5. If (Energy is Medium) and (Distance is High) then (Sig/Mul-Selection is Multi-hop_routing) (1)
6. If (Energy is High) and (Distance is Low) then (Sig/Mul-Selection is Single-hop_routing) (1)
7. If (Energy is High) and (Distance is Medium) then (Sig/Mul-Selection is Single-hop_routing) (1)
8. If (Energy is High) and (Distance is High) then (Sig/Mul-Selection is Multi-hop_routing) (1)

Fig.8 Fuzzy Rules used in system

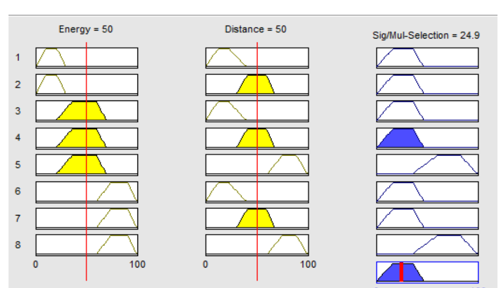

Fig.9 Fuzzy Rule Inference system

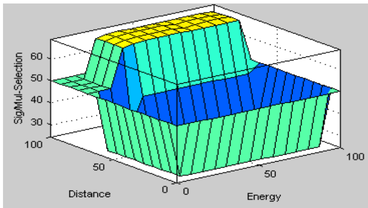

Fig.10 Surface Viewer of Fuzzy System.

6. RESULTS AND DISCUTIONS

FAICP : A WSN consists of sensor nodes which are energy-constrained devices. Hence, many protocols and algorithms have been developed to overcome this constraint of sensor nodes. Existing protocols such as LEACH [2], TEEN [3], and CHEF [5] are based on the formation of clusters followed by selection of cluster-heads. The cluster-heads are either selected randomly or based on parameters like number of times the node has become cluster-head previously. They are aimed at minimizing the energy consumption and increasing the lifetime of the network, but have not achieved the desired efficiency. Hence, proposed FAICP protocol: Adaptive Intra Clustering protocol using Fuzzy logic is based on routing of packets within a cluster in wireless sensor networks.

The experimental simulation was implemented in mat lab and its parameters as shown in Table 1. energy consumption of cluster heads, and network life time shows that the recommended FAICP is relatively more effective when compared with LEACH, TEEN, and CHEF.

A. Energy consumption distribution among cluster heads

Table 1. Simulation Setup of Proposed FAICP

Simulation parameters	Default values
Deployment type	Random topology
Field size	200m × 200m
Network Size	100 Nodes
MAC layer	TMAC
Packet size	512 bytes
Initial energy of the node, E_{init}	200J
Transmitter electronics, E_{TX}	0.2 Watts
Receiver electronics, E_{RX}	0.1 Watts
Amplification for multipath Transmission coefficient, E_{amp}	0.0013 pJ. m²/bit
Amplification for free space coefficient, E_{fs}	10 pJ.m²/bit
Simulation time	4000 s
Round length	500 s

The average energy consumption among different CHs are measured in a round (500 seconds per round) through the simulation, where data transmission and reception by CHs and total energy used by the CHs in a round which is demonstrated in the figure 11. Therefore the energy consumed by CHs in our proposed work FAICP is less than CHEF,TEEN and LEACH.

B. Network Lifetime

The FAICP has better performance for network lifetime compared to LEACH, TEEN, and CHEF. The figure 12 gives a brief illustration on the alive notes are distributed for each protocol to guess the life time of the network. The proposed FAICP shows more stability because the death of the node begins later in this approach.

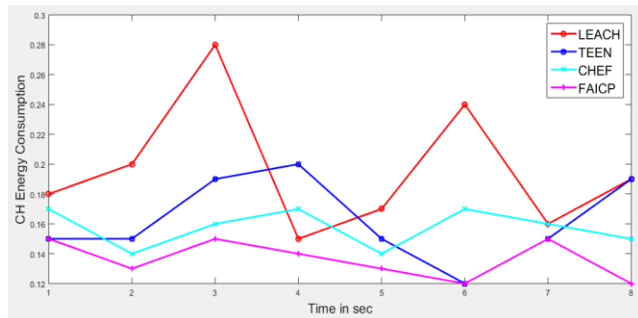

Fig. 11. Energy consumption by cluster heads

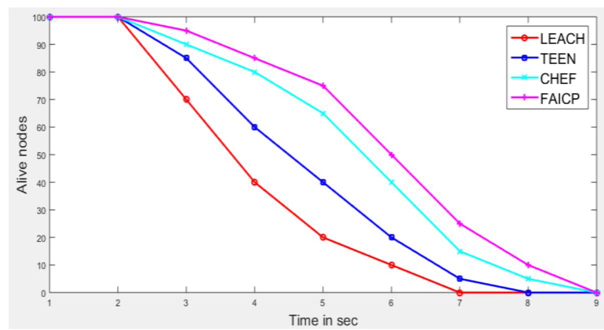

Fig.12. Lifetime of the network with respect to alive nodes.

7. CONCLUSION

We have proposed a novel algorithm to overcome the drawbacks in the existing protocols regarding routing in wireless sensor networks since it is a major issue in these networks as they are energy-constrained. We used fuzzy logic model for our convenience as it best suits the process of computation and implemented it in mat lab. The proposed algorithm is aimed at increasing the network lifetime and throughput and hence minimizes energy consumption.

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