Fuzzy Logic Based Clustering in Wireless Sensor Network

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Abstract—*Minimization of energy consumption is one of the most important research areas in Wireless Sensor Networks. Nowadays, the paradigms of computational intelligence (CI)are widely used in WSN, such as localization, clustering energy aware routing, task scheduling, security, etc. Though many fuzzy based clustering techniques have been proposed earlier, many of them could not increase the total network life time in terms of LND (Last Node Dies) with comparing to LEACH. In this paper, a fuzzy logic based energy-aware dynamic clustering technique is proposed, which increases the network lifetime in terms of LND. Here, two inputs are given in the fuzzy inference system and a node is selected as a cluster head according to the fuzzy cost (output). The main advantage of this protocol is that the optimum number of cluster is formed in every round, which is almost impossible in LEACH (low-energy adaptive clustering hierarchy). Moreover, this protocol has less computational load and complexity. the simulation result demonstrates that this approach performs better than LEACH in terms of energy saving as well as network lifetime.*

Key words: - wireless sensor networks, Energy-efficiency, Leach, sensor network; fuzzy logic; network lifetime

I. INTRODUCTION

The recent developments in making energy efficient Wireless Sensor Network is giving a new direction to deploy WSN in applications like surveillance, industrial monitoring, traffic monitoring, habitat monitoring, cropping monitoring, crowd counting etc . The growing use of these networks is making engineers to evolve innovative and efficient ideas in this field. A lot of research in data routing, data compression and in network aggregation has been proposed in recent years [1]. A wireless sensor network consists of a large number of nodes spread over a specific area where we want to look after at the changes going on there. A sensor node generally consists of sensors, actuators, memory, a processor and they do have communication ability. Wireless sensor nodes, which are compact, light-weighted, and battery-powered devices that can be used virtually in any environment. Because of these special characteristics, sensor nodes are usually deployed near the targets of interest in order to do close-range sensing. All the sensor nodes are allowed to communicate through a wireless medium. The wireless medium may either of radio frequencies, infrared or any other medium, of course having no wired connection. These nodes are deployed in a random fashion and they can communicate among themselves to make an ad-hoc network. Basically nodes are driven by batteries and in many applications it is not easy to replace the batteries or sometimes not even recharge the batteries so each node has a limited energy supply [2] [3]. If the node is not able to communicate with

other through direct link, i.e. they are out of coverage area of each other. The data can be sent to the other node by using the nodes in between them. This property is referred as multihoping. A network with clustering is divided into several clusters. Within each cluster, one of the sensor nodes is elected as a cluster head (CH) and with the rest being cluster members (CM).

All sensor nodes work cooperatively to serve the requests. Cluster head collects the data locally from the cluster members and transmits the aggregated data either directly or via multi-hop transmission to the sink. Since the cluster heads spend more energy than the non-cluster heads so to distribute the workload of the cluster heads among the wireless sensor nodes their role is rotated among all nodes in order to equalize energy consumption [3]. Generally WSNs are not centralized one as there is peer-to-peer communication between the nodes. So there is no requirement of prior established infrastructure to deploy the network. WSN gives flexibility of adding nodes and removing the nodes as required. But this gives rise to many drastic changes to deal with in the network topology such as updating the path, or the network tree, etc. In a WSN the node that gathers the data information refers to sink. The sink may be connected to the outside world through internet where the information can be utilized within time constraints. The main problem in using these networks is limited battery life. This is due to fact that the size of a sensor node is expected to be small and this leads to constraints on size of its components i.e. battery size, processors, data storing memory, all are needed to be small. So any optimization in these networks should focus on optimizing energy consumption. In WSN a lot of sensed data and routing information has to be sent which often 3 have some time constraints so that the information can be utilized before any mishap occurs, e.g. industrial monitoring, machinery monitoring, etc. The energy power consumption is much higher in data communication than internal processing. So energy conservation in WSN is needs to be addressed. Usually sensor nodes rely on a battery with limited lifetime, and their replacement is not possible due to physical constraints. Moreover the architecture and protocol of sensor networks must be able to scale up any number of sensor nodes. Since the battery lifetime can be extended if we manage to reduce the amount of communication caching only the useful data for each sensor either in its local store or in the neighborhood nodes can prolong the network lifetime

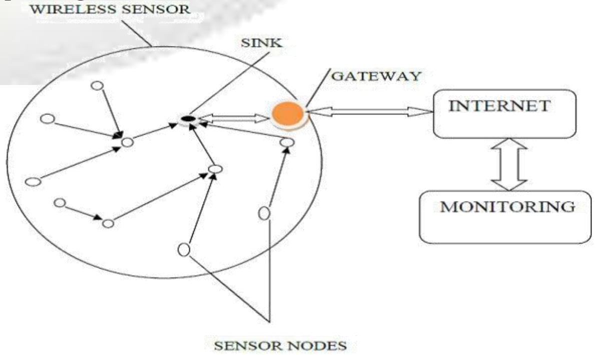


Fig. 1:

II. Background And History

This Chapter describes relevant background knowledge and related work for readers to easily understand the proposed protocol and the methodology and analysis of our experiments,. In Section 1.1, wireless sensor networks

and their significant characteristics are discussed. Section 1.2 presents swarm intelligence and how the optimal position of the base station is obtained using the particle swarm optimization method. Finally, section 1.3 addresses Fuzzy Logic, as well as the structure and operations of Fuzzy Inference Systems.

A. Wireless Sensor Network

Wireless sensor network consists of large number of wireless sensor nodes located over a geographic area. The “wireless sensor node” term is for devices that use low power and are equipped with one or more sensors, a radio unit, power supply, processor and an optional actuator. The sensor node can have sensors for the detection and measurement of thermal, mechanical, optical, magnetic, chemical or biological signals. In a basic WSN, the integrated radio unit in a sensor node sends the data collected to the base station. The base station is normally located far from the sensor nodes and acts as a gateway between the network and subsequent communication centers. A general structure of WSN is presented in Figure 1. The WSN can be structured or unstructured. A basic wireless sensor network requires very little infrastructure. In one such network, nodes can be deployed in an ad hoc fashion. The network is not attended after deployment and does monitoring and reporting on its own. However, the sensor network deployed to obtain data from the environment may require a large number of sensor nodes, numbering thousands to tens of thousands depending on the area to be covered. Due to large number of nodes the management of network becomes difficult and complex structure is required. The structured wireless sensor network has planned deployment of sensor nodes, and this means that fewer nodes are required to cover the area compared to an unstructured network. Cost of maintenance and management is reduced. The wireless sensor network nodes have limitations in terms of limited power available for working, low bandwidth, limited processing capabilities, small range and limited data storage. The network design is based on the environment of operation. Thus, network topologies, the schemes of deployment are decided on a case-to-case basis. Normally, small numbers of nodes are sufficient for indoor coverage whereas outdoor coverage requires large numbers of nodes.[1] For inaccessible areas only ad hoc deployment is used. Ad hoc deployment is also used whenthe number of nodes ranges from 100s to1000s

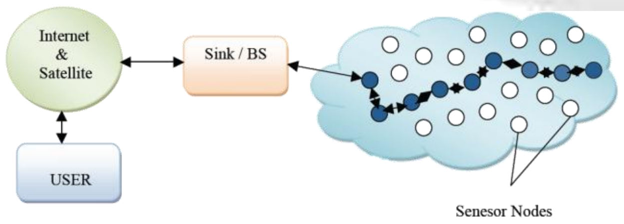


Fig. 2: WSN overview

The protocol stack of sensor network is extremely similar to the protocol stack of the traditional ad-hoc networks, with the following layers: Application, Transport, Network, Data Link , and Physical

- Application layer: The application layer is responsible for user interface and data processing.
- Transport layer: This layer specifies the methodology for reliable packet transportation.
- Network layer: The network layer’s function is to take care of addressing and forwarding packets.
- Data link layer: The data link layer’s function is data streams multiplexing, error control, frame detection and ensuring reliable connections.
- Physical layer: The physical layer functions are to define frequency in use, signal characteristics such as modulation scheme and encryption of a wireless sensor device (node) are illustrated in Figure 2. A wireless sensor device is generally composed of four basic components: a sensing unit, a processing unit, a transceiver unit and a power unit usually in the form a battery Sensing unit Processing Unit

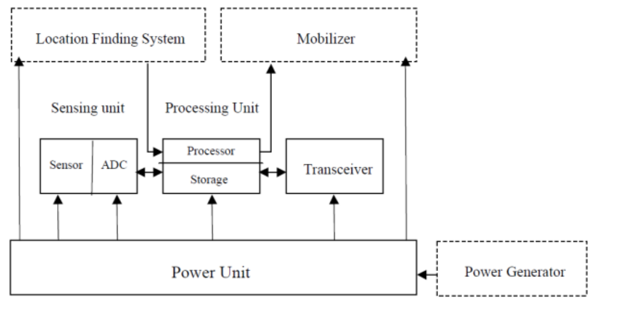


Fig.3: general hardware architecture of a sensor node

Figure .3: General hardware architecture of a sensor node Each sensing unit comprises of sensor(s) for sensing environment and analog-to-digital converter (ADC) . Nodes transmit their sensed data if certain pre-defined conditions are met. The environmental signal is received in the form of an analog signal by the sensor and then is converted into a digital signal by the ADC. The Processing unit consists of a microcontroller or in some applications a microprocessor and is responsible for analyzing the attributes of the sensed data by using digital signals. The Transceiver is for connecting the nodes and the BS through a radio transmitter. Lastly, the power unit is usually a battery. Based on different applications, there might be extra components such as localization unit, energy producer, position changer, etc. These components are shown in Figure .2 by the dashed boxes.

B. WSN routing protocols

Many new energy saving protocols distinctively designed for sensor networks, are results of the recent advancements in WSN. Wireless communication is considered the primary component of energy consumption in WSN So particular attention was given to the routing protocols, which can vary contingent on the application and network architecture. The routing protocols in WSNs are broken down into three categories. First, direct communication (DC), which is the simplest protocol, where sensor nodes send data directly to the BS. The second category involve Minimum

Transmission Energy (MTE) protocols, where nodes route data to the base station through intermediate nodes, each node acting as a router for the other nodes. The third and perhaps most interesting category are made up of clustering protocols. Hierarchical or cluster-based routing, originally presented in wire-line networks, are recognized techniques with particular advantages related to scalability and efficient communication. Cluster-based routing has been shown to be more effective than DC and MTE and is hence focused on in this work.

C. Cluster-based Wireless Sensor Networks

In WSN, some of the issues are very critical and complex, such as energy-efficient operation, latency, channel disputation and management. In particular, in large-scale sensor networks, the nodes that reside far away from the BS either have to count on significant amount of intermediate nodes or use high transmission power to forward their sensed data. Various algorithms suggest solutions to the above issue, which is based on the decomposition of the entire network into smaller groups called clusters. In general, neighboring nodes are grouped into the same cluster and a cluster–head as shown in Figure 3 manage each cluster The cluster-head acts as a local base-station and it is responsible for collecting the sensed data from the member nodes of that cluster. The cluster head forwards the collected data to the other cluster-heads or directly to the sink/BS Communication among cluster-heads can be via either single or multi hops. The cluster-heads are responsible for managing both inter-cluster and intra-cluster communication .Clustering has advantages and disadvantages Nodes inside a cluster are only required to broadcast to its cluster-head, and this decreases each node's connection variety. This also permits the spatial reuse of communication channels while decreasing collisions. By aggregating data, the number of messages that flow through the network can be lowered. Another

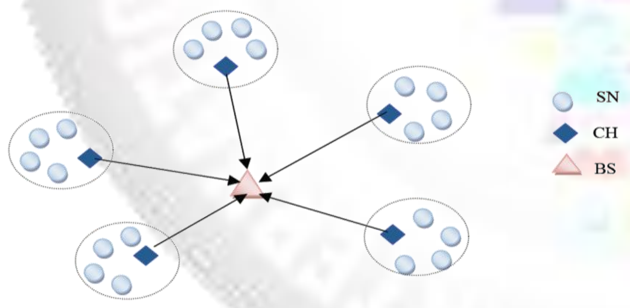


Fig.4: Cluster based architecture for WSN

important feature of clustering is the rotation cluster-head roles among the sensor nodes in order to not drain the battery of a single node (as the CH consumes the most energy among all nodes in a cluster).Cluster-head selection can be based on different parameters such as node ID [1], node degree, residual energy or probabilistically methods . One of the simplest selection methods is Max-Min d-clustering , but this solution is not directly applicable because it is not energy aware. On the other hand, LEACH [4] is a well-known cluster-based solution that is relatively simple to implement yet achieves longer network life time by selecting cluster-heads based on residual energy of the nodes and data aggregation.

III. Literature Review

A. Energy Analysis of Routing Protocols

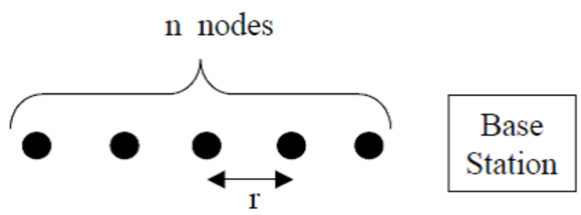
There have been several network routing protocols proposed for wireless networks that can be examined in the context of wireless sensor networks. We examine two such protocols, namely direct communication with the base station and minimum-energy multi-hop routing using our sensor network and radio models. In addition, we discuss a conventional clustering approach to routing and the drawbacks of using such an approach when the nodes are all energy-constrained. Using a direct communication protocol, each sensor sends its data directly to the base station. If the base station is far away from the nodes, direct communication will require a large amount of transmit power from each node (since d in Equation 1 is large). This will quickly drain the battery of the nodes and reduce the system lifetime. However, the only receptions in this protocol occur at the base station, so if either the base station is close to the nodes, or the energy required to receive data is large, this may be an acceptable (and possibly optimal) method of communication. The second conventional approach we consider is a "minimum-energy" routing protocol. There are several power-aware routing protocols discussed in the literature In these protocols, nodes route data destined ultimately for the base station through intermediate nodes. Thus nodes act as routers for other nodes' data in addition to sensing the environment. These protocols differ in the way the routes are chosen. Some of these protocols [4, 5, and 6] only consider the energy of the transmitter and neglect the energy dissipation of the receivers in determining the routes. In this case, the intermediate nodes are chosen such that the transmit amplifier energy is minimized; thus node

$$E_{Tx-amp}(k, d = d_{AB}) + E_{Tx-amp}(k, d = d_{BC}) < E_{Tx-amp}(k, d = d_{AC})$$

or

$$d_{AB}^2 + d_{BC}^2 < d_{AC}^2$$

A would transmit to node C through node B if and only if: However, for this minimum-transmission-energy (MTE)routing protocol, rather than just one (high-energy) transmit of the data, each data message must go through n (low energy) transmits and n receives. Depending on the relative costs of the transmit amplifier and the radio electronics, the total energy expended in the system might actually be greater using MTE routing than direct transmission to the base station. To illustrate this point, consider the linear network shown in Figure below, where the distance between the nodes is r. If we consider the energy expended transmitting a single -bit message from a node located a distance nr from



the base station using the direct communication approach and Equations 1 and 2, we have:

$$E_{direct} = E_{Tx}(k, d = n * r)$$
$$= E_{elec} * k + \epsilon_{amp} * k * (nr)^2$$
$$= k(E_{elec} + \epsilon_{amp} n^2 r^2)$$

In MTE routing, each node sends a message to the closest node on the way to the base station. Thus the node located a distance nr from the base station would require n transmits a distance r and n-1 receives

$$E_{MTE} = n * E_{Tx}(k, d = r) + (n-1) * E_{Rx}(k)$$
$$= n(E_{elec} * k + \epsilon_{amp} * k * r^2) + (n-1) * E_{elec} * k$$
$$= k((2n-1)E_{elec} + \epsilon_{amp} n r^2)$$

distance nr from the base station would require n transmits a distance r and n _ _ receives. Therefore, direct communication requires *less* energy than MTE routing if: Using Equations 1 - 6 and the random 100-node network shown in Figure 3, we simulated transmission of data from every node to the base station (located 100 m from the closest sensor node, at (x=0, y=-100)) using MATLAB. Figure 4 shows the total energy expended in the system as the network diameter increases from 10 m _ 10 m to 100 m _ 100 m and the energy expended in the radio electronics i.e., Eelec increases from 10 nJ/bit to 100 nJ/bit, for the scenario where each node has a 2000-bit data packet to send to the base station. This shows that, as predicted by our analysis above, when transmission energy is on the same order as receive energy, which occurs when transmission distance is short and/or the radio electronics energy is high, direct transmission is more energy-efficient on a global scale than MTE routing. Thus the most energy-efficient protocol to use depends on the network topology and radio parameters of the system.

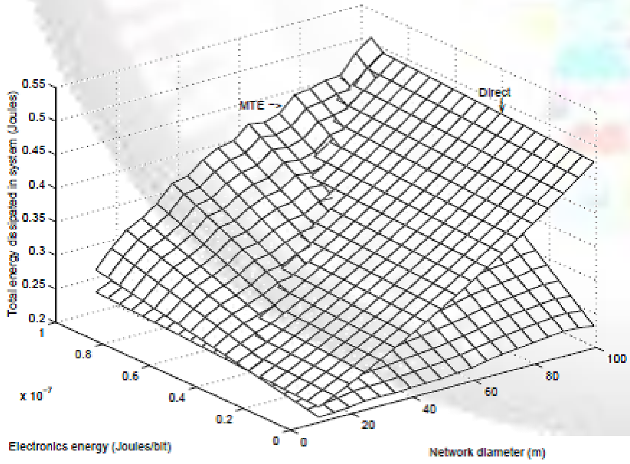
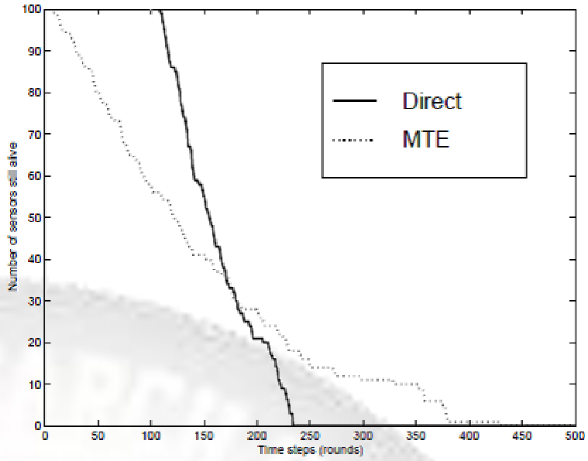


Fig. 5:



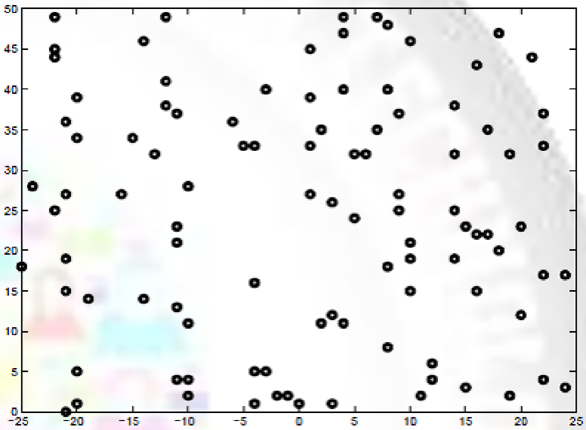


Fig. 5:

It is clear that in MTE routing, the nodes closest to the base station will be used to route a large number of data messages to the base station. Thus these nodes will die out quickly, causing the energy required to get the remaining data to the base station to increase and more nodes to die. This will create a cascading effect that will shorten system lifetime. In addition, as nodes close to the base station die, that area of the environment is no longer being monitored. To prove this point, we ran simulations using the random 100-node network shown in Figure 5 and had each sensor send a 2000-bit data packet to the base station during each time step or "round" of the simulation. After the energy dissipated in a given node reached a set threshold, that node was considered dead for the remainder of the simulation. Figure 6 shows the number of sensors that remain alive after each round for direct transmission and MTE routing with each node initially given 0.5 J of energy. This plot shows that nodes die out quicker using MTE routing than direct transmission. Figure 6 shows that nodes closest to the base station are the ones to die out first for MTE routing, whereas nodes furthest from the base station are the ones to die out first for direct transmission. This is as expected, since the nodes close to the base station are the ones most used as "routers" for other sensors' data in MTE routing, and the nodes furthest from the base station have the largest transmit energy in direct communication.

A final conventional protocol for wireless networks is clustering, where nodes are organized into clusters that communicate with a local base station, and these local base stations transmit the data to the global base station, where it is accessed by the end-user. This greatly reduces the distance nodes need to transmit their data, as typically the local base station is close to all the nodes in the cluster

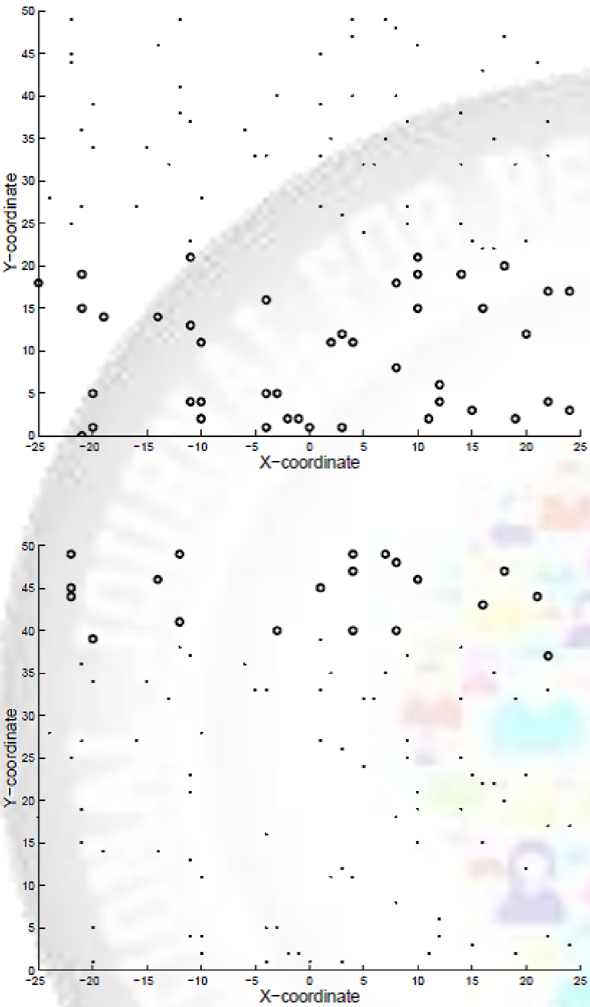


Fig.7:

Thus, clustering appears to be an energy-efficient communication protocol. However, the local base station is assumed to be a high-energy node; if the base station is an energy-constrained node, it would die quickly, as it is being heavily utilized. Thus, conventional clustering would perform poorly for our model of micro sensor networks. The Near Term Digital Radio (NTDR) project [5, 6], an army-sponsored program, employs an adaptive clustering approach, similar to our work discussed here. In this work, cluster-heads change as nodes move in order to keep the network fully connected. However, the NTDR protocol is designed for long-range communication, on the order of 10s of kilometers, and consumes large amounts of power, on the order of 10s of Watts. Therefore, this protocol also does not fit our model of sensor networks.

IV. RELATED WORKS

Leach is called "Energy efficient Adaptive protocol for clustered Wireless sensor networks". This protocol facilitates the nodes with more residual energy have more chances to be selected as cluster head. In order to extend the lifetime of the whole sensor network, energy load must be evenly distributed among all sensor nodes so that the energy at a single sensor node or a small set of sensor nodes will not be drained out very soon. Low Energy Adaptive Clustering Hierarchy (LEACH) is the first energy efficient routing protocol for hierarchical clustering. It reduces the energy significantly. The LEACH protocol forms clusters in the sensor networks and randomly selects the Cluster-heads for each cluster. Non cluster-head nodes sense the data and transmit to the cluster-heads. the cluster-heads aggregate the received data and then forward the data to the sink. The basic principle is that it assigns overall energy consumption of the network uniformly to each sensor node through periodically selecting different nodes as cluster-head. This makes the survival time of nodes close to the lifetime of network. Thus, the energy consumption can be reduced and the lifetime of the entire network can be prolonged. There are two phases in LEACH protocol: i) Setup phase ii) steady-state phase. In the setup phase the clusters are formed and the cluster-heads are selected. In the steady-state phase, the data from non-cluster heads are transmitted to the sink. The sensor nodes communicate to the cluster-heads using TDMA schedule. The nodes communicate to the cluster-head only in their allotted slots. It avoids collision. The cluster-heads are selected randomly for every round [4], [5], [6]. The operation of LEACH is divided into several rounds. Each round begins with a set-up phase when the clusters are organized, followed by a steady–state phase. In the set-up state when the clusters are organized, the LEACH sets a threshold value $T(n)$ first, and then sensor node I generates a random number between 0 and 1 automatically by distributed computing. If the random number $< T(n)$, the node will become the cluster-head of the current round r, and common nodes join in the nearest cluster. After a period of data transmission, the network starts cluster reconstruction of the new round. And the circular processes

$$T(n) = \begin{cases} p/1-p*(r \mathrm{mod} 1/p) & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

Where p is the probability of the nodded being selected as a cluster-head node; r is the number of rounds passed, and G is the collection of ordinary nodes; mod denotes modulo operator. The value of p is the expected number of cluster head nodes. In the LEACH algorithm, all nodes in the cluster take it turns to act as the head node, to achieve the purpose of balancing node energy consumption. Therefore, only the nodes that have not already been cluster-heads recently and have more energy available may become cluster-heads at round r +1. Once the cluster-head is selected, all nodes join the corresponding cluster according to the broadcast signal intensity of the cluster-head node. Then, the cluster set-up phase of this round is completed. When the cluster-head assigns time slots for its members using TDMA mode, the network will enter the steady-state. In this phase, after all member nodes sent monitoring data information, the head node will process data fusion, and then send data information to the base station. After this round, it turns to the next round, and starts cluster reconstruction of the new round [6]

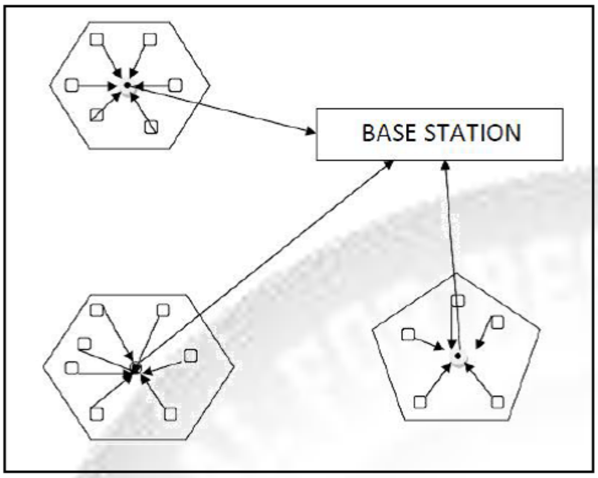


Fig.8:

A. *Disadvantages Of The Leach Protocol*

Although LEACH protocol prolongs the network lifetime in contrast to plane multi-hop routing and static routing, it still has problems. The cluster heads are elected randomly, so the optimal number and distribution of cluster heads cannot be ensured. The nodes with low remnant energy have the same priority to be a cluster head as the node with high remnant energy. Therefore, those nodes with less remaining energy may be chosen as the cluster heads which will result that these nodes may die first. 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 limit effective communication range of the sensor nodes.

V. PROPOSED WORK

Minimization of energy consumption is one of the most important research areas in Wireless Sensor Networks. Nowadays, the paradigms of computational intelligence (CI)are widely used in WSN, such as localization, clustering, energy aware routing, task scheduling, security, etc. Though many fuzzy based clustering techniques have been proposed earlier, many of them could not increase the total network life time in terms of LND (Last Node Dies) with comparing to LEACH. In this paper, a fuzzy logic based energy-aware dynamic clustering technique is proposed, which increases the network lifetime in terms of LND. Here, two inputs are given in the fuzzy inference system and a node is selected as a cluster head according to the fuzzy cost (output). The main advantage of this protocol is that the optimum number of cluster is formed in every round, which is almost impossible in LEACH (low-energy adaptive clustering hierarchy). Moreover, this protocol has less computational load and complexity. the simulation result demonstrates that this approach performs
better than LEACH in terms of energy saving as well as network lifetime

VI. CONCLUSION

Total lifetime is an important issue, which is directly related to the energy. In this paper, an energy efficient dynamic clustering protocol is proposed for WSN, which uses fuzzy logic to select the cluster heads. Here, the cluster head selection is centralized, but the data collection is distributed. Comparing to LEACH, this approach can prolong the sensor network lifetime and also can achieve the optimum number of clusters in every round. This algorithm is simple as well as it has less computational load. So, this algorithm can be efficiently used in larger WSN. For future work, the performance can also be compared with other well-known protocols, such as LEACH-C (LEACH-Centralized), HEED (Hybrid Energy Efficient Distributed). further research will be continued to expand this algorithm to meet the requirements of QoS (Quality of Service) for WSN. The sensor nodes are stationary in this proposed algorithm; so another research can be done to apply this technique to the mobile sensor nodes.

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