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# Energy-Aware Performance Evaluation of WSNs using Fuzzy Logic

**Santosh Kumar Bharti, Shashi Kant Dargar, Abha Nyati**

***Abstract***— ***Wireless Sensor Networks (WSNs) are being used to form large, dense networks for the purpose of long term environmental sensing and data collection. Unfortunately, these networks are typically deployed in remote environment where energy source are limited. WSN's, present a new generation of real-time embedded systems with limited computation, energy and memory resources that are being used in a wide variety of applications where traditional networking infrastructure is practically infeasible. Appropriate cluster-head node election can drastically reduce the energy consumption and enhance the lifetime of the network. In this paper, a fuzzy based energy-aware sensor network communication protocol is developed based on three descriptors - energy, concentration and centrality. Further we have to compared fuzzy based approach with other popular protocol LEACH and improved hierarchy scheme DBS. Simulation shows that depending upon network configuration, a substantial increase in network lifetime can be accomplished as compared to probabilistically selecting the nodes as cluster-heads using only local information.***

***Index Terms***— ***Wireless Microsensor networks, LEACH, cluster head election, distance based Segmentation, Fuzzy C-Mean Algorithms***.

## I. INTRODUCTION

Wireless Sensor Network (WSN) owes its success mainly to the modern technological advancements in recent years that have enabled low-cost, low-power and minute sensor nodes in production. These tiny nodes work in the order of a few to tens of hundreds in areas ranging from sophisticated urban homes to extremely hostile, remote areas. The major restrictions in wireless and mobile systems related to communication bandwidth and energy also underline the challenge in designing a wireless ad hoc network. It is required to develop innovative communication techniques to increase the amount of bandwidth per user and innovative design techniques and protocols to increase energy efficiency.

Several useful and varied applications of WSNs include applications requiring information gathering in harsh, inhospitable environments, weather and climate monitoring, detection of chemical or biological agent threats, and healthcare monitoring. These applications demand the usage of various equipment including cameras, acoustic tools and sensors measuring different physical parameter. WSN's consist of many inexpensive, portable wireless nodes, with limited power, memory and computational capabilities. The energy supply of the sensor nodes is one of the main constraints in the design of this type of network [7].

Since it is infeasible to replace batteries once WSNs are deployed, an important design issue in WSNs is to lessen the energy consumption with the use of energy conserving hardware, operating systems and communication protocols.

The energy consumption can be reduced by allowing only some nodes to communicate with the base station. These nodes called cluster-heads collect the data sent by each node in that cluster compressing it and then transmitting the aggregated data to the base station [1]. Appropriate cluster-head selection can significantly reduce energy consumption and enhance the lifetime of the WSN. In this paper, a fuzzy logic approach to cluster-head election is proposed based on three descriptors - energy, concentration and centrality. Simulation shows that depending upon network configuration a substantial increase in network lifetime can be accomplished as compared to probabilistically selecting the nodes as cluster-heads using only local information. For a cluster, the node elected by the base station is the node having the maximum chance to become the cluster-head using three fuzzy descriptors - node concentration, energy level in each node and node centrality with respect to the entire cluster, minimizing energy consumption for all nodes consequently increasing the lifetime of the network.

There are diverse applications of intelligent techniques in wireless networks [5]. Fuzzy logic control is capable of making real time decisions, even with incomplete information. Conventional control systems rely on an accurate representation of the environment, which generally does not exist in reality. Fuzzy logic systems, which can manipulate the linguistic rules in a natural way, are hence suitable in this respect. Moreover it can be used for context by blending different parameters - rules combined together to produce the suitable result.

We compare our approach with LEACH (Low Energy Adaptive Clustering Hierarchy) localized clustering, and DBS (Distance-Based Segmentation). In LEACH [1] and [2], the nodes select themselves as cluster-heads without the base station processing, and DBS [3], is a cluster-based protocol that significantly decreases the energy imbalance in the network by integrating the distance of the sensor nodes from the BS into clustering policies. Other nodes in the vicinity join the closest cluster-heads and transmit data to them. Simulation results show that our approach increases the network lifetime considerably as compared to LEACH and DBS.

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## II. RELATED WORK

A typical WSN architecture is shown in Figure 1.The nodes send data to the respective cluster-heads, which in turn compresses the aggregated data and transmits it to the base station.

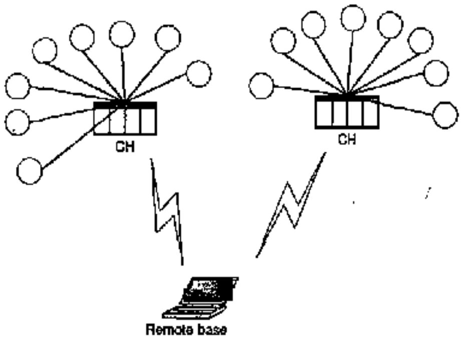


Figure 1: Wireless Sensor Networks

For a WSN we make the following assumptions:

- The base station is located far from the sensor nodes and is immobile.
- All nodes in the network are homogeneous and energy constrained.
- Symmetric propagation channel.
- Base station performs the cluster-head election.
- Nodes have location information that they send to the base station with respective energy levels during set up phase.
- Nodes have little or no mobility

Many proposals have been made to select cluster-heads. In the case of LEACH [1], to become a cluster-head, each node n chooses a random number between 0 and 1. If the number is less than the threshold T(n), the node becomes the cluster-head for the current round.

The Threshold is set at:

$$T(n) = \begin{cases} \dfrac{p}{1-p*(r \bmod \frac{1}{p})} : & if\ n \in G \\ 0 \quad : & otherwise \end{cases} \quad (1)$$

Where, P is the cluster-head probability, r the number of the current round and G the set of nodes that have not been cluster-heads in the last 1/P rounds.

Several disadvantages are there for selecting the cluster-head using only the local information in the nodes. 1) since each node probabilistically decides whether or not to become the cluster-head, there might be cases when two cluster-heads are selected in close vicinity of each other increasing the overall energy depleted in the network. 2) the number of cluster-head nodes generated is not fixed so in some rounds it may be more or less than the preferred value. 3) the node selected can be located near the edges of the network; wherein the other nodes will expend more energy to transmit data to that cluster-head. 4) each node has to calculate the threshold and generate the random numbers in each round, consuming CPU cycles.

LEACH-C [2] uses a centralized algorithm and provides another approach to form clusters as well as selecting the cluster-heads using the simulated annealing technique.

In [3], DBS divides the sensor field into multiple segments with equal area by drawing concentric circles around the BS and differentiates the number of clusters for each segment in terms of the distance from the BS. In closer segments the probability of becoming cluster head is more than distant segments and thus the number of cluster heads in these segments is more. By applying this idea, to moderate the difference of energy consumption among all nodes and to lower wasteful transmissions and the system's energy-efficiency will be enhanced.

In [4] each node calculates its distance to the area centroid which will recommend nodes close to the area centroid and not the nodes that is central to a particular cluster, cluster centroid. Thus it leads to overall high energy consumption in the network for other nodes to transmit data through the selected node.

## III. SYSTEM MODEL

In this paper the cluster-heads are elected by the base station in each round by calculating the chance each node has to become the cluster-head by considering three fuzzy descriptors – node concentration, energy level in each node and its centrality with respect to the entire cluster. In our opinion a central control algorithm in the base station will produce better cluster-heads since the base station has the global knowledge about the network. Moreover, base stations are many times more powerful than the sensor nodes, having sufficient memory, power and storage. Considering WSNs are meant to be deployed over a geographical area with the main purpose of sensing and gathering information, we assume that nodes have minimal mobility, thus sending the location information during the initial setup phase is sufficient.

The cluster-head collects n number of k bit messages from n nodes that joins it and compresses it to cnk bit messages with $c \leq 0.1$ as the compression coefficient. The operation of this fuzzy cluster-head election scheme is divided into two rounds each consisting of a setup and steady state phase similar to LEACH. During the setup phase the cluster-heads are determined by using fuzzy knowledge processing and then the cluster is organized. In the steady state phase the cluster-heads collect the aggregated data and performs signal processing functions to compress the data into a single signal. This composite signal is then sent to the base station.

The radio model we have used is similar to [1] with $E_{elect}$ = 50 nJ/bit as the energy dissipated by the radio to run the transmitter or receiver circuitry and $\mathcal{E}_{amp}$ = 100 pJ/bit/m$^2$ as the energy dissipation of the transmission amplifier.

The energy expended during transmission and reception for a k bit message to a distance d between transmitter and receiver node is given by:

$$E_{TX}(k,d) = E_{elect} * k + \mathcal{E}_{amp} * k * d^{\lambda} \quad (2)$$

$$E_{RX}(k,d) = E_{elect} * k \quad (3)$$

### *Fuzzy Logic Control*

A Fuzzy system basically consists of three parts: fuzzifier, inference engine and defuzzifier.



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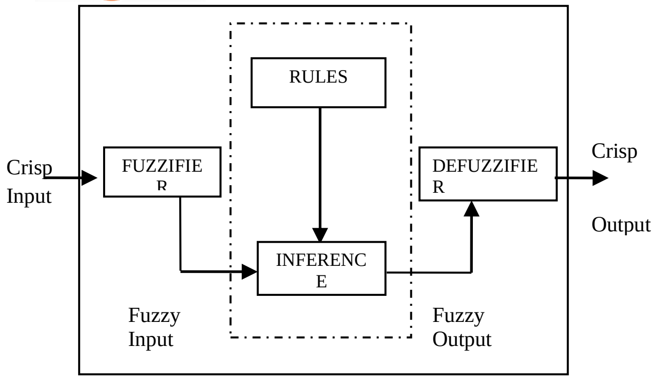


Figure2: Fuzzy Logic System

We have used the most commonly used fuzzy inference technique called Mamdani Method [9] due to its simplicity. The fuzzifier maps each crisp input value to the corresponding fuzzy sets and thus assigns it a truth value or degree of membership for each fuzzy set. The fuzzified values are processed by the inference engine, which consists of a rule base and various methods for inferring the rules. The rule base is simply a series of IF-THEN rules that relate the input fuzzy variables with the output fuzzy variables using linguistic variables, each of which is described by a fuzzy set, and fuzzy implication operators AND. OR etc. The part of a fuzzy rule before THEN is called predicate or antecedent, while the part following THEN is referred to as consequent. The combined truth of the predicate is determined by implication rules such as MIN-MAX (Zadeh) and bounded arithmetic sums. All the rules in the rule-base are processed in a parallel manner by the fuzzy inference engine. Any rule that fires contributes to the final fuzzy solution space. The inference rules govern the manner in which the consequent fuzzy sets are copied to the final fuzzy solution space.

The defuzzifier performs defuzzification on the fuzzy solution space. That is, it finds a single crisp output value from the solution fuzzy space. During defuzzification, the COG (Center of Gravity) is calculated and estimated over a sample of points on the aggregate output membership function, using the following formula:

$$COG = \left(\sum \mu(x) * x\right) \Big/ \sum \mu(x) \qquad (4)$$

Where $\mu(x)$ is the membership function in set A.

### *Expert Knowledge Representation*

Expert knowledge is represented based on the following three descriptors:

• Node Energy - energy level available in each node, designated by the fuzzy variable energy,

• Node Concentration - number of nodes present in the vicinity, designated by the fuzzy variable concentration,

• Node Centrality - a value which classifies the nodes based on how central the node is to the cluster, designated by the fuzzy variable centrality.

To find the node centrality, the base station selects each node and calculates the sum of the squared distances of other nodes from the selected node. Since transmission energy is proportional to $d^2$, in eqn. (2), the lower the value of the centrality, the lower the amount of energy required by the other nodes to transmit the data through that node as cluster-head.

The linguistic variables used to represent the node energy and node concentration, are divided into three levels: low, medium and high, respectively, and there are three levels to represent the node centrality: close, adequate and far, respectively. The outcome to represent the node cluster-head election chance was divided into seven levels: very small, small, rather small, medium, rather large, large, and very large. The fuzzy rule base currently includes rules like the following: if the energy is high and the concentration is high and the centrality is close then the node's cluster-head election chance is very large. Thus we used $3^3 = 27$ rules for the fuzzy rule base. We used triangle membership functions to represent the fuzzy sets medium and adequate and trapezoid membership functions to represent low, high, close and far fuzzy sets. The membership functions developed and their corresponding linguistic states are represented in Table 1 and Figures 3-6.

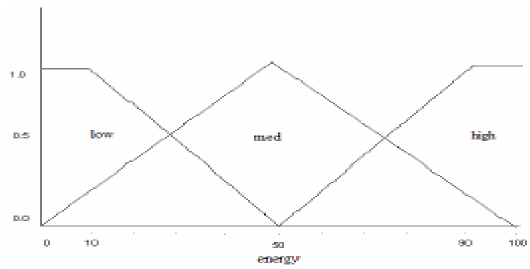


Figure 3. Fuzzy set for fuzzy variable Energy

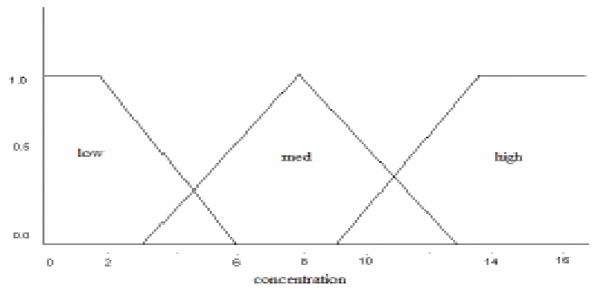


Figure4. Fuzzy set for fuzzy variable Concentration


Figure 5. Fuzzy set for fuzzy variable centrality

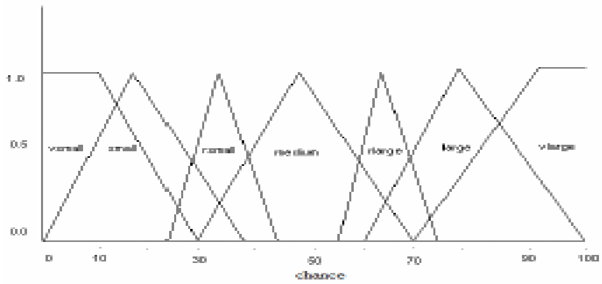


Figure 6.Fuzzy set for fuzzy variable chance


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Table 1. FUZZY RULE BASE

| | Energy | Concentt | Centrality | Chance |
|---|---|---|---|---|
| 1 | low | low | close | small |
| 2 | low | low | adeq | small |
| 3 | low | low | far | vsmall |
| 4 | low | med | close | small |
| 5 | low | med | adeq | small |
| 6 | low | med | Far | small |
| 7 | low | high | close | rsmall |
| 8 | low | high | adeq | small |
| 9 | low | high | Far | vsmall |
| 10 | med | low | Close | rlarge |
| 11 | med | low | Adeq | med |
| 12 | med | low | Far | small |
| 13 | med | med | Close | large |
| 14 | med | med | Adeq | med |
| 15 | med | med | Far | rsmall |
| 16 | med | high | Close | large |
| 17 | med | high | Adeq | rlarge |
| 18 | med | high | Far | rsmall |
| 19 | high | low | Close | rlarge |
| 20 | high | low | Adeq | med |
| 21 | high | low | Far | rsmall |
| 22 | high | med | Close | large |
| 23 | high | med | Adeq | rlarge |
| 24 | high | med | Far | med |
| 25 | high | high | Close | vlarge |
| 26 | high | high | Adeq | rlarge |
| 27 | high | high | Far | med |

Legend: adeq=adequate, med=medium, vsmall=very small, rsmall=rather small, vlarge=very large, rlarge=ratherlarge

## IV. RESULTS

To test and analyze the algorithm, experimental studies were performed. The simulator was programmed using Matlab. We modeled the energy consumption in WSN as given in equation (2-3). To define the lifetime of the sensor network we used the metric First Node Dies (FND) [10], meant to provide an estimate for the quality of the network.

### *A. Sample network 1*

The reference network consists of 150 nodes randomly distributed over an area of 100X100 meters. The base station is located at (200, 50). Each node has a random energy between 0 and 100. The base station computes the concentration for each node by calculating the number of other nodes within the area of 20X20 meters, with that node in the center. The best nodes in terms of fuzzy overall, centrality and energy are shown in Figures 7a and 7b.

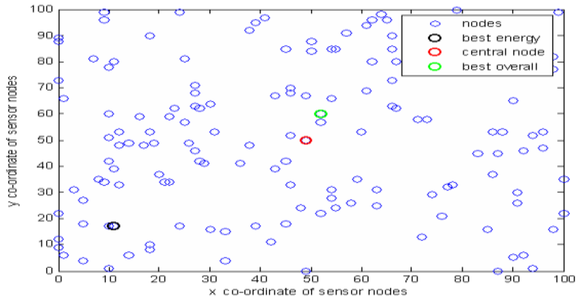


Figure 7a. Network cluster showing the best nodes

Round: 0
Best node Overall:
Node no: 29 Co-ordn no: 54 60 Chance: 77
Energy: 97 Conc: 7 Centrality: 15

Central node:
Node no: 31 Co-ordn no: 52 47 Chance: 65
Energy: 64 Conc: 3 Centrality: 4

Best Energy node:
Node no: 101 Co-ordn no: 11 20 Chance: 80
Energy: 100 Conc: 7 Centrality: 5

Figure 7b. Different node parameters

### ***B. Sample network 2***

At the beginning of the simulation, each node is supplied with an energy of 0.1J. Each node transmits a 200 bit message, per round, to the elected cluster-head. Cluster-head compresses the collected data to 5% of its original size. Figure 8a shows a simulation run for round number 48 with fuzzy elected cluster-head nodes. Figure 8b shows parameters for elected cluster-heads during two consecutive rounds 47 and 48. It takes about 2500 rounds for the FND in the network.

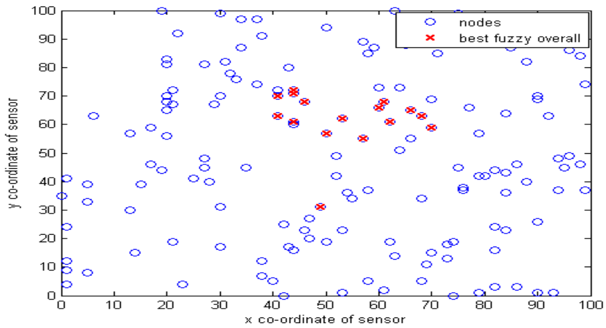


Figure 8a. Simulation in progress



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Round: 47
Fuzzy bestnode Overall:
Node no: 135 Co-ordn no: 02 71 Chance: 73
Energy: 0.0897 Conc: 8 Centrality: 23

Energy spent at the clusterhead: 0.0758
…………………………
Round: 48
Fuzzy bestnode Overall:
Node no: 44 Co-ordn no: 49 60 Chance: 73
Energy: 0.0864 Conc: 4 Centrality: 11

Energy spent at the clusterhead: 0.0718
…………………………

Figure 8b. Elected Cluster-heads for two consecutive rounds

### *C. Sample network 3*

To compare with LEACH, the cluster-head probability of 0.05, i.e. about 1 node per round becomes cluster-head.

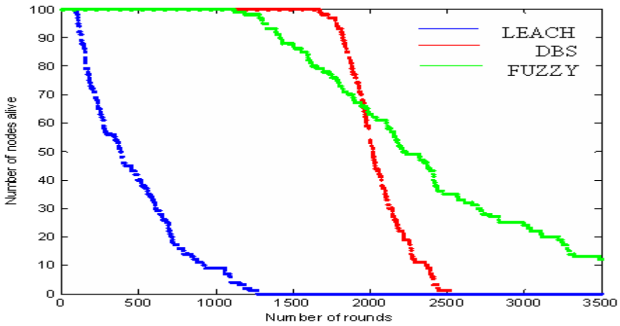


Figure 9. System Lifetime of LEACH, DBS and fuzzy based system.

Figure 9. shows the comparison of lifetime of the network b/w LEACH, DBS and Fuzzy based system when 100 nodes in the vicinity, initial energy is 0.1J given to each node, and keeping 3500 iterations.

Table 2 shows four simulation runs to calculate the number of rounds taken by LEACH, DBS and the fuzzy cluster-head election algorithm for FND, HND (Half node dies), LND (last node dies), at different initial energy levels.

Initially when 0.1J energy given to each node, fuzzy based system takes less rounds to first node dies, as compare to DBS, but finally overall response is much better than both LEACH, and DBS

**Table 2.**

| Initial Energy Eo (J/node) | Protocol | Round (FND) | Round (HND) | Round (LND) |
|---|---|---|---|---|
| 0.1 | LEACH | 277 | 1144 | 2573 |
| | DBS | 1437 | 1848 | 3016 |
| | Fuzzy Based | 1079 | 3185 | N.D (only 90) |
| 0.5 | LEACH | 1401 | 4096 | N.D (only 59) |
| | DBS | 2174 | 4993 | N.D (only 51) |
| | Fuzzy Based | 3395 | N.D (only 2) | N.D |
| 1.0 | LEACH | 2572 | N.D (only 31) | N.D |
| | DBS | 3887 | N.D (only 9) | N.D |
| | Fuzzy Based | N.D | N.D | N.D |

## V. CONCLUSION

A conclusion Cluster-heads were elected by the base station in each round by calculating the chance each node has to become the cluster-head using three fuzzy descriptors. Our approach is more suitable for electing cluster-heads for medium sized clusters. With this system model a substantial increase in the network lifetime is accomplished as compared to LEACH and DBS protocol. By modifying the shape of each fuzzy set accurately, a further improvement in the network lifetime and energy consumption can be achieved. Since centrality, calculated on the basis of the sum of the squared distances of other nodes from the given node, is one of the descriptors for electing suitable cluster-head, a network with biased distribution of nodes can be tested in the future with further experiments.

## VI. ACKNOWLEDGMENT

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