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# Performance Analysis of ERA Using Fuzzy Logic in Wireless Sensor Network

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***Abstract*—**In Wireless Sensor Network (WSN), the main limitation is generally inimitable energy consumption during processing of the sensor nodes. Cluster head (CH) election is one of the main issues that can reduce the energy consumption. Therefore, discovering energy saving routing protocol is the focused area for research. In this paper, fuzzy-based energy aware routing protocol is presented, which enhances the stability and network lifetime of the network. Fuzzy logic ensures the well-organized selection of CH by taking four linguistic variables that are concentration, energy, centrality, and distance to base station (BS). The results show that the proposed protocol shows better results in requisites of stability and throughput of the network.

***Keywords*—**ERA, fuzzy logic, network model, WSN.

## I. Introduction

WSN becomes a progressing technology that is capable of rebuilding the process of gathering, aggregating, and distributing data [1]. Due to same sizes of nodes, limited resources like battery potential and external memory can reduce the network performance. The WSN has the capability to expand the huge number of sensors in areas without any groundwork for auditing target tracking, sound, pressure, temperature, etc. [7]. Various applications of WSN are used in hospital monitoring, industries, military defense, and aircrafts. Sensor nodes utilize power for performing different actions in the network. Battery recharging is infeasible for a long duration of the network [7]. For this reason, all sensor nodes must be designed for balancing energy efficiently. The entire network can be divided into the number of clusters with one node as the CH. CH is the coordinator of data collecting and data aggregation within a cluster. Then, CHs send the compressed data to the BS. Energy efficiency and clustering are the key factors while designing WSN so that network can achieve more scalability and lifetime of the network [8]. Clustering provides the surety of performance improvement and scalability with the nodes in the sensor network. ERA is a clustering routing protocol which can efficiently utilize energy for working in sensor nodes.

ERA helps in saving energy in the network [12]. But, this protocol can deplete their energy at some expand, which enhances the performance of ERA with fuzzy logic technique.

This paper presents a protocol ERA-FL which gave better network lifespan and cluster configuration. CH election uses four linguistic variables that are concentration, energy, centrality and distance which can use fuzzy rules for output evaluation. Simulation and evaluation show that ERA-FL provides better results in terms of stability and throughput of the network. Various clustering routing protocols are considered enhancing the network performance. Taheri et al. [2] worked on the protocol named as Hybrid Energy Efficient Distributed Clustering approach using Non-Probabilistic Fuzzy logic (HEED-NPF). HEED-NPF uses fuzzy logic as well as the non-probabilistic approach for electing CH. Two types of fuzzy variables are used, node degree (number of nodes in the network) and node centrality (how central the node within the cluster) as control variables. Mostafa et al. [3] proposed the protocol called Stable Election Protocol using Fuzzy Logic (SEP-FL). It improves the stability period by applying fuzzy logic on SEP protocol. SEP-FL is more energy efficient in prolonging the network lifetime. This protocol uses two parameters that are distance to BS and energy level to evaluate the chance of sensors to become CH. Nehra et al. [4] proposed a protocol Power-Efficient Gathering in Sensor Information System using Fuzzy Logic (PEGASIS-FL). It uses two parameters for CH election as extra energy and distance from the BS. Gajjar et al. [5] worked on CH selection protocol using Fuzzy Logic (CHUFL) by using three parameters for CH selection that are: quality of the link, distance from BS, extra energy. It can give 20% more efficient results as compared to other protocols. Amgoth et al. [6] proposed an energy aware routing algorithm which is based on clustering. The algorithm is based on two linguistic variables that are the energy of the node and distance for cluster arrangement. The algorithm has two phases, i.e. clustering and routing phase. Nayak et al. [9] proposed Low Energy Adaptive Clustering Hierarchy using Fuzzy Logic (LEACH-FL). This protocol works on three descriptors for the election of CH that are: the power of the battery, the centrality of the node and mobility. Simulation results show that LEACH-FL protocol is a more efficient protocol as compared to the results of LEACH protocol. Priya et al. [10] purposed the algorithm that analyzes the performance of compression based ERA for the sensor network. Compression based ERA uses compression techniques which are used to the efficiency of ERA. As the compression ratio is increased, throughput and remaining energy are increased, and we choose optimal compression ratio. All these protocols can enhance the network performance using the fuzzy logic technique as an advance model for improvement.

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Open Science Index, Electronics and Communication Engineering Vol:11, No:7, 2017 publications.waset.org/10007582/pdf

## II. Network Model

Network model contains sensor nodes, BS and CH. The node which has maximum energy is considered as CH that sends data to the BS. Sensor network consists of two types of nodes as homogenous nodes (all the nodes have same energy) and heterogeneous nodes (all the nodes have different amount of energy). The proposed protocol considers homogenous set of nodes for the network lifespan. The following properties of the sensor network are:

1. The entire cluster member is connected to one CH within the cluster.
2. All the nodes are mobile within the network.
3. Energy constraint nodes
4. Radio energy model is used for measure BS
5. Each node has GPS system to find the destination.

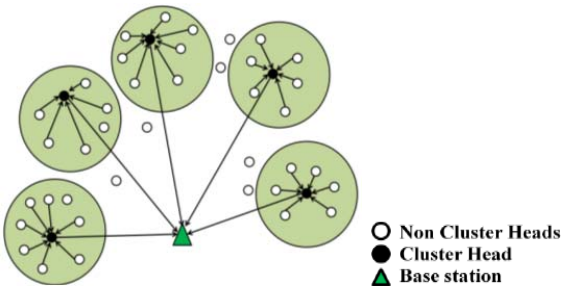



Fig. 1 WSN architecture [9]

## III. Energy Aware Routing Protocol

Energy Aware Routing is a routing protocol for improving the lifetime of a WSN. The protocol is based on brilliant approach for the selection of CH, extra energy of CH, and the intra cluster for the cluster formation. For data routing, essential backbone of CHs is formulated that is from the sink. ERA uses various paths from source nodes to the information sink with an assertive probability, so the span of entire work is increased. The algorithm includes two phases that are [6]:

### *A. Clustering*

The process of clustering consists of nodes that are standardized into specific groups called clusters, and each specific group has its coordinator associated which is known as CH, and the remaining nodes in a cluster take action as Cluster members (CM). Each sensor node should be connected to one cluster in the network. Each sensor node sets its own timer independently. Let *t(i)* sensor node timer which is equated from (1) [6]:

$$t(i) = \frac{E_m(i) - E_r(i)}{E_m(i)} \times T_{CH} \quad (1)$$

Here, TCH is the maximum given time for selection of CH, Em(i) is the initial maximum energy, and Er(i) is the sensor node's residual energy. From (1), nodes which have more residual energy are considered as CH. After the expiration of timer, node i elects itself as CH and forwards CH reporting information in the communication range. When node j receives information, it loses the hope of becoming CH, thus it leaves its candidature with cancelling its timer and acts as the non-CH node for the upcoming communication round. After that, node j keeps on tracking of sensor nodes by receiving CH reporting information by considering a neighbor CH set denoted by NCH(i). For the formation of the cluster network, each candidate CH node sets its cluster membership by setting node j which needs the connection with CHs that belong to the set NCH(j). After that, node j figures out the CH's average residual energy which is denoted by μ(j) that is calculated as follows [6]:

$$\mu(J) = \frac{\sum_{i=1}^{m} Er(vi)}{m} \quad (2)$$

Node $j$ connects to the closest CH which has residual energy which is equal to μ.

### *B. Routing*

Energy efficient routing also plays important role in the WSN [13]. For providing the message to the BS, a Directed Virtual Backbone (DVB) rooted at the BS is constructed. First of all, the BS generates a route request message in the communication range. The reporting information has its ID, rank (L) and destination data. The rank of the BS is set as zero. When a CH gets the reporting information, then the node increments its level to the one higher than the sink and sets the sink as its parent node. Before it sends the data packets, node u calculates the average residual energy that is referred from (3) [6]:.

$$\eta(u) = \frac{\sum_{i-1}^{p} E_r(vi)}{p} \quad (3)$$

If the residual energy is higher or equal to η(u), then node u gives all arriving data packets and sends these data packets to the equivalent CH.

## IV. Proposed Approach

This section describes the new method that presents to improve the network lifetime and energy efficiency of the previous protocol by using fuzzy logic in it. Firstly, fuzzy logic is an expansion of crisp logic which contains transitional values between extremely true and extremely false. Fuzzy logic is based on analytical control system for solving the suspicions that provide easy accurate solution. Fuzzy Inference System is used to map input variables to output variables. The lifetime of network is based on the efficient selection of CH. The purposed protocol uses fuzzy logic for the efficient selection of CH. In this proposed protocol, four linguistic variables are taken, i.e. energy, distance, centrality and concentration. This proposed schema enhanced the lifetime of the network by improving ERA CH selection using Fuzzy Logic.

### *A. Fuzzy Inference System(FIS)*

FIS performs mapping of given inputs to outputs by using the fuzzy logic technique. Fuzzy logic has four modules: a fuzzifier, Fuzzy inference engine, Fuzzy rules, and a De-

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fuzzifier [11]. The utmost used fuzzy method is Mamdani method which is the default. The FIS model for the presented ERA-FL protocol is shown in Fig. 2. The main four steps are needed to complete the process. Four steps of the FIS are as follows [11]:

1. Fuzzification: In fuzzifier, inputs that have crisp values are given and changed into a fuzzy set.
2. Rule Evaluation: It contains If-Else rules. Results are based on these rules. The rule evaluator is the second step in fuzzy logic. The output is based on the input variables.
3. Fuzzy Inference Engine: FIS work is based on the input variables and IF-THEN rules to imitate the analysis to produce a fuzzy inference.
4. De-fuzzification: De-fuzzifier converts the fuzzy sets into the crisp value. It uses a technique named as centroid to find the maximum value among the input values.

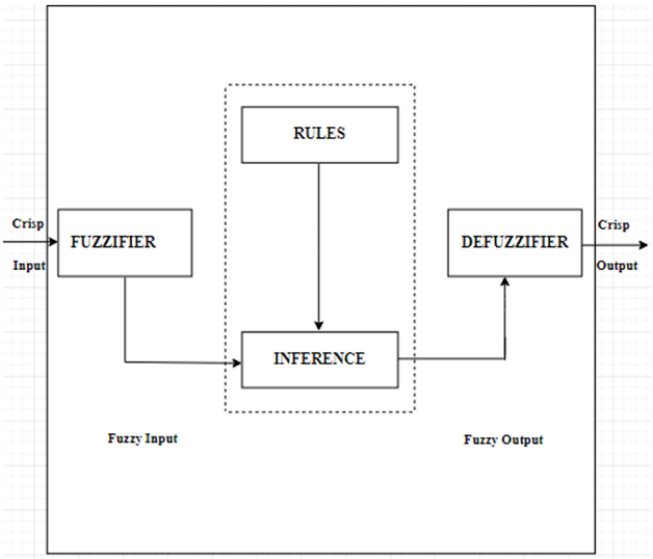



Fig. 2 ERA-FL Fuzzy Inference System [11]

*B. Linguistic Variables*

In this paper, four linguistic variables are used that are combined to give resultant as chance value [14]. Each linguistic variable is evaluated by using fuzzy engine with IF ELSE rules. In this paper, according to fuzzy variable, 82 possible rules are produced with the help of average formula by using four linguistic variables that are:

1. Concentration: Number of nodes connected to the CH.
2. Energy: Energy of the node is the remaining energy of the node in proportion to total network energy.
3. Centrality: This variable shows how close a node is from the cluster.
4. Distance: Distance of the node from the BS.

All the input variables have different membership function depending upon the value of chance. Concentration is split into the low (L), medium (M) and high (H)values. Energy variable is split into the low (L), medium (M) and high (H) values. Centrality is spitted into the close (C), adequate (A) and far (F) values. Distance is split into the near (N), medium (M) and far (F) values. The output variable is the chance to become CH. Trapezoidal and Triangle membership functions are used for convenient value.

## V. Simulation and Results

Results are simulated after creating a 100*100 m region of 100 sensor nodes spread randomly. The total number of sensor nodes is n=100. The sink is in the center, and so, the maximum distance of any node from the sink is approximately 70 m. The initial energy of node is set to Eo=0.5 J. The sink or BS is located at the centre point (50*50). The size of the packet that nodes can send to the CH or vice versa is set to 1500 bits.

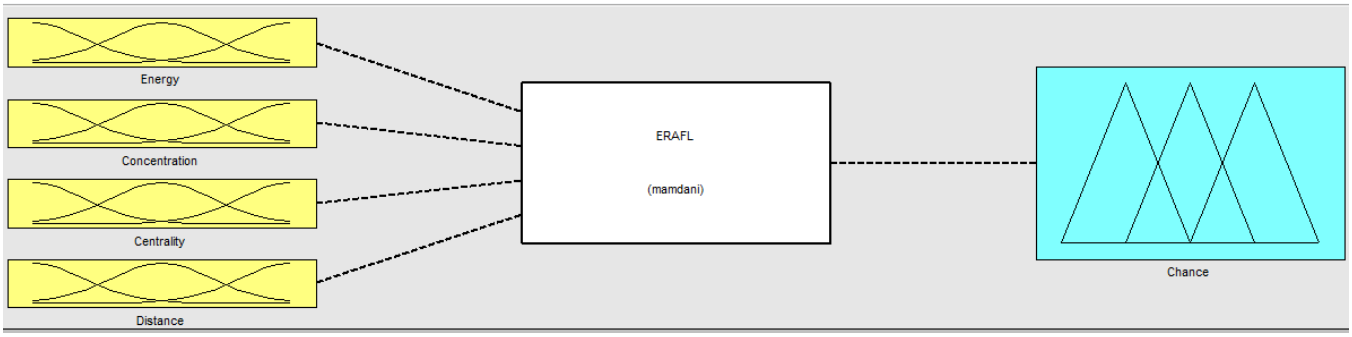



Fig. 3 ERA-FL: four inputs, one output, 82 rules

Performance metrics used in simulations are:

*A. Stability Period*

Stability period is the period from the start of the network operation until the first dead node. Fig. 4 illustrates lifespan of the network for Eo =0.3 over 1500 rounds where all the sensor nodes expire near around 916 rounds. In Fig. 5 where Eo =0.5, over 1500, all the nodes expire near around 1451. Stability period always shows the dead node in the network. From Figs. 4 and 5, it is clear that for Eo=0.3, the first node is dead at round 550 and for Eo=0.5, the first node is dead at 953. So, network is alive for about maximum 4th half at the fixed number of rounds.

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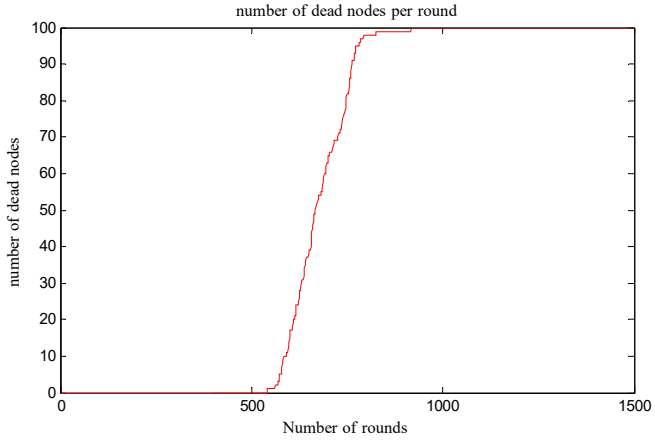



Fig. 4 Number of dead node for Eo = 0.3

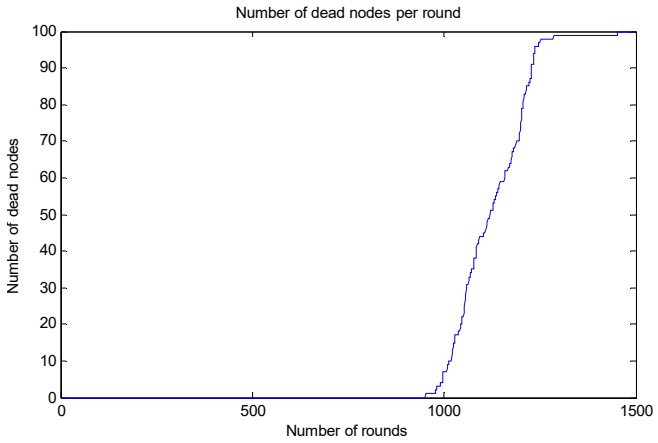



Fig. 5 Number of dead node for Eo = 0.5

### *B. Throughput of the Network*

Figs. 5 and 6 illustrate that proposed protocol has different throughput depending upon different initial energy (Eo). For Eo=0.3, throughput of the network is up to 824 rounds whereas for Eo=0.5, throughput of the network is up to 1288 rounds.

TABLE I
SIMULATION RESULTS

| Metrics | Eo=0.3 | Eo=0.5 |
|---|---|---|
| Stability | 916 | 1451 |
| Throughput | 824 | 1288 |

## VI. CONCLUSION

Enhancement in the energy consumption of the WSN can be achieved by using the fuzzy logic. The purposed protocol uses fuzzy logic for the efficient selection of CH. To enhance lifetime of network and to reduce the energy consumption, the fuzzy logic is used with energy aware routing. The simulation results of proposed protocol show that ERA-FL increases the network performance and efficiently selects CH using fuzzy logic. The proposed protocol provides service to select the best CH on the basis of predetermined criterion. It also discovers proficient path from CM to BS via CH.

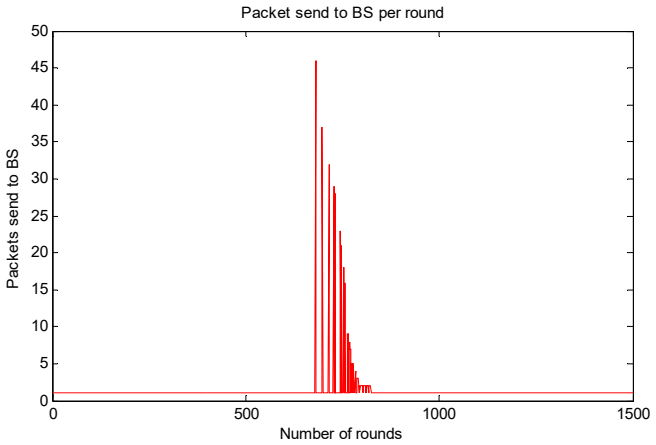



Fig. 6 Throughput of the network for Eo = 0.3

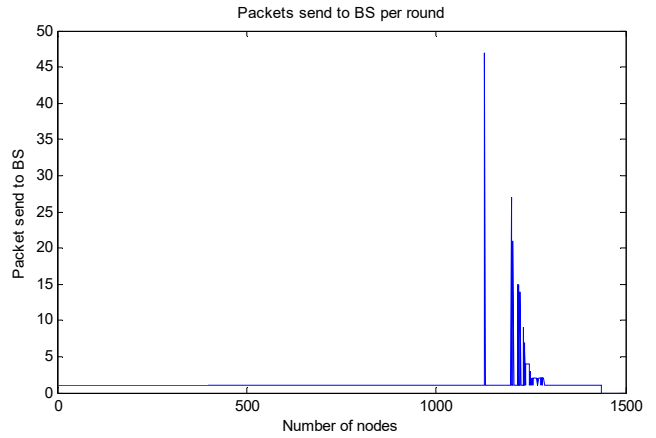



Fig. 7 Throughput of the network for Eo = 0.5

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