Fuzzy Based Routing Mechanism For Lifetime Boosting In Wireless Sensor Networks

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Abstract- *Energy is an extremely critical resource for battery-powered Wireless Sensor Networks (WSNs), thus making energy-efficient protocol design - a key challenging problem. Most of the existing routing protocols always forward packets along the minimum energy requirement paths to merely minimize energy consumption, which causes an Uneven Energy Consumption (UEC) problem and eventually results in a significant reduction of network lifetime thereby causing network partitioning. The distributed and dynamic nature of WSNs, demand for special requirements in routing protocols in order to minimize the energy consumption and enhance the network lifetime. Therefore, this paper proposes an energy-efficient routing scheme which is capable of finding the optimal routing path form the source to the destination by favoring some of the routing criteria and balancing among them to prolong the network lifetime. The paper brings out a new routing method for WSNs to extend network lifetime using a fuzzy approach.*

Keywords- Fuzzy logic, network lifetime, routing, wireless sensor networks (WSNs).

I. INTRODUCTION

Wireless communication technologies are undergoing rapid advancements. The last few years have experienced a steep growth in research in the area of wireless sensor networks (WSNs). WSNs typically consist of large number of cheap and tiny sensors with limited resources, where the sensors possess sensing, computing and communicating capabilities [1]. The WSNs are used for gathering information in the situations where terrain, climate and other environmental constraints may deteriorate in the deployment of conventional networks.

- In WSNs, communication takes place with the help of spatially distributed autonomous sensor nodes equipped to sense specific information. WSNs, especially the ones that have gained much popularity in the recent years, find a variety of applications in both the military and the civilian population worldwide such as in cases of enemy intrusion in the battlefield, object tracking, habitat monitoring, patient monitoring, fire detection, and so on. In such applications, primarily these sensor nodes are used for data acquisition and are required to transmit the acquired parameters to special nodes called sinks or base-stations over the wireless link as shown in Fig. 1. The base-station or sink collects data from all the nodes, and then communicate with the task manager node
- via internet or satellite. Sinks or base- stations being powerful data processors can act as gateways to other existing

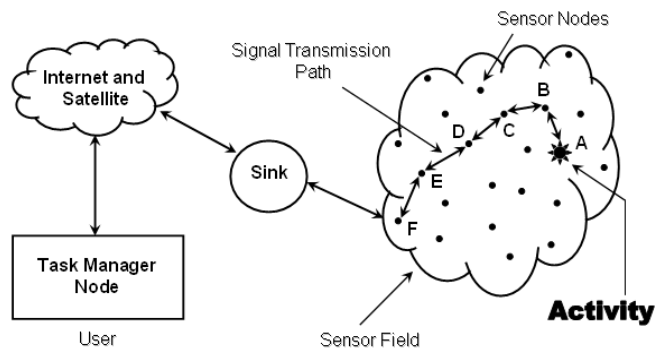

Fig.1. Sensor Nodes scattered in a Sensor Field.

- communications infrastructure or to the Internet where a user can have access to the reported data. Sensor nodes in the large-scale data-gathering networks are generally powered by small and inexpensive batteries in expectation of longevity of survival.
- Such sensor nodes are mainly made up of four basic components as shown in Fig. 2; a sensing unit, a processing unit, a transceiver unit, and a power unit. They may also have additional dependent components such as the location finding system, power generator, and mobilizer.

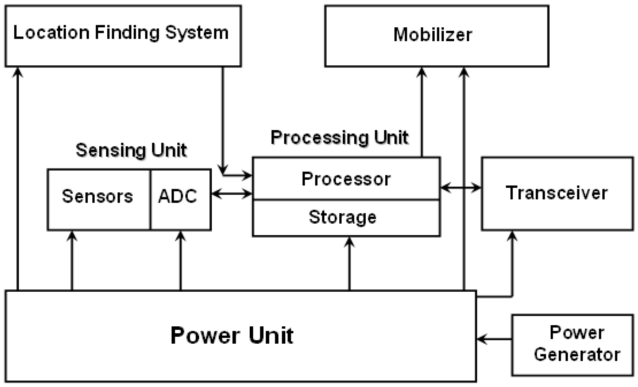

Fig.2. Components of an Ideal Sensor Node.

Sensing units are usually composed of sensors and ADCs. The processing unit, which is generally associated with a small storage unit, manages the procedures that make the sensor node collaborate with the other nodes to carry out the assigned sensing task . A transceiver unit connects the sensor node to the overall network. Power unit which is one of the most important components of a sensor node may be supported by power scavenging units such as solar cells. Most of the sensor network routing techniques and sensing tasks require precise knowledge of its own location. Thus, it is common that sensor nodes should have a location finding system within it. A mobilizer may sometimes be needed to move the sensor node when it is required to carry out the assigned tasks. All of these subunits may need to fit into a module of size smaller than even a square centimeter or less. This has to be light enough to remain suspended in the air or water. Apart from size, there are some other stringent constraints for sensor nodes. These nodes must consume extremely less power, operate in high volumetric densities, and have low production cost, be dispensable and autonomous, operate unattended, and be adaptive to the environment.

In most of the scenarios of WSNs, sensor nodes are densely deployed in large areas. Once deployed, nodes can never be recharged or replaced. After depleting their energy, nodes lead to death and stop working. Since, Sensor nodes used in sensor networks are very special in nature, so networks cannot perform assigned tasks after nodes die out. The lifetime of WSNs is a crucial parameter when evaluating performance of routing protocols. Fig. 3 shows the network partitioning (one part of the network may become disconnected from the destination) due to the death of some sensor nodes.

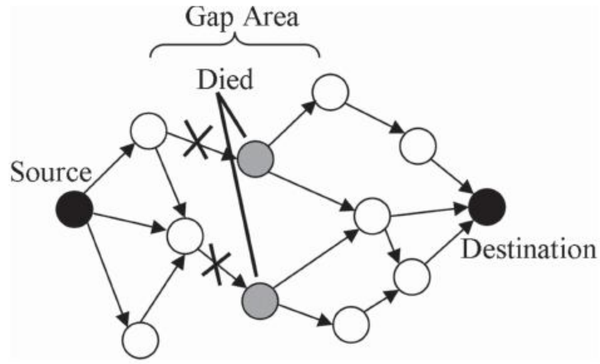

Fig.3. Network partition due to the death of certain nodes.

In many cases, the lifetime of a sensor network is over as soon as the battery power in critical nodes is depleted. The problem then consists of determining the set of routes to be used by each node and the associated some of routing parameters (i.e., the routing configuration) that maximize the network lifetime. So, the maximization of lifetime can be formulated as an optimization problem with variables of this optimization problem as routing parameters at nodes [1].

From the literatures of WSNs, we note that a variety of criteria have been used to prolong the lifetime of the sensor networks. Some of these metrics are as follows:

1. ***Remaining Energy (RE):*** The most crucial aspect of routing in WSNs is the energy efficiency. Under this criterion, the focus is on the energy capacity (i.e. the current battery charge level) of the nodes. A routing protocol that uses this metric would then favor routes that have the largest total energy capacity from source to destination. In other words, nodes having greater remaining energy participate more than the nodes with limited power. Fig.4 shows an example of a small sensor network, where a source node wishes to transmit a packet to a destination node. The numbers inside the nodes indicate the remaining energy capacity of corresponding nodes.

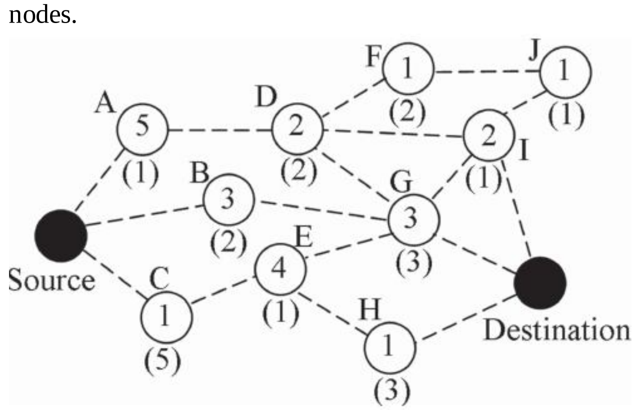

Fig.4 Routing options in a small WSN using different metrics.

In this example, a routing protocol could select path A–D–G since it has the largest total capacity (i.e. 10).

2. ***Minimum Hop (MH):*** The basic idea behind this metric is that using the shortest path will result in low end-to-end delays and low resource consumptions, since the smallest number of forwarding nodes will be involved. Under this criterion, a routing protocol could select the path B-G which has the minimum hop (i.e. 3) in Fig. 4.

3. ***Traffic Load (TL):*** The high traffic load causes a data queue overflow in the sensor nodes, resulting in loss of important information. In addition, since the battery energy of the sensor nodes is quickly exhausted, the entire lifetime of wireless sensor networks would be shortened. Therefore, the traffic load in the nodes will affect the lifetime of the networks. In Fig. 4, the numbers in parentheses below the nodes indicate the traffic load of the corresponding nodes. A routing protocol under this criterion could select the path A-D-I which has the lowest total traffic load (i.e. 4).

II. RELATED WORK

In traditional optimal path routing schemes over WSNs, each node selects specific nodes to relay data according to some criteria in order to maximize network lifetime. Therefore, a good routing method in WSNs involves finding the optimal transmission path form the sender through relay nodes to the destination in order to prolong the network lifetime. Due to this conception, the lifetime problem in WSNs has received significant attention in the recent past.

Following are the salient features of the routing algorithms proposed in the past:

Energy-Efficient Multi-path Routing Protocol (EEMRP): This protocol has a capability of searching multiple node-disjoint paths and utilizes a load balancing method to assign the traffic over each selected path. In this both the residual energy level of nodes and the number of hops are considered to be incorporated into the link cost function. They use a fairness index to evaluate the level of load balancing over different multi-paths. Furthermore, since EEMRP only takes care of data transfer delay, the reliability of successful paths sometimes is limited.

Optimal Forwarding by Fuzzy Inference Systems (OFFIS): The OFFIS protocol selected the best node from candidate nodes in the forwarding paths by favoring the minimum number of hops, shortest path and maximum remaining battery power, etc.

A-Star algorithm based Energy Efficient Routing (ASEER): This approach is mainly used to extend lifetime of Wireless Sensor Network. In ASEER, using A-Star algorithm the relay schedule is computed by some centralized entity, with an assumption that the average amount of data generated by each cluster is known. Once schedule is computed, it is broadcasted by the base station. All relay nodes follows this schedule for the current round. After every round, residual energy information of each relay node is updated and current energy level is considered to decide next route for the next round.

Fuzzy Logic Systems (FLS): This present a novel algorithm for routing analysis in WSNs utilizing a fuzzy logic at each node to determine its capability to transfer data based on its relative energy levels, distance and traffic load to maximize the lifetime of the sensor networks.

To avoid network partitioning and to extend the network lifetime, this paper proposes a new routing method using a combination of Fuzzy approach and A-star algorithm. The proposed routing method is used to select the optimal routing path from source to destination by considering the above criteria (Remaining Energy, Minimum Hop, and Traffic Load) and balancing between them to lengthen the lifetime of the sensor network as much as possible.

III. FUZZY LOGIC AND A-STAR ALGORITHM

A. Fuzzy Approach

Fuzzy logic was first introduced in the mid-1960s by Lotfi-Zadeh in [5]. This soft computing paradigm is a flexible mathematical and computational model that deals with fuzziness and uncertainty of data. As WSN is an uncertain environment with some insufficient data, it needs special decision making through some flexible and tunable procedures that deploy routing and enhance the overall network lifetime. Fuzzy based approach has the advantages of easy implementation, robustness, and ability to approximate to any nonlinear mapping [1]. Fuzzy logic analyzes information using fuzzy sets, each of which is represented by a linguistic term such as “small,” “medium,” or “large.” Fuzzy sets allow an object to be a partial member of a set. Unlike classical reasoning in which, a proposition is either true or false, fuzzy logic establishes approximate truth value of a proposition based on linguistic variables and inference rules. A linguistic variable is a variable whose values are words or sentences in natural or artificial language. By using connectors like “AND”, “OR”, “NOT” with linguistic variables, an expert can form rules, which will govern the approximate reasoning. In the context of crisp sets, a certain element is either a member or a nonmember of a set (in other words, membership is either 1 or 0), whereas in fuzzy logic, a certain element may have partial membership in a set (membership is in the range [0-1]).

Fuzzy inference is a process of formulating the mapping from a given input to an output using Fuzzy Logic mapping process. In other words, the decision is made based on the process. Fuzzy inference process involves with a few important fuzzy concepts including concepts of fuzzy sets, fuzzy operations, and fuzzy rules. Generally, fuzzy inference steps are invoked for each of the relevant rules to provide an output result. The result depends on the degree of input membership functions. Fuzzy inference can be applied via two techniques, Mamdani Fuzzy Inference and Sugeno Fuzzy Inference. In this paper, Mamdani Fuzzy Inference is used to model the energy-efficient routing strategy, as shown in Fig.7. Basically, fuzzy inference involves five important steps that need to be applied. The steps are fuzzification of input variables, application of fuzzy operator, application of implication method (IF antecedent(s) THEN consequent(s)), aggregation of output and defuzzification.

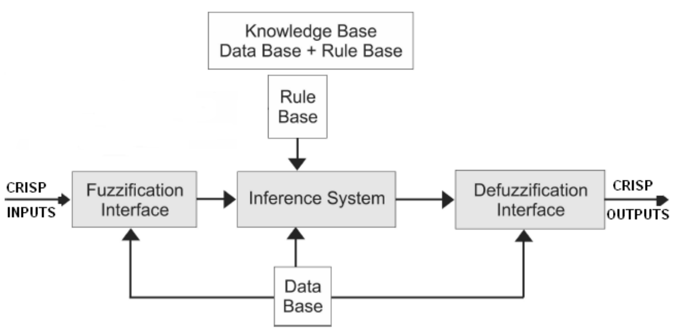

Fig.5. Fuzzy Inference System.

Fig. 5 shows the typical structure of a fuzzy inference system. The processes of making crisp inputs are mapped to their fuzzy representation in the process called fuzzification. This involves application of membership functions such as triangular, trapezoidal, Gaussian etc. The inference engine maps fuzzified inputs to the rule base to produce a fuzzy output. A consequent of the rule and its membership to the output sets are determined here. The defuzzification process converts the output of a fuzzy rule into crisp outputs by one of defuzzification strategies.

B. A-Star Algorithm

A-star search algorithm is a very popular searching algorithm. It is also a highly efficient heuristic algorithm used in finding a variable or low cost path. It is considered as one of the best intelligent search algorithms that combines the merits of both depth-first search algorithm and breadth-first algorithm.

A-star path searching algorithm uses the evaluation function (usually denoted *f (n))* to guide and determine the order in which the search visits nodes in the tree. The evaluation function is given as:

$$f(n) = g(n) + h(n)$$

where, g(n) is the actual cost from the initial node (start node) to node n (i.e. the cost finding of optimal path), h(n) is the estimated cost of the optimal path from node n to the target node (destination node), which depends on the heuristic information of the problem area [1].

Generally, A-star algorithm maintains two lists, an OPEN list and a CLOSE list. The OPEN list is a priority queue and keeps track of the nodes in it to find out the next node with least evaluation function to pick. The CLOSE list keeps track of nodes that have already been examined.

Pseudo-code: Standard A-Star Algorithm

Input: Source and Destination node

Output: Route from Source to Destination node

1. BEGIN
2. Initialize OPEN list
3. Initialize CLOSED list; initially empty
4. Create start node; call it start
5. Add start node to the OPEN list
6. WHILE the OPEN list is not empty
7. BEGIN
8. Get node n from the OPEN list with the lowest f (n)
9. Add n to the CLOSED list
10. IF n is the same as goal node we have found the solution;
11. Return Solution (n)
12. ELSE
13. Move the current node n to the closed list and consider all
    of its neighbors
14. FOR each neighbor node n' of n
15. Set the parent of n' to n
16. h (n') = heuristically estimate distance to goal node
17. g (n') = g(n) + the cost to get to n' from n
18. f (n') = g(n') + h(n')
19. Insert n' to the OPEN queue
20. END FOR
21. END WHILE

22. END

IV. IMPLEMENTATION OF FUZZY APPROACH

The Fuzzy Inference System has two inputs - remaining energy *RE(n)* and the traffic load *TL(n)* of node n, and produces one output - the optimal value of the node cost *NC(n)* of node n, as shown in Fig.6. Figure 7 to Figure 13 illustrate the implementation of complete Fuzzy Inference process. Fig. 10 shows the output membership functions of the fuzzy inference system. The optimal route to the destination is determined in terms of energy-optimized lifetime prolonging metrics for WSNs. and output) and fuzzy rules. MATLAB is used to identify the system membership functions (input and output) and fuzzy rules.

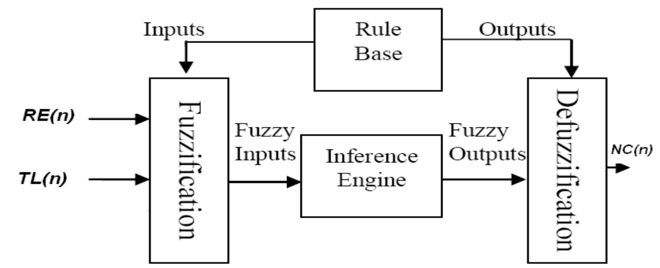

Fig.6. Fuzzy structure with two inputs (remaining energy and traffic load) and one output (node cost).

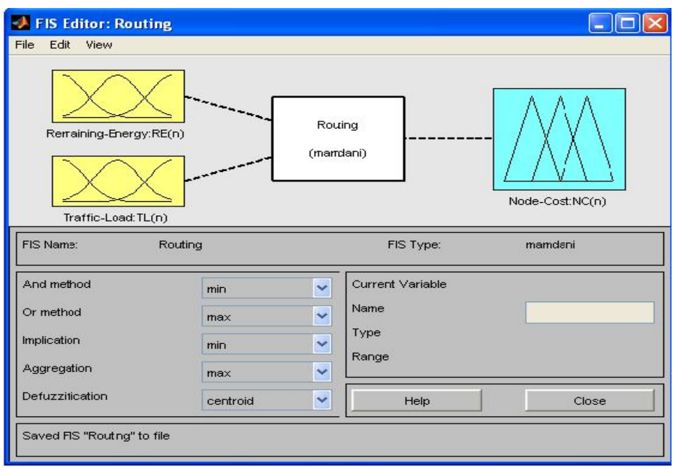

Fig.7. Fuzzy Inference System in MATLAB

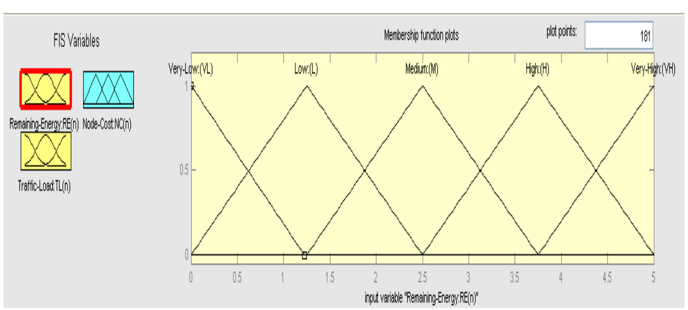

Fig.8. Remaining Energy as membership function in MATLAB

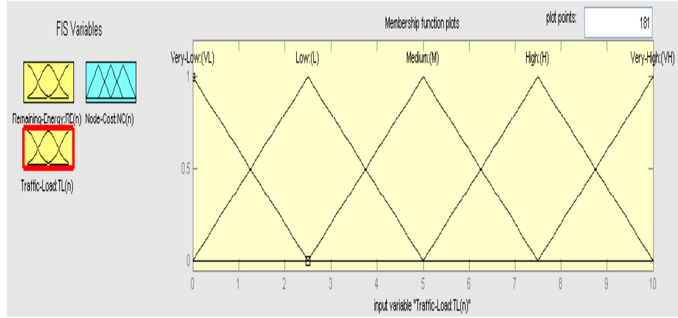

Fig.9. Traffic Load as membership function in MATLAB

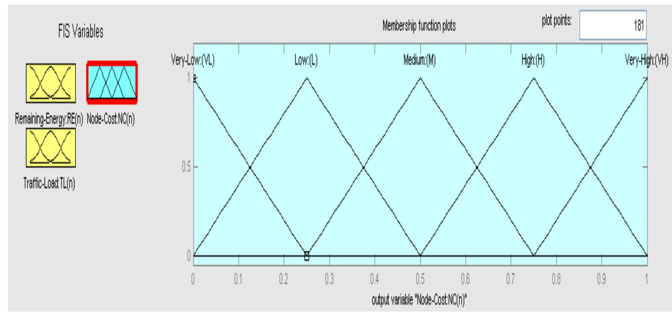

Fig.10. Node Cost as membership function in MATLAB

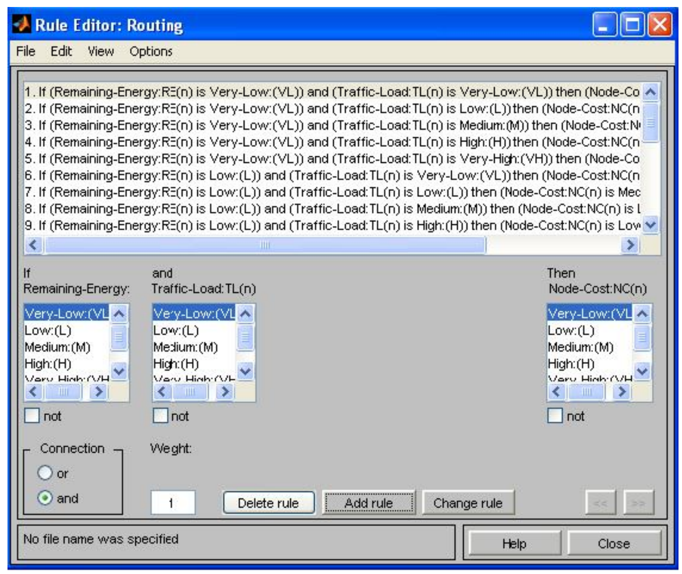

Fig.11. Rule editor (Fuzzy Rules)

Fig.11 shows the system rule editor. This rule base is a set of implication statements that relate the input fuzzy variables and the output variable using linguistic terms and the connective AND. These rules are built based on expert knowledge and experimentation. The implication statement is used to capture the human knowledge by evaluating the rule antecedent (input) using IF statement and applying the result (output) by THEN statement.

Fig. 12 shows the system rule viewer with 25 plots nested in single figure. The rule viewer illustrates the rules that are fired for specific input combinations. The implication results (output) of each rule are combined into a single fuzzy set. The last plot in the third column of plots represents the aggregate weighted decision for the given inference system. This decision will depend on the input values for the system. The defuzzified output (Node Cost) is displayed as a bold vertical line on this plot. Fig. 13 shows a surface viewer where we can see a three-dimensional curve that represents the mapping from Remaining Energy *RE(n)* and Traffic Load *TN(n)* to Node Cost *NC(n).*

V. IMPLEMENTATION OF A STAR ALGORITHM

In this, the sink prepares the routing schedule and broadcast it to each node. A-star algorithm which is used to find the optimal route from the node to the sink is applied to each node.

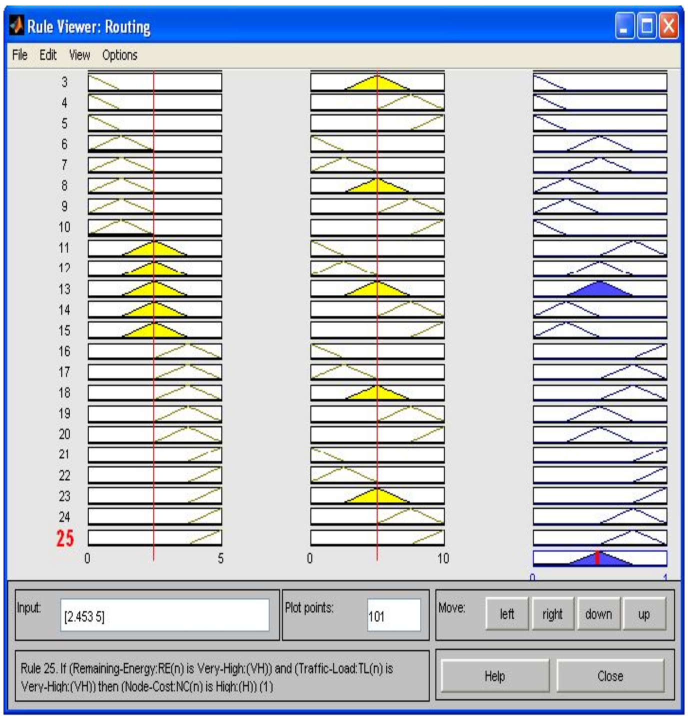

Fig.12. Rule Viewer

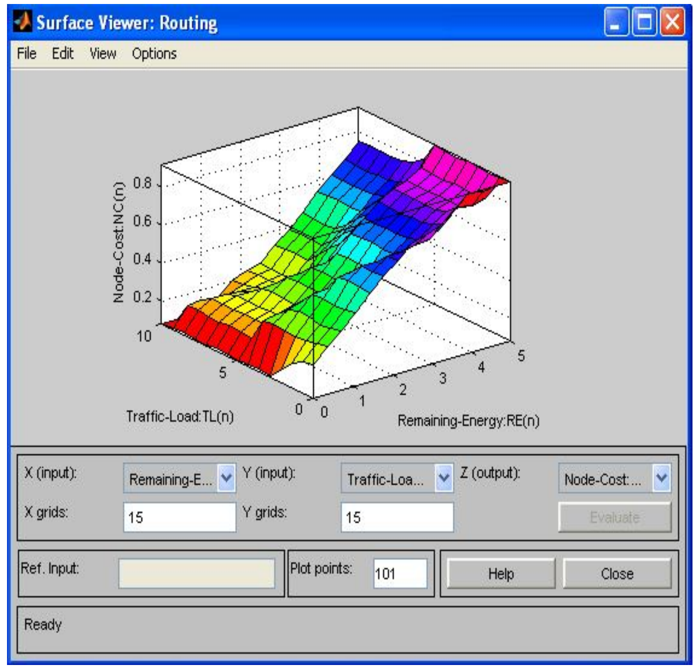

Fig.13. Surface Viewer

A-star algorithm creates a tree structure in order to search optimal routing path from a given node to the base station. The tree node is explored based on its *evaluation function f(n)* given as:

$$f(n) = g(n)+h(n)$$

For every intermediate node n, ($1 \le n \le N$, where N is total number of relay nodes in WSN), g(n) will be actual cost to reach to node n from source node S and h(n) will be estimated heuristic cost from the current node n to the destination node. The sink prepares routing schedule and will be broadcasted to each relay node. A-Star algorithm, to find optimal route from relay node to the base station will be applied for each relay node. The relay node where this algorithm is applied will be the source node and the sink will be destination node. Such N different routes will be created and this all information is consolidated. Array has N number of indices. Value at i^{th} index will represent node number as to where node i will be sending data, which in turn, goes to the base station in a same way. After current routing schedule is broadcasted, all relay nodes will follow it and will send data accordingly. At the end of the current round, the sink calculates and updates energy level information for each relay node. Then sink will again search for a new routing schedule which will consider current energy levels. This will be another round. This process will continue until any of the relay nodes is failed due to depletion of energy. Total number of rounds is calculated and is used as a parameter to count network life time.

Generally energy efficient decision for choosing best route is the path which consumes less energy. Only considering total amount of energy consumed, will not be efficient because it will drain some of the nodes which are on the efficient path. Those nodes will participate in more number of schedules and will get drained earlier. This may result in network partition. This scenario is avoided by introducing different levels of energy of node. While making decision for routing, in a route if a node is below a threshold level of residual energy, then alternate route is selected with node having more energy than threshold level. This alternate route will give life extension to those nodes which were selected in the first attempt, thus the network life too, gets prolonged. Out of many possible solutions, those will be strong candidate to win who have more number of nodes having energy greater than Level1. Thus, healthy nodes will participate in routing and weak nodes will get rest, thus overall network lifetime can be extended.

Pseudo Code for ASEER Algorithm:
Input : Sensor Network
Output : Life of Sensor Network in terms of rounds

1. BEGIN
2. Initialize network in terms of node id, node energy, node
   neighbors, etc.
3. Estimate distance from each node to sink
4. WHILE residual energy of any node≠ 0
5. Initialize solution array for storage of routing schedule
6. FOR each node i in the network DO
7. Create Tree(i) using A-Star algorithm
8. Prepare solution array
9. END FOR
10. Broadcast solution so that each node will obtain next node
    as to where to transmit data, from this routing schedule
11. Update residual energy level of each node as per the
    routing schedule, stored in the solution array
12. COUNT_ROUND = COUNT_ROUND + 1
13. END WHILE
14. PRINT COUNT_ROUND
15. END

VI. CONCLUSION

Resource scarcity has to be taken into account when designing a WSN infrastructure. Energy is one of the most critical resources for WSNs. Most of works in the literatures about WSN routing have emphasized energy savings as a major optimization goal. However, merely saving energy is not enough to effectively maximize the network lifetime. The Uneven Energy Consumption (UEC) often results in network partition and lesser coverage ratio, which deteriorates the overall performance. To address the UEC problem in WSN, this paper proposed an energy-efficient routing strategy using a Fuzzy based approach and compared with A-star algorithm results from the literature [8] under the same conditions. The results so obtained typically show that the Fuzzy logic approach gives better results than the A-star algorithm.

REFERENCES

[1] Imad S. AlShawi, Lianshan Yan, Wei Pan and Bin Luo, “Lifetime Enhancement in Wireless Sensor Networks Using Fuzzy Approach and A-Star Algorithm”, IEEE Sensors Journal, Volume 12, Issue 10, October 2012, pp. 3010-3018.
[2] Anitha, M. Selvi and Dr. N. Saravana Selvam, “Life Time Enhancement Techniques in Wireless Sensor Network: A Survey”, International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 10, October 2013, pp. 224-231.
[3] Mourad Hadjila, Hervé Guyennet, Mohammed Feham, “A Routing Algorithm based on Fuzzy Logic Approach to Prolong the Lifetime of Wireless Sensor Networks”, International Journal of Open Scientific Research, Volume 1, Issue 5, October 2013, pp. 24-35.
[4] Hamid Rafiei Karkvandi, Efraim Pecht, and Orly Yadid-Pecht, “Effective Lifetime-Aware Routing in Wireless Sensor Networks”, IEEE Sensors Journal, Volume 11, Issue 12, December 2012, pp. 3359-3367.
[5] Lotfi A. Zadeh, “Soft computing and fuzzy logic” ,IEEE Software, Volume 11,Issue 6, November 1994, pp. 48–56.
[6] L. A. Zadeh, “Fuzzy Sets”, Information and Control, 1965, pp. 338-353.
[7] Lotfi A. Zadeh, “Toward a perception-based theory of probabilistic reasoning with imprecise probabilities”, Journal of Statistical Planning and Inference, 2002, pp. 233-264.
[8] Keyur M Rana and Mukesh A Zaveri, “ASEER; a Routing method to extend life of two-tiered wireless sensor network”, International Journal of Advanced Smart Sensor Network Systems, Volume 1, Issue 2, October 2011,pp. 1-16.