Energy Efficient Routing Protocol for Maximizing Lifetime in Wireless Sensor Networks using Fuzzy Logic

Safa Khudair Leabi
Dept. of Information Technology, Technical College of Management, Middle Technical University
Baghdad, Iraq

Turki Younis Abdalla
Dept. of Computer Engineering, College of Engineering, University of Basrah
Basrah, Iraq

ABSTRACT
Wireless sensor networks applications have widely increased in recent years. Energy limitations have become fundamental challenge for designing wireless sensor networks. One of the important and interested features is network lifetime. Many works have been developed to maximize wireless sensor network lifetime, in which one of the important work is routing. Several attempts have been made for efficient utilization of energy in terms of energy aware routing. This paper proposes a new routing technique for maximizing the lifetime of wireless sensor networks by using Fuzzy System. Fuzzy logic system is used to determine the optimal path for sending data packets. The proposed routing technique seeks to determine the optimal route path from source to destination so that the energy consumption is balanced and minimized. The proposed routing technique is compared with classical method. Simulation results show significant increase in network lifetime when the proposed technique is used. The proposed technique proved that energy consumption is well managed.

Keywords
Routing, fuzzy logic, network lifetime, wireless sensor networks.

1. INTRODUCTION
Recent years advances show serious progress in wireless networking. The progress and growth in wireless communication technology have made WSNs attractive for multiple application areas, such as medical and health, security surveillance, habitat monitoring, military reconnaissance, disaster management, industrial automation, etc. [1-4]. The development of small and ubiquitous WSNs computing devices is ultimately required. WSNs are comprised of considerable number of limited capabilities sensor nodes with one or more high capability base stations. Each sensor node is a small embedded system, low-power, low-cost, multi-functional [3] Each sensor node performs several functions: sensing, data processing, and communication. Sensor nodes perform wireless communications with each other in order for delivering gathered data to base station. The development of ubiquitous, inexpensive, small and low-power computing devices became available through miniaturization technologies [3]. Due to this, using multi-hop communication help to reduce transmission distance as well as increasing network lifetime. Every node consists of four parts: a processer, sensor, transceiver, and battery. Nodes involve bounded power source with abilities of sensing, datum processing along with communication. The onboard sensors collect datum about the environment through event driven or continuous working mode. The gathered datum may be temperature, pressure, acoustic, pictures, videos, etc. The gathered datum is then transferred across the network in order to form a global monitoring view for objects [5,6].
Since bounded energy source is involved, energy exhaustion is the most important metric for WSNs. In order for maximizing networks lifetime, energy exhaustion must be well managed [7,8]. Balancing energy exhaustion refer to the major problem in characterizing WSNs. Network lifetime might reduce significantly if the energy exhaustion is not balanced, and may lead to network partitioning quickly. Several techniques can be used for maximizing network lifetime, in which one of the important technique is network layer routing. Generally, in network layer routing algorithm, choosing the best route between nodes and base station represent the main objective of routing algorithms. If same path would be choose for all new communication by taking the benefit of fast transmission at the expense of battery energy exhaustion, sensor nodes of this path would drain its energy quickly and may cause network partitioning.

In this paper, a new improved routing technique is proposed. The main goal of the proposed routing technique is to make energy consumption balance and prolonging wireless sensor network lifetime.

This paper is organized as follows: related work is presented in section 2. Section 3 describes the proposed routing technique. Simulation settings are presented in section 4. Simulation results and discussion are presented in section 5. Conclusion is presented in section 6.

2. RELATED WORK
One of the primary considerations in wireless sensor networks is the design of energy efficient system. Wireless sensor networks routing protocols have been widely used to minimize energy consumption and maximize the overall lifetime of the network. Routing protocols is responsible for finding the optimal path from sensor node to the sink. The good routing protocol involves finding the optimal path with the investigating of minimum energy consumption. As a result, network lifetime is maximized. Prolonging network lifetime has gained significant interest in recent years.

The work proposed by Ahmed et al. [9] suggests a solution to address the problem of extending the network lifetime by using hybrid routing approach. This hybrid approaches combines two routing strategies, flat multi-hop routing and hierarchal multi-hop routing. The proposed approach has minimized the total power consumption and decrease the amount of traffic by utilizing data compression. The hierarchal routing is used for the area outside the hotspot and flat routing is used inside the hot spot area. Simulation results show an increase in the lifetime and decrease in the total power consumption.

Umarani G. et al. [10] proposed a swarm intelligence ant colony optimization routing protocol for maximizing the lifetime of the network. This approach uses the principle of ant colony algorithm to find the optimal path. Simulation results show an increase in the lifetime of the network and power consumption balance.

The work proposed by Jin Wang et al. [11] suggests a distance-based energy aware routing algorithm to ensure energy efficiency and maximize network lifetime. Two metrics have been used in this algorithm, individual distance and residual energy. These metrics are used for searching for the optimal path. In comparison with other routing algorithms, simulation results show that the proposed algorithm ensure energy balance and maximize network lifetime.

Rahim Khan et al. [12] proposed a routing method that takes into account the importance of particular node for the connectivity of the network for all routing decisions. Some of nodes are highlighted as more important for network connectivity than others based on their physical location and their importance for forwarding data packets. The method proposes a mechanism for avoiding the use of the important node so that the lifetime of the network is prolonged.

Mahmood R. et al [13] suggest a routing algorithm for maximizing the network lifetime by distributing the sender node to sink traffic for a given routing request along a set of paths. Fuzzy logic is used to design the weight function by using the metric residual energy. The proposed method uses the weight function to find the optimal path from sender node to sink. Simulation results show an increase in the network lifetime.

The work suggested by S. Bhuvaneshwari et al. [14] proposes a bee hive algorithm for maximizing the network lifetime. Bee hive algorithm is used to find the optimal path for sensor node depending on the energy as a fitness value and also find the minimum energy consumption path for given paths. Simulation results show an increase in network lifetime.

The work suggested by Vinay K. et al. [15] proposes a method for finding the optimal energy efficient path by combining the Elitist genetic algorithm and simulated annealing algorithms. The objective function uses the nodes distance from the sink and the lifetime as a function of the maximum energy dissipated by a node in the route. Simulation results show energy balance and increase in the network lifetime.

Tarique H. et al. [16] suggest an energy aware routing method for wireless sensor networks based on fuzzy logic approach. Several routing metrics has been used in the proposed method. According to the proposed method, avoiding nodes that have remaining energy less than 40% extends the network lifetime.

The work proposed by Lun Zhang [17] suggests an energy saving routing algorithm based on Dijstra in wireless sensor networks. This algorithm is designed to be economic to energy consumption as an improvement of the energy saving least hop algorithm. Energy and min hop are the two metrics used for the proposed method. The proposed algorithm search for a reliable shortest path with least energy consumption.

Sajid H. et al. [18] proposed an alternate algorithm for maximizing the lifetime of the network. This algorithm uses a save factor as an indication of sensor node energy, so that the routing method select the highest energy node. The proposed routing method is quick for data execution and performs near optimal results for maximizing network lifetime.

Michał K. et al. [19] proposed an optimization framework for maximizing network lifetime. An opportunistic routing together with random linear network coding is used. They proposed a probability scheme for receiving from nodes, so that receiving data packets energy consumption is done with a probability scheme. The proposed method show increase in the lifetime by more than 20%.

3. PROPOSED ROUTING PROTOCOL

The proposed energy efficient routing protocol involves using fuzzy logic system. The goal of the proposed routing protocol is minimizing energy consumption and maximization of network lifetime. Fuzzy system is used to find the optimum path from sensor nodes to sink.

Sensor nodes are responsible for collecting data from its neighbor's nodes. In this paper, time driven routing schedule is supposed. Each node finds the optimal rout for sending data packets to the sink in every time cycle. Using this scheduling for routing, the procedure of determining optimum route while sending data packets to the sink for all nodes will repeated for each round. For the proposed routing protocols: (1) for a specified field random deployment is involved for whole nodes along with knowledge about their positions and their neighbors positions within its range and the position of the sink; (2) initial energy and maximum transmission range are identical for all sensor nodes.

Energy management efficiency is the most important WSNs design challenges; it gives a measure about WSN lifetime which perhaps the most serious metric owing to evaluating WSNs. The definition of net lifetime gives a meaning for time from turning on till first node die within net. The lifetime is the most challenging problem in WSN. Several techniques might be used to maximize network lifetime in which one of them is improving the routing protocols.

In this paper, a new adaptive routing protocol is proposed for managing energy consumption and maximizing the overall lifetime of the network. The proposed routing protocol maximize the network lifetime by using fuzzy system. Two metrics have been used in our new routing method are the remaining energy (RE) and the shortest hop (SH) to select the optimal next hop node to the current node. Shortest hop (SH) is the distance from sensor node to the sink. Selecting the next hop of highest remaining energy (RE) and shortest hop (SH) to sink is the responsibility of proposed routing algorithm. Hence, energy consumption is balanced and the lifetime of the network is maximized.

The general structure of the proposed routing protocol is illustrated in figure 1. When a sensor node likes to send or forward data packets, firstly find all of its neighbors. Fuzzy system is used to find optimum node from neighbor nodes to send or forward it the data packets. Fuzzy system make a decision for computing edge cost related to the remaining energy and shortest hop metrics. The favor edge cost is that involves highest remaining energy and shortest hop to sink. Hence, node with highest edge cost value will selected as next hop node. Depending on this process next hop node is selected and added to OPEN list along with fag it as current node. If this node is inside sink's range then optimum path is OPEN list. If current node is not inside sink's range, the fuzzy system process is repeated to find optimum next hop node. This process is repeated for every node like send or forward data packets to other nodes.

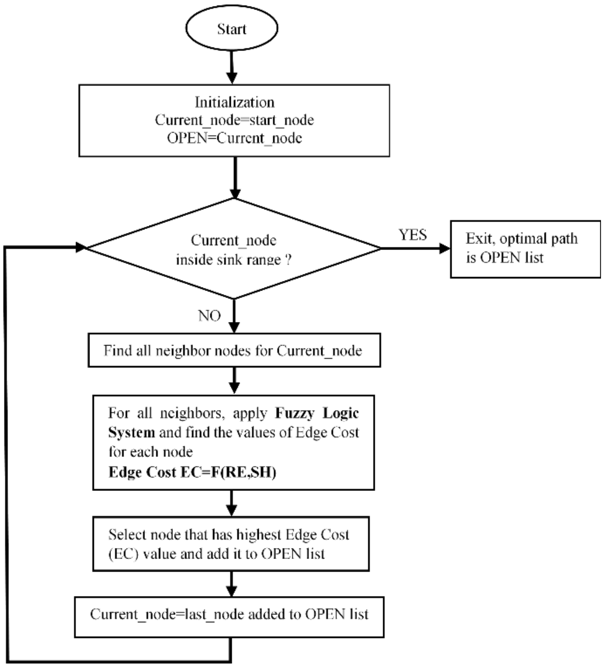

Fig 1. General Structure of the Proposed Routing Protocol

3.1 Fuzzy System Implementation

Fuzzy logic was first proposed by Zadeh in 1965 [20]. Fuzzy logic is an extension of the classical propositional and predicate logic that rests on the principles of the binary truth functionality. Fuzzy systems implementation was expanded for wide applications like systems identification and control. Fuzzy systems are robust, easy to implement and has the advantage of processing non-linear systems.

For the proposed routing technique, the objective of the fuzzy system is to determine the optimal value of the node edge cost EC(n) of node n depending on the remaining energy RE(n) and shortest hop SH(n). The shortest hop (SH) is the distance from sensor node to the sink. Figure 2 depicts the proposed fuzzy system with two inputs remaining energy RE(n) and shortest hop SH(n). The universal of discourse for inputs remaining energy (RE) and shortest hop (SH) and output node cost C, are [0…0.5], [0…60] for net 1; [0…100] for net 2, [0…1], respectively. The design of our fuzzy system uses five membership functions for the two inputs and output as illustrated in figure 3.

For fuzzy system, the inference engine consists of the rule base and processes the fuzzified values. The rule base is a series of IF-THEN rules, which related to fuzzy input variables and fuzzy output variable, and by using linguistic variables, each of which is qualified by fuzzy set. We have used 25 fuzzy rules in our design. Table 1 shows the rules used in the proposed routing technique. Any rule that fire share out in the final fuzzy solution calculation. Using center of area method for defuzzification, the final crisp value is calculated which represent the node edge cost EC(n) in per unit. Equation (1) describes the center of area defuzzification method.

$$Node\ Edge\ Cost\ EC(n) = \frac{\sum_{i=1}^{n} R_i * c_i}{\sum_{i=1}^{n} R_i} \qquad (1)$$

where, R_i is the output of rule base i, and c_i is the center of the output membership function.

This fuzzy design is involved for determining the optimal path from sensor nodes toward the sink along with ensuring energy consumption is balanced and network lifetime is maximized.

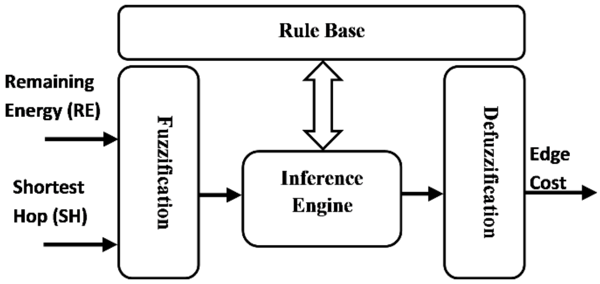

Fig 2. Designed fuzzy system structure

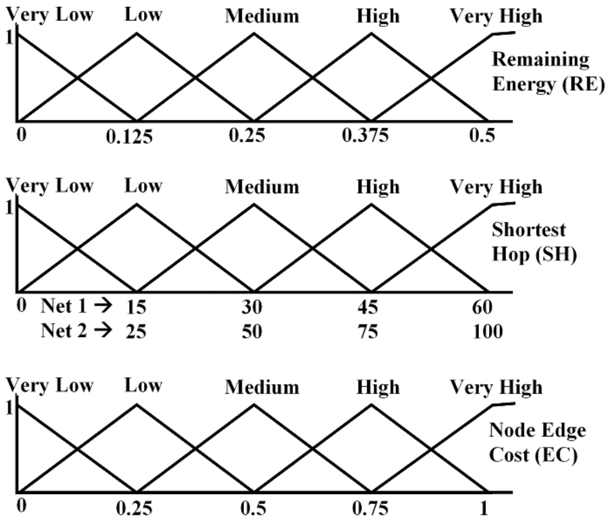

Fig 3. Designed fuzzy system membership functions

Table 1: Fuzzy If-Then Rules

No	Antecedent		Consequent
	Remaining Energy RE(n)	Shortest Hop SH(n)	Edge Cost EC(n)
1	*Very Low*	*Very Low*	*Low*
2	*Very Low*	*Low*	*Very Low*
3	*Very Low*	*Medium*	*Very Low*
4	*Very Low*	*High*	*Very Low*
5	*Very Low*	*Very High*	*Very Low*
6	*Low*	*Very Low*	*Medium*
7	*Low*	*Low*	*Medium*
8	*Low*	*Medium*	*Low*
9	*Low*	*High*	*Low*
10	*Low*	*Very High*	*Very Low*
11	*Medium*	*Very Low*	*High*
12	*Medium*	*Low*	*Medium*
13	*Medium*	*Medium*	*Medium*
14	*Medium*	*High*	*Low*
15	*Medium*	*Very High*	*Low*
16	*High*	*Very Low*	*Very High*
17	*High*	*Low*	*High*
18	*High*	*Medium*	*High*
19	*High*	*High*	*Medium*
20	*High*	*Very High*	*Medium*
21	*Very High*	*Very Low*	*Very High*
22	*Very High*	*Low*	*Very High*
23	*Very High*	*Medium*	*Very High*
24	*Very High*	*High*	*High*
25	*Very High*	*Very High*	*High*

4. SIMULATION SETTINGS AND CONFIGURATION

Simulation is carried out in MATLAB. Two topological areas is considered in this paper, which are A1 and A2. A 100 sensor nodes are randomly deployed for each of the two topological areas. The topological areas A1 and A2 have the dimension of 100mx100m for area A1 and 200mx50m for area A2. One base station "Sink" has been used for each topological area. The position of the sink is (50m,50m) for topological area A1, and is (100m,25m) for topological area A2. Every node operate with maximum transmission range equal to 30m. Each node has initial energy equal to 0.5J. A 200 bit packet length is used for simulation. Performance evaluation of the proposed new routing protocol is tested for each of the two topological areas A1 and A2. The proposed routing technique utilized with first order radio model proposed by Heinzelman [21], which is largely used in the field of evaluating routing techniques for WSNs. This model is shown in the following equations.

$$E_{TX}(pkt_{length}) = E_{elec} * pkt_{length} + E_{amp} * pkt_{length} * d^2 \quad (2)$$

$$E_{RX}(pkt_{length}) = E_{elec} * pkt_{length} \quad (3)$$

where, E_{Tx} and E_{Rx} are the energy consumption for transmitting and receiving respectively. pkt_{length} is the number of bits per packet. d is the distance from sender node to receiver node. E_{elec} is the per bit energy dissipation for transmitting or receiving for electrical circuitry. E_{amp} is the per bit per meter square energy dissipation. The values of E_{elec} and E_{amp} used for simulation are 50nJ/bit and 100pJ/bit/m2, respectively.

5. SIMULATION RESULTS AND DISCUSSION

Simulation is carried out for the two topological areas. Two routing protocols have considered in the simulation, which are Dijkstra routing and the proposed fuzzy routing. Number of alive nodes in each round has used to give the indication about the lifetime of the wireless sensor networks. A comparison has been made for the two routing protocols in term of overall network lifetime, and work improvement is depicted. Network lifetime considered is the time from starting work of the network till the first sensor node die or exhaust its energy.

Figure 4 (a and b) depicts simulation results of areas A1 and A2, respectively, for number of still alive nodes in each round till network partition. From this figure, it can be seen that the proposed routing protocol is better than the classical Dijkstra routing. It shows an increase in network lifetime of about 54% for area A1 and 73.38% for area A2. Result figures show the improvement of the proposed routing technique in comparison with a classical routing method. The proposed method shows the improvements in term of balancing energy consumption and maximizing overall network lifetime. Depending on our experiments trace for searching optimal path, the proposed routing protocol change the optimal path every round depending on the metrics used, the remaining energy and the shortest hop. This change in the path used to send data packets from any node to sink prove the balance in energy consumption and as a result maximizing network lifetime. Network partitioning feature has been activated for the simulation. Network partitioning is work out when any of the 100 deployed sensor nodes has not find a neighbor nodes to send data packet. This is due to the dyed sensor nodes. Hence, simulation is stopped when network partitioning is occurred. Table 2 details the overall network lifetime and network partitioning time for the two methods and for the two topological areas A1 and A2.

Figure 5 (a and b) illustrates the network minimum remaining energy till network partitioning in each round and for the two topological areas A1 and A2, respectively, and also a comparison between the proposed fuzzy routing protocol and Dijkstra routing. It is obvious from these figures, that the minimum remaining energy of the proposed routing protocol is higher than the Dijkstra routing. These results reflect energy consumption balance. This figure shows that the Dijkstra routing method has some nodes exhaust its energy quickly due to the continuous usage of these nodes. This reflects the unbalanced energy consumption in the Dijkstra routing. This is due to the usage of the same path for sending data packets from sensor node to sink. The proposed fuzzy routing technique results in energy consumption balance and maximization of the overall lifetime of the network.

Figure 6(a,b) with figure 7(a,b) illustrate samples of consumed energy with regard to nodes that hold ids 2 and 81 for area A1 and for nodes ids 18 and 77 for area A2, respectively. From these figures, consumed energy for proposed fuzzy routing is less than the classical Dijkstra routing. The effect feature of proposed routing protocol is investigating energy exhaustion balance and avoiding the continuous using of same nodes, which led to minimize total energy exhaustion. This reflects the effectiveness of proposed fuzzy routing protocol for decreasing energy exhaustion along with prolonging network lifetime.

Figure 8(a,b) and figure 9(a,b) depict samples of simulation time for nodes that hold id 23 and 86 for area A1 and for nodes id 20 and 89 for area A2, respectively. From these figure, simulation time for proposed fuzzy routing is approximately equal or little less than of classical Dijkstra routing. So applying the proposed fuzzy routing will not affect on computation time for finding the optimal path for sending packets from source to destination.

Figure 10(a,b) and figure 11(a,b) depicts samples of end-to-end delay in term of number of hops for nodes that hold ids 40 and 95 for area A1 and for nodes 21 and 94 for area A2, respectively. These figures show that proposed fuzzy routing is better than Dijkstra routing, which change the path for sending packets continuously depending on the remaining energy and shortest hop metrics instead of using the same path as Dijkstra routing. Changing transmission path leads to energy exhaustion balance by using more hops and avoid continuous using for some nodes. Using more hops helps to investigate energy exhaustion balance leads in minimizing overall energy exhaustion of WSN. This adaptive operation regards to propose fuzzy routing protocol that increase network lifetime significantly.

Table 2: Network Lifetime and Partitioning Time

Routing Technique	Area	Lifetime	Partitioning Time
Dijkstra Routing	A1	2534	6035
Fuzzy Routing	A1	5509	6519
Dijkstra Routing	A2	785	3077
Fuzzy Routing	A2	2949	3579

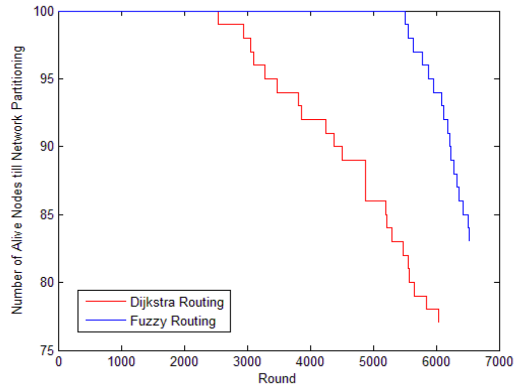

Fig 4(a). Number of alive nodes for area A1

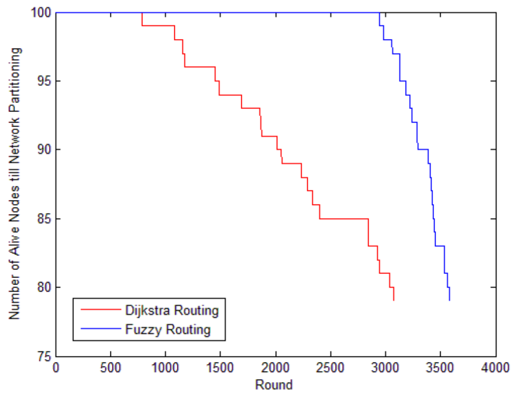

Fig 4(b). Number of alive nodes for area A2

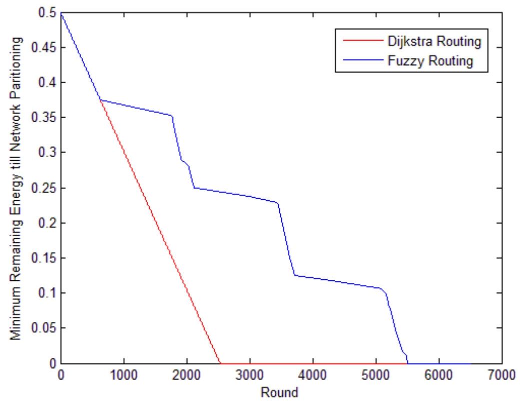

Fig 5(a). Minimum remaining energy for area A1

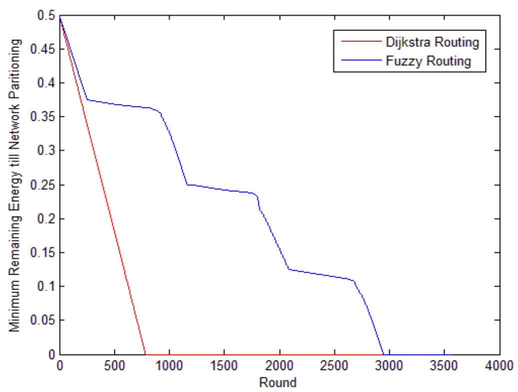

Fig 5(b). Minimum remaining energy for area A2

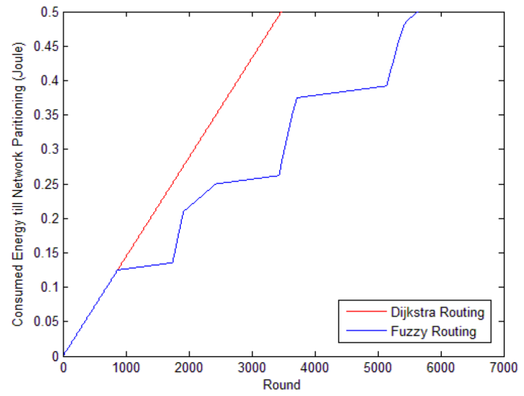

Fig 6(a). Consumed energy for node id (2) for area A1

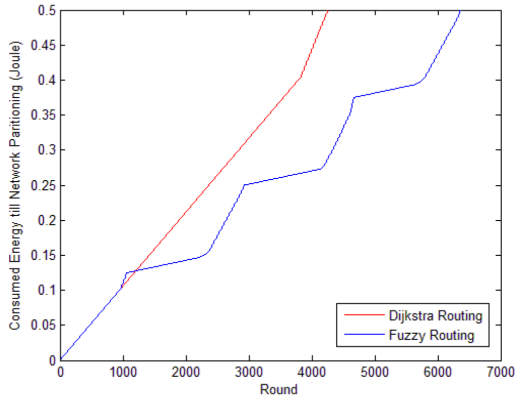

Fig 6(b). Consumed energy for node id (81) for area A1

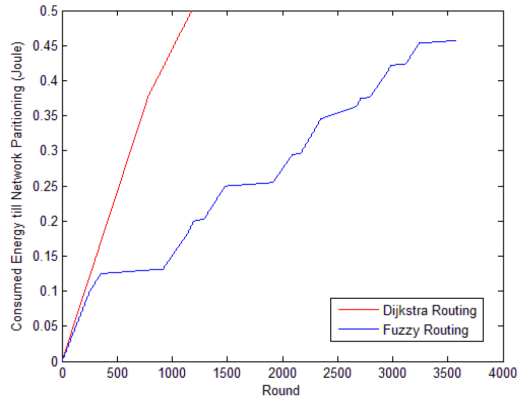

Fig 7(a). Consumed energy for node id (18) for area A2

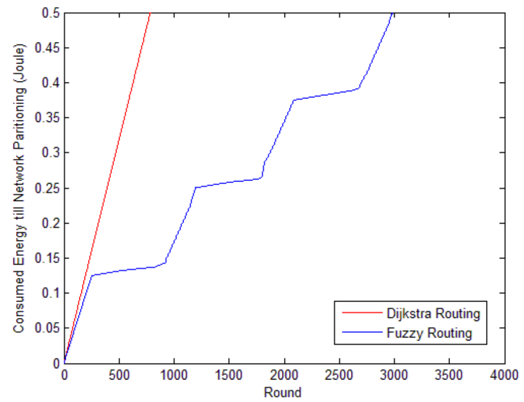

Fig 7(b). Consumed energy for node id (77) for area A2

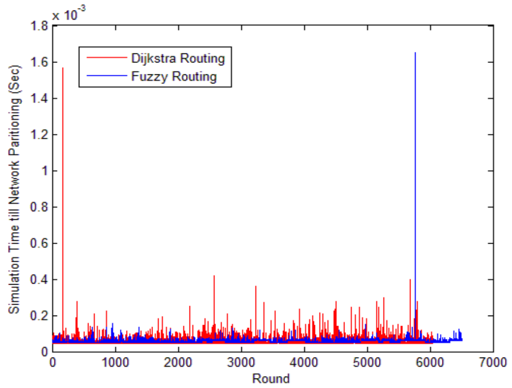

Fig 8(a). Simulation time for node id (23) for area A1

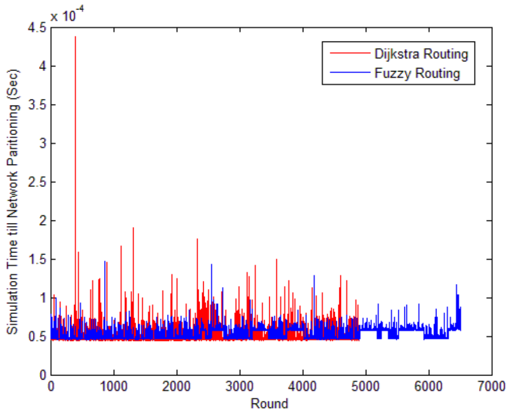

Fig 8(b). Simulation time for node id (86) for area A1

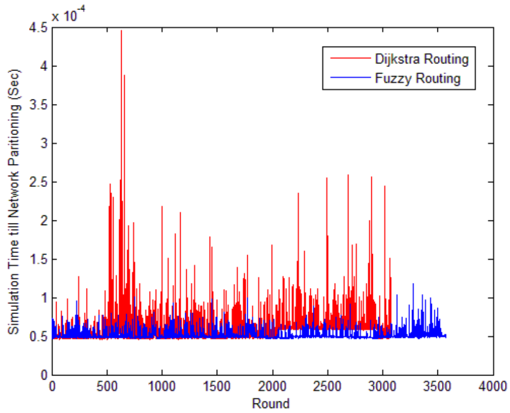

Fig 9(a). Simulation time for node id (20) for area A2

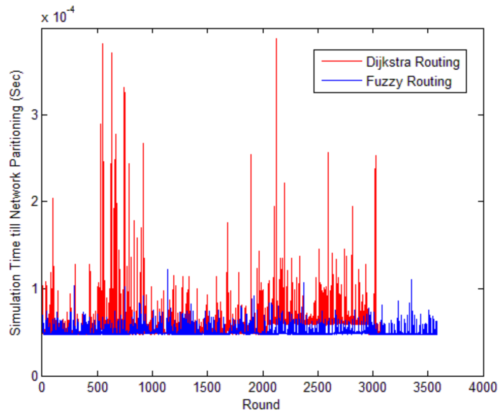

Fig 9(b). Simulation time for node id (89) for area A2

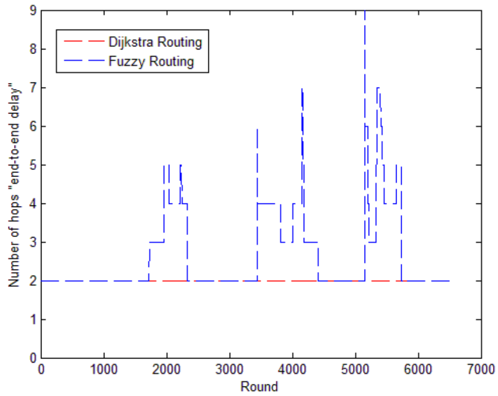

Fig 10(a). Number of hops for node id (40) for area A1

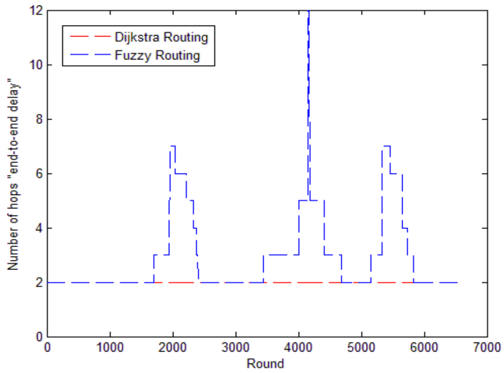

Fig 10(b). Number of hops for node id (95) for area A1

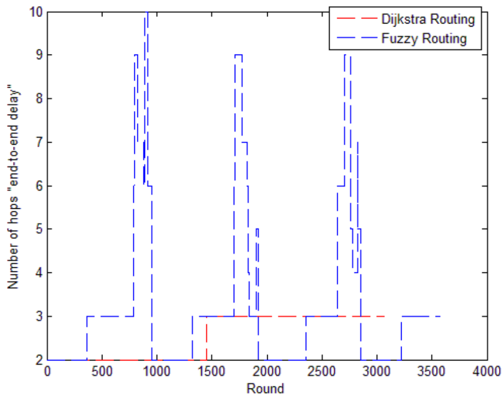

Fig 11(a). Number of hops for node id (21) for area A2

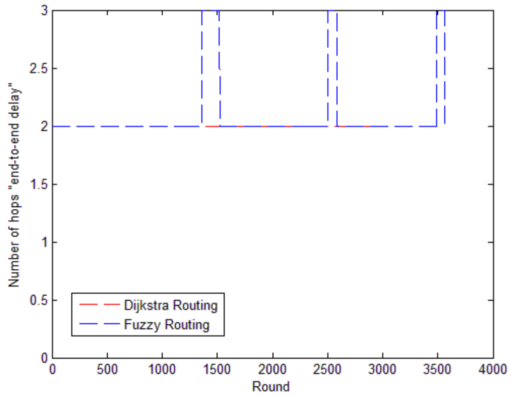

Fig 11(b). Number of hops for node id (94) for area A2

6. CONCLUSION

Wireless sensor networks available with limited source power through their life cycle. Since the battery of the sensor node cannot be replaced or recharged, energy conservation is a crucial issue in the design of the wireless sensor network infrastructure. In this paper, an energy efficient adaptive fuzzy routing technique is presented for maximizing the network lifetime. The fuzzy system is used to determine the optimal path for sending data packets. The proposed routing protocol ensures that the optimal path from source to destination is determined along with energy conservation. Two topological areas have been used for simulation, which are topological areas A1 and A2. Simulation results show that the proposed fuzzy routing method is better than the classical Dijkstra routing. Simulation results show an increase in network lifetime of about 54% for area A1 and 73.38% for area A2 when using the proposed method. Simulations show that the lifetime is maximized and the energy consumption is balanced for the proposed routing technique. The performance of the proposed method depicts a good improvement in the field of maximizing network lifetime using adaptive routing techniques. Simulation results prove the generality of the proposed fuzzy routing technique, so that the proposed routing technique could be used for any design framework.

7. REFERENCES

[1] Ian F. Akyildiz and Mehmet Can Vuran, "Wireless Sensor Network", John Wiley & Sons Ltd., 2010.

[2] A. Hac, "Wireless Sensor Network Designs", John Wiley & Sons Ltd, 2003.

[3] I. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "A Survey on Sensor Networks," IEEE Communications Mag., Vol. 40, No. 8, Aug. 2002, pp: 102–114.

[4] Al-Karaki, J.N. Kamal and A.E., "Routing Techniques In Wireless Sensor Networks: A Survey", IEEE Wireless Communication, Vol. 11, 2004, pp:6–28.

[5] Ananthram Swami, Qing Zhao, Yao-Win Hong and Lang Tong, "Wireless Sensor Networks: Signal Processing and Communications Perspectives", John Wiley & Sons Ltd, 2007.

[6] Amiya Nayak and Ivan Stojmenovic, "Wireless Sensor and Actuator Networks: Algorithms and Protocols for Scalable Coordination and Data Communication", John Wiley & Sons, Inc., 2010.

[7] C. Hua and T. P. Yum, "Optimal Routing And Data Aggregation For Maximizing Lifetime Of Wireless Sensor Networks", IEEE ACM Transection on Network., Vol. 16, No. 4, pp. 892–903, Aug. 2008.

[8] H. R. Karkvandi, E. Pecht, and O. Yadid, "Effective Lifetime-Aware Routing In Wireless Sensor Networks", IEEE Sensors Journal, Vol. 11, No. 12, pp. 3359–3367, Dec. 2011.

[9] Ahmed E.A.A. Abdulla, Hiroki Nishiyama and Nei Kato, "Extending the lifetime of wireless sensor networks: A hybrid routing algorithm", Elsevier Computer Communications. Vol. 35, pp.1056–1063, 2012.

[10] Umarani G. And M.Akilandeswari B., "Computational Intelligence Routing For Maximizing Lifetime In Heterogeneous Wireless Sensor Networks", International Journal of Computer Science and Network Security, VOL. 12, No. 4, April 2012.

[11] Jin Wang, Jeong-Uk Kim, Lei Shu, Yu Niu and Sungyoung Lee, "A Distance-Based Energy Aware Routing Algorithm for Wireless Sensor Networks", Journal of Sensors, Vol. 10, pp. 9493-9511, 2010.

[12] Rahim Khan, Shah Nawaz Khan, Mushtaq Ahmad and Tufail Muhammad, "Increasing Network Lifetime and Data Transfer through Node Vulnerability Aware Routing in Wireless Sensor Networks", IEEE International Conference on Information and Emerging Technologies (ICIET), pp.1-5, June 14-16, 2010.

[13] Mahmood R. Minhas, Sathish Gopalakrishnan and Victor C. M. Leung, "An Online Multipath Routing Algorithm for Maximizing Lifetime in Wireless Sensor Networks", IEEE Sixth International Conference on Information Technology: New Generations, pp.581-586, April 27-29, 2009.

[14] S. Bhuvaneshwari and P.S. Balamurugan, "A Bee-Hive Optimization Approach to Improve the Network Lifetime in Wireless Sensor Networks", International Journal on Computer Science and Engineering, Vol. 5, No. 05, May 2013.

[15] Vinay Kumar Singh and Vidushi Sharma, "Lifetime Maximization of Wireless Sensor Networks using Improved Genetic Algorithm based Approach", International Journal of Computer Applications, Vol. 57, No. 14, pp.36-40, November 2012.

[16] Tarique Haider and Mariam Yusuf, "A Fuzzy Approach to Energy Optimized Routing for Wireless Sensor Networks", International Arab Journal of Information Technology, Vol. 6, No. 2, pp.179-188, April 2009.

[17] Lun Zhang, Wenchen Yang, Qian Rao, Wei Nai and Decun Dong, "An Energy Saving Routing Algorithm Based on Dijkstra in Wireless Sensor Networks", Journal of Information & Computational Science, Vol. 10, No. 7, pp. 2087–2096, May 2013.

[18] Sajid Hussain, Richard Peters and Obidul Islam, "A Quick and Energy Efficient Algorithm to Maximize Lifetime of Wireless Sensor Networks", IEEE International Conference on Information Technology, pp.874 – 875, April 2-4, 2007.

[19] Michał Kaliszan and Sławomir Sta´nczak, "Maximizing Lifetime in Wireless Sensor Networks under Opportunistic Routing", IEEE The forty fourth Asilomar Conference on Signals, Systems and Computers; , pp.1913 – 1917, November 7-10, 2010.

[20] Zadeh L. A., "Fuzzy Sets, Information and Control", Vol. 8, pp.338-353, 1965.

[21] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy Efficient Communication Protocol For Wireless Microsensor Networks", Proceedings of the 33rd Annually Hawaii International Conference on Systems Sciences, pp.1–10, 2000.