Journal of Advances in Computer Research
Quarterly pISSN: 2345-606x eISSN: 2345-6078
Sari Branch, Islamic Azad University, Sari, I.R.Iran
(Vol. 5, No. 3, August 2014), Pages: 113-123
www.jacr.iausari.ac.ir

A Routing Algorithm Based on Fuzzy Clustering and Minimum Cost Tree (FCMCT) in Wireless Sensor Network

Maryam Javaherian✉, Abolfazl T.Haghighat

Faculty of Computer and Information Technology Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran

maryam_javaherian@yahoo.com; at_haghighat@yahoo.com

Received: 2014/01/01; Accepted: 2014/02/15

Abstract

Nowadays, wireless sensor network has been of interest to investigators and the greatest challenge in this part is the limited energy of sensors. Sensors usually are in the harsh environments and transit in these environments is hard and impossible and moreover the nodes use non- replaceable batteries. Because of this, saving energy is very important. In this paper we tried to decrease hard and complex computing with using soft computing such as fuzzy logic and we used it in cluster head selection part. Hard and complex computing can waist energy, because of this, we used some techniques to solve this problem. Minimum cost tree (MCT) helps to find minimum path, so we used this technique for intra cluster routing and again more over we used distributed source coding (DSC) technique for aggregating data. Finally all of methods could reduce energy consumption and increase network lifetime. Proposed algorithm is called FCMCT and simulation and results show improvement.

Keywords: *wireless sensor networks, routing, clustering, fuzzy logic, network lifetime*

1. Introduction

Wireless sensor networks include a large number of inexpensive sensors with limited energy and the ability to sense, confined computing ability [1]. The sensors monitor the environment and collect data from the environment next send to the sink. These sensors are equipped by a radio, a limited power source such as batteries, memory limitations to be able to monitor their surroundings. Some of these sensors are equipped by secondary power source such as solar energy [2].

Recent studies have attempted to design a network that can save energy and increase network lifetime and this issue have been proposed as one of the main challenges in recent years. The proposed various routings are solution for this [6, 7]. References [3, 4] used a minimum -cost path to send data to the sink, in a large sensor network. In this algorithm, the optimal cost was found and each node broadcast its optimal cost to its neighbors. Sending many of these messages makes a lot of Overflow. The DSC technique, a technique in information theory for compress the data, can solve this problem.

Source [5] used the DSC technique to reduce the energy consumption of nodes in wireless sensor network. The other ways to help increase life time of the network are hierarchical techniques such as clustering [8]. In the cluster based network, the network is divided into small groups which is called cluster and each cluster includes number of nodes, one node is selected as cluster head (CH) which is responsible for collecting data from cluster members and sends it to the sink. Sending data through the cluster heads to the sink can be directly or multi hop routing [9]. We have discussed about some related works in Section II, in Section III, we explain a preliminary of DSC. Finally we will explain the proposed algorithm, a routing algorithm based on fuzzy clustering and minimum cost tree in wireless sensor network (FCMCT) and then simulation and result are proposed.

2. Related Works

Proposed routing protocols in wireless sensor networks and ad-hoc network can reduce energy consumption and end -to-end delay [10]. Source [18] has proposed an energy-aware routing protocol that can reduce power consumption and end- to-end delay in the same time. It can minimize the number of hops for sending data to the remote distances.

LEACH [11] is a well-known hierarchical protocol, in this algorithm, the network is divided into small groups that are called clusters and each cluster has a cluster head (CH). The role of cluster head rotates randomly between cluster members in per round and it can balance the energy consumption in the network, cluster heads send data by single hop and directly. Another routing protocol that uses clustering is ECP [12]. Unlike LEACH, in this protocol multi hop routing is used for sending data to the sink.

Protocol CHEF [13] and EAUCF use fuzzy method in clustering such as [14]. HEED [15] has been able to improve LEACH algorithm. In this algorithm cluster head selection was not random, cluster heads are selected according to their residual energy. Algorithm LEACH-FL [17] uses fuzzy logic and an approach similar to [16]; it improves the LEACH and uses three- parameters: residual energy, node degree and the distance to the sink as input of fuzzy system. Reference [23] modes routing overhead generated by reactive routing protocol and this algorithm has two main phases: rout discovery and rout maintains and it uses the expanding ring search algorithm for controlling flooding generated by blind flooding mechanism. Reference [24] studied on design requirements for routing link metrics and it selected Expected Transmission Count (ETX), Minimum Delay (MD), Minimum Loss (ML) and its proposed metric and again in [26] proposed a new quality link metrics and it compared performance of three existing QLMs; Expected Transmission Count (ETX), Minimum Delay (MD), Minimum Loss (ML) in Static Wireless Multi-hop Networks.

[25] Considered impact of mobility on the behavior of three reactive protocol (AODV, DSR, DYMO) and three proactive protocol (DSDV, FSR, OLSR).

Reference [27] proposed EAST algorithm and it has two phases, initial and run-time. In first phase, reference node builds a model for nodes in network. In the second phase based on previous model, this algorithm adapted the link quality to dynamically maintain each link with respect to time. [29] Proposed an algorithm with unequal clustering, called EAUCF (Energy-Aware Unequal Clustering with Fuzzy), It makes local decisions for determining competition radius and electing cluster-heads. In order to estimate the competition radius for tentative cluster-heads, EAUCF employs both residual energy and distance to the base station parameters.

3. Fuzzy Logic

Fuzzy logic uses the human experiences and human decisions. This system is used infinite set between zero and one instead of an Aristotelian system that is a finite set include zero and one. Input and output of the system under a set of linguistic rules are created. The system has four main parts including a fuzzifier, a fuzzyrules, an inference engine and a defuzzifier as shown in Figure1. In the fuzzifier state, each input variable is assigned to linguistic value which is needed by inference engine. In the rule base state, a set of fuzzy rules is defined that the fuzzy system uses for evaluation, inference engine draws conclusions from fuzzy rules and finally defuzzifier gets inference engine's output as input and gives us the final output. We used the most common inference technique, called the mamdani methods, because of its simplicity. The membership functions can have different shapes. Some of the most frequently used shapes include triangular, trapezoidal, and Gaussian shaped. The rule- base has a set of linguistic statements, called rules. The forms of these rules are IF-THEN rules, so we Consider a t-input 1-output FLS with rules of the form:

R^i : IF x_1 is S_1^i and x_2 is S_2^i and… and x_t is S_t^i THEN y is A^i.

When input $x = \{\acute{x}_1, \acute{x}_2, \dots, \acute{x}_t\}$ is applied, the degree of Firing of some rule Ri can be computed as:

$\mu_{S_1^i}(\acute{x}_1) * \mu_{S_2^i}(\acute{x}_2) * \dots * \mu_{S_t^i}(\acute{x}_t) = T_{l=1}^{t} \mu_{S_l^i}(\acute{x}_l)$

Here l represents the membership function and both * and T indicate the chosen triangular norm. A triangular norm is a binary operation such as AND or OR applied to the fuzzy sets provided by the membership functions [28].

In this paper we use triangular membership function, when membership function is triangular, using triangular fuzzifier causes to reduce calculates in the inference engine and triangular fuzzifier can avoid of noises in input.

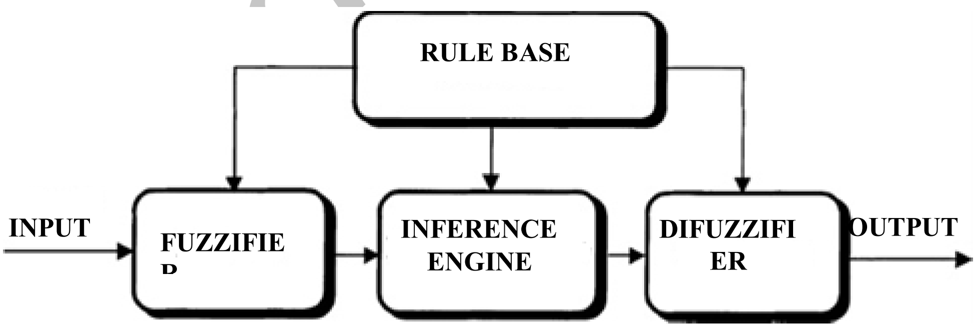

Figure.1. fuzzy set diagram [22]

4. Proposed algorithm

The proposed algorithm consists of three phases: the selection cluster head, aggregation data and MCT routing in intra-cluster, cluster heads send data to the sink. For increasing network life time, we use some methods such as fuzzy logic in cluster heads selection, using DSC techniques for data aggregation and use MCT algorithm to find the minimum path. All of distances are the Euclidean distance that has been obtained by (1).

$$d_{x,y} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (1)$$

4.1. Phase1- Cluster heads selection

We use fuzzy logic for cluster heads selection and the rules that are used are If-Then rules (Table 1). This algorithm is using the two parameters as input: distance to the sink (Distance to BS) and the residual energy of the nodes (Energy Level) for selecting cluster heads. First parameter is valued by Far, Medium and Close and second parameter can be valued by Low, Medium and High. The output would have value of Very Weak, Weak, Little Weak, Little Medium, Medium, High Medium, Little Strong, Strong and Very Strong.

In the first stage, the input energy and the distance to the sink has received and evaluated by the rules defined in Table 1 and finally the output will be a constant. Figures 2, 3 and 4in the input fuzzy parameters and output fuzzy sets are shown.

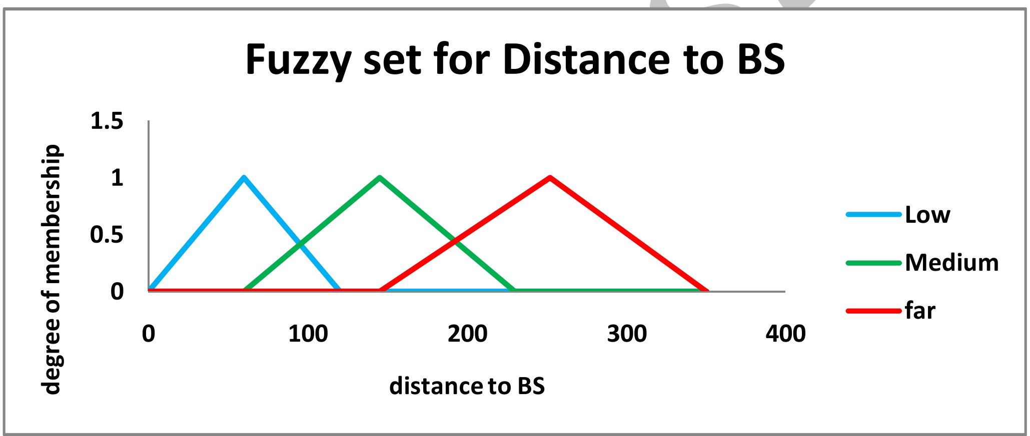

Figure.2. Input parameters from a fuzzy set to sink

Figures 2 and 3 are input parameters for fuzzy system and based on these parameters, determine chance for becoming cluster head (CH). The node which has more chance, is selected as CH. The diagram of chance is shown in figure 4. If a node has less distance to the sink and it has more energy level, its chance for becoming CH is high.

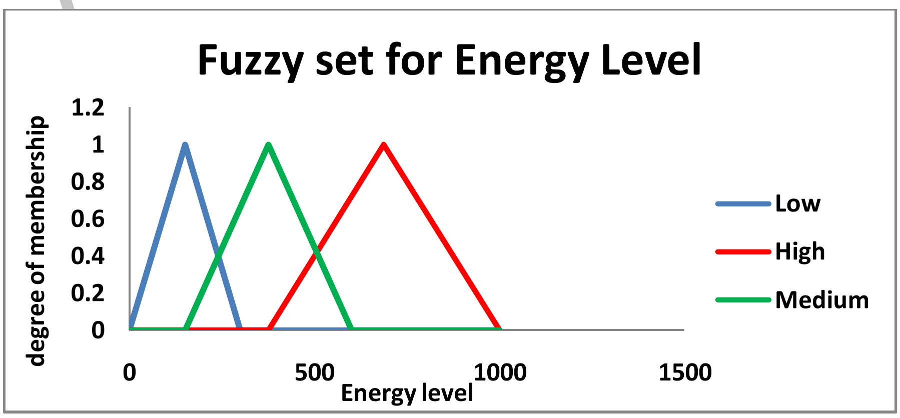

Figure.3.Energy level parameters of the fuzzy set of nodes

Figure 4 shows the chance for becoming CH in fuzzy set and the linguistic values for this variable can be Very Weak, Weak, Little Weak, Little Medium, Medium, High Medium, Little Strong, Strong and Very Strong.

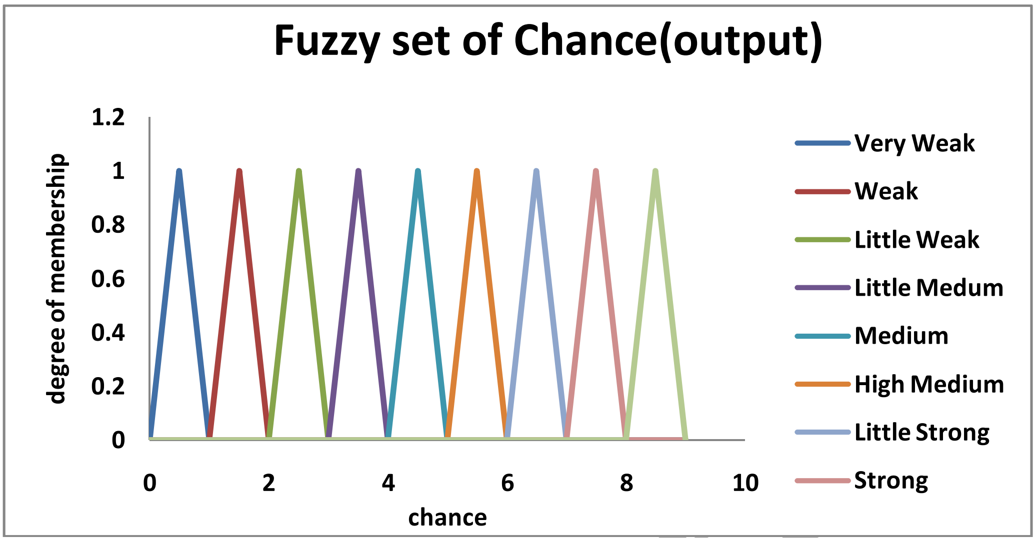

Figure.4. chance for becoming cluster heads in fuzzy set as output

Table1. Fuzzy If-Then rules in selecting cluster heads

	Energy Level	Distance to BS	Chance
1	Low	Far	Very Weak
2	Low	Medium	Weak
3	Low	Close	Little Weak
4	Medium	Far	Little Medium
5	Medium	Medium	Medium
6	Medium	Close	High Medium
7	High	Far	Little Strong
8	High	Medium	Strong
9	High	Close	Very Strong

4.2. Phase2-MCT routing in intra-cluster and aggregation data

Before introducing the MCT algorithm, at first we must have some basic definitions that will help us to understand the algorithm.

(I) The basic definitions

For data aggregation is used the DSC technique. In fact, the main idea of this technique is reducing the redundancy as much as possible and to reduce the data size. A sensor network with N nodes (X_1, X2,..., XN), its entropy will be shown by H (X_1, X_2, ..., X_N).

DSC techniques are used to reduce data redundancy. According to the information theory, we have:

$$H(x_1, x_2, \dots, x_N) \leq H(x_1) + H(x_2) + \cdots + H(x_N) \quad (2)$$

$$H(x_1, x_2, \dots, x_N) = H(x_1) + H(x_2|x_1) + \dots + H(x_N|x_1, x_2, \dots, x_N) \quad (3)$$

And also:
And $H(x_2|x_1)$ is entropy of $x_2$that has the information of x_1 too, also $H(x_N|x_1, x_2, \dots, x_N)$ is defined similar to $H(x_2|x_1)$.

DSC implementation in large networks with many nodes is an NP-Complete problem [19], so we cluster the network and implement these algorithms in each cluster.
$L_{0,2}(\mathrm{d})$ is part of the energy factor when the data is sent from node S_2 to S_0.
$L_{S_3}(\mathrm{d})$is part of the energy factor when the data is sent from node $S_3$to the sink S_0.

$$L_{0,2}(\mathrm{d}) = 2\mathrm{E_{elec}} + \mathrm{E_{amp}}.\mathrm{d}(S_0, S_2)^2 \quad (4)$$

$$L_{S_3}(\mathrm{d}) = L_{0,2}(\mathrm{d}) + L_{2,3}(\mathrm{d}) \quad (5)$$

Where d (S_0, S_2) is the distance between two nodes S_0, S_2that S_3 sensor is sent your data through S_2 to S_0.
The cost functions when S4 sends its data from node S_0 to node $S_1$is:

$$\mathrm{C}_{S_1}[\mathrm{S}_4, \mathrm{S}_0] = \mathrm{k}_1 \left(L_{1,4}(\mathrm{d}) + L_{S_1}(\mathrm{d}) \right) \quad (6)$$

And if sends through node S_3:

$$\mathrm{C}_{S_3}[\mathrm{S}_4, \mathrm{S}_0] = \mathrm{k}_3 \left(L_{3,4}(\mathrm{d}) + L_{S_3}(\mathrm{d}) \right) \quad (7)$$

k1 and k2 are the number of transmitted bits which is obtained through the theory information and following formula:

$$\mathrm{k}_1 = \mathrm{n_{data}} \times \left(\mathrm{Entropy}(\mathrm{S}_1, \mathrm{S}_4) - \mathrm{Entropy}(\mathrm{S}_4) \right) \quad (8)$$

$$\mathrm{k}_3 = \mathrm{n_{data}} \times \left(\mathrm{Entropy}(\mathrm{S}_3, \mathrm{S}_4) - \mathrm{Entropy}(\mathrm{S}_4) \right) \quad (9)$$

Entropy (S_4) is entropy data that is obtained from S4 and the entropy (S_1, S_4) is the entropy of the combination of S1 and S_4 and n_{data} is the number of data bits.
Total energy expense is as follows:

$$\bar{C} = \sum_{i=1}^{N} C_{path-i}[S_i, R] \quad (10)$$

N is the total number of sensor nodes in the network, C_ (path-i) [S_i, R] is energy costs, when Si sends data to Ri through path i.

(II) MCT routing within a cluster

In the intra- cluster routing, a routing algorithm is used based on the minimum cost tree (MCT). At first we consider a set Ω that represents the minimum cost or minimal. It begin from the cost of a cluster heads and will continue until it includes all minimum cost nodes. The minimum cost of cluster heads to its own is considered zero. The cost of other sensor nodes is the sum of Edge cost function connected to the node and edge cost function which is supposed to be added to that node.

At each step, a node is added to the set Ω and a node is added to the collection, so this node is not selectable in the later stages. This algorithm chooses a minimum path definitely to prove see the source [21].

To obtain the optimal path, if C (Ssink, S *) is cost of each sensor to the sink, cluster head send a message with the minimum cost to its direct neighbors (cost of cluster heads to its own is considered zero).A node which receive the message do this way: in the first stage if Sj is cluster head and Si is a node which receive message we have:

While si receives the message from sj
If message contain cost C (ssink, sj)
If C (Ssink, sj) + C (sj, si) <C (Ssink, si)
C (Ssink, si) = C (Ssink, sj) + C (sj, si);
Set sj as si parent sensor;
sj broadcast a message to its directly connected neighbor sensors with C (Ssink, si);

So in this phase we use MCT routing for gathering data from intra cluster nodes which its own use DSC technique for gathering data. In this phase sink is the main center which the data send to.

4.3. Phase3-Send to sink

In this phase when the clusters were formed, Cluster heads collect data from its cluster members and according to the DSC techniques, compress data from sensor to sensor, and place in a packet in the cluster heads and send it to its neighbor cluster heads which is closer to the sink to be delivered to the sink.

5. Results of the simulation algorithm

The proposed algorithm is simulated with MATLAB R2010a. We distribute 100 nodes randomly in a 100 m × 100 m screen coordinates. The parameters used in the implementation of this algorithm are shown in Table 2.

We compare our proposed algorithm with a clustering MCT algorithm (in this research is called briefly CMCT). The results of our implementation show that the proposed algorithm by using a fuzzy cluster heads choose the very best acts of the previous algorithm and enhance the network lifetime and reduce energy costs of nodes. The MCT algorithm to compress data that is sent from sensor to sensor - is used compression method based entropy.

Radio model

Radio model for communication between nodes used in this paper comes from sources [21] and [20]. Equation (11) shows k bits power consumption at a distance d to the node transmitter and (12) shows k bits power consumption for nodes receiving energy:

$$\mathrm{E_{Tx}(k, d) = E_{elec} \times k + E_{amp} \times k \times d^{\,2}}. \tag{11}$$

$$R_{Tx}(k, d) = E_{elec} \times k. \tag{12}$$

Equation (13) shows the total energy consumption:

$$\mathrm{E}_{total} = E_{Tx}(k, d) + R_{Tx}(k, d) = \left(2E_{elec} + E_{amp} \times d^2\right) \times k = L(d) \times k \tag{13}$$

Table 2 describes the parameters used in the implementation.

Table.2. Parameters of the algorithm in radio Model

Values	Parameters
50 nJ	E_{elec}
(50,50)m	Sink Location
10pJ/bit/m^4	E_{amp}

The following charts compare the energy consumption and the number of surviving nodes in per iteration for different nodes; we examine the number of sensor nodes to the network to see what will be changed.

In this scenario, the numbers of sensor nodes in the network are considered 100, Figure 5 shows the numbers of the live nodes in per iteration for four algorithms. FCMCT is compared with three different clustering algorithms, namely LEACH, HEED, CMCT; improvement in network lifetime in the diagram is visible.

This figure shows our algorithm has been improved, as you see in fig.5, our algorithm, FCMCT is %24 better than LEACH and it is %21.71 better than HEED and again it is %15.14 better than CMCT algorithm .

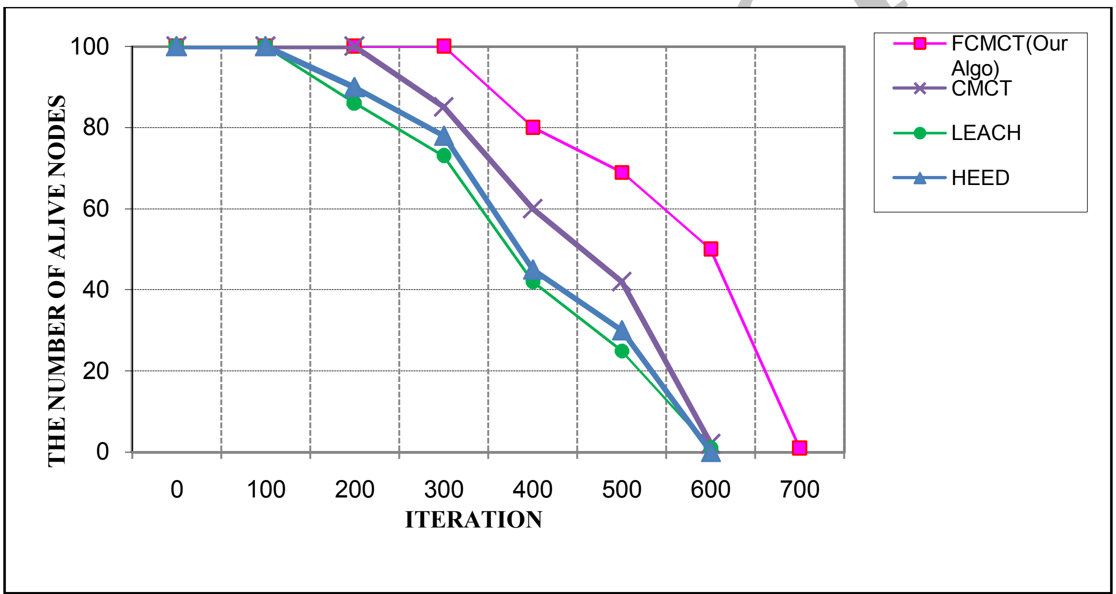

Figure.5.Comparison between four algorithms and number of live nodes with a 100 -node sensor

In the next experiment, by assuming different number of nodes, we compared the network lifetime in our algorithm (FCMCT) to LEACH, HEED and CMCT algorithms. Results of this experiment are shown in figure.6.

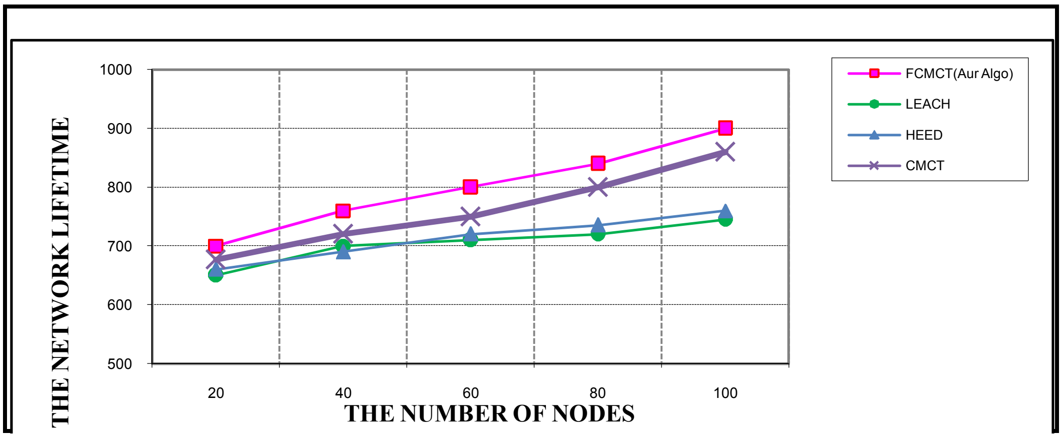

Figure.6.Comparison network lifetime between four algorithms with a 100 -node sensor

Handy et al. used the metrics first node dies (FND) in [30] to estimate the lifetime of the WSNs. As seen in table.3, simulation results show nodes in LEACH algorithm start to die earlier than the nodes in the other algorithm.

Table.3. FND metric in four algorithms

Algorithm	FND
LEACH	152
HEED	165
CMCT	278
FCMCT	367

Table 3 shows FCMCT is %24.26 more efficient than CMCT and %55.05 more efficient than HEED and %58.5 more efficient than LEACH algorithm considering in FND metric. Figure 7 shows power consumption of different nodes in two algorithms (FCMCT and CMCT. It shows that nodes in FCMCT algorithm are more balanced than nodes in CMCT algorithm.

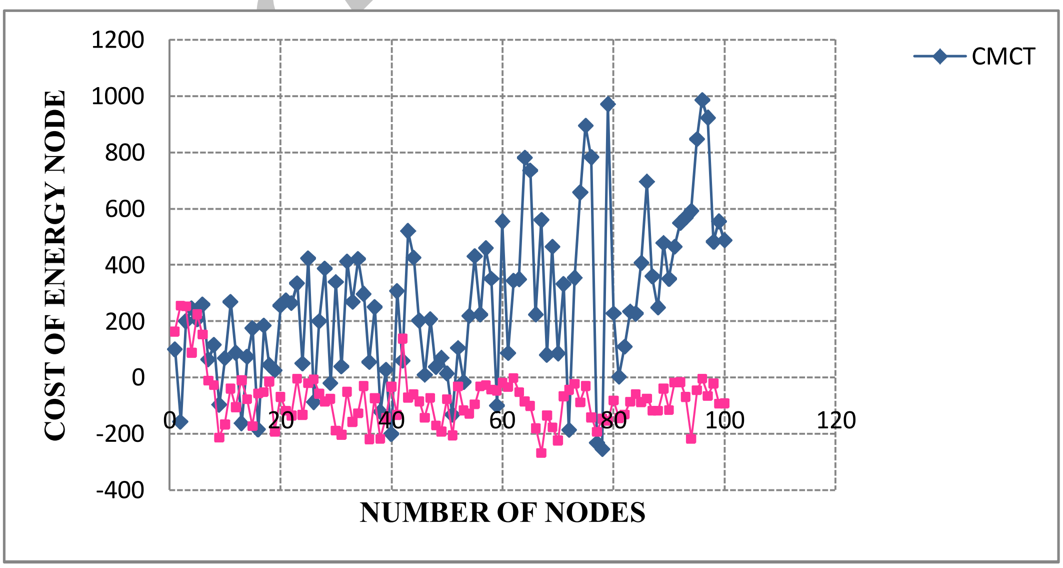

Figure.7.Comparison of the two algorithms on the energy cost of nodes to 100 nodes

This figure shows the proposed algorithm (FCMCT) from each 100 node, 91 nodes had a lower cost than CMCT algorithm and only 9 nodes in CMCT had a lower cost than the proposed algorithm. Implementation shows that the nodes in our algorithm have more balanced energy consumption and they use less energy. Several experiments show the improvement in the proposed algorithm.

6. Conclusion

In this paper, the most important goal was increasing network time life and saving more energy. The proposed algorithm (FCMCT) is able to achieve this. In comparison with CMCT, nodes in our algorithm consumed less and balanced energy, so they lose their energy later and it can help increasing the network life time. We can say methods are used such as fuzzy logic, MCT algorithm and distributed source coding (DSC) have been able to operate efficiently.

References

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, "A survey on sensor networks", *IEEE Communications Magazine* 40 No.8, pp104-112,2002.

[2] Jennifer Yick, Biswanath Mukherjee, Dipak Ghosal," Wireless sensor network survey ", *published by Computer Networks*, No52, pp.2292–2330, 2009.

[3] G. J. Pottie, W. J. Kaiser. "Wireless integrated network sensors" [J]. *Communications of the ACM,* 43(5) pp. 51 – 58, 2000.

[4] F. Ye, A. Chen, L. Zhang. "A scalable solution to minimum cost forwarding in large sensor networks[C]*"Proceedings of the10th International Conference on Computer Communications and Networks."* Piscataway: IEEE, 304 – 309.2001.

[5] P. Wang, C. Li, J. Zheng." Distributed data aggregation using clustered Slepian-Wolf coding in wireless sensor network*"[C]//IEEE International Conference on Communications. Piscataway: IEEE*, 3616 – 3622, 2007.

[6] L. Villalba, A. Orozco, A. Cabrera and C.Abbas,"Routing Protocols in Wireless Sensor Network", Vol 9, No.11, pp 8399-8421, 2009.

[7] L. Wang, C. Wang and C. Liu, "Optimal Number of Clusters in Dense Wireless Sensor Networks: A Cross- Layer Approach," *IEEE Transactions on VehTechnology*, Vol. 58, No. 2, pp. 966-976, 2009.

[8] W. Heinzelman, A. Chandrakasan, H. Balakrishnan, An application specific protocol architecture for wireless microsensor networks, *IEEE Trans. Wireless Comm.* 1 (4) 660–670. October 2002.

[9] Tao Liu, Qingrui Li, Ping Liang," An energy-balancing clustering approach for gradient-based routing in wireless sensor networks", *Computer Communications* No. 35pp. 2150–2161, 2012.

[10] H. Chen, S. Megerian. Efficient data collection through compression centric routing *[C]//IEEE Globecom. Piscataway: IEEE*, 2006.

[11] L. Almazaydeh, E. Abdelfattah, M. Al-Bzoor and A. Al- Rahayfeh, "Performance Evaluation Of Routing Protocols in Wireless Sensor Networks," *Internationalof Computer Science and Information technology"* .Vol 2No. 2, pp. 64-73, 2010.

[12] P. Loh and Y. Pan, "An Energy-Aware Clustering Ap-proach for Wireless Sensor Network," *Internationalnal of Communications, Network and System Sciences*, Vol. 2, No. 2, pp. 131-141, 2009.

[13] J. Kim, S. Park, Y. Han, T. Chung, CHEF: cluster head election mechanism using fuzzy logic in wireless sensor networks, in: *Proceedings of the ICACT,* pp.654–659, 2008.

[14] I. Gupta, D. Riordan, S. Sampalli, Cluster-head election using fuzzy logic for wireless sensor networks, in: *Proceedings of the 3rd Annual Communication Networks and Services Research Conference*, pp. 255–260, 2005.

[15] O. Younis, S. Fahmy, HEED: A hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks, *IEEE Trans. Mobile Comput.* 3 (4) 660–669, 2004.

[16] I. Gupta, D. Riordan, S. Sampalli, Cluster-head election using fuzzy logic for Wireless Sensor Networks, in: *Communication Networks and Services Research Conference, Proceedings of the 3rd Annual*,, pp. 255–260,2005.

[17] G. Ran, H. Zhang, S. Gong, "Improving on LEACH protocol of Wireless Sensor Networks Using Fuzzy Logic", *Journal of Information and Computational Science* pp. 767–775.2010.

[18] Youssef, M.A., M.F. Younis, and K.A. Arisha. "A constrained shortest- path energy-aware routing algorithm for wireless sensor networks."*Wireless Communications and Networking Conference*, 2002.

[19] Zhang, Liang, Xiangdong Wang, and Shujiang Li. "A routing algorithm based on clusters and balanced use of energy for wireless sensor networks." *Journal of Control Theory and Applications* 8, no. 1, 81-85, 2010.

[20] W.R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient Communication Protocol for Wireless Microsensor Networks", *in IEEE Computer Society Proceedings of the Thirty Third Hawaii International Conference on System Sciences (HICSS '00), Washington, DC, USA*, , vol. 8, pp. 8020, Jan. 2000.

[21] H. Chen, S. Megerian. "Efficient data collection through compression centric routing" *[C]//IEEE Globecom. Piscataway:* IEEE, 2006.

[22] Hoda Taheri, Peyman Neamatollahi, Ossama Mohamed Younis, Shahrzad Naghibzadeh, Mohammad Hossein Yaghmaee," An energy-aware distributed clustering protocol in wireless sensor networks using fuzzy logic", *Ad Hoc Networks* No.10,pp. 1469–1481,2012.

[23] Javaid, N.; Bibi, A.; Javaid, A.; Malik, S.A., "Modeling routing overhead generated by wireless proactive routing protocols," *GLOBECOM Workshops (GC Wkshps), 2011 IEEE*, vol., no., pp.1072,1076, 5-9.dec.2011.

[24] Javaid, N.; Ullah, M.; Djouani, K., "Identifying Design Requirements for Wireless Routing Link Metrics," *Global Telecommunications Conference (GLOBECOM 2011), 2011 IEEE*, vol., no., pp.1, 5, 5-9 Dec. 2011.

[25] Javaid, N.; Yousaf, M.; Ahmad, A.; Naveed, A.; Djouani, K., "Evaluating impact of mobility on wireless routing protocols," *Wireless Technology and Applications (ISWTA), 2011 IEEE Symposium* on , vol., no., pp.84,89, 25-28 Sept. 2011.

[26] N. Javaid, A. BiBi, A. Javaid, Z. A. Khan, K. Latif, M. Ishfaq, "Investigating Quality Routing Link Metrics in Wireless Multi-hop Networks", *Springer's Annals of Telecommunications - Annals des Telecommunications*, 2013.

[27] M. Tahir, N. Javaid, A. Iqbal, Z. A. Khan, N. Alrajeh, "On Adaptive Energy Efficient Transmission in WSNs", *International Journal of Distributed Sensor Networks*, Volume 2013, Article ID 923714, 10 pages, 2013.

[28] G.J. Klir, B. Yuan, "Fuzzy Sets and Fuzzy Logic: Theory and Applications*", Prentice-Hall Inc., Upper Saddle River, NJ, USA*, 1995.

[29] Hakan Bagci, Adnan Yazici," An energy aware fuzzy approach to unequal clustering in wireless *sensor networks", Applied Soft Computing (*journal homepage: www.elsevier.com/locate/asoc.*)* No.13 p. 1741–1749, 2013.

[30] M. Handy, M. Haase, D. Timmermann, Low energy adaptive clustering hierarchy with deterministic cluster-head selection, in: *IEEE MWCN, Citeseer*, 2002.