FCA - An Approach On LEACH Protocol Of Wireless Sensor Networks Using Fuzzy Logic

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In order to gather information more efficiently, wireless sensor networks are partitioned into clusters. The most of the proposed clustering algorithms do not consider the location of the base station. This situation causes hot spots problem in multi-hop wireless sensor networks. In this paper, we propose a fuzzy clustering algorithm (FCA) which aims to prolong the lifetime of wireless sensor networks. FCA adjusts the cluster-head radius considering the residual energy and the distance to the base station parameters of the sensor nodes. This helps decreasing the intra-cluster work of the sensor nodes which are closer to the base station or have lower battery level. We utilize fuzzy logic for handling the uncertainties in cluster-head radius estimation. We compare our algorithm with LEACH according to first node dies, half of the nodes alive and energy-efficiency metrics. Our simulation results show that FCA performs better than other algorithms in most of the cases. Therefore, our proposed algorithm is a stable and energy-efficient clustering algorithm.

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1. INTRODUCTION

Most of the clustering algorithms utilize two techniques which are selecting cluster-heads with more residual energy and rotating cluster-heads periodically to balance energy consumption of the sensor nodes over the network . These clustering algorithms do not take the location of the base station into consideration. This lack of consideration causes the hot spots problem in multi-hop wireless sensor networks. The cluster-heads near the base station die earlier, because they will be in a heavier relay traffic than the cluster-heads which are relatively far from the base station.. In order to solve this problem and to balance energy consumption of cluster-heads, a periodically rotating cluster-head mechanism is firstly proposed by [I. Gupta and Sampalli 2005] namely LEACH is a clustering algorithm that utilizes randomized rotation to balance energy consumption of cluster-heads over the network (Low-Energy Adaptive Clustering Hierarchy). LEACH. Randomized periodical rotation property of LEACH is used in many clustering algorithms. Although periodical rotation is a vital property for clustering algorithms, it is not sufficient by itself. Most of the clustering algorithms, use periodical rotation as a base property and build their approach on top of it.

In this paper, a fuzzy clustering approach (FCA) is introduced to make a further improvement in maximizing the lifetime of the WSN. FCA is a distributed competitive algorithm. It selects the cluster-heads via energy-based competition among the tentative cluster-heads which are selected us-

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ing a probabilistic model. FCA mostly focuses on wisely assigning competition ranges to the tentative cluster-heads. In order to make wise decisions, it utilizes the residual energy and the distance to the base station parameters of the sensor nodes. In addition to this, FCA uses fuzzy logic to handle uncertainties in competition range estimation.

FCA is a clustering algorithm assigns competition ranges to the tentative cluster-heads considering only the distance to the base station parameter. However, FCA utilizes both the residual energy and the distance to the base station parameters of the tentative cluster-heads for estimating competition ranges. FCA assigns greater competition ranges to the tentative cluster-heads which have higher residual energy levels, because they can serve to a larger region.

2. RELATED WORK - FUZZY CLUSTERING ALGORITHMS

There are several clustering algorithms for WSNs in recent years. In this section, we review fuzzy clustering algorithms [Huruiala et al. 2010]. Fuzzy logic is useful for making real time decisions without needing complete information about the environment. On the other hand, conventional control mechanisms generally need accurate and complete information about the environment. Fuzzy logic can also be utilized for making a decision based on different environmental parameters by blending them according to predefined rules.

Some of the clustering algorithms [Bagci and Yazici 2010] employ fuzzy logic to handle uncertainties in the wireless sensor networks. Basically, fuzzy clustering algorithms use fuzzy logic for blending different clustering parameters to elect cluster-heads. They assign chances to tentative cluster-heads according to the defuzzified output of fuzzy if-then rules. The tentative cluster-head becomes a cluster-head if it has the greatest chance in its vicinity. There are distributed and centralized fuzzy logic clustering approaches.

In the fuzzy clustering approach proposed by [Yu and Chong 2005] the cluster-heads are elected at the base station. In every round, each sensor node forwards its clustering information to the base station. There are three fuzzy descriptors which are considered by the base station during cluster-head election. These fuzzy descriptors are node concentration, residual energy in each node and node centrality [J.M. Kim and Chung 2008]. The definitions of these fuzzy descriptors are given below:

(1) Node Concentration: Number of the nodes in the vicinity
(2) Residual Energy: Remaining battery energy of each sensor node
(3) Node Centrality: A parameter that indicates how central the node is to the cluster

There are 27 fuzzy if-then rules which are defined at the base station [Zimmermann 2001]. The base station elects the cluster-heads according to these fuzzy rules. After the base station elects the cluster-head, it forwards the election results to entire network. This algorithm is a centralized clustering algorithm, because all clustering decisions are made at the base station. Gupta et al. claims that a centralized clustering approach will produce more accurate cluster-heads, because the base station has all clustering information about the network and base stations are more powerful than ordinary nodes [Bagci and Yazici 2010]. However, this centralized approach have some disadvantages [D. Turgut et al. 2005]:

(1) The base station must collect all clustering information from the network. Repeating this process in every round brings a high overhead to sensor nodes. Thus, the battery levels of the sensor nodes may run low quickly
(2) In this approach the simulation is done for electing only one cluster-head per round. Therefore, this simulation is not a realistic one.

3. LEACH CLUSTERING PROTOCOL

LEACH (Low-Energy Adaptive Clustering Hierarchy) [Ibriq and Mahgoub 2004] is a distributed algorithm which makes local decisions to elect cluster-heads. If the cluster-heads are selected for once and do not change throughout the network lifetime, then it is obvious that these static cluster-heads die earlier than the ordinary nodes. Therefore, LEACH includes randomized rotation of cluster-head locations to evenly distribute the energy dissipation over the network. LEACH also performs local data compression in cluster heads to decrease the amount of data that is forwarded to the base station.

In LEACH, cluster-head election is done periodically to enable randomized rotation of cluster-heads. Every round consists of two phases, namely set-up phase and steady-state phase. In set-up phase, cluster-heads are elected and clusters are formed. In steady-state phase, data transfers to the base station are performed through the clustered network. A particular sensor node decides whether it is going to become a cluster-head or not by generating a random number between 0 and 1. If this number is less than the predefined threshold *T*(n), then the sensor node becomes a cluster-head. G represents the set of sensor nodes that have not been cluster-heads in the last $\frac{1}{P}$ where *P* is the desired percentage of cluster-heads. r represents the current round number. Using these parameters, *T*(n) is formulated as follows: If the sensor node n belongs to G:

$$T(n) = \frac{P}{1 - P * (r \quad mod \frac{1}{P})} \tag{1}$$

If the sensor node n does not belong to G, then the T (n) is set to 0. Thus, n cannot become a cluster-head. At round 0, the probability of becoming a cluster-head for each node is equal to P. However, this situation changes in the following rounds. The cluster-heads of round 0 cannot become cluster-heads during the following $\frac{1}{P}$ rounds. This restriction prevents a particular node to become a cluster-head frequently. However, this restriction brings a drawback. It causes rapid decrease in the number of cluster-heads. To handle this drawback, as r increases, the chance of the remaining sensor nodes to be a cluster-head is also increased by adjusting the threshold *T*(n) for the remaining sensor nodes. This critical balance is a significant property of LEACH.

After cluster-heads are elected for a particular round, each cluster-head broadcasts an advertisement message to the remaining sensor nodes. As each non-cluster-head node receives these advertisement messages, they decide the cluster to which they belong. Each non-cluster-head joins to the cluster from which it has received the largest signal strength. In order to join to the selected cluster, it transmits a *JoinClusterHeadMessage* to that cluster. Once all the cluster-heads are selected and the clusters are formed, data transmission continues up to the next round. The simulations in [Ibriq and Mahgoub 2004] showed that LEACH reduces communication energy as much as 8 times as compared to direct transmission. In other words, the first node death in LEACH occurs 8 times later than the first node death in direct transmission. Since we compare our proposed algorithm with LEACH, we have developed a LEACH simulation.

Figure 1 and Figure 2 shows two different cluster-head distribution examples over the network for two different particular rounds [F. Kuhn and Wattenhofer 2004]. In both of the examples, the number of deployed sensor nodes is 200. The desired percentages of cluster-heads are 0.05 and 0.1, respectively for the examples in Figure 1 and Figure 2

4. PROPOSED FUZZY CLUSTERING ALGORITHM (FCA)

FCA is a distributed competitive unequal clustering algorithm. It makes local decisions to determine competition radius and to elect cluster-heads.FCA employs both residual energy and distance to the

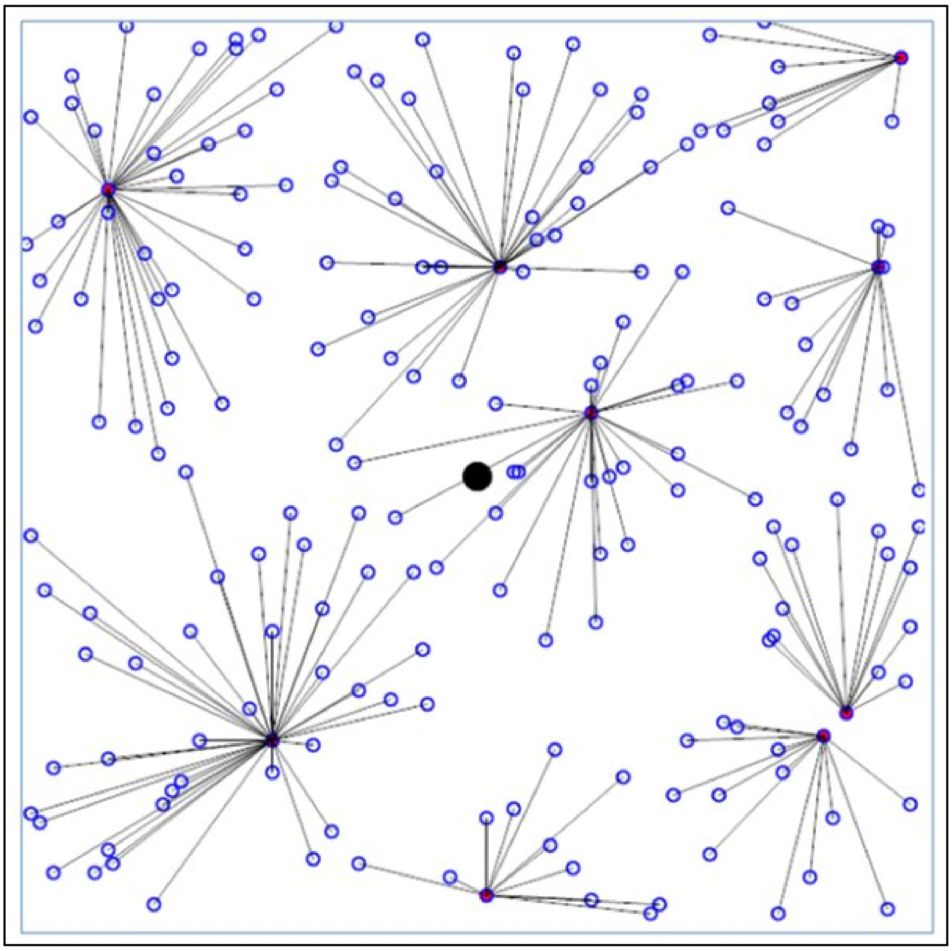

Fig. 1. Cluster-head distribution example for LEACH with P = 0.05

base station parameters of the sensor node. Moreover, FCA takes advantage of using fuzzy logic to calculate competition radius. LEACH protocol rotates the cluster-heads periodically in each round by using a probabilistic model. FCA also employs a probabilistic model, but it does not elect the final cluster-heads by just depending on this model. FCA clustering algorithm is explained in algorithm 1 below

In every clustering round, each sensor node generates a random number between 0 and 1. If the random number for a particular node is smaller than the predefined threshold T , which is the percentage of the desired tentative cluster-heads, then that sensor node becomes a tentative cluster-head. The competition radius of each tentative cluster-head changes dynamically in FCA, because FCA uses residual energy parameter with distance to the base station metric of the sensor node to calculate competition radius. It is logical to decrease the service area of a cluster-head while its residual energy is decreasing. If the competition radius does not change as the residual energy decreases, the sensor node runs out of battery rapidly. FCA takes this situation into consideration and decreases the competition radius of each tentative cluster-head as the sensor node battery level decreases. Radius computation is accomplished by using predefined fuzzy if-then mapping rules to handle the uncertainty. These fuzzy

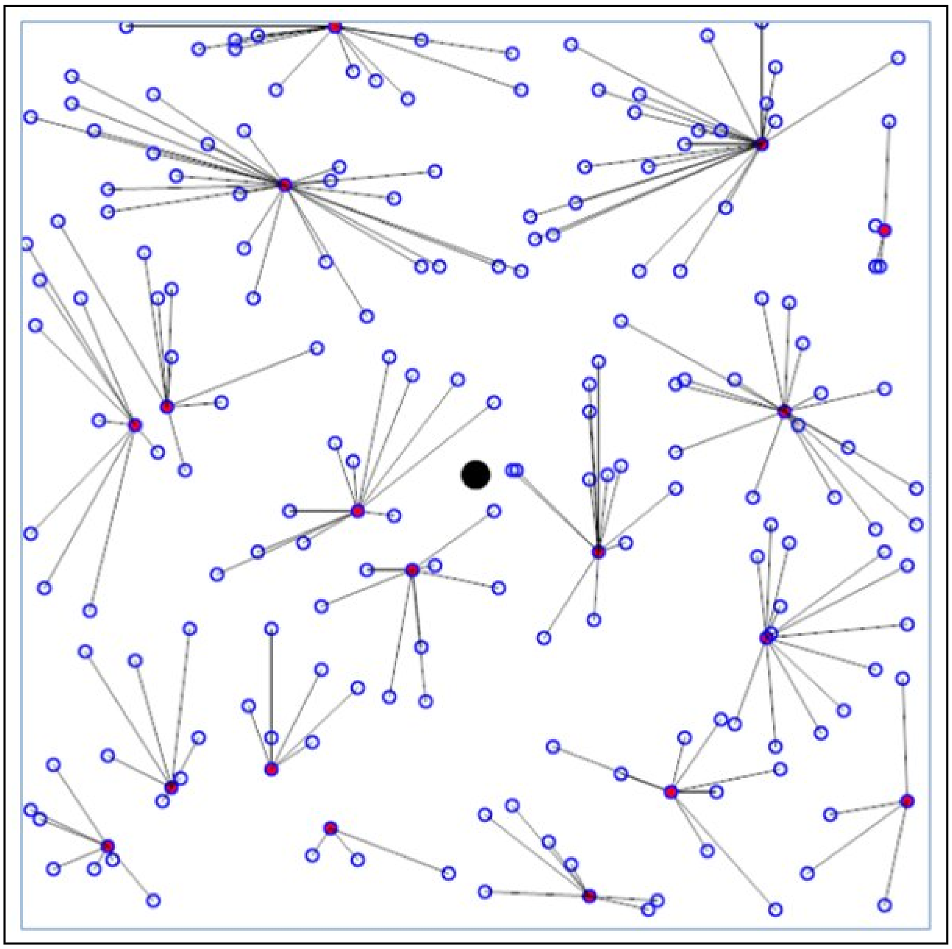

Fig. 2. Cluster-head distribution example for LEACH with P = 0.1

if-then mapping rules are given in Table 3.2. We have used Mamdani Method [Negnevitsky 2001] as fuzzy inference technique, because it is the most frequently used fuzzy inference technique

In FCA cluster-head competition radius calculation, we use two fuzzy input variables. The first one is the distance to the base station of a particular tentative cluster-head. The fuzzy set that describes the distance to base the station input variable is depicted in Figure 3. The linguistic variables for this fuzzy set are *close*, *medium* and *far*. We choose a trapezoidal membership function for *close* and *far*. On the other hand, the membership function of medium is a triangular membership function.

The second fuzzy input variable is residual energy of the tentative cluster-head. The fuzzy set that describes residual energy input variable is illustrated in Figure 3 low, medium and high are the linguistic variables of this fuzzy set. low and high linguistic variables have a trapezoidal membership function while medium has a triangular membership function.

The only fuzzy output variable is the competition radius of the tentative cluster-head. Fuzzy set for competition radius fuzzy output variable is demonstrated in Figure 4. We have linguistic variables which are *very small, small, medium, large, large* and *very large*. *very small* and *very large* have a

ALGORITHM 1: Proposed Fuzzy Clustering Algorithm (FCA)

```
T ← probability to become a tentative cluster-head
nodeState ← CLUSTERMEMBER
clusterMembers ← empty
myClusterHead ← this
beTentativeHead ← TRUE
μ ← rand(0,1)
IF μ < T THEN
   Calculate R_comp using fuzzy if-then mapping rules
   Advertise CandidateClusterHeadMessage (ID, R_comp, residualEnergy)
   On receiving CandidateClusterHeadMessage from node N
   if this.residualEnergy < N.residualEnergy then
    beTentativeHead ← False
    Advertise QuitElectionMessage(ID)
   end if
end if
if beT entativeHead = TRUE then
   Advertise ClusterHeadMessage(ID)
   ← CLUSTERHEAD
   On receiving JoinClusterHeadMessage(ID) from node N
   add N to the clusterMembers list
   EXIT
else
   On receiving all ClusterHeadMessages
   myClusterHead ← the closest cluster-head
   Send JoinClusterHeadMessage(ID)
   EXIT
end if
```

Table I. Fuzzy if-then mapping rules for competition radius calculation in FCA

Rule No	Distance to Base	Residual Energy	Competition Radius
1	Close	Low	Very Small
2	Close	Medium	Small
3	Close	High	Small
4	Medium	Low	Small
5	Medium	Medium	Medium
6	Medium	High	Large
7	Far	Low	Large
8	Far	Medium	Large
9	Far	High	Very Large

trapezoidal membership function. The remaining linguistic variables are represented by using triangular membership functions.

If a particular tentative cluster-heads battery is full and it is located at the maximum distance to the base station, then it has the maximum competition radius. On the contrary, if a particular cluster-heads battery is near empty and is the closest node to the base station, then it has the minimum competition radius. The remaining intermediate possibilities fall between these two extreme cases.

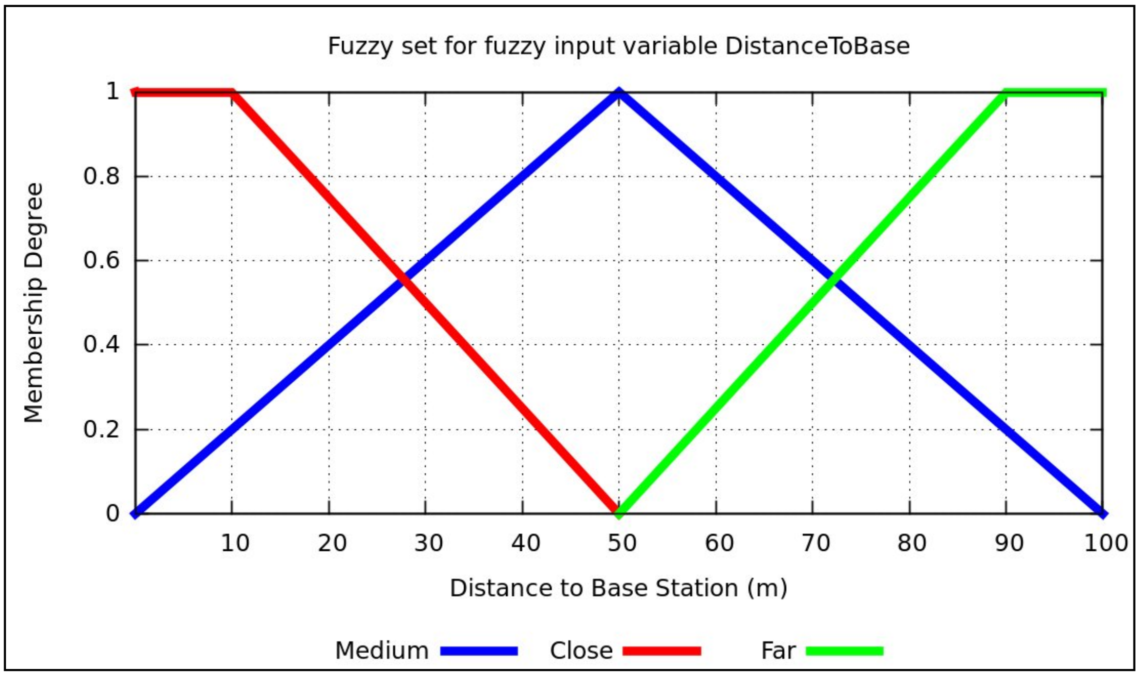

Fig. 3. Fuzzy set for fuzzy input variable *DistanceToBase*

The maximum competition radius is a static parameter for a particular wireless sensor network. The base station broadcasts the value of this parameter to the entire network. Thus, all the sensor nodes know the maximum competition radius, in advance. Each of the sensor nodes can calculate their relative competition radius according to the value of this parameter. The maximum distance to the base station is also a static parameter, because we assume that the sensor nodes are stationary. Each sensor node can determine their relative position to the base station considering the maximum distance to the base station in the WSN.

5. RESULTS AND DISCUSSION

We compare our clustering algorithm FCA with LEACH using WiseNet Simulator used by [Chen 2010].

5.1 Scenarios

In order to evaluate our proposed algorithm FCA, we have compared FCA with LEACH.

In each round of the scenario, clusters-heads are elected and clusters are formed. Afterwards, each ordinary node forwards a certain bits of data to its cluster-head. Each cluster-head aggregates the received data and forwards it to the base station with a particular routing protocol or directly transmits the aggregated data to the base station. LEACH cluster-heads transmit their data packets to the base station directly

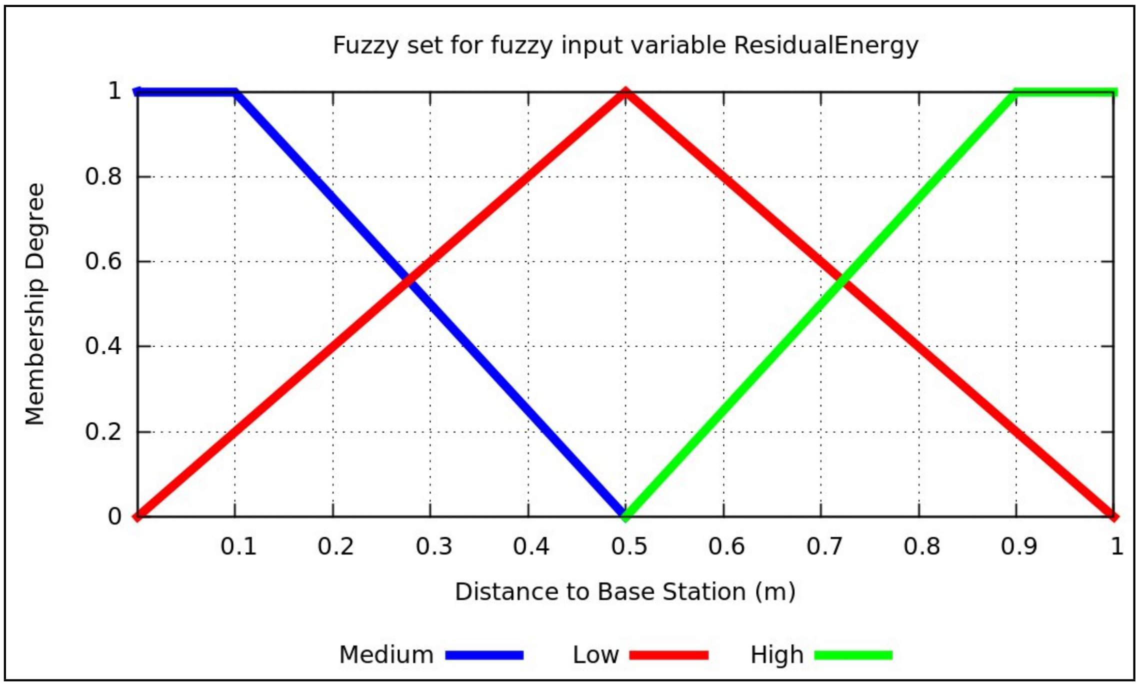

Fig. 4. Fuzzy set for fuzzy input variable *ResidualEnergy*

The area of deployed wireless sensor network is same for all scenarios and is 200x200 m. In each round, each ordinary sensor node transmits 4000 bits of data to its cluster-head. The cluster-head which receives the data from its cluster members, aggregates the received data with a certain aggregation ratio. This aggregation ratio is set to 10% in our simulations.

In order to produce more reliable results, every scenario is simulated for 50 times, and the average of the results are taken. For each of the scenarios, we provide a summary result table which represents the values of First Node Dead FND and Half Node Alive HNA metrics for each of the algorithms simulated. After that, we provide a summary chart which illustrates the values of FND and HNA metrics visually. We also generate charts for the distribution of the number of alive sensor nodes and the distribution of the number of clusters per each round. By using these simulation results, we comment on the performance of the simulated algorithms.

5.1.1 *Scenario 1.* In this scenario, the base station is located at the center of the wireless sensor network [Haining Shu and Gao 2008]. Each cluster-head forwards the aggregated data to the base station directly without using a relay node. The detailed configuration of this scenario is depicted in Table II The simulation of this scenario yielded the following results. Table III shows the rounds in which the first node died (FND) and half of the nodes alive (HNA) for each simulated algorithm.

As seen in Table III, our proposed algorithm FCA performs better than LEACH. FCA is more efficient than LEACH about 36.4%

Table II. Configuration parameters of Scenario 1

Parameter	Value
Network Size	200 X 200m
Base Station Location	(100,100)m
No. Of Sensor Nodes	75
Initial Energy	1 J
Data Packet Size	3000 Bytes
Aggregation Ratio	10%

Table III. Scenario 1: Values of FND and HNA metrics for each algorithm

Algorithm	FND	HNA
LEACH	280	610
FCA	420	810

LEACH performance is the poorest one, because it does not consider the residual energy level of the sensor nodes during clustering. It uses a pure probabilistic model for clustering, but this model itself is not sufficient for providing the best solution
The summary chart in Figure 5 illustrates the comparison of algorithms according to FND and HNA metrics visually. Figure 6 depicts the distribution of the number of alive sensor nodes with respect to

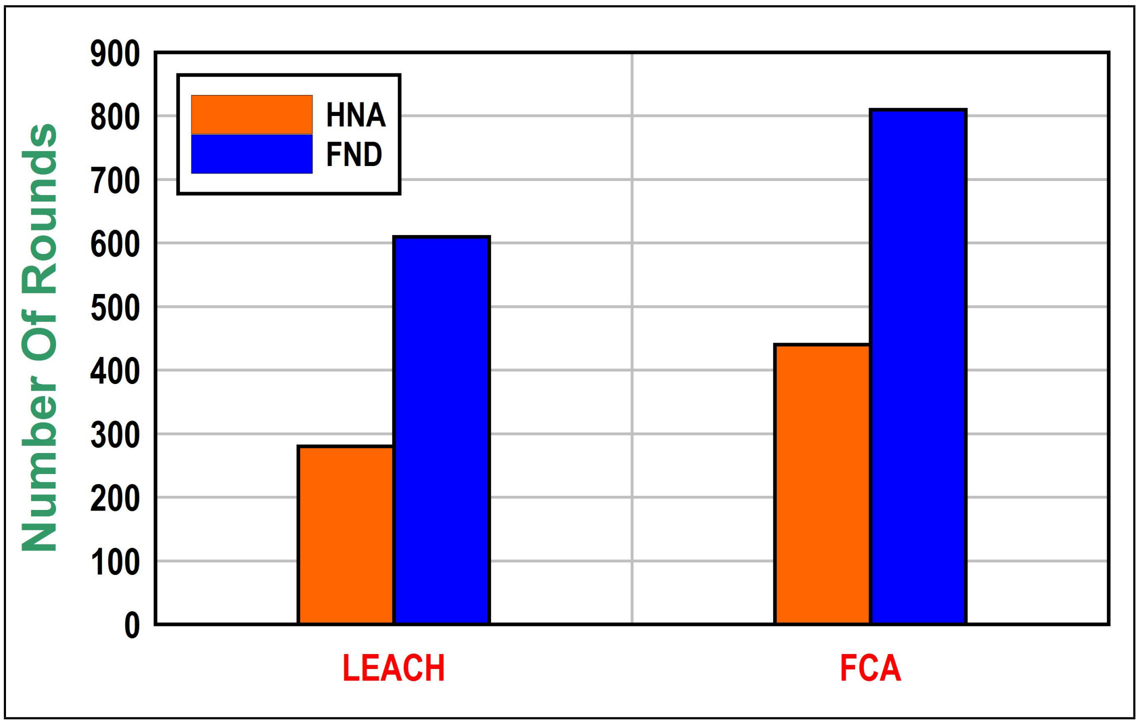

Fig. 5. Scenario 1: Values of FND and HNA metrics for each algorithm

the number of rounds for each algorithm. This figure clearly depicts that deaths of sensor nodes for FCA begin after LEACH algorithm.

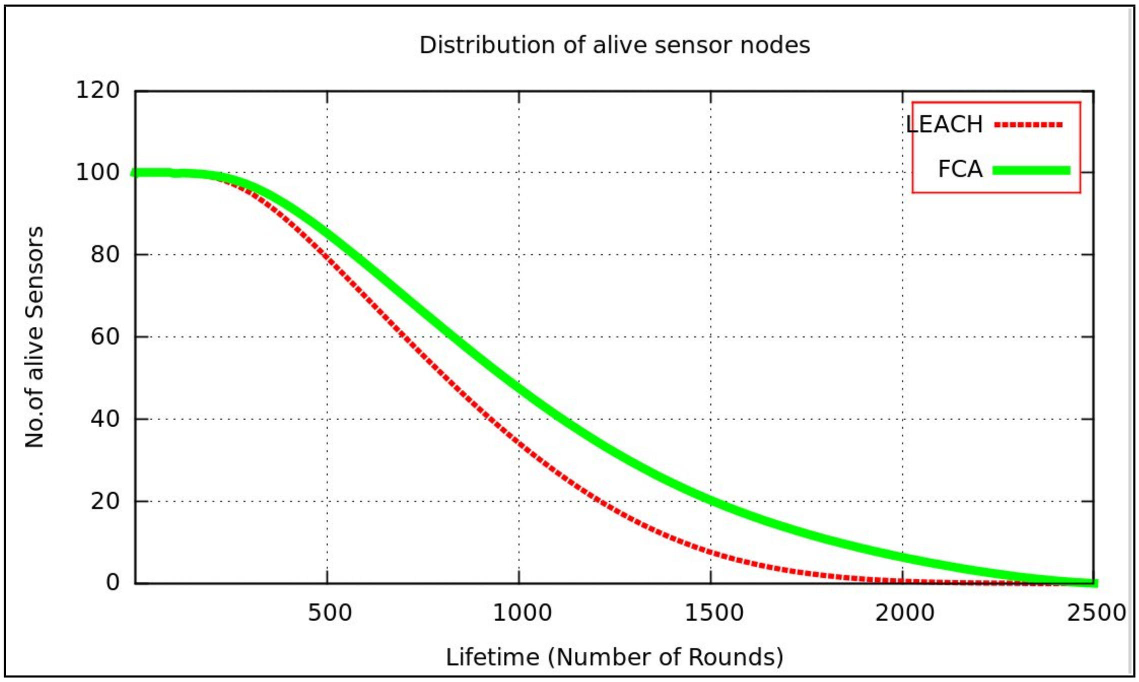

Fig. 6. Scenario 1: Distribution of alive sensor nodes according to the number of rounds for each algorithm

5.1.2 *Scenario 2.* In this scenario, the density of the deployed sensor nodes is doubled with respect to Scenario 1. We aim to test the behaviours of the clustering algorithms in different sensor network topologies which have different number of deployed sensor nodes which is similar to used by [4 2012]. In other words, we try to find out how clustering algorithms perform in relatively dense and sparse sensor network deployments. The detailed configuration of this scenario is illustrated in Table IV

Table IV. Configuration parameters of Scenario 2

Parameter	Value
Network Size	200 X 200m
Base Station Location	(100,100)m
No. Of Sensor Nodes	150
Initial Energy	1 J
Data Packet Size	3000 Bytes
Aggregation Ratio	10%

The simulations of this scenario provided the following results. The values for FND and HNA metrics for each algorithm are shown in Table V

Table V. Scenario 1: Values of FND and HNA metrics for each algorithm

Algorithm	FND	HNA
LEACH	400	790
FCA	790	980

As seen in Table V the HNA performance of LEACH is increased significantly in this scenario. LEACH sensor nodes start to die earlier than the sensor nodes of FCA. FCA is more efficient than LEACH about 84.7%

In this scenario, FND performance of LEACH is significantly lower than FCA. Figure 7 demonstrates the comparison of the values of FND and HNA metrics for each simulated algorithm in a visual manner.

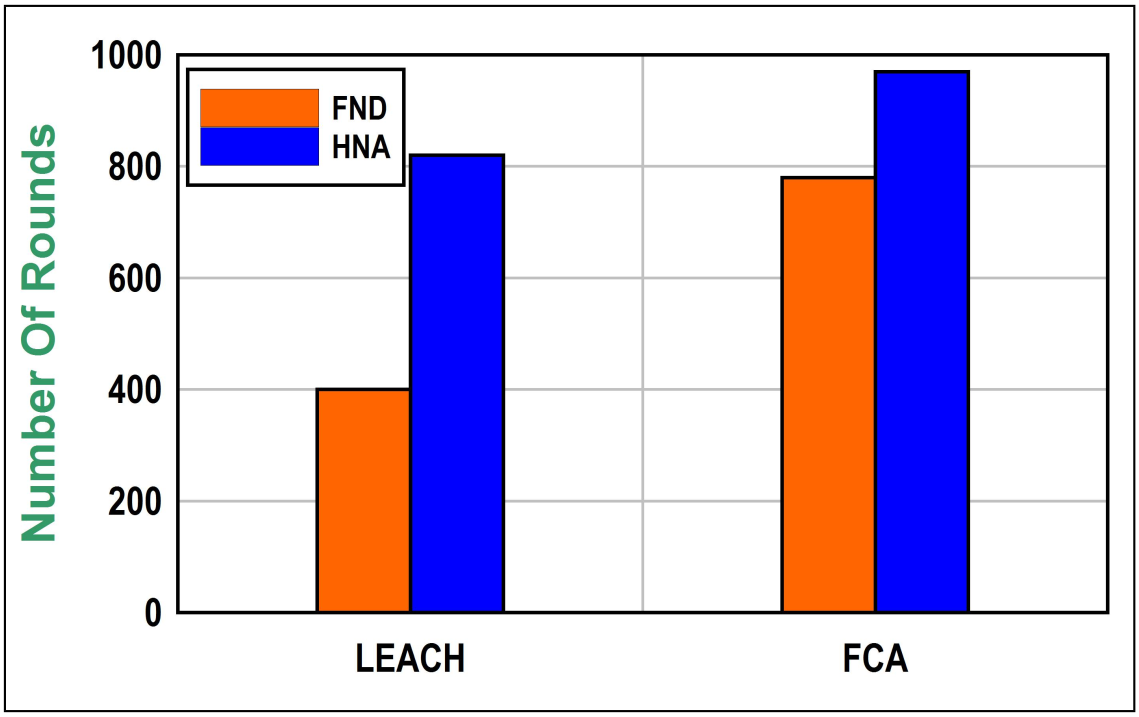

Fig. 7. Scenario 2: Values of FND and HNA metrics for each algorithm

Figure 8 shows the distribution of the alive sensor nodes according to the number of rounds for each simulated algorithm. As seen in this figure, the number of sensor nodes of FCA algorithm is significantly greater than the other algorithms when the number of alive sensor nodes is 100. This situation implies that FCA keeps the wireless sensor network stable for a longer time than the other algorithms.

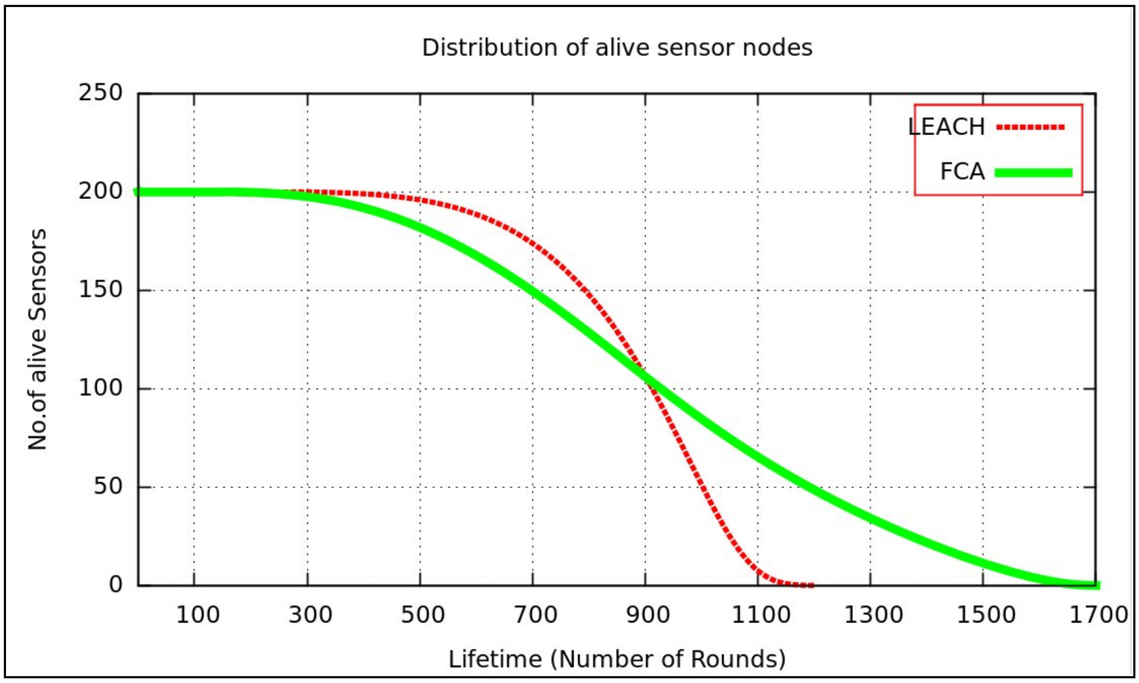

Fig. 8. Scenario 2: Distribution of alive sensor nodes according to the number of rounds for each algorithm

6. CONCLUSION AND FUTURE WORK

In this paper we have proposed a fuzzy clustering algorithm for wireless sensor networks, namely FCA. The main objective of our algorithm is to prolong the lifetime of the wireless sensor network by evenly distributing the workload.

FCA adjusts the cluster-head radius values considering energy and distance to the base station parameters of the sensor nodes. We blend these parameters by using fuzzy logic to obtain an appropriate cluster-head radius. If a particular sensor node has a higher residual energy and is located far from the base station, then it has a greater cluster-head radius. On the other hand, if a particular sensor node has a lower residual energy and is close to the base station, then it has a smaller radius. The network traffic increases as we approach to the base station in multi-hop wireless sensor networks. Therefore, the sensor nodes close to the base station die earlier. Our radius adjustment mechanism solves this hot spots problem by reducing the intra-cluster work of the cluster-heads closer to the base station.We have shown that our proposed algorithm has a better performance compared to LEACH

As a result of these experiments, we conclude that fuzzy unequal clustering algorithm FCA is a stable and energy-efficient clustering algorithm for wireless sensor networks. FCA algorithm is designed for the wireless sensor networks that have stationary sensor nodes. As a future work, the fuzzy clustering approach of our algorithm can be extended for handling mobile sensor nodes.

Residual energy, distance to the base station and competition radius fuzzy sets can be adjusted in order to find optimal cluster-head radius values. In addition to this, the optimal maximum competition radius values for each scenario can be estimated by applying extensive tests.In cluster-head competition, we only consider the residual energy of the tentative cluster-heads. Some additional parameters such as node degree, density and local distance may also be employed to improve the performance of FCA.

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