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A Survey on Fuzzy Based Clustering Routing Protocols in Wireless Sensor Networks: A New Viewpoint

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Abstract **– In recent times, wireless sensor networks (WSNs) have become progressively more attractive and have found their way into a wide variety of applications and systems because of their low cost, self-organizing behavior, and sensing ability in harsh environments. A WSN is a collection of nodes organized into a network. Routing is a vital technology in WSNs and can be roughly divided into two categories: flat routing and hierarchical routing. In a flat routing topology, all nodes have identical functionality and carry out the same task in the network. Nodes in a hierarchical topology do different tasks in WSNs and are usually arranged into clusters. We analyze a fuzzy clustering algorithm (FCA) which aims to prolong the lifetime of WSNs. This algorithm adjusts the cluster-head radius considering the residual energy and distance to the base station parameters of the sensor nodes. This helps to decrease the intra-cluster work of the sensor nodes, which are closer to the base station or have lower battery level. Fuzzy logic is utilized for handling the uncertainties in cluster-head radius estimation. We compare this algorithm with the low energy adaptive clustering hierarchy (LEACH) algorithm according to the parameters of first node dies half of the nodes alive and energy-efficiency metrics. Therefore, the FCA is a stable and energy-efficient clustering algorithm.**

Keywords **– Fuzzy Clustering, Wireless Sensor Network, Algorithm.**

I. Introduction

A wireless sensor network (WSN) [3] consists of spatially distributed autonomous sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants. The development of WSNs was motivated by military applications such as battlefield surveillance. They are now used in many industrial and civilian application areas, including industrial process monitoring and control, machine health monitoring, environment and habitat monitoring, healthcare applications, home automation, and traffic control [10].

In addition to one or more sensors, each node in a sensor network is typically equipped with a radio transceiver or other wireless communications device, a small micro-controller, and an energy source, usually a battery. A sensor node might vary in size from that of a shoebox down to the size of a grain of dust, although functioning "motes" [5] of genuine microscopic dimensions have yet to be created. The cost of sensor nodes is similarly variable, ranging from hundreds of dollars to a few pennies, depending on the size of the sensor network and the complexity required of individual sensor nodes. Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed and bandwidth [2]. Figure 1 shows a typical WSN for more understanding.

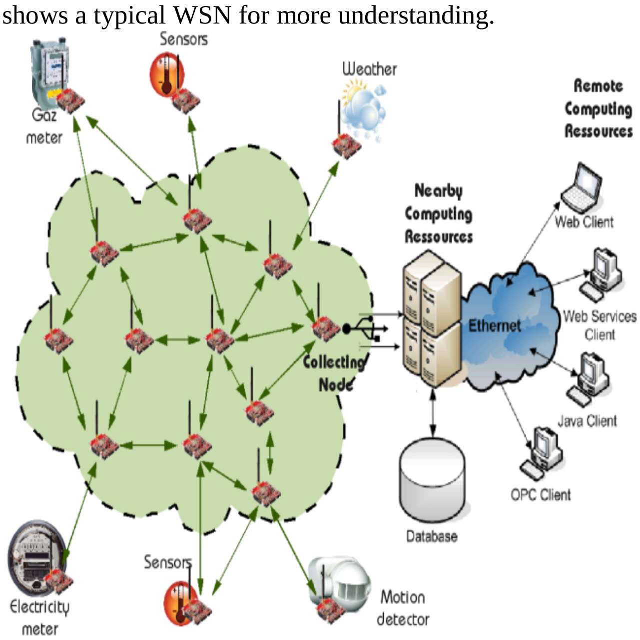

Fig.1. A typical WSN architecture

Based on network structure, routing protocols in WSNs can be coarsely divided into two categories: flat routing and hierarchical routing. In a flat topology, all nodes perform the same tasks and have the same functionalities in the network. Data transmission is performed hop by hop usually using the form of flooding. The typical flat routings in WSNs include Flooding and Gossiping [16], Sensor Protocols for Information via Negotiation (SPIN) [9], Directed Diffusion (DD), Rumor [4], Greedy Perimeter Stateless Routing (GPSR) [7], Trajectory Based Forwarding (TBF) [1], Energy-Aware Routing (EAR) [14], Gradient-Based Routing (GBR) ‘[17], Sequential Assignment Routing (SAR) [6], etc. In small-scale networks, flat routing protocols are relatively effective.

Most clustering algorithms utilize two techniques, which are selecting cluster-heads with more residual energy and rotating cluster-heads periodically to balance the 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 hot spot problems in multi-hop WSNs [9]. The cluster-heads near the base station die earlier, because they will be in heavier relay traffic than the cluster-heads, which are relatively far from the base station. In order to

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solve this problem and to balance energy consumption of cluster-heads, a periodically rotating cluster-head mechanism was proposed by Yu and Chang [16], namely low-energy adaptive clustering hierarchy (LEACH), which is a clustering algorithm that utilizes randomized rotation to balance energy consumption of cluster-heads over the network.

A fuzzy clustering approach [4] to the WSNs is analyzed to maximize its lifetime [7]. This approach is a distributed competitive algorithm. It selects the cluster-head via energy-based competition among the tentative cluster-heads which are selected using a probabilistic model. This approach mostly focuses on wisely assigning competition ranges to the tentative cluster-heads. In order to make wise decisions, it utilizes the residual energy and distance to the base station parameters of the sensor nodes. In addition to this, the clustering approach uses fuzzy logic to handle uncertainties in competition range estimation [4]. This allows the algorithm to assign greater competition ranges to the tentative cluster-heads which have higher residual energy levels, because they can serve a larger region [1].

II. Related Work - Fuzzy Clustering Algorithms

There are several clustering algorithms for WSNs in recent years [14]. Fuzzy logic is useful for making real time decisions without needing complete information about the environment [9]. 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 [17]. Some of the clustering algorithms [6] employ fuzzy logic to handle uncertainties in the WSNs. Basically; FCAs use fuzzy logic for blending different clustering parameters to select cluster-heads [4].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. Figure 2 shows a sample WSN with a series of red circles surrounded by gray circles. The red circles represent a sensor/node, and the surrounding green circle is the sensor detection range.

Analysis of Prominent Clustering Routing Protocols in WSNs

In this section, we present a more comprehensive and critical survey of prominent clustering routing protocols for WSNs compared with previous work.

We analyze 16 classical WSN clustering routing algorithms in detail based on the classification of different algorithm-stages, and highlight their characteristics with advantages and disadvantages. Figure 3 shows Taxonomy of Clustering Methods in WSNs.

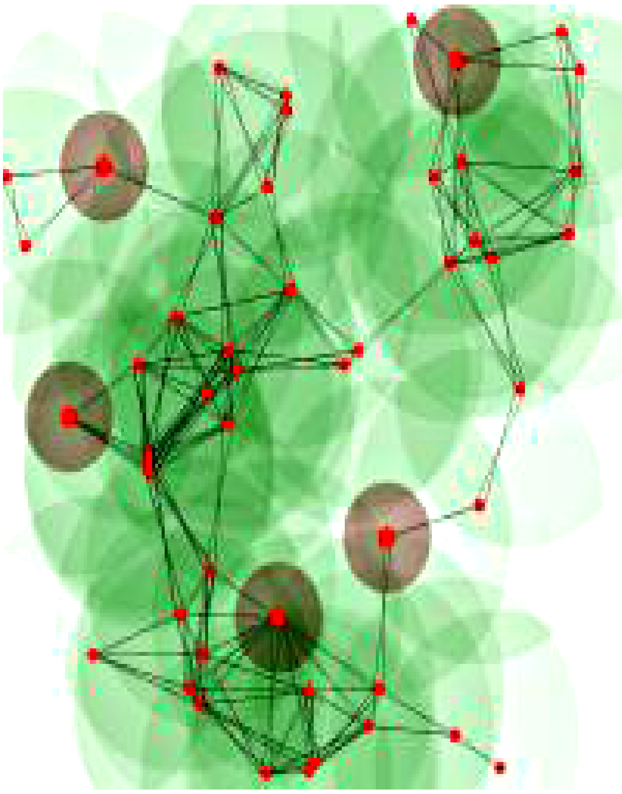

Fig.2. A sample of cluster based WSN.

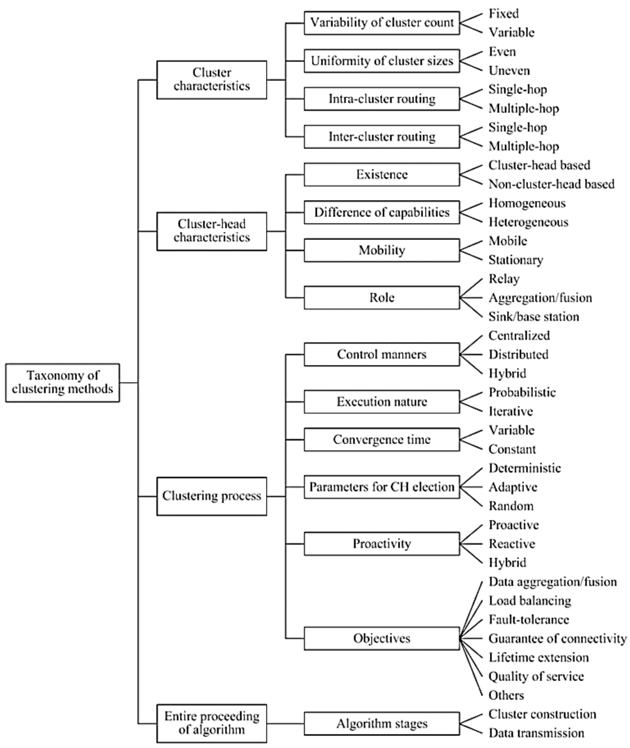

Fig.3.Taxonomy of Clustering Methods in WSNs

III. LEACH Clustering Protocol

LEACH [6] is a distributed algorithm which makes local decisions to elect cluster-heads. If the cluster-heads are selected 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. LEACH, cluster-head selection 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 the set-up phase, cluster heads are selected and clusters are formed. In the steady-state phase, data transfers to the base station are performed through the clustered network [6]. 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 where P is the desired percentage of cluster-heads and r represents the current round number. If the sensor node n belongs to G using these parameters, T (n) is formulated as follows [8]:

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

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 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 [8].

IV. Application of FCA to WSN

Fuzzy clustering algorithm is explained below (Algorithm 1). In every clustering round, each sensor node generates a random number between 0 and 1 [13]. 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. In FCA, the competition radius of each tentative cluster-head changes dynamically. FCA uses residual energy [11] 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. This approach 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 [12] to handle the uncertainty. These fuzzy if-then mapping rules are given in Table 1. The Mamdani method used by [9] is used as fuzzy inference technique, because it is the most frequently used fuzzy inference technique.

Algorithm 1: The proposed FCA for WSN.

```
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 1: Fuzzy if-then mapping rules for competition radius calculation in FCA.

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

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 [15].

V. Results and Discussion

Based on my evaluation and we compare proposed FCA with LEACH using WiseNet Simulator, which is an open source Java based tool used to simulate the sensor network topology with secured protocols. Wise Net has the following features:

- Graphical interface for reading the results of important parameters (eg. power consumption, reliability, coverage of the network.)
- Modeling types of attacks, programming of malicious sensors behavior and measuring the impacts on the parameters mentioned above.

In each round of the design, clusters-heads are selected and clusters are formed. Next, eachordinary node forwards certain bits of data to its cluster-head. Each cluster-head

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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. The area of deployed wireless sensor network is same for all designs and is 200 m x200 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 design is simulated for 50 times, and the average of the results is taken. For each of the designs, 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 live 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.

Design

In this design, the base station is located at the center of the WSN [5]. Each cluster-head forwards the aggregated data to the base station directly without using a relay node. The detailed configuration of this design is depicted in Table 2. The simulation of this design yielded the results shown in Table 3, which shows the rounds in which the FND and HNA for each simulated algorithm.

Table 2: Configuration parameters of Design.

Parameter	Value
Network Size	200 m X 200 m
Base Station Location	(100,100) m
Num. Of Sensor Nodes	75
Initial Energy	1 J
Data Packet Size	3000 B
Aggregation Ratio	10 %

Table 3: Design: Values of FND and HNA metrics for each algorithm.

Algorithm	FND	HNA
LEACH	280	610
FCA	420	810

As seen in Table 3, the FCA performs better than LEACH. This algorithm is more efficient than LEACH by about 36.4%. LEACH's performance is poor 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.

Figure 4 depicts the distribution of the number of live sensor nodes with respect to the number of rounds for each algorithm. This figure clearly depicts the number of non-functional (dead) sensor nodes for fuzzy clustering approach begins after LEACH algorithm.

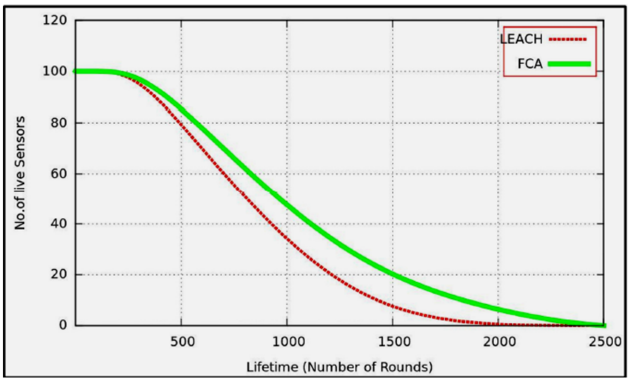

Fig.4. Design Distribution of alive sensor nodes according to the number of rounds for each algorithm.

V. Conclusion

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

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