Extending Network Lifetime of Clustered-Wireless Sensor Networks Based on Unequal Clustering

Arunkumar V S, Manu J Pillai
Student/Kerala University, Assistant Professor/Kerala University

Abstract
In wireless sensor network (WSN), sensor nodes are partitioned into clusters in order to gather information more efficiently in terms of energy consumption. In clustered networks, each node transmits acquired data to a cluster-head which the nodes belong to. After a cluster-head collects all the data from member nodes, it transmits the data to the base station (sink) in aggregated manner. This data transmission occurs through other cluster-heads in a multi-hop network environment. The sensor nodes closer to the base station consume more energy, because the network traffic increases as it approaches the base station. As a result, cluster-heads close to the sink tend to die earlier because of the heavy inter-cluster traffic. This problem is named as hotspots problem. To solve this problem, decrease the cluster sizes as they approach the base station by reducing cluster range radius, that is cluster-head closer to the base station has less intra-cluster work, then it can contribute more to inter-cluster data forwarding. A fuzzy logic approach is adopted in order to handle uncertainties in cluster-head radius estimation. The proposed algorithm is compared with fuzzy energy-aware unequal clustering algorithm (EAUCF). The experiment results shows that proposed algorithm performs better in terms of number of dead nodes and residual energy. Therefore, proposed algorithm is stable and energy efficient clustering algorithm to be utilized in any application.

Index Terms
wireless sensor network, clustering, network lifetime, network traffic.

1. Introduction

Wireless sensor network consists of large number of small, low power, low cost sensor nodes with limited memory, computational, and communication resources and Base Station (BS). These nodes continuously monitor environmental conditions and collect detailed information about the physical environment in which they are installed, and then transmit the collected data to the BS. Sensor nodes consume energy while receiving, processing and transmitting data. In most of the cases, these sensor nodes are equipped with batteries which are not rechargeable. Therefore, energy efficiency is still a major design goal in WSNs [1].

In order to aggregate data through efficient network organization, nodes can be partitioned into a number of small groups, called clusters [1]. In general, each cluster has a cluster-head which coordinates the data gathering and aggregation process in a particular cluster. Clustering in WSNs guarantees basic performance achievement with a large number of sensor nodes [2]. In other words, clustering improves the scalability of WSNs [3]. This is because clustering minimizes the need for central organization and promotes local decisions. Most of the clustering protocols utilize two techniques, selecting cluster-heads with more residual energy and rotating cluster-heads periodically to balance energy consumption of the sensor nodes over the network [4]. 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 WSNs i.e, cluster-heads near the base station tend to die earlier, because they are in heavier relay traffic than the cluster-heads which are located relatively far from the base station. In order to avoid this problem, some unequal clustering algorithms have been proposed in the literature [4,5]. In unequal clustering, the network is partitioned into clusters of different sizes. The clusters close to the base station are smaller than the clusters far from the base station. In this paper, an Extending Network Lifetime of Clustered-Wireless Sensor Networks Based on Unequal Clustering is introduced to make a further improvement in maximizing the lifetime of the WSN. This is a distributed competitive algorithm which selects the cluster-heads via energy-based competition among the tentative cluster-heads selected using a probabilistic model. Proposed algorithm mostly focuses on assigning appropriate range radius to the tentative cluster-heads. In order to make wise decisions, the proposed approach uses the residual energy, the distance to the base station and cluster-head degree. This approach is assigns smaller cluster sizes to cluster-heads that take larger roles in data forwarding process effectively.

In order to evaluate the proposed algorithm, its performance is compared with fuzzy energy-aware unequal clustering algorithm (EAUCF). The experimentation results show that proposed algorithm performs better in terms of number of dead nodes and residual energy. Therefore, proposed algorithm is a stable and energy-efficient clustering algorithm that can be used in any WSN application.

The rest of the paper is structured as follows. Section II discusses related work about our model. Section III describes the system model. Then our proposed clustering algorithm is introduced in Section IV. In Section V, we

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present simulation results and finally, we conclude in Section VII.

2. Related work

The following presents a review of some famous clustering protocols. LEACH is a distributed algorithm which makes local decisions to elect cluster-heads. If the cluster-heads that are selected do not change throughout the network's 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 [9]. LEACH also performs local data compression in cluster-heads to decrease the amount of data that is forwarded to the base station.

Kuhn et al. Propose a probabilistic cluster-head election algorithm. In this approach, the probability of each node depends on the node degree [10]. This algorithm tries to find a dominating set of nodes which will be assigned as cluster-heads.

In the CHEF (Cluster-Head Election using Fuzzy logic for wireless sensor networks) [11] protocol it performs cluster-head election in a distributed manner. Thus, the base station does not need to collect clustering information from all sensor nodes [12]. There are two fuzzy descriptors that are employed in cluster-head election. These are the residual energy of each node and local distance. Local distance is the total distance between the tentative cluster-head and the nodes within a predefined constant competition radius.

Equal clustering approaches suffer from the hotspots problem in multi-hop WSNs. To over-come this problem, unequal (uneven) clustering approach has emerged. Main idea behind this methodology is to adjust the cluster sizes with respect to the distance between the CH and the sink. As a result, it is possible to distribute the energy consumption over the network by changing the effect of inter-cluster and intra-cluster work of the CHs according to their distances to the sink.

EEUC is a distributed competitive unequal clustering algorithm. In the algorithm, each node has a pre-assigned competitive radius and CHs are elected by local competition [13]. Competition radius decreases as the nodes approach the sink. In addition to being an unequal clustering algorithm, this method is also a probabilistic approach since for every clustering round, a node probabilistically chooses to attend or not to the CH election competition. The term round here refers to the time interval between two successive cluster formation process.

EAUCF algorithm is introduced to address the hotspots problem and extends the lifetime of WSNs. This algorithm utilizes randomized periodical rotation together with fuzzy logic, however, does not follow a pure probabilistic approach to elect final CHs and considers only the stationary nodes [5]. Fuzzy descriptors employed in the EAUCF are residual energy and distance to sink of the tentative CHs. EAUCF solves the hotspots problem in statically deployed networks. However, it still suffers from the hotspots problems in evolving networks.

3. System model

Before describing the proposed algorithm in detail, the characteristics of the system model that are used in the implementation are introduced. First, the assumptions that are made about the network model are listed:

- Sensor nodes are deployed randomly.
- All sensor nodes and the base station are stationary after the deployment phase.
- Nodes are capable of adjusting the transmission power according to the distance of the receiver nodes.
- The distance between nodes can be computed based on their co-ordinate position. Therefore, each sensor nodes need to know their exact locations.
- All sensor nodes have the same amount of energy when they are initially deployed.
- The base station need not be located far away from the sensing region.
- All sensor nodes are identical.

Eq. (1) represents the amount of energy consumed in transmitting l bits of data to d distance. E_circuit is the energy consumption per bit in the transmitter and receiver circuitry. E_amp is the energy dissipated per bit in the RF amplifier.

$$ETx(l, d) = l * E\_circuit + l * E\_amp * d * d \qquad (1)$$

Eq. (2) represents the amount of energy consumed in receiving l bits of data.

$$ERx(l) = l * E\_circuit \qquad (2)$$

4. Proposed algorithm

In this section, the proposed clustering algorithm Extending Network Lifetime of Clustered-Wireless Sensor Networks Based on Unequal Clustering is described in detail. The preliminary version of this study is included in [6].The proposed algorithm is a distributed range unequal clustering algorithm. It makes local decisions for electing cluster-heads and determining cluster-head range radius. In order to estimate the cluster-head range radius for tentative cluster-heads, algorithm uses residual energy, distance to the base station and cluster-head. Moreover, it takes advantage of fuzzy logic to calculate cluster-head range radius. It is also based on a probabilistic model which is employed for electing tentative cluster-heads. However, it does not elect the final cluster-heads just by depending on this model. The main flow of proposed algorithm is explained in Algorithm 1. based on the range radius, density of the node and the residual energy of a particular sensor node, respectively.

Algorithm 1. Proposed Clustering algorithm.

```
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 radius using fuzzy if-then mapping rules
  CandidateCHMessage(ID, Rcomp, resEnergy)
  On receiving CandidateCHMessage from node N
  if this.resEnergy < N.resEnergy then
     beTentativeHead←FALSE
     Advertise QuitElectionMessage(ID)
   end if
end if
if beTentativeHead = TRUE then
   Advertise CHMessage(ID)
   nodeState←CLUSTERHEAD
   On receiving JoinCHMessage(ID) from node N
   add N to the clusterMembers list
   EXIT
else
  On receiving all CHMessages
  myClusterHead←the closest cluster-head
  Send JoinCHMessage(ID) to the closest cluster-head
  EXIT
end if
```

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 range radius of each tentative cluster-head changes dynamically in proposed algorithm, because it uses residual energy, cluster-head degree and distance to the base station to calculate range radius. It is logical to decrease the service area of a cluster-head while its residual energy is decreasing. If the range radius does not change as the residual energy decreases, the sensor node runs out of battery power rapidly. Proposed algorithm takes this situation into consideration and decreases the range radius of each tentative cluster-head as its battery power decreases. Radius computation is accomplished by using predefined fuzzy if-then mapping rules to handle the uncertainty. In order to evaluate the rules, the Mamdani Method [7], which is one of the most frequently used methods [8], is used as a fuzzy inference technique. The center of area (COA) method is utilized for defuzzification of the range radius.

In order to calculate cluster-head range radius, three fuzzy input variables are used. The first one is the distance to the base station, the linguistic variables for this fuzzy set are close, medium and far. The second fuzzy input variable is the residual energy of the tentative cluster-head, the linguistic variables for this fuzzy set are Low, medium and high. The third fuzzy input variable is the residual energy of the tentative cluster-head, the linguistic variables for this fuzzy set are Low, medium and high. The different fuzzy input variable and corresponding linguistic variable are shown in Table.1.

Fuzzy input variable	Linguistic variable
Distance to Base Station	Close, Medium, Far
Residual Energy	Low, Medium, High
Density of node	Low, Medium, High

The only fuzzy output variable is the range radius of the tentative cluster-head. The fuzzy if-then mapping rules are given in Table.2. If a particular tentative cluster-head's battery is full and it is located at the maximum distance to the base station, then it has the maximum range radius. On the contrary, if a particular cluster-head's battery is near empty and it is the closest node to the base station, then it has the minimum range radius. The remaining intermediate possibilities fall between these two extreme cases. The maximum radius is a static parameter for a particular WSN. The base station broadcasts the value of this parameter to the entire network. Thus, all the sensor nodes know the maximum range radius, in advance. Each of the sensor nodes can calculate their relative range radius according to the value of this parameter. The maximum distance to the base station is also a static parameter, because it is assumed that the sensor nodes are stationary. Each sensor node can determine its relative position to the base station considering the maximum distance to the base station in the WSN. After each tentative cluster-head determines its range radius, cluster-head competition begins. Each tentative clusterhead advertises CandidateCH Message to compete with other tentative cluster-heads locally. This message is advertised to the tentative cluster-heads which are inside the maximum clusterhead range radius. It includes node ID, competition radius and the residual energy level of the source node. Residual energy is the key parameter in cluster-head range. If a tentativecluster-head receives a CandidateCHMessage from another tentative cluster-head which is in its range and the residual energy of the source node is greater than the residual energy of the receiving node, then the receiving node quits the cluster-head range and broadcasts a QuitElectionMessage. If a particular tentative cluster-head has the highest residual energy level among the tentative cluster-heads which it receives a CandidateCHMessage from, then it becomes a cluster-head.

This range guarantees that no other cluster-head exists in the competition radius of a particular cluster-head.

Table 2. Fuzzy if-then mapping rules for competition radius calculation

Distance to Base Station	Remaining Energy	Cluster-Head degree	Competition Radius
Close	Low	Low	Small
Close	Low	Medium	2*Small
Close	Low	High	3*Small
Close	Medium	Low	4*Small
Close	Medium	Medium	5*Small
Close	Medium	High	6*Small
Close	High	Low	7*Small
Close	High	Medium	8*Small
Close	High	High	9*Small
Medium	Low	Low	Medium
Medium	Low	Medium	2*Medium
Medium	Low	High	3*Medium
Medium	Medium	Low	4*Medium
Medium	Medium	Medium	5*Medium
Medium	Medium	High	6*Medium
Medium	High	Low	7*Medium
Medium	High	Medium	8*Medium
Medium	High	High	9*Medium
Far	Low	Low	Large
Far	Low	Medium	2*Large
Far	Low	High	3*Large
Far	Medium	Low	4*Large
Far	Medium	Medium	5*Large
Far	Medium	High	6*Large
Far	High	Low	7*Large
Far	High	Medium	8*Large
Far	High	High	9*Large

Fig. 1 illustrates a WSN which is clustered by using fuzzy energy-aware unequal clustering (EAUCF) algorithm. In this example, the number of deployed sensors is 100.

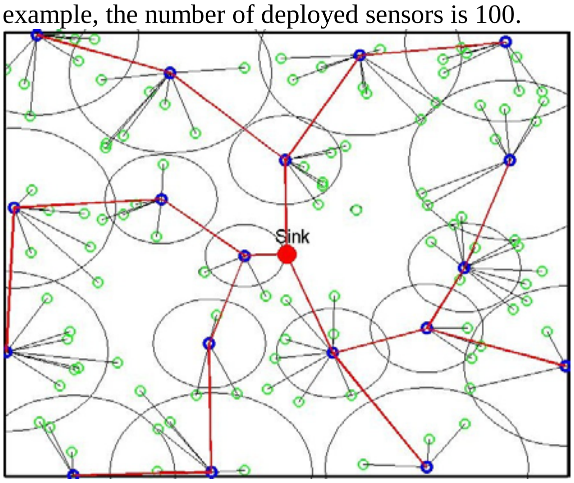

Fig.1. Network model clustered by using EAUCF

Fig. 2 illustrates a WSN which is clustered by using the proposed algorithm. In this example, the number of deployed sensors is 100. The base station(sink) is colored in solid red with a larger size when compared to ordinary nodes, each CH is colored in solid blue, and cluster member nodes are colored in green circle.

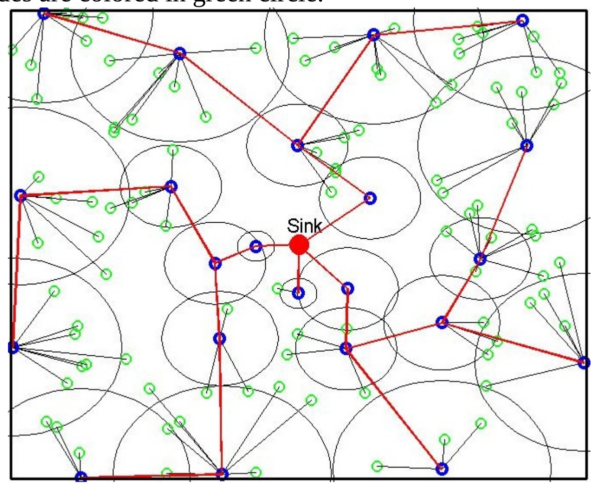

Fig 2. Proposed network model

5. Simulation results

In this section, we evaluate the performance of proposed algorithm using MATLAB, and compare it's performance with equal clustering and unequal clustering, using the same initial values and same energy model. The algorithm is tested in Matlab. The experiments are performed with diverse number of nodes placed in a 100m × 100m field (see fig.2). Each sensor node is assumed to have an initial energy of 1joules. A node is considered dead if its energy level reaches to under threshold value. The general simulation parameters are shown in Table 2.

Parameter	Value
Simulation Area	100×100
Initial energy	1J
Base station	50m×50m
Number of nodes	100
Number of rounds	1500
Eelec	10pJ/bit/m
Eamp	0.0013pJ/bit/m
Aggregation ratio	10%

For example, if a particular cluster has 20 cluster members each transmitting 100 bits of data to their cluster-head where the aggregation ratio is set to 10%, then the length of the aggregated data is (100 + (100×0.1×20)) which is equal to 300 bits.

The results about system lifetime in terms of residual energy are described in fig.3. We deduct that the proposed algorithm improve lifetime and stability of nodes. This plot shows the residual energy that remains over the number of rounds of activity of the 100m × 100m network scenario. With our approach, it improves the residual energy compared to EAUCF.

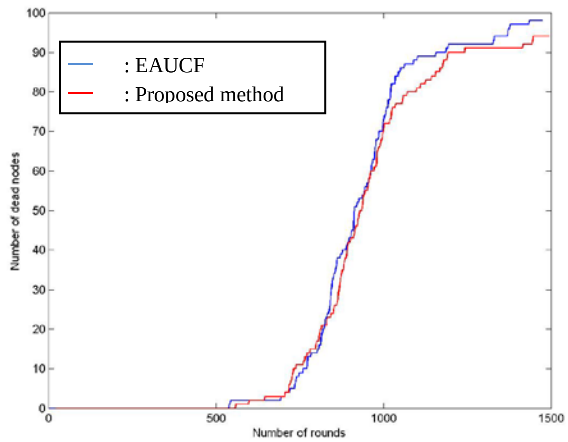

Fig.3. Number of dead nodes vs rounds

The results about system dead nodes are described in fig.4. We deduct that the proposed algorithm reduces the number of dead nodes. This plot shows the number of dead nodes over the number of rounds of activity of the 100m × 100m network scenario. With our approach, all the nodes remain alive for 1000 round, while the corresponding numbers for equal clustering are 890. This is because equal clustering treats all the cluster-heads have same intra-cluster work plus those which are near to base station need to forward inter-cluster data. As a result cluster heads that is close with the base station run out of energy faster than the other cluster heads, and the network becomes isolated from the base station.

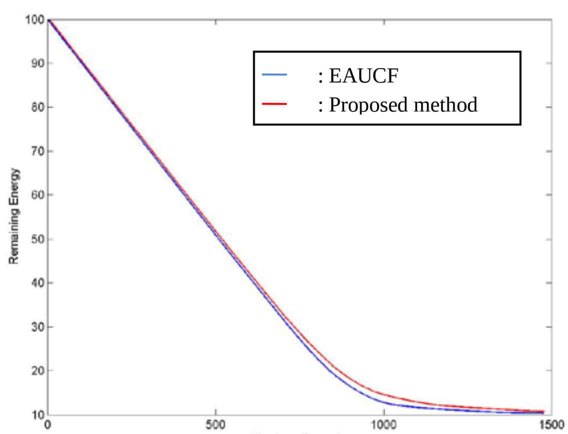

Fig.4. Residual energy vs rounds

6. Conclusion

The network relay traffic increases while getting closer to the base station in multi-hop WSNs. Therefore, the sensor nodes close to the base station tend to die earlier. In this paper, an extending network lifetime of clustered-wireless sensor networks based on unequal clustering algorithm is introduced to solve this hot spots problem. The radius adjustment mechanism of this algorithm solves the problem by reducing the intra-cluster work of the cluster-heads closer to the base station. Proposed algorithm aims to distribute the workload among all sensor nodes evenly. In order to achieve this goal, it mostly focuses on assigning appropriate cluster-head range radius to the sensor nodes. Proposed algorithm calculates the range radius values of tentative cluster-heads by considering their residual energy, cluster-head and distance to the base station.

According to the simulation results, proposed algorithm has a better performance compared to EAUCF. The sensor nodes that are clustered with proposed algorithm start to die later than the sensor nodes that are clustered with other algorithms. This result implies that the workload is distributed evenly among all sensor nodes and the sensor nodes tend to die later within the lifetime of the WSN. Proposed algorithm is more energy-efficient than the other tested clustering algorithms. As a result of the experiments, it is concluded that proposed algorithm extends the network lifetime compared with other algorithm.

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