Distributed Energy Efficient Cluster Formation for Wireless Sensor Networks

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Abstract

In large scale wireless sensor networks clustering is often used for improving energy efficiency and achieving scalable performance. In the clustered environment, data gathered by the nodes is transmitted to the base station through cluster-heads (CHs). As the nodes will communicate data over shorter distances in such an environment, the energy spent in the network is likely to be substantially lower compared to when every sensor communicates directly to the base station. The essential operation in sensor node clustering is to select a set of cluster-heads from the set of nodes in the network, and then cluster the remaining nodes with these heads. In this paper, we propose a distributed energy efficient cluster formation (DEECF) algorithm for wireless sensor networks. The cluster-head selection algorithm of DEECF is extended the LEACH's stochastic cluster-head selection algorithm by considering the additional parameters, the residual energy of the node relative to the residual energy of the network. We also compare our DEECF with LEACH in terms of network lifetime. The simulation results demonstrate that DEECF can achieve high energy efficiency and prolong network lifetime.

Keywords- Cluster formation, Energy efficiency, LEACH, Network Lifetime, Wireless Sensor Networks

1. Introduction

Wireless Sensor Networks (WSNs) are networks of tiny, battery power sensor nodes with limited on-board processing, storage and radio capabilities. Each node in a sensor network is typically equipped with one or more sensors, a radio transceiver or other wireless communication devices, a small microcontroller, and an energy source, since in most WSNs applications the energy source is battery, energy plays an important role in WSNs, and preserving the consumed energy of each node is an important goal that must be considered when developing a routing protocol for wireless sensor networks [9].

Typically, wireless sensors are placed to monitor physical or environmental phenomenon, like: temperature, sound, vibration, pressure, motion or pollutants, at different locations. The development of the wireless sensor networks was originally motivated by military applications for battlefield surveillance. Thereafter, wireless sensor networks are used in many civilian application areas, including environment and habitat monitoring, healthcare applications, home automation, traffic control [10].

Neighboring sensor nodes generally have the data of similar events because they collect events within a specific area. If each node individually transmits the collected data to the sink node, a lot of energy will be wasted to transmit similar data to the sink node. The sensor nodes are organized into a number of clusters in order to avoid such energy wastes. Cluster-based architectures improve the resource allocation and reduce the energy consumption, thus prolong the network lifetime as much as possible [5].

In clustering, sensors in the monitoring area are grouped into clusters; all sensor nodes within the same cluster send their data to the cluster head, which then forwards the aggregated data to the base station. The performance metrics of a clustering algorithm are the number of clusters and the count of the neighbor nodes which are the adjacent nodes between clusters that are formed.

In clustering protocols data aggregation can be used for reducing energy consumption. Data aggregation, also known as data fusion, can combine multiple data packets received from different sensor nodes. It reduces the size of the data packet by eliminating the redundancy. Wireless communication cost is also decreased by the reduction in the data packets. Therefore, clustering protocols improve the energy consumption and the network lifetime of the WSNs [2].

The essential operation in sensor node clustering is to select a set of cluster-heads from the set of nodes in the network, and then cluster the remaining nodes with these heads. In this paper, we present a distributed energy efficient cluster formation

(DEECF) algorithm for wireless sensor networks by modifying of the LEACH's cluster-head selection to further reduce and balance the total energy dissipation of sensors.

The rest of this paper is organized as follows. Section 2 briefly describes the related work. The proposed algorithm discusses in Section 3. Section 4 shows the simulation and its results. Finally, Section 5 concludes the paper.

2. Related work

The main task of a sensor network is to forward the sensing data gathered by sensor nodes to the base station. One simple approach to the fulfillment of this task is direct data transmission. In this case, each node in the network directly sends sensing data to the base station. However, if the base station is remote from the sensor node, the node will soon die due to excessive energy consumption for delivering data. To solve this problem, some algorithms aimed at saving energy have been proposed.

LEACH [4] is perhaps the first cluster-based routing protocol for wireless sensor networks, which use a stochastic model for cluster-head selection, and has motivated the design of many other protocols which follow a similar concept.

Sajjanhar et al. [7] proposed a Distributive Energy Efficient Adaptive Clustering (DEEAC) Protocol, which is extended LEACH's stochastic cluster-head selection algorithm for networks having spatio-temporal variations in data reporting rates across different regions. DEEAC selects a node to be a cluster-head depending upon its hotness value and residual energy.

Liang et al. [6] presented a Maximize Network Lifetime Clustering Protocol (MNLC) which adapts to heterogeneous sensor network. MNLC determines which cluster the ordinary nodes join in according to the minimum communication cost and the residual energy level of cluster-heads.

Cano et al. [3] introduced a new cluster-based architecture for spare WSNs. Nodes are only capable of communication with their direct neighbors.

Yassein et al. [8] proposed VLEACH protocol to solve the problem of CH die earlier than the other nodes in the cluster in LEACH. In VLEACH, besides having a CH in the cluster, there is a Vice-CH that takes the role of the CH when the CH dies. The cluster nodes will always reach to the BS and no need to elect a new CH each time.

All these algorithms try to prolong the network lifetime and to balance the load among the nodes, using some metrics for cluster-head selection and maintenance.

3. Distributed Energy Efficient Custer Formation (DEECF)

3.1. Network model

For our proposed DEECF algorithm, we assume the network model as follows:

(i)The base station located far away from the square sensing field.

(ii) All nodes are homogenous, and having the same capabilities.

(iii) No mobility of sensor nodes.

(iv) All nodes are able to reach BS.

(v) Symmetric propagation channel.

3.2. Radio energy dissipation model

In order to predict the performance of DEECF, we use a simple model for the radio hardware energy dissipation as discussed in [5]. For the experiments described here, both the free space (***d^2*** power loss) and the multi path fading (***d^4*** power loss) channel models were used, depending on the distance between the transmitter and the receiver. If the distance is less than a threshold, the free space (***fs***) model is used; otherwise, the multi path (***mp***) model is used. Thus, to transmit an ***l***-bit message a distance ***d***, the radio expends:

$$E_{Tx}(l,d) = E_{Tx-elec}(l) + E_{Tx-amp}(l,d)$$

$$E_{Tx}(l,d) = \begin{cases} l * E_{elec} + l * \varepsilon_{fs} * d^2 & if\ d < d_o \\ l * E_{elec} + l * \varepsilon_{mp} * d^4 & if d \geq d_o \end{cases} \quad (1)$$

where the threshold ***d_o*** is:

$$d_o = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$$

The electronics energy (E_{elec}) depends on many factors such as the digital coding, the modulation, the filtering, and the spreading of the signal, whereas the amplifier energy, $\varepsilon_{fs}d^2$ or $\varepsilon_{mp}d^4$, depends on the distance to the receiver and the acceptable bit-error rate. To receive an l-bit message, the radio expands:

$$E_{Rx}(l) = E_{Rx-elec}(l) = l * E_{elec} \quad (2)$$

3.3. Cluster-Head selection

In LEACH, cluster-heads are randomly selected. The operation is divided into rounds. Each round contains the setup phase and the steady-state phase. Each node decides whether or not to become a cluster-head for the current round based on the probability calculated by the suggested percentage of cluster-heads for the network (determined in advance) and the number of times the node has been a cluster-head so far. This decision is made by the node n choosing a random number between 0 and 1. If the number is less than a threshold *T(n)*, the node becomes a cluster-head for the current round. The threshold is set as

$$T(n) = \begin{cases} \dfrac{p}{1 - p(r \bmod \frac{1}{p})} & , if\ n \in G \\ 0 & , otherwise \end{cases} \quad (3)$$

where p, r, and G represent, respectively, the desired percentage of cluster-heads, the current round number, and the set of nodes that have not been cluster-heads in the last 1/p rounds. Using this threshold, each node will be a cluster-head, just once at some point within 1/p rounds.

LEACH randomly elects cluster-head and prone lead to the unbalanced energy level reserved in nodes and thus increase the total energy dissipated in system. To ensure an even energy load distribution over the whole network, additional parameters should be considered to optimize the process of cluster-head selection. Our aim is to achieve energy efficiency in terms of network lifetime, not only in terms of energy consumption. So we extend LEACH's stochastic cluster head selection by adjusting the threshold *T(n)* denoted in equation (3), relative to the node's remaining energy.

$$T(n) = \left(\frac{p}{1 - p\left(r \bmod \frac{1}{p}\right)} \frac{E_{residual}}{E_{initial}} k_{opt}\right) \quad (4)$$

where the $E_{residual}$ is the remaining energy of the node and $E_{initial}$ is the initial energy of the node before the transmission. Using this threshold each node decides whether or not to become a cluster-head in each round.

$$k_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}} \frac{\sqrt{\varepsilon_{fs}}}{\sqrt{\varepsilon_{mp}}} \frac{M}{d_{toBS}^2} \quad (5)$$

To determine the optimal number of cluster for the network, we use equation (5). Where k_{opt} is the optimal cluster-head number, *N* is total number of sensor nodes, *M* is the length of nodes distributing fields, d_{toBS} is the distance between nodes and the base station.

3.4. Cluster formation

The proposed clustering algorithm is an iterative method. At each node, the clustering process requires a number of iterations. During a set-up phase, all nodes compute their residual energy. Once, the nodes that have elected to be cluster-heads using the modified threshold in equation (4) begin to announce their new state to all neighbors. To do this, each cluster-head node broadcasts an advertisement message. Based on the received signal strength of the advertisement, each non-cluster head node determines its clusters for this round.

After each node has decided to which cluster it belongs, it must inform the cluster-head node that it will be a member of the clusters and send the information including its join-request message and its current residual energy level. A flow chart of this distributed cluster formation method is shown in Figure 1.

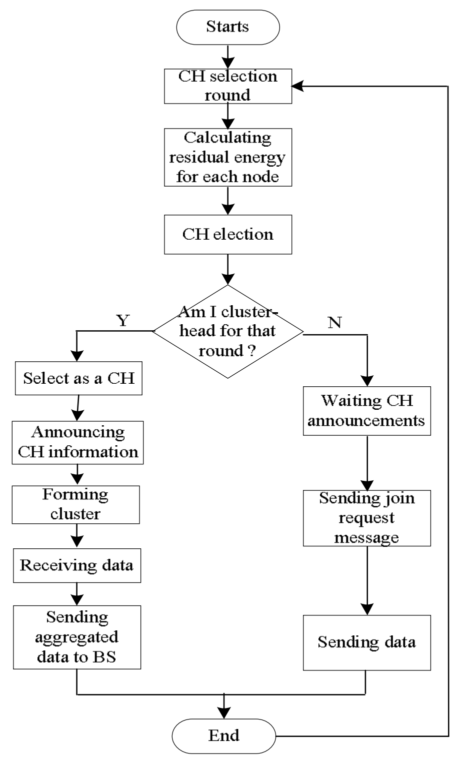

Figure 1. Flowchart of Distributed Cluster Formation

The cluster-heads in DEECF act as the local control centers to coordinate the data transmissions in their cluster. The cluster-head node sets up a duty schedule and transmits this schedule to all nodes in its cluster. After a duty schedule is known by all nodes in the cluster, the setup phase is completed and the steady state operation can begin.

4. Simulation

To demonstrate random cluster-head selecting affect on communication energy consumption, we consider a network with 100-nodes randomly distribution in a play size field 100m×100m shown in Figure 2.

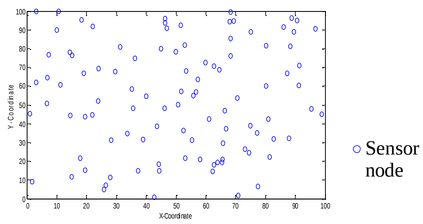

Figure 2. 100-Nodes Random Network

The parameters used in our simulations shown in Table 1.

Table 1. Simulation Parameters

Parameter	Value
Field size (M×M)	100m×100m
Location of BS (Base Station)	50m,50m
Number of nodes, N	100 nodes
Cluster-Head (CH) probability	0.1
Initial Energy of sensor node	0.5J
E_{TX} and E_{RX} (E_{elec})	50 nJ/bit
Free space (ε_{fs})	10 pJ/bit/m^2
Multi path fading (ε_{mp})	0.0013 pJ/bit/m^4
The energy for aggregation (E_{DA})	5 nJ/bit/signal
The data packet size (l)	4000 bits

To maximize the network lifetime, it is required to prolong the time of first node dies as far as possible. Network lifetime is defined as the round number when the first node runs out of energy. At the same time from the overall point of view, the algorithm should try to meet all the nodes dead in a short time, thus to ensure the sensor networks is completely available in most of the time.

To compare our DEECF with the LEACH in terms of network lifetime, we simulate with different amount of initial energy of the sensor node. According to the simulation results shown in Table 2, our DEECF prolong the time of first node dies so that it can maximize the network lifetime.

Table 2. Lifetime using different amounts of initial energy for the sensors

Energy (J/node)	Protocol	Round first node dies
0.25	LEACH	460
	Proposed	518
0.5	LEACH	966
	Proposed	1129
1	LEACH	1939
	Proposed	2178

Figure 3 shows the number of nodes still alive after 1200 rounds and each node initially 0.5J of energy for the two protocols.

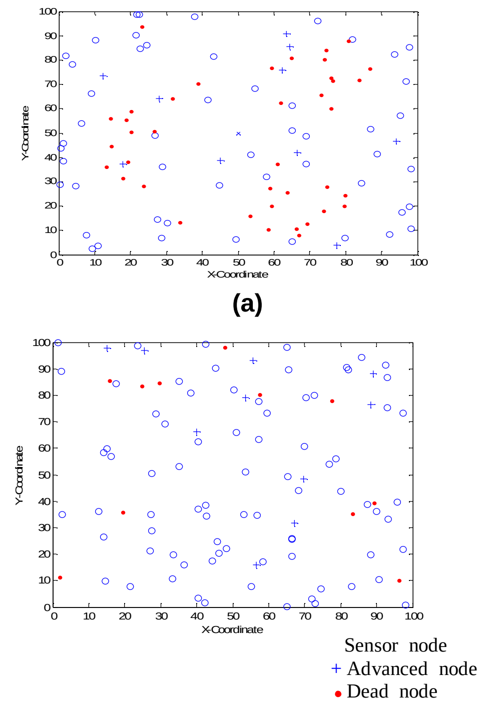

Figure 3. The number of sensor nodes still alive and dead after 1200 rounds with 0.5 J/node (a) LEACH (b) DEECF

Figure 4 shows how many nodes are still alive and how many nodes are no longer alive with transmission rounds, compared with LEACH after 1200 rounds. LEACH selects cluster-heads assuming that each time a node becomes a cluster-head it dissipates the same amount of energy. This lead to inefficient selection of heads towards the end of simulation thereby depleting the network fast. DEECF selects cluster-heads based on the remaining energy of a node with respect to the residual energy of the network, thereby prolonging the network lifetime.

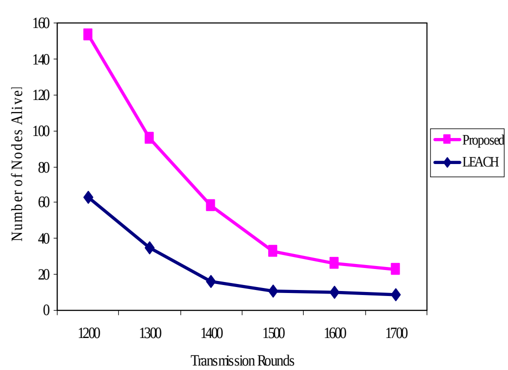

Figure 4. Number of nodes alive in different transmission rounds

Figure 5 shows the number of data received at BS over transmission rounds. The cluster-heads are selected based on the residual energy of each node in DEECF. This reduces the energy loss due to transmission for the nodes expected to transmit frequently, thereby delivering the more amount of data with less energy dissipation.

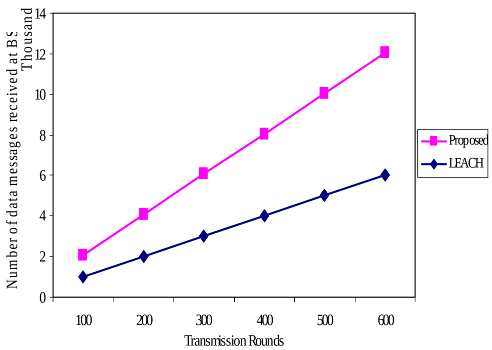

Figure 5. Total number of data messages received at base station (BS)

A cluster-based WSN with 100 nodes dynamically formed by DEECF algorithm in play size field 100m 100m is shown in Figure 6. All nodes marked with a given symbol belong to the same cluster, and the cluster-head nodes are marked with (•).

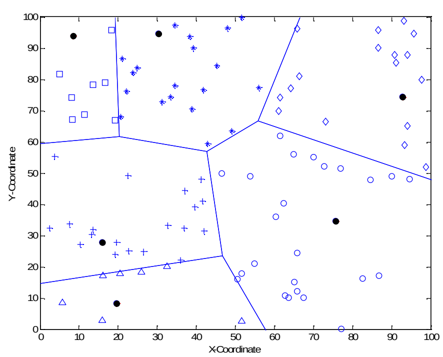

Figure 6. Dynamic Cluster Formation based on DEECF

5. Conclusion

In this paper, we propose a distributed energy efficient cluster formation algorithm for WSNs. The cluster-head selection of DEECF is extended the LEACH stochastic cluster-head selection algorithm by considering the additional parameters, the residual energy of a sensor node. We compare our DEECF with LEACH, simulation results show that DEECF consumes the energy fairly and reduces the energy of the sensor and thus prolongs the network lifetime.

6. References

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