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A Novel Energy-Efficient Clustering Algorithm (NEEC) for Wireless Sensor Networks

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Abstract: ***Wireless Sensor Networks (WSNs) consist of small nodes with sensing, computation, and wireless communications capabilities. Many routing, power management, and data dissemination protocols have been specially designed for WSNs where energy awareness is an essential design issue. The clustering algorithm is a kind of key technique used to reduce energy consumption. It can increase the scalability and lifetime of the network. Energy-efficient clustering protocols should be designed for the characteristic of heterogeneous wireless sensor networks. We propose and evaluate a novel energy-efficient clustering scheme for heterogeneous wireless sensor networks, which is called NEEC. In NEEC, the nodes are randomly generated in a fixed square region. Initially the nodes are considered as homogeneous and for the first round, the cluster heads are elected using Euclidean distance between the nodes. From the second round onwards the nodes are considered as heterogeneous and the cluster-heads are elected based on the residual energy of each node. The nodes with high initial and residual energy will have more chances to be the cluster-heads than the nodes with low energy. Finally, the simulation results show that NEEC achieves longer lifetime and more effective message transmission.***

Keywords: Wireless sensor networks; clustering algorithm; heterogeneous environment; energy-efficiency

1. Introduction

Wireless sensor network (WSN) consists of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations [1]. This network contains a large number of nodes which sense data from an impossibly inaccessible area and send their reports toward a processing center which is called ”sink”. Since, sensor nodes are power-constrained devices, frequent and long-distance transmissions should be kept to minimum in order to prolong the network lifetime [2], [4]. Thus, direct communications between nodes and the base station are not encouraged. One effective approach is to divide the network into several clusters, each electing one node as its cluster head [6]. The cluster head collects data from sensors in the cluster which will be fused and transmitted to the base station. Thus, only some nodes are required to transmit data over a long distance and the rest of the nodes will need to do only short-distance transmission. Then, more energy is saved and overall network lifetime can thus be prolonged. Many energy-efficient routing protocols are designed based on the clustering structure where cluster-heads are elected periodically [11], [7]. These techniques can be extremely effective in broadcast and data query [10], [5]. DEEC [8] is a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks which is based on clustering, when the cluster-heads are elected by a probability based on the ratio between residual energy of each node and the average energy of the network. The round number of the rotating epoch for each node is different according to its initial and residual energy. DEEC adapt the rotating epoch of each node to its energy. The nodes with high initial and residual energy will have more chances to be the cluster-heads than the low-energy nodes. Thus DEEC can prolong the network lifetime, especially the stability period, by heterogeneous aware clustering algorithm. The DDEEC [3], Developed Distributed Energy-Efficient Clustering, permits to balance the cluster head selection overall network nodes following their residual energy. So, the advanced nodes are largely solicited to be selected as cluster heads for the first transmission rounds, and when their energy decrease sensibly, these nodes will have the same cluster head election probability like the normal nodes. BEENISH [9] implements the same concept as in DEEC, in terms of selecting CH which is based on residual energy level of the nodes with respect to average energy of network. However, DEEC is based on two types of nodes; normal and advance nodes. BEENISH uses the concept of four types of nodes; normal, advance, super and ultra-super nodes.

The remainder of the paper is organized as follows. In section 2, we briefly review related work. Section 3 describes the network setup used in the algorithm. In section 4, we present the details of the proposed NEEC algorithm. The simulation results are given in section 5. Finally, conclusion and scope for future work is presented.

2. DEEC Protocol

DEEC uses the initial and residual energy level of the nodes to select the cluster-heads. To avoid that each node needs to know the global knowledge of the networks, DEEC estimates the ideal value of network life-time, which is use to compute the reference energy that each node should expend during a round. In this protocol, different n_i based on the residual energy $E_i(r)$ of node s_i at round r. Let $p_i = 1/n_i$, which can be also regarded as average probability to be a cluster-head during n_i rounds. When nodes have the same amount of energy at each epoch, choosing the average probability p_i to be p_{opt} can ensure that there are $p_{opt}N$ cluster-heads every round and all nodes die approximately at the same time. If nodes have different amounts of energy, p_i of the nodes with more energy should be larger than p_{opt}. Let $\bar{E}(r)$ denote the average energy at round r of the network, which can be obtained by $\bar{E}(r) = 1/N \sum_{i=1}^{n} E_I(r)$ To compute $\bar{E}(r)$, each node should have the knowledge of the total energy of all nodes in the network. They calculate the optimal cluster-head number that they want to achieve. They get the probability threshold, that each node s_i use to determine whether itself to become a cluster-head in each round, as follow:

$$T(s_i)=\begin{cases} \frac{p_i}{1-p_i\left(r mod \frac{1}{p_i}\right)} & if\ s_i \in G \\ 0, otherwise \end{cases}$$

where G is the set of nodes that are eligible to be cluster heads at round r. If node s_i has not been a cluster-head during the most recent n_i rounds, then there is a possibility for it to become a cluster head. In each round r, when node s_i finds it is eligible to be a cluster-head, it will choose a random number between 0 and 1. If the number is less than threshold $T(s_i)$, the node s_i becomes a cluster-head during the current round. The epoch n_i is the inverse of p_i. n_i is chosen based on the residual energy $E_i(r)$ at round r of node s_i The rotating epoch n_i of each node fluctuates around the reference epoch. The nodes with high residual energy take more turns to be the cluster-heads than lower ones.

They evaluated the performance of DEEC protocol using MATLAB. For they considered a wireless sensor network with N = 100 nodes randomly distributed in a 100m X 100m field and assumed the base station is in the center of the sensing region. To compare the performance of DEEC with other protocols, they ignore the effect caused by signal collision and interference in the wireless channel. The radio parameters used in their simulations are shown in Table 1.

Table 1: Parameters used in simulations

Parameter	Value
E_{elec}	5 nJ/bit
ε_{fs}	10 pJ/ bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
E_0	0.5 J
E_{DA}	5 nJ/bit/message
d_0	70 m
Message size	4000 bits
p_{opt}	0.1

The protocol compared with DEEC include LEACH, SEP, and LEACH-E. In multi-level heterogeneous networks, the extended protocols of LEACH and SEP. They examined several performance measures under two-level heterogeneous networks and observed the performance of LEACH, SEP, LEACH-E, and DEEC. And have shown the results of the case with m = 0.2 and a = 3, and the results of the case with m = 0.1 and a = 5. It is obvious that the stable time of DEEC is prolonged compared to that of SEP and LEACH-E. SEP performs better than LEACH. But the unstable region of SEP is also larger than DEEC protocol. It is because the advanced nodes die more slowly than normal nodes in SEP. They increased the fraction m of the advanced nodes from 0.1 to 0.9 and a from 0.5 to 5 and compared the number of round when the first node dies. They observed that LEACH takes few advantages from the increase of total energy caused by increasing of m and a. The stability period of LEACH keeps almost the same in the process. Being an energy-aware protocol, DEEC outperforms other clustering protocols. Especially when a is varying, DEEC obtains 20% more number of round than LEACH-E.

3. Network Setup

In our proposed algorithm we consider the network setup used in DEEC, which consists of N nodes, which are uniformly dispersed within a M X M square region. The network is organized into a clustering hierarchy, and the cluster-heads collect measurements information from cluster nodes and transmit the aggregated data to the base station directly. Moreover, we suppose that the network topology is fixed and no-varying on time. We assume that the base station is located at the center. We consider two-level heterogeneous network consisting of m - advanced nodes each with initial energy $E_o(1+a)$ and N – m, normal nodes each with the initial energy E_o. The total initial energy of the heterogeneous networks is given by:

$$E_{total} = mE_o(1+a) + (N-m)\ E_o$$

The energy expended by the radio to transmit an L-bit message over a distance d is given by:

$$E_{tx}(L; d) = LE_{elec} + LE_{fs}d^2 \text{ if } d < d_0$$
$$LE_{elec} + LE_{mp}d^4 \text{ if } d \geq d_0$$

where E_{elec} is the energy dissipated per bit to run the transmitter (E_{TX}) or the receiver circuit (E_{RX}). The E_{elec} depends on many factors such as the digital coding, the modulation, the filtering, and the spreading of the signal. E_{fs} and E_{mp} depend on the transmitter amplifier model used, and d is the distance between the sender and the receiver. 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. In DEEC they have fixed the value of d_0 randomly as d_0 = 70. But in our proposed algorithm we are calculating the value of d_0 using the concept of Euclidean distance between the nodes.

Given a network of n nodes we are interested in identifying the clusters of nodes along with their cluster heads. Our algorithm starts with random generation of n nodes in a fixed square region. Basically it is assumed that each and every node can communicate to the base station and to all other nodes in the network. The square region selected is subdivided into squares of equal side and the distances between the center of each sub square and all other nodes in that sub square are calculated. The node whose distance is minimum is selected as the cluster head of the nodes belonging to that sub square. The cluster heads are connected to the base station and hence all the n nodes of the network will have a unique path for communication with the base station through their corresponding cluster head. NEEC is implemented using the same parameters used in DEEC.

4. NEEC Algorithm

In this section, the proposed NEEC algorithm is presented which consists of two modules. In the first module, the generation of the nodes, cluster formation and initial routing in the network are achieved. In the second module, node which is to communicate with the base station is received as an input and the path through which the communication takes place is identified. The initial energies to the nodes are given in two categories as normal node and head node. The energy calculations are done as similar to the DEEC. The cluster heads to the subsequent round are selected according to the residual energies of the nodes.

Algorithm: Module I

Input: $N \text{ −> } Number\ of\ Nodes, S \text{ −> } User\ Selected\ Node$
Output: $Graph\ Plot\ of\ Nodes\ \&\ Clusters.$
Procedure:

$$BaseStaion(x,y) = \left(\frac{Side}{2}, \frac{Side}{2}\right)$$
$$Location_x = rand(1,N),\ Location_y = rand(1,N)$$
$$Side = Range/4$$
$$if\ (Location_x > Side)\ \&\&(Location_x \le Side)\&\&\left(Location_y > Side\right)\&\&\ (Location_y \le Side)$$
$Spot\ the\ Cluster$
$$minimum_x = \min(Location_x)$$
$$maximum_x = \max(Location_x)$$
$$minimum_y = \min(Location_y)$$
$$maximum_y = \max(Location_y)$$
$$center = \frac{maximum_x + minimum_x}{2}, \frac{maximum_y + minimum_y}{2}$$
$$distance = \sqrt{(Location_x - center(x))^2 - (Location_y - center(y))^2}$$
$$headNode(x,y) = \min_{distance}\ Location_x, Location_y$$
$$Connect: \forall\ headNodes\ \rightarrow BaseStation$$

Algorithm: Module II

Input: $N \text{ −> } Number\ of\ Nodes, S \text{ −> } User\ Selected\ Node$
Output: $Graph\ Plot\ of\ Nodes\ \&\ Clusters.$
Initialize: $E_0, \alpha, E_{da}, E_{Elec}, E_{mp}$
Procedure:

$$BaseStaion(x,y) = \left(\frac{Side}{2}, \frac{Side}{2}\right)$$
$$Location_x = rand(1,N),\ Location_y = rand(1,N)$$
$$Side = Range/4$$
$$if\ (Location_x > Side)\ \&\&(Location_x \le Side)\&\&\left(Location_y > Side\right)\&\&\ (Location_y \le Side)$$
$Spot\ the\ Cluster$
$$minimum_x = \min(Location_x),\ maximum_x = \max(Location_x)$$
$$minimum_y = \min(Location_y),\ maximum_y = \max(Location_y)$$
$$center = \frac{maximum_x + minimum_x}{2}, \frac{maximum_y + minimum_y}{2}$$
$$distance = \sqrt{(Location_x - center(x))^2 - (Location_y - center(y))^2}$$
$$headNode(x,y) = \min_{distance}\ Location_x, Location_y$$
$$Connect: \forall\ headNodes\ \rightarrow BaseStation$$
Initialize: $Energy_{FreeNode} = E_0,\ Enery_{HeadNode} = E_0(1+\alpha)$
$$d_{toCH} = \frac{M}{\sqrt{2 * \pi * k}}$$
$$d_{toBS} = 0.765 * \frac{M}{2}$$
$$Energy_{CH} = E_0 - L * (2 * E_{Elec} + E_{mp} * d_{toBS}^4 + E_{da})$$
$$Energy_{BS} = E_0 - L * (2 * E_{Elec} + E_{mp} * d_{toBS}^2)$$

While GET NODE FROM USER % Repeat it until user stops
Trace path of the transaction
Subtract Energy of that Node
$if\ Energy\ of\ Location_x(S), Location_y(S) < threshold$
$Isolate : Location_x(S), Location_y(S)$
end

5. Simulation Results

The above algorithm is coded using MATLAB and tested for different user input values for the number of nodes. Figure1(a) is the clustered network of 30 nodes whose cluster heads are connected to the base station, in which any node can communicate to the base station through its cluster head. Figure 1(b), depicts that there is a transaction takes place between node 11 and the base station through the cluster head 12. Similarly, Figure 2(a) and Figure 2(b) are the networks of 75 nodes. Module II is also coded using the same parameters used in DEEC. Accordingly, the energies of the nodes will be reduced using the calculations explained in the algorithm.

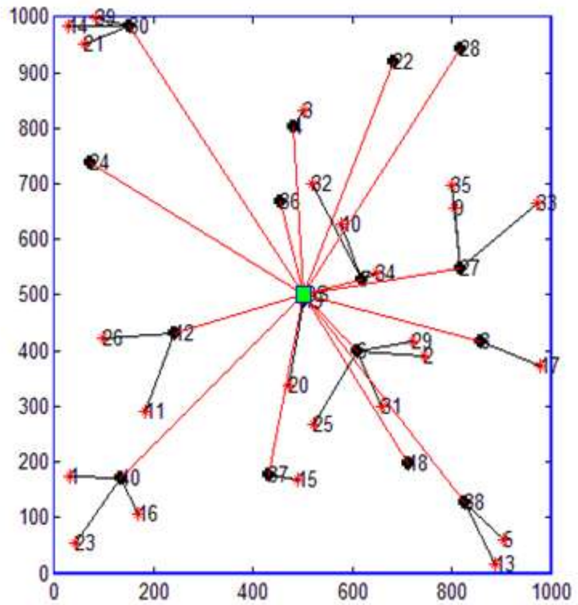

Figure 1(a)
A network with N=30

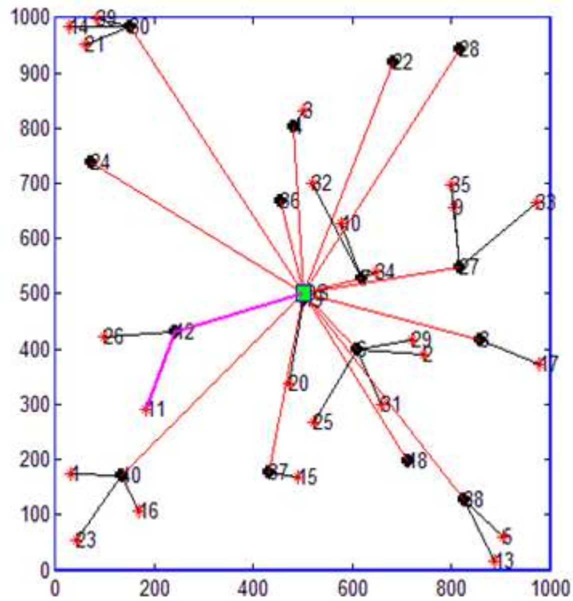

Figure 1(b)
Network of N=30 with transaction

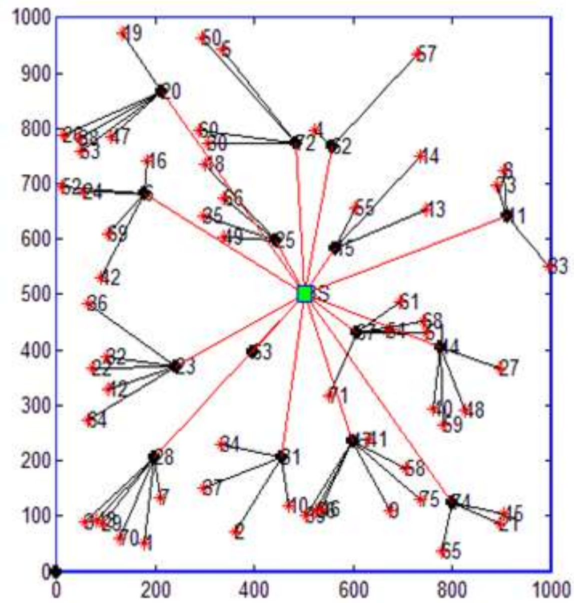

Figure 2(a)
A network with N=75

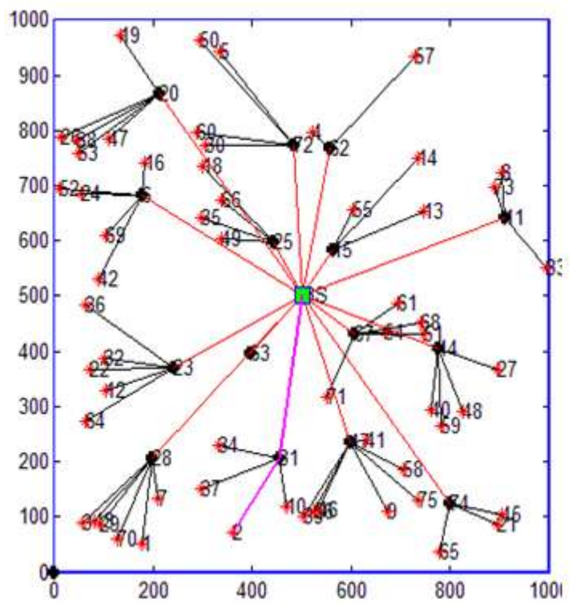

Figure 2(b)
Network of N=75 with transaction

6. Conclusion

In this paper we proposed a novel energy efficient clustering algorithm for heterogeneous wireless sensor networks. In our proposed system, initially the nodes are considered as homogeneous one and the clustering and identification of cluster head are achieved using the Euclidean distance between the nodes. Cluster heads are connected to the base station to get a complete routing in the network. Then the nodes are initialized with two kinds of energies respectively for head nodes and normal nodes. After a transaction, new clustering and cluster heads are selected based on the residual energies of the nodes. Proposed NEEC algorithm is simulated using MATLAB. Further, the comparison of our algorithm with other existing algorithms such as DEEC, DDEEC etc. could be done and the efficiency of the algorithm is to be verified.

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