A Dual Head Clustering Mechanism for Energy Efficient WSNs

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Abstract. Wireless sensor network are resource constrained. Clustering techniques are used to conserve energy and to prolong the lifetime of the wireless sensor network. A number of clustering techniques have been presented based on single cluster head. In single cluster head mechanisms, the single cluster head is responsible for both data gathering and data forwarding so it consumes more energy compared to the other member nodes and dies earlier. In this paper we propose a Dual Head Clustering Mechanism (DHCM) for wireless sensor network. The DHCM is based on two cluster head, one cluster head selects the data and the other head is responsible for data forwarding set for a specified number of rounds. The simulation results show that the DHCM reduce the overhead over a single head and improves the life time of the network.

1 Introduction

The current development in micro-sensor networks has made it feasible to manufacture very small sensor devices. Wireless sensor network can be made by connecting a large number of sensor nodes. The network formed by these sensor nodes depends upon the area or events to monitor and the proposed application domain for which the wireless sensor network is developed. Usually these sensors are unattended, immovable and energy constrained. Once these nodes are deployed, they start sensing the environment, make computations and disseminate this information to the base station [1, 2, 3]. The base station is normally stationary (can be mobile as well) and energy sufficient. Each sensor node is specified with a specific task or mission and can gather context information using available computational power, energy and bandwidth. A typical wireless sensor network is shown in the figure 1. Wireless sensor networks have a large number of applications which includes military, weather monitoring, tactical surveillance, distributed computing, security, habitat monitoring, detecting events such as moments, temperature, sound, industrial manufacturing [4] etc.

Cluster routing has been introduced to reduce the energy usage in routing. In cluster routing all nodes in the network organize themselves in form of clusters (or groups). There are usually three steps involved in clustering algorithms. In the first phase the cluster head (CH) is selected in a cluster and this information is disseminated to all the nodes in the cluster. Member nodes also inform the cluster head (CH)

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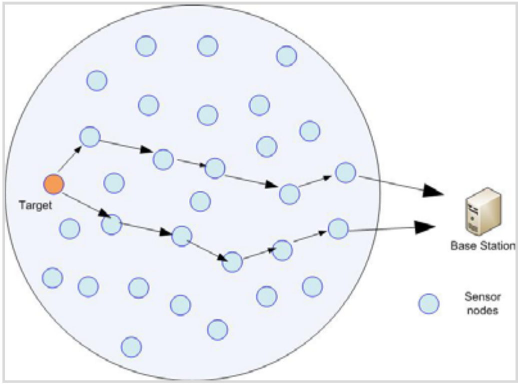

Fig. 1. Wireless Sensor Network

about their presence in the cluster. In the second phase all the member nodes sense the environment, collect the data and communicate with their cluster heads alone. In the third and last phase the cluster heads aggregates all the collected information and sends it to the base station either directly or by using multi-hop routing as in figure 2. Whichever WSN mechanisms are in place, they must have desirable attributes that include to be power aware, capable of optimum routing, adaptive, reliable, scalable and fault tolerant.

In this paper we propose a Dual Head Clustering Mechanism (DHCM). The communication between the cluster head and the sink is multi-hop. There are still challenges with the multi-hop routing as the cluster head close to the base station dies earlier, an issue that was attempted to be resolved by Energy Efficient Unequal Clustering (EEUC); however there is still burden on the cluster head. Unlike other previously proposed algorithms, we have taken two cluster nodes as cluster heads with different responsibilities and have compared their performance which is further elaborated in section 4 and section 5.

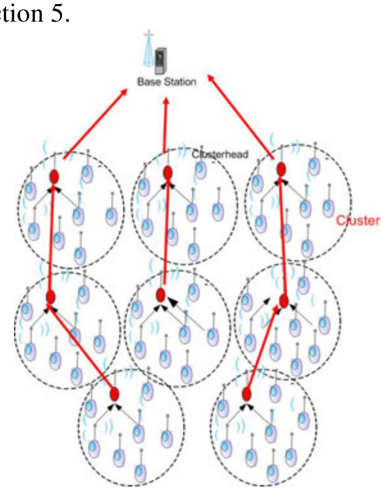

Fig. 2. Cluster based wireless sensor network

The rest of this paper is organized as follows: section 2 presents related work; section 3 describes the network model; in section 4 our algorithm is presented; section 5 presents the simulation parameters and results, and section 6 gives the conclusions and future work.

2 Related Work

A number of clustering techniques have been introduced all focusing on saving energy and thus increasing the overall lifetime of wireless sensor networks. Brief descriptions of some of the proposed clustering mechanisms are presented here.

Heinzelman, et al. [5] introduced a clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH solves the problem of static clustering mechanisms in which the cluster heads, once selected, will remain assigned throughout the lifetime of network. LEACH selects a few sensor nodes as cluster heads and rotates the role of cluster heads depending upon the energy of the nodes. The operation of LEACH consists of two phases, the setup phase and the steady state phase. In the setup phase, the clusters are organized and cluster heads are selected. Only 5 % of nodes are selected as cluster heads. During the steady state phase, the sensor nodes begin sensing the environment and collect data and then transmit this data to the cluster heads. The cluster head aggregates the received data and sends it to the base station. In [6], an enhancement over the LEACH protocol was proposed. The protocol is called Power-Efficient Gathering in Sensor Information Systems (PEGASIS). In PEGASIS nodes do not communicate directly with the base station, instead they communicate with their closest neighbours which in turn communicate with the BS. Thus PEGASIS extends the lifetime of network. To locate the closest neighbor node in PEGASIS, each node uses the signal strength to measure the distance to all neighboring nodes and then adjusts the signal strength so that only one node can be heard. The aggregated data is sent to the sink by any node in the chain. The Simulation results show that PEGASIS is able to increase the lifetime of the network to twice that of the LEACH protocol. An extension to PEGASIS, called Hierarchical PEGASIS, was introduced in [7]. The main objective of Hierarchical PEGASIS is to decrease the delay incurred for packets during transmission to the sink. Results shows that that Hierarchical PEGASIS perform better than the regular PEGASIS scheme by a factor of about 60. In [8] Energy Efficient Clustering Scheme (EECS) a new approach has been introduced. EEUC is hierarchal clustering algorithm that partitions the nodes into clusters of unequal size, and clusters closer to the base station have smaller sizes than those further away from the base station. With this scheme cluster heads closer to the base station will save energy for the inter-cluster data forwarding. EEUC is a distributed competitive algorithm and with no iteration so EEUC is different from LEACH and HEED. The node's competition range to become cluster head decreases as its distance to the base station decrease. In the proposed multi-hop routing protocol for inter-cluster communication, a cluster head chooses a relay node from its adjacent cluster heads according to the node's residual energy and its distance to the base station. The simulation results presented shows that EEUC performs better than LEACH and HEED. To improve EEUC Energy-Efficient Level based and Time-based Clustering (EELTC) have been introduced in [9].

EELTC is hierarchical clustering algorithm and has the ability of creating unequal clusters with very low controlling overhead. In EELTC all sensors determine their level by receiving a message from the base station. The main idea is the optimal selection of CHs based on their level and residual energy. The number of clusters formed near the base station is less in number than the number of clusters formed away from the base station. The proposed mechanism has then been compared with the previous existing LEACH and EEUC. The results show that EELTC saves more energy in setup phase since it has lower message overhead than LEACH AND EEUC.

3 Network Model

We consider N sensors in our network and make the following assumptions.

- All sensors have equal significance.
- The base station and all the sensor nodes are stationary after the network is deployed and the base station is located far from the sensor field.
- All the sensors are location aware and not equipped with GPS and are capable to compute the distance by signal strength.
- All the sensor nodes have a unique ID.
- The Data cluster head is responsible to aggregate the data packets received from the members' nodes and hand over to the routing cluster head. The routing cluster head receives data from other clusters.

We have used a simplified energy model used in [8, 9], which has been used in most of the previous related work. The d^2 power loss model is used if the distance d between transmitter and receiver is less than the threshold $d_0$otherwise d^4 power loss model is used, so in order to transmit k-bits massage over distance d the electrical energy is given by:

$$E_s\,(k\,,d) = \begin{cases} k.E_{elec} + k.\varepsilon_{fs}.d^2 & d < d_0 \\ k.E_{elec} + k.\varepsilon_{mp}.d^4 & d \geq d_0 \end{cases} \tag{1}$$

Where E_{elec} denotes the electrical energy; and the ε_{fs} and ε_{mp} are the amplifier energy.

To receive a massage k the energy spent is given by the following equation.

$$E_r\,(k\,) = k\,.E_{elec} \tag{2}$$

For fusion: if we have n massages and each with k-bits, the energy is:

$$E_f\,(m\,,k) = m\,.k\,.E_{fuse} \tag{3}$$

4 DHCM Approach

The DHCM has three phases: cluster setup, multi-hop routing formation and data transmission. The DHCM is based on rounds, but unlike other algorithms the setup phase remains the same for some specified number of rounds. Let's suppose x is the number of rounds for which the setup phase will restart. If the initial value of x is 10 then it means that after 10 rounds the setup phase will restart and new heads will be selected. This x value will be decreased as time passes and will eventually reach 1. Thus with this method we can save the energy that is consumed in the setup phase in the early life time of network. Initially the value of x is high because all the nodes have high energy and this level decreases when they start their operations. We have used the dual cluster heads because with single cluster head a considerable amount of energy is consumed in each round and we may not be able to fix the same cluster head for a specified number of rounds.

4.1 Cluster Setup

When the network is deployed the base station sends a broadcast message to all the sensor nodes at a certain power level. Based on the received signal strength each node then computes its approximate distance d to the base station. This distance d calculation is used in the calculation of the radius for the cluster. Let R_{max} be the maximum value for the radius, R_{min} be the minimum value for the cluster and d_j is the distance of node j from the base station: then we define the cluster size of node j as

$$R_j = \frac{d_j \cdot (R_{\max} - R_{min})}{d_{max}} + R_{min} \tag{4}$$

Once the cluster radius is specified and each node knows its cluster then each node broadcasts a *HELLO* massage which has the *id* and energy of the node. Each node receives a broadcast massage and saves this information. Then based on the information on each node the node j is elected as Data Cluster Head (DCH). Once a node is selected as DCH it broadcast an information massage to all nodes. Each node in the radius then computes its distance to the DCH and if it is less than R_j it considers node j as cluster head and saves the information. Once the DCH is selected the next step is to elects the Routing Cluster Head (RCH). The node with highest energy and minimum distance to the DCH is selected as the RCH.

4.2 Inter-Cluster Multi-hop Routing

Hierarchal routing is one of the best routing techniques used for energy conservation in wireless sensor network and hence adopted in this network. After the setup phase the RCH, which is responsible for routing, broadcasts a message to the RCHs electives of other clusters. This broadcast massage contains the id, energy level and the distance from the base station. On receiving the broadcast massage, each RCH computes the distance to the other RCH and selects the shortest route to the base station. This route selection is also restricted by the number of rounds value.

4.3 Data Transmission

In the data transmission phase each member node in the cluster starts sensing the data and sends it to the DCH. The DCH on receiving the data, aggregates it, and send it to the RCH. The RCH, on receiving the data from other clusters, forwards the data to the base station. Due to short DCH-RCH distance, less energy is consumed by the DCH in the data transmission phase. Furthermore, each RCH has the option to select short but high energy paths to forward the data to the base station.

5 Simulation Results

This section presents the performance evaluation of DHCM via simulations. We assume an ideal MAC layer and error free communication link for this simulation. We run extensive experiments and the results presented here are the average of all those simulation results. The parameters used in the simulation are listed in table1. We have compared DHCM with the previously proposed LEACH and EEUC algorithms.

Table 1. Simulation Parameters

Parameters	**Value**
Area	200 x 200
Location of Base station	100, 350 m
Algorithms used	LEACH, EEUC,DHCM
Number of Sensors	200
Initial energy	4J
E_{elec}	50nJ/bit
ε_{fs}	10pJ/bit/m^2
ε_{mp}	0.0013pJ/bit/m^4
E_{fuse}	5nJ/bit/signal
Packet size	4000 bits
d_0	87 m
R_{max}	70 m
R_{min}	30 m

5.1 Energy Consumpton of Cluster Heads

The calculation of energy consumption by the cluster heads in 40 rounds are shown in the figure 3. In LEACH the data is directly sent to the base station by the cluster heads so the energy consumption is very high. In EEUC and DHCM, multi-hop communication is used to forward the data from the cluster heads to the base station, so due to the small distances between the cluster heads compared to the direct distance to the base station, a considerable amount of energy is saved. We have considered the combined energy consumption by both cluster heads. Furthermore, the energy consumption of DHCM is lower than EEUC beacuse the EEUC consumes energy during the setup phase of each round, while the DHCM uses the same set of clusters for a specified number of rounds.

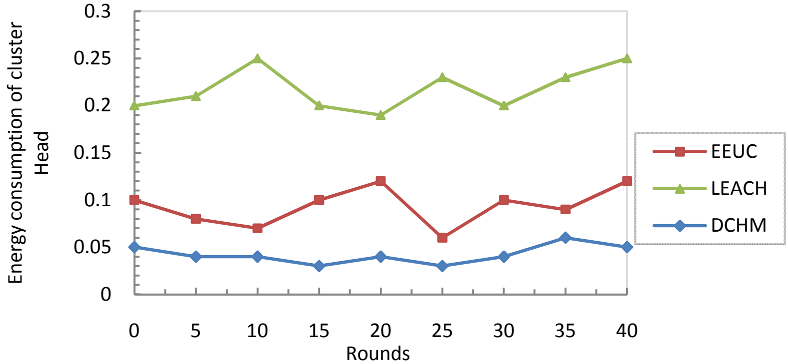

Fig. 3. Energy consumption of cluster heads

5.2 Network Life Time

DHCM improves the lifetime of the network in terms of the amount of time until the first and last node die as shown by figure 4. Due to single-hop routing, the node dies earlier in the LEACH protocol as the nodes further away from the base station consume more energy to send data directly to base station. By using multi-hop routing in EEUC the network lifetime significantly increases over LEACH. Moreover, as in DHCM the heads are set for a specified number of rounds so a considerable amount of energy is saved and this improves the overall network life time e.g. if we set the value for the number of rounds to be 5, this means new cluster heads will be selected after 5th round and thus we can save the setup phase energy consumption 5 rounds. Due to the above mechanism, DHCM outperforms LEACH and EEUC.

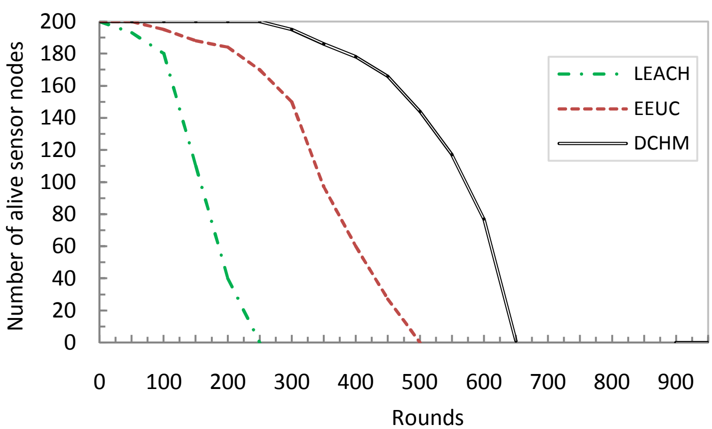

Fig. 4. The number of alive sensor nodes

6 Conclusions

In this paper we have presented a novel energy aware multi-hop cluster routing protocol for WSN called DHCM. DHCM has two cluster heads; one is responsible for the data gathering and the other for data forwarding. In the cluster setup phase, the cluster heads are set for a specified number of rounds and this value decreases with time. The simulations results have shown that the DHCM outperforms the LEACH and EEUC, and significantly increases the network lifetime.

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