

A Novel Energy Efficient Algorithm for Heterogeneous Wireless Sensor Networks Using Clustering Technique

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ABSTRACT

In order to achieve energy efficiency in wireless sensor networks, the important technique used is clustering. A group of nodes forms the cluster and these members forward their sensed data to the cluster head. Cluster head, on the other hand, aggregates and transmits the data to the base station. This minimizes the data traffic between individual nodes and base station and in turn maximizes network life time. In this paper, we present a novel energy conservation method based on clustering algorithm for heterogeneous wireless sensor networks. Algorithm uses three types of heterogeneity viz. normal, advanced and super nodes with different energy levels. Experiments were conducted with different numbers of above three categories of nodes. It is clear from the experimental results that the proposed method elongates network life time in a better way, allows more messages to be transmitted to the base station and stability period is also high when compared to traditional methods.

Keywords: Wireless Sensor Networks, Cluster Head Selection, Energy Efficient, Heterogeneous WSN, Network Life Time

1. INTRODUCTION

A group of spatially distributed autonomous devices which monitors the physical and environmental conditions are called Wireless Sensor Networks (WSN)[1]. By definition, WSN's are wireless and contains thousands of inexpensive, tiny sensor devices which are capable of computing, communicating and sensing the environments. WSNs are deployed over a vast geographical area for tracking changes in temperatures, humidity, vibrations, seismic events, etc. It is also having wide applications in areas like health care, utilities, remote monitoring, environmental monitoring, structural monitoring, industrial machine monitoring and process monitoring [2].

A sensor node is a tiny device that contains three basic components viz. sensing unit which senses the environment and generates data, a processing unit for local processing of data, and a wireless communication unit to transmit the processed data[3]. Apart from this, a sensor node contains power source that supplies power to these units to perform the task for which they have been deployed. Sensor node contains battery which is the power source for them and it is limited. Since sensor nodes are deployed on harsh working area, it is impossible to recharge as well as to replace the battery[4].

Sensor node uses energy to sense the environment, process the sensed data as well as to communicate the data to the other nodes. Among these activities, communicating data to the other nodes or stub node consumes much energy[5]. Since energy is required for all the activities of the sensor nodes and life time of the WSN is dependent on the availability of live nodes in the network, it is important to use the energy in an economical and feasible way[6]. Hence energy conservation among sensor nodes is a key issue in designing wireless sensor networks.

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A common method to achieve energy efficiency is to use clustering technique[7]. Sensor nodes are grouped, called as clusters, achieve good energy efficiency and prolong network life time in WSN environments. Clusters will have cluster heads which acts as a coordinator[8]. It results in two-tier architecture where cluster heads are placed in higher tier and cluster member nodes are placed in lower tier. Cluster members send the data to cluster heads and cluster heads aggregates and send it to the base station. This minimization in traffic greatly enhances the network life time[9].

Clustering has been extensively studied in data processing and in WSN's. Since WSN's are deployed in an adhoc manner, clustering approaches cannot be directly applied in WSN's[10]. Another issue with cluster head is that, one node cannot be assigned as cluster head always because it may lose its energy at rapid speed and whole network will sink. It is always necessary to perform periodic reclustering so that one node should not get affected. The goal of this research article is to introduce a new clustering algorithm for heterogeneous wireless sensor networks. The paper is structured as follows. Section 1 presents introduction about wireless sensor networks. Section 2 provides important literature review relevant for our research work. Details of heterogeneous wireless sensor networks are discussed in section 3. Need for energy efficiency, clustering algorithm and proposed method are detailed in section 4. Experimental results are discussed presented in section 5. Paper ends by presenting lucid conclusion in section 6.

2. BACKGROUND

Pratyay Kuila and Prasanta K J [11] presented a paper on energy efficient load balanced clustering algorithm for wireless sensor networks. It is a min-heap based clustering algorithm and using this, cluster heads are built. The algorithm shows $O(n \log m)$ time for n sensor nodes and m cluster heads. This algorithm treats equal load for all the sensor nodes and cluster heads.

Zhu Yong and Qing Pei[12] presented an energy efficient clustering routing protocol for wireless sensor networks. This method uses distance and residual energy for achieving energy conservation. This improves the process of cluster head selection and data transmission. This method reduces the adverse effect of energy consumption of cluster heads and non-uniform distribution of nodes in network. Another strategy it uses is that it avoids direct communication between cluster head and base station. The experimental results show that this method effectively balances the energy consumption and network life time is prolonged to 31%.

Salim Khediri *et al.* [13] presented a new approach for clustering in wireless sensor networks based on LEACH. According to the residual energy of nodes, cluster heads are dynamically selected. The whole work reported uses traditional LEACH method with additional features of dynamic cluster head selection. Simulation results show that this method extends the life time of the network in a better way.

Jun Yue *et al.* [14] proposed energy efficient, balanced clustering algorithm for wireless sensor networks. It uses data aggregation technique for achieving energy efficiency. This work addresses the problem of unbalanced energy dissipation. It divides the network into rectangular grids of unequal size and makes cluster heads rotate among the nodes in each grid. Cluster head rotation and sharing load provides energy dissipation. This method enhances energy efficiency, provides energy dissipation and prolong network life time.

Selim Bayrak and Senol Zafer Erdogan[15] presented energy efficient clustering method for wireless sensor networks based on genetic algorithm. The proposed method has two phase; set-up phase and steady-state phase. In the first state, fixed clusters are created and throughout the network there is no change in clusters. But in each round, cluster heads are changed. Experimental results show that the proposed method is more efficient than LEACH.

From the above, it is clear that plenty of work has already been carried out for clustering based energy efficiency protocol for wireless sensor networks.

3. BACKGROUND

3.1. Heterogeneous WSN

In heterogeneous WSNs, different types of battery functionalities are used by different nodes[16]. Moreover, network topology of WSN is also different which makes very complex to understand. This generates a requirement that extra battery energy and complex hardware embedding is needed for cluster heads to tackle heterogeneous WSNs. Heterogeneous WSNs are using the concept of multiple hopping to reach the cluster head and the nodes that are close to the cluster head are having more energy burden as they are involved in relaying[17].

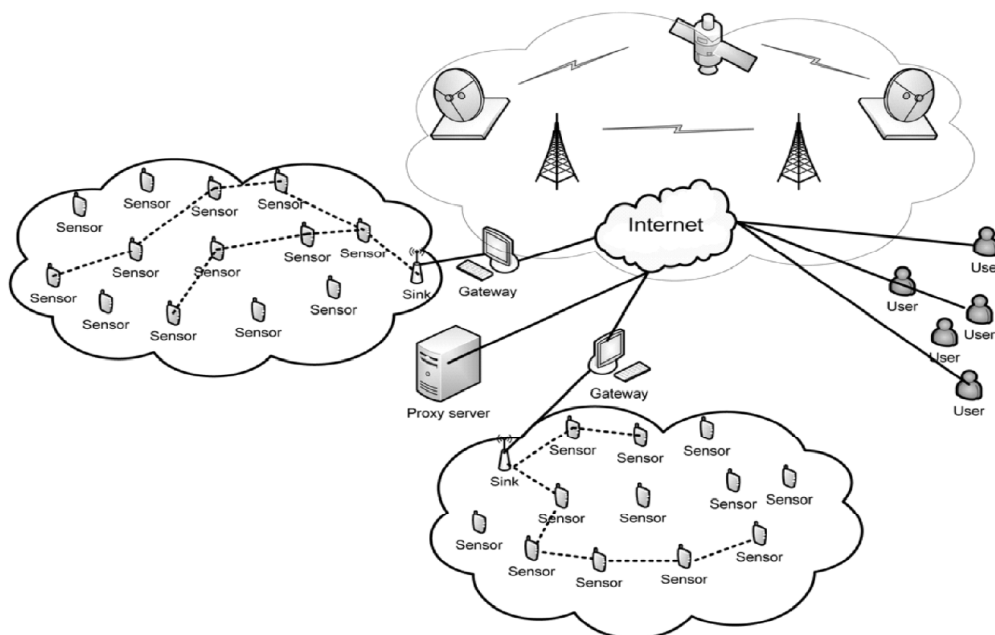


Figure 1: Heterogeneous WSN

Heterogeneity can be observed in three important aspects. Computational heterogeneity deals with the different computational resources that are integrated together to form a network and used for processing complex data[19]. Link heterogeneity deals with different bandwidths that are used in WSN. Link heterogeneity has to ensure reliable data transmission. Energy heterogeneity is the different battery requirements of the nodes in WSN[20]. Among these, energy heterogeneity is important as it deals with the life time of the network[18]. Deploying heterogeneous nodes in the network will impact on prolonging the network life time, improving reliability of data transmission and decreasing the latency of data transportation.

4. ENERGY EFFICIENT CLUSTERING ALGORITHM

The primary objective of our work is to propose an energy conservation heterogeneous wireless sensor network model using clustering technique. We use three types of nodes viz. normal, advanced and super to create a heterogeneous environment as well as to evaluate the proposed method. Based on the types of nodes with respect to energy levels present in the hardware, they are termed as two, three or multi-level heterogeneous WSNs. We use three-level heterogeneous network and nodes in each level are said to be normal, advanced and super nodes. The normal nodes have E_0 energy. Advanced nodes have 'a' times more

energy than the normal nodes and super nodes have 'b' times more energy than normal nodes. Their energy levels are represented as E_0 , $E_0(1+a)$, $E_0(1+b)$ for normal, advanced and super nodes respectively. The total initial energy is represented as

$$\begin{aligned} E_{\text{normal}} &= N(1-m)E_0 \\ E_{\text{advanced}} &= Nm(1-m_0)E_0(1+a) \\ E_{\text{super}} &= Nmm_0 E_0(1+b) \\ E_{\text{total}} &= E_{\text{super}} + E_{\text{advanced}} + E_{\text{normal}} \end{aligned}$$

where 'N' represents number of nodes in a particular category. E_{total} represents total energy available in the WSN. Mathematically this can be represented as

$$E_{\text{total}} = Nmm_0 E_0(1+b) + Nm(1-m_0)E_0(1+a) + N(1-m)E_0$$

On simplification, we get

$$E_{\text{total}} = NE_0 (1+m(a+m_0b))$$

Energy conservation can be achieved by two ways viz. reducing the power consumption of nodes and minimizing the impact of external radio environment. The total energy required by a node depends on the functionalities of a node such as sensing, processing and communicating. The total energy required for a node is given by

$$E = E_{\text{sense}} + E_{\text{process}} + E_{\text{communicate}}$$

where E_{sense} , E_{process} and $E_{\text{communicate}}$ are the energy required for sensing the environment, processing the gathered data and communicating the data to the cluster head or sink node correspondingly. The details of energy required for sensing are the energy required for signal sampling, signal conversion and modulation of signals. Mathematically E_{sense} can be written as

$$E_{\text{sense}} = E_{10} + E_{01} + E_{11}$$

where E_{10} represents energy required for the node to change from *ON* state to *OFF* state, E_{01} for transition from *OFF* state to *ON* state, and E_{11} is the energy required for sensing.

The details of energy required for processing the gathered data include sensor controlling, communication and processing such as aggregation, consolidation, etc. Here the sensors will be in sleep state, idle state or in running state. Mathematically E_p can be written as

$$E_p = E_{\text{stat}} + E_{\text{xion}}$$

Where E_{stat} and E_{xion} represents the energy required in a particular state and transition respectively.

The details of energy required for communication can be given as

$$E_{\text{communicate}} = E_{\text{Tx/Rx}}(l, d)$$

Where E_{Tx} is the energy required by the transmitter, 'l' is the length of the message transmitted and 'd' represents the distance.

4.1. Cluster Head Selection

Cluster heads are selected based on the initial and residual energy of nodes along with average energy of the network. The cluster head is selected based on CH percentage. To make a node cluster head, no. of alive nodes are calculated. The average energy for a round is calculated as

$$\bar{E}(r) = \frac{1}{N} E_{\text{total}} \left(1 - \frac{r}{R} \right)$$

Where ‘ R ’ represents total rounds, ‘ N ’ represents number of nodes in the network. The energy dissipated in a network during a single round is calculated as

$$E_{round} = K(2N E_{elec} + NE_{DA} + lE_{mp} d^4 \text{ to BS} + NE_{fs} d^2 \text{ to CH})$$

Where ‘ K ’ is the number of clusters, E_{DA} represents data aggregation energy and d_{toBS} is the distance between CH and base station, d_{to} is the distance between cluster members and cluster head.

To decide for a particular node to become a cluster head or not, the minimum energy threshold is calculated as

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

Where ‘ G ’ represents sets of nodes eligible to become cluster head for the round ‘ r ’ and ‘ p ’ represents the probability to become CH. Since we are using three different nodes in our method viz. normal, advanced and super, the probabilities for each category is given as

$$P_{normal} = \frac{P_{opt} E_i(r)}{(1 + m(a + m_0 b)) \bar{E}(r)} \text{ for normal nodes}$$

$$P_{advanced} = \frac{P_{opt} (1 + a) E_i(r)}{(1 + m(a + m_0 b)) \bar{E}(r)} \text{ for advanced nodes}$$

$$P_{super} = \frac{P_{opt} (1 + b) E_i(r)}{(1 + m(a + m_0 b)) \bar{E}(r)} \text{ for super nodes}$$

where P_{opt} is the probability of optimal clusters. The expression balances the energy consumption between nodes of heterogeneous nature and hence network life time is increased. The above equation can be more generalized so that it can be used for all the node levels. Mathematically, probability for all the nodes to become cluster head is given by the equation

$$P_n = c \times \frac{P_{opt} (1 + b) E_i(r)}{(1 + m(a + m_0 b)) \bar{E}(r)}$$

The proposed method work as follows: In order to select a cluster head, live nodes are calculated and cluster head percentage is also calculated. Next, average energy of the network for a round is estimated. If the receiving energy is greater than initial energy of the node, make the node as cluster head. If not, modify the probability of that node to become the cluster head.

5. EXPERIMENTAL RESULTS

In order to test the effectiveness of our method, we use 100 nodes, which are randomly deployed on a field of 100 m x 100m dimension, and base station is centrally located. The experiments are conducted on NS2 simulator. We have made two assumptions that all the nodes are fixed or micro-mobile and there is no energy loss due to collision, interference of signals.

The primary objective of the research is to increase the network life time, we test other parameters also for the effectiveness of the proposed method. The other parameters are stability period, packets sent to base station, and no. of live nodes at different rounds of network. The details used for our experiment are as follows:

Number of nodes in the network	:	100
Energy required to transmit the data to the base station	:	50 nj/bit
Length of the data	:	4000bits
Energy required to transmit data to a long distance	:	0.0013pj/bit/m ⁴
Energy required to forward a received data	:	10nj/bit/m ²
Energy required to aggregate the data	:	5nj/bit/signal

In the first scenario, we consider 20 normal nodes, 32 advanced nodes and 48 super nodes. The first node dies at 1810 round and all the nodes die at 8832 rounds. From this it is clear that our method is efficient in terms of stability period, network life time and number of packets sent to the base station. The results are shown in the below Table.

Table 1
Experimental Results

<i>Method</i>	<i>Scenario - 1</i>		<i>Scenario - 2</i>		<i>Scenario - 3</i>	
	<i>First Node</i>	<i>All the Nodes</i>	<i>First Node</i>	<i>All the Nodes</i>	<i>First Node</i>	<i>All the Nodes</i>
DEEC	1697	5928	1703	5718	1437	4952
LEACH	1552	6876	1567	5659	1525	4998
M-LEACH	1649	7698	1668	5720	1321	5072
B-LEACH	1625	7841	1624	5568	1489	5106
Out Method	1810	8832	1736	5856	1518	5253

Another advantage of the proposed method is that it adjusts the cluster head selection probability dynamically. This method consumes less energy which prolongs the network life time and provides stability. These two points provides capability to nodes to send packets at any time.

In another scenario, we took 70 normal nodes, 24 advanced nodes and 6 super nodes with the energy differences as 1:2 times and 2:5 times for advanced and super nodes respectively. Again the number of rounds taken for the first node to die and round at which all the nodes die is evaluated. Our proposed method survive upto 1736 rounds for the first node to die and all the nodes die at 5856 rounds. It is again clear that network life time, stability period and no. of packets sent to the base station are efficient compared to other traditional protocols.

In the last scenario, we equally distribute energy to all the nodes, regardless of type of nodes. The energy assigned is in the range [0.5, 2]. The first node in our proposed method dies at 1518 round and all the nodes in the network die at 5263 rounds. This test assigns energy to all the nodes between 0.5 to 2j and number of normal nodes is relatively less. Thus the network which is initially equipped with relatively more energy in first two scenarios.

The experimental results from all the three scenarios indicates that the proposed method is most efficient and network parameters such as stability period, network life time and number of packets transmitted are good. This method exhibits good performance under heterogeneous environments.

6. CONCLUSION

This paper presents a new method for energy conservation in heterogeneous wireless sensor networks. The proposed method contains three levels of heterogeneity viz. normal nodes, advanced nodes and super nodes with different energy requirements such as E_o , $(1+a)$, $(1+b)$ differences. Experiments were conducted with three different scenarios. During each scenario, changes are made in number of normal, advanced and super nodes, and their energy levels are also differs. In all the three cases, the rounds at which first node dies and round at which all the nodes die is evaluated. The simulation results show that our method performs best and it takes many more rounds for the first node to die as well as for all the nodes in the network to die. The increase in number of rounds to die indicates that there is a prolong in network life time. The method also exhibits increase in number of packets sent to the base station and stability period is also quite high.

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