

Energy Efficient Hierarchical Clustering Routing Protocol for Wireless Sensor Networks

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Abstract. Advanced technology of Wireless Sensor Networks used in many applications like health, environment, battle field etc. The sensor nodes equipped with limited power sources. Therefore, efficiently utilizing sensor nodes energy can maintain a prolonged network lifetime. One of the major issues in sensor networks is developing an energy-efficient routing protocol to improve the lifetime of the networks. In this paper, we propose EEHCRP (Energy-Efficient Hierarchical Clustering Routing Protocol), a protocol for wireless sensor networks. Network partitioned into annular rings by using various power levels at base station and each ring having various sensor nodes. The mathematical formulae for choosing the cluster head are provided. The model developed is simulated in MATLAB. The results are obtained in terms of three metrics, lifetime of the network, and number of clusters and energy consumption of clusters heads. From the results of simulation, it is observed that the performance of EEHCRP is better in terms of energy consumption of CH, number of clusters and lifetime of network compared with LEACH.

Keywords: Wireless Sensor Network, Energy Efficiency, Network Lifetime, Clustering, LEACH protocol.

1 Introduction

Wireless Sensor networks (WSN) consist of large number of sensor nodes and these nodes are directly interacting with their environment by sensing the physical parameters such as temperature, humidity, etc[1]. All the sensor nodes send or receive data to/from a fixed wired station called base station (BS). The base station usually serves as a gateway to some other network. WSNs have a comprehensive range of applications in this field including [6, 9, 10]; environmental applications, military applications, home security, etc.

The main challenge is related to the limited, usually unrenewable energy supply of the sensor nodes. Hence, the available energy at the nodes should consider as a major constraint while designing the routing protocols.

Hierarchical-based routing protocols also known as cluster based routing protocols. This type of protocols enforces a structure on the network to use the energy efficiency, extend the lifetime and scalability. In this protocol, nodes of the network are organized into the clusters in which higher energy nodes (e.g. assume the job of the cluster

head) can be used to process and forwarding the information, while lower energy nodes can be used to do the sensing the target. Clustering is an efficient way to reduce energy consumption and extend the life time of the network, doing data aggregation and fusion in order to reduce the number of transmitted messages to the BS [2].

In this paper, we present EEHCRP (Energy Efficient Hierarchical Clustering Routing Protocol) based on different power levels for Wireless Sensor Networks. EEHCRP reduces the number of dead nodes and the energy consumption, to extend the network lifetime.

The rest of the paper is organized as follows. An overview of related work is given by section 2. In section 3, propose an energy efficient hierarchical clustering routing protocol. Simulations and results of experiments are discussed in the section 4. In section 5, concludes the work presented in this paper and the scope of further extension of this work.

2 Related Work

The first hierarchical routing protocol for WSN is Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH is a cluster-based routing protocol which includes cluster formation in distributed manner. In LEACH [3], the nodes form themselves into local clusters, with one node acting as the local cluster-head. LEACH includes randomized rotation of the high-energy cluster-head position such that it rotates among the several sensors nodes in order to not deplete the battery of a single sensor. In addition, CHs performs local data fusion to “compress” the amount of data arriving from the nodes that belong to the respective cluster and transmit aggregate data to the base station, further reducing energy dissipation and enhancing system lifetime.

In LEACH, the cluster head receive data directly from each node and the sink uses single-hop routing. Therefore, it is not applicable for large networks. Also, it is not obvious how the number of predetermined number of cluster heads is going to be uniformly distributed through the network. Therefore, it is possible no or lots of CHs selected and also possible that too many CHs are located in a specific area. Furthermore, the dynamic clustering routing implemented with extra overhead, e.g. cluster head changes, advertisements etc., which consumed more energy.

LEACH-C protocol is the extended version of LEACH protocol. In which, all nodes in the network transmit their information to the BS, includes their ID, remaining energy, and position information. After this, the BS calculate the average energy of the network and select a set of CHs that have more energy than the average energy of the network and sends information about CHs ,their members and TDMA schedule. The member nodes decide own TDMA slot and transmit data in its time slot [4]. A non-sovereign cluster-head selection is the main drawback of this protocol. Moreover, LEACH-C needs location information of all nodes in the network. However, the location information in wireless sensor networks is only available through GPS (Global positioning system) or a location sensing technique, such as triangulation which requires additional communication among the nodes [5].

Power-efficient gathering in Sensor Information Systems (PEGASIS) is an enhancement of the LEACH protocol. A single node in a chain is used by PAGASIS to send data to BS rather than multiple nodes. The chain is constructed in a greedy way. Each node only communicates with their closest neighbors along the communication

chain. Gathered data moves from node to node, aggregated and finally transmit to the BS [6]. In PAGASIS, Each sensor node is required to have additional local information about the wireless sensor network. When the PEGASIS protocol selects the head node, there is no consideration about the energy of nodes, location of the BS. This applies to the greedy algorithm for construct chain, some delay may occur. Since the head node is a single, it may happen to a bottleneck at the head node.

In [11], clustering of network is done symmetrically and cluster head node is selected by the comparisons of remaining energy and distance with the other nodes. Determine the cluster head of next hope by using the weight function in [12].

3 EEHCRP: Energy Efficient Hierarchical Clustering Routing Protocol

Hierarchical clustering algorithms are very important to increasing the lifetime of network. We propose EEHCRP (Energy Efficient Hierarchical Clustering Routing Protocol), which is a hierarchical clustering routing protocol. EEHCRP reduces the number of dead nodes and the energy consumption to extend the network lifetime. Before studying the details of the proposed algorithm, we define the expected network model and energy model.

3.1 Network Model

Let us consider a sensor network, consisting of n sensor nodes, which are randomly deployed over in an area of wireless sensor network. To prepare the network model, the following assumptions are made about sensor nodes.

Assumptions:

1. There is one base station which is fixed and located at middle in a given sensor network.
2. All sensor nodes are fixed and homogeneous with a limited stored energy.
3. Base station can transmit various power levels.
4. The sensed data by the sensor nodes are routed to the base station.
5. Each node is equipped with power constrain capabilities and vary their transmitted power.
6. Nodes are not equipped with GPS unit.

3.2 EEHCRP Algorithm

In this section, we describe our protocol in detail. This protocol is divided into three phases, setup phase, cluster setup phase and inter cluster routing phase.

3.2.1 Setup Phase

On the initial deployment, the base station (BS) transmits a level-1 signal with minimum power level. All nodes, which hear this message, set their level as 1. After that, the base station increases its signal power to attain the next level and transmit a level-2 signal. All the nodes that receive the message but do not set the previous level set their level as 2.

This procedure continuous until the base station transmits corresponding messages to all levels. The total number of messages of levels is equivalent to the number of distinct transmit signal at which the BS can sends [7].

BS broadcast a hello message, fig [1]. This message contains the information of upper limit and lower limit of each level.



Fig. 1. Structure of Hello message

Where

U_i : Upper limits of level i

L_i : Lower limit of level i

Each node calculates the distance from the BS based on the received signal strength.

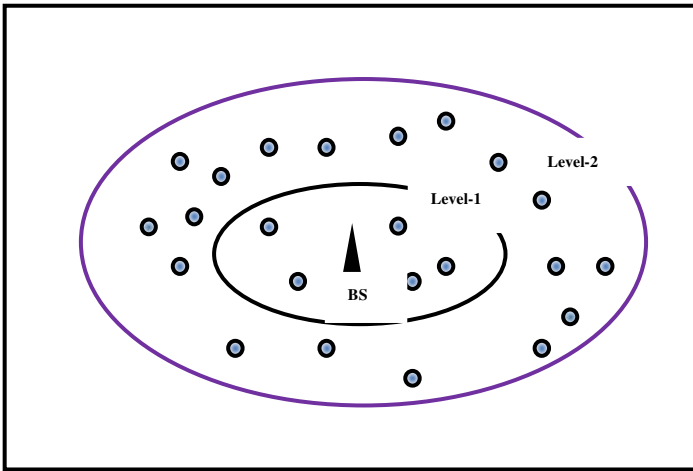


Fig. 2.

Algorithm 1. Setup phase

#No. of nodes N

BS can transmit i levels; $i \geq 1$

1. For each level i , message transmitted by BS
2. If (Nodes does not assign previous level and hear new message or BS transmit level $i = 1$)
3. Assign level i
4. End if
5. End for
6. BS broadcast hello message, which contains the information of upper limit and lower limit of each level.
7. Each node calculates the distance from the BS based on received signal strength

3.2.2 Cluster Setup Phase

In this phase, each level is divided into clusters. The operation of cluster-setup phase is the same as LEACH [3] except the difference of threshold formula. For each level i , each node decide whether or not to become a cluster head for the current round by choosing a random number x between 0 and 1. The node becomes a cluster head for the current round if this number is less than the threshold $T_i(n)$. The threshold defined in ways. First approach is:

$$T_i = \begin{cases} \frac{P \times c}{1 - P \times (r \bmod \frac{1}{P})} \times \frac{U_i - d(n, BS)}{(U_i - L_i)} & \text{if } n \in Z \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Where

- P = the desired percentage of the cluster heads.
- r = the current round.
- Z = the set of nodes which have not been CHs in the last $1/P$ rounds.
- c = the constant factor between the 0 and 1.
- U_i = the upper limit of level- i .
- L_i = the lower limit of level- i .
- $d(n, BS)$ = the distance between node n and base station.

The second approach is

$$T_i(n) = \begin{cases} \frac{P \times c}{1 - P \times (r \bmod \frac{1}{P})} \times \left(\frac{U_i - d(n, BS)}{U_i - L_i} \right) \times \frac{E_{cur}(n)}{E_{ini}(n)} & \text{if } n \in Z \\ 0 & \text{Otherwise} \end{cases} \quad (2)$$

Where

- $E_{cur}(n)$ = current energy of node n .
- $E_{ini}(n)$ = initial energy of node n .

Each node that elected itself a cluster head for the current round, broadcast an advertisement message to the rest of the node by using CSMA Mac protocol. All cluster heads broadcast their advertisement message with the same transmit energy. All non- cluster head nodes receiving these messages from all cluster head nodes and each non-cluster node decided the cluster to which it will belong for the current round. This decision is based on received signal strength of the advertisement messages. Each node must inform to the cluster head that it will be a cluster member by using CSMA Mac protocol. After that, each cluster head creates a TDMA schedule for its cluster members. This information is broadcasted back to the nodes in the cluster. Once the clusters are created and TDMA schedule is fixed, data transmission can begin. Each cluster member can be turned off until the node's allocated time.

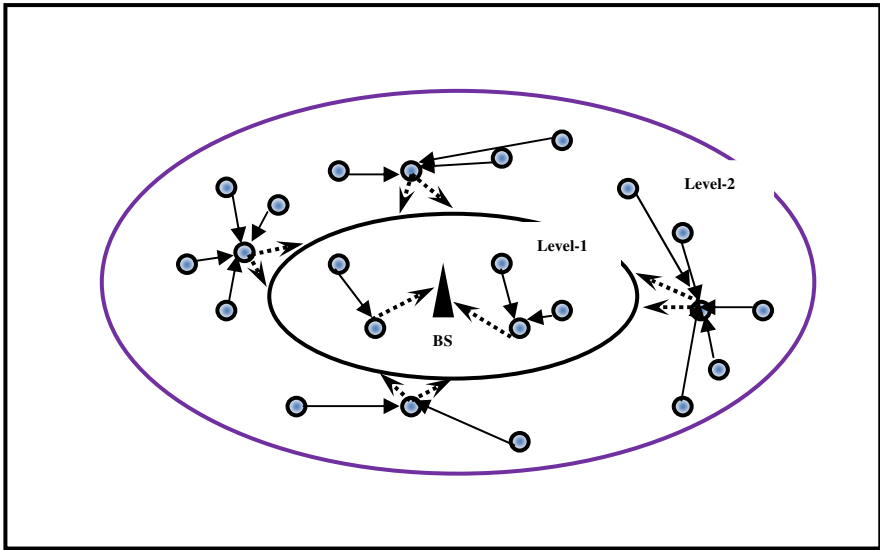


Fig. 3. Cluster formation

Each node sends data to its cluster heads with minimal transmission power. This power is estimated by received signal strength of the advertisement message. So that data transmission uses a minimal amount of energy.

When all the data has been received from the cluster members, then cluster head node perform data aggregation function to compress the data into a single signal. After a certain time the next round begin.

Algorithm 2. Cluster setup phase

1. for each (node N)
2. N selects random number x between 0 and 1.
3. If ($x < T(n)$)
4. N becomes CH.
5. N broadcasts an advertising message for its CH status.
6. Else
7. N becomes a NCH node.
8. N chooses the CH, this selection is based on the received signal strength of advertise.
9. N informs the selected CH and become a member of its cluster.
10. End if.
11. for each (CH)
12. CH creates TDMA schedule for each cluster member.
13. Each cluster member communicates to the CH in its time slot.
14. End for

3.2.3 Inter Cluster Routing

After the cluster formation, the cluster heads broadcast the aggregate data to the next level. At the next level, the nodes aggregate their data and sends to their cluster heads.

In this manner the cluster heads at the last level transmit the final information to the BS.

Algorithm 3. Inter cluster routing

1. For each (level i)
2. for each CH
3. CH receives the data from the cluster member
4. Aggregate the data.
5. If (i ==1)
6. CH transmits data to the BS.
7. Else
8. CH broadcasts data in the next level.
9. End if
- 10.End for
- 11.End for

3.3 Energy Model

We use a free space model. This model is used to calculate the power of received signal of each packet. There is only one clear line of sight path between receiver and transmitter is assumed by the free space propagation.

The energy consumed during the transmission is the main part of the total energy consumption. The received signal power in free space at a distance r is calculated by using the following equation [8].

$$p_r \text{dBm} = p_t \text{dBm} + 10 \log_{10}(G_1) + 20 \log_{10}(\lambda) - 20 \log_{10}(4\pi) - 20 \log_{10}(r) \quad (3)$$

Where the transmitted signal power is denoted by p_t , product of receive and transmit antenna field radiation patterns in the line-of-sight (LOS) direction is G_1 and λ is the carrier wavelength.

The minimum transmission power level p_{t_min} at the sender is calculated as.

$$p_{t_min} \text{dBm} = p_{r_min} \text{dBm} - 10 \log_{10}(G_1) - 20 \log_{10}(\lambda) + 20 \log_{10} + 20 \log_{10}(r) \quad (4)$$

from (3) and (4), we obtain.

$$p_{t_min} \text{dBm} = p_{r_min} \text{dBm} - p_r \text{dBm} + p_t \text{dBm} \quad (5)$$

where p_{r_min} is the receiver's sensitivity?

The non-cluster head nodes calculate the strength of the advertisement messages from equation (1) and join the cluster which has the maximum strength of the received signal. These nodes also calculate the minimum transmission power for sending data to the cluster head with the help of eqn (5).

In free space model, to transmit a l bit message over the distance r, transmission energy consumption $E_{T(x)}(l, r)$ [3] is-

$$E_{T(x)}(l, r) = E_{T(x)-elec}(r) + E_{T(x)-amp}(l, r) \tag{6}$$

$$E_{T(x)}(l, r) = E_{elec} * l + \epsilon_{amp} * l * r^2 \tag{7}$$

where $E_{T(x)-elec}$ is the energy dissipated by the transmitter electronics and ϵ_{amp} is the energy dissipated by the transmit amplifier.

$$E_{R_x}(r) = E_{R_x-elec}(r) \tag{8}$$

$$E_{R_x} = E_{elec} * r \tag{9}$$

Where $E_{R(x)-elec}$ denote the receiver electronics.

4 Simulation Results

In this section, the simulated results are obtained to evaluate the performance of EEHCRP using MATLAB. We simulated the energy consumption, number of clusters and resulting lifetime of the network. The results obtain in terms of three metric, energy consumption of CHs, number of clusters and life time of WSN are represented

Table 1. Shows the simulation parameter

Parameters	Value
Network size	100 x 100 m
BS station	(50, 50)
Number of sensor nodes	100
Initial energy	.05 J
E_{elec}	50 nJ/b
ϵ_{mp}	10pJ/b/m ²
EDA	5nJ/b/signal
Data packet size	4000 bits
n (level)	3

in form of graphs. We define the two version of EEHCRP: EEHCRP-1 and EEHCRP-2. The only difference between these two versions is EEHCRP-1 approach uses eqn (1) and EEHCRP-2 approach uses eqn (2).

We assume that 100 sensor nodes are randomly deployed over 100 x 100 m square area sensor field and the whole network is divided in three levels (n=3). The BS located at (50, 50). The initial energy of each node is .05 J and a node is considered dead when its energy is less than equal to 0.

A. Energy Consumption of Cluster Heads(CHs)

Fig.[4] shows the results for the energy consumed by CHs in EEHCRP by using both approaches eqn(1) and eqn(2) and LEACH protocol for 30 rounds. The energy consumed by CHs for each round in EEHCRP is much lower than that in LEACH. This is due to fact that in LEACH, CHs transmit their data direct to the BS. Therefore, the energy consumption is much higher. In EEHCRP, CHs sends their data to the BS through multihop communication. So a significant amount of energy is saved. For example, after the 25 rounds, the LEACH consumed the about 40% of the initial energy while in EEHCRP is about 12%.

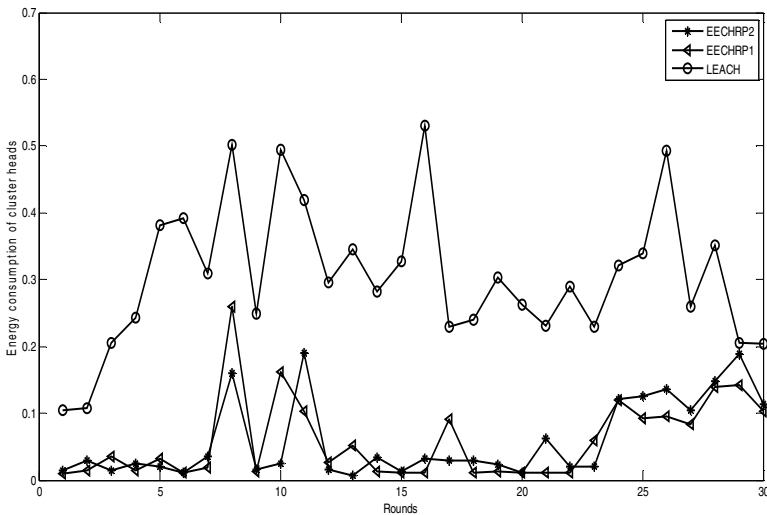


Fig. 4. Energy consumed by CHs

B. Number of Clusters

Fig [5] shows the distribution of the number of clusters in EEHCRP-1, EEHCRP-2 and LEACH for 25 rounds. Its shows that the number of clusters in EEHCRP-1 and EEHCRP-2 is fewer than LEACH. Further it is also observed the numbers of clusters in EEHCRP-2 are less that EEHCRP-1.

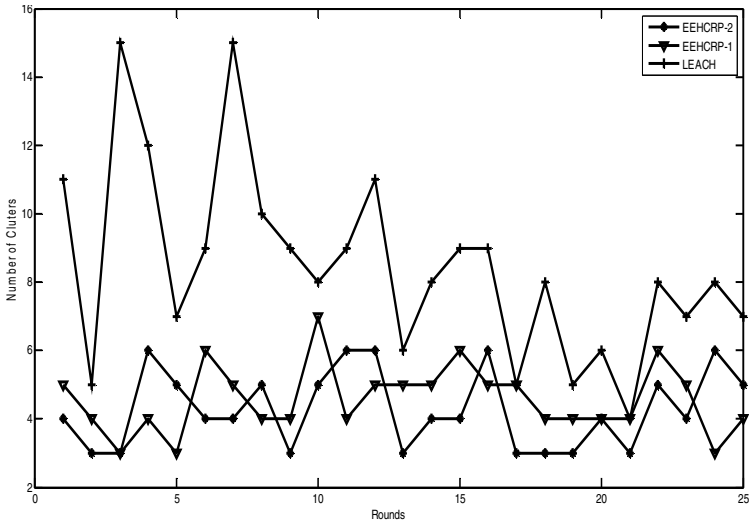


Fig. 5. Number of clusters

C. Lifetime of WSN

The result between the number of nodes alive and the number of rounds is shown by Fig [6]. The result obtained by measuring of time until the first node dies to time until

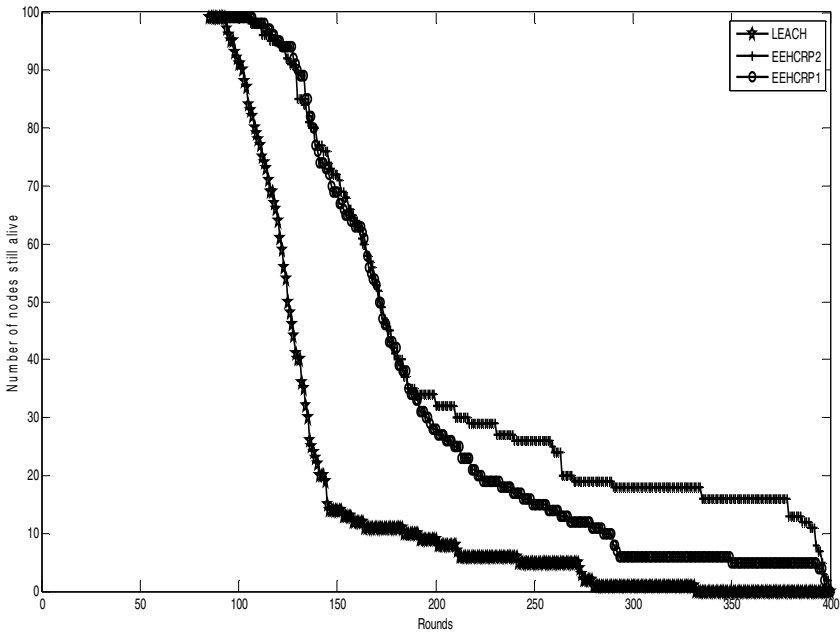


Fig. 6. Network lifetime

the last node dies for 400 rounds. The first dead node appeared in 90 rounds for EEHCRP-1 and in round 92 for EEHCRP-2, in 86 rounds for LEACH and the last dead node appeared in 393 rounds for EEHCRP-1, in 398 rounds for EEHCRP-2, in 333 rounds for LEACH. It is observed that the EEHCRP much better improves the life time of network than the LEACH protocol. Further, it also observed that EEHCRP-2 improves the life time of the network better than EEHCRP-1.

5 Conclusion and Future Work

In this paper, a hierarchical clustering based routing protocol has been proposed. The network model based on power levels is being developed. The mathematical formulae for choosing the cluster head are provided. The model developed is simulated in MATLAB. The simulation results of energy consumption of cluster heads, numbers of clusters and network lifetime are provided. It has been observed that the energy consumed by CHs for each round in EEHCRP is much lower than that in LEACH. For example, after the 25 rounds, the LEACH consumed the about 40% of the initial energy while in EEHCRP is about 12%. It has been also observed that the number of clusters in EEHCRP-1 and EEHCRP-2 is fewer than LEACH and the numbers of clusters in EEHCRP-2 are lesser than that of using EEHCRP-1. Furthermore, It is observed that the EEHCRP much better improves the life time of network than the LEACH protocol and EEHCRP-2 improves the lifetime of the network better than that of using EEHCRP-1. Finally, it is concluded that the performance of EEHCRP is better than LEACH.

In future research, we will study to optimize the number of levels to efficiently consume the energy of all nodes and improve the network lifetime. We also want to extend our algorithm to heterogeneous WSNs.

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