EAPHRN: Energy-Aware PEGASIS-Based Hierarchal Routing Protocol for Wireless Sensor Networks

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Abstract. Power management is considered as one of the most critical researching issues in the area of wireless sensor networks (WSN), as it plays the main role in increasing the sensor nodes life time. This paper proposes a new hierarchical routing protocol for stationary wireless sensor networks, called EAPHRN Energy-Aware PEGASIS-Based Hierarchal Routing Protocol for Wireless Sensor Networks (EAPHRN). The proposed scheme attempts to increase both the lifetime and the throughput of the wireless sensor network. The efficiency of proposed protocol is evaluated. The simulation results showed that the EAPHRN protocol can solve the main problems in PEGASIS since it uses a new chain construction algorithm that is completely different that the PEGASIS and is more efficient. It also uses a new chain leader election method that plays a very critical role in the energy saving.
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1. Introduction

A wireless sensor network (WSN) consists of numerous tiny autonomous sensing nodes that are deployed across a wide geographical area. Routing in WSN differs according to the type of its network structure. Two basic network structures are used: Hierarchal structure and Flat structure. The Hierarchal routing is the routing that operates in the hierarchal structures of WSNs. The main goal of the hierarchal routing protocols is to save the energy of sensor nodes as much as possible, and hence it prolongs the WSN lifetime. To design an energy aware hierarchal routing protocol, two main issues must be considered: the network model and the leader election method. The network model is considered as the environment of routing. Designing an energy-aware network model requires the routing protocol to be an energy-aware protocol. A good network model is one that guarantees that the routing paths will be as short as possible and that the sensor nodes will communicate with adjacent neighbors; thus they do not need to increase the transmission power which is considered to be one of the most important factors in the node's energy consumption [11, 12, 13].

As previously mentioned, in the hierarchal routing there are elected nodes (one or more) that are acting as a local base station inside a cluster or a chain, those nodes collect the data gathered by sensor nodes and combine it together, then they send it to the BS or to other further regions inside the WSN. It is very important to change the leader(s) frequently, since being a leader means a high rate of power consumption and the reason is clear. For this, it is important to have a leader election method, which attempts to elect a new leader with good conditions to do the job. Choosing the wrong leader means a fast depleting for it and a decreasing for the total lifetime of the WSN, while choosing a leader with reasonable conditions means prolonging the network's life time.

In this paper, we propose a new hierarchical routing protocol for stationary wireless sensor networks, called Energy-Aware PEGASIS-Based Hierarchal Routing Protocol for Wireless Sensor Networks (EAPHRN) and compare it with PEGASIS scheme.

The rest of the paper is organized as follows. Section 2 provides a brief overview of the related work. Section 3 explains the system and energy models. In section 4 we present the proposed EAPHRN. In section 5 we evaluate and analyze the performance of EAPHRN. Finally, we draw the conclusion and future work in section 6.

2. Related Work

In this section, we present a review of some hierarchal routing protocols that attempt to prolong the network's life. LEACH protocol [2, 10] is one of the classical hierarchal routing protocols. It uses a clustered network topology that has a number of groups. Each group contains sensor nodes that share some geographical parameters. All nodes within one cluster communicate with an elected cluster head node, which in turn communicates directly with the

BS on behalf of the nodes within the cluster. The election of a new cluster leader is performed at each round and it is based on the randomization selection.

PEGASIS [1] is another classical hierarchal routing protocol that is examined in this study. As mentioned before, PEGASIS forms a chain covering all nodes in the network using a greedy algorithm so that each node communicates with only the neighboring nodes. In each round of communication, a randomly selected node in the chain takes turns to transmit the aggregated information to the BS to save the energy. Furthermore, the elimination of the cluster setup phase, like the one employed in LEACH, allows considerable energy saving. However, the communication delay can be large due to the long single chain and the possibility of having large distances between neighbors inside the chain.

CHIRON [3] is a very new hierarchal routing protocol that has the benefits of both clustering and chaining. In CHIRON, the geographical area is divided into zones using the BeemStar technique [4]. In each zone a chain is formed covering all nodes in the zone using a greedy algorithm. The farthest node(s) within each chain is (are) elected as chain leader(s) for the first round. After the zoning phase is completed, another chaining that covers all chain leaders starting from the farthest node in the network is performed. Finally the closest leader to be BS is elected to be the leader of leaders. CHIRON changes its leaders for each round based on the maximum residual energy of nodes within each zone, which means that the second layer of chaining must be constructed for each round.

3. The System and Energy Models

3.1 The System Model and Assumptions

The system model of the wireless sensor network is considered to be consisting of one sink node (Base Station) and a large number of immobile sensor nodes. The sensor nodes are uniformly deployed over the target area to continuously monitor the environment. Assumptions about the sensor nodes and the underlying network are as follows:

1- There is a BS located far away from the geographical area where sensors are randomly scattered. The sensors and the BS are all stationary after deployment. Figure 1 below illustrates an example of such network topology.
2- All nodes are homogeneous and have the same capabilities.
3- Each node is under the coverage of the BS as well as all under other nodes coverage.
4- The nodes can vary in the amount of transmission power depending on the distance to the receiver. Each node can reach the BS directly.
5- Data are periodically transmitted from the sensor node to the remote BS.
6- The links are bi-directional.
7- All packets that are transmitted are of the same size.

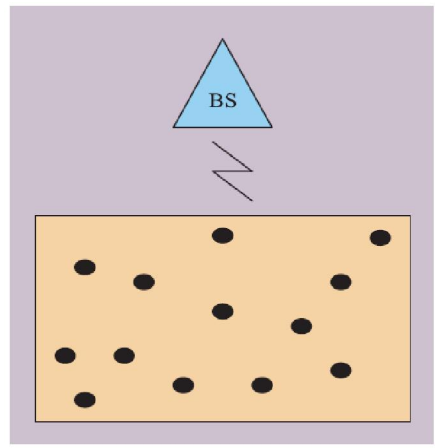

Figure 1: Typical wireless sensor network topology

3.2 Energy Model

We adopt the same radio model as stated in [1, 5] with *Eelec*=50*nJ/bit* as the energy being dissipated to run the transmitter or receiver and ∊amp = 100 pJ/bit/m2 for the transmitter amplifier. The radios have power control and can expend the minimum required energy to reach the intended recipients. The radios can be turned off to avoid receiving unintended transmissions. The equations used to calculate transmission costs and receiving costs for a *k*-bit message and a distance *d* are shown below.

For transmitting:

$$ETx(k, d) = ETx\text{–}elec(k) + ETx\text{–}amp(k,d) \quad (1)$$

$$ETx(k, d) = Eelec*k + \epsilon amp * k* d^2 \quad (2)$$

For receiving:

$$ERx(k) = ERx\text{-}elec(k) \quad (3)$$

$$ERx(k) = Eelec*k \quad (4)$$

The energy of data aggregation (EDA) is 5 nJ/bit/signal.

4. The Proposed EAPHRN

The goal of the proposed protocol is to design a hierarchal chain-based routing protocol that attempts to be as optimal as possible in terms of power consumption. The idea is to find a low cost chain that covers all nodes of the network as in the PEGASIS [1] protocol. As mentioned before, the PEGASIS uses a greedy algorithm to build the chain starting from the farthest node in the network until all nodes are connected .This chain is appropriate because the greedy algorithm tries always to find the next closest neighbor to connect to. However, in large networks, the greedy algorithm causes serious problems and leads to the problem of long chain [3, 4, 6, 7]. To have a clear understanding of this problem, consider the following scenario illustrated in figure 2 below:

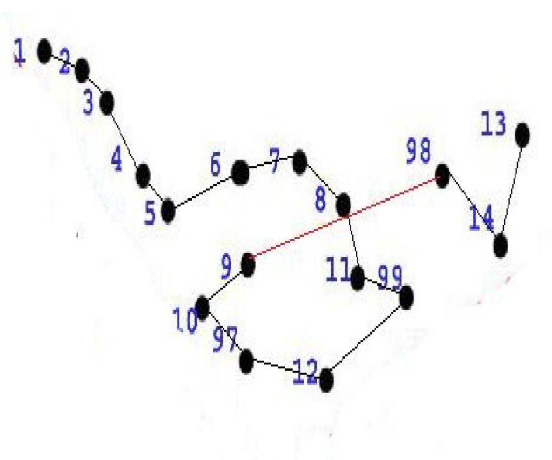

Figure 2 The Long Chain problem

The greedy algorithm starts operating from node labeled "1",and the process continues by connecting the next closest neighbor that is not included in the chain until the node labeled "9" is connected . After that, this node must connect to the next closest node but the next one, node 98, will be extremely far because the close neighbors of node 9 have already been connected to the chain. In this situation both nodes "9" and "98" will consume a high rate of energy while keeping other nodes operated in very good conditions. Furthermore, when nodes 9 and 98 die. The nodes directly connected to them, which are node 10 and node 14 will be operating in the same bad conditions and will be expected to die sooner than the other nodes and so on.

To solve this problem, the new chain construction algorithm in the proposed EAPHRN makes an enhancement over the greedy algorithm, so that the new algorithm does not connect the "next closest node" .Instead, it connects a random node that is located not farther than a Distance Threshold (DT).

In this situation the algorithm will connect nodes as follows: "pickup a random node from a group of potential nodes, all are within a distance threshold DT. The DT should be a reasonable distance that can be applied to all nodes in the network so that nodes do not consume a high rate of energy. By using this algorithm, the chain connects nodes so that all distances between neighbors (edges) do not exceed a reasonable distance, and hence all nodes have fair energy consumption. Figure 3 below illustrates the result of applying this algorithm with the case presented in figure 2.

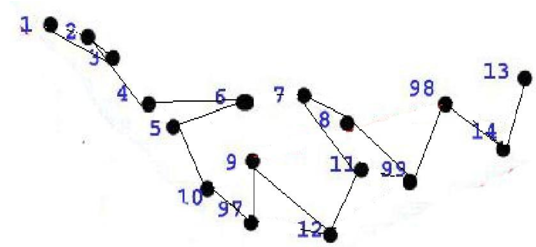

Figure 3 Solving the Long Chain problem

The procedure of EAPHRN is divided into two main phases: the chain setup phase and the leader election method phase.

A. Chain Setup Phase

Before the chain is constructed, the DT must be computed first. Both the BS and the sensor nodes do some contribution in the algorithm that computes DT. Each node must compute a Local DT (LDT), which is the average of distances between the node and the closest *n* nodes to it where *n* is a constant that is determined based on the number of all nodes in the WSN. The Equation of computing LDT is as the following:

$$LDT= \frac{\sum_{i=1}^{n} dst(i)}{n} \qquad (5)$$

Where *dst(i)* is the distance between the node that runs the computation and the closest i^{th} node to it.

After the LDT is computed, the node sends it to the BS as a low cost control message. When the BS gathers all LDTs from all nodes, it computes the DT and sends it to all nodes in the WSN to start forming the chain. The equation to compute the DT is as the following:

$$DT= \frac{\sum LDT}{m} \qquad (6)$$

Where, *m* is the number of nodes in the wireless sensor network.

After the DT is computed and sent to all nodes in the WSN, the chain formation is started at the farthest node from the BS. At each node , all neighbors that are within the range of DT distance are considered potentials to be the next connected node .One of those potentials is picked randomly and is connected to the chain , and the process continues at this connected node.

Finally, when the chain is formed, a one chain leader is elected, which will be the closest node to the BS in the initial stage of the operation. Each node starts sensing and forwarding the gathered data to the next node in the chain, which in turn fuses it with its own data and forwards it to the next node and so on. Once the chain leader receives the data, it makes the last step of aggregation and sends the data to the BS.

B. Leader Election

As in all hierarchal routing protocols, the leader must be changed frequently since it usually consumes the highest rate of battery energy [8]. Most hierarchal routing protocols change the leader of the chain/cluster at each round. The new leader election is most likely based on the maximum residual energy, as in the case in CHIRON [3], or it is based on a randomization election as in LEACH [2] and PEGASIS [1]. However, in the proposed routing protocol, the election will be based on both of those criteria. The goal of the leader election method is not to find an acceptable leader; rather it is to find an optimal leader using the same factor that causes the power consumption which is the distance between the sender and the receiver [11]. Since each node knows the distance between itself and the BS, and since each node can compute how much the residual energy will be consumed if it has been elected to be a leader using the energy consumption equation number (1), then the least ratio of energy consumption can be easily detected and the node with the least ratio of power consumption will definitely be the best leader for the next round. The equation of the energy consumption ratio is as the following:

$$Ratio=\frac{EnCons}{EnResidual}\times 100\% \qquad (7)$$

Where, *EnCons* is the amount of energy that is consumed if the node is elected as a leader, and *EnResidual* is the amount if residual energy in the node's battery.

This election method guarantees that no nodes with bad conditions will be elected at all to be leaders even for one round. It is run at every round and the same leader can still be operating for many continuous rounds, and will not be changed unless another node becomes in a better situation in terms of energy consumption ratio.

The main advantage of this proposed routing protocol is that it attempts to save the energy for each node as well as make a balance of energy consumption in the WSN. The chain construction algorithm attempts to distribute the distances (edges) between nodes in order to avoid the existence of large distances between the nodes in the chain like those which occur using the greedy algorithm in PEGASIS [1].The leader election method guarantees that the best leader node with the least energy consumption ration will be elected. This plays a significant role in energy consumption and prolonging the networks lifetime.

5. Performance Evaluations

5.1 Simulation Environment

The simulation was run on a computer system, and the tool that is used to evaluate the proposed protocol is Omnet++. Omnet++ is an extensible, modular, component-based C++ library and framework for building network simulators [9].

The simulation tool and the computer system parameters are illustrated in table 1.

Table 1 The simulator and the computer system parameters

Parameter	Value
Simulator	OmNeT++ v4.0
System model	HP Pavilion dv 2500 Notebook
CPU	Core2 Duo CPU 2.00GHz(2CPUs)
RAM	2550 MB RAM
Operating System	Windows Vista Business

5.2 The Simulation Environment Parameters

For the simulation, 100 nodes are randomly scattered over a 1000m × 1000m geographical region. The simulation was run with the new proposed protocol as well as the PEGASIS protocol. The simulation environment parameters are illustrated in table 2.

Table 2 The simulation environment parameters

Parameter	Value
Network size	1000m × 1000m
Base station location	(995,995)
Nodes	100
Initial Energy	0.5 J
Eelec	50 nJ/bit
EDA	5nJ/bit
Data packet size	2000 bits

5.3 The Simulation Operation

The simulation was run according to the following steps:

Step1: The PEGASIS [1] protocol was simulated. The key metric for the simulation was to compute the number of rounds during the lifetime of the network. When a node dies, the simulation notifies the user that a node has died and the number of rounds that were completed at that point is reinforced. The PEGASIS chain construction phase with the simulation scenario phase is illustrated in fig. 4.

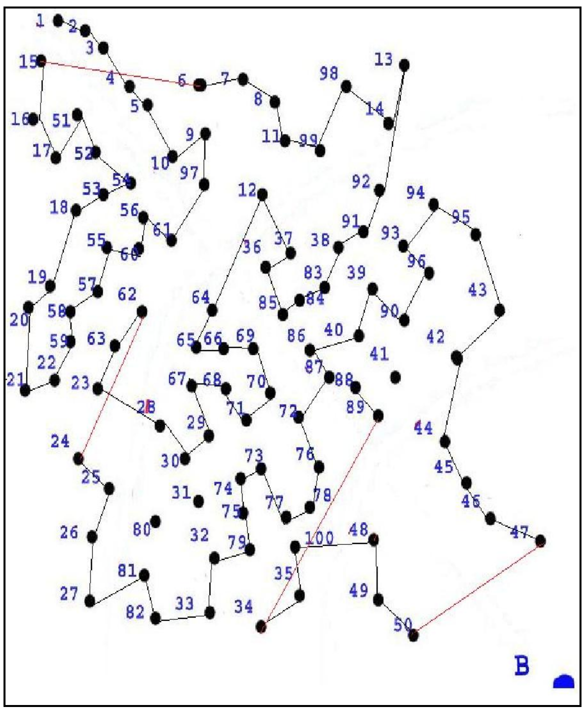

Figure 4. The PEGASIS chain construction phase with the simulation scenario

According to figure 4, the long chain problem of PEGASIS is obvious; there are many large distances, such as the distances between node 15 and 6, node 24 and 62, node 47 and 50, and node 34 and 89.

Step2: In this step, the proposed EAPHRN routing protocol was simulated. The same process that was done in step1 was applied. The LDT value was computed using the equation number (6),and the degree of *n* was 5 .The EAPHRN protocol's chain construction phase with the simulation scenario phase are illustrated in figure 5 below.

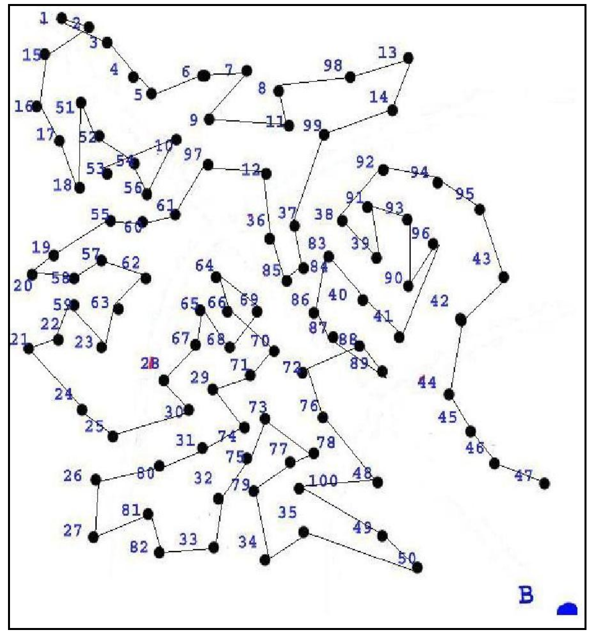

Figure 5. The EAPHRN protocol's chain construction phase with the simulation scenario

According to Figure 5 no large distances exist, like those that were found after applying the greed algorithm of PEGASIS, which implies that the proposed routing protocol will operate with reasonable rate of energy consumption.

5.4 Simulation Results

The goal of the simulation is to compute the number of rounds that each of the compared protocols can achieve against the number of dead nodes lost by the network when that number of rounds is achieved. This measurement proves the efficiency of a simulated protocol, in terms of power consumption.

For each protocol, the simulation was run and the number of achieved rounds was computed against different values of dead nodes as shown in table 3.

As shown in table 3, the efficiency analysis for results can be summarized as follow:

1- The proposed protocol (EAPHRN) is keeping node lifetime double times than PEGASIS.

2- For the network utilization in the proposed protocol (EAPHRN) the throughput is increased. There are no nodes died for the first 50 rounds, while in the PEGASIS the nodes started to die in the first of 14 rounds.

According to the simulation results, the proposed EAPHRN protocol is more energy efficient than PEGASIS as shown in fig. 6.

Table 3 Simulation results in terms of number of rounds against number of dead nodes

Percentage of dead nodes	Number of Rounds/PEGASIS	Number of Rounds/ EAPHRN
1%	14	49
10%	68	164
25%	116	232
50%	170	332
75%	216	416

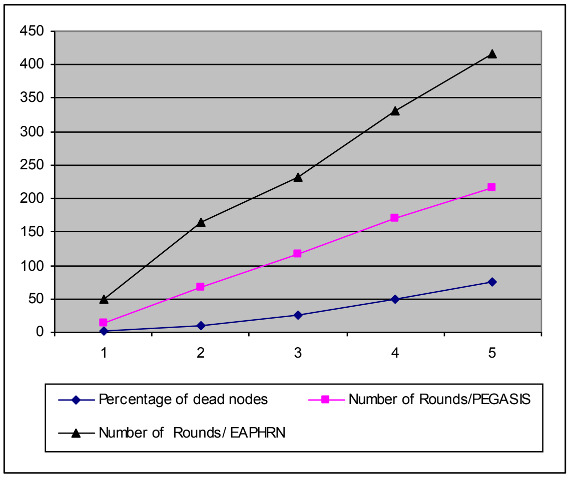

Figure 6. Column chart of the simulation comparison

6. Conclusion and Future Work

A new hierarchal routing protocol called Energy-Aware PEGASIS-Based Hierarchal Routing Protocol for Wireless Sensor Networks (EAPHRN) was proposed, which attempts to increase both the lifetime and the throughput of the wireless sensor network. We evaluate the efficiency of our proposed protocol and the simulation results showed that the EAPHRN protocol solved the main problems in PEGASIS, since it uses a new chain construction algorithm that is completely different that the PEGASIS one and is more efficient. Also it uses a new chain leader election method that plays a very critical role in the energy saving.

In the future works, EAPHRN will be compared with CHIRON [3] that is considered a new PEGASIS-based protocol.

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