MEHR: Multi-hop Energy-aware Hierarchical Routing for wireless sensor networks

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Abstract

Nowadays, wireless sensor networks are known as a new challenge in network science. New features of these networks have made it impossible to use the traditional routing protocols. The most important challenge of these networks is the limited energy of nodes. In this paper, we will introduce MEHR as a multi-hop location-unaware hierarchical routing protocol to decrease the energy consumption in nodes, and to increase the network lifetime, we also apply MEHR to reach to a scalable routing. We will introduce a new factor to select candidate nodes and to send intra-cluster messages. We will use place-advertisement messages of sink, and a limiting parameter and also overhearing concept to create cluster hierarchies with no extra message.

1. Introduction

As we need monitoring and collecting data from various physical environments, wireless sensor networks have become one of the greatest interests of research community today. In this type, hundreds, thousands or millions of densely deployed tiny and cheap sensor nodes are applied to sense the environment changes and to communicate to other sensors to monitor the network field and to send the data to the Sink. [1]

To make the nodes tiny and cheap, each wireless sensor node usually has limited battery power, low power processor, tiny memory, sensing devices and R/F Module. [2]

Wireless sensor networks are applied in many applications in miscellaneous fields, such as military applications and wherever it is impossible for human being to reach.

Ad-hoc network is another kind of network which is most similar to the networks we are discussing about [3].

There are some important differences between sensor and ad-hoc networks. For example, in sensor networks we have more nodes than the other kinds, capabilities and the price of each node is certainly low, also, these two different types of networks have different applications and aims.

Because of the features of wireless sensor networks, the typical protocols are not usable for these networks.

The most important challenge of these networks is power consumption; each node has a limited power resource and it will be vanished after consuming the power.

According to the applications we discussed for sensor networks, usually, it is impossible to access the nodes to make them repaired, and when we lose all nodes, the network will eventually die. Hence, all protocols containing these networks must seriously take this challenge into account. The most energy-consuming component of a sensor node is the R/F module that generates the capability for wireless communications. The energy consumed in wireless channel while it transmits 1 bit of data is equal to thousands of cycles of CPU instructions [4]. So the routing is extremely important to decrease the communicating messages.

Scalability is another important challenge of wireless sensor networks. Again, in accordance with the applications discussed, these networks may be used in miscellaneous places with different scales; so, all algorithms have to be in charge for each scale.

Generally, routing protocols of sensor networks can be classified into 3 main genres: Flat protocols, hierarchical protocols and geographical protocols [5].

The main goal of hierarchical protocols is to decrease energy consumption and to increase the network lifetime.

For this reason, today there is a special attention to these protocols. In hierarchical routing protocols there

is a multi level routing, that the roles of the nodes are not similar and they are mostly based on clustering.
In cluster based protocols, each node senses the environment changes, then it sends the data to its cluster-head in the first level, after that, in the next level, cluster-heads aggregate the received data and send it to the sink (single-hop or multi-hop).

As a location-unaware hierarchical routing protocol, the proposed protocol uses a completely distributed algorithm which is based on random numbers. The sink sends place-advertisement messages to the nodes, then, each node diagnoses its distance to the sink by analyzing the power received. The algorithm applies the distances of nodes to sink, and a limitation parameter and also overhearing concept to create cluster hierarchies without any extra message.

Energy-factor is another applied parameter in the algorithm to send intra-cluster messages to increase network lifetime. Cluster-head selects the node with most Energy-factor, to send aggregated data to the next hop.

The rest of the paper is as follows.

In section 2 we have an overview on some of the related hierarchical routing protocols, and then in section 3 we focus on the proposed protocol with details. In section 4, we consider the analysis and simulation results, and in the last section we have conclusion.

2. Related works

The first and also the most well-known hierarchical routing protocol in wireless sensor networks field is LEACH [6] .It is a location-unaware cluster-based routing protocol that works with a distributed algorithm based on random numbers. In this protocol, the lifetime of network is divided into repetitive rounds and each round contains 2 phases, Setup phase and Steady-state phase (Figure1).

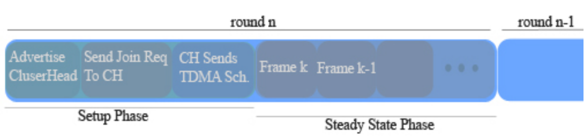

Figure 1. Timeline of LEACH

In the setup phase, clusters and cluster-heads are selected according to the initial probability of nodes. Each node generates a random number between 0 and 1, if the generated number is less than the defined threshold, T(n), then the node will be cluster-head.

$$T(n) = \begin{cases} \dfrac{p}{1 - p \times (r \bmod 1/p)} & if\ n \in G \\ 0 & othrewise \end{cases} \qquad (1$$

Where p is the desired number of cluster-heads (usually p is 0.05), r is the current round and G is the set of nodes that were not cluster-head in last 1/p rounds.

If a node is cluster-head, it sends an advertising message to all other nodes of the network. Each non-head node which receives the advertising messages joins to the nearest cluster-head and sends a join-message to its related cluster-head. Then Cluster-head generates a TDMA schedule and sends it to cluster nodes. In steady state phase, each non-head node senses the environment changes, and then it sends data to cluster-head based on received schedule; after that, cluster-head aggregates the received data and sends it to the sink using the CDMA.

LEACH has many problems, as a sample, it works only by using the generated random numbers, without any interference of nodes information. Also in LEACH cluster-heads send data to sink directly and it assumes all nodes have equal initial energy and capabilities.

Heinzelman at [7] introduced LEACH-C as a centralized version of LEACH. LEACH clustering is based on probability law and random numbers; so that clusters may not have a good shape and it may cause energy leak. Therefore in LEACH-C, this task is leaved for sink; each node sends its location and energy information to the sink at the first part of the setup phase, and then sink solves an np-complete problem using the annealing algorithm to find the best clusters in order to minimize the energy consumption. Having found the best clusters, sink sends the clusters information and TDMA scheduling to the nodes. In the steady state phase, like LEACH, each node sends the sensed data to the cluster-head based on its schedule, then the cluster-head aggregates and sends data to the sink.

Another protocol in this category is PEGASIS [8]; this protocol uses a chain of neighbor nodes and a TSP heuristic to decrease the energy consumption of message-passing. Here, each node sends its data to its neighbor in the chain and the receiver node aggregates the received data to its own data, then it sends them ahead to the chain till the aggregated data reach the sink.
Clearly, message delay in this protocol is a matter of some wonder. Certainly, this problem is not a desired result for a network with great number of nodes.

HEED [9] extends LEACH by incorporating and considering communicative range-limits and intra-cluster communication cost information, where the cluster-head selection is carried out periodically according to a hybrid of the node residual energy and node proximity to its neighbors through constant time iterations. But, to select the best, this protocol uses the energy of nodes, without paying any attention to distance of nodes to targets; also in this protocol cluster-head sends data to sink directly, so this protocol is not scalable too.

3. Proposed Protocol

3.1. Network Architecture

The assumed architecture of a wireless sensor network in proposed protocol is almost like assumed architecture in LEACH;

Nodes unremittingly sense the environment changes, they gather data in the sink; sink as an end-user uses the gathered (and aggregated) data.

- Nodes can be homogeneous with the same capabilities (not necessarily with equal initial energy); they can be even heterogeneous without the same capabilities.
- Nodes are highly connected to each other and each node is capable to send the data directly to other nodes and to the sink.
- Propagation channel is asymmetric.
- The Nodes have the ability to control their power to change the transmission range amount.
- Nodes can compute the distance by analyzing the received signal.
- The radio model used here is like we assumed in LEACH; refer to [10] for more details.

The energy consumed to send l bit of data to distance $d, E_T(l,d)$, is:

$$E_T(l,d) = E_{Tx\_elec}(l) + E_{Tx\_amp}(l,d) = \begin{cases} l \times (E_{elec} + \varepsilon_{fs} d^2), d < d_0 \\ l \times (E_{elec} + \varepsilon_{mp} d^4), d \geq d_0 \end{cases} \quad (2$$

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$$

The first item represents the energy consumption of radio dissipation;

The next item represents the energy consumed to amplify radio. If d is less than d_0, the free space (fs) model will be used; otherwise, the multi-path (mp) model will be used. The electronic energy, E_{elec}, depends on factors such as digital coding, modulation, filtering, and signal spreading, whereas the amplifier energy depends on its distance to the receiver and the acceptable bit-error rate.

The consumed energy to receive l bit of data is:

$$E_R(l) = l \times E_{elec} \quad (3$$

3.2. Protocol Details

MEHR is a multi-hop location-unaware hierarchical routing protocol for wireless sensor networks.

The proposed protocol has a completely distributed algorithm which is based on random numbers.

It uses a new factor to select candidate nodes to send intra-cluster messages. Energy-factor ($E\_fact(n)$), is the number of bits that each node is able to send to node n,

it can be obtained by Equation4.

$$E\_fact(n) = \frac{CurrentEnergy}{E_T(1, dist\_to(n))} \quad (4$$

Where $CurrentEnergy$ is the remained energy of node and $E_T(1, dist\_to(n))$ is the required energy to send 1 bit of data to node n.

So Energy-factor depends on two factors: Remained energy of nodes and those distances to target.

Message overhearing is another applied fact here; when a node sends a message with range d all nodes with lower distance will hear the message. We use this fact to create cluster hierarchies without any extra message.

In Wireless sensor networks nodes are not accessible, they have also limited energy. Remember that sink is free of these limitations; It is completely accessible without any limitation on resources and energy.

So we assume that sink continuously announces its place by place-advertisement messages, all nodes can compute their distance to sink according to the received power.

In accordance with this policy, sink can be mobile. The sink with this important feature has many advantages, for example: in a network with mobile sink, the distance between nodes and sink, and the required energy to send data to the sink is not constant. Hence, the network lifetime will surely be increased by using a suitable mobile sink. Higher security is another advantage of this kind of network. Note that all sensed information will gather in sink, we consider sink as an information center. Generally, in military applications mobile targets are more secure than fixed targets. The protocol proposed here uses these facts to reach to an energy-aware and scalable routing.

The lifetime of network is divided into repetitive rounds; each round contains 2 different phases, Setup phase and Steady-state phase.

3.2.1. Setup phase. At the first of this phase, each node generates a random number between 0 and 1. If the generated number is less than T(n) (in Equation1), as we previously discussed, the node will be cluster-head. Cluster-head nodes send an advertising message to all other nodes of the network. This short message contains the id of cluster-head and its distance to sink.

Non-head nodes save received information of advertisement messages and distances in a table, and then they join to the nearest cluster-head by sending a join-message to it.

Cluster-head nodes save the information of the other cluster-heads which are closer than a pre-defined limitation parameter (*d*), then, they select the nearest cluster-head as next-hop. If the node is closer to sink than next-hop, then next-hop will change to sink.

After all these processes, cluster-heads create the TDMA schedule, and send it together with the id of next-hop to cluster nodes.

After receiving schedule message, every non-head node diagnoses its schedule and its next-hop node. Note that next-hop node is cluster-head and all nodes have received its advertisement message, so. They are able to compute their distance to it.

Non- head nodes after receiving schedule go to sleep and wait for their turn.

The pseudo code of this phase is depicted in Figure2.

3.2.2. Steady State. In this phase non-head nodes monitor the environment.

They wake up at their special time and send their data together with their $E\_fact(NextHop)$ to the cluster-head using a spreading code which is known as transmitter-based code assignment [11], then they will sleep for their next turn.

Every cluster-head aggregates them by receiving data from nodes, and it saves the received E_facts in a table.

```
SetUp Phase:
  µ ← Rand(0,1)
  T ← T(n)       // Based on Equation1
  ISCH ← false
  if (HasBeenCH = false)
     if (µ < T)
        Advertise_CH(self.id,distance_to_sink)
                 ISCH ← true
     endif
  endif
  Receive ADV_MSGs, save the contents and distances
  if(ISCH = true)
    Next_Hop ← FindTheNearsetToSink(d)

if(Next_Hop.distanceto(sink)>this.distanceto(sink))
         Next_Hop ← Sink
    endif
  else
           CH ← FindTheNearest()
           SendJoinReq(CH)
  endif
  WaitToReceiveJoinMsgs()
  if(ISCH = true)
           Sch ← Create_Schadule()
           Sch ← Merge(Next_Hop,Sch)
           Send_Schadule()
  endif
  WaitToReceiveSch()
  if(ISCH = false)
           MyTime ← FindMyTime(Sch)
           Next_Hop ← FindNext_Hop(Sch)
           GotoSleep()
```

Figure 2. Pseudo Code of Setup Phase

```
Steady State Phase:
  if(ISCH = false)
           WakeUpOn(MyTime)
           data ← MonitorTheEnvironment()
           data ← Merge(E_fact(Next_Hop),data)
           SendData(data,CH)
           GoToSleep(EndOfRound)
  endif
  if(ISCH = true)
           content ← RecvData()
           Update(E_factTable,content.E_fact)
           Aggrigate(AggrigatedData,content.data)
           if(all nodes sent)
             sender ← FindBestE_fact()
             if(E_factTable(sender)<E_fact(Next_Hop)
                 SendDataTo_CSMA(Next_Hop)
             else
                 Send_ReqToSend(sender,data)
             endif
           endif
           on Recv AgData
                 Aggrigate(AggrigatedData,AgData)
  endif
  if(ISCH = false)
           WakeUpOn(EndOfRound)
           if(Recv(ReqToSendMsg))
                   SendDataTo_CSMA(Next_Hop)
                   GoToSleep()
           endif
  endif
```

Figure 3. Pseudo Code of Steady State Phase

It selects the node with the most E_fact when it receives data from entire cluster nodes. If the E_fact of selected node is less than its own E_fact, it will send the aggregated data to next-hop directly; otherwise it will send the aggregated data to the selected node.

Selected node sends aggregated data to next-hop node after receiving them from cluster-head

To prevent message interference intra-cluster messages use a CSMA coding.

The pseudo code of this phase is depicted in figure3.

4. Analysis and Simulation Results

In this section, we will evaluate performance of the proposed protocol. We implemented LEACH and MEHR and verified found results of LEACH with the results of an implementation of LEACH on ns-2 in MIT University as µAMPS project [12].

Like we assumed in LEACH, we used simple radio and energy consumption model (Equations 2, 3).

As mentioned in Section 3-1, it's not necessary in MEHR to have homogenous or heterogeneous nodes, or to have identical initial energy for all nodes,

Here, as we are to compare MEHR with LEACH, we consider nodes homogenous with identical initial energy. Sink assumed to be fixed, although it can be mobile.

Table 1 shows the simulation and energy consumption parameter.

Table 1 – Simulation parameters

Parameter	Value
Initial energy	2J
E_{elec}	$50\ nJ/bit$
ε_{fs}	$9.6\ pJ/\left(bit \times m^2\right)$
ε_{mp}	$0.0013\ pJ/\left(bit \times m^4\right)$
d_0	86 m
bandwidth	1 Mbps
Packet size	500 bytes
Header size	30 bytes
Frame time	20 sec

The first sample is a network with 100 nodes in which nodes are distributed between (x = 0, y = 0) and (x = 100, y = 100) with the sink at location (x = 100, y = 175). Figures 4and 5 show the simulation results of running LEACH and MEHR on this network.

LEACH simulation results (with 5 cluster-heads) on this network shows that first nodes die at second 410 and just 3 nodes remain alive at second 560, and subsequently network stops working.

By using MEHR the lifetime of network increased, it is because of multi-hop routing and using E_Fact of nodes. The results show that the first node dies at second 460 and network stops working at 660.

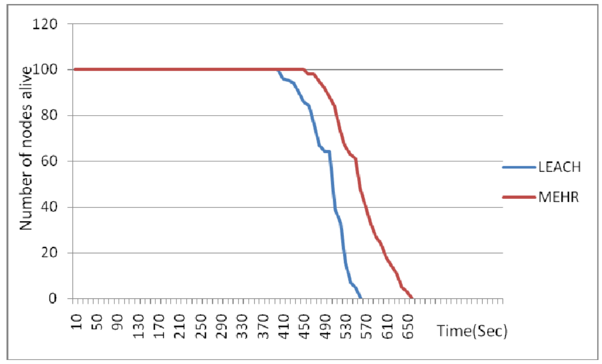

Figure 4. Sample1: Number of nodes alive over time

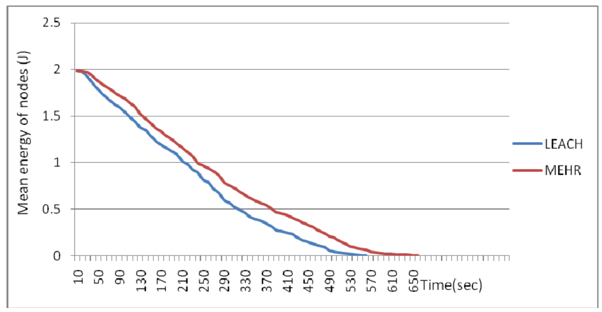

Figure 5. Sample1: The mean energy of nodes

Next sample is a network with 200 nodes which are distributed between (x = 0, y = 0) and (x = 200, y = 200) with the sink at location (x = 200, y = 275). Figures 6 and 7 show the simulation results of LEACH and MEHR in this network.

Cluster-heads send data to sink directly in LEACH; the information of nodes is not used to send data in this case. LEACH simulation results (with 10 cluster-heads) on this network shows that first nodes die at second 40and the network stops working at second 310.

Because of the fact of multi-hop routing and by using the nodes with most Energy_factor to send data to next-hop, MEHR can be a qualified substitution for these networks. Simulation results of MEHR (d=70) show that the first node dies at second 310 and network stops working at second 570.

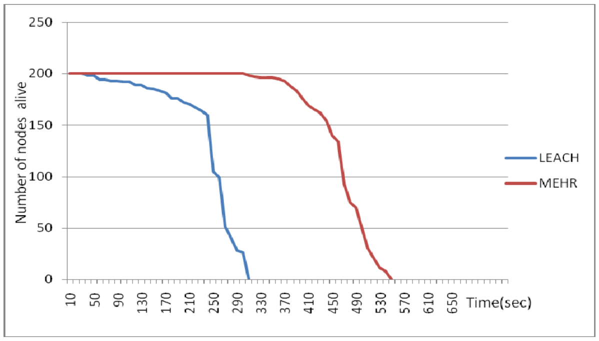

Figure 6. Sample2: Number of nodes alive over time

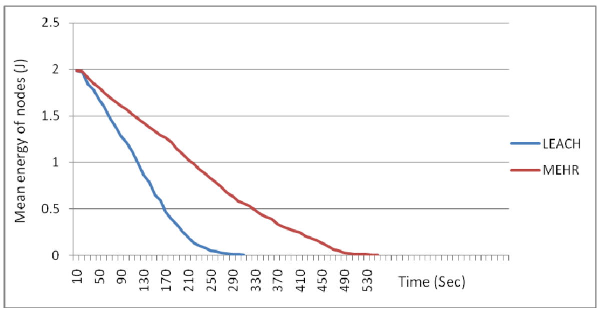

Figure 7. Sample2: The mean energy of nodes

5. Conclusion

In this paper, we introduced a multi-hop location-unaware hierarchical routing protocol for wireless sensor networks to decrease power consumption, to increase network lifetime and to reach to a scalable routing.

The proposed protocol uses a completely distributed algorithm based on random numbers. It also uses place-advertisement messages of sink and of a new factor to select candidate nodes to send intra-cluster messages.

Firmly, the simulation results confirmed that MEHR increased the network lifetime .it can be used in networks with different scales.

10. References

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