ENERGY EFFICIENT ROUTING PROTOCOL FOR LARGE-SCALE WIRELESS SENSOR NETWORKS

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ABSTRACT

Recently wireless sensor networks (WSN) get great attention in both research and industrial fields. The fast development in WSNs raises many new issues in the field. One of the interesting and of great needs issues is extending the scale of WSN, in order to have large-scale WSNs. In this paper, we propose an enhancement to Pairs Energy Efficient Routing Protocol (PEER) [1] for wireless sensor networks, to fit large-scale WSN. We showed the detailed enhanced algorithms and compared the new proposed protocol with the LEACH protocol (a well-known hierarchical routing protocol for WSNs). The results clearly show that the new protocol outcomes LEACH especially for large-scale deployment of wireless sensors motes.

KEYWORDS

Wireless Sensor Networks, Large-Scale WSNs, Routing Protocols, Energy-Aware Routing, Dual Power Assignment

1 INTRODUCTION

Recently wireless sensor networks (WSN) get great attention in both research and industrial fields. The fast development in WSNs raises many new issues in the field. WSNs consist of small nodes with sensing, computation, and wireless communica-tions capabilities [2]. Recent advances in wireless communications and electronics have enabled the development of low power, low cost, multifunctional sensor nodes that are small and communicate in short distances. Wireless sensor networks are now used for data collection in many applications and according to that, many routing protocols have been proposed for WSNs [3]. Most of these protocols are designed for small-scale WSN. The extended use of WSN raises the need for extending these protocols or implementing new protocols to cover large-scale areas.

In this paper, we propose an enhancement of PEER [1] for large-scale WSNs. The PEER protocol was designed for monitoring applications, but has limited area and limited number of sensors. In this paper, we targeted both increasing the number of sensors and enlarging the area of deployment. The proposed protocol divides the network field into a number of regions and hence minimizes the number of packets transmitted from nodes to sink, which will lead to a decrease in power consumption. The protocol is divided into three phases: Two major phases joining pair phase (setup phase) and transmission phase (steady state phase), and one minor phase (changing pair phase, which is similar to the setup phase).

The rest of this paper is organized as follows: The next section introduces different phases of the protocol, and mentions the details of the algorithms used in each phase. In Section 3, the network model used in the simulation is described. Section 4 presents the results of the different simulation runs. Finally, we conclude the paper and discuss future work directions in section 5.

2 PROTOCOL ALGORITHMS

In this section, we introduce the algorithms used in our proposed routing protocol for large-scale WSNs. As in [1], we have assumed that every node can determine its position information. The recent availability of small-sized, low power, now available low cost GPS receivers and position estimation techniques based on signal strength measurements, give great justification for position-based routing protocols and makes our assumption trivial. Different studies have discussed this issue for WSNs and have proposed low cost solutions for determining the position of nodes [4-6]. The area in which sensor nodes are deployed is divided into regions. Each node can determine to which region it belongs according to its location.

In [7], it has been proved that the network connectivity of a WSN remains strong using dual power management. By using dual power, each node has the availability to transmit using two power levels, high and low. The high (respectively, low) power level is equivalent to long (respectively, short) distance transmission. Each two nodes will form a pair; one node transmits data to the sink using high power. The other node transmits data to its partner using low power. The roles of the node pair will be changed periodically to fairly distribute the far-transmission load between both of them. The three phases of the protocol are:

2.1 Joining Pair Phase

The first phase is the joining pair phase. Each node tries to find another one to form a pair; this is done by discovering its set of neighbors in the network to choose one of them to be its partner.

The number of neighbors of a node depends on the node density and the low power level used [8, 9]. For a fixed node density, the low power level will determine the average number of neighbors around a node. The low power level should be chosen to compromise between energy consumption and number of isolated nodes.

The joining pair phase starts by nodes sending a HELLO message using low power level to introduce themselves to their neighbors. In order to avoid broadcast collisions, a randomly chosen delay is imposed before sending the HELLO message. Any node that receives one or more HELLO messages chooses the nearest neighbor and reply to it with a JOIN message. The nearest neighbor is chosen by measuring the *Received Signal Strength* (*RSS*); the highest RSS is corresponding to the nearest neighbor [10]. A node, that receives a JOIN message and agrees that the neighbor is the nearest one, should reply with an ACK message. Nodes that do not get ACK message have to try to join other nodes using JOIN message. HELLO, ACK, and JOIN messages are sent using a *Carrier Sense Multiple Access with Collision Avoidance* (*CSMA/CA*) MAC protocol [11] to reduce the collisions during this phase for forming pairs. Anyhow, the interference between different messages during this phase is minimized as all nodes are sending using the low power level.

We name nodes sending JOIN messages "seconds" and those sending ACK message "firsts". The naming is used only to distinguish between two nodes forming a pair, but actually, both of them are working as "peer" to "peer". After forming a pair, firsts will send data using high power level, and seconds will send data at low power level. The role of them will be changed as explained later in the transmission phase. After the cycle of the HELLO-JOIN-ACK messages, most of the nodes have formed pairs and only few numbers still have no pairs. The task of individual nodes is explained in the next phase.

2.2 Transmission Phase

After the establishment of pairs, nodes are now able to send data to the sink or toward the sink if the node is far away from the sink. Nodes set at their low (respectively, high) power level are named simply low (respectively, high) nodes. Nodes that did not form a pair during the previous phase are called individual nodes.

2.2.1 Sink Tasks

- Turn on its receiver.
- Listen and process data messages coming from nodes.
- Send control messages to nodes to define the regions through setting the number of bits indicating the region.
- Keep track of different routes through which the data messages are coming in order to know how nodes in each region are loaded.
- Update routing table according to information retrieved from sensor nodes.
- Send control messages to nodes informing them with routing table updates.
- Send control messages to nodes to inform them whether to send data on regular bases or only through inquiries.

2.2.2 Low Node Tasks

- Turn off its receiver until it becomes a high node.
- Sense the environment periodically every time step (round) to record a reading.

- If the reading changes from the previous one, send the reading to high node; otherwise do not send the reading to the high node.
- Set a flag in its message to the high node every 100 rounds to know whether they should change their role or not.
- Turn on its receiver after setting the flag, and wait for a reply from the high node.
- According to the reply from high node, the low node becomes high node or turns off its receiver and continues working as low node.
- Also according to the previous reply coming from the high node, the low node will be informed with all updates coming from the sink (updates include changes of regions, routing table updates, and inquiries)
- Notify high node with the death of the low node when energy drops to the minimum level of energy.

2.2.3 High Node Tasks

- Turn on its receiver.
- Sense the environment periodically every round to record a reading.
- If it receives a data message from its partner, it aggregates its reading with the reading of the low node, process a data message, and send the message to the sink after waiting a delay. This delay ensures that one high node sends data messages before the others and ensures that far transmissions are distributed fairly. The delay is anti-proportional to the absolute value of the difference between the node's reading and a nominal value set by the sink, in order to give priority to large variations in readings.
- If it listens to a data message from another high node in the same region, it compares the coming data with the data it has. If both are equal the node should discard its own data message, otherwise it should send it.
- If it listens to a data message from a high node in another region, it checks its routing table to know whether it should forward the message toward the sink or not. If it has to forward the message, the node should aggregate the contents of the coming message to its own data and prepare a new message to send to the sink.
- Reply to partner’s requests indicating whether they should change their roles between high and low power levels, or not.
- Include in its reply to partner updates coming from sink, which includes routing table updates, and inquiries related to the partner.
- Look for another partner, if its partner is dead. This will be explained later in the joining pair phase.

2.2.4 Individual Node Tasks

- Turn on its receiver.
- Sense the environment periodically every 5 rounds to record a reading.
- Send the message to the sink after waiting a delay. The average delay of individual nodes is larger than that of high nodes, to have less far transmissions than high nodes.
- If it listens to a data message from another high node in the same region, it compares the coming data with its own readings. If both are equal the node should discard its own data message, otherwise it should send it.
- If it listens to a data message from a high node in another region, it checks its routing table to know whether it should forward the message toward the sink or not. If it has to forward the message, the node should aggregate the contents of the coming message to its own data and prepare a new message to send to the sink.
- Reply to HELLO messages to join another node to form a pair. This happens when one node of an old pair is dead.

2.2.5 Changing Roles of a Pair

Nodes start the transmission phase with approximately 100% of their energy as the joining pair phase only consumes a little amount of energy. Table 1 shows when the transitions between high and low power levels take place (letters between parentheses show the power level, H for high and L for low).

Table 1 Energy levels for transition between low and high power states for a node pair

	First Energy Status	Second Energy Status
1st Period	100% (H)	100% (L)
2nd Period	60% (L)	<100% (H)
3rd Period	<60% (H)	40% (L)
4th Period	20% (L)	<40% (H)

At startup first (respectively, second) will be a high (respectively, low) node. They change their roles when the energy status of the first drops to 0.6 from its initial value. At this point, the second energy level is a little bit less than 100%, because the node consumes power in sensing, processing, and sending data at the low power level to its partner. The role changes at the following statuses: Second reaches 40%, and finally first reaches 20% of their total initial energy. Second remains high until it loses all its power (node death). These values are chosen in order to keep the nodes at near levels of consumed energy percentage and to decrease the number of transitions between high and low.

Data transmission within a region, i.e. from low nodes to high nodes and vice versa, is done through low power level using CSMA/CA MAC protocol to reduce intercluster collisions. High nodes and individual nodes are sending data out of their region toward the sink using CDMA codes. CDMA codes differ from one region to another to avoid intracluster collisions. The sink is responsible for the assignment of CDMA codes to different regions.

Sensor nodes forwarding messages from one region (or more) to another region should be informed with the CDMA code corresponding to the region from which the messages are coming. Informing the nodes with the CDMA codes of regions is done by the sink, and could be done through one of two methods: First, it can be done only once at startup, if the nodes have enough memory to store all CDMA codes corresponding to all regions. Second, it could be done dynamically using routing table updates coming from the sink. The CDMA code of the wanted region or regions will be included in this routing table updates, i.e. the routing table will inform nodes in a certain region which messages they are going to forward together with the CDMA code that has generated these messages.

2.3 Changing Pairs Phase

When the second is dead, the first should look for a node to form a pair. This is done by sending a HELLO message to the neighbors and waiting for a JOIN message from an individual node or another first that has also lost its second. The individual nodes play an important role in this stage, as they can work as higher nodes for those firsts that reach low level of energy. We have partially saved the energy of individual nodes to allow them to serve poor-energy nodes at this stage.

3 NETWORK MODEL

This section introduces both the radio and the network models of the proposed protocol.

3.1 Radio Model

We used a first order radio model that has been used as a model in many of the previous studies related to WSNs [12–15]. The radio model is described as follows:

A simple model have been assumed where the radio dissipates $E_{elec} = 50\text{nJ/bit}$ to run the transmitter or the receiver circuitry and $\varepsilon_{amp} = 100\text{pJ/bit/m}^2$ for the transmitter amplifier to achieve an acceptable E_b / N_0. 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.

An r^2 energy loss is used due to channel transmission. Thus, to transmit a *k*-bit message a distance *d* using the first order radio model, the radio expends:

$$\begin{aligned} E_{Tx}(k,d) &= E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \\ &= E_{elec} * k + \varepsilon_{amp} * k * d^2 \end{aligned} \tag{1}$$

To receive a *k*-bit message the radio expends:

$$E_{Rx}(k) = E_{Rx-elec}(k) = E_{elec} * k \tag{2}$$

As equation (2) implies, receiving is not a low cost operation, therefore, the protocol should not only minimize the transmission distances, but also the number of receptions and transmissions should also be minimized.

The radio channel has been assumed symmetric such that the energy required transmitting a message from node A to node B is as the same as the energy required transmitting a message from node B to node A for a given *signal to noise ratio* (*SNR*).

3.2 Network Model

In the simulation, we have chosen three different sizes for the field in which the nodes are deployed, namely 50m x 50m field, 100m x 100m, and 200m x 200m. For each of the mentioned three fields we have varied the number of nodes deployed to be 100, 200, and 400 nodes. That means we have nine different network scenarios, which is the main contribution in our work in this paper, by extending both the number of nodes and the deployment area when compared to the previous work.

We have considered two cases in our simulations. First, all nodes start the simulation with the same energy level. In the second case, nodes are given different amounts of energy at the beginning of the simulation; the energy level of each node is given randomly using normal distribution with a certain mean *m* and a standard deviation σ .

Each network consists of one fixed sink and is located at least 50m from the nearest node. The sink has a constant power supply; consequently, it has no power constraints, through the sink, the user can get data from the wireless sensor nodes. The sink can broadcast with high power to all nodes and therefore there is no need for routing from the sink to any specific node.

The nodes, on the other side, have restricted energy constraints and are located randomly in the field. Nodes have limited energy, they cannot always send data to the sink directly; otherwise, they will quickly lose their power and become useless. Therefore, there should be a certain routing criteria that will try to minimize the power consumption of nodes in order to maximize the lifetime of the nodes, and hence the lifetime of the whole network.

3.3 Performance Evaluation

To evaluate the performance of the new proposed protocol, we simulated both LEACH and PEER using several random networks. In our simulation, we were interested in comparing the performance of both protocols based on several metrics:

- Average energy dissipated: This metric show the average energy dissipated by the nodes over the time. An efficient routing protocol should have low energy consumption over the time.
- Network lifetime: This metric is measured through the number of nodes alive over the time. It gives an idea about how long the nodes are surviving and more importantly gives information about the area covered by the network over the time. A competent algorithm should have large number of nodes alive over the time.
- Distribution of nodes alive: The number of nodes alive is an important metric, but in addition, the distribution of nodes alive over the deployment field is very important. A protocol with large number of nodes alive, but concentrated in a certain region, will lead to partially or may be total information loss from regions that have no or small number of nodes alive.

We have simulated an environment with variant temperature and variant levels of carbon monoxide gas in different regions. The area covered by the sensor nodes is divided into regions, each of which is a square of 25m x 25m. Each region is assigned a random temperature between 0°C and 100°C every 5 rounds and a random carbon monoxide level between 0 and 400 *parts per million* (*ppm*).

We have assumed that 90% of the nodes in a certain region have almost the same reading. More precisely, the nodes do not have the same reading, but it is better to say that the differences between the readings in the same region are to 90% below a certain threshold. The other 10% of the reading are above the threshold. This 10% of data has higher priority, and should be sent to the sink prior the others. We have set the threshold of the difference to be 5°C for temperature and 20 ppm for the carbon monoxide gas level.

This previous assumption is worthy as adjacent nodes usually have similar data especially for some applications such as fire detection, and implosion detection. In the mentioned application, readings from one region are almost the same until crisis occurs. In other applications, where adjacent nodes do not have the same reading, a data collection algorithm should be used to gather data from all nodes.

4 SIMULATION RESULTS

The simulation results of the proposed protocol are compared with some previous work in order to show advantages and limitations of the new protocol. We have mainly compared our protocol with LEACH [12]; a recognized and well-known cluster based routing protocol for WSN. LEACH is one of the pioneer routing protocols and has been considered as a reference to compare with in the establishment of many WSN routing protocols [13–15].

For each experiment, we have run each protocol 10 times and have averaged the energy dissipated by all nodes and the number of nodes alive every 100 rounds.

4.1 Percentage of Nodes Forming Pairs

The first group of experiments was concerned only with the new proposed protocol to simulate the forming of pairs in the joining pair phase. Figure 1 and Figure 2 introduce the percentage of nodes forming pairs vs. low power coverage distance for 100m x 100m and 200m x 200m fields. When looking to the figures together we get that the percentage number of nodes having pair for the same number of nodes deployed and for the same low power coverage distance decreases by increasing the deployment area. Increasing the deployment area leads to decreasing the node density, which increases the probability of nodes getting isolated and hence decreasing the percentage number of nodes having pairs. Using the curves a low power level can be chosen to allow a certain coverage distance and hence a percentage number of nodes having pair, and vice versa, i.e. a certain percentage number of nodes having pair can be chosen and the corresponding low power level will be determined.

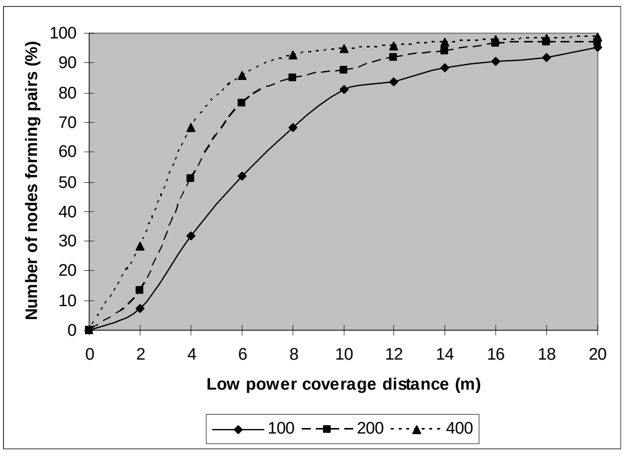


Figure 1 Percentage of nodes forming pairs vs. low power coverage distance (m) for 100, 200, and 400 random nodes in a 100m x 100m field

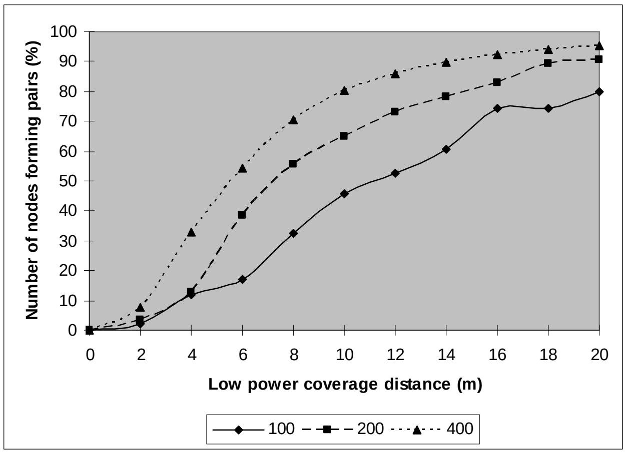


Figure 2 Percentage of nodes forming pairs vs. low power coverage distance (m) for 100, 200, and 400 random nodes in a 200m x 200m field

The number of nodes having pair will greatly affect the energy consumption and network lifetime, as will be shown later. We have chosen the low power level always to allow 80% of the nodes to have pairs. Through a group of simulations, we have found out that this value is a compromise between energy consumption and number of nodes having pair.

4.2 Average Energy Dissipated

Next set of experiments is a comparison between energy dissipated by both LEACH and PEER over the time. Figure 3 compares between the average energy dissipated per node for the two protocols, but for two different cases for each protocol. LEACH with all nodes having equal energy level, and LEACH(NE) is LEACH with nodes having "not equal (NE)" amount of energy at startup with 100 nodes deployed in a 200m x 200m field. PEER outperforms LEACH by a factor of more than 2. It is clear that short distance transmissions in PEER are much less that in LEACH. Moreover, short distances in LEACH from nodes to their cluster heads are on the average much longer than short distances between pairs in PEER. In LEACH, at any time 5% of the nodes are cluster heads, which means that 95% of the nodes are going to send short distance transmissions to the cluster heads. At the beginning, both LEACH and LEACH(NE) have the same energy dissipation, but after that, LEACH(NE) loses low-energy nodes and hence the rest of nodes get cluster heads more frequently, which leads to a higher energy consumption rate. Both PEER and PEER(NE) are almost the same because the protocol distributes the load between the nodes according to their energy level and not just equally between nodes. PEER(NE) average energy dissipation is slightly higher than in PEER, as nodes with low energy at startup die quickly, which requires earlier extra energy consumption for forming new pairs.

Figure 4 and Figure 5 are also comparisons between both protocols for different scenarios. Below each figure, we mentioned the mean value of the initial energy level of sensor nodes, the variance, number of nodes, and field size. Experiments show that PEER outperforms LEACH with a factor of at least 2. In addition, PEER(NE) is very close to PEER with an increase of 5% or less in the average energy dissipated. The same metric in LEACH (NE) has an increase of about 25% more than LEACH. This makes PEER an appropriate choice for heterogeneous networks with nodes having different levels of energy at startup.

The figures also show that increasing the node density will decrease the average energy dissipated over the time, which is clear as the number of nodes involved in transmission is constant per time and hence increasing this number allow the network to spend its energy over a larger period. It is clear that increasing number of nodes decreases energy dissipated. It should be also considered that increasing number of nodes is a matter of cost.

For a fair simulation, we used the first order radio model discussed earlier in this section. Actually, using this model in the simulation of LEACH is feasible for small deployment areas only, but is not realistic for larger areas, as the transmission exceeds the crossover point, which is less than 100m. Our protocol does not suffer from this dilemma as it sends hop by hop over the regions, where the transmission distance lays below the reference distance. LEACH experiences real trouble when applying the extended radio model where the energy dissipated is proportional to r^4 instead of r^2. We simulated both LEACH and PEER using the extended radio model for the deployment field 200m x 200m for 100, 200, and 400 nodes. As shown in Figure 6 to Figure 8, PEER remains the same, but LEACH has a dramatic increase in the average energy dissipated.

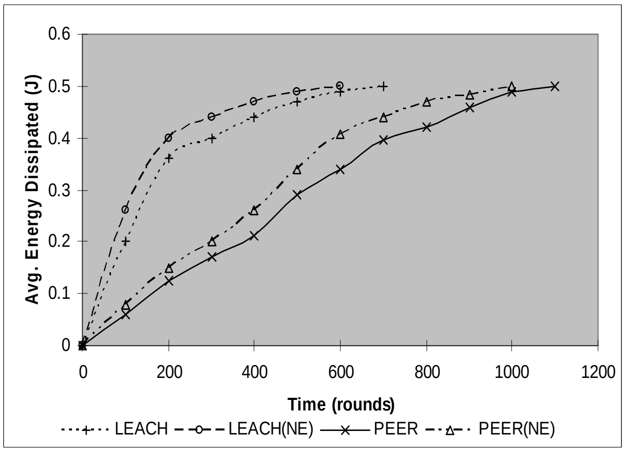


Figure 3 Average Energy Dissipated (J) vs. Time (rounds) (m = 0.5 Joule, $\sigma = 0.2$, 100 nodes, 200m x 200m)

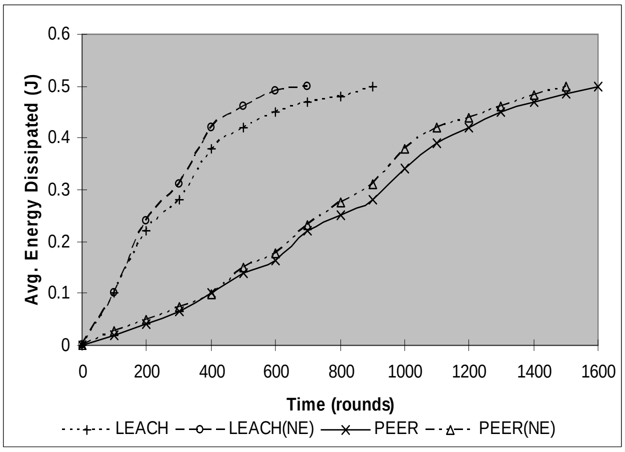


Figure 4 Average Energy Dissipated (J) vs. Time (rounds) (m = 0.5 Joule, $\sigma = 0.2$, 200 nodes, 200m x 200m)

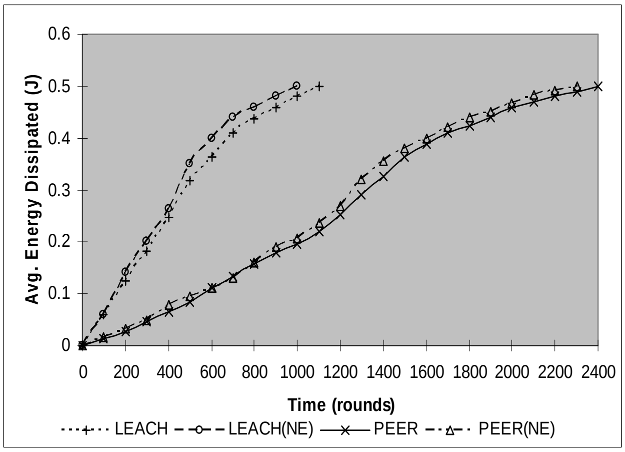


Figure 5 Average Energy Dissipated (J) vs. Time (rounds) (m = 0.5 Joule, $\sigma = 0.2$, 400 nodes, 200m x 200m)

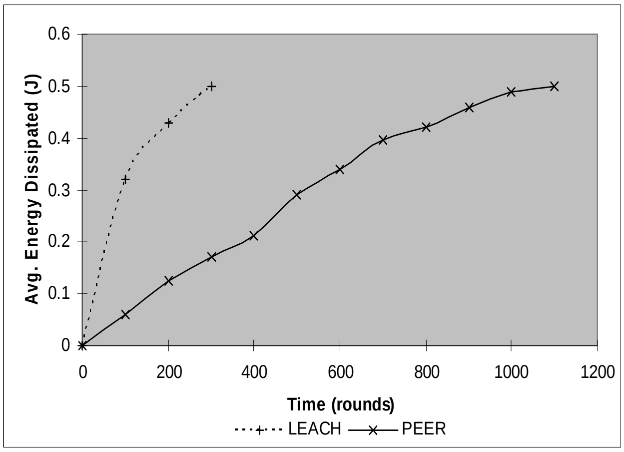


Figure 6 Average Energy Dissipated (J) vs. Time (rounds) (0.5 Joule, 100 nodes, 200m x 200m, using extended radio model)

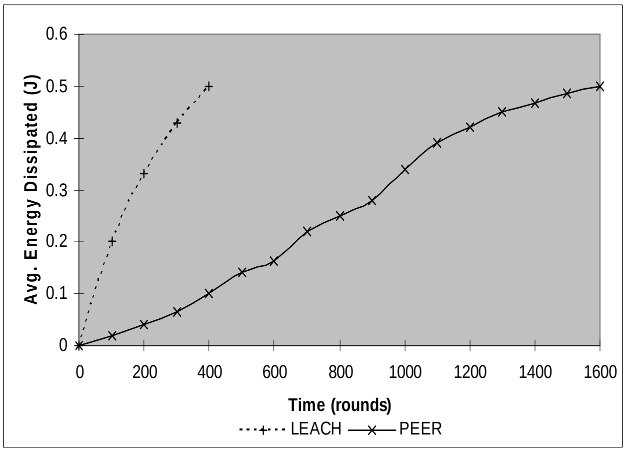


Figure 7 Average Energy Dissipated (J) vs. Time (rounds) (0.5 Joule, 200 nodes, 200m x 200m, using extended radio model)

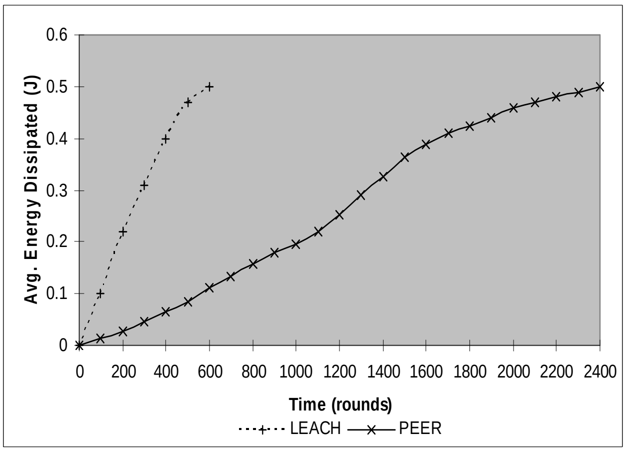


Figure 8 Average Energy Dissipated (J) vs. Time (rounds) (0.5 Joule, 400 nodes, 200m x 200m, using extended radio model)

4.3 Number of Nodes Alive (Lifetime)

Figure 9 to Figure 11 compare between both protocols for number of nodes alive over the time. When comparing when each protocol loses all the nodes, the lifetime of PEER protocol is twice that of LEACH as the energy dissipated by nodes in PEER is much less than that by LEACH. Long-distance transmission in LEACH from nodes to sink lead to more energy consumption, faster node death, and hence lower lifetime. It is also important to compare between the protocols when they reaches the 90% value of nodes alive, as this is a sign for whether the protocol distributes the energy dissipation between the nodes uniformly or not. When comparing both protocols at 90% value, we see that PEER is better with a factor of 2.5 or more. This is an indication that PEER distributes the energy consumption more uniformly between the nodes, and so loosing most of his nodes at the end of the simulation instead than at earlier stages.

The two cases of PEER for homogenous (PEER) and heterogeneous (PEER(NE)) nodes are almost the same. LEACH(NE) loses low-energy nodes quickly as the load is distributed equally between nodes regardless to their energy level and that is why LEACH(NE) is of about 20% lower performance than LEACH. PEER proves once more that it is capable to deal with heterogeneous networks almost as with homogenous ones. Finally, the set of figures confirms that the lifetime of the network increases with increasing the node density for the same reasons mentioned in the previous point.

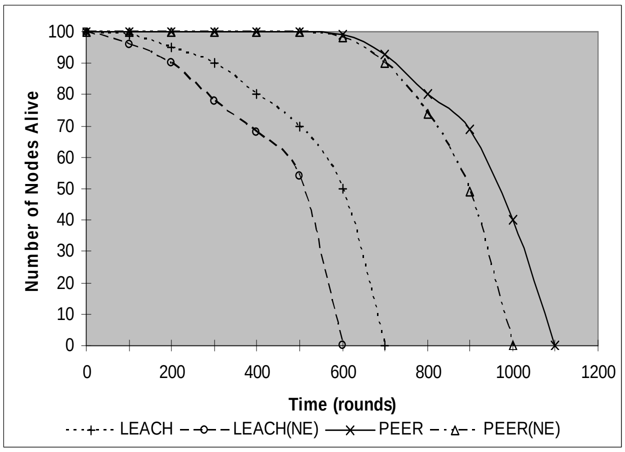


Figure 9 Number of Nodes Alive (%) vs. Time (rounds) (m = 0.5 Joule, $\sigma = 0.2$, 100 nodes, 200m x 200m)

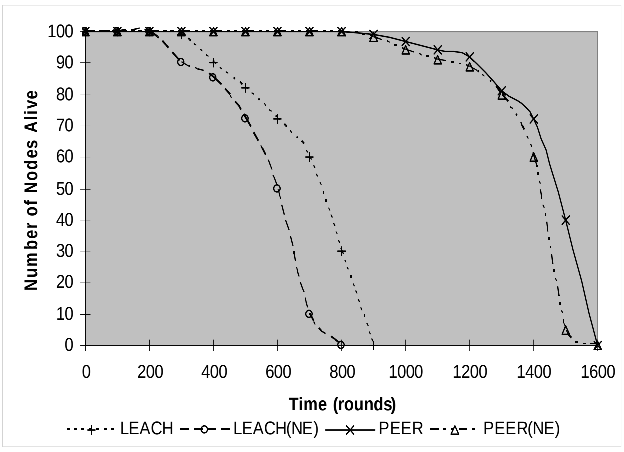


Figure 10 Number of Nodes Alive (%) vs. Time (rounds) (m = 0.5 Joule, $\sigma = 0.2$, 200 nodes, 200m x 200m)

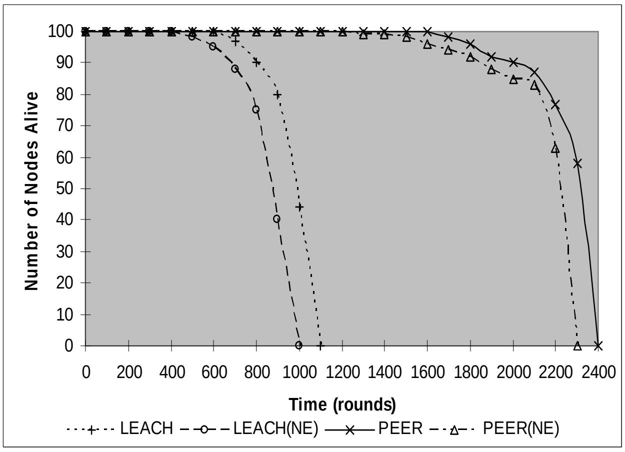


Figure 11 Number of Nodes Alive (%) vs. Time (rounds) (m = 0.5 Joule, $\sigma = 0.2$, 400 nodes, 200m x 200m)

4.4 Distribution of Nodes Alive

As mentioned before the number of nodes alive over the time is an important metric, but also the distribution of nodes alive is important. As the distribution of nodes alive shows, whether a protocol succeeds in covering all the deployment area or suffers from isolated regions.

We have run a group of simulations for both LEACH and PEER having 400 nodes deployed in a 200m x 200m region with all nodes having 0.5 Joules at startup. We have recorded the nodes alive when there are 100 and 50 nodes alive. Figure 12 and Figure 13 indicate the locations of both alive and dead nodes at the mentioned conditions.

As shown in the figures, nodes alive in PEER are uniformly distributed over the time allowing a better covering of the field, and that is because the nodes send over multihop and not direct to the sink. That means that most parts of the deployment area are covered by some sensor nodes as long as there are nodes alive, and therefore the required data can be always sent to the sink.

In LEACH, nodes that are away from the sink lose their lives faster as they suffer from long distance transmissions more than nodes near the sink. The figures clearly illustrate that by losing more nodes in LEACH, the regions far away frosm the sink are getting out of nodes, and thus these regions are not covered any more. Loosing nodes in LEACH is like a wave coming far away from the sink toward the sink itself, while in PEER dead nodes appear at random everywhere in the deployment area, and accordingly PEER demonstrates that it has one more important advantage over LEACH.

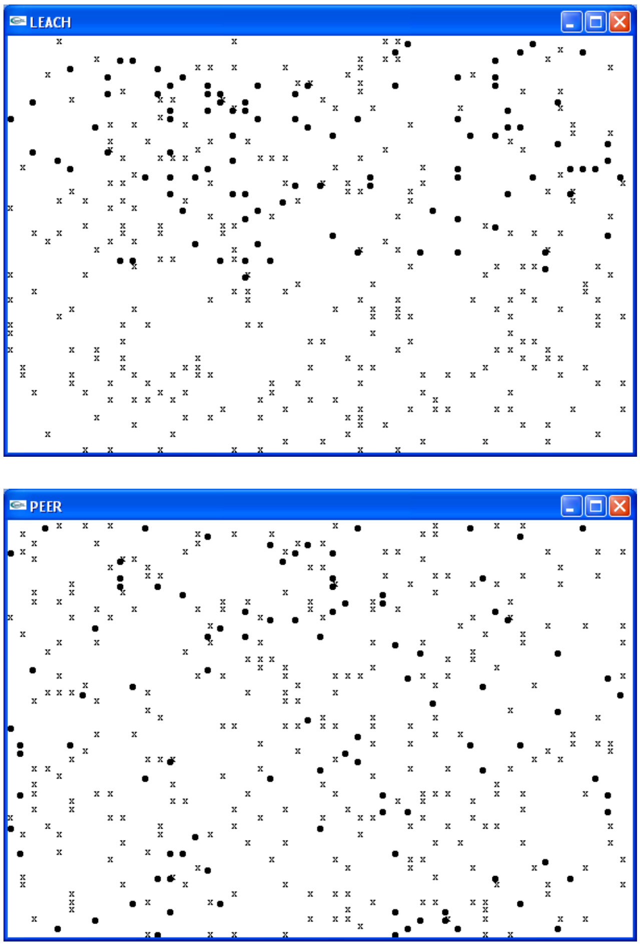
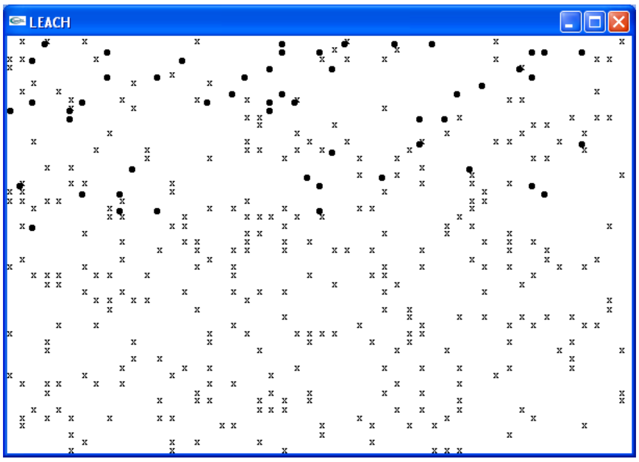


Figure 12 Distribution of Nodes Alive (100 nodes alive)

(a) LEACH (b) PEER

● alive node **× dead node**



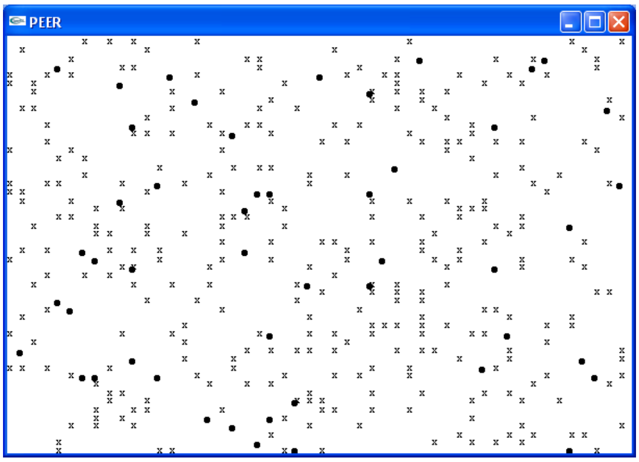


Figure 13 Distribution of Nodes Alive (50 nodes alive)

(a) LEACH (b) PEER

• alive node × dead node

5 CONCLUSIONS AND FUTURE WORK

In this paper, we enhanced PEER Routing Protocol for Wireless Sensor Networks to fit in large-scale deployments. The protocol uses dual power assignment to distribute the load between nodes; each pair of nodes work together to reduce the energy consumption. One of the pair sends at low power level and the other uses high power level. High node from a certain region does not send data directly to the sink; instead, it sends data to another region closer to the sink.

We evaluated the proposed protocol in terms of average energy consumption, network lifetime, and distribution of nodes alive. We compared the protocol with the well-known hierarchical routing protocol LEACH using a first order radio model for transmission, a network model of 200m x 200m field size, and assuming that all nodes have the same energy level at startup. There were 100, 200, and 400 nodes deployed. As the experiments illustrate, PEER considerably outperforms LEACH. When compared with LEACH, PEER reduces the energy consumption to more than the half, increases the network lifetime by a factor more than two, and has a uniform distribution of nodes alive. When using the more realistic extended radio model instead of the first order one, our protocol has energy consumption less than LEACH by four times.

Another case is also simulated; with nodes have different energy levels at startup. Simulation results show that this variation has an insignificant effect on PEER; about 5% increase in average energy dissipated and almost same network lifetime, while this variation has an effect of 25% increase and 20% decrease for the same two metrics in LEACH, respectively.

As WSNs protocols are application specific, our proposed protocol is best used in monitoring applications, where nodes in a large region have almost the same reading. PEER has only one sink, and assumes that sensor nodes and sink are stationary. PEER could not be used in data gathering applications, as this will much degrade the performance of the protocol.

The future work from the networking point of view includes achieving QoS requirements, increasing number of sensor nodes to be several hundreds or thousands, allowing larger fields of deployment, allowing nodes, sinks, and even regions to be mobile, and having multiple sinks.

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