

Research Article

A Two-Level Routing Scheme for Wireless Sensor Network

Jinglun Shi,¹ Zhilong Shan,² and Xuxun Liu¹

¹ School of Electronic and Information Engineering, South China University of Technology, Guangzhou 510641, China

² School of Computer, South China Normal University, Guangzhou 510631, China

Correspondence should be addressed to Jinglun Shi, scutshijinglun@gmail.com

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A new two-level routing scheme is proposed using the energy features of wireless sensor network. The proposed scheme consists of two levels: (i) sink node level and (ii) sensor node level. The proposed scheme exploits independent gradients for each sink node so that the exploratory messages forwarded by the intermediate sensor nodes can be significantly reduced. Experiments are conducted using two evaluation criterions, which are average dissipated energy and hop counts, to demonstrate the superior performance of the proposed scheme.

1. Introduction

With recent rapid development wireless sensor networks [1], various routing protocols [2–5] have been developed. The challenges of designing routing algorithms are summarized as follows. First, since the sensor nodes in the wireless sensor network usually have limited energy and it is very difficult to replace the battery, how to save energy [6–8] to prolong the lifetime is a major challenge in the wireless sensor network research. Second, as time goes, the energy distribution will change. How to adjust the load in the network according to the energy distribution is very important [9, 10]. Third, the sensor nodes are prone to failures due to their limited resource. As the density of network gets higher, more messages are needed to be forwarded, and the energy decreases significantly. How to improve the reliability for the network is also a challenge [11, 12].

In the aforementioned routing algorithms for wireless sensor network, the sensor nodes need to execute complex methods, such as maintaining cluster, forwarding amount of messages. It is usually difficult to perform such methods, due to limited computational capability in the sensor node in the wireless sensor network. Moreover, a large amount of battery power needs to be consumed as the number of the sensor nodes increases. On the other hand, the sensor node near the sink node will dissipate energy faster than other

sensor nodes, since they need to forward more messages. How to take effective measures to compromise the three issues is our main challenge for wireless sensor network. For that, multiple sink nodes are proposed [13–15], since it can decrease the energy consumption, balance the load, and improve the reliability of the network.

To tackle the above challenge, a *two-level routing scheme* (TRS) is proposed in this paper to use multiple sink nodes. Inspired by the fact that the sink nodes have more energy, and more communication capability than that of sensor node, the proposed TRS exploits two different protocols in the sink node level and the sensor node level, respectively. The new features of the proposed TRS lie in the following three aspects. (i) The communications among the sink nodes do not need to be executed by the intermediate sensor nodes; that is, the sink nodes will communicate with each other directly. (ii) Independent gradients are used for each sink node so that the source nodes just need to communicate with the nearest sink node. (iii) More computational tasks are assigned on the sink nodes to reduce the computational load of the intermediate nodes.

The rest of the paper is organized as follows. A summary of related work is presented in Section 2. Section 3 presents the proposed TRS, which is evaluated in experimental results presented in Section 4. Finally, Section 5 concludes this paper.

2. Related Work

There are several approaches developed in the literature to decrease energy consumption, such as *lower energy adaptive clustering hierarchy* (LEACH) [5] and *multilayer clustering routing algorithm* (MLCRA) [17]. LEACH is a clustering-based protocol that minimizes energy dissipation in sensor networks, which uses randomization to distribute the energy load evenly among the sensors in the network. It exploits localized coordination and control for cluster setup and operation; randomized rotation of the cluster “base stations” or “cluster-heads” and the corresponding clusters; as well as local compression to reduce global communication. In LEACH, the nodes are grouped into local clusters, in each of which one node acts as the local base station or cluster-head. The operations of LEACH consist of advertisement phase, cluster setup phase, schedule creation, and data transmission.

Inspired that the sink node has more energy and large capability of communication and processing than that of the sensor nodes, some algorithms with multiple sink nodes are proposed. The advantage of using multiple sink nodes is that the sink nodes execute the main communication and processing to replace the cost for cluster in LEACH. In our previous research work, we have developed an *energy-efficient dissemination framework* (EDF) [16] using multiple sink nodes. In EDF, as the density of the network increases, the sensor nodes between the sink nodes get dissipate energy faster than other sensor nodes, since they need to forward a larger number of messages between the different sink nodes. In order to further use the advantages of the sink nodes to prolong the lifetime of the whole network, a two-level routing algorithm is proposed in this paper, in which the sink nodes will communicate with each other directly and do not need to be executed by the sensor nodes; the details of the proposed scheme will be described in the next section.

3. Proposed Two-Level Routing Scheme

In the wireless sensor networks, compared with the sensor node, the sink node has more energy and larger capability of communication and processing. In view of this, multiple sink nodes are applied in the proposed TRS. Furthermore, the following assumptions are made about the wireless sensor networks in the development of TRS in our paper. (i) All sink nodes have enough energy, which means that the energy cost in the sink nodes do not affect the lifetime of the network. (ii) The sink node has large communication capability and can support the two kinds of protocols of sink node level and the sensor node level. (iii) Each sink node can communicate with other sink nodes in the sink node level, which means the request can reach the other sink nodes.

The overview of the proposed TRS is shown in Figure 1. As seen in Figure 1, multiple sink nodes are deployed, and the routing process is divided into the sink node level (the dotted rectangle A) and the sensor node level (the dotted rectangle B), and different protocol is used in each level. The detail of each level will be described in the following.

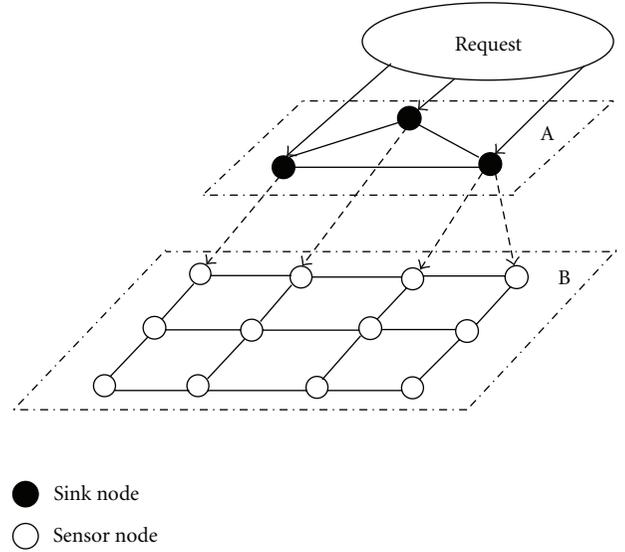


FIGURE 1: The system overview of the proposed TRS.

TABLE 1: An example of interest.

| |
|---|
| IDRequest = //The only ID for each request |
| IDSinknode = //ID for each sink node |
| Type = //class of request |
| Description of type = //detail of request |
| Interval = 20 ms //send back events every 20 ms |
| Rect = [0, 0, 200, 200] //from sensors within rectangle |
| Timestamp = 01 : 20 : 20 |
| Expireat = 01 : 30 : 20 |

3.1. The Sink Node Level. When the request reaches a sink node by Internet or other networks, the sink node will create a unique ID for the request, and then broadcast the ID with the request in the sink node level with the protocol only supported in the sink node level. According to our assumptions, (i) and (ii), some kinds of related complicated protocols can be adopted directly in this level such as WiFi. After the broadcast, each sink node will create an interest according to the request received. Here the interest is constituted by the description of the request, and each interest has the same ID for the request, but with different ID for each sink node. An example of interest is shown in Table 1.

3.2. The Sensor Node Level. After the interest is created, all the sink nodes will flood the interest in sensor node level. As an intermediate sensor node gets the interest, it will take the following action.

Action 1. If the ID Request value of the interest is same with the value of an interest that it cached recently, it will not forward it to its neighbors; otherwise, it will forward the interest to its neighbors. These action means that only the first reaching interest will be forwarded; the other interests of the same request from the same sink node or other sink node will not be forwarded. As the interest reaches the source

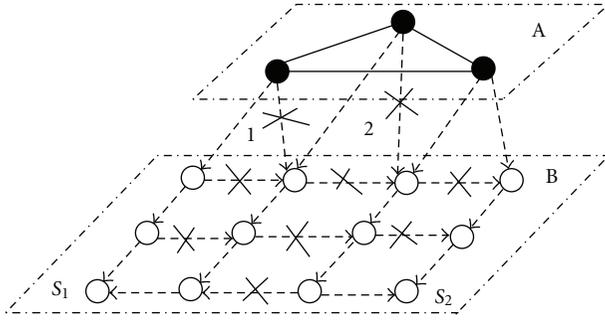


FIGURE 2: Phase for independent gradients.

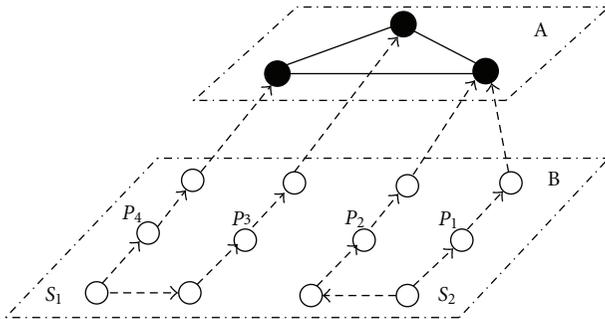


FIGURE 3: Phase for exploratory message.

nodes, the independent gradients from source nodes to each sink nodes are set up. This phase is introduced in Figure 2. In Figure 2, the dotted line 1 and 2 marked with \times means that it is not the first reach interest and will be not forwarded, so the marked gradients are invalid.

Action II. If a sensor node has required data for the interest, which means it is a source node; it will take the same action I as an intermediate node, at the same time as a source node; it needs to send the exploratory data message to its neighbors according to the gradients setup. So for the source nodes, we need to execute action I and send the exploratory data message to its neighbors according to the gradients just setup.

In Figure 3, the source nodes S_1 and S_2 can send exploratory data messages by the paths P_1 , P_2 , P_3 , and P_4 . The IDRequest and the IDSinknode are also included in the exploratory data message. Table 2 shows an exploratory data message example. If the exploratory data message received has the same IDRequest and IDSinknode with the cached interest, the intermediate nodes will forward the exploratory data message according to the gradients; otherwise, it will ignore the message. This phase is illustrated in Figure 3.

As a sink node gets exploratory data message, it will send the reply message reversely hop by hop to the source node. After the source node gets the reply message, it will choose one or multiple gradients to send the data according to some metrics, such as the hop counts or the delay time. By actions I and II, each source node can find the nearest path to the sink nodes. Compared with the single sink node, we can distribute the load on the multiple sink nodes and put more work to the sink nodes which have enough energy (consistent with our

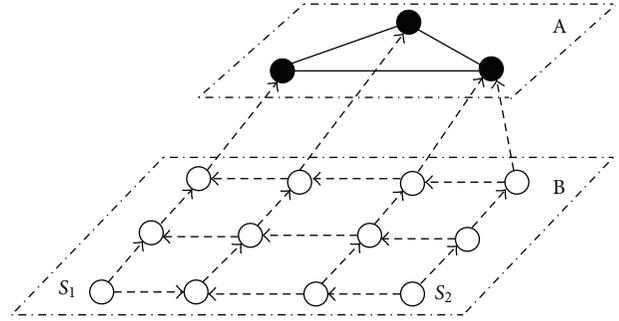


FIGURE 4: Phase in EDF [16].

TABLE 2: An example of exploratory data message.

| |
|--|
| Type = //class of request |
| Description of type = //detail of request |
| IDRequest = //The only ID for each request |
| IDSinknode = //ID for each sink node |
| Hop counts = //distance from source to gateway |
| Delay time = //delay time since interest was flooding |
| Timestamp = 01 : 23 : 20 //local time when event was generated |

assumption A) and save the intermediate node's energy cost by the deployment of sink nodes.

3.3. The Analysis of the Proposed TRS. Compared with conventional EDF [16], one can see that both TRS and EDF have one time flooding in the whole sensor network for setting up the gradients. As the source node sends the exploratory data message to the sink node, the data message which has the same IDRequest and IDSinknode will be forwarded by the intermediate node, so that the independent gradients for each sink node are chosen. This measure can reduce a lot of exploratory data messages reforwarded in the network. This case is illustrated in Figure 4.

Comparing Figures 3 and 4, one can see that the proposed TRS can support multiple sources and multiple paths. For a source node, the multiple paths are connected with one sink node (i.e., paths P_1 and P_2), or some of the multiple paths are connected with multiple sink nodes (i.e., path P_3 and P_4). In the first case, we can adjust the load of intermediate nodes between the sink node and the source. In the second case, we can get the nearest path from the source node to the sink node level according to the metrics for hop counts or delay time.

To find paths from the source nodes to the sinks nodes, the overhead occurred in TRS can be divided into two parts. The first is the overhead in the sink node level O_{sink} , and the second one is the overhead in the sensor node level O_{sensor} . We represent the sensor network as a graph $G = (N, E)$ with a diameter d in terms of hops (i.e., the longest path between sink nodes and sensor nodes) and the average node connecting degree is D and K represents the number of the multiple paths from the source nodes to the sink nodes. L_w represents the average length of a working path, and L_b

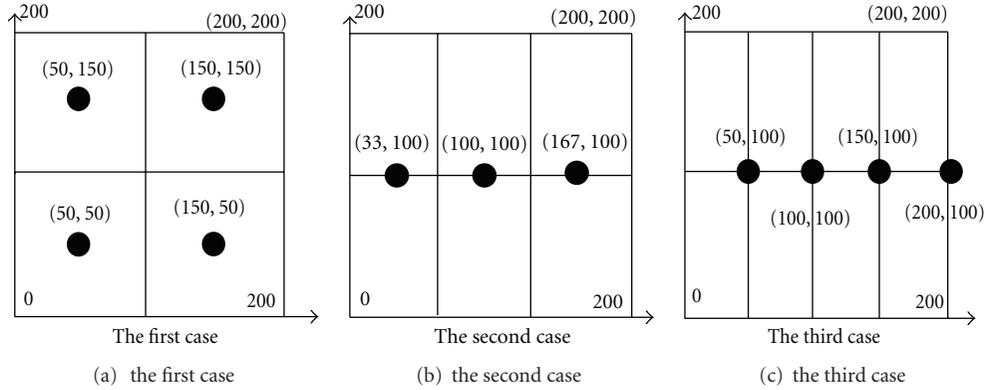


FIGURE 5: The sink nodes in the network.

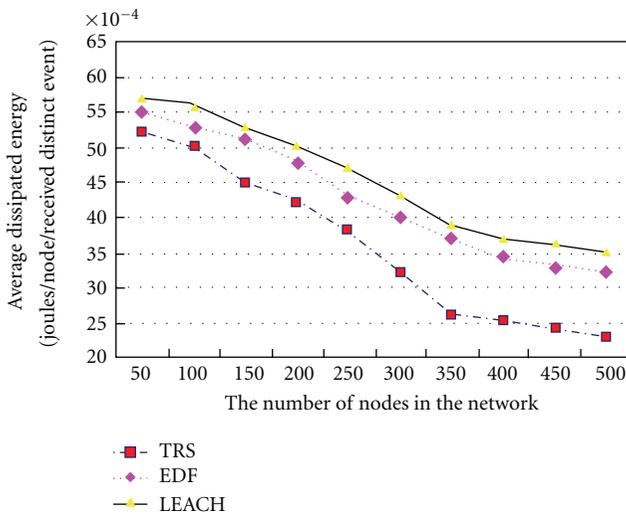


FIGURE 6: Average dissipated energy in the first case.

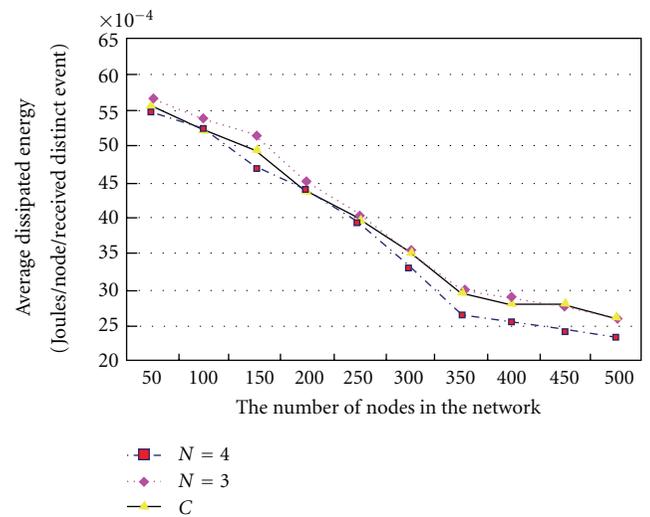


FIGURE 8: Three cases of proposed TRS.

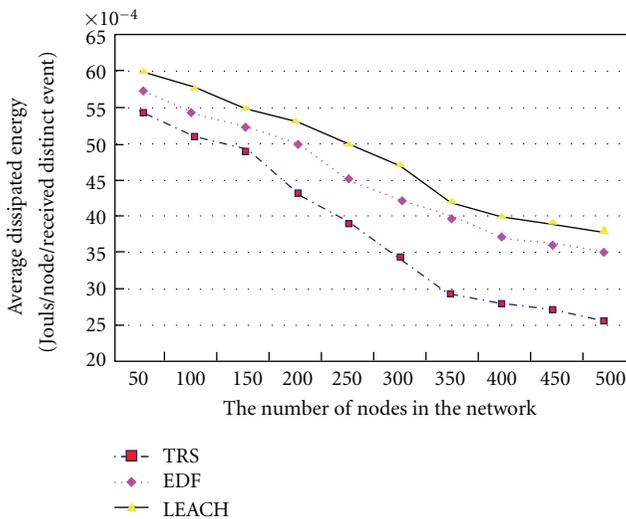


FIGURE 7: Average dissipated energy in the second case.

represents the average length of a backup path $L_w \leq L_b$. The total overhead $O_{total} = O_{sink} + O_{sensor}$. According to our assumption (i), the sink node has enough energy, so we can put more work on the sink node level, which means how to adjust the load from the sensor node to the sink node is crucial. In the proposed TRS, the overhead of O_{sensor} is as follows: interest flooding + exploratory message + reinforce message = $D \times |N| + K \times |N| + L_w + L_b = (K + D) \times O(|N|)$. Therefore, the total overhead $O_{total} = (K + D) \times O(|N|) + O_{sink}$. In the proposed TRS, the diameter d of graph G is far less than the diameter d of graph G in conventional Leach [5] and EDF [16], since the diameter d in Leach and EDF represents the longest path between any sensor nodes, and the diameter d in the TRS represents the longest path between sink nodes and sensor nodes, which means the $|N|$ of TRS is less than the $|N|$ of Leach and EDF, and the O_{sensor} of TRS is less than the O_{total} in LEACH and EDF. To summarize, the proposed TRS does not always achieve less total overhead than that of conventional LEACH [5] and EDF [16]. However, the

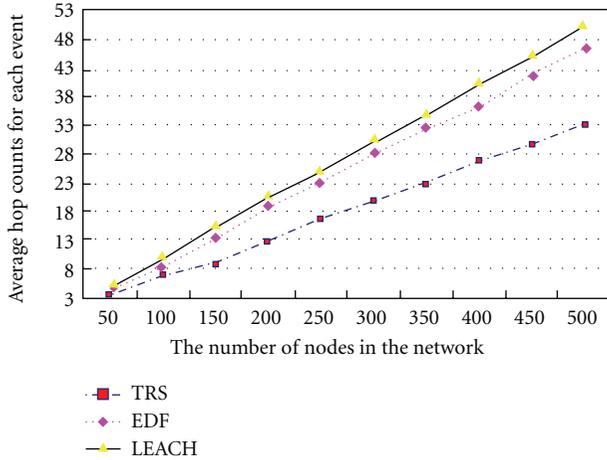


FIGURE 9: Hop counts in the first case.

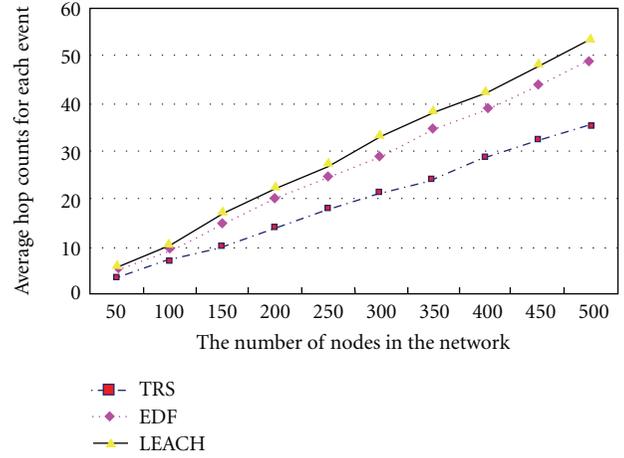


FIGURE 10: Hop counts in the second case.

TABLE 3: Experimental parameter setup.

| | |
|--------------------------------|---------------|
| Network area | 200 m × 200 m |
| MAC layer protocol | DCF |
| Sensor nodes | 50 to 500 |
| Radio rang of sensor node | 30 meters |
| Radio rang of sink node | 250 meters |
| Idle time power dissipation | 35 mW |
| Receiving power dissipation | 395 mW |
| Transmitting power dissipation | 660 mW |

overhead of sensor nodes with limited energy of the proposed TRS is less than that of LEACH and EDF.

4. Performance Evaluation

In this section, the Qualnet is used to evaluate the performance of various routing algorithms. The *distributed coordination function* (DCF) of IEEE 802.11 (b) for wireless LANs is used as the MAC layer with different parameters in both the sink node level and the sensor node level. In the experiments, we use 50 to 500 static nodes to study the density effects, and these nodes are uniformly distributed within a 200 m × 200 m area. Each source generates two events per second, events are modeled as 64 byte packets, interests as 32 byte packets, interests are periodically generated every 5 seconds, and the interest duration is 15 seconds. The idle time power dissipation is about 35 mW, which is 10% of its receiving power dissipation (395 mW), and about 5% of its transmitting power dissipation (660 mW). Table 3 shows the parameters for the network. The radio range of the sensor node is set as 30 meters in the sensor node level. To ensure the sink node can communicate each other, the radio range of the sink node is set as 250 meters.

Experiments are conducted to evaluate the effects of different parameters on the algorithm's performance. These parameters include the number of the sink node, the density of the network, and the location of the sink nodes. We use two metrics: (i) average dissipated energy and (ii) hop counts

for the performance evaluation. The average dissipated energy measures the ratio of total dissipated energy per node in the network to the number of distinct events seen by sinks. This metric is used to quantify the average work done by a node in delivering each sensory data to the sink. It also hints the overall lifetime of sensor nodes.

In our experiments, the number of the sink nodes N is set to be 4 and 3, respectively. In the first case, the sink nodes are, respectively, deployed at the points (50, 50), (150, 50), (50, 150), and (150, 150). In the second case, the sink nodes are, respectively, deployed at the points (33, 100), (100, 100), and (167, 100), which are shows in Figure 5.

The performance of average dissipated energy in the first case and the second case is shown in Figures 6 and 7, respectively. From these two figures, one can see that the average dissipated energy per event of the proposed TRS is significantly lower than that of EDF [16] and LEACH [5]. As the network's density gets higher, the cost gets lower in each algorithm. Comparing the average dissipated energy value of he proposed TRS with that of EDF [16] and LEACH [5], one can see that as the network's density gets higher, the gap of the value gets larger. Comparing Figures 6 and 7, one can see that the energy cost decreases as the number of the sink node gets higher that means we can improve the performance by deploying more sink nodes at decent position in the network.

In the third case, we deploy the four sink nodes at the points (50, 100), (100, 100), (150, 100), and (200, 100). In Figure 8, the performance of TRS is compared with the performance in first case and the second case. From it, we can see the performance in the first case is better than that in the third case; that means the locations of the multiple sink nodes have affection on the performance.

The performance of hop counts is shown in Figures 9 and 10, where one can see that the performance of TRS is significantly better than that of EDF and LEACH. Furthermore, if the network's density gets higher, the gap of the value gets larger; that means the improvement of TRS is more significant at the high density network. This result is

also consistent with the result in terms of average dissipated energy.

5. Conclusions

In this paper, a novel two-level routing scheme based on the unique features of wireless sensor networks is proposed. In the proposed scheme, according to the characteristics of the sink nodes and the sensor nodes, the routing process is divided into two parts. The first one is the routing in the sink node level, and the second one is the routing in the sensor node level. Experimental results show that the proposed scheme outperforms conventional LEACH [5] and EDF [16], in terms of the performance of average dissipated energy and hop counts. Since the experimental results verify that the placement of the multiple sink nodes and the cover problem have important effects on the performance, it is worthwhile investigating this problem in future research work.

Acknowledgments

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