An Energy-Efficient Mobile Sink Routing Algorithm for Wireless Sensor Networks

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Abstract—**the main goal of routing protocol for wireless sensor networks is energy-efficiency. By reducing the hops and data quantity in data transmission, the lifetime of nodes can be prolonged, and the communication is guaranteed. However, these nodes around the sink will be exhausted easily because of high traffic load. Sink mobility can be used to prolong network lifetime. Aiming at this problem, this paper proposes a new routing algorithm supporting sink mobility. This algorithm uses cluster-based model to implement the mobile sink routing protocol, and the sink moves based on the average energy in each cluster. Simulation results indicate that the proposed EEMSRA (an Energy-Efficient Mobile Sink Routing Algorithm) is energy efficient and energy balanced, it can provide longer lifetime as compared to other algorithms.**

Keywords-wireless sensor networks; routing; mobile sink; energy-balanced

I. INTRODUCTION

Routing protocol is a very active area of research in wireless sensor networks (WSNs) [1, 2]. Many solutions are proposed in this area. The early researches mainly focus on the above topic with static sink and sensor nodes. All packets are sent to the only one static sink through the funnel-shaped (n to 1) multi-hop routing. Nodes near the sink become bottleneck nodes easily because they have to forward all the data from other nodes that are away from the sink and they will be exhausted easily because of high traffic load. We name the n to 1 data stream model "funnel model" in WSNs. In order to avoid the disadvantages of funnel model, a feasible solution is to introduce mobile sink [3, 4] into network. With the movement of sink, funnel position (the nodes near the sink) will change accordingly which will transmit load to different nodes. However, some of the algorithms using sink mobility are not energy efficient and energy balanced. Therefore, we propose an Energy-Efficient Mobile Sink Routing Algorithm (EEMSRA) which provides a better performance for energy consumption.

This paper is organized as follows. Section II explains the existing cluster-based routing protocol such as LEACH and a random-moving scheme where a mobile sink moves randomly in network region. Section III, we propose EEMSRA. Next, section IV, we analyze the simulation results. Finally, section V, we conclude this paper and introduce the future work.

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II. RELEATED WORK

A. LEACH

LEACH [5] (Low-energy adaptive clustering hierarchy) is one of the most popular hierarchical routing algorithms [6] for WSNs. The main goal of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink

LEACH is a clustering-based protocol for WSNs. The idea behind LEACH is to randomly select sensor nodes as cluster-heads and use them as routers to the sink. Cluster-heads change randomly after a period of time in order to balance the energy consumption of nodes. The sensor node chooses a random number between 0 and 1, and it becomes a cluster-head for the current round if the number is less than the threshold *T (n)*:

$$T(n) = \begin{cases} \dfrac{p}{1-p\times[r \bmod (1/p)]}, n\in G \\ 0, others \end{cases} \tag{1}$$

Where p is the desired percentage to become a cluster-head (e.g. 0.05), r is the current round, and G is the set of nodes that have not been cluster-heads in the last $1/p$ rounds.

After the clusters are formatted, the cluster-head node creates a TDMA schedule noticing each node when it can transmit data to the cluster-head. The cluster-head also aggregates the data before transmitting these data to the sink. Fig.1 shows the cluster formation in LEACH.

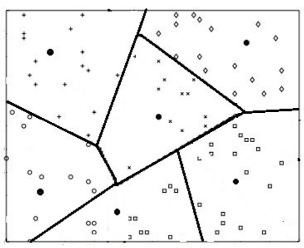


Figure1. The cluster formation in LEACH

B. Random Waypoint Mobility Model(RM)

The Random Waypoint Mobility Model [7] is a widely used mobility model. A mobile sink begins by staying in one location for a certain period of time and in this period the sink collects the information from the sensor nodes. Once this time expires:

1) The mobile sink chooses a random destination in the monitoring area.

2) Then the mobile sink travels towards the newly chosen destination at a random speed between [minspeed, maxspeed].

3) Upon arrival, the mobile sink pauses for a specified time period and collects information from sensor nodes.

4) And then repeat 1~3.

III. EEMSRA

A. Network Model Assumptions

In this paper, we suppose that all sensor nodes are uniformly distributed in the sensor field with one mobile sink. Sensor node has limited energy and cannot move after being deployed. Compared to the sensor node, sink has unlimited energy. Because of the sink mobility, we do not consider the initial location of sink. We assume that each node knows its own location through location techniques [8, 9].

B. Energy Consumption Model

In this paper, we use the radio energy model proposed by Heinzelman in LEACH protocol. To transmit a *k*-bit message a distance *d*, the radio extends:

$$E_{Tx}(k,d)=\begin{cases}kE_{elec}+k\varepsilon_{fs}d^2, d<d_0\\ kE_{elec}+k\varepsilon_{mp}d^4, d\geq d_0\end{cases} \tag{2}$$

And to receive this message, the radio extends:

$$E_{Rx}(k)=kE_{elec} \tag{3}$$

Where E_{elec} is the energy consumption of transmitting or receiving 1 bit message, and d_0 shows the threshold value, when the distance is less than d_0, the free space channel model(d^2 power loss) is used; when the distance is more than d_0, the multi-path fading channel model(d^4 power loss) is used.

C. Mobile Sink Routing Schedule Model

Before implementing the Mobile Sink Routing Algorithm, sink need establish a Distance Vector Table about the clusters information as below:

Table1. Distance Vector Table

Cluster#ID	D_{avg}	Cluster-Head's Location
Cluster#0	10m	(X_0,Y_0)
….	….	….
Cluster#n	9m	(X_n, Y_n)

Firstly, we establish the cluster-based wireless sensor network by LEACH. Sink moves by random way-point to collect some information such as the cluster-head's location. Then sink can calculate the average distance from one cluster-head to the others by the equation as following:

$$D_{avg}=\frac{\sum_{i=0}^{m-1}\sqrt{(X_i-X_c)^2+(Y_i-Y_c)^2}}{m-1}\quad i\neq c \tag{4}$$

Where (X_i, Y_i) is the location of other cluster-head, and (Xc, Yc) is location of current cluster-head, and *m* is the total number of the cluster-heads.

The Distance Vector Table information needs to be updated while the cluster-head of the cluster is changed. But we discuss it later.

In this paper, we consider two factors when deciding the next location where the mobile sink will move. The average energy of each cluster is an important factor, and the other one is the maximum distance (D_{avg}) every time the mobile sink moves. The parameter D_{avg} represents the maximum distance that the mobile sink moves from current cluster-head to another cluster-head. Let *S* be the current location of the mobile sink; and $\Omega(S, D_{avg})$ is the set of the cluster-heads within the scope of the sink's maximum movement and also is the set of locations where the mobile sink will move next time. When the mobile sink decides to move, it chooses one of the locations in $\Omega(S, D_{avg})$ and then travels towards the newly chosen destination. We will discuss the details later.

D. Mobile Sink Routing Protocol

To implement the Mobile Sink Routing Algorithm, we introduce three data packets, a timing parameter *T*, and an energy parameter E_{avg}.

Table2. Hello Packet

Cluster ID	Time Period T

Table3. Information-head Packet

Data	E_i

Table4. Information-sink Packet

Data	Cluster Head's Location

Hello packet is used to inform the sensor nodes that sink will visit this cluster area. The "Cluster ID" field in Hello packet is the cluster-head'ID that the mobile sink will visit. The "Time Period T" field in Hello packet is a timing parameter. While the time period is up, cluster-head will be reselected and the node that has the maximum energy will be selected as the cluster-head. It is equal to the time that how long the mobile sink needs to move through the entire cluster-heads once.

Information-head packet is the packet that is used to be transmitted to cluster-head by sensor node. It consists of the sensing data and sensor node's residual energy information.

Information-sink packet is the packet which is used to be transmitted to the mobile sink by cluster-head. The packet contains the fusion sensing data and cluster-head's location information that can be used to update Distance Vector Table. If the cluster-head is changed in one cluster, the mobile sink will update the Distance Vector Table.

$$T = \frac{\sum_{i=0}^{m-1} \sqrt{(X(i+1) - X_i)^2 + (Y(i+1) - Y_i)^2}}{V} \pm \varepsilon \qquad (5)$$

Where (X_i, Y_i) is the location of the cluster-head and m is the total number of the cluster-heads, and V is the speed of the mobile sink, and ε is a constant value.

$$E_{avg} = \frac{\sum_{i=0}^{n-1} E_i}{n} \qquad (6)$$

Where i is node number in this cluster, and E_i is node i's current energy, and n is the total number of nodes in this cluster.

Finally we implement our proposed method (EEMSRA) by the algorithm as following:

1) Initialization Phases:

a) Cluster the WSNs by LEACH.

b) The mobile sink moves by random way-point to collect cluster-heads information and establishes Distance Vector Table.

c) Compute the time period T according to Distance Vector Table.

2) Data Transmitting Phase:

a) The mobile sink moves to one cluster-head and broadcast Hello packet.

b) After receiving the Hello packet, the Cluster-head stores the time parameter T and starts a time period T_1 to receive data from its cluster members. Cluster members compare their Cluster ID with the "Cluster ID" received from the Hello packet. If they have the same Cluster ID, they send the sensing data to their cluster-head. Otherwise they abandon the Hello packet.

c) Cluster-head will reselect the cluster-head when the time period T is up. The node that has the maximum energy will be selected as the new cluster-head. Cluster-head sends the Information-sink packet to the mobile sink when the time period T_1 is up.

d) The mobile sink starts updating the Distance Vector Table according to the received Information-sink packet.

3) Sink Moving Phase:

Then the mobile sink decides the next location to move:

a) The mobile sink communicates with the cluster-heads contained in the set of $\Omega(S, D_{avg})$ by broadcasting a REQ message.

b) Each cluster-head in this set receives the REQ message and collects the current energy information of their member nodes. Cluster-head computes the energy parameter E_{avg} and store it into the REQ message and then sends the REQ message back to the mobile sink.

c) The mobile sink compares the energy parameter (E_{avg}) of the current cluster with the others received from other cluster-heads: if the energy parameter (E_{avg}) is more than any of the received energy parameters (E_{avg}) from other cluster-heads, the mobile sink will not move. Otherwise the mobile sink will move to the cluster which has the maximum energy parameter (E_{avg}).

4) Repeat 2~3.

IV. PERFORMANCE EVALUATION

A. Simulation Environment

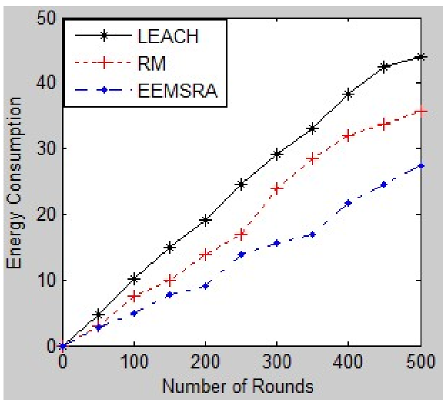
In this section, we evaluate the performance of the EEMSRA mechanism via simulations. We compare EEMSRA with LEACH and RM. RM is a mechanism that a mobile sink moves randomly in network region and data transmits by flooding. In this paper, the network lifetime is defined as the time when the first sensor node dies.

In our analysis, we use the radio energy model in section III. Every result shown is the average of 100 independent experiments. For each experiment, 100 sensor nodes were dispersed in a square of 100m *100m field. Each node has the same initial energy (0.5J). The message size is 4000bits and the number of cluster-heads is 5. The speed of the mobile sink is 10m/sec. The other parameters of the experiment are shown in Table 5:

Table5. Experimental Parameters

Parameter	Value
E_{elec}	50nJ/bit
ε_{fs}	10pJ/bit/m^2
ε_{mp}	0.0013pJ/bit/m^4
d_0	87m

B. Simulation Results



Firure2. Energy Consumption

Fig.2 shows the energy consumption of the three models. As is shown in the figure above, EEMSRA has better energy efficiency than the others.

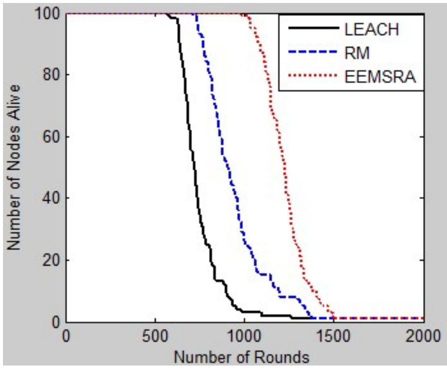


Figure 3.Number of Nodes Alive

Fig. 3 shows the number of nodes alive of the three models. It can be seen from the figure that EEMSRA has better performance.

The Table 6 and Table 7 show the concrete data obtained from the results of Fig. 3. We also set an improved rate to show the enhanced percentage in order to have a clear comparison.

Table6. Comparison of EEMSRA and LEACH

Time/Protocol	LEACH	EEMSRA	Improved Rate
The 1st dead time	612	1000	63.4%
50% dead time	711	1232	73.2%
100% dead time	1200	1800	50.0%

Table7. Comparison of EEMSRA and RM

Time/Protocol	RM	EEMSRA	Improved Rate
The 1st dead time	700	1000	43.0%
50% dead time	900	1232	36.9%
100% dead time	1600	1800	12.5%

C. Simulation Analysis

From the Fig. 2, Fig. 3 and Table 6, Table 7, we can see that our proposed EEMSRA algorithm has made a great improvement compared with LEACH and RM. The main reasons are as following:

1) Comparison of EEMSRA and LEACH: EEMSRA considers sink mobility and the sink moves towards the location of cluster-head to collect data, the distance between sink and cluster-head in our proposed algorithm is much shorter than that in LEACH. EEMSRA can conserve much more energy than LEACH and can prolong the life of WSNs.

2) Comparison of EEMSRA and RM: EEMSRA considers balancing the energy consumption in each cluster, the sensor node will die while all sensor nodes' average energy is low. However the RM consumes energy too fast, all sensor nodes die soon for a short while.

V. CONCLUSION AND FUTURE WORK

In this paper we have studied the performance of using mobile sink for data collecting in WSNs and propose EEMSRA, an Energy-Efficient Mobile Sink Routing Algorithm which provides a better performance for energy consumption. We also analyze the results in our simulation and simulation results indicate that EEMSRA is energy efficient and energy balanced.

For future work, we will strength the flexibility of the EEMSRA to adapt broader network conditions, e.g., there can be more than one mobile sink and normal sensor nodes can also have mobility.

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