

GLRM: An Improved Grid-based Load-balanced Routing Method for WSN with Single Controlled Mobile Sink

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Abstract— Different from the previous duster-based structure, in this paper, we present a grid-based load-balanced routing method (GLRM) that aims to use a controlled sink to achieve load-balance in a non-uniform distributed network. Cell-header election of each cell is based on three parameters, i.e. the number of data packets that nodes need to relay, the Euclidean distance to the mid-point of cells and residual energy of each node, respectively. The GLRM also considers other factors that waste battery power, such as packet collision. Simulation results demonstrate that our routing method has shown better performance.

Keywords— Wireless Sensor Network, Sink Mobility, GLRM, Load Balance, Packet Collision

I. INTRODUCTION

Nowadays, the wireless sensor technology has been applied to different application domains, such as health care, military surveillance and tracking, and environmental monitoring [1-3]. However, the battery capacity of microsensors is limited and batteries are unable to be replaced by humans in an unreachable environment. Hence, energy efficiency is always considered as a key problem full of challenges which hinders the development of the wireless sensor technology.

Traditional static nodes deployment [4] shows n-to-1 communication. This makes that sensor nodes in the vicinity of sink consume more battery power than other regular nodes and also leads to the energy-hole phenomenon more easily. For this purpose, sink mobility is proposed to alleviate the hot spot problem which prevents local nodes from suffering more workload.

Sink mobility also has security benefits [5] where mobile sinks are more difficult to track than static sinks. Moreover, mobile sinks can link the isolated network segment by accessing the portions of the network to improve the network connectivity, which is impossible for static sinks to realize.

Despite a lot of benefits, sink mobility also brings a series of new problems, such as data dissemination, routes adjustment and energy dissipation. Locating the sink is a primary problem for data dissemination that source nodes

have to know the destination location. Unlike static sink scenarios, the network topology becomes dynamic as the sink changes its own position. Frequent location updates give rise to frequent unpredictable topology change. Once the sink gets to a new position, it must broadcast its latest location to the whole network thereby causing significant overhead.

To copy with these problems, in this paper, we propose a virtual Grid-based Load-balanced Routing Method (GLRM) with a controlled mobile sink to collect data from a WSN. Unlike some existing solutions, which improve data delivery performance by using several super sinks in a predetermined path, our proposed method has no such constraints. The method employs a single controlled sink to move in the network to collect the sensing data, aiming to seek the tradeoff between node energy dissipation and the network performance. In addition, the method can also maintain the optimal routes to the latest location of mobile sinks.

The remainder of this paper is organized as follows: Section II gives a brief introduction of related work. Section III introduces the system model. In Section IV, the GLRM algorithm is described in detail. Section V shows simulation results and performance evaluation. Finally, we conclude this paper in section VI.

II. RELATED WORK

Many people focus on hierarchical routing methods. These methods all construct a virtual hierarchical structure and determine a multi-tier hierarchy of roles among the nodes. A successful network with a hierarchical structure can access to the high-layer nodes easily and has a corresponding strategy for the hot spot problem.

A modified stable election protocol (MSE) [6] was proposed to predetermine the sink's trajectory which is a straight line through the network. In Figure 1(a), the whole network is divided into clusters and MSE forwards the sensing data aggregated to the mobile sink via cluster-head nodes. MSE establishes a node failure maintenance mechanism for the whole network. The failed cluster-head nodes will be removed from the network automatically and MSE will select

a new cluster-head node for data forwarding. However, after several node deletion operations, the network will become sparse and the distance between cluster-head nodes will be increased, which will result in significant transmission power consumption and shorten the network lifetime.

In [7], Two-Tier Data Dissemination (TTDD) is one of the hierarchical approaches which have been put forward long ago. As shown in Figure 1(b), TTDD is a virtual grid-based approach, which provides scalable and efficient data delivery to multiple mobile sinks. Each source node with the sensor data proactively constructs a rectangular grid and becomes a crossing point of this grid. Sinks receive data on the move continuously by flooding queries within a local cell only whenever needed. Location-aware sensor nodes are also needed. In general, overhead for constructing grids in TTDD is immense for periodic data reporting applications.

TTDD is not suitable for the network where events occur frequently. In order to send data to multiple mobile sinks efficiently and reduce the power consumption of sensor nodes, a grid-based energy-efficient hierarchical routing protocol (GBEER) [8] is proposed, which constructs a grid structure for all the source nodes using global location information. As a mobile sink reaches a new position, data request will be sent to the closest cell-header along the grids by local flooding, and then data is sent back to the sink along the opposite direction of the original path. The approach enables high overhead to be limited in a separate cell. But nodes residing on the grid may become hot spots and drain out their battery energy in the sensor network using GBEER.

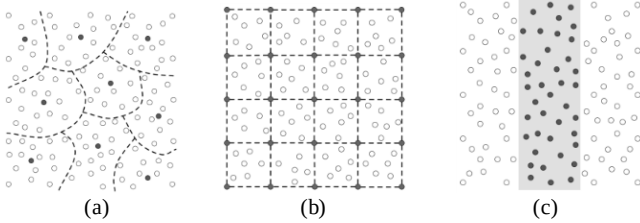


Figure 1. Various hierarchical structures: (a) Clusters (MSE [6]), (b) Rectangular grid (TTDD [7], GBEER [8], VGDRA [9]), (c) Line (LBDD [10])

Similarly with GBEER and TTDD [8, 9], a novel Grid-Based Dynamic Routes Adjustment Scheme is put forward in [9], aiming to reduce the routes reconstruction cost of the sensor nodes to extend the network lifetime. VGDRA adopts four propagation rules to adjust routes to copy with the routes readjustment. The scheme can realize routes readjustment by just adjusting part of routes, thereby minimizing communication consumption significantly. In addition, to prevent the energy-hole problem, the cell-header will be re-selected when its energy is less than a threshold. Even though dynamic routes adjustment in VGDRA shows good performance in prolonging the network lifetime, cell-headers adjacent to the sink deplete energy quicker than others and the network still might appear energy-hole phenomenon.

Apart from rectangular structures and cluster-based structure, the line-based network structure is also adopted in [10], but it has the same defect that local nodes will consume

more energy and die earlier than other nodes. This will decrease network connectivity.

III. SYSTEM MODEL

We design a virtual grid-based network structure which partitions the sensor field into some rectangular cells with the same size, and the mobile sink receives data packets along the straight-line trajectory through the network.

A. Basic Assumptions

Before describing the specific method of GLRM, we give the following assumptions about network characteristics.

- Different nodes are randomly deployed and remain static.
- Sensor nodes adjust their transmission power in accordance with the distance between nodes.
- The sink moves along the center line of the network and has no resource constraints.
- There is no communication block within the network.

B. Network Model

We construct a virtual grid-based structure according to the number of static regular nodes. In this paper, N sensor nodes with different energy are randomly deployed in a WSN which is shown in Figure 2.

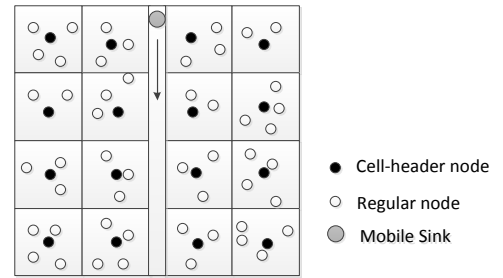


Figure 2. Grid-based network structure

To determine the optimal number of cells and the mobile sink's trajectory, we adopt the heuristics used in LEACH [11] which considers 5% of the total number of sensor nodes. GLRM uses the following Equation 1 to divide the sensor field with N sensor nodes into K cells of uniform size.

$$K = \begin{cases} 4 & N \times 0.05 \leq 6; \\ 9 & 6 < N \times 0.05 \leq 12; \\ 16 & 12 < N \times 0.05 \leq 20; \\ \vdots & \vdots \end{cases} \quad (1)$$

Considering the straight-line moving trajectory of the mobile sink in GLRM and network load balancing. We set K as a square number, and $K=4, 9, 16$ when $N=100, 200, 300$, respectively.

C. Energy Model

We adopt the first order radio energy model [12] as energy consumption model of performance simulation. When the distance between two nodes is greater than a threshold called

d_0 , the multi-path channel path model (d^4 power loss) will be used instead of the free space (d^2 power loss). To transmit 1-bit length message at distance d_0 , the energy consumed can be calculated by Equation 2.

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

E_{elec} is the energy consumed to transmit or receive one-bit length data, ε_{fs} and ε_{mp} are the energy required for the transmitter amplifier, $d_0 = \sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$ is a constant.

$$E_{Rx}(l) = lE_{elec} \quad (3)$$

Equation 3 is used to calculate the energy consumed for receiving this message.

IV. THE PROPOSED GLRM ALGORITHM

In this paper, we come up with a virtual Grid-based Load-balanced Routing Method (GLRM) which enables a controlled mobile sink to collect the sensing data in a non-uniform distributed WSN. Similarly with most hierarchical routing methods, cell-headers obtain and store the latest location of the sink and regular nodes only need to retrieve their corresponding cell-headers to relay information. Cell-header election in cells follows three parameters, the number of data packets that nodes need to relay, the Euclidean distance to the center of the cell, residual energy of each node, respectively. The sink position updates have no influence on the entire routing, just readjusting the local routing.

A. Cell-header Election Phase

GLRM first constructs a virtual grid structure and selects the nodes closest to the mid-point of cells as cell-headers. The cell-header of each cell sends a message to tell member nodes its role. Member nodes of each cell relay data packets by TDMA schedule. To avoid inter-cell interference, each cell-header selects a unique CDMA code [13] and informs its member nodes within the cell to use this spreading code to transmit data packets.

Three parameters are used for election of cell-headers, the number of data packets called n_i that nodes need to relay, the Euclidean distance to the mid-point of the cell called $d_{i,M}$, residual energy of each node called E_i , respectively. So the weight of a sensor node called W_i is calculated by the Equation 4.

$$W_i = (n_i \times E_i) / d_{i,M} \quad (4)$$

Assuming that the length of the side of the rectangular network is L, we can get the result below:

$$\begin{aligned} d_{i,M} &\leq (\sqrt{K} \times \sqrt{2}) / 2 \\ &\leq \sqrt{2K} / 2 \end{aligned} \quad (5)$$

As described in Figure 3, the position of a cell-header in the cell also affects uniform energy consumption of nodes of different cells. So we require the cell-headers selected must be closest to the mid-point of cells to balance energy dissipation.

In addition, nodes which relay more data packets will suffer more communication consumption, selecting this kind of nodes to be cell-headers will prevent energy holes from forming in a WSN.

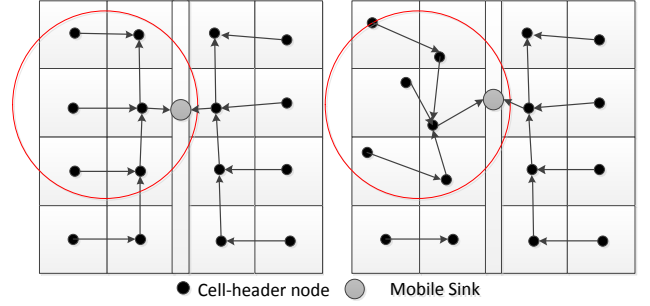


Figure 3. Example of routes re-adjustment

We define an energy threshold called T which is equal to one third of the total energy of a node. When the energy of a node is less than T , the cell-header re-election within the cell will happen.

B. Route Steady Phase

In our proposed GLRM, some mechanisms are used to ensure the normal operation of a WSN.

(1) Collision Avoidance Mechanism

Since the mobile sink moves along a straight-line trajectory through the network, there are two originating cell-headers in both of its sides which may deliver data to the mobile sink at the same time, causing packet collision. In our proposed GLRM, a collision avoidance mechanism is used to seek tradeoff between both sides.

No matter which side of data packets reaches the originating cell-headers first, the sensing data is not sent to the mobile sink directly, instead, it is stored in the originating cell-headers first and an interactive request message (IREQ_Msg) for data delivery will be sent to the mobile sink. If the mobile sink is communicating with the other side, a wait message (Wait_Msg) will return and the originating cell-header will also enter the wait state. When the sink is idle, it will send an acknowledgement message (ACK_Msg) to the previous cell-header for data delivery along the original direction. To ensure reliable data forwarding, ACK_Msg will be sent for three times between the sink and the originating cell-header. If the mobile sink does not receive any reply, it will move to the next position.

(2) Dynamic Routes Adjustment Mechanism

The general routing methods change the mobile sink's position will cause the entire routes update, which will give rise to non-negligible energy dissipation. In this paper, GLRM uses a dynamic routes adjustment mechanism to readjust the routes. Starting from the originating cell-header, the downstream cell-header checks whether the sender cell-header is the same as its previous hop or different. If it is the same, the downstream cell-header drops the data packet of the mobile sink's position update and does not transmit it to the

next downstream cell-header. If different, the downstream cell-header updates itself as the new sender cell-header and performs the same operation. The procedure is repeated until all source nodes adjust their routes. From Figure 4, we can know that only one-hop route change around the mobile sink when S1 moves to S2.

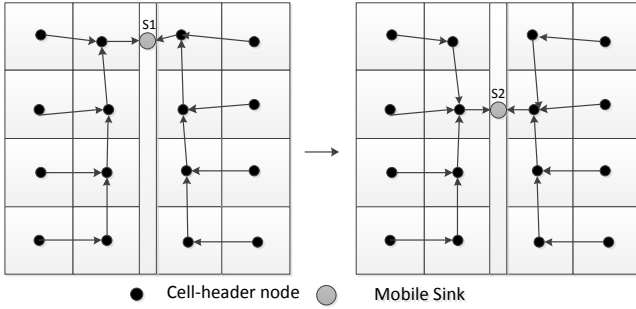


Figure 4. Example of the sink's position changes

C. Route Maintenance Phase

Our grid-based network model is non-uniformly distributed, so the total battery energy of each separate cell is different. It may occur that nodes in some cells die prematurely, causing the network failure.

In GLRM, when the average residual energy of all nodes in a cell is less than the energy threshold T , this cell will be classified as the protected cell and does not collect data from the external environment but forward data from other cell-headers to maintain the network normal operation.

V. PERFORMANCE EVALUATION

We use MATLAB to evaluate the performance of our proposed algorithm. As shown in Table 1, 100 sensor nodes are randomly deployed in a rectangular region of $100 \times 100m^2$ and specific simulation parameters are listed in Table 1.

TABLE 1. SIMULATION PARAMETERS

Parameter	Definition	Unit
N	Number of sensor nodes	100
E_0	Initial energy of sensor nodes	2J
E_{elec}	Energy dissipation to run the radio device	50nJ/bit
ϵ_{fs}	Free space modes of transmitter amplifier	10pJ/bit/m ²
ϵ_{mp}	Multi-path model of transmitter amplifier	0.0013pJ/bit/m ⁴
l	Packet length	2000bits
d_0	Distance threshold	$\sqrt{\epsilon_{fs}/\epsilon_{mp}}$ m
R	Transmission radius	50m

We compare our proposed GLRM algorithm with LEACH protocol. In our GLRM algorithm, three parameters are adopted to participate in cell-header election. Therefore, in a given period of time, GLRM can save more energy. As shown

in Figure 5, the residual energy of GLRM is higher than that of LEACH.

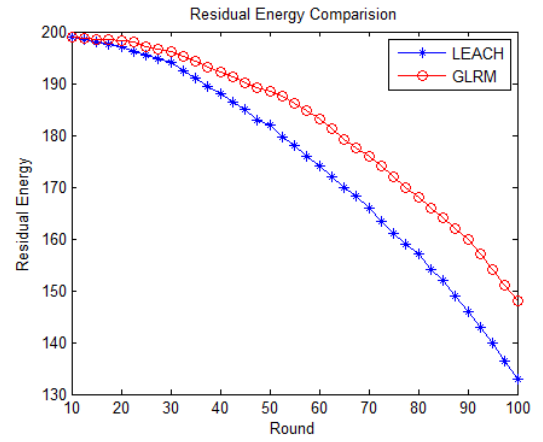


Figure 5. Residual Energy Comparison

Figure 6 describes the network lifetime of GLRM and LEACH with different rounds. It is clear that GLRM has more performance in prolonging network lifetime than LEACH. The round of the first death node and last node is list in Table 2.

TABLE 2. THE ROUND OF FIRST DEATH NODE AND LAST NODE

Algorithms	Rounds	
	First death node	Last node
LEACH	136	185
GLRM	164	204

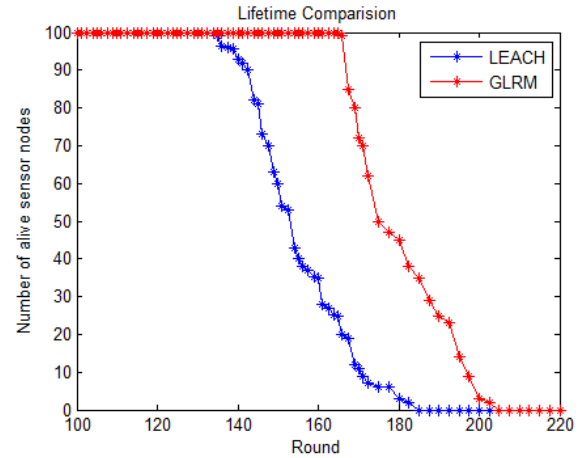


Figure 6. Lifetime Comparison

VI. CONCLUSION

In this paper, we introduced a load-balanced method called GLRM for the WSN and it shows good performance in decreasing energy dissipation and prolonging network lifetime. However, the sink's moving trajectory of GLRM is predetermined. When some nodes die near the sink's path, our predetermined moving trajectory may not be suitable for data collection. We hope to use multiple mobile sinks or other sink moving pattern to improve the network performance.

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