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Energy Optimized Routing Algorithm in Multi-sink Wireless Sensor Networks

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Abstract: Learning from the concept of potential field in physics, the hybrid virtual potential field of the wireless sensor network was constructed based on the hop and the residual energy of nodes. Aimed at maximizing the network lifetime, we proposed an energy optimized routing algorithm for multi-sink wireless sensor networks, using virtual force of the virtual potential field as the routing decision criteria. Avoid strategy for low-energy nodes and load balancing strategy for multiple sinks were applied to dynamically adjust the potential value and achieve balanced energy consumption of nodes. Simulation results show that the routing algorithm balances the energy consumption of nodes effectively and extends the network lifetime, compared with similar algorithms.

Keywords: Wireless sensor networks, routing, energy optimized, virtual potential field, network lifetime

1 Introduction

Wireless Sensor Networks (WSNs) are composed by a large number of micro-sensor nodes through wireless communication [1,2]. In contrast to traditional wireless networks, wireless sensor nodes are usually powered by batteries and deployed in unmanned outdoors or dangerous regions. So, constrained energy is a prominent feature for wireless sensor networks. Since the radio transceiver typically consumes more energy than any other hardware component onboard a sensor node, designing energy optimized routing algorithm is of great importance to prolong network lifetime.

In multi-sink wireless sensor networks, routing mechanisms continue to attract the attention of researchers. Based on the mobility of the sink, the research work can be divided into two categories: mobile multi-sink wireless sensor networks [3,4] and fixed multi-sink wireless sensor networks. In the research of routing protocols for fixed multi-sink WSNs, multi-sink deployment and routing for data transmission are formulated as an integer linear programming task [5,6]. In [7,8,9], the routing is built based on the minimum hop from sensor nodes to the sink. The residual energy of sensor nodes is considered when finding efficient routes in [10,11]. In [12,13], multi-sink wireless sensor networks are simulated as electrostatic field and a series of partial differential equations are exported depending on the nature of electric field. By solving partial differential equations, the optimal route and load distribution are determined.

In this paper, we develop an energy optimized routing algorithm (EORA) for multi-sink wireless sensor networks using the concept of potential in classical physics. The cornerstone of the EORA is to construct a hybrid virtual potential field based on the hop and residual energy of sensor nodes. Avoid strategy for low-energy nodes and load balancing strategy for multiple sinks are designed to adjust the potential value of sensor nodes, so as to achieve the balanced energy consumption of sensor nodes. Simulation results show that the proposed routing algorithm EORA has a better balancing for node energy consumption and has prolonged network lifetime.

2 System Model and Defination

Sensor nodes periodically sense the environment and send the data to sinks. In order to describe the routing algorithm more clearly, we define wireless sensor networks and neighbors.

Wireless sensor networks. A wireless sensor network can be expressed by an undirected graph $G(V,E)$, in which V denotes the set of all nodes and E

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denotes the set of wireless links among nodes which can communicate directly.

$V = V_N \cup V_S$, where V_N represents the set of sensor nodes and V_S represents the set of sinks.

$E = \{(i, j)|i, j \in V_N\} \cup \{(i, j)|i \in V_N, j \in V_S\}$, the distance of node i and j is less than the maximum communication distance R.

Neighbor. The neighbor set of node i is defined as $N(i) = \{j|j \in V, d_{ij} < R\}$, where d_{ij} denotes the distance between node i and j.

3 Virtual Potential Field

Fig. 1 shows the topology of a typical multi-sink wireless sensor network. The data collected by sensor nodes is transmitted to the sink through the intermediate nodes with hop-by hop manner. Data transmission in WSNs is the many-to-one traffic pattern and the spatial distribution of the data shows obviously centripetal feature, which has similarities with the potential field in physics [14, 15]. In this paper, we will borrow the concept of potential in classical physics and construct multiple potential fields using different network state variables, and then superpose them into a hybrid virtual potential field. Field strengths are used to drive data packets toward the sink along the direction of the great change of the potential gradient.

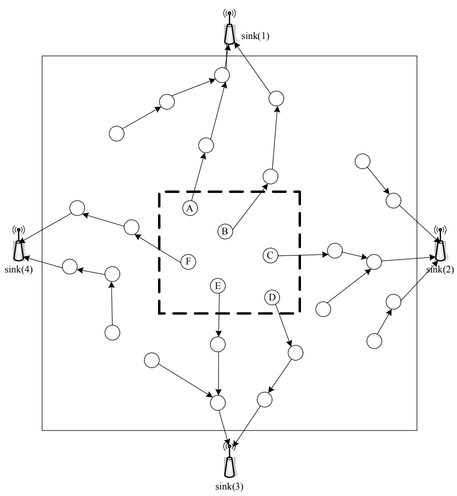

Fig. 1: Topology of wireless sensor networks

3.1 Hop Virtual Potential Field

At the beginning, the sinks in turn broadcast the update message, nodes one hop away from the sink will get their own hop count by adding 1 to the hop in the update message. Then, the other nodes will also obtain their own hop by receiving update message from its neighbors which already have its hop just in the same way as the nodes one hop away. For example, the hop of sensor node i to sink v can be expressed as $H(i, v)$. When the hop of sensor nodes to all sinks are determined, the minimum will be chosen as the hop of senor nodes, which can be expressed as

$$H(i) = \min\{H(i, v)|i \in V_N, \forall v \in V_S\}. \quad (1)$$

To provide the basic routing function, namely to relay packets toward the sink, we define the hop of sensor i as the potential value in hop virtual potential field $P_h(i)$:

$$p_h(i) = H(i). \quad (2)$$

Set node j as node i's neighbor, in accordance with the definition of the potential field, the virtual force between node i and j is given by

$$F_h(i, j) = \frac{P_h(i) - P_h(j)}{C_{ij}}, i \in V_N, j \in N(i), \quad (3)$$

where C_{ij} denotes the cost of link between these two nodes, which is expressed by the distance between nodes. Considering that forwarding data is between one hop neighbor nodes, so the distance between sending and receiving nodes can be unified set as 1. The virtual force can be expressed as follows:

$$F_h(i, j) = P_h(i) - P_h(j). \quad (4)$$

If only to build hop potential field, the data will be transmitted to the sink along the shortest path in the role of the maximum virtual force. Nodes on the forwarding path, especially near the sink, will suffer heavy forwarding task and cause fast energy consumption, easy to premature failure. In order to prolong network lifetime, it should be rational and practical to make an appropriate trade-off between energy efficiency and balanced energy consumption.

3.2 Residual Energy Virtual Potential Field

We define the potential value of node i in residual energy virtual potential field as:

$$P_e(i) = -\frac{RE(i)}{E_0}, \quad (5)$$

where, $RE(i)$ denotes the residual energy of node i and E_0 denotes its initial energy. The virtual force between node i and j is defined as follows:

$$F_e(i, j) = P_e(i) - P_e(j), i \in V_N, j \in N(i). \quad (6)$$

From (5) and (6), we can get

$$F_e(i, j) = \frac{RE(j) - RE(i)}{E_0} \quad (7)$$

In residual energy potential field, the neighbor node with the most remaining energy will be chosen as the next hop node. This method can achieve the balanced energy consumption of sensor nodes, but can not guarantee that data sent towards the sink and eliminating the routing loops. Therefore, it should add residual energy potential field with hop potential field to build the hybrid potential field, so as to achieve the combination of energy efficiency and energy balance.

3.3 Hybrid Virtual Potential Field

Hybrid virtual potential field has both characteristics of hop potential field and residual energy potential field and adjusts the proportion of different potential fields through variable $\alpha(0 \leq \alpha \leq 1)$. The potential value of node i in hybrid virtual potential field is defined as

$$P_m(i) = (1-\alpha)P_h(i) + \alpha P_e(i). \quad (8)$$

Virtual force between node i and j in hybrid potential field is given by

$$\begin{aligned} F_m(i,j) &= P_m(i) - P_m(j) \quad (9) \\ &= (1-\alpha)(P_h(i) - P_h(j)) + \alpha(P_e(i) - P_e(j)). \end{aligned}$$

From (4), (6) and (9), the virtual force can be simplified as follows:

$$F_m(i,j) = (1-\alpha)F_h(i,j) + \alpha F_e(i,j). \quad (10)$$

In hybrid potential field, the neighbor node with maximum virtual force is selected to forward data, which will guarantee the data flows to the sink and achieve balanced energy consumption among sensor nodes.

4 Dynamic Adjustment Strategy for Potential field

4.1 Avoid Strategy for Low-energy Nodes

Nodes with less residual energy should be reduced the opportunity to be selected as the relay node through dynamically adjusting its potential value in residual energy potential field. In this paper, we set the node as low-energy node when its residual energy is less than 10% of the initial energy. In the routing process, the low-energy node with less hop is avoided by adjusting its potential value and the node with the same hop will be selected as relay node. In this section, we will describe the avoid strategy for low-energy nodes.

When $j,k \in N(i), H(i) = H(j) = H(k)+1$, virtual force between node i and j, node i and k in hybrid potential field can be expressed respectively as follows:

$$F_m(i,j) = (1-\alpha)(P_h(i)-P_h(j)) + \alpha(P_e(i)-P_e(j)). \quad (11)$$

$$F_m(i,k) = (1-\alpha)(P_h(i)-P_h(k)) + \alpha(P_e(i)-P_e(k)). \quad (12)$$

If low-hop node k is the low-energy node, it should be avoided in the routing process. $F_m(i,j) > F_m(i,k)$ is required. For $H(i) = H(j) = H(k)+1$, we can get

$$P_e(k) > \frac{1-\alpha+\alpha P_e(j)}{\alpha}. \quad (13)$$

Due to node j is not a low-energy node, so $P_e(j) < -0.1$. The right part of (13) can be expressed as follows:

$$\frac{1-\alpha+\alpha P_e(j)}{\alpha} < \frac{1-1.1\alpha}{\alpha}. \quad (14)$$

If the potential value of low-energy node k is set to

$$P_e(k) = \frac{1-1.1\alpha}{\alpha}, \quad (15)$$

it will be discarded in the routing process and the node with more hop will be selected as relay node.

4.2 Load Balancing Strategy for Multiple Sinks

When sending data to the sink, sink's neighbors must be used as relay nodes. The average residual energy of sink's neighbors can reflect the load of the corresponding sink. If the average residual energy of a sink's neighbors is relatively low, it indicates that the amount of data received by this sink is large, and some measures should be taken to make some sensor nodes transmit data to the other sink. In this paper, we dynamically adjust the hop of node to the sink which is suffering heavy load, so as to achieve the load balancing of multiple sinks.

Shown in Fig. 1, the network contains four sinks and the node hop to the corresponding sink within the dotted box area in the Fig. is three. In initial stage of the network operation, the nodes have the same amount of residual energy. In accordance with the minimum hop routing, the direction of the arrow in the Fig. indicates the path of data transmission. After some network operational time, the difference of average residual energy of sink's neighbors is larger because of different sink's load. Assume that the average residual energy of Sink(1)'s neighbors is the least, we adopt the load balancing strategy for multiple sinks to appropriately increase node hop to Sink(1). In this paper, we increase one hop. Node A and B in the dotted box area, which have selected Sink(1) as destination, renew the choice of the destination after the increase of hop. Shown in Fig. 2, the data of node A and B is sent to Sink(4) and Sink(2) respectively. So the amount of data sent to Sink(1) is reduced and the load balancing of multiple sinks is achieved.

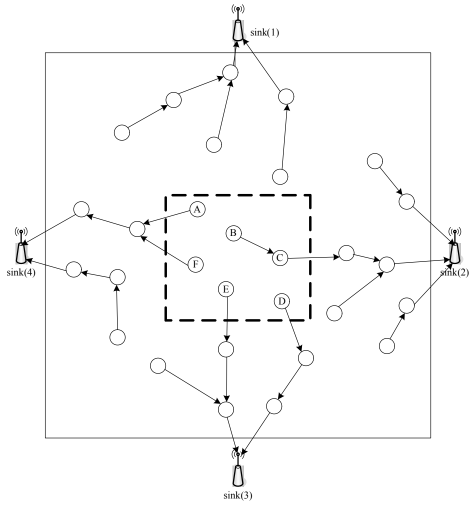

Fig. 2: Routing after hop adjustment

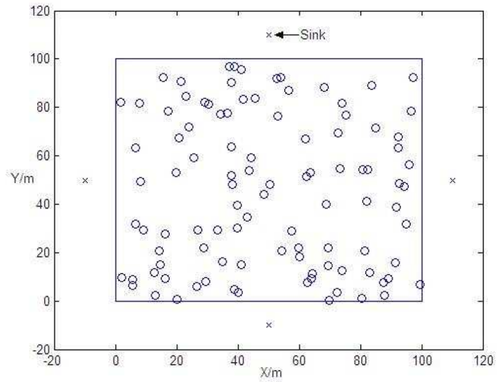

Fig. 3: Distribution of nodes in wireless sensor network

5 Results and Discussion

In this section, we evaluate the performance of our proposed Energy Optimized Routing Algorithm (EORA) for multi-sink wireless sensor networks via matlab. For simplicity, an ideal Media Access Control (MAC) layer and error-free communication links are assumed. We calculate the energy consumption of each node from data packet transmission and reception. We define the lifetime of the wireless sensor network as the time when the residual energy of the sensor node becomes zero firstly, which is counted by round. We compare the performance of EORA with Energy Level-Based Routing (ELBR) [9] and Shortest Path Based Routing (SPBR) [7]. In our simulations, sensor nodes are randomly and uniformly deployed over the square monitoring area. Sinks are uniformly distributed at the outside of the monitoring area. Other simulation parameters are given in Table 1.

Table 1: Simulation parameters

Parameter	Value
Network coverage / m^2	100*100
Number of sensors	100
Number of sinks	1∼ 8
Initial Energy / J	0.5
$E_{elec}/(nJ \cdot bit^{-1})$	50
$\varepsilon_{amp}/(pJ \cdot bit^{-1} \cdot m^{-2})$	10
Data packet size/B	500
Control packet size/B	12
Maximum transmission range	30
α	0.75

If the network contains 4 sinks which are uniformly distributed at peripheral 10m outside of the monitoring area, the distribution of nodes is shown in Fig. 3. In the initial stage of the network, the potential value of sensor nodes in the hybrid virtual potential field is shown in Fig. 4. In the subsequent simulation, the number of sinks changes from 1 to 8. For further evaluating the performance of EORA, the following of this paper will give the behavior of this algorithm with different number of sinks. EORA will be compared with ELBR and SPBR on network lifetime, residual energy of nodes, the average hop of packets and the variance of data received by sinks.

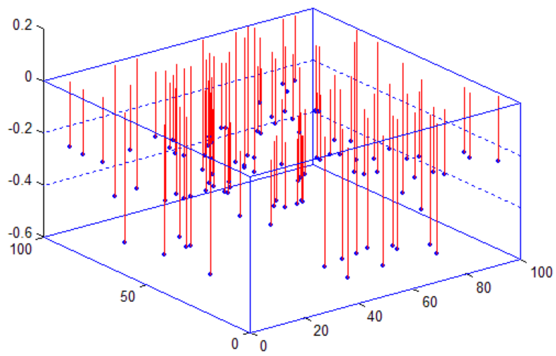

Fig. 4: Potential value

Fig. 5 gives the network lifetime when the number of sinks changes from 1 to 8. It can be seen from the figure that EORA has extended the network lifetime compared with ELBR and SPBR. SPBR only considers the node hop when making routing decisions and has the shortest network lifetime. The routing path once be constructed

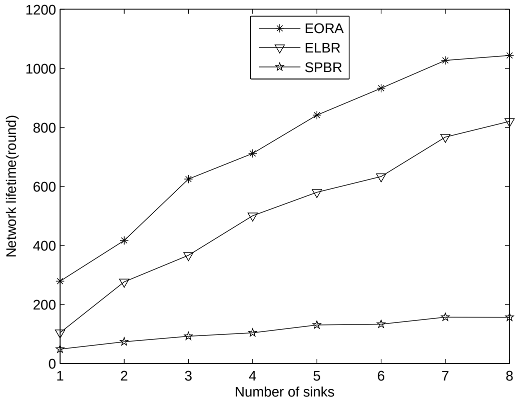

Fig. 5: Network lifetime

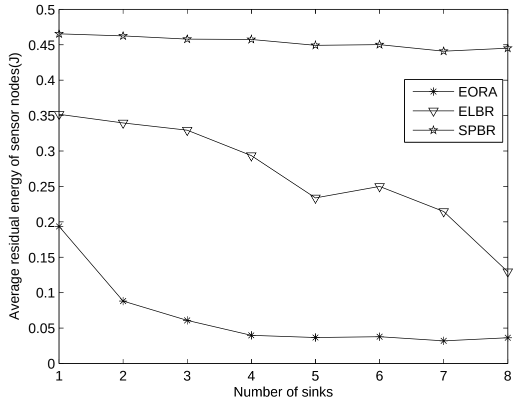

Fig. 6: Average residual energy of sensor nodes

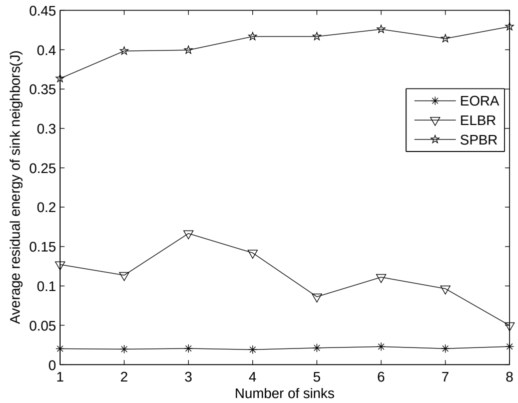

Fig. 7: Average residual energy of Sink's neighbors

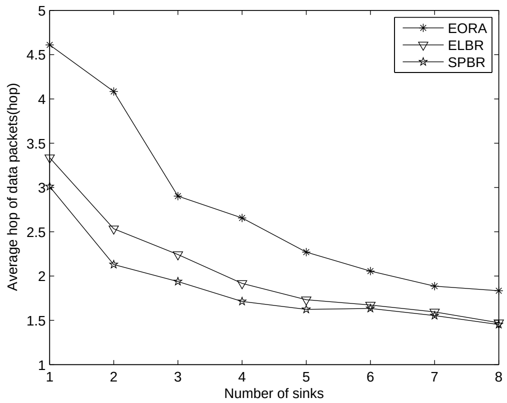

Fig. 8: Average hop of data packets

will no longer change, so the nodes on the forwarding path suffer heavy load and has serious impact on network lifetime. ELBR has considered the residual energy of sensor nodes in routing, but more energy is consumed in the process to obtain the energy level of the path. So its network lifetime is between EORA and SPBR.

Fig. 6 and 7 show the average residual energy of sensor nodes and the average residual energy of sink's neighbors when the first node is failure in the network. The figures show that the average residual energy of sensor nodes and the average residual energy of sink's neighbors in EORA is less than ELBR and SPBR. In EORA, residual energy potential field is superimposed on hop potential field and the avoid strategy for low-energy nodes is adopted, so the energy consumption of sensor nodes is balanced. As the result of load balancing strategy for multiple sinks, EORA has balanced the energy consumption of sink's neighbors which play a decisive role on the network lifetime. SPBR has not taken any measures to balance node's energy consumption, so the average residual energy of nodes is the most.

Fig. 8 describes the average hop when data packets are transmitted to sink in different routing algorithms. In this figure, the average hop decreases with the increasement of the number of sinks, because the average distance from sensor nodes to sinks is decreased. Comparing the average hop of data packets in different routing algorithms, the average hop in SPBR is the least. In EORA, the residual energy of sensor nodes is considered when making routing decisions and some sensor nodes select long path to transmit data, so its average hop of data packets is the most.

6 Conclusion

Energy is one of the most critical resources for WSNs. It should make an appropriate trade-off between energy efficiency and energy balance. With this mind, in this paper we construct hybrid virtual potential field based on the hop of nodes to sinks and the residual energy of nodes and design a virual potential field based multi-sink routing algorithm, according to the feature of concentric in data transmission. The avoid strategy for low-energy nodes and load balancing strategy for multiple sinks are adopted to achieve effective and balanced energy consumption. Simulation results show that the routing algorithm proposed in this paper has extended the network lifetime and balanced energy consumption, compared with ELBR and SPBR.

In our future work, we will deploy sinks within the monitoring region and research the optimization of multi-sink deployment and data routing with the goal of maximizing network lifetime.

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