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Energy Efficiency Geographic Routing Through Improved Landmark Mechanism in Wireless Sensor Networks

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***Abstract*—Both "local minimum" and energy efficiency are hot issues for Geographic Routing in Wireless Sensor Networks. The local minimum problem is caused by hole that blocks the greedy forwarding process, thus long detour path is produced. Various solutions were proposed to solve this problem. A common approach is to find landmarks and generate a routing path from the source sensor to a landmark node first, then the landmark resumes routing until to the destination to avoid long detour path. However, most existing landmark based geographic routing protocols are energy-inefficient because a constant path is set up prior to routing process, then the forwarding nodes in the path are busy while other nodes are idle even if they are very close to the pre-setup routing path, thus the busy nodes run out of their energy quickly and the hole is larger. In this paper, we present a novel approach, in which the idle nodes near the routing path participate in the forwarding to substitute some busy nodes; therefore, our new mechanism combines geographic routing and energy efficiency routing techniques. Simulation results demonstrate that our approach significantly prolong the lifetime of sensors over peer approaches while almost keep the same short path as state-of-art landmark based routing algorithms.**

***Index Terms*—Geographic routing, sensor networks, local minimum, landmark, energy efficiency.**

I. Introduction

Wireless sensor networks (WSN) deploys a large number of dense sensors(nodes). A node communicates with its neighbor nodes directly. However, when a node intends to send packets to a destination node such as the sink node farther away out of the range of its wireless signal, it relies on other nodes to relay its packets step by step until they reach the destination. Many routing protocols [1]-[5] have been proposed to find a routing path from a source node to a destination node. They can be classified into proactive routing protocols and on-demand routing protocols depending on when paths are determined. Proactive protocols, such as DSDV [6] and TBRPF [7], exchange routing information periodically between hosts, and constantly maintain a set of available routes for all nodes in the network. In contrast, on-demand (or reactive) routing protocols, such as AODV [8], DSR [9], and TORA [10], delay route discovery until a particular route is required, and propagate routing information only on demand. There are also a few hybrid protocols, such as ZRP [11], HARP [12], and ZHLS [13], which combine proactive and reactive routing strategies.

Many scholars are interested in the energy consuming in sensor nodes because they have limited power and the battery recharging is usually not easy. A lot of energy efficiency routing protocols have been studied with different approaches [14], [15], such as changing the nodes' status as off, on, or sleeping with different scenarios [16], or minimizing the energy consumption for data delivery [17].

In the common paradigms for current WSNs, the location information of sensors can be obtained either through GPS or by virtual coordinates [18]-[20]. Scholars developed geographic routing in WSNs, making the routing in WSNs scalable. In such approach, a source node first acquires the location of the destination node it intends to communicate with, then forwards the packet to one of its neighbors that is closest to the destination. This process is repeated until the packet reaches the destination. A path is found via a series of independent local decisions rather than flooding. However, such geographic routing has to deal with the so-called local minimum phenomenon, in which a packet may get stuck at a node that does not have a closer neighbor to the destination, even though there exists a path from the source to the destination in the network. This typically happens when there is a void area (or hole) that has no active nodes. In WSNs, the holes are caused by various reasons [21]. For instance, malicious nodes can jam the communication to form jamming holes. If the signal of nodes is not strong enough to cover everywhere in the network plane, coverage holes may exist. Moreover, routing holes can be formed either due to voids in node deployment or because of failure of nodes due to various reasons such as obstacles.

Many solutions have been proposed to deal with the local minimum problem. Karp and Kung proposed the Greedy Perimeter Stateless Routing (GPSR) protocol [22], which guarantees the delivery of the packet if a path exists. When a packet is stuck at a node, the protocol will route the packet around the faces of the graph to get out of the local minimum. GPSR guarantees valid routing, but the perimeter routing often results in long detour path. Many scholars proposed landmark based routing. Their algorithms find the landmarks at first, then the packet is sent from the source node to a landmark which is considered as the intermediate target, and then the packet is sent from the landmark to the real destination node. The landmark based protocols avoid long detour path, but their shortcoming is also obvious.

In this paper, we present a new approach which combines geographic routing and energy efficiency routing techniques.

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The source node figures out a circle with the three points of itself, a landmark node and the destination. Then the forwarding is along the curve decided by the three points. Our new mechanism creates the short path as other landmark based geographic routing, but distributes the forwarding afford to many nodes that close the path generated by landmark based routing protocols. Simulation shows that our approach makes sensors' lifetime longer and keep the short path as landmark based routing algorithms.

The rest of the paper is organized as follows. Section II discusses related work. Section III proposes our new approach. Section IV describes our algorithms. Section V evaluates the proposed schemes by simulations and describes performance results. Section VI concludes the paper.

II. Related Work

Many geographic routing protocols have been developed for WSNs. In early protocols, each intermediate node in the network forwards packets to its neighbor closest to the destination, till the destination is reached. Packets are simply dropped when greedy forwarding causes them to end up at a local minimum node. To solve the local minimum problem, geometric face routing algorithm (called Compass routing) [23] was proposed that guarantees packet delivery in most (but not all) networks. By combining greedy and face routing, Karp and Kung proposed the Greedy Perimeter Stateless Routing (GPSR) algorithm [22]. It consists of the greedy forwarding mode and the perimeter forwarding mode, which is applied in the regions where the greedy forwarding does not work.

GPSR works for most networks, but it results in long detour path when hole issue is involved in routing. To make a shorter path, scholars developed landmark based routing. M. Duckham *et al.* [24] incorporated cognitively salient landmarks in computer-generated navigation instructions geographic routing in WSNs. They described how landmarks can be identified from geographic feature types and how specific landmarks should be selected from this set for a specific route, based on knowledge about landmark types.

Scholars also studied energy efficiency routing. K. Zeng *et al.* [25] studied Geographic Routing with environmental Energy Supply. They consider the realistic lossy wireless channel condition and the renewal capability of environmental energy supply, and then designed a routing algorithm that combine geographic routing and energy efficient routing techniques. Eunil Park *et al.* [15] developed PBLE (Protocol considering Both sides of Link-quality and Energy) to consider asymmetric and unreliable links with residual energy of a node. They proposed a new route-selection and blacklisting methods suitable for geographic routing over distance. In addition, they did Mathematical analysis of networks efficient working that is applied to both sides of link-quality and blacklisting methods.

H. Huang *et al.* [14] presented a novel energy-aware geographic routing (EAGR) protocol that attempts to minimize the energy consumption for end-to-end data delivery. EAGR adaptively uses an existing geographic routing protocol to find an anchor list based on the projection distance of nodes for guiding packet forwarding. Each node holding the message utilizes geographic information, the characteristics of energy consumption, and the metric of advanced energy cost to make forwarding decisions, and dynamically adjusts its transmission power to just reach the selected node.

III. The New Mechanism

A. Motivation

Current WSNs make nodes' locations available either through GPS or virtual coordinates [18]-[20], thus routing in sensor networks can be much more efficient. Geographic routing exploits the location information and makes the routing in sensor networks scalable. However, geographic routing suffers from the so-called local minimum phenomenon, in which a packet may get stuck at a node that fails to continue greedy forwarding. Perimeter routing mechanism makes forwarding continually be conducted but it results in long detour path. Many scholars proposed landmark based routing. Their algorithms find the landmarks at first, then the packet is sent from the source node to a landmark which is considered as the intermediate target, and then the packet is sent from the landmark to the real destination node. These landmark based protocols are valid to send packet from source to destination in the area with holes, but their limitations are also obvious. First, the routing path is created proactively as a constant. The nodes in the path are busy but other nodes even they are close to the path are idle. Hence the busy nodes will run out of their energy quickly, meaning that the energy utilization is neither balanced nor efficient. Second, such poor energy utilization may result in additional "dead nodes" and the holes will be larger. Third, larger holes or even the change of status of on, off, or sleeping will trigger the routing algorithm to reshuffle the network, resulting in high complexity. We intend to develop a novel algorithm, which finds alternative nodes along the supposed routing route to keep short path and then distributes the work load to more nodes in order to achieve balanced and efficient energy utilization.

B. The Basic Idea

A simple example is used to illustrate the basic idea of the new approach in this paper. It is assumed that all nodes are static and distributed in a two dimensional space. As shown in Fig. 1, we assume that S is the source node and D is the destination node. When S intends to send a packet to D with a landmark based routing path, S sends the packet to the landmark B along p_1, p_2, p_3,... first, then B sends the packet to D along q_1, q_2, q_3,...

Because of the limitations of landmark based routing we have proposed, we would like to find an approach to balance the energy utilization while not resulting in a long detour path. In landmark based routing, the source node S knows the coordinates of the points B and D, so S is able to figure out a circle C with the three points S, B and D, where the curve SBD is part of the circle C. We don't care where the real center O is. Then the forwarding nodes are along the curve SBD. In particular, they will be close but inside and outside the curve alternatively. Although the coordinates of the two nodes B and D are known to S ahead, S no longer generate a proactive path. Instead, the next hop is created reactively along the curve *SBD*. In our example shown in Fig. 2, *S* sends a packet to node p_1, which is inside the circle *C*. Then p_1 finds the next hop p_1' outside *C*. Because p_1' is outside the circle *C*, it finds p_3 inside *C* as the next hop...The same approach is applied for q_1(inside *C*), then q_1' (outside *C*), then q_2' (inside *C*)...

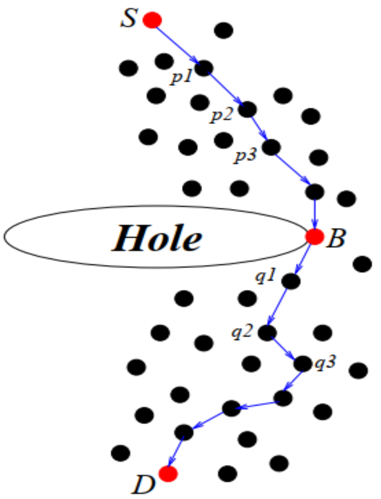

Fig. 1. Example of landmark based routing.

The example shows that *S*- > p_1- > p_1'- > p_3...*B*- >q1- > q_1'- > q_2'…- > *D* is a path created by our approach. If any node in the path is not working, its previous node will find an alternative one rather than a reshuffle for the network.

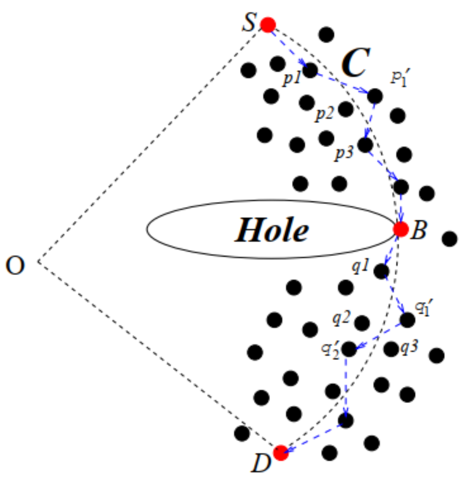

Fig. 2. Example of routing with our new mechanism.

C. Description of the Approach

Because *S* knows the coordinates of the three points *S* (x_s, y_s), *B* (x_b, y_b) and *D* (x_d, y_d), Let

$$U = \begin{vmatrix} x_s & y_s & 1 \\ x_b & y_b & 1 \\ x_d & y_d & 1 \end{vmatrix},$$

$$V = -\begin{vmatrix} x_s^2 + y_s^2 & y_s & 1 \\ x_b^2 + y_b^2 & y_b & 1 \\ x_d^2 + y_d^2 & y_d & 1 \end{vmatrix},$$

$$W = \begin{vmatrix} x_s^2 + y_s^2 & x_s & 1 \\ x_b^2 + y_b^2 & x_b & 1 \\ x_d^2 + y_d^2 & x_d & 1 \end{vmatrix},$$

$$and\ Z = -\begin{vmatrix} x_s^2 + y_s^2 & x_s & y_s \\ x_b^2 + y_b^2 & x_b & y_b \\ x_d^2 + y_d^2 & x_d & y_d \end{vmatrix}$$

Let x_t, y_t be the coordinates of the center of *C*, and *R* be the radius, then:

$$x_t = -\frac{V}{2U},$$

$$y_t = -\frac{W}{2U},$$

$$and\ R = \sqrt{\frac{v^2 + w^2 - 4UZ}{4U^2}}$$

Then the equation of *C* is written as:

$$(x - x_t)^2 + (y - y_t)^2 = R^2 \quad (1)$$

$$Let \quad F(x, y) = (x - x_t)^2 + (y - y_t)^2 - R^2 \quad (2)$$

$$It\ is\ F(x, y) = 0 \text{ be circle's equation} \quad (3)$$

In the forwarding process, the current node needs to find a node either inside or outside the circle *C* as its next hop. How does it determine the two cases? When a point *n* (*x*, *y*) is inside *C*, *F*(*x*, *y*) < 0. When the point is outside or on the perimeter of *C*, *F*(*x*, *y*) >= 0.

$$F(xy): \begin{cases} \geq 0, n\ is\ outside\ C\ or\ on\ its\ perimrter, \\ < 0, n\ is\ inside\ C \end{cases} \quad (4)$$

When *S* begins to forward a packet to *B*, *S* first uses GPSR, most likely greedy forwarding to find the next hop n_1. If n_1 is outside the circle *C* or on its perimeter, n_1 will use right-hand rule and the rule of equation (4) to find the next hop n_2 inside *C* (Fig. 3). Otherwise, n_1 will use left-hand rule and the rule of equation (4) to find the next hop n_2 outside *C* (Fig. 4). Hence, the forwarding nodes on the routing path will be inside and outside the *C* alternatively. If one of the nodes fails or turns to off, the previous nodes will find an alternate.

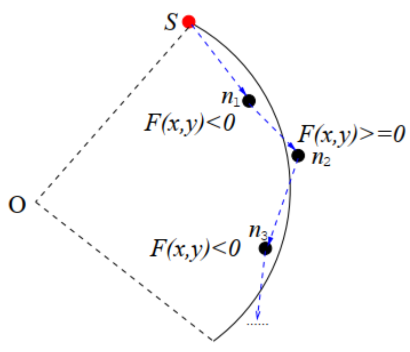

Fig. 3. n_1 inside *C* finds n_2 outside *C*.

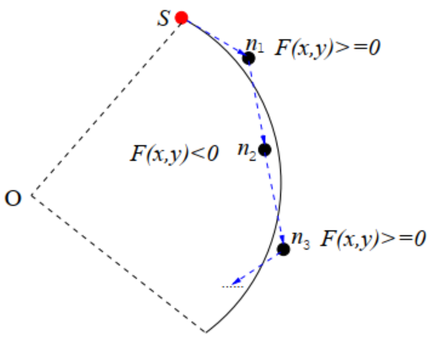

Fig. 4. n_1 outside C finds n_2 inside C.

IV. Algorithms

Node $n_i(x_i, y_i)$ calls algorithm 1 to find its next hop n_{i+1}. When a node $n_i(x_i, y_i)$ intends to send a packet to its next hop, it first calculate $F(x_i, y_i)$. A non-negative value indicates that n_i is outside the circle or on the perimeter of the circle, meaning n_i needs to find the next hop inside the circle. So n_i uses right-hand rule to find the first n_{i+1} satisfying $F(x_{i+1}, y_{i+1}) < 0$. Otherwise, a negative values of $F(x_i, y_i)$ shows that n_i is inside the circle so it uses left-hand rule to find the first n_{i+1} satisfying $F(x_{i+1}, y_{i+1}) >= 0$ as the next hop. Fig. 3 and Fig. 4 show the two situations.

A source node S knows the locations of landmark B and destination D, so S calls algorithm 2 to send a packet to D. S first figures out a circle C by S, B and D. Then it uses GPSR to find next hop n_i, and forwards the packet and information of circle C to n_i. If n_i is D, the forwarding will be ended. If n_i is not D but the landmark B, B will use GPSR to find next hop n_j, and then forwards the packet and information of circle C to n_j. Then n_j will use algorithm 1 to find next hop n_{j+1} to forward the packet to n_{j+1}. Then n_{j+1} will find the next hop and forward the packet as step 5.

Algorithm 1 *Finding next hop*

1: Calculate $F(x_i, y_i)$
2: If $F(x_i, y_i) >= 0$
  by right-hand rule, finds the first n_{i+1} satisfying $F(x_{i+1}, y_{i+1}) < 0$
3: If $F(x_i, y_i) < 0$
  by left-hand rule, finds the first n_{i+1} satisfying $F(x_{i+1}, y_{i+1}) >= 0$

Algorithm 2 *Routing algorithm*

1: S figures out a circle C by S, B and D.
2: S uses GPSR to find next hop n_i, then forwards the packet and information of circle C to n_i.
3: If n_i is D, end.
4: else if n_i is B, B uses GPSR to find next hop n_j, then forwards the packet and information of circle C to n_j.
5: n_j calls algorithms 1 to find its next hop n_{j+1} and then n_j forwards the packet to n_{j+1}.
6: n_i=n_{j+1}, go to step 5.

V. Simulation

The new mechanism is evaluated in a simulated noiseless radio network environment by MATLAB. A topology is created that consists of a number of randomly distributed nodes. We compare our approach ILM (Improved Landmark) with two other algorithms. One is a typical landmark based algorithm [26], say LM. The other one is GPSR [22]. The compared metrics are percentage of alive sensors over time and the average length of path over network size. We performed a sequence of experiments in which the number of nodes varies from 100 to 400 in increments of 25 in an area of 100x100 meters in the reference network with time changes from 30 seconds to 150 seconds. We conduct our experiments 10 times and present the average value. Fig. 5 shows that our approach maintain the most alive sensors while GPSR results in the least alive sensors. It is because GPSR generates long detour path with more nodes involved in the routing process and all are always, making the sensors die faster, while our approach provide the shift for the work load in routing process so the sensors die more slowly. Fig. 6 shows that our approach and landmark based scheme generate almost the same average length of path because the path created with our approach is very close to that created with landmark based approach and both generate shorter path than GPSR.

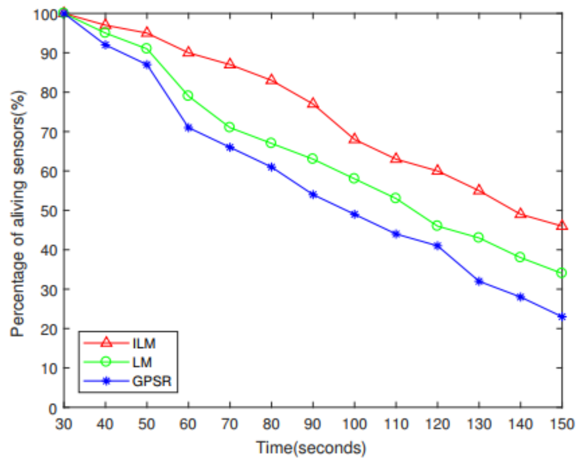

Fig. 5. The percentage of alive sensor over time.

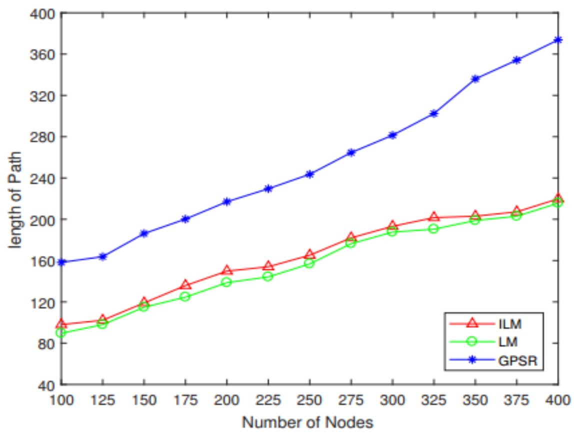

Fig. 6. The length of path over nodes.

VI. Conclusion

In this article, we present a new approach which take account both landmark based geographic routing and energy efficiency routing techniques in wireless sensor networks. When the source node knows the coordinates of a landmark node and the destination nodes, together with its own coordinates, it figures out a circle with the three points. Then the forwarding nodes are along the curve but inside and outside the circle alternatively, this energy balance and efficiency are achieved. Our new mechanism creates the short path as other landmark based geographic routing protocols, but let the nodes have work load shift and then make the lifetime of sensors longer.

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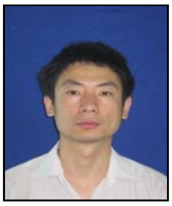

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