무선 센서 네트워크에서 라우팅 홀을 우회하기 위한 에너지 효율적 데이타 전달 프로토콜

(Energy-efficient Data Dissemination Protocol for Detouring Routing Holes in Wireless Sensor Networks)

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요 약 위치정보기반 라우팅을 이용하는 무선 센서망은 자연환경 혹은 센서 노드들의 불균형적인 에너지 소비로 인한 라우팅 홀(hole)로 인해 높은 통신 장애 가능성이 존재한다. 이에 대해 연구된 대부분의 기법들은 그런 라우팅 홀을 우회하는 방법으로 접근하는 경향을 보인다. 그러나 홀 우회를 위한 라우팅은 홀 주변 센서노드들의 불균형적인 에너지 소비를 유도하기 때문에, 그들의 통신장애 및 네트워크 수명에 장애를 발생시킬 수 있다. 우리는 이미 홀 우회를 위한 라우팅 방안을 제안하였지만, 그 또한 갖는 문제점 때문에 가우시안 함수를 활용하여 그 연구에 대한 확장 방안을 새롭게 제안한다.

키워드 : 무선 센서 망, 위치정보 기반 라우팅, 에너지 효율 라우팅 기법, 라우팅 홀 문제

Abstract Void areas (holes) as an inevitable phenomenon exist in geographic routing of wireless sensor networks, because the unpredictable and harsh nature application environment or uneven energy consumption. Most of the existing schemes for the issue tend to construct a static detour path to bypass a hole. The static detour path may lead to uneven energy consumption of the nodes on the perimeter of the hole; thus it may enlarge the hole. At the same time, traffic would concentrate on the peripheral node of the hole; thus the nodes on the perimeter of the hole tend to be depleted quickly. In previous work, we have proposed a hole geometric model to reduce the energy consumption and packet collisions of the nodes on the hole boundary. This scheme, however, still has the static detour path problem. Therefore, we extend the previous work by constructing a dynamic detour path hole geometric model for wireless sensor networks in this paper. The location of hole detour anchors is dynamically shifted according to Gaussian function, just generating dynamic hole detour paths.

Key words : sensor networks, geographic routing, energy efficient, hole problem

1. 서 론

A wireless sensor network (WSN) consists of a large number of unattended sensor nodes which self-organize themselves into a communications network. These sensor nodes collaborate among themselves to collect, process, analyze and disseminate data. Limitation of sensor nodes in terms of memory, energy, and computation capacities give rise to many research issues in wireless sensor networks. Among these limitations, energy consumption of sensors is a major issue when designing routing protocols in wireless sensor networks.

Geographic routing has been considered as an attractive approach since it exploits pure location information instead of global topology information

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to route data packets, this location based scheme makes it a more efficient, simple and scalable routing protocol in wireless sensor networks [1-5]. This mechanism can minimize the hops from the source to the destination.

Holes, it also called local minimum phenomenon [5], as an inevitable phenomenon exist in geographic routing. Among existing routing protocol in the literature [6], most existing geographic routing protocols adopt static and peripheral mode bypass holes.

GPSR [1] handles hole problem by deriving a planar graph out of the original network graph. In GPSR, traffic would concentrate on the peripheral node of the hole. Compass Routing II algorithm [7], guarantees that the data packets can reach destination even when holes existing in greedy forwarding. They proposed routing protocol using the least deviation angle from the line joining the node to the destination when trying to transmit a packet to the next hop. [3] proposed the FACE-1 and FACE-2 routing algorithms to guarantee packet delivery in MANETs. The adopted solution is also based on getting a connected planar subgraph by using Gabriel Graph and then traversing the edges of the graph using right-hand rule. In contrast to GPSR, all routing is done through the perimeter of the GG formed at each node. FACE-2 modifies FACE-1 in that the perimeter traversal follows the next edge whenever that edge crosses the line from the source to destination.

To sum up the above protocols, the routing holes problem is addressed by always using the static and perimeter mode routing. Before the nodes in the perimeter die, packets are always delivered by the peripheral node of the hole. Consequently, the derived planar graph is much sparser than the original one, and the traffic concentrates on the perimeter of the planar graph. Thus, the nodes on the perimeter tend to be depleted quickly, at the same time, it may incur data collisions.

In previous work [8], we have proposed a hole geometric model to reduce the energy consumption and data collisions on the perimeter of the planar graph. This scheme, however, still using the static detour path routing holes which means the nodes along this path their energy deplete quickly than general nodes. Therefore we extend the previous work by constructing a dynamic detour path hole geometric model for balance energy consumption. The location of hole detour anchor location is dynamically shifted according to Gaussian function, just generating dynamic hole detour paths.

The rest of this paper is organized as follows: We briefly discuss related work in Section 2. We explain our protocol in Section 3 and detailed analysis of our protocol is given in section 4. Section 5 concludes the paper.

2. Related work

2.1 A Modeling for Hole Problem in Wireless Sensor Networks

To make every detail clearly, we first briefly introduce the previous work [8].

As shown in Fig. 1(a) by real line, when a data packet sent by geographic forwarding mechanism reaches a node (suppose node U) on the ellipse (not hole), node U redirects the data packet along the tangent direction of the ellipse with a distance L to another location. When the node (suppose node V) which is geometrically closest to that location receives the data packet, it redirects the data packet to original destination by geographic forwarding mechanism. The rest of this section explains how to construct the ellipse to cover the hole and define a proper length L.

The rest figures of Fig. 1 shows hole geometric modeling processes. A node can detect whether it is locating on the boundary of a hole by the mechanism proposed in [5]. The node which firstly detects a hole sends out a Hole Boundary Detection (HBD) packet along the boundary of the hole by the well-known right hand rule [9]. The mission of HBD packet is to trace the location information of all nodes on the boundary of the hole. We suppose that nodes B_0, $B_1 \cdots B_n$ with the coordinates (x_0, y_0), $(x_1, y_1) \cdots (x_n, y_n)$ are on the boundary of a hole. As shown in Fig. 1(b), node B_0 firstly detects that it is locating on the boundary of the hole, it initiates a HBD packet marked with its ID and forwards the HBD packet to hole boundary node B_1 by right hand rule. Node B_1 inserts its location information into the received HBD packet and forwards it to node B_2 by right hand rule too. This process repeats until the HBD packet has traveled around the hole and eventually been received by the ini-

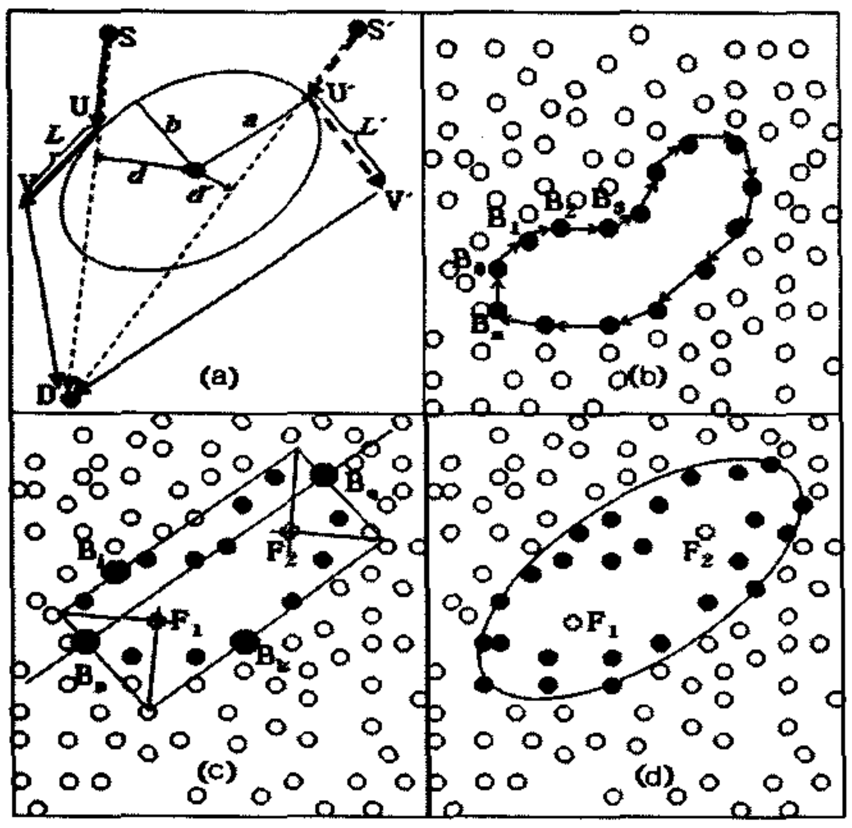

Fig. 1 Hole geometric modeling processes

tiator node B_0. Node B_0 gets the location information of all boundary nodes of the hole from receiving HBD packets. Then node B_0 selects two nodes B_p and B_q from $\{B_0, B_1 \cdots B_n\}$ so that the distance between B_p and B_q is the longest distance among the distances between any two nodes in $\{B_0, B_1 \cdots B_n\}$. Then on each side of $\overline{B_p B_q}$ must exist a node that the vertical distance from it to $\overline{B_p B_q}$ is longer than other hole boundary nodes on corresponding side of $\overline{B_p B_q}$ e.g., B_j and B_k, is selected by node B_0. Then through B_p, B_j, B_q and B_k, node B_0 can obtain a rectangle, and the bisectors of four right angles of the rectangle intersect at point F_1 and F_2 with the coordinates (x_1,y_1) and (x_2,y_2) as shown in Fig. 1(c). Then node B_0 selects B_m from $\{B_0, B_1 \cdots B_n\}$ so that the sum distances of $\overline{B_m F_1}$ and $\overline{B_m F_2}$ is the longest than that of other nodes in $\{B_0, B_1 \cdots B_n\}$. Assume that $\overline{B_m F_1} + \overline{B_m F_2} = 2a$, then according ellipse definition function, B_0 defines an ellipse as:

$$\sqrt{(x-x_1)^2+(y-y_1)^2}+\sqrt{(x-x_2)^2+(y-y_2)^2}=2a \quad (1)$$

Where a is the semimajor axis of the ellipse. Assume the distance between F_1 and F_2 in Fig. 1 (b) is 2c, and then according to ellipse property, we can get the semiminor axis of the ellipse b as:

$$b=\sqrt{a^2-c^2} \quad (2)$$

Now, we get the ellipse which can cover the hole exactly. Then node B_0 initiates an Ellipse Distribution (ED) packet which includes all information about the ellipse, and geocasts the ED packet to all nodes inside the ellipse. Then all nodes inside the ellipse are aware of the ellipse as shown in Fig. 1(d).

Now, we introduce how to calculate the agent location. In proposed algorithm that the agent point locates on the tangent through tangent point U to the ellipse. As shown in Fig. 1(a) by real line, V is agent point of U for the packet destined to destination D. Line $\overline{UV}$ is tangent to the ellipse through tangent point U. According to plan geometric theory, node U can get the location of V if it knows the length L. Node U calculates L by following formula:

$$L=\sqrt{a \cdot b}(1+\alpha)-d, \quad 0 \le \alpha \le 1, \quad (3)$$

Where a is the semimajor axis of the ellipse, b is the semiminor axis of the ellipse, d is the vertical distance from the centre of the ellipse to line $\overline{UD}$ and α is a balance parameter set by system. Since node U knows the location of itself and all information about the ellipse (got from ED message). The location of destination D can be gotten from the received data packet. Then it is positive that node U can calculate out d (the calculation method is not covered in this paper). Up to now, L becomes a known quantity, thus node U can get the location information of V.

3. Energy-efficient Data Dissemination Protocol for Detouring Routing Holes in Wireless Sensor Networks

3.1 Preparation Work

So far, we already get the location of anchor point which is defined in static condition. It means the path between tangent point and destination does not change unless the network topology changes. As a result, the nodes on this path drain their energy much faster than general nodes. The rest of this section describes our promoted algorithm.

We balance energy consumption through the dynamically anchor point. Same to previous work, the dynamically anchor point is still determined by the node which is on the boundary of the hole. In addition, for optimizing entire routing process, we modify the set of all possible values of the balance parameter α. As step 1, the tangent node calculates L will follow (4):

$$L=\sqrt{a\cdot b}(1+\alpha)-d\,,\quad 0.2\le\alpha\le 1.2, \tag{4}$$

The length L between the tangent point node and the anchor point node which is defined in (4) is longer than length L which is defined in (3).

In previous work, we get the location of anchor point through (3), and we suppose the coordinate of the anchor point is (a, b). Our promoted protocol has two main steps about how to get the dynamically anchor point. Step1, tangent point node gets the basic location information of anchor point using (4). Step2, base on the 2-dimensional Gaussian function anchor point dynamically shifted. The 2-dimensional Gaussian function is following:

$$f(u,v)=\frac{1}{2\pi\sigma^2}e^{-\frac{(u^2+v^2)}{2\sigma^2}} \tag{5}$$

In our promoted protocol, the coordinate of the anchor point node (a, b) is substituted by the dynamically shifted coordinate (a + u, b + v), u, v is the location increment variable. Original anchor point only as the centre point of concentric circles, we call it basic anchor point. And then, the tangent point node of the hole will send the packet to the dynamically changed anchor point instead of the static anchor point. It may occur that no node at the location (a+u, b+v). In this situation, we select the geographically nearest one as the dynamically anchor point.

3.2 Data Delivery under Hole Geometric Modeling

Up to now, all of the prepare work has done. As shown in Fig. 2 where only hole geometric modeling ellipse and data delivery paths are represented. In Fig. 2, real line indicates only one of the probability routing paths according to our algorithm. Circle indicates entire possible area where anchor point may locate in. Data transmission process follows the one of the existing geographic routing protocol. Source node S initiates data packets and transmits them to destination node D and each data packet header contains an anchor location field and a flag field which indicating the data packet transmission in anchor transmission mode or in destination transmission mode.

At the initial phase, all data packets are set to destination transmission mode and their anchor location field is set to void state by source. Source also adds the geographic location information of the destination in data packets. Destination location field is only set by source, and left unchanged as the packet is forwarded through the network.

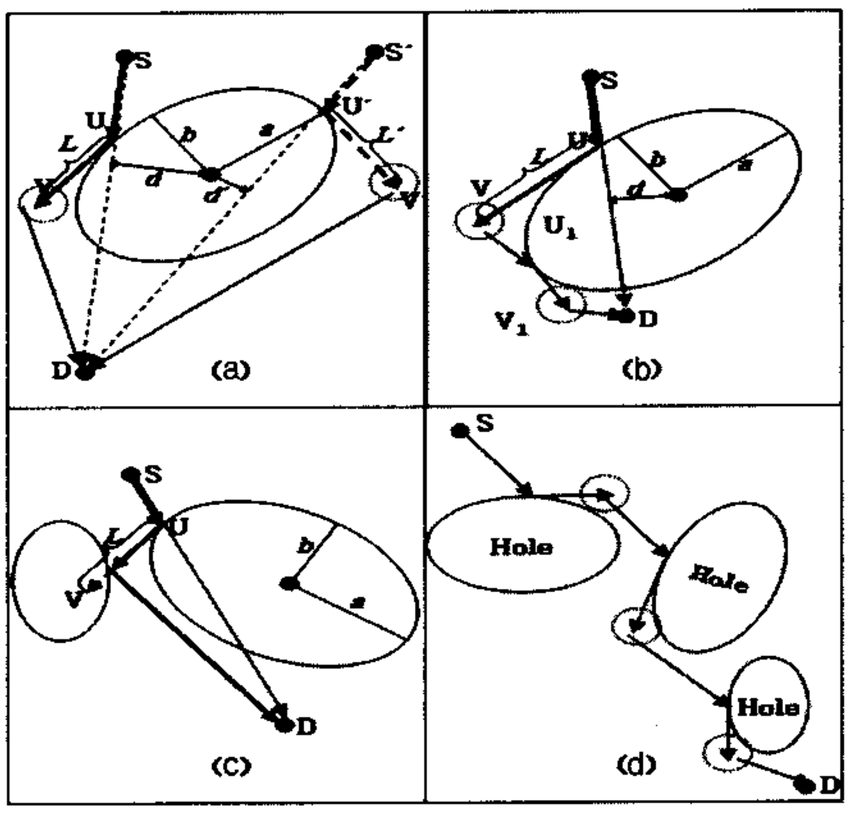

Fig. 2 Dynamically data delivery scenarios of hole geometric modeling

In Fig. 2(a), source node S transmits a data packet to destination D along the line $\overline{SD}$ by one of the existing geographic routing protocol. Nodes on the ellipse are distinguished with the others by ED packet information which is existent in nodes on the ellipse. When data packet reaches the boundary of the ellipse, it sets the data packet to anchor mode, and adds the anchor location information to the data packet which is calculated by (4) and (5), and then forwards the data packet to the node which is geographically closest to the anchor location. When the node closest to the anchor location receives the data packet, it resets the data packet to destination mode and resets anchor location field to void state, then transmits the data packet to destination directly.

4. Analysis

Geographic protocols, that take advantage of the location information of nodes, are very valuable for sensor networks. The state required to be maintained is minimum and their overhead is low. Its routing path fleetly adapts to variational location of mobile source or destination, source node is not required to be aware of network global information, thus it competently supports source mobility.

In some sense, we can regard the ellipse as a shield. In our algorithm, different source nodes may have same tangent point nodes, but their anchor point nodes must different based our formulas of anchor point. And the routing path changing with time can totally avoid uneven energy consumption. In (d) the L and d is a constant value, and we extend the set of all possible values of the balance parameter α, so that decrease the probability of the data packet reencounter the circle. For balance energy consumption, we adopt 2-dimensional Gaussian function. In practice, when computing a discrete approximation of the Gaussian function, points outside of approximately 3σ are small enough to be considered effectively zero. Thus, anchor point outside of that range can be ignored. In our algorithm, we set the standard deviation of two-dimensional Gaussian distribution equal to sensor node transmission range.

From (4) we can see the balance parameter α affects the length of L, a short L may cause the data packet from anchor node to destination node encounter the ellipse again. We cannot prevent such things from occurring in our protocol because the unpredictable and harsh nature application environment or uneven energy consumption. Another condition is that the destination node D locates closely to the ellipse, as shown in Fig. 2(b). In this case, the data packet is redirected to another anchor point from node U_1. In Fig. 2(c), the anchor location of node U locates in another ellipse. In this case, when the node on the ellipse receives the data packet from U, it also resets the packet in destination mode and set anchor location in void state, then forwards the packet to original destination by geographic forwarding mechanism. Fig. 2(d) shows that our algorithm is available in the condition of several holes existing between source and destination. If the data packet from the first agent location to destination encounters another ellipse, the data packet is redirected to another agent location again. This process repeats until the data packet reaches original destination.

5. Conclusions

Our algorithm is not only models a hole by an ellipse to solve holes problem but also construct a dynamically routing path to balance energy consumption in sensor network. The node on the boundary of ellipse redirects the received data packets to anchor location, therefore bypassing hole area. Our algorithm has three prominent advantages: (a) it prevents data packets from entering the stuck area of a hole, thus reducing route rediscovery overhead; (b) it reduces energy consumptions and data collisions of the node on the boundaries of holes.(c) it balances energy consumption of the entire hole existing area.

References

[1] Karp B, Kung H, "GPSR: Greedy perimeter stateless routing for wireless networks," In Proc. of the 6th Annual Int'l Conf. on Mobile Computing and Networking. Boston, ACM Press, 2000. pp.243-254.

[2] F. Kuhn, R. Wattenhofer, Y. Zhang, and A. Zollinger, "Geometric adhoc routing of theory and practice," in Proc. ACM Symposium on the Principles of Distributed Computing (PODC), Boston, MA, Jul. 2003, pp. 243-254.

[3] P. Bose, P. Morin, I. Stojmenovic, and J. Urrutia, "Routing with guaranteed delivery in ad hoc wireless networks," in Proc. of the 3rd International Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications, pp. 48-55, 1999.

[4] Y. B. Ko and N. H. Vaidya, "Location-aided routing (LAR) in mobile ad hoc networks," in Proc. ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom), Dallas, TX, Oct. 1998, pp. 66-75.

[5] Q. Fang, J. Gao, und L. J. Guibas, "Locating and bypassing routing holes in sensor networks," In Proc. of INFOCOM 2004, Vol.4, March 2004 pp. 2458-2468.

[6] N. Ahmed, S. S. Kanhere and S. Jha, "The Holes Problem in Wireless. Sensor Networks: A Survey," ACM SIGMOBILE Mobile Computing. and Communications Review, Vol.9, pp.4-18, 2005.

[7] E. Kranakis, H. Singh, and J. Urrutia, "Compass routing on geometric networks," In Proceedings of the 11th Canadian Conference on Computational Geometry (CCCG'99), 1999.

[8] F.C. Yu, E. Lee, Y.Choi, S. Park, D. Lee, Y. Tian, and S. Kim, "A Modeling for Hole Problem in Wireless Sensor Networks," In Proc. of the IWCMC'07, August 12-16, 2007, Honolulu, Hawaii, USA.

[9] J.A. Bondy and U.S.R. Murty, Graph Theory with Applications (Elsevier North-Holland, 1976).