Virtual Convex Polygon Based Hole Boundary Detection and Time Delay Based Hole Detour Scheme in WSNs

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Abstract. In wireless sensor networks, an important issue often faced in geographic routing is the “local minimum phenomenon.” To mitigate the local minimum issue, when the routing process becomes stuck at hole boundary nodes, the existing perimeter routing tends to route data packets along the boundaries of the holes. However, this may enlarge the hole, causing the “first hole diffusion” problem. On the other hand, the existing hole detour scheme based on the virtual ellipse forwards data packets to outside the virtual ellipse. This may generate other holes around the existing hole - the “second hole diffusion” problem. Therefore, we propose a novel virtual convex polygon based hole boundary detection and time delay based hole detour scheme. The proposed scheme solves first and second hole diffusion problems. Comprehensive simulation results show that the proposed scheme provides approximately 22% and 16% improvements in terms of the packet delivery ratio and the network lifetime, respectively.

Keywords: Wireless Sensor Networks (WSNs), Geographic Routing, Hole Problem.

1 Introduction

Geographic routing protocol [1], efficient and scalable strategy, can minimize the hops from the source to the destination by forwarding the data packet to the 1-hop neighbor which is closest to the destination. However, the geographic routing fails if there is no neighbor that is closer to the destination than the current node, this is well known as the local minimum problem [2]. To mitigate the local minimum issue, the several schemes have been proposed [1-11]. These existing schemes, however, still have the first and second hole diffusion problems.

In this paper, we propose a novel hole boundary detection method based on the virtual convex polygon to solve the first hole diffusion problem. It can reduce the overhead incurred by distribution of hole information of all nodes inside the virtual polygon since the number of nodes inside a convex polygon is smaller than other polygons. In addition, unnecessary establishment of the detour routing path is eliminated. We also present energy efficient hole detour scheme based on time delay

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mechanism. When the data packet reaches the boundary node of virtual convex polygon, it is forwarded to outside of the convex polygon along the dynamic path founded by time delay mechanism. This reduces the energy consumption and data congestions on the hole boundary nodes. Moreover, the hole detour method using time delay evenly distributes the load among peripheral nodes around the virtual convex polygon. Therefore, the second hole diffusion problem could be relieved.

The reminder of this paper is organized as follows: in Section 2, we briefly discuss related work. Section 3 presents our hole boundary detection and detour schemes. The performance of our proposed scheme is evaluated in Section 4. Finally, we conclude with the main findings and contributions of our research in the last section.

2 Related Work

Geographic greedy forwarding [1] is the most promising routing scheme in wireless ad-hoc sensor networks (WASNs). In such a scheme, it is assumed that each node knows its own location and the location of its 1-hop neighbors, source knows the location of the destination and encapsulates the destination location in each data packet, a node sends data packets to 1-hop neighbor closest to the destination. However, geographic forwarding suffers from the so called local minimum phenomenon. Specifically, a packet gets stuck at a node whose 1-hop neighbors are all further away from the destination. In the existing perimeter routing scheme [1][2], the data packets tend to be routed along the boundaries of holes to solve local minimum phenomenon. However, hole diffusion problem may arise due to the energy exhaustion of the hole boundary nodes. In addition, data collisions may occur in the hole boundary nodes if multiple data streams are bypassing a hole simultaneously.

Hole Detour scheme based on Ellipse (HDE) [3][4] detects the hole using virtual ellipse. The node which firstly detects a hole (the initiator) sends out a Hole Boundary Detection (HBD) packet along the boundary of the hole by the well-known right hand rule. This process repeats until the HBD packet has traveled around the hole and eventually been received by the initiator. The initiator gets the location information of all boundary nodes of the hole from receiving HBD and then calculates the ellipse which can cover the hole exactly. Then initiator distributes an Ellipse Distribution (ED) packet which includes all information about the ellipse, and sends out the ED packet to all nodes inside the ellipse. The mission of the defined the ellipse is to prevent data packets from entering the ellipse. When a node locating on the boundary of the ellipse receives the data packet, HDE forwards the data packet to outside of virtual ellipse by geographic forwarding mechanism. HDE solves the first hole diffusion problem. However, HDE increases overhead incurred by distribution of hole information of all nodes inside the virtual ellipse and generate unnecessary hole detour since the ellipse does not cover in the exactly close proximity to the hole. HDE also generates the second hole diffusion problem if the source and destination are same.

3 Proposed Scheme

3.1 Virtual Convex Polygon Based Hole Boundary Detection

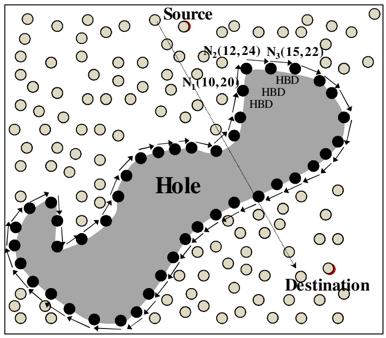
In this section, we introduce the method of the virtual convex polygon based hole boundary detection. The node that firstly detects a hole sends a HBD packet including its location information along the boundary of the hole by the right hand rule [2]. The node receiving the HBD packet refers to the table of movement patterns as in Table 1 to determine if its upstream node is a convex or concave node. In a polygon drawn by connecting the nodes forming the boundary of the hole, a convex node is a vertex bulging outward further than its neighboring nodes. The use of a movement pattern may reduce the size of the packet that traverses the boundary nodes to form the information of a convex polygon. The possible movement patterns of the convex and concave nodes that may take place while traversing hole boundary nodes, in accordance with the right hand rule, are shown in Table 1. Blank spaces in Table 1 may contain any of +, –, and 0.

Table 1. The movement patterns of the convex and concave nodes

Pattern of Concave node	Pattern of Convex node	Pattern of common node
(+,) → (, +)	(+,) → (, –)	**No change of pattern** **Ex.** (+, +) → (+, +)
(. –) → (+, –)	(, –) → (–,)	
(, +) → (–,)	(, +) → (+,)	
(–,) → (, –)	(–,) → (, +)	

Convex nodes and concave nodes may be determined using the movement pattern as follows: Assume that the HBD packet is transferred through nodes N_1, N_2 and N_3, in that order, as shown illustrated in Fig. 1. Given the node location information (x, y), the transfer of the packet from N_1 to N_2 would result in the location information changing from (10, 20) to (12, 24). As both x and y values increased, the movement in this case may be summarized as (+, +). Using the same method, the movement from N_2 to N_3 would be (+, –). As shown in the drawing, N_2 is a convex node that is bulging outward than N_1 and N_3. Therefore, a given node is determined to be a convex node if the movement from its upstream node and that to its downstream node are (+, +) and (+, –), respectively.

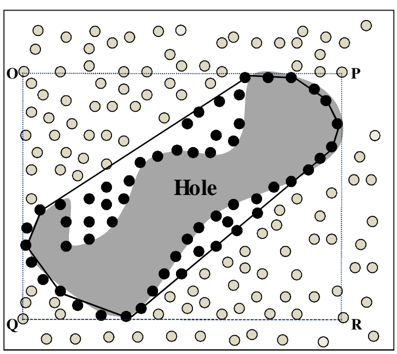
Each node judges its upstream node by making reference to the movement pattern, and if the upstream node is a convex node, it states in the HBD packet that the upstream node is convex, and then adds the location information of the current node to the packet before handing it to its downstream node. The location information of convex nodes is stored while the packet traverses boundary nodes. The location information of non-convex nodes is deleted from the HBD packet when it becomes no longer needed. As the location information of any node is required to judge the node as well as its immediate upstream and downstream nodes, the information of any non-convex node is communicated no further than a boundary node following the downstream node. This process continues until the HBD packet has traveled around the hole and eventually been received by the initiator. The initiator then uses the Graham scan algorithm [12] on the list of the convex nodes extracted. This process results in a complete convex polygon.



● Hole boundary node

Fig. 1. Tracing the hole information

The initiator assembles a Convex Polygon Distribution (CPD) packet for use the information of the recognized convex polygon to search for detour points. The CPD packet contains the information of the convex polygon and transfers it to all nodes found to form the polygon. Each node receiving the CPD packet uses the convex polygon information to determine if it belongs to the polygon, and obtains the maximum and minimum x and y values to store information O (minimum x, maximum y), P (maximum x, maximum y), Q (minimum x, minimum y) and R (maximum x, minimum y) which are the detour points, as shown in Fig. 2.



● Node inside the virtual convex polygon

Fig. 2. Selecting 4-detour points

3.2 Time Delay Based Hole Detour Scheme in WSNs

In this section, we depict the data transmission process from source to destination. When a data packet is transferred, a hole is detoured in a following manner: Inside each data packet is a node flag that determines the mode of transfer. The data packet is transferred in the same manner as in Greedy Perimeter Stateless Routing (GPSR) [1] until it reaches a node containing hole information, where the transfer mode of the packet is a basic mode. If a data packet has reached a node containing hole information, appropriate detour points to avoid the hole are determined. If the calculation of detour points result in the conclusion that no detouring is necessary, the transfer mode of the packet remains the basic mode. If detour points may be calculated, the transfer mode of the packet is switched to the detour mode. The detour mode is a transfer mode indicating that the dynamic transfer route must be determined with energy and distance taken into account until the packet nears the calculated detour points.

The detour points are determined using the intersection relationship between (i) segment $\overline{SD}$ connecting the source (S) and destination (D), and (ii) segments $\overline{OP}, \overline{OP}, \overline{OQ}$, and $\overline{PR}$ connecting O, P, Q and R as in Table 2. Detour points are established only when $\overline{SD}$ intersects two segments. If there are two possible detour routes, a route offering the shortest distance to D is selected. After the selection of detour points, the transfer mode of the packet is switched to the detour mode, and the next node is found by using the time delay mechanism while the packet goes through the detour points.

Table 2. The selected detour points by intersection relationship

The intersection of the segment $\overline{\mathrm{SD}}$	Detour Points
$\overline{\mathrm{OP}}$, $\overline{\mathrm{QR}}$	(O, Q) or (P, R)
$\overline{\mathrm{OQ}}$, $\overline{\mathrm{PR}}$	(O, P) or (Q, R)
$\overline{\mathrm{OP}}$, $\overline{\mathrm{PR}}$	P
$\overline{\mathrm{OQ}}$, $\overline{\mathrm{QR}}$	Q
$\overline{\mathrm{OQ}}$, $\overline{\mathrm{OP}}$	O
$\overline{\mathrm{PR}}$, $\overline{\mathrm{QR}}$	R

The Time Delay value (TD) is calculated by (1).

$$TD = \begin{cases} \omega \times N_e + (1-\omega) \times N_d, & if\ \forall_{N_e} \rangle\, 0 \\ \infty, & if\ \exists_{N_e} = 1 \end{cases} \tag{1}$$

where, N_e denotes the residual energy level using logarithmic properties; N_d denotes the distance between the current node and the destination. Each attribute can be adjusted by weight factor, $\omega \in [0,1]$. A large ω gives more weight to the node's residual energy than to the distance.

$$N_e = \min\{1, -\log_{10}\frac{E_{residual}}{E_{initial}}\}$$
$$N_d = \min\{1, \frac{(D_{destination} - D_{shortest})}{(D_{longest} - D_{shortest})}\} \tag{2}$$

where, $E_{residual}$ and $E_{initial}$ are defined as the residual energy and initial energy, respectively; $D_{destination}$ is the distance between the current node and the destination; $D_{longest}$ is the longest distance between the neighbor and the destination; and $D_{shortest}$ is the shortest distance between the neighbor and the destination. When the data packet reaches the boundary node of the convex polygon, it sets the data packet to detour mode, and adds the detour location information to the data packet. This node broadcasts Request Time Delay (RTD) packet to its neighbors. The nodes receiving the RTD packet sets a timer after calculating TD. The timer value is proportion to TD. TD increases when the residual energy decreases and distance to the destination increases. The neighbor whose timer expires at first sends Clear of Time Delay (CTD) packet to the node sending RTD packet. The nodes sending RTD packets forward data packet to the node firstly sending CTD packet. This process repeats until the packet reaches the node closest to the detour point. When the node closest to the detour location receives the data packet, it resets the data packet to basic mode, and then transmits the data packet to destination directly by the existing geographic routing. The time delay mechanism could guarantee more uniform energy consumption among peripheral nodes around virtual convex polygon including boundary nodes of the hole, so this can relieve the second hole diffusion problem.

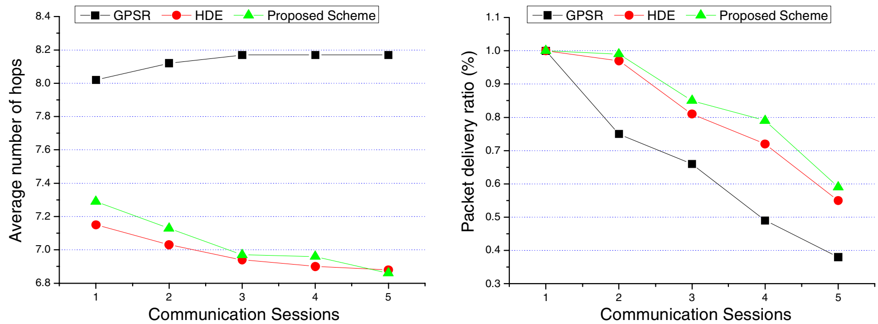
4 Performance Evaluation

We have implemented the proposed scheme, GPSR, and HDE using a simulator built in JAVA to evaluate their performance. In the simulations, nodes with a transmission radius of 40m are deployed to cover an interest area of 500m x 500m. The residual energy below 2.5J is randomly assigned to each node. We manually set one hole in the center of the network. The main parameters of our simulation are listed in Table 3.

Table 3. Simulation parameters

Initial energy	2.5J
Data packet size	500Bytes
Control packet size	15Bytes
Energy consumption model E_{tx}	$\alpha_{11}, \alpha_2 r^2$
Energy consumption model E_{rx}	α_{12}
α_{11}, α_{12}	80nJ/bit
α_2	1pJ/bit/m^2

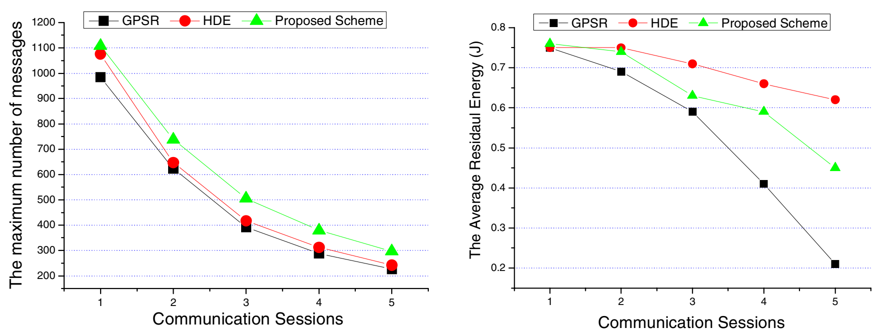
Our simulation environment uses the following energy model [13]: $E_{tx}=\alpha_{11}+\alpha_2 r^2$, $E_{rx}=\alpha_{12}$ where E_{tx} and E_{rx} denote the energy consumed to transmit and receive a bit over a distance r, respectively. α_{11} is the energy/bit consumed by the transmitter electronics. α_2 is the energy dissipated in the transmit op-amp and α_{12} is the energy/bit consumed by the receiver electronics.



(a) (b)

Fig. 3. Average number of hops and Packet delivery ratio

We compare the average number of hops of routing path, packet delivery ratio, maximum number of transmitted messages, and average residual energy of boundary nodes with GPSR, and HDE. Fig. 3(a) shows the average number of hops of routing path. Comparing with HDE and the proposed scheme, GPSR need more hops because they forward the data packet by right hand rule regardless of the location of destination. Fig. 3(b) shows the delivery ratio with different number of communication sessions when 500 packets are forwarded. GPSR forwards data packets along hole boundaries. Therefore, with the number of communication session increasing, multiple communication sessions may need to bypass a hole simultaneously. So the probability that data collisions occur in the nodes around the hole increases with an increasing number of communication sessions. However, the



(a) (b)

Fig. 4. The maximum number of message and the average residual energy

data packets in HDE and the proposed scheme are redirected once they encounter a hole, the detour location is different with different sources or destinations. HDE uses same path when source and destination are same. On the other hand, the proposed scheme changes the path from first boundary node to detour node using time delay mechanism although source and destination are same. Thus, the performance of the proposed scheme is slightly better than that of HDE.

Fig. 4(a) shows the proposed scheme attains approximately 16% improvement in terms of the maximum number of messages before first node on the path depletes its batteries. The maximum number of messages is the performance metric to show the network lifetime indirectly. Fig. 4(b) shows the average residual energy of the nodes around the holes after 500 packets are forwarded. The average residual energy of GPSR is drastically decreased with an increasing number of communication sessions because data packets are forwarded along the boundary of the hole. Thus the energy consumption of nodes on boundary holes is quite high in GPSR. The average residual energy of HDE is always higher than that of other schemes because it does not use boundary nodes. However, there is high probability to make other holes beside the existing hole because the boundary nodes of the virtual ellipse tend to be depleted quickly. The performance of the proposed scheme is higher than that of GPSR and lower than that of HDE. This result means that the proposed scheme evenly distributes the load among peripheral nodes around the virtual convex polygon.

5 Conclusion

In this paper, we propose the virtual convex polygon based hole boundary detection and hole detour scheme using time delay in WSNs. The virtual convex polygon based hole boundary detection solves the first hole diffusion problem. In addition, hole detour method using time delay evenly distribute the load among peripheral nodes around virtual convex polygon, so the second hole diffusion problem can be relieved. The network lifetime of the proposed scheme could be improved by reducing speed of the hole diffusion. This also results in the increasing delivery ratio. In our future work, we will extend our approach for selection of detour points. Because the proposed scheme only considers 4-detour points for detouring the hole, this is the cause of earlier exhaustion of their energy.

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