Energy Efficient Hole Bypassing Routing in Wireless Sensor Networks

Shiow-Fen Hwang  Chia-Hsuan Yang  Yi-Yu Su  Chyi-Ren Dow
Department of Information Engineering and Computer Science
Feng Chia University
Taichung, Taiwan 40724, R.O.C.
sfhwang@mail.fcu.edu.tw, m9702696@fcu.edu.tw, pioneer.su@mail.fcu.edu.tw, crdow@fcu.edu.tw

Abstract—In wireless sensor networks with holes(obstacles), to identify holes and deliver data packets efficiently are challenging issues. Most existing researches require sensor nodes to exchange messages multiple times for hole identification and thus depleting energy of sensors. In some researches, even with the assumption of knowing the information of the hole, due to the lack of efficient hole bypassing routing considerations, sensors still consume excessive energy for hole bypassing and data packets may still fail to be delivered to the destination. In this paper, we design an effective hole identification mechanism and propose efficient hole bypassing routing scheme in wireless sensor networks with holes. With the proposed scheme, data packets are able to bypass holes and be delivered to the destination along a shorter path. Simulation results demonstrate that our scheme is more energy efficient and has a shorter average path length.

Keywords—wireless sensor networks; hole; obstacle; energy; routing

I. INTRODUCTION

In most applications of wireless sensor networks (WSNs) [2, 3], data collected by sensors is sent back to the sink or a base station. Since the battery power of each sensor is limited, energy conservation becomes a critical issue when designing a routing scheme. Geographic greedy forwarding scheme[8] is extensively employed for energy-aware routing, since it generates low control overhead and delivers data through a short path, both implies the better energy conservation. However, holes can be formed in a wireless sensor network either due to irregular sensor deployment, sensor failure, signal interference, or environmental obstacles (building, lake, etc.)[1]. Without identifying holes in advance and applying appropriate mechanisms, ordinary greedy based geographic routing schemes perform inefficiently or even fail to deliver data to the destination in WSNs with holes.

Several researches addressed the issues cause by holes, and proposed schemes to detect and identify holes, appropriate routing schemes were further proposed[6, 7, 9, 10, 11, 13]. Fucai Yu et al. proposed a hole modeling and bypassing routing scheme[12]. First, the node which first detects a hole sends a message around the hole to exchange the location information of the hole. Then, the hole is modeled as a circle region to prevent data packets from entering the hole. When a node located on the edge of the circle receives the data packet from the source, it will calculate an anchor location and then forwards the data packet to the node which is the closest to the anchor location by geographic greedy forwarding mechanism. When the node closest to anchor location receives the data packet, then it forwards the data packet to the destination. However, since the hole closest to anchor location receives the data packet, then it forwards the data packet to the destination. However, since the hole is modeled as a circle region that has to be larger than the size of the hole, and data packets are forwarded to an anchor location that may be far from the edge of the circle, and thus may consume more energy since a longer path is used to bypass the hole. In [4], the active route guiding protocol (RGP) is proposed to enable the existing location-based routing protocols resisting obstacles. First, border nodes that surround the obstacles will actively establish a forbidden region for concave obstacles and make the obstacle information transparent by exchanging information of these border nodes. Then, packets will be guided to bypass the obstacle and delivered along the path that connected by the encountered border nodes to the sink. However, this protocol requires multiple times information exchange and complicated calculation/operation. Besides, how to efficiently bypass multiple holes is also omitted. C.-Y. Chang et al. proposed the weight-aware route guiding protocol (WRPG)[5]. Like that of the RGP, this protocol also removes the impact of obstacles on the greedy forwarding routing. Initially, it applies the previous research (RGP) to specify the border nodes of the obstacle. To prevent the packets from entering the concave region, the border nodes in the concave region of the obstacle initiate the weight assigning process and establish a forbidden region. Finally, WRGP specifies some border nodes to act as the effective border nodes for constructing the optimal routes from themselves to the sink node. In addition, the M-WRGP is further developed to deal with the multi-obstacle problem. However, even with the capability to bypass multiple obstacles, the optimal routes construction process generates additional control overhead and consumes more energy.

In this paper, we design an effective hole identification mechanism and propose efficient hole bypassing routing scheme in wireless sensor networks with holes. With the proposed scheme, data packets are able to bypass holes and be delivered to the destination along a shorter path. The rest of this paper is organized as follows: Section II describes the proposed scheme. Section III demonstrates the performance of the proposed scheme. Finally, the conclusion is given in Section IV.

576
II. ENERGY EFFICIENT HOLE BYPASSING ROUTING SCHEME

Since the information of holes is essential for data packets to bypass holes, sensors that are located at the boundary of the hole are selected as boundary nodes. The location of the hole can be identified by exchanging neighbor information of boundary nodes.

A. Construction of Hole Information

We assume that sensor nodes are uniformly deployed, stationary, and energy-constrained. Each sensor node is aware of its location. The \( L \times L \) sensor field is partitioned into several 2D logical grids. Each grid is a square of \( d \times d \). The origin of the coordinates is at the left-bottom corner of the sensor field. In each grid, one node is designated to be a grid head. Each grid head is responsible for sensing, receiving and forwarding packets. Other nodes in the grid enter to sleep mode for conserving energy. Let \( sr \) and \( tr \) be sensing range and transmission range of a node, respectively. \( sr, tr \) and \( d \) are defined as \( sr = \sqrt{2} d \) and \( tr = 2\sqrt{2} d \). By exchanging information with neighboring grids, each grid head can identify itself as a boundary node candidate. Assuming that a grid head is located at grid \( [x,y] \) and it has \( n \) neighboring grids, the grid head will be a boundary node candidate if any of the following conditions is satisfied:

1. \( n < 8 \) and \( 1 \leq x < L - 1, 1 \leq y < L - 1 \).
2. \( n < 5 \) and \( (x = 0, 1 \leq y < L - 1) \) or \( (x = L - 1, 1 \leq y < L - 1) \) or \( (y = 0, 1 \leq x < L - 1) \) or \( (y = L - 1, 1 \leq x < L - 1) \).
3. \( n < 3 \) and \( (x,y) = [0,0] \) or \( [0,L-1] \) or \( [L-1,0] \) or \( [L-1,L-1] \).

Based on the above conditions, grid heads that are located at the boundary of a hole can be selected as boundary node candidates, as shown in Fig. 1. However, some unnecessary boundary node candidates can be further unselected and thus data packets can bypass holes through a shorter path. For each boundary node candidate \( p \), if the number of neighboring boundary node candidates is more than 2, and they can communicate with each other without node \( p \), then \( p \) will not be a boundary node. Finally, the rest boundary node candidates will become boundary nodes, as shown in Fig. 2.

In order to exchange the information of the hole, once the boundary nodes are identified, the boundary node that is closest to the grid \( [0,0] \) will be a starting node and start sending the HBD (Hole Boundary Detection) packet to one of its neighboring boundary nodes by using the right hand rule. The boundary node that receives the HBD packet inserts its own ID and location into the HBD packet and forwards this packet to next boundary node. If the boundary node that receives the HBD packet has more than 2 neighboring boundary nodes, this boundary node marks itself as a junction node. If a boundary node cannot find next boundary node to forward the HBD packet, the following two cases are applied:

Case 1: if a junction node can be found in the ID list of the HBD packet, the HBD packet is transmitted back to the junction node, and the junction node will continue forward the HBD packet by using the right hand rule. For example, in Fig.3, node \( A \) sends HBD packet to node \( C \), node \( C \) marks itself as a junction node and forwards the HBD packet to node \( D \) and so forth. After receiving the HBD packet from node \( E \), there is no next boundary node for node \( F \) to forward. In this case, node \( F \) transmits the HBD packet back to node \( C \), since node \( C \) is a junction node. Afterwards, node \( C \) forwards the HBD packet to node \( B \) by using the right hand rule.

Case 2: if no junction node can be found in the ID list of the HBD packet, then:

1) If the boundary node is located at the border of the sensing field, the HBD packet will be transmitted backward to the boundary node at the other end, as shown in Fig. 5.
2) If the boundary node is not located at the border of the sensing field, the HBD packet can be forwarded to the next boundary node with the help of neighboring grid heads. As the example shown in Fig. 6, since the hole blocks the communication between node \( C \) and \( D \), node \( C \) cannot forward the HBD packet to node \( D \) directly. After exchanging information with neighboring grid heads, node \( C \) will forward the HBD packet to node \( F \) which is the nearest grid head to node \( E \), and node \( F \) will become a boundary node. Afterwards, boundary node \( E \) becomes
unnecessary since its neighboring boundary nodes can communicate with each other without itself, and finally it becomes an ordinary sensor node, as shown in Fig. 7.

If the HBD packet is forwarded back to a junction node, this junction node will become an ordinary boundary node and the ID list in the HBD packet will be updated (unnecessary boundary nodes will be deleted), as shown in Fig. 7. If the HBD packet is forwarded pass through two junction nodes that are adjacent (Fig. 8), boundary nodes between these two junction nodes will become ordinary sensor nodes and the ID list in the HBD packet will be updated correspondingly, as shown in Fig. 9. Eventually, the HBD packet that collects the information of the hole will be forwarded to the starting node. The starting node then sends the HBL(Hole Boundary Location) packet to all boundary nodes of this hole, and thus all boundary nodes will have the information of this hole (including the ID and location of all boundary nodes).

B. Concave Region Identification

In this subsection, we describe how to identify concave regions of a hole and thus avoiding data packets to be transmitted into these regions. For each boundary node $p$, an angle $\theta$ is defined to be the angle spanned by a pair of angularly adjacent neighboring boundary nodes of $p$ in clockwise order. Moreover, the value of the flag $f(p)$ is assigned based on the following conditions:

1) If $\theta > 180^\circ$, then $f(p) \leftarrow +1$.
2) If $\theta < 180^\circ$, then $f(p) \leftarrow -1$.
3) If $\theta = 180^\circ$, then $f(p) \leftarrow 0$.

Assuming that there are two boundary nodes $p$ and $q$, and $f(p) = +1, f(q) = +1$, “$a$” is defined to be the number of boundary nodes whose flag values are “$+1$” between nodes $p$ and $q$, and “$b$” is defined to be the number of boundary nodes whose flag values are “$-1$” between nodes $p$ and $q$. If $a + b \geq k$ (the values of $a$, $b$, and $k$ can be adjusted based on the environment, application and requirement), the region enclosed by nodes $p$, $q$ and nodes between $p$ and $q$ is identified as a concave region. Then, the boundary of the concave region is identified by sending the FNL(Forbidden Node Location) packet from node $p$ to node $q$, as shown in Fig. 10 and Fig. 11. Subsequently, data packets will not be forwarded into the concave region (when the destination is not located in this region).

C. Hole Bypassing Routing Scheme

In an environment with one hole, the first data packet is transmitted from the source($S$) toward the destination($D$) by using greedy routing scheme. If the data packet is forwarded to a boundary node $p$, node $p$ calculates the distances from line $SD$ to the farthest boundary nodes at two sides of the hole by using vertical lines. Then, node $p$ forwards the data packet to the boundary node of one side that has a shorter distance to bypass the hole. For example, in Fig. 12, boundary node $B$ forwards the first data packet from the source($S$) to the boundary node $E_R$ that has a shorter distance($d_1 < d_2$). After receiving the first data packet, $E_R$ can forward this packet to the destination by using greedy
routing scheme. For the rest data packets to bypass holes more efficiently, after receiving the first data packet, the destination sends the information of the hole encountered by the first data packet back to the source. With this information, the source is able to forward the rest data packet to the proper boundary node directly, and thus reducing the distance of the detour path from the source to the destination, as shown in Fig. 13.

In an environment with multiple holes, if the first data packet is forwarded to the boundary node of the first hole, a boundary node with a shorter distance is selected for the data packet to bypass the first hole. Similarly, if this data packet is forwarded to a boundary node of another hole, the data packet will be forwarded to a corresponding boundary node that has a shorter distance to bypass this hole (Fig. 14). Eventually, the first data packet will bypass multiple holes and be forwarded to the destination. The information of these encountered holes is transmitted back to the source, and the rest data packets can be transmitted to the destination by passing through multiple boundary nodes of different holes efficiently (Fig. 15).

Moreover, a mechanism is designed to shorten the path when the source or the destination is located in the concave region: assuming that the source(destination) is located in the concave region and the corresponding FNL packet is sent from node $p$ to node $q$. Boundary nodes $E_L$, $E_R$ are located at different sides of $SD$ and both have the longest distance to $SD$. Before starting to send data packets, the source first calculates the total distance from itself to $p(E_L)$, $E_L(p)$ to $E_L$, $E_R(q)$ to the destination, and the total distance from itself to $q(E_R)$, $E_R(q)$ to the destination. Then, the source will start sending data packets to the destination along the path which has a shorter total distance. As the example shown in Fig. 16, the source forwards data packets along the path $S-p(E_L)-E_L(p)-D$, because $d_1 + d_1 + d_1 < d_2 + d_2 + d_2$.

III. PERFORMANCE EVALUATIONS

In this section, the performance of the proposed scheme was evaluated by carrying out various simulation studies. The communication energy dissipation is based on the first order radio model. The evaluated performance metrics include average path length and average energy consumption. The network size is 50$\times$50 grids, the size of each grid is 12.5m$\times$12.5m, and 5000 nodes are uniformly deployed in the network. One irregular hole (radius is 100m) is placed in the central of the network region. We compared our scheme with EHDS[14] and EEHM[12] in terms of average path length, control overhead and energy consumption.

![Figure 12. The delivery path of the first data packet.](image)

![Figure 13. The delivery path after the first data packet.](image)

![Figure 14. The delivery path of the first data packet – with multiple holes.](image)

![Figure 15. The delivery path after the first data packet – with multiple holes.](image)

![Figure 16. The path selection when the source(destination) is in a concave region.](image)

![Figure 17. Average path length (hops).](image)

Average path length is defined as the average number of hops of the data packets that are transmitted from the source to the destination. In Fig. 17, the proposed scheme has shorter path length than that of EHDS and EEHM. Since in our scheme, most data packets are forwarded along a shorter
detour path to bypass the hole. In EEHM, the detour path used for bypassing hole may be too far away from the hole, and thus it has the longest path length. The number of communication sessions has almost no effect upon the path length.

![Figure 18. Control overhead.](image1)

The control overhead is the summation of control packets for hole identification and path optimization. All of these three schemes require nodes to exchange neighbor information for hole identification. However, the proposed scheme generates least control packets by using grid-based approach to identify holes, the information exchange of holes is also more efficient with the grid structure.

![Figure 19. Energy consumption.](image2)

The energy consumption is the total energy consumed for delivering data packets from the source to the destination. As expected, energy consumption increases with the number of communication sessions. In our scheme, the lowest energy consumption is achieved by using shorter paths for data packets delivery.

IV. CONCLUSIONS

In this paper, we propose efficient hole bypassing routing scheme in wireless sensor networks. With the proposed scheme, data packets are able to bypass holes and be delivered to the destination along a shorter path. Simulation results demonstrate that our scheme is more energy efficient and has a shorter average path length.

ACKNOWLEDGMENT

This research is supported by the National Science Council of the Republic of China, Taiwan, under grant No. NSC-98-2221-E-035-048.

REFERENCES