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Averting Void Routing In Geo Graphic Routing Protocol Using Virtual Co-Ordinates in WSN

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Abstract:

To solve the routing void problem in geographic routing, high control overhead and transmission delay are usually taken in wireless sensor networks. Inspired by the structure composed of edge nodes around which there is no routing void, an efficient bypassing void routing protocol based on virtual coordinates is proposed in this paper. The basic idea of the protocol is to transform a random structure composed of void edges into a regular one by mapping edge nodes coordinates to a virtual circle. By utilizing the virtual circle, the greedy forwarding can be prevented from failing, so that there is no routing void in forwarding process from source to destination and control overhead can be reduced. Furthermore, the virtual circle is beneficial to reduce average length of routing paths and decrease transmission delay. Simulations show the proposed protocol has higher delivery ratio, shorter path length, less control packet overhead, and energy consumption.

Index Terms:

Wireless sensor networks, geographic routing protocol, routing void, virtual coordinate.

1. INTRODUCTION:

Over the past decades, wireless sensor networks (WSNs) have been widely applied in many different fields in which routing protocol is one of the key technologies. Since a sensor node exploits a path depending only on the location information of neighbor nodes in geographic routing [4], routing protocol based on geographic information is more efficient.

Due to its high expansibility and low influence by network size, geographic routing has wide application prospects in large scale WSNs. For example, plenty of nodes equipped with geophones are distributed uniformly on the ground and have the ability to get their own locations by global positioning system (GPS) or localization algorithms in seismic exploration, where geographic routing has potential to serve as routing protocol. However, if a routing void, called local minimum [13], is encountered resulting from the random distribution of sensor nodes, the greedy algorithm in geographic routing will fail, and ultimately data transmission also fails in such situation.

To reduce the impact of the routing void, a strategy to isolate certain region around a routing void is proposed in [14]. Nodes located in this region are banned from being selected as a relay node in order to prevent data packets from accessing to the routing void. Ring-constraint forwarding (RCF) proposed in [15] establishes a multi-ring region around a routing void, in which relay nodes are selected to avoid routing void and balance energy consumption.

In [16], relay nodes are selected according to the geographic location relationship between the destination node and the routing void in order to prevent failing of greedy algorithm. These algorithms above have low complexity, but high overhead of control packet and time delay result in high energy consumption and inefficient transmission. Beyond that, routing void problem still exists around those established regions, and that no further scheme is proposed to solve this problem.

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Greedy perimeter stateless routing (GPSR) composed of greedy forwarding and face mode is proposed in [17]. When routing void is encountered, GPSR works under face mode instead of greedy forwarding until finding a neighbor node closer to the destination. Routing protocols based on virtual coordinate have various forms, which make them flexible to implement according to practical network conditions without constraint from the physical locations.

Though greedy algorithm is simple in principle and low in complexity, it cannot be applied to all sensor nodes when some routings based on virtual coordinate are adopted in the network. To solve previous problems, an efficient bypassing void routing protocol based on virtual coordinate mapping (BVR-VCM) is proposed in this paper.

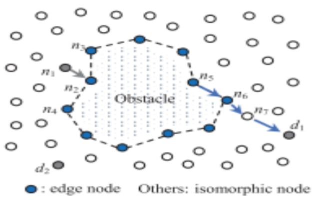

Fig. 1. Routing void in greedy forwarding.

The basic idea of BVR-VCM is to build virtual coordinates of the whole void edge nodes by mapping their geographic coordinates to a virtual circle that covers the void, and then establish a path by using these virtual coordinates. The virtual circle composed of edge nodes can solve routing void problem and make greedy algorithm work in entire forwarding process, in this way overhead of control packets are reduced.

Furthermore, the establishing and maintaining for virtual coordinates are not affected by alternation of destination node, thus energy consumption can be reduced. Due to the establishing process of virtual coordinates, the proposed routing protocol is more suitable for stationary sensor networks, such as seismic exploration, in which nodes are stationary during their working periods.

II. PROBLEM DEFINITIONS:

We consider the following situation: sensor nodes are modeled by a unit graph. All nodes within communication range Rc of a node n are considered as neighbors of n and bidirectional links exist between n and its neighbors.

A. Routing Void in Geographic Routing

In geographic routing, when greedy forwarding is adopted, it can be easily interrupted due to the terrain or radio coverage, for example, pools, hills or buildings which locate in the sensor area. The finite distance of communication range can also cause greedy forwarding failing. When a sensor node tries to forward the packet to one neighbor node that is geographically closer to the destination node than itself, but such node doesn’t exist, then a routing void is encountered. Greedy forwarding fails in this situation. As shown in Fig. 1, a node n1 tries to forward a packet to the destination node d1 by greedy forwarding in multi hops. First, node n1 sends the packet to n2 by greedy forwarding. Since the neighbor nodes set of n2 is {n1, n3, n4}, none of which is closer to the node destination d1, and then a routing void is encountered and greedy forwarding fails to deliver the packet. Similarly, a routing void is encountered at node n5 when it tries to forward a packet to the destination node d2.

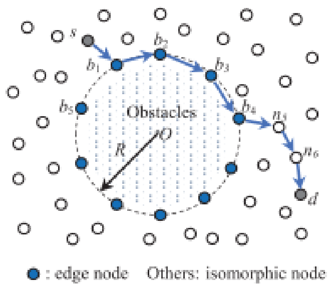

Fig. 2. Edge structure without routing void.

B. Structure Without Routing:

Void Assuming the number of edge nodes around an obstacle in WSNs is Nb, the set of edge nodes is {bk |

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k = 1,··· Nb}, both of the following conditions should be satisfied:

$$\begin{cases} d(b_k, b_{k+1}) < T_c, \quad k = 1, \cdots N_b - 1 \\ d(b_1, b_{N_b}) < T_c \end{cases} \tag{1}$$

and

$$\begin{cases} \{b_{k+i} \mid d(b_k, b_{k+1}) < T_c, \quad k = 2, \ldots N_b - 2, \\ \qquad\qquad 2 \le i \le N_b - k\} = \varnothing \\ \{b_k \mid d(b_1, b_k) < T_c, \quad k = 3, \ldots N_b - 1 = \varnothing \end{cases} \tag{2}$$

where d(x, y) represents the Euclidean distance between node x and y, Tc represents the communication distance of nodes, i is an integer. According to formula (1), (2), every edge node can only communicate with its two neighbors belonging to the set {bk|k = 1,··· Nb}. If all the edge nodes around the obstacle have the same distance to a point O as following:

$$d(b_k, O) = R, \quad k = 1, \ldots N_b \tag{3}$$

where R is a constant. In this situation, all the edge nodes locate on a circle with center point O and radius R as shown in Fig. 2. In this type of structure composed of the edge nodes, every edge node has two and only two neighbors locating on the circle. According to the geometrical features of circle, there is no routing void around this obstacle area for any destination node in the network.

III. BVR-VCM ROUTING PROTOCOL:

The proposed routing protocol BVR-VCM consists of greedy mode and void processing mode. In BVR-VCM, greedy algorithm is adopted to select relay node in greedy mode. If greedy mode fails when a routing void is encountered, void processing mode is activated. Void processing mode is composed of three phases, according to processing in the order, respectively void detecting, virtual coordinate mapping and void region dividing. After the implement of void processing mode, the virtual coordinates of edge nodes are established. Then greedy mode is reactivated, these edge nodes that have the virtual coordinates can be selected as the relay node by greedy algorithm.

In the following section, three main phases in void processing mode and the main steps of entire process in BVR-VCM are described.

A. Void Detecting Phase

The main function of the void detecting phase is to collect edge node information around the routing void after the void is encountered. When routing void emerges in the transmission process, the node at which the greedy mode fails is defined as the discovery node. After the discovery node discovers a void, it stores data packets temporarily at first, then generates a void detecting packet for starting a void detecting process. During the process, the void detecting packet records the time when the void is encountered, edge node's label and geographical coordinate. The detecting process can be performed by left-hand (right-hand) rule. Eventually the detecting package returns to the discovery node. The information of edge nodes can be represented as set {bk|k = j, j + 1,··· imax }.

In the process of void detecting, there may be multiple discovery nodes in the same void region, so there may be multiple detecting packets around current void at the same time. In this condition, in order to avoid the repetition that different detecting packets detect and forward around the same void, the edge nodes record the time when void is encountered after receiving a detecting packet. Based on the sequence of discovery time, a node discards the detecting packet if the time recorded in the current packets is later than their records; otherwise the node forwards the detecting packet. Finally, in the current void region, only the detecting packet send by the earliest discovery node can complete the entire void detecting process.

B. Virtual Coordinate Mapping:

Phase The virtual coordinate mapping phase is responsible for mapping the edge node coordinates stored in the detecting packed to a virtual circle, i.e., converting a structure composed of edge nodes to the structure without routing void as described in section II.B. The detecting packet that returns to the discovery node stores all the information of the current void,

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including node's label and geographic coordinates. (x j, y j), (x j+1, y j+1), ··· (ximax , yimax) represent the nodes coordinates, thus the center coordinate of the void is

$$(x_o, y_o) = (\frac{1}{(i_{max} - j + 1)} \sum_{k=j}^{i_{max}} x_k, \frac{1}{(i_{max} - j + 1)} \sum_{k=j}^{i_{max}} y_k) \quad (4)$$

Algorithm 1 The Virtual Coordinate Mapping Algorithm

```
initialize i = j, m = ∅
while i ≤ i_max do
  if only one interaction x', y' between r_i and U then
    (x'_i, y'_i) = (x', y')
    if M = ∅ then
      x_temp, y_temp = (x', y')
    else
      while c! = 0 do
        x'_{i-c} = x' + x_c
        y'_{i-c} = y' + y_c
        Remove b_{i-c} from M
      end while
    end if
  else
    Add b_i to M
  end if
  i++
end while
```

The maximum distance between edge nodes and the void center is

$$d_o = max\{d_k | d_k = \sqrt{(x_k - x_o)^2 + (y_k - y_o)^2}, \; k = j, j+1, \cdots i_{max}\} \quad (5)$$

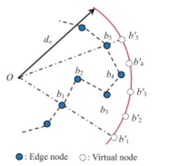

Fig. 3. Sample of virtual coordinate mapping.

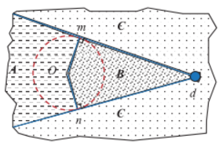

Fig. 4. Void region dividing.

C. Void Region Dividing Phase:

The main function of the void region dividing phase is to divide the surrounding area of the void into three different regions, in which different routing strategies are applied.

According to the void position and the location of destination node of the packets, the surrounding area of a void is divided into approaching region, departing region and free region, as shown in Fig. 4. O is the center of mapping virtual circle, d is the destination node; the circle shown in dotted line is the virtual mapping circle. Two tangents to the mapping virtual circle through the destination node have the intersections at point's m and n respectively. The quadrilateral region formed by O, m, d, and n is defined as departing region of the virtual mapping circle, as the region B shown in Fig. 4. The area formed by two tangents of the virtual mapping circle, except the departing region, is defined as approaching region of the virtual mapping circle as the region A shown in Fig. 4. The area outside of the two tangents is defined as free region of the virtual mapping circle as region C shown in Fig. 4. It should be noted that three regions are divided according to the current routing void; and, the division of three regions is different for different destination nodes.

D. Routing Based on Virtual Coordinate

After implementing the three phases above, the edge nodes of void contain two types of location information which are geographic coordinates and virtual coordinates, and that surrounding area of routing void has been divided into three different regions according to the destination node. Discovery node restarts greedy mode by utilizing the virtual coordinates, the packet stored in the first phase is forwarded to relay nodes. In the greedy mode, the ways to select relay node in three regions are different, but they all use the greedy algorithm. The main steps of BVR-VCM are as follows:

Step 1: Node receives data packet;
Step 2: Determine if virtual coordinate is used by itself or its neighbors, if any, go to step 3, or go to step 4;
Step 3: If node locates in the approaching region, it uses virtual coordinate to select the relay node; if locating in departing region, it uses geographic coordinate to select the relay node in priority; if locating in free region, it uses geographic coordinate to select the relay node;

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Step 4: If there is no routing void encountered in greedy algorithm during the process of selecting relay node, go to step 6, or go to step 5;
Step 5: Void process mode is activated, and virtual coordinates of edge nodes around routing void are established. Then go to step 3;
Step 6: Node sends packet to the relay node. All the data packets arriving at destination mainly experience three different routing processes in BVR-VCM.

The first is arriving at destination without void problem: step 1→step 2→step 4→step 6. In this process, no void is encountered; the selection of relay nodes is depending on greedy forwarding only. If a void is encountered for the first time during the packet delivery, the process in BVR-VCM is: step 1→step 2→step 4→step 5→step 3→step 6. In this process, virtual coordinates of edge nodes around current void are established.

The third process is: step 1→step 2→step 3→step 6. In this process, packets reach the surrounding area of void, relay nodes are selected by utilizing virtual coordinates of edge nodes. Since the virtual mapping circle of void constitutes the structure without routing void, packets can bypass the void, and that the location of source node or destination node has no influence on the greedy algorithm.

IV. PROTOCOL ANALYSIS

A. Routing Path Analysis According to the description of section III.B, after the virtual coordinate mapping phase, the neighbors of the edge nodes around the routing void receive the broadcasting messages. These neighbor nodes have the opportunity to establish a short path by utilizing the routing void information before void is encountered. As shown in Fig. 5, the node bs tries to send a packet to a destination node. After bs sends the packet to bv by greedy algorithm, a routing void is encountered at node bv

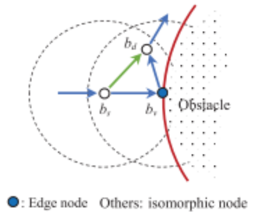

Fig. 5. Routing discovery in BVR-VCM.

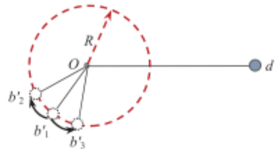

Fig. 6. Path exploring around void.

The BVR-VCM can utilize the information of the edge nodes which are obtained during the void detecting phase to explore a shorter bypassing path. As shown in Fig. 6, the dotted circle with center O and radius R is the virtual circle,

b

1,
b

2 and
b

3 represent virtual nodes of three corresponding edge nodes, and node d represents the destination. Assuming routing void is encountered at node
b

1, according to BVR-VCM,
b

1 will choose relay node in its neighbor,
b

2 and
b

3. Because the three virtual nodes are located at the same virtual circle,
b

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1 can obtain the result of
dOb

3
<dOb

1
<dOb

2 by the virtual coordinates of virtual circle center O and neighbor nodes it learns from distributing packet. In this situation,
b

1 chooses
b

3 as relay node instead of
b

2. However, in face forwarding,
b

1 choose
b

2 as relay node if left-hand rule is adopted.

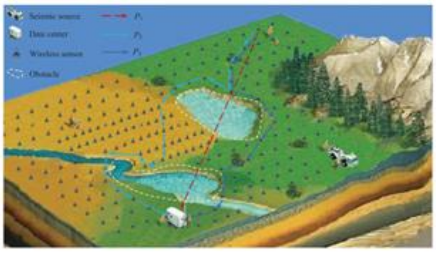
B. Control Overhead Analysis

Assuming the length of control packet header in the greedy algorithm is Lg, the lengths of detecting packet and distributing packet in BVR-VCM are Lde and Ldi respectively, the edge node number of routing void is Ns, the average number ofhops from source to destination is hBVR-VCM. When n packets are sent, the length of the control packet is

$$(L_{de} + L_{di}) \times N_s + L_g \times h_{BVR\text{-}VCM} \times n \qquad (7)$$

V. SIMULATION RESULTS:

A. Routing Path Analysis Simulations are performed in NS2 to demonstrate and evaluate the performance of BVR-VCM. In the simulations three scenarios are provided, the first scenario is to evaluate the affection of different void sizes, the second is to evaluate the affection of multiple routing voids, and the third is to evaluate the performance in random distribution network. In order to evaluate the affection of different void sizes in the first scenario, 900 nodes are deployed uniformly in a square region, a cross-shaped void is assumed to locate at the center area of the square region where there is no node deployed. In order to compare, a destination node is randomly selected below the center area, while source node is randomly selected above. In every simulation, one node is assumed to be destination node and four nodes are source nodes, the radius of routing void is changed from 90m to 270m. In the second scenario, different numbers of the cross-shaped voids are deployed randomly in the simulation area, one destination node and four source nodes are randomly selected



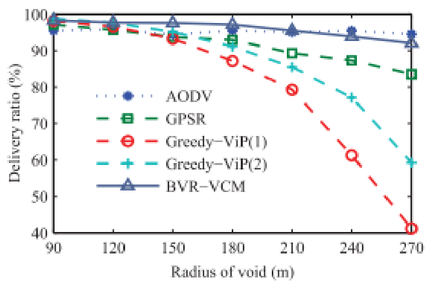


Fig. 8. Void size versus delivery ratio.

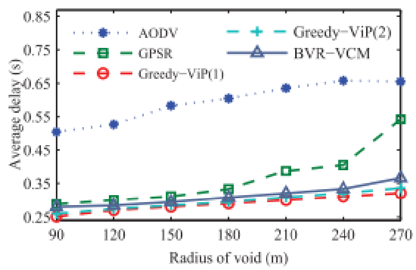


Fig. 9. Void size versus average delay.

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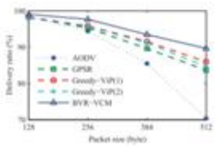

Fig. 12. Packet size versus delivery ratio.

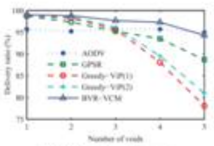

Fig. 14. Multi-void versus delivery ratio.

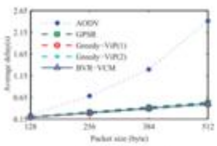

Fig. 13. Packet size versus average delay.

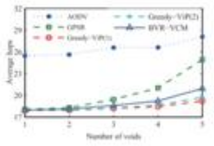

Fig. 15. Multi-void versus average hops.

VI. CONCLUSION:

To solve routing void problem in geographic routing, BVR-VCM is proposed by utilizing the edge structure without routing void. BVR-VCM uses void detecting, virtual coordinate mapping and void region dividing to solve void problem, and then establishes the path around void according to the virtual coordinates of edge nodes.Because void processing mode is performed only once for a routing void, the complexity of routing protocol can be reduced. Simulations show that the proposed BVR-VCM routing protocol has advantages in terms of average delivery ratio,transmission delay, et al. Besides, lower control overhead in BVR-VCM also reduces the energy consumption. Due to the hardware resource, the application range of the proposed protocol may be confined to special fields in which sensor nodes are equipped with enough redundant resources, such as seismic exploration. Future work will be to make proposed protocol generalized to common applications. To eliminate the possibility that the discovery packet could overload when detecting large voids, the alternative method of void detecting will be taken into consideration.

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