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A New Approach of Opportunistic Routing for Bypassing Void Region in WSNs

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ABSTRACT: Wireless sensor networks (WSNs) are widely applied in many different fields in which routing protocol is one of the key technologies. In geographic routing, a sensor node exploits a path depending only on the location information of neighbor nodes. Routing protocol based on geographic information is more efficient. When transmitting packets, the void problem occurring cannot be predicted in advance. Thus, how to improve greedy forwarding in geographic routing with void avoidance becomes an important issue. This paper proposed an enhanced bypassing void routing protocol based on virtual coordinate mapping (EBVR-VCM) to solve the routing void problem. Based on optimal path to reach the destination, relay node is moved to the optimal position that can shorten the average routing path length and decrease the transmission delay. Reducing routing distance can be more economical and efficient to forward packets to improve the current geographical void problem in wireless sensor network, and to enhance the performance of network routing.

KEYWORDS: Wireless sensor networks; geographic routing protocol; routing void; virtual coordinate; optimization framework

I. INTRODUCTION

With wireless network technology's advancement, variety of applications are there. Among that wireless sensor network is the popular research area in recent years. As the wireless sensor network node move at any time and the topology fast change feature, nodes often have void problem. When node transports packet, the void problem occurring cannot be predicted in advance. This will produce packet losing, resending, rerouting, additional transmission cost and electric power output. Thus, how to improve wireless network technology's geographic routing method is more important.

Due to its high expansibility and low influence by network size, geographic routing has wide application in large scale WSNs [1]. 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 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 solve routing void problem, an enhanced bypassing void routing protocol based on virtual coordinate mapping (EBVR-VCM) is proposed in this paper. The protocol not only maps the routing void of edge node coordinate to a void in the center of the cavity so as to cover a virtual circle in the network, but also creates the virtual coordinate of the edge node. Therefore the edge node with a virtual coordinate can be selected as a relay node. For the void area on the network, a circular virtual structure can effectively bypass routing void. Compared with the traditional protocols, the proposed protocol selects the relay node by greedy algorithm. Based on the transmission range of source node and destination node, this paper find the most shortest path to reach the destination. So greedy forwarding place relay nodes in this optimal path to transmit the packet to destination. Thus the communication delays and the overhead are reduced. Also the energy consumption is significantly reduced compared to other methods. Through establishing the virtual location, it is independent of the destination node. There is no need to rebuild the virtual location information even if the destination node changes.

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II. LITERATURE SURVEY

In [2] authors used a strategy to isolate certain region around a routing void inorder to reduce the impact of routing void. 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. In [3] authors proposed Ring constraint forwarding (RCF). It establishes a multi-ring region around a routing void, in which relay nodes are selected to avoid routing void and balance energy consumption. In [4] authors proposed route-guiding protocols (RGP) for resisting obstacles in wireless sensor networks. 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. In [5] authors proposed Greedy perimeter stateless routing (GPSR) protocol. GPSR composed of greedy forwarding and face mode. When routing void is encountered, GPSR works under face mode instead of greedy forwarding until finding a neighbor node closer to the destination. In [6] authors proposed Boundary state routing (BSR), which adopts the same strategy as GPSR to detour the void. In High-reliable low-cost geographical routing protocol [7], network is divided into some hexagon sub-nets, each of them is considered as a virtual node. When void is encountered, face forwarding mode begins to work among the virtual nodes. However, paths established by face forwarding are not optimized, a longer path may be chosen even if there exists a short one.

Recently, to solve void problem by using virtual location information, some novel routing protocols have been proposed. The key problem of these routing protocols is to build sensor node's virtual coordinate according to certain referenced nodes [8]-[10] or neighbor nodes [11] . When the destination node is changed, virtual coordinates of corresponding nodes on the routing path have to be rebuilt, so current routing protocols based on virtual coordinates are more suitable to the scenarios with fixed destination nodes. Furthermore, routing voids still exist in the network.

III. RELATED WORK

A. *Routing Void Generation:*

For routing based geographic information, use the greedy algorithm to choose the relay nodes which is closer than their neighbor nodes to the destination. If such neighbor node does not exist, there will be routing void. Fig. 1 illustrates the void generate schematic. As shown in Fig. 1, node $n2$ receives the data transmitted by $n1$, and the destination node is $d1$. A set of neighbor nodes for the node $n2$ is { $n1$, $n3$, and $n4$ }; since the distances from the nodes $n1$, $n3$, and $n4$ to the destination node $d1$ are greater than that of $n2$, the route appears void according to the greedy algorithm. The data will not be able to pass through. Similarly, when the node $n5$ sends data to the destination node $d2$, routing void will appear too.

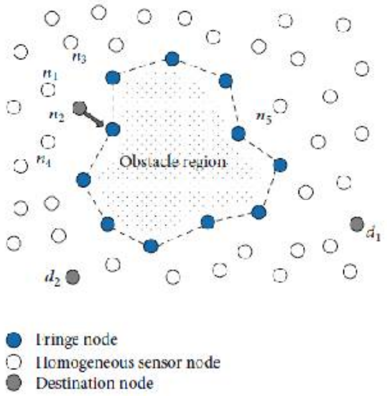

Fig.1. Void Generate Schematic

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B. *No Routing Void Network Edge Structure:*

Suppose, in WSN, the number of edge nodes around an obstacle area is Nb and the set of edge nodes is $\{bk|\ k = 1,2,. . . , Nb\}$. The edge node must meet

$$\begin{cases} d(b_k, b_{k+1}) < Tc, & k = 1,\cdots Nb-1 \\ d(b_1, b_{Nb}) < Tc \end{cases} \quad \text{eq. (1)}$$

and

$$\begin{cases} \{ b_{k+i}\ | d(b_k, b_{k+1}) < Tc, & k = 2,\ldots Nb-2, \\ & 2 \le i \le Nb-k\} = \emptyset \\ \{b_k \mid d(b_1, b_k) < Tc, & k = 3,\ldots Nb-1 = \emptyset \end{cases} \quad \text{eq. (2)}$$

where $d(x, y)$ is the Euclidean distance between the nodes x and y, Tc is the communication radius of the node, i is an integer, the edge node set is $\{bk|\ k = 1, . . . , Nb\}$, and any node can only communicate with the two adjacent nodes. If the distance between the edge node of obstacle and a fixed node O satisfies

$$d(b_k, O) = R, \qquad k = 1, . . . Nb \quad \text{eq. (3)}$$

the distribution of the edge node to the center of the circle O is determined. R is the radius of the circle, as shown in Fig 2. In the edge of the structure around the area of the obstacle, each edge node has only two neighbor edge nodes. From isotropic circular geometry, the packet routing is not void for any destination node while going through the region. Each node uses the greedy algorithm to select the relay node path. As an example, the source node s sends packets to destination node d and shows the generation of free routing void. The edge node $b1$ receives the packet and uses the greedy algorithm to find the next hop relay node. The same is for edge node $b2$. The two nodes are distributed in a concentric circle, and the distance of $b2$ to destination node d is less than that of $b1$.Then $b1$ selects $b2$ as the next hop node, and the routing void problem does not occur. Packets in the edge node $b3$ will not either incur routing void problem. The edge node $b4$ uses greedy algorithm to select the next hop node $n5$, and the packet is sent to the edge node $b4$. Until the data is sent to the destination node d, in this process, the greedy algorithm mechanism has not failed.

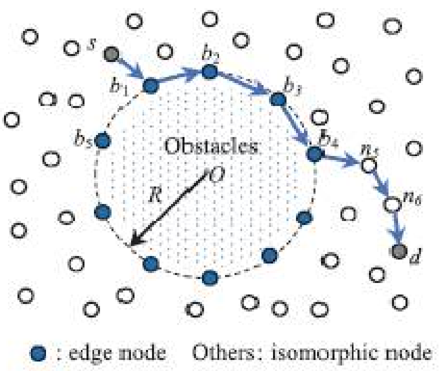

Fig.2. No Routing Void Network Diagram

IV. EBVR-VCM Routing Protocol

EBVR-VCM is composed of the greedy mode and the void processing mode. In this protocol, the relay node uses the conventional greedy mode to forward data. If the greedy mode fails, and the routing void appears, it changes to the void processing mode. According to the execution sequence, the void processing is divided into void detection, virtual coordinate mapping, and void area division. Through the void processing, the virtual coordinates of edge node are established. After starting the greedy mode again, these edge nodes with virtual coordinates can be selected as relay nodes.

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A. *Void Probe Stage:*

The void detection stage is responsible for collecting information of the void edge node after routing void appears. When the packets meet the routing void during data transmission within the network, it is called the failed node of the greedy algorithm and try to find a substitute node. When the substitute node detects the routing void, it caches the data packets, generates a void robe packet, and initiates the process of void detection. The void probe packet stores the whole founded time and labels each edge node and geographic coordinates. The detection process can be implemented through using left (right) hand technology. When the detection packet goes back to the founded node, it contains the information of the edge node set that is named $\{bk|\ k = 1, 2, . . . , Nb\}$.

In the detection process, it is found that there are multiple nodes and multiple probe packets within the same void detection area simultaneously. To reduce the detection of repeated forwarding different probe packets to the same node, the node receives probe packets and labels the void founded time recorded in the probe packets. According to the void founded time, it discards the probe packets if the founded time in the node labeled by new probe packets is later than that in the node and otherwise continues to probe until it reaches the corresponding founded node. Eventually only the probe packets sent by the earliest founded node complete the void detection in the entire void region.

B. *Virtual Coordinate Mapping Stage:*

The virtual coordinate mapping stage mainly maps the node information to a virtual circle, where the founded node is obtained from the void edge node. Eventually it is converted into the structure without the routing void network edge. Define a circle with center point O and radius R as the virtual mapping circle of the void. The process of virtual coordinate mapping is implemented after the virtual mapping circle is determined.

Once the virtual coordinate mapping is completed, the discovered node initializes the virtual location distribution package. Also it distributes the virtual location coordinates of the edge nodes and the void center to the edge of the corresponding node and sends the probe packets along with the path (void edge). After receiving the virtual location of the distribution package, each edge node broadcasts the information to the neighbor nodes. The broadcast message contains a virtual coordinate of edge node itself and that of the void center point.

C. *Void Zone Division Stage:*

In order to perform different routing strategies in different regions, the void zone division stage is responsible for the current void surrounding dividing. According to the location of void and the destination node, the void and the surrounding area are divided into the closer region and the free zone, as shown in Fig. 3.

In Fig. 3, O is mapped as the virtual circle center, d is the destination node, and the dotted line, as shown in the circle, determines the mapping of virtual circle. We draw two tangents from the destination node d to the mapped virtual circle which crosses at the points m and n, respectively. The quadrilateral region surrounded by O, m, d, and n is the detachment area of the mapped virtual circle, which is the area B shown in Fig. 3. The rest of the region within the two tangent lines and mapped virtual circle with the removal of detachment area is called the closer region of the mapped virtual circle, that is, the area A shown in Fig. 3.The lateral region from the tangent of the mapped virtual circle is known as the free zone of the mapped virtual circle, which is the area C shown in Fig. 3.The three areas are divided according to the current route void based on the different destination node correspondingly.

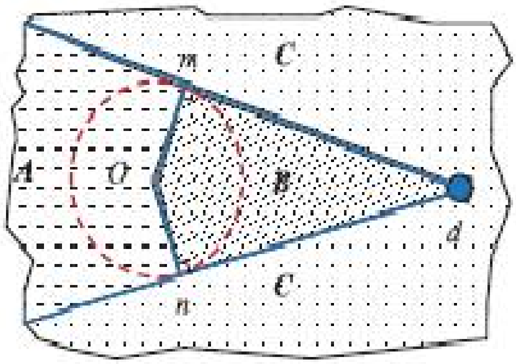

Fig.3. Void Region Dividing

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D. *Virtual Coordinate Based Routing Design:*

After performing above three phases, the edge node of the void contains the location information of the actual coordinates and virtual coordinates. According to the destination node, the peripheral void is divided into three different regions. The founded nodes use the virtual coordinate to initiate a routing event and send the cached packets in the first phase to the related nodes. In route search, the nodes distributed in three different regions select the relay nodes in different ways. But they adopt the conventional greedy algorithm. The main steps of EBVR-VCM are as follows.

Step 1: A node receives a data packet.

Step 2: The node determines whether itself or a neighbor uses the virtual coordinates. If it does, go to Step 3, otherwise to Step 4.

Step 3: If the node is closer to the area, it uses the virtual coordinates to select a relay node; if the node is out of the area, it uses the actual coordinate prior to selecting nonedge node as the relay node; if it is in the free zone, it uses the actual coordinate to select a relay node.

Step 4: Find the optimal position for relay node.

Step 5: Move the relay node to that position

Step 6: The node sends data packets to the selected relay node.

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.

V. Configuring Relay Nodes

This paper use low-cost disposable mobile relays to reduce the total energy consumption of data intensive WSNs. Different from mobile base station, mobile relays do not transport data; instead, they move to different locations and then remain stationary to forward data along the paths from the sources to the base station. Thus, the communication delays can be significantly reduced compared with using mobile sinks or data mules. Moreover, each mobile node performs a single relocation unlike other approaches which require repeated relocations.

A. *Energy Optimization Framework:*

This section formulate the problem of Optimal Mobile Relay Configuration (OMRC) in data-intensive WSNs. Unlike mobile base stations and data mules, our OMRC problem considers the energy consumption of both mobility and transmission. The Optimal Mobile Relay Configuration (OMRC) problem is challenging because of the dependence of the solution on multiple factors such as the routing tree topology and the amount of data transferred through each link. For example, when transferring little data, the optimal configuration is to use only some relay nodes at their original positions.

Assume the network consists of one source si−1, one mobile relay node si and one sink si+1. Let the original position of a node sj be oj = (pj , qj), and let uj = (xj , yj) its final position in configuration U. According to our energy models, the total transmission and movement energy cost incurred by the mobile relay node si is

$$C_i(U) = k\|u_i - o_i\| + am + b\|u_{i+1} - u_i\|^2 m \qquad \text{eq. (4)}$$

Now need to compute a position ui for si that minimizes Ci(U) assuming that ui−1 = oi−1 and ui+1 = oi+1; that is, node si's neighbors remain at the same positions in the final configuration U. Calculate position ui = (xi, yi) for node si by finding the values for xi and yi where the partial derivatives of the cost function Ci(U) with respect to xi and yi become zero. Position ui will be toward the midpoint of positions ui−1 and ui+1.

B. *Static Tree Construction*

Construct the tree for our starting configuration using a shortest path strategy. First define a weight function w specific to our communication energy model. For each pair of nodes si and sj in the network, define the weight of edge sisj as:

$$w\left(s_i, s_j\right) = a + b\left\|o_i - o_j\right\|^2 \qquad \text{eq. (5)}$$

where oi and oj are the original positions of nodes si and sj and a and b are the energy parameters. Observe that using this weight function, the optimal tree in a static environment coincides with the shortest path tree rooted at the sink. So apply Dijkstra's shortest path algorithm starting at the sink to all the source nodes to obtain our initial topology.

Improve the routing tree by greedily adding nodes to the routing tree exploiting the mobility of the inserted nodes. For each node sout that is not in the tree and each tree edge sisj, compute the reduction in the total cost along with the optimal position of sout if sout joins the tree such that data is routed from si to sout to sj instead of directly from si to sj. Repeatedly insert the outside node with the highest reduction value modifying the topology to include the selected node

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at its optimal position, though the node will not actually move until the completion of the tree optimization phase. Compute the reduction in total cost and optimal position for each remaining outside node for the two newly added edges (and remove this information for the edge that no longer exists in the tree) after each node insertion occurs. At the end of this step, the topology of the routing tree is fixed and its mobile nodes can start the tree optimization phase to relocate to their optimal positions.

C. *Tree Optimization Algorithm*

This section consider the subproblem of finding the optimal positions of relay nodes for a routing tree given that the topology is fixed. Assume the topology is a directed tree in which the leaves are sources and the root is the sink. Also assume that separate messages cannot be compressed or merged; that is, if two distinct messages of lengths m1 and m2 use the same link (si, sj) on the path from a source to a sink, the total number of bits that must traverse link (si, sj) is m1 + m2. Let the network consists of multiple sources, one relay node and one sink such that data is transmitted from each source to the relay node and then to the sink. Modify our solution as follows. Let si be the mobile relay node, S(si) the set of source nodes transmitting to si and d(si) the sink collecting nodes from si. The cost incurred by si in this configuration U is:

$$C_i(U) = k\|u_i - o_i\| + am_i + bm_i\|u_{i+1} - u_i\|^2 \qquad \text{eq. (6)}$$

The optimal position is the valid value yielding the minimum cost.

VI. SIMULATION RESULTS

Simulations are performed in NS2 to demonstrate and evaluate the performance of EBVR-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, 60 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 in the network. In the third scenario, nodes are deployed randomly in a square region, one destination node and four source nodes are randomly selected in the network as well. BVR-VCM, AODV [12], GPSR and Greedy-Vip(n) (n = 1, 2) are implemented and compared in terms of delivery ratio, end-to-end delay, average number of hops and control overheads.

Fig. 4 shows the delivery ratio at different routing void sizes. As a whole, delivery ratios in Greedy-ViP(n), AODV, BVR-VCM and GPSR decrease as routing void size increases, but ratio in EBVR-VCM keeps around 95%. Because it has high probability to establish a path between source and destination. Therefore delivery ratio in EBVR-VCM is rarely affected by void size. And ratios in Greedy-ViP(n) decrease quickly, that means greedy algorithm fails frequently as void size increases.

Fig. 5 shows that delivery ratio in Greedy-ViP(n), GPSR, AODV and BVR-VCM are smaller compared to EBVR-VCM. However, establishing of routing path is optimized in EBVR-VCM, so the congestion is dispersed and alleviated around the routing void. Fig. 6 shows that the average transmission delay in AODV is sensitive to packet size. While in other protocols such as EBVR-VCM, BVR-VCM, Greedy-ViP(n) and GPSR, the affection on average delay suffering from packet size is smaller.

Fig. 7 shows the impact of multiple routing voids on the average number of hops. Average hops in AODV are bigger than other protocols but more stable as the number of routing voids increases. Because there is no optimal strategy in GPSR, longer paths might be established especially when multiple routing voids are deployed in the network. In BVR-VCM and Greedy-ViP(n) , the average hops have slower rate of descent. As a whole, EBVR-VCM outperforms other protocols in average hops, because the paths have been optimized.

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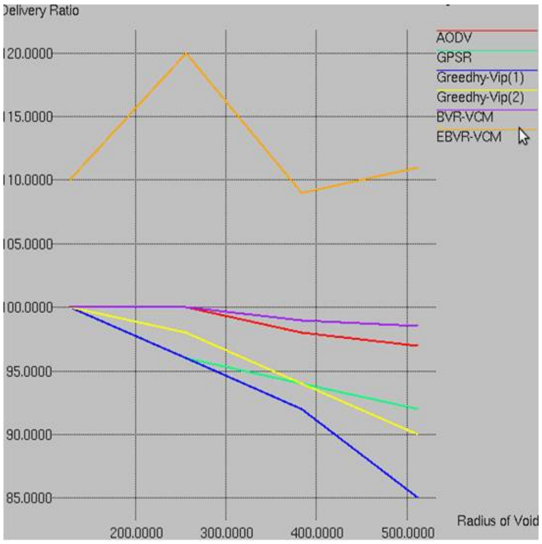

Fig.4. Void Size vs Delivery Ratio

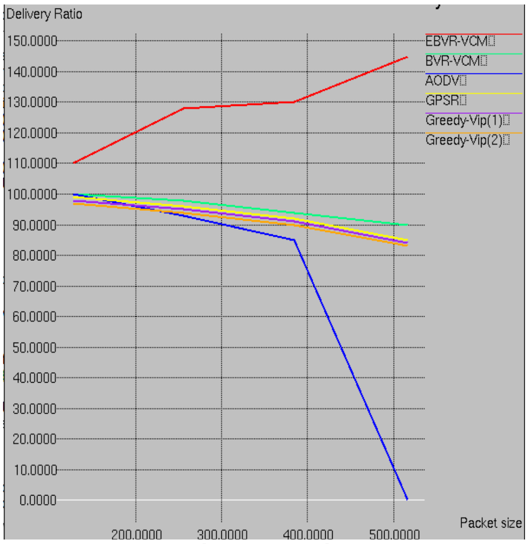

Fig.5. Packet Size vs Delivery Ratio

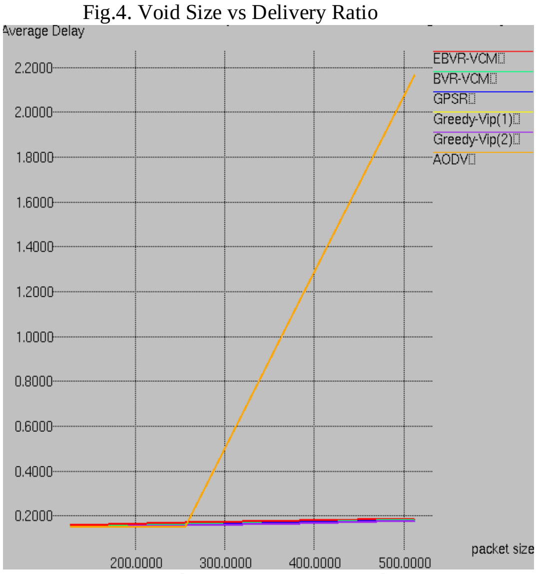

Fig.6. Packet Size vs Average Delay

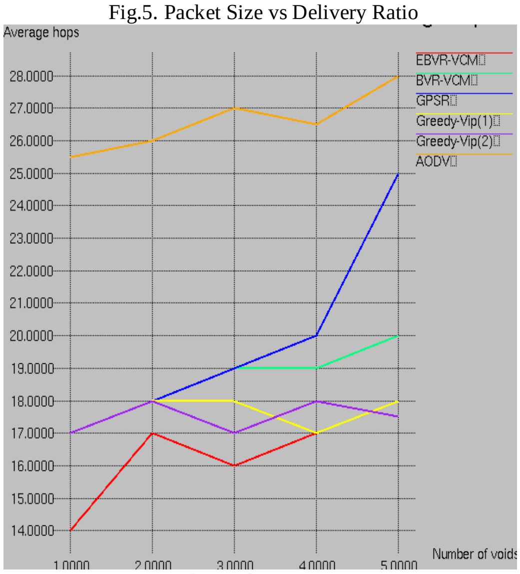

Fig.7. Multi-void vs Average Hops

VII. CONCLUSION

This paper develop two algorithms that iteratively refine the configuration of mobile relays. The first improves the tree topology by adding new nodes. It is not guaranteed to find the optimal topology. The second improves the routing tree by relocating nodes without changing the tree topology. It converges to the optimal node positions for the given topology. Thus it can greatly reduce the complexity of routing protocols. Simulation results show that the proposed EBVR-VCM routing protocol has a better performance of average delivery ratio and average hops. The control packet overhead and the communication delay is less, and the proposed EBVR-VCM is conducive to save network energy.

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BIOGRAPHY

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