Tendency-based Geographic Routing for Sensor Networks

Jiaxi You, Dominik Lieckfeldt, and Dirk Timmermann
University of Rostock, Germany
{jiaxi.you, dominik.lieckfeldt, dirk.timmermann}@uni-rostock.de

***Abstract*— As sensor networks are deployed over various terrains, the complexity of their topology continues to grow. Holes in networks often cause existing geographic routing algorithms to fail. In this paper, we propose a novel geographic routing algorithm called Greedy Forwarding with VIrtual Position (GF-ViP). We introduce virtual position as the middle position of all neighbors of a node. Instead of comparing nodes' geographic position, GF-ViP employs virtual position for selecting the next hop. Such virtual position reflects the neighborhood of a sensor node, as well as the tendency of further forwarding. For network with routing holes, GF-ViP significantly increases success rate of packet routing, while the overhead is kept low.**

Furthermore, multiple levels of virtual position can be obtained with localized iteration. We propose the Greedy Forwarding with Multi-level Virtual Position (GF-MVP) algorithm. According to various context information of a sensor network, different levels of virtual position can be used alternatively to increase success rate of packet routing in sensor networks.

***Key words*— geographic routing, greedy forwarding, routing hole, wireless sensor networks.**

I. Introduction

Among various routing algorithms, geographic routing (georouting) with greedy forwarding is attractive for Wireless Sensor Networks (WSNs) [1]. In a basic geographic routing algorithm, a node communicates only with its direct neighbors [2]. The neighboring node that further minimizes the remaining distance of a packet to its destination will be selected as the next hop. Such localized approach is effective and can be dynamically adapted to changes, which only require position information of sensor nodes [1].

As modern WSNs are becoming popular in various applications, their topology is becoming complicated. Due to limited precision of deployment, voids can cause routing holes in the network, which often cause failures in traditional geographic routing algorithms [3]. The reason is the local minimum phenomenon illustrated in Fig. 1. With greedy forwarding, forwarding packets towards the sink can fail at node A, since there is no neighbor closer to the destination than node A itself. Furthermore, uneven power consumption on sensor nodes can also lead to new routing holes in the later lifetime of WSN.

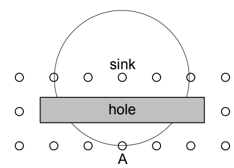

Fig. 1. An example of local minimum.

In this work, we present two novel geographic routing algorithms "Greedy Forwarding with Virtual Position (GF-ViP)" and "Greedy Forwarding with Multi-level Virtual Position (GF-MVP)". The objective of our approach is to improve the success rate of geographic routing for sparsely-deployed WSNs and WSNs with small routing holes. The main advantage of our idea is that it simply employs greedy forwarding throughout the routing process. Furthermore, the amount of control messages of the proposed algorithm is strictly limited and only 1-hop transmissions are necessary.

II. Algorithm Design

Various geographic routing algorithms [3] have been proposed recently to address the routing hole problem of WSNs. Most of the algorithms (e.g. GPSR [4], FACE-1 and FACE-2 [5]) start with greedy forwarding and recover from local minimum with different strategies. Such approaches have high success rate, but high control overhead due to the maintenance of the planar graph [4] information on sensor nodes or the switching between greedy forwarding mode and sophisticated hole-bypassing mode.

We introduce the *virtual position* of a node as the middle position of all its neighbors. The information of *virtual position* is stored on nodes and their geographical direct neighbors. The set of neighbors of a node is defined by the geographical position of nodes. E.g. a node $A(x_1,y_1)$ has node $B(x_2,y_2)$, node $C(x_3,y_3)$, and node $D(x_4,y_4)$ as its neighbors, the *virtual position* of node A is:

$$(x_1', y_1') = ((x_2 + x_3 + x_4)/3, (y_2 + y_3 + y_4)/3) \quad (1)$$

The *2nd-level virtual position* is calculated in the same way using *virtual position* of the neighbors:

$$(x_1'', y_1'') = ((x_2' + x_3' + x_4')/3, (y_2' + y_3' + y_4')/3) \quad (2)$$

This information gives the neighborhood of sensor nodes,

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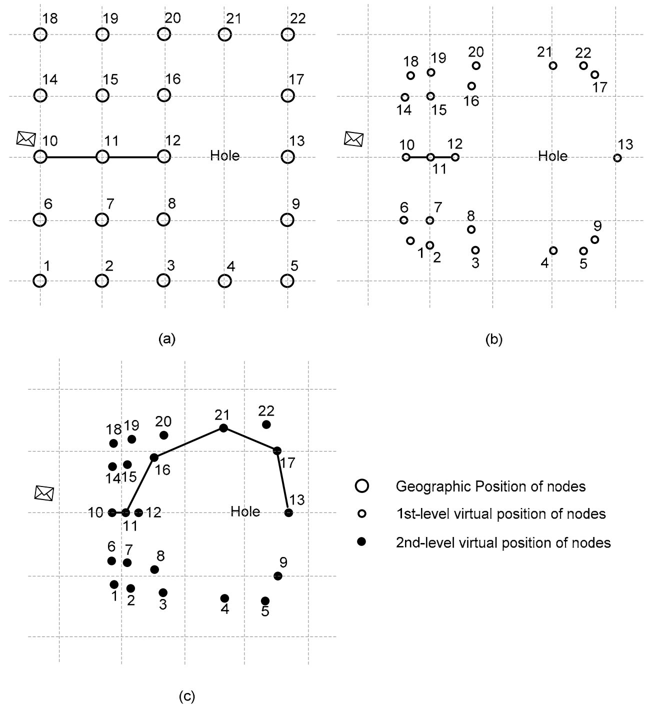

Fig. 2. Example of using virtual position with greedy forwarding. The packet is routed from node 10 to node 13. When using the geographic position of nodes, node 12 becomes a local minimum for that packet. Using virtual position (algorithm GF-ViP) cannot detour the packet around the hole. A detour path (10-11-12-16-21-17-13) is found by using 2nd-level virtual position (algorithm GF-MVP).

as well as the tendency of forwarding during geographic routing. The calculation of *Nth-level virtual position* can be done with N iterations of local broadcast between nodes and their direct neighbors. Fig. 2(a) shows the geographic position of nodes, where each node has the knowledge of the geographic position of itself, and the geographic position of its direct neighbors. Fig. 2(b) shows the calculated *virtual position* of each node. Here each node also has the knowledge of its own *virtual position*, and the *virtual position* of its direct neighbors, in addition. Fig. 2(c) shows the *2nd-level virtual position* of each node, where each node additionally knows its own *2nd-level virtual position*, and the *2nd-level virtual position* of its direct neighbors.

When a packet with the destination address (x_d,y_d) arrives, node $A(x_A,y_A)$ using the GF-ViP algorithm compares its own *virtual position* (x_A',y_A') and the *virtual position* of all its direct neighbors. The neighbor that has the *virtual position* which will further minimize the distance to the destination is selected as the next hop. The next-hop node $B(x_B,y_B)$ satisfies:

$$\sqrt{(x_B'-x_d)^2+(y_B'-y_d)^2} = \min_{N\in N(A)} (\sqrt{(x_N'-x_d)^2+(y_N'-y_d)^2} \quad (3)$$

and:

$$\sqrt{(x_B'-x_d)^2+(y_B'-y_d)^2} < (\sqrt{(x_A'-x_d)^2+(y_A'-y_d)^2} \quad (4)$$

where N(A) is the set of direct neighbors of node A.

As an extension to GF-ViP, the GF-MVP algorithm employs higher levels of *virtual position*. Fig. 2(c) is an example of GF-MVP using *2nd-level virtual position*, which demonstrates that using *virtual position* of higher level indicates better forwarding tendency in geographic routing, since it takes farther neighbors into consideration.

III. Simulation Results And Future Work

We simulated the proposed algorithms with Matlab. The simulated network was a 1000 m × 1000 m square plane, where 500 sensor nodes were randomly deployed. Packets were generated with random pairs of source-destination addresses. The success rate of greedy forwarding with geographic position and *Nth-level virtual position* is compared. Different communication ranges of sensors are used. For the same deployment density, smaller communication range implies sparser layout of a network and bigger chance to encounter routing holes during packet forwarding. Fig. 3 shows the success rates of packet forwarding from our simulation.

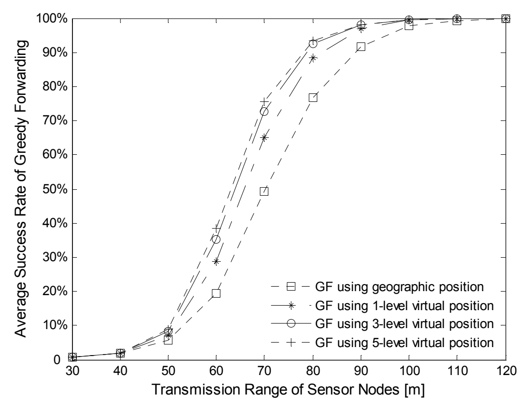

Fig. 3. Success rate. GF-ViP (using 1st-level virtual position) improves the success rate significantly when the network is sparse deployed (comparing to the transmission range). GF-MVP (using 3rd-level and 5th-level virtual position) shows better performance than GF-ViP.

For future work, the trade-off between the overhead caused by using higher level of *virtual position* and the performance will be formalized. Using combinations of different levels of *virtual position* will also be studied.

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