Poster Abstract: Force-based Geometric Routing *

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ABSTRACT

Routing is the foremost issue in mobile ad hoc networks (MANETs) and sensor networks. To guarantee delivery and improve performance, most position-based routing protocols, e.g. *greedy-face-greedy*, forward a message in greedy routing mode until the message is forwarded to a *local minimum* where greedy forwarding is impossible. They then switch to a less efficient mode known as face routing. Face routing requires the underlying network to be a planar graph. Localized planar graph construction requires the radio model to be a *unit disk graph* and it is only applicable to two-dimensional networks. Localized geometric routing protocols applicable to three-dimensional networks include *greedy-random-greedy* and DFS. This paper presents an efficient force-based geometric routing algorithm which is applicable to general network models and has a worst-case bound for arbitrary three-dimensional networks. Simulations are performed in three-dimensional networks to compare our proposed protocols with *greedy-random-greedy* and DFS. Simulation results show that our protocols features interesting performance improvements.

Categories and Subject Descriptors

C.2.2 [**Computer Systems Organization**]: COMPUTER-COMMUNICATION NETWORKS—*Network Protocols*

General Terms

Algorithms, Performance.

Keywords

Geometric routing, simulation, three-dimensional networks.

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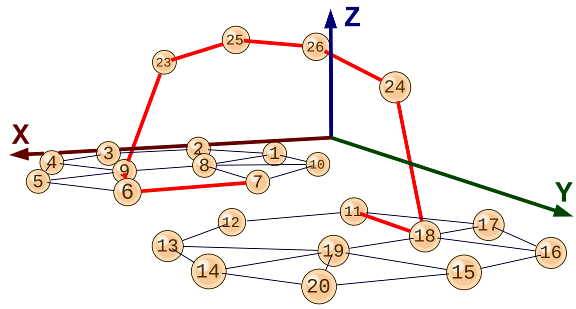


Figure 1: A network in a geometric area consists of two islands and a bridge. In this network, the geometric routing algorithms, which assume that the network is on a plane, will erroneously conclude that a routing failure has occured. The thick lines represent a path from nodes 9 to 11 found by the force-based routing protocol.

1. INTRODUCTION

Geometric routing (also called *position-based routing or geographic routing*) is attractive as a routing protocol in quasi-static MANETs because it features lower route discovery overhead than the proactive/reactive topology-based routing protocols. In geometric routing, it is assumed that each node is aware of its position and the positions of its neighbors, and that the source is aware of the destination's position. All efficient geometric routing protocols use greedy forwarding as their basic operation. In greedy forwarding, if a node knows its neighbors' positions, the locally-optimal choice for next hop is the neighbor geographically closest to the destination of the message. Greedy forwarding, however, fails in a local minimum where the only route to the destination requires a packet to move temporarily farther in geometric distance from the destination.

In order to recover from a local minimum, most existing geometric routing protocols switch to a less efficient mode known as face routing [1]. Face routing runs on a planar graph (a graph without crossing edges). Efficient geometric routing protocols switch from greedy routing to face routing when they encounter local minima, including *greedy-face-greedy* (GFG) [2], and its variant *greedy perimeter stateless routing* (GPSR) [3], *greedy other adaptive face routing* (GOAFR) [4], and GOAFR+ [5]. Although these algorithms guarantee delivery, they rely on planar graphs which can only be constructed locally in a unit disk graph (UDG). Therefore, they are not directly applicable to three-dimensional networks such as the one featured in Figure 1.

To the best of our knowledge, the only localized geometric routing protocols that do not rely on any virtual infrastructure and guarantee eventual delivery are *greedy-random-greedy* [6] and DFS [7]. However, *greedy-random-greedy* does not have a worst case bound in arbitrary networks. Though DFS has the optimal worst-case bound $O(N)$, it is too conservative to have an average efficient performance. In this paper, we use a new localized, force-based method to recover from local minima. Our protocols are simple to implement and have a worst-case bound. Simulation results in random networks show that our proposed protocols are more efficient than *greedy-random-greedy* and DFS.

2. FORCE-BASED GEOMETRIC ROUTING

Our force-based geometric routing protocol is a greedy protocol. Unlike the distance-based greedy protocol, the goal of our greedy algorithm is greater force instead of smaller distance. A message travels in the network driven by the composition of one or more forces. These forces do not have direction, and their composition is simply their summation. Initially, the message is only driven by a positive force $F_t(i)$ from the destination t, which is defined as follows:

$$F_t(i) = M - d(i,t) \qquad (1)$$

In Equation 1, M is a constant and $d(i,t)$ is the distance between the current node i and the destination t. A message has an increasing $F_t(i)$ as it gets closer to the t.

Whenever the message gets to a local minimum m, where no neighbor node has a greater force, a negative force F_m is added to the message. This new negative force decreases the total force the message gets in m more than in any neighbor of m, which recovers the message from m. The absolute value of F_m decreases as the message moves away from m. F_m is defined in Equation 2, where K_m is the number of times m has been a local minimum of the message, and K is the total number of local minima that the message encounters ($K = \sum_{i \in N} K_i$, where N is the set of nodes.).

$$F_m(i) = \begin{cases} -\frac{2K_m}{1+d(i,m)} & \text{if } i \neq m \\ -2K_m K & \text{if } i = m \end{cases} \qquad (2)$$

Equation 2 shows that, as K increases, a message will have a much greater force when it is in a local minimum ($i = m$). The summation of the force $F(u)$ of a message in a node u in shown in Equation 3.

$$F(u) = F_t(u) + \sum_i K_i F_i(u) \qquad (3)$$

Our force-based protocol requires the message to piggyback all of the local minima it encounters. This enables the message to recover from the local minima by having a smaller force near them. Simulation results show that in most cases, messages only have a small number of local minima. Therefore, our protocol does not significantly increase the size of the routing messages.

An example of our force-based routing is shown in Figure 1. The message from node 9 first comes to a local minimum (node 7), and it is successfully delivered to node 11 after a negative force is added corresponding to the local minimum.

2.1 Worst-case bound

LEMMA 1. *If u and v are neighbors, $|K_u - K_v| \leq 1$.*

PROOF. The protocol increases K_u whenever u is currently a local minimum. This requires that $F(u) > F(v)$.

$$\begin{aligned} F(u) &= F_t(u) + \sum_i K_i F_i(u) \\ &= F_t(u) - 2K_u K - K_v \frac{2}{1+d} - \sum_{i \neq u,v} \frac{2K_i}{1+d(u,i)} \\ &< F_t(u) - 2K_u K - K_v \frac{2}{1+d} \end{aligned}$$

On the other hand,

$$\begin{aligned} F(v) &= F_t(v) - 2K_v K - K_u \frac{2}{1+d} - \sum_{i \neq u,v} \frac{2K_i}{1+d(v,i)} \\ &> F_t(v) - 2K_v K - K_u \frac{2}{1+d} - 2(K - K_u - K_v) \end{aligned}$$

Also, $|F_t(u) - F_t(v)| = |M - d(u,t) - M + d(v,t)| < d$. Hence,

$$\begin{aligned} & F(u) > F(v) \\ & \Rightarrow (K_u - K_v)(2K - \frac{2}{1+d}) < d + 2(K - K_u - K_v) \\ & \Rightarrow (K_u - K_v)(2K - 1) < 1 + 2(K - K_u - K_v) \\ & \Rightarrow (K_u - K_v)(2K - 1 + 2) < 1 + 2(K - 2K_v) \\ & \Rightarrow (K_u - K_v)(2K + 1) < 1 + 2K \\ & \Rightarrow K_u - K_v < 1 \end{aligned}$$

Since K_u can be increased only when $K_u - K_v < 1$, we have $K_u - K_v \leq 1$. Symmetrically, we have $K_v - K_u \leq 1$. □

THEOREM 1. *The force-based routing protocol is bounded by $O(N^3)$ hops.*

PROOF. In the worst case, for any 2 neighbors u and v, $|K_u - K_v| = 1$ (a linear network structure is required). We have the maximum $K = O(N^2)$. Since each greedy routing is bounded by $O(N)$, the force-based routing protocol is bounded by $O(N^3)$. □

3. EXTENSIONS

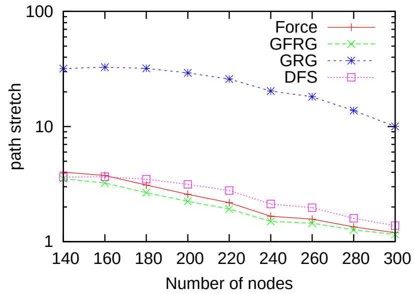
We combine the distance-based greedy protocol with our force-based protocol, greedy-force-greedy (GFRG). The force-based protocol is used only as a recovery scheme in the same way that face routing is used in the greedy-face-greedy protocol.

Localized construction [8] of a connected dominating set (CDS) of the network can reduce the set of nodes visited by our protocol from N to the size of the CDS C, which decreases the worst-case bound to $O(C^3)$. In this preliminary work, we did not implement this extension in our simulation.

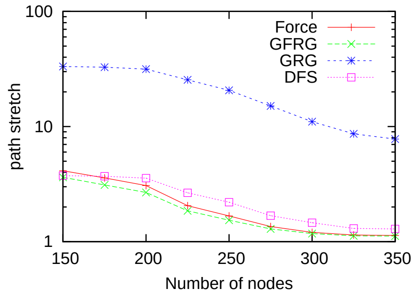
4. SIMULATION

4.1 Simulation settings

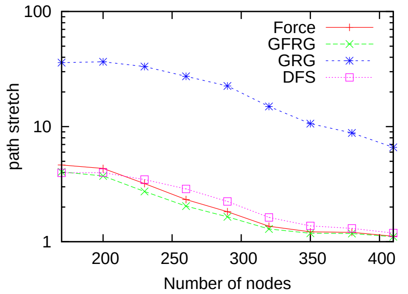
We generate random 3D networks of size $1000 \times 1000 \times Height$, where $Height$ varies among 1, 50, 100, and 200. For each $Height$, networks of different densities are generated. For each $Height$ and each network density, 100 networks



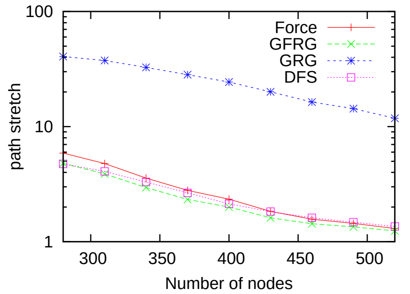
(a) Path stretch (Height=1).



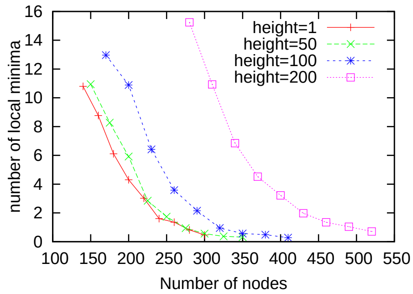
(b) Path stretch (Height=50).



(c) Path stretch (Height=100).



(d) Path stretch (Height=200).



(e) Number of local minima.

Figure 2: Path stretch and number of local minima in 3D networks of different heights.

are generated. These networks are generated by randomly selecting an (x, y, z) coordinate for each node within the specific space, and disconnected networks are discarded.

In each network, we selected each node as a source, and for each node we select 10 other nodes as destinations. The routing performance in terms of hop count in a network with N nodes is the average path length of the $10N$ routing attempts in this network.

The routing protocols implemented and their abbreviations are (1) force-based routing (Force), (2) greedy-force-greedy (GFRG), (3) greedy-random-greedy (GRG), (4) DFS, and (5) Flooding. For simplicity and fairness, we only implement the simplest form of GRG in [7] which does not implement region-limited random walks, RW on the surface, or RW on the sparse sub-graph.

4.2 Simulation results

Figures 2(a), 2(b), 2(c), and 2(d) show that GFRG has a much better path stretch (the hop-count ratio to that of Flooding) than GRG, and it also has a significant improvement over DFS.

Figure 2(e) shows that our algorithm has a small average overhead since the volume of the local minima information piggybacked in the routing message is small (the number of average local minima is small even when the network is very sparse).

5. CONCLUSION

This paper presents an efficient force-based geometric routing algorithm which is localized and does not rely on face routing. Therefore it is applicable to general network models. We show a worst-case bound of our force-based geometric routing algorithm in arbitrary three-dimensional networks. Simulation results show that our proposed protocols are more efficient than GRG and DFS.

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