

# 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 are based on face routing, which 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. This paper presents an efficient force-based geometric routing algorithm, which is applicable to general networks and has a worst-case bound for arbitrary three-dimensional networks.

## 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.

## 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. All efficient geometric routing protocols use greedy forwarding as the underlying mechanism. However, greedy routing fails in a local minima 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 intersecting edges). Efficient geometric routing protocols switch from greedy routing to face routing when they encounter local minima, which include

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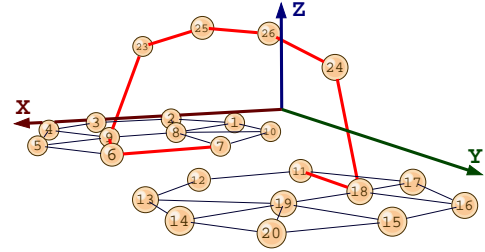


Figure 1: A network in a geometric area consists of two islands and a bridge. In this network, the geometric routing algorithms, which assume that the network is on a plane, will erroneously conclude that a routing failure has occurred. The thick lines represent a path from nodes 9 to 11 found by the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

*greedy-face-greedy* (GFG) [1], and its variants *greedy perimeter stateless routing* (GPSR) [2], *greedy other adaptive face routing* (GOAFR) [3], and GOAFR+ [4]. 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.

Proposed localized geometric routing protocols applicable to three-dimensional networks include *greedy-random-greedy* [5] and DFS [6]. In this paper, we use a new localized, force-based method to recover from local minima. Our protocols are simple 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, a message is always forwarded to another node that has a greater force instead of a 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 an attractive force  $F_t(i)$  from the destination  $t$ :

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

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  $t$ .

Whenever the message gets to a local minimum  $m$ , where no neighbor node has a greater force, a repulsive force  $F_m$  is added to the message. This new repulsive 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).

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

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  $u$  is shown in Equation 3.

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

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.

The worst-case bound of the route length of our force-based routing protocol is given in Theorem 1. The proof of Lemma 1 is omitted due to space limitation.

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

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 route is bounded by  $O(N)$ , the force-based routing protocol is bounded by  $O(N^3)$ .  $\square$

The greedy-force-greedy (GFRG) is the combination of our force-based protocol and the greedy protocol, where the force-based protocol is used as a recovery scheme.

### 3. SIMULATION

We generate random 3D networks of size  $1,000 \times 1,000 \times H$ , where  $H$  is the height of the networks which can take a value of 50, 100, or 200. For each  $H$ , networks of different densities are generated. For each  $H$  and each network density, 100 networks are generated. These networks are generated by randomly selecting an  $(x, y, z)$  coordinate for each node within the specified space, and disconnected networks are discarded.

In each network, we selected each node as a source, and for each node we selected 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.

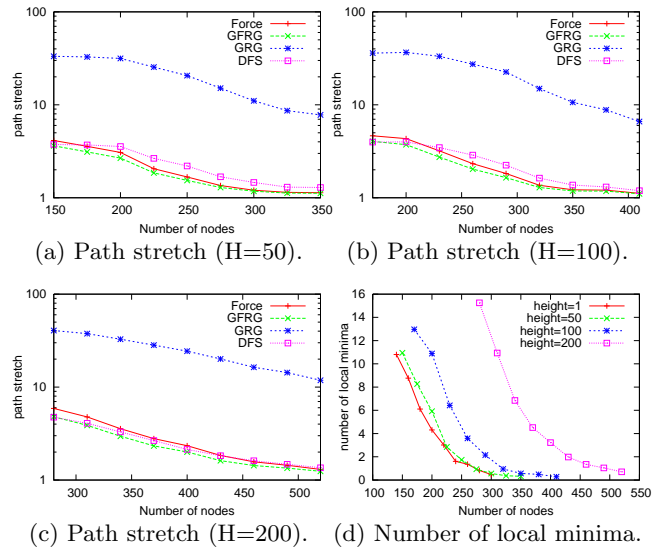


Figure 2: Path stretch and number of local minima in 3D networks of different  $H$ s.

The routing protocols implemented (with 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 [6], which does not implement region-limited random walks (RW), RW on the surface, or RW on the sparse sub-graph.

Figures 2(a), 2(b), and 2(c) 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(d) 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).

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