Geometric Ad-Hoc Routing: Of Theory and Practice

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Greedy Routing

- Each node forwards message to “best” neighbor
Greedy Routing

- Each node forwards message to “best” neighbor

- But greedy routing may fail: message may get stuck in a “dead end”
- Needed: Correct geometric routing algorithm
What is Geometric Routing?

• A.k.a. location-based, position-based, geographic, etc.

• Each node knows its own position and position of neighbors
• Source knows the position of the destination
• **No routing tables stored in nodes!**

• Geometric routing is important:
  – GPS/Galileo, local positioning algorithm,
    overlay P2P network, Geocasting
  – Most importantly: **Learn about general ad-hoc routing**
# Related Work in Geometric Routing

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<th><strong>Geometric Routing</strong> proposed</th>
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<td>Kleinrock et al.</td>
<td>Various 1975ff</td>
<td>MFR et al.</td>
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<td>Kranakis, Singh, Urrutia</td>
<td>CCCG 1999</td>
<td>Face Routing</td>
<td>First <strong>correct</strong> algorithm</td>
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<td>Bose, Morin, Stojmenovic, Urrutia</td>
<td>DialM 1999</td>
<td>GFG</td>
<td>First average-case <strong>efficient</strong> algorithm (simulation but no proof)</td>
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<td>Karp, Kung</td>
<td>MobiCom 2000</td>
<td>GPSR</td>
<td>A <strong>new name</strong> for GFG</td>
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<td>Kuhn, Wattenhofer, Zollinger</td>
<td>DialM 2002</td>
<td>AFR</td>
<td>First <strong>worst-case</strong> analysis. Tight $\Omega(c^2)$ bound.</td>
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<td>Kuhn, Wattenhofer, Zollinger</td>
<td>MobiHoc 2003</td>
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<td>Worst-case optimal <strong>and</strong> average-case efficient, percolation theory</td>
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<tr>
<td>Kuhn, Wattenhofer, Zhang, Zollinger</td>
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<td>GOAFR+</td>
<td><strong>Improved</strong> GOAFR for average case, analysis of <strong>cost metrics</strong></td>
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Overview

• Introduction
  – What is Geometric Routing?
  – Greedy Routing

• Correct Geometric Routing: Face Routing

• Efficient Geometric Routing
  – Worst-Case Optimality: Adaptively Bound Searchable Area
  – Average-Case Efficiency: GOAFR+

• Analysis of Cost Metrics
  – Linearly Bounded vs. Super-Linear Cost Metrics

• Conclusions
Face Routing

- Based on ideas by [Kranakis, Singh, Urrutia CCCG 1999]
- Here simplified (and actually improved)
Face Routing

- Remark: Planar graph can easily (and locally!) be computed with the Gabriel Graph, for example.

Planarity is NOT an assumption
Face Routing
Face Routing
Face Routing

\[ S \rightarrow t \]
Face Routing

Diagram showing a network with nodes labeled as S and t, with a red arrow indicating the path.
Face Routing
Face Routing
Face Routing
Face Routing Properties

• All necessary information is stored in the message
  – Source and destination positions
  – Point of transition to next face

• Completely local:
  – Knowledge about direct neighbors’ positions sufficient
  – Faces are implicit

• Planarity of graph is computed locally (not an assumption)
  – Computation for instance with Gabriel Graph

“Right Hand Rule”
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Face Routing

- Theorem: Face Routing reaches destination in $O(n)$ steps
- But: Can be very bad compared to the optimal route
Bounding Searchable Area

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Adaptively Bound Searchable Area

What is the correct size of the bounding area?
- Start with a small searchable area
- Grow area each time you cannot reach the destination
- In other words, adapt area size whenever it is too small

→ Adaptive Face Routing AFR

Theorem: AFR algorithm finds destination after $O(c^2)$ steps, where $c$ is the cost of an optimal path from source to destination.

Theorem: AFR algorithm is asymptotically worst-case optimal.

[Kuhn, Wattenhofer, Zollinger DIALM 2002]
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GOAFR+ – Greedy Other Adaptive Face Routing

- AFR Algorithm is not very efficient (especially in dense graphs)
- Combine Greedy and (Other Adaptive) Face Routing
  - Route greedily as long as possible
  - Overcome “dead ends” by use of face routing
  - Then route greedily again
- Similar as GFG/GPSR, but adaptive

- Counters p: closer to t than u
- Counters q: farther from t than u
- Fall back to greedy routing if $p > \sigma q$
GOAFR+ Is Worst-Case Optimal

• GOAFR+
  – Early fallback technique with counters
  – Bounding searchable area with circle centered at t

Theorem: GOAFR+ is asymptotically worst-case optimal.

• Remark: GFG/GPSR is not
  – Searchable area not bounded
  – Immediate fallback to greedy routing

• GOAFR+’s average-case efficiency?
Simulation on Randomly Generated Graphs

Network Density [nodes per unit disk]

Performance

better

worse

GFG/GPSR

GOAFR

GOAFR+

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Analysis of Cost Metrics

- Dropping $\Omega(1)$-model / civilized graphs
- Cost metric: nondecreasing function $c : ]0,1] \mapsto \mathbb{R}^+$

### Linearly Bounded Cost Metrics
- Link/hop metric $c(d) \equiv 1$
- Euclidean metric $c(d) = d$

### Super-Linear Cost Metrics
- Energy metric $c(d) = d^2$
Linearity vs. Super-Linearity Cost Metrics

**Linearly bounded cost metrics**
- Backbone graph constructible for general Unit Disk Graphs
- All linearly bounded cost metrics asymptotically equivalent
- Asymptotically optimal geometric routing

**Super-linear cost metrics**
- No geometric routing algorithm can perform competitively
Conclusion

- “Geometric Ad-Hoc Routing: Of Theory and Practice”

Asymptotic worst-case optimality

GOAFR+

Average-case efficiency

Analysis of cost metrics

Ω(1) model

Drop assumption on distance between nodes
Questions?
Comments?
Demo?