Geographic Routing without Planarization

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Greedy Distributed Spanning Tree Routing (GDSTR)

• New geographic routing algorithm
  – **DOES NOT** require planarization
  – uses spanning tree, not planar graph
  – low maintenance cost
  – better routing performance than existing algorithms
Overview

• Background
• Problem
• Approach
• Simulation Results
• Conclusion
Geographic Routing

- Wireless nodes have $x$-$y$ coordinates
  - can use virtual coordinates (Rao et al. 2003)
- Nodes know coordinates of immediate neighbors
- Packet destinations specified with $x$-$y$ coordinates
- In general, forward packets greedily
Geographic Routing
Geographic Routing

Source

Destination
Greedy Forwarding

Source

Destination
Greedy Forwarding
Greedy Forwarding
Geographic Routing: Dealing with Dead Ends

Whoops. Dead end!
Face Routing

Source

Destination
Face Routing

Source

Destination
Back to Greedy Forwarding
Back to Greedy Forwarding
Back to Greedy Forwarding

Source

Destination
Planarization is Costly!

- Planarization is hard for real networks
  - GG and RNG don’t work
- Planarization is complicated & costly!
  - CLDP (Kim et al., 2005)
Greedy Distributed Spanning Tree Routing (GDSTR)

- Route on a spanning tree
- Use convex hulls to “summarize” the area covered by a subtree
  - convex hulls tells us what points are possibly reachable
  - reduces the subtree that must be traversed (smaller search problem)
Hull Tree
Hull Tree
GDSTR Example
GDSTR Example

Source

Destination
GDSTR Example

Source

Destination
GDSTR Example
Revert to Greedy Forwarding

Source

Destination
Revert to Greedy Forwarding
Revert to Greedy Forwarding
Issues

• Choosing forwarding direction
  – multiple hull trees
• Undeliverable packets
  – conflict Hulls
Using Multiple Trees

Source

Destination
Using Multiple Trees

With one tree, may be forced to route in “bad” direction.
Using Multiple Trees

Two extremal-rooted trees are usually sufficient to “approximate” a void.
Using Multiple Trees

Pick tree with root closest to the destination
Summary: Routing

- Try greedy forwarding
- Dead end:
  - choose tree
  - record start node
  - traverse subtree
- If possible, revert to greedy forwarding
- Back to start node: packet undeliverable
Theorem

Given a pair of nodes $s$ and $t$ in connected graph $G$, GDSTR guarantees packet delivery from $s$ to $t$. 
Building Hull Trees

- Convex hull info in *keepalive* messages
- Choose roots:
  - minimal and maximal x-coordinates
- Want compact trees
  - minimal hop count from root
- Aggregate convex hulls from leaves to root
- Conflict hull info percolates from root to leaves
Simulation Results

• Measured 2 routing metrics:
  – Path Stretch
  – Hop Stretch

• Topologies
  – range of network densities (average node degree)
  – larger networks up to 5,000 nodes
    • low/high density
    • low/high obstacle density
Simulation Results

• Compare with
  – GPSR (Karp, 2001),
  – GOAFR+ (Kuhn, 2003) and
  – GPVFR (Leong et al., 2005)
under CLDP planarization (Kim et al., 2005)

• Measured costs and compared with CLDP:
  – storage
  – bandwidth
Hop Stretch

![Graph showing average hop stretch as a function of average node degree for different protocols. The protocols include GPSR/CLDP, GOAFR+/CLDP, GPVFR/CLDP, and GDSTR. The graph demonstrates the variation in hop stretch across different node degrees.]
Hop Stretch

![Graph showing the relationship between the average hop stretch and the average node degree for different tree configurations. The graph includes lines for One Tree, 2 Trees, 3 Trees, and 4 Trees, each with a different color. The x-axis represents the average node degree, ranging from 0 to 16, and the y-axis represents the average hop stretch, ranging from 0.9 to 1.3. The peak of the graph occurs at around an average node degree of 6, with the One Tree configuration showing the highest stretch, followed by 2 Trees, 3 Trees, and 4 Trees.]
Costs

• Computation:
  - convex hull computation: $O(\log n)$ operations [Graham’s scan]

• Storage: < 1 kb

• Bandwidth
Messages for Startup

![Graph showing packets sent per node (logscale) vs. average node degree for CLDP and GDSTR (2 Trees).]
Messages for Stabilization

![Graph showing packets sent per node (log scale) vs. average node degree for CLDP and GDSTR with join and failure scenarios.](Image)
Summary

• Maintenance cost one order of magnitude less than CLDP (face routing)
• Better routing performance (stretch) – up to 20% better
Large Voids

- GPSR/CLDP
- GOAFR+/CLDP
- GPVFR/CLDP
- GDSTR (2 Trees)
Small Voids

![Graph showing Average Hop Stretch vs Network Size for different protocols: GPSR/CLDP, GOAFR+/CLDP, GPVFR/CLDP, and GDSTR (2 Trees).](image)
Explaining Performance
Explaining Performance

Source

Destination
Explaining Performance

Source

Destination
Explaining Performance

Source

Destination
Explaining Performance

Source

Destination
Explaining Performance

Source

Destination
Explaining Performance

- Source
- Destination
- Extra overhead
Summary

- **Sparse networks**
  - GDSTR chooses correct forwarding direction more often than face routing

- **Moderately dense networks**
  - Faces are small, forwarding direction is inconsequential
  - Trees do not “approximate” small voids well

- **Ultra-dense networks**
  - Greedy forwarding works all the time!
Conclusion

- Cheaper to maintain two hull trees than a planar graph
- “Global” information allows GDSTR to choose good forwarding direction more often
- GDSTR achieves improved routing stretch at lower maintenance cost than CLDP
Future Work

• Evaluate GDSTR in a practical and mobile setting
• Geographic routing in higher dimensions
  – convex hulls generalizable to higher dimensions
Geographic Routing without Planarization

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Reducing Convex Hulls
Reducing Convex Hulls
Reducing Convex Hulls
**Conflict Hulls**

- Undeliverable packets will be forwarded to the root.
- *Conflict hulls* allow us to avoid forwarding to the root.
- **Key idea**: parent nodes tell child nodes about other nodes with intersecting hulls.
Example: Conflict Hull
Example: Conflict Hull
Example: Conflict Hull
Example: Conflict Hull
Example: Conflict Hull
Example: Conflict Hull

Forward to parent …
Example: Conflict Hull

Packet undeliverable!
Example GDSTR Hull Trees

Minimal-x Tree  Maximal-x Tree
Comparing Routing Topologies

Planar Graph (CLDP)

Two Trees