Location-based Routing in Ad hoc Networks

3/3/06
Routing protocols in communication networks obtain route information between pairs of nodes wishing to communicate.

- **Proactive protocols**: the protocol maintains routing tables at each node that is updated as changes in the network topology are detected.
- **Reactive protocols**: routes are constructed on demand. No global routing table is maintained.
  - Ad hoc on demand distance vector routing (AODV)
  - Dynamic source routing (DSR)
- However, both depend on flooding for route discovery.
Geographical routing

- Geographical routing uses a node’s location to discover path to that route.
- Assumptions:
  - Nodes know their geographical location
  - Nodes know their 1-hop neighbors
  - Routing destinations are specified geographically (a location, or a geographical region)
  - Each packet can hold a small amount (O(1)) of routing information.
  - The connectivity graph is modeled as a unit disk graph.
Geographical routing

- The information that the source node has
  - The location of the destination node;
  - The location of itself and its 1-hop neighbors.

- **Geographical forwarding**: send the packet to the 1-hop neighbor that makes **most progress** towards the destination.
  - No flooding is involved.

- Many ways to measure “progress”.
  - The one closest to the destination in Euclidean distance.
  - The one with **smallest angle** towards the destination: “compass routing”.
  - Etc.
Greedy progress
Geographical routing may get stuck

- Geographical routing may stuck at a node whose neighbors are all further away from the destination than itself.

Send packets to the neighbor closest to the destination
Compass routing may get in loops

- Compass routing may get in a loop.

Send packets to the neighbor with smallest angle towards the destination.
How to get around local minima?

• Use a planar subgraph: a straight line graph with no crossing edges. It subdivides the plane into connected regions called faces.
Face Routing

- Keep left hand on the wall, walk until hit the straight line connecting source to destination.
- Then switch to the next face.
Face Routing
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Face Routing Properties

• All necessary information is stored in the message
  – Source and destination positions
  – The node when it enters the perimeter mode.
  – The first edge on the current face.

• Completely local:
  – Knowledge about direct neighbors’ positions is sufficient
  – Faces are implicit. Only local neighbor ordering around each node is needed

“Right Hand Rule”
What if the destination is disconnected?

- The perimeter routing will get back to where it enters the perimeter mode.
- Failed – no way to the destination.
- Guaranteed delivery of a message if there is a path.
Planar Graph Subtraction

Compute a planar subgraph of the unit disk graph.

– Preserves connectivity.
– Distributed computation.
A little detour on Delaunay triangulation
Delaunay triangulation

- First proposed by B. Delaunay in 1934.
- Numerous applications since then.
Voronoi diagram

- Partition the plane into cells such that all the points inside a cell have the same closest point.
Delaunay triangulation

• Dual of Voronoi diagram: Connect an edge if their Voronoi cells are adjacent.
• Triangulation of the convex hull.
Delaunay triangulation

- "Empty-circle property": the circumcircle of a Delaunay triangle is empty of other points.
- The converse is also true: if all the triangles in a triangulation are locally Delaunay, then the triangulation is a Delaunay triangulation.
Greedy routing on Delaunay triangulation

• Claim: Greedy routing on DT never gets stuck.
Delaunay triangulation

- For an arbitrary point set, the Delaunay triangulation may contain long edges.
- Centralized construction.
- Next: 2 planar subgraphs that can be constructed in a distributed way: relative neighborhood graph and the Gabriel graph.
Relative Neighborhood Graph and Gabriel Graph

- **Relative Neighborhood Graph (RNG)** contains an edge $uv$ if the lune is empty of other points.
- **Gabriel Graph (GG)** contains an edge $uv$ if the disk with $uv$ as diameter is empty of other points.
- Both can be constructed in a distributed way.
Relative Neighborhood Graph and Gabriel Graph

- Claim: MST $\subseteq$ RNG $\subseteq$ GG $\subseteq$ Delaunay

- Thus, RNG and GG are planar (Delaunay is planar) and keep the connectivity (MST has the same connectivity of UDG).
MST $\subseteq$ RNG $\subseteq$ GG $\subseteq$ Delaunay

1. RNG $\subseteq$ GG: if the lune is empty, then the disk with uv as diameter is also empty.
2. GG $\subseteq$ Delaunay: the disk with uv as diameter is empty, then uv is a Delaunay edge.
MST $\subseteq$ RNG $\subseteq$ GG $\subseteq$ Delaunay

3. MST $\subseteq$ RNG:
   - Assume uv in MST is not in RNG, there is a point w inside the lune. $|uv|>|uw|$, $|uv|>|vw|$.
   - Now we delete uv and partition the MST into two subtrees.
   - Say w is in the same component with u, then we can replace uv by wv and get a lighter tree. $\Rightarrow$ contradiction.

RNG and GG are planar (Delaunay is planar) and keep the connectivity (MST has the same connectivity of UDG).
An example of UDG

200 nodes randomly deployed in a 2000×2000 meters region. Radio range = 250 meters
An example of GG and RNG
Two problems remain

A subgraph $G'$ of $G$ is a $\alpha$-spanner if the shortest path in $G'$ is bounded by a constant $\alpha$ times the shortest path length in $G$.

Both RNG and GG are not spanners $\Rightarrow$ a short path may not exist!

Even if the planar subgraph contains a short path, can greedy routing and face routing find a short one?
Other problems

- **Localization:**
  - Nodes need to know their geographical locations.

- **Location service:**
  - How does a source know the location of destination?
  - What if the nodes move around?

- **Planar graph construction:**
  - Requires a unit disk graph assumption, which is not always the case in practice.
  - What if the nodes are in 3d?
Summary

- Location-based routing
- Greedy forwarding
- Planar graph routing
- How to construct a planar graph?