CS649
Sensor Networks
Lecture 17: Routing

Andreas Terzis
http://hinrg.cs.jhu.edu/wsn06/

Outline

- Tree Routing
- Geography-based routing
  - GPSR

Taming the Underlying Challenges of Reliable Multihop Routing in Sensor Networks

Alec Woo, Terence Tong, David Culler

UC Berkeley

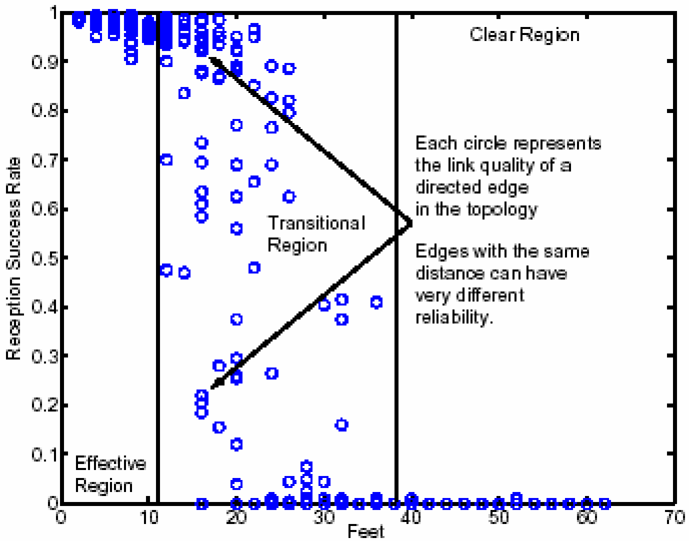
Presented at Sensys 2003

Outline

- Goal: Tree Routing
  - Many-to-one routing from all sensors to sink
- Question: What metric should be used?
  - Hop Count
  - Link Quality
    - How to estimate link quality?
- Metric: Create *high quality* trees
  - Percentage of packets delivered at the sink

Hop Count is a bad metric

- Reception rate deteriorates quickly as transmission range grows
- Hop count tends to pick long links -> lossy links
- Pick instead high quality links
  - How do we estimate link quality?



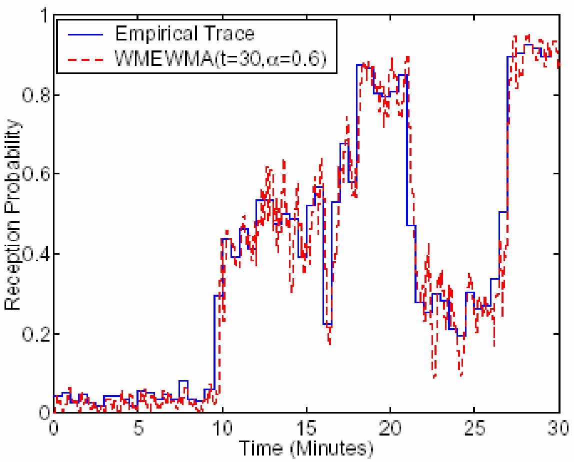
(a) Reception probability of all links in a network with a line topology.

Link Quality Estimation

- Estimate rate of successful reception from neighboring nodes
  - RSSI may not work well
  - Neighbors exchange estimations to derive bi-directional link quality
- 2 Techniques: Passive vs. Active
  - Key decision factor: broadcast medium
    - Passive: snoop on neighbor packets
- Packet sequence number for inferring packet loss
  - Issue: cannot infer loss until hearing the next packet
    - E.g. dead node or mobility
- Can infer losses based on time
  - Assume minimum data rate is known
  - Likely to be true in periodic data collection

WMEWMA Estimator

- Compute an average success rate over time, T, and smoothes with an exponentially weighted moving average (EWMA)
- Average calculation
  - Packet Received over T divided by
  - Max of
    - Number of packets expected over T
    - Number of packets sent over T suggested by sequence number
- Tuning parameters:
  - T and history size of EWMA
- Performance
  - Yields agile and stable estimations
  - Uses constant memory, and is very simple

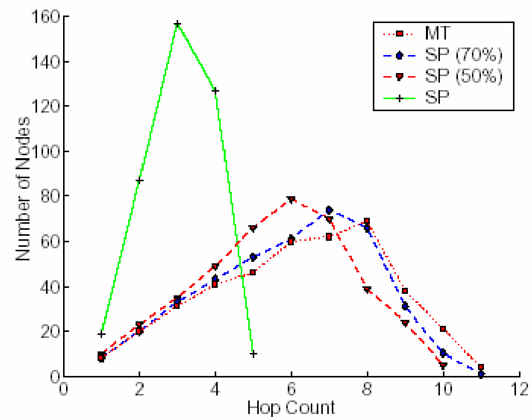


Routing Algorithms

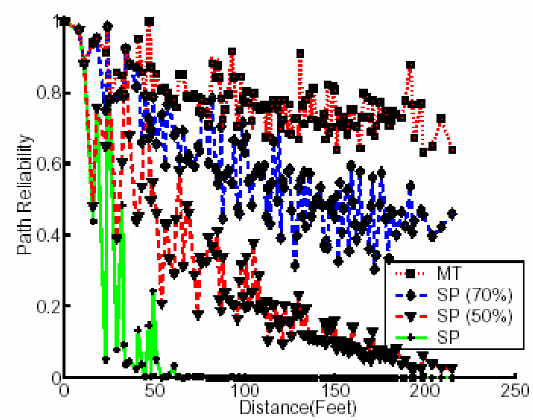
- Shortest Path (SP)
- Shortest Path with threshold (SP(t))
  - Use a link only if link quality estimate > threshold
- Minimum Transmission (MT)
  - Link cost = 1/linkquality_fw * 1/linkquality_bk

Evaluation (I)

- Evaluation Metrics
  - Hop Distribution
  - Path reliability
- Network Graph analysis
  - 400 nodes, 20x20 grid
  - Sink placed at corner
- Results
  - SP produces more shallow trees
    - Most nodes < 3 hops away ->links 40-50 feet
  - Path reliability < 5% after 50 feet
  - SP(50%) performs worse than SP(70%)
  - MT performs comparably without need to set threshold



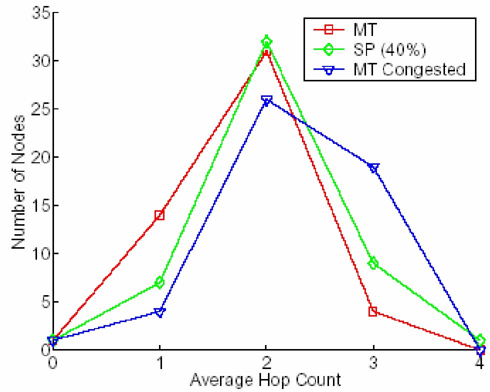
(a) Hop Distribution



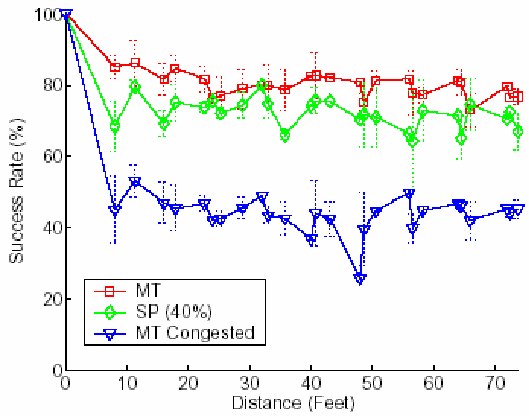
(b) Path Reliability

Evaluation (II)

- Empirical Evaluation
  - 50-node network, 5x10 grid, 8 foot spacing, indoors
- Results
  - SP(70%) failed to create a tree!
  - MT has comparable performance to SP(40%)



(a) Hop Distribution



Geographical Routing

Motivation

- Two dominant factors in the scaling of a routing algorithm are:
  - The rate of change of the topology.
  - The number of routers in the routing domain.
- Both factors affect the message complexity of DV and LS routing algorithms.
- On-demand ad-hoc routing algorithms require state at least proportional to the number of destinations a node forwards packets toward.
- GPSR uses geographical routing to achieve scalability, allowing routers to be nearly stateless.

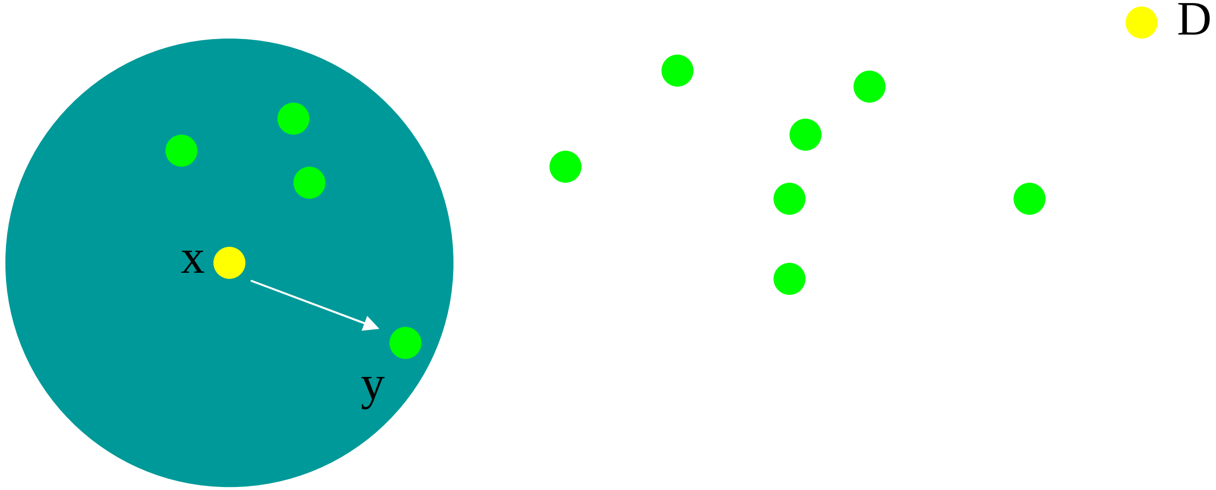
Assumptions

- All wireless routers know their own positions (GPS device).
- Bidirectional radio reachability - a set of nodes with radios, where all radios have identical, circular radio range.
- Topologies where wireless nodes are roughly in a plane.
- Packet sources can determine the locations of packet destinations, to mark packets they originate, with their destination's location.
  - local registration, lookup service

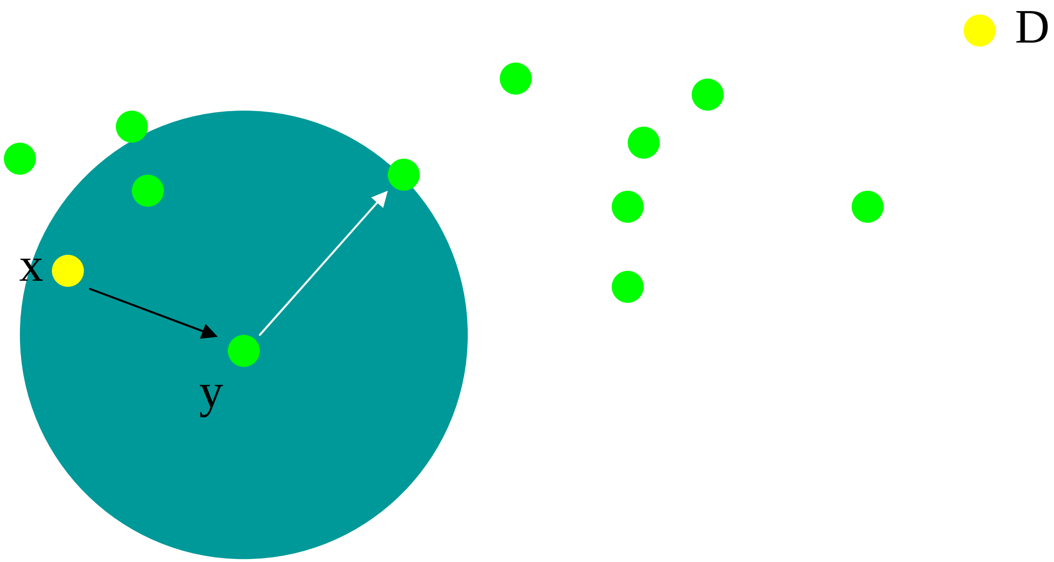
Greedy Forwarding

- Packets are marked by the originator with the destination's location.
- A forwarding node can make a locally optimal, greedy choice in choosing a packet's next hop.
- Specifically, if a node knows its radio neighbor's positions, the locally optimal choice of next hop is the neighbor geographically closest to the packet's destination.
- On a dense network, greedy forwarding approximates to shortest-path routing.

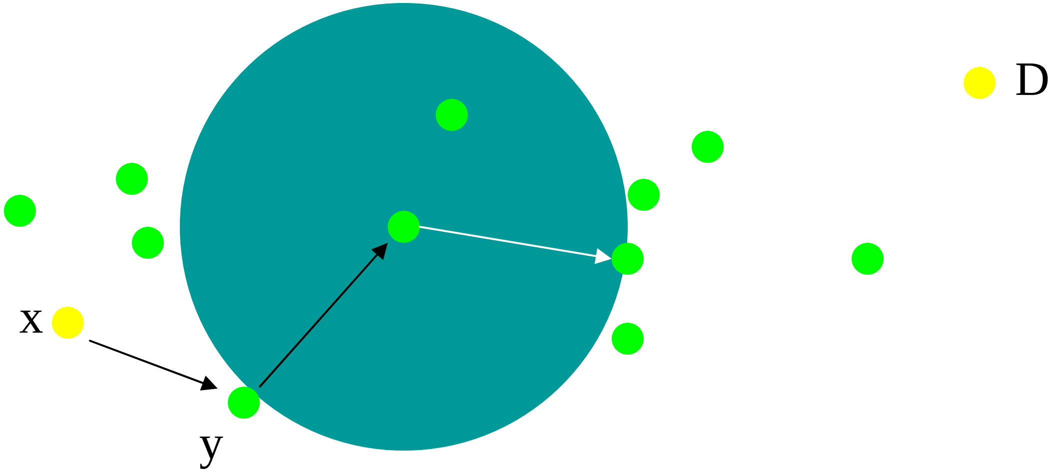
Greedy Forwarding



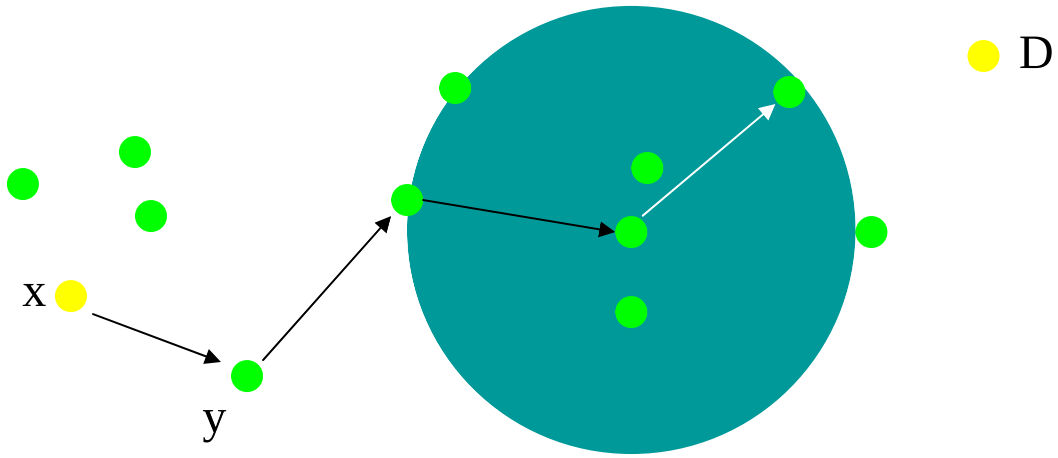
Greedy Forwarding



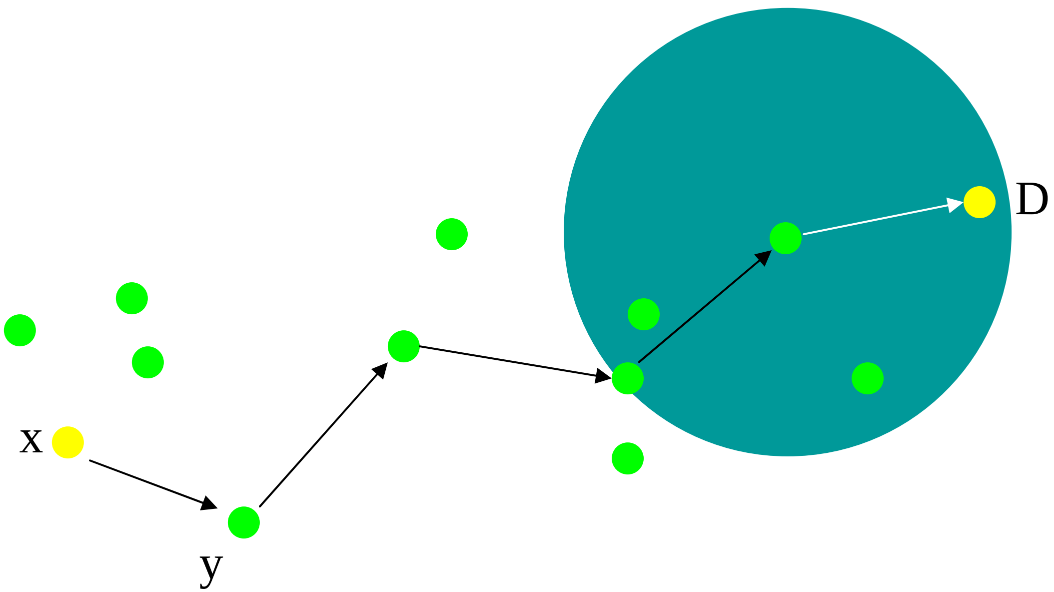
Greedy Forwarding



Greedy Forwarding



Greedy Forwarding

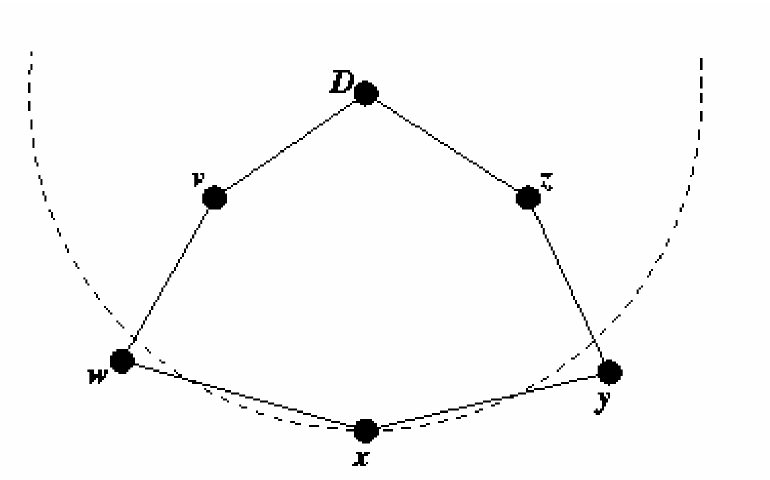


Greedy Forwarding

- Advantages:
  - Reliance on knowledge of the forwarding node's immediate neighbors only.
  - State required is negligible, and dependent on the density of nodes in the wireless network, not the total number of destinations in the network.
  - Consumes considerably less bandwidth than
    - protocols which distribute state globally throughout the routing domain (DV and LS).
    - Protocols which accumulate state along an entire source route (DSR).

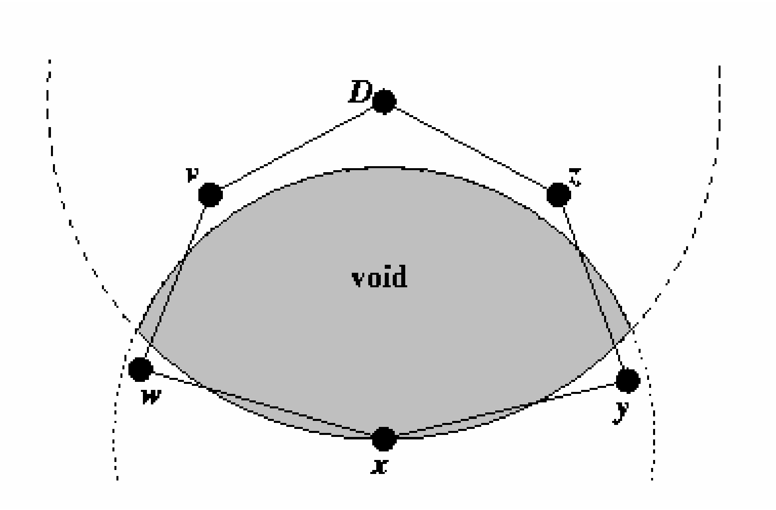
Greedy Forwarding Failure

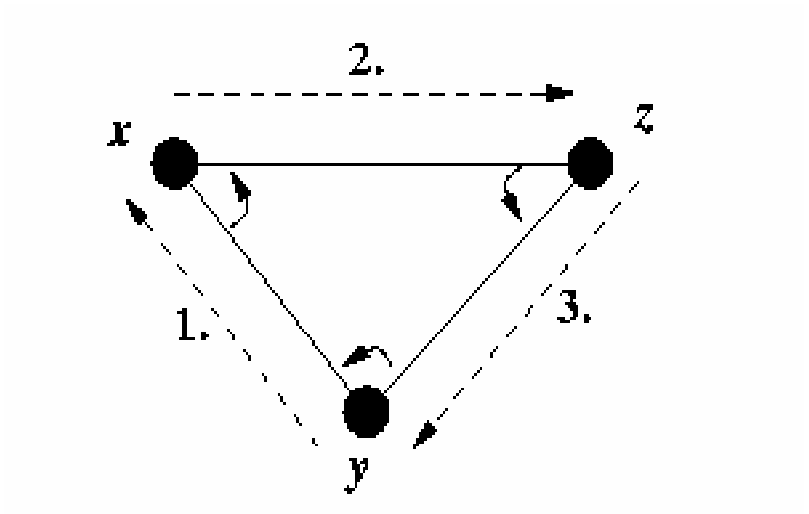
- Drawbacks:



  - There are topologies where the only route to a destination requires a packet move temporarily farther in geometric distance from the destination.

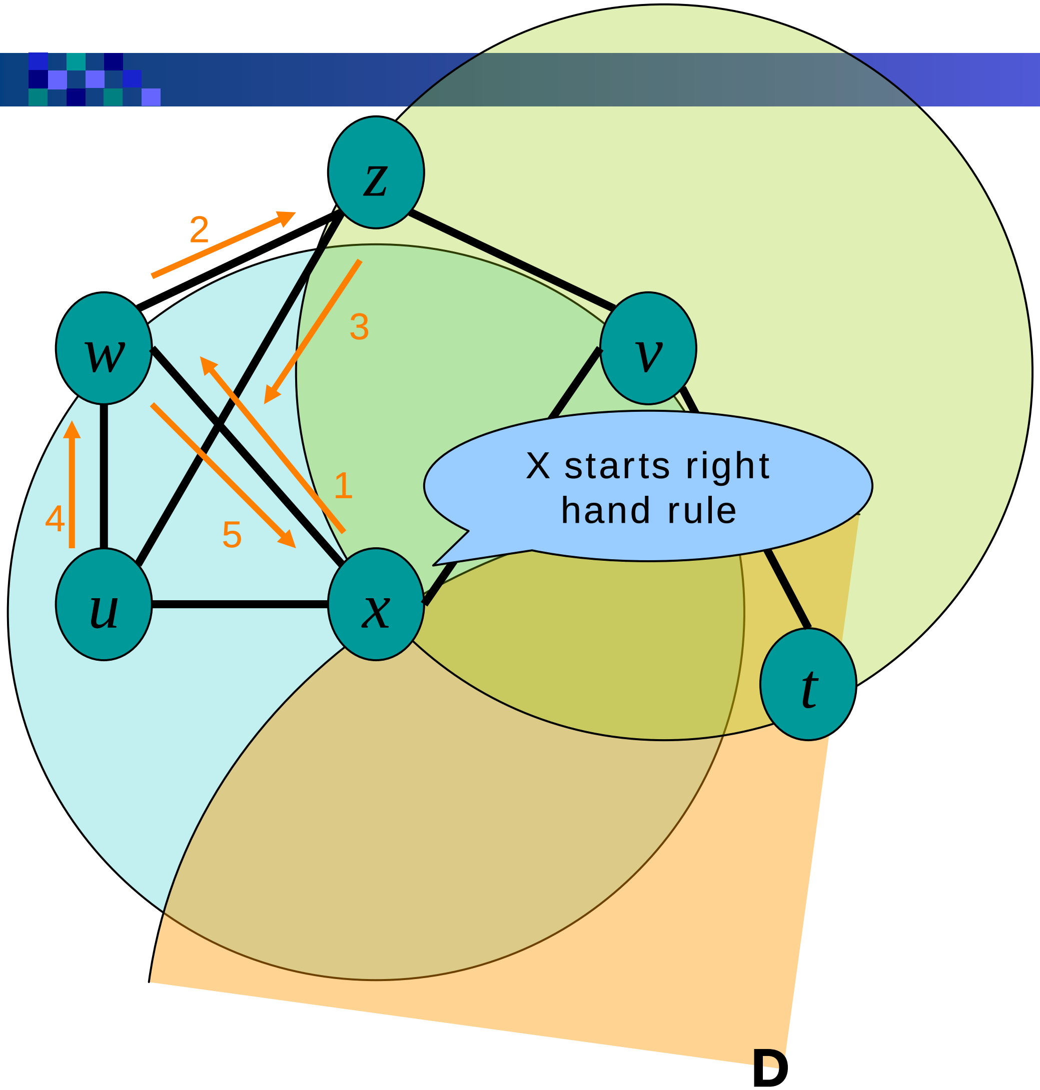
The Right-Hand Rule





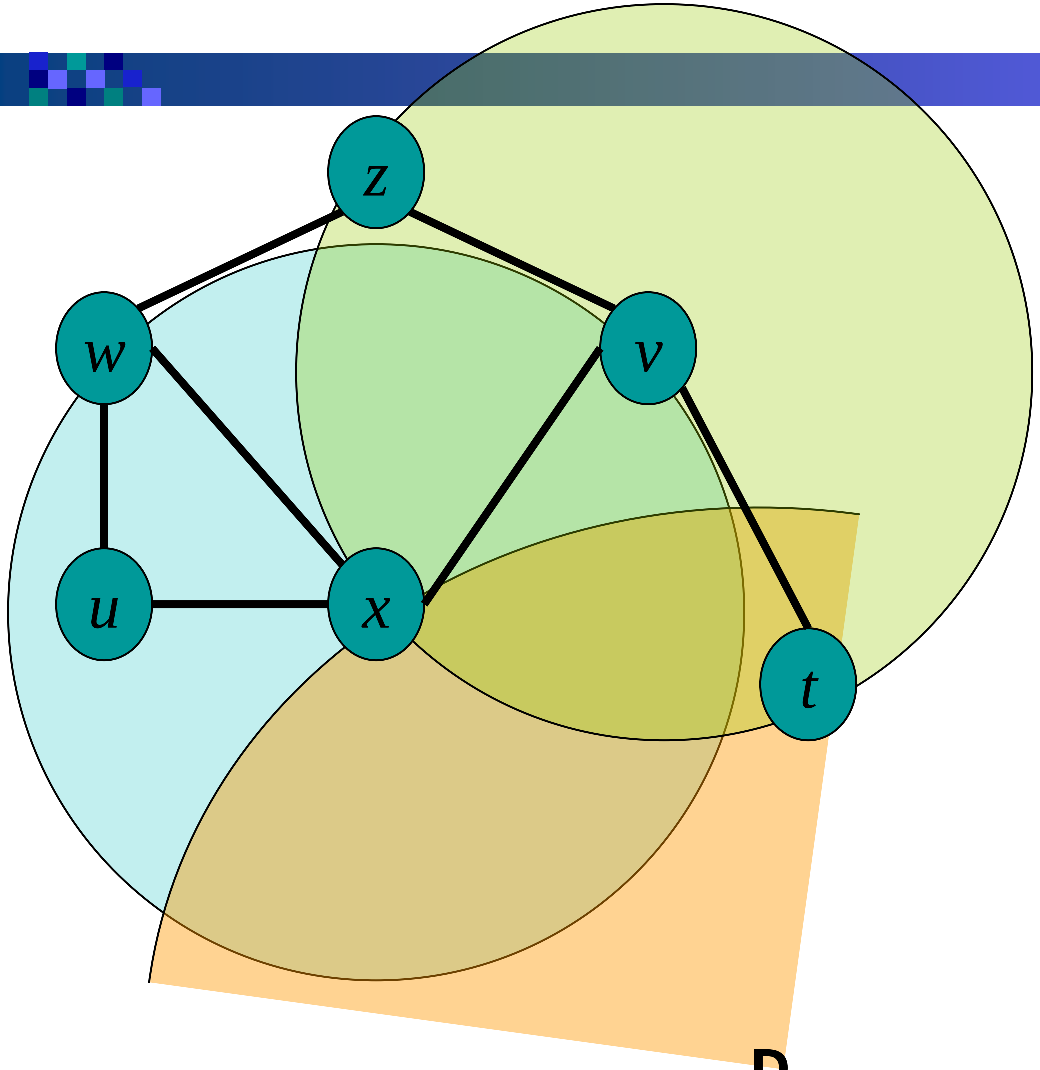
Sequence of edges traversed by the right-hand rule is called a perimeter – hence the name perimeter forwarding

Problems with the Right-Hand Rule



- x originates a packet to D
- Right-hand rule results in the tour x-w-z-u-w-x-u…
- Packet never arrives at v where it can be forwarded to t and finally D

Solution



- Remove (u,z) from the graph
- Right-hand rule results in the tour x-w-z-v-x

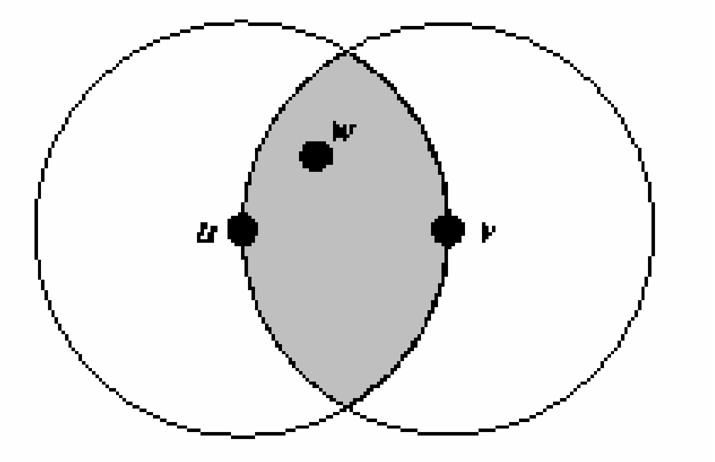
Solutions

- Methods for eliminating crossing links from a network:
  - Relative Neighborhood Graph.
  - Gabriel Graph.
- Remove edges from the graph that are not part of the RNG or GG - yields a network with no crossing links.
- The resulting graph is still connected.

Relative Neighborhood Graph

- An edge (u,v) exists between vertices u and v if the distance between them, d(u,v), is less than or equal to the distance between every other vertex w, and whichever of u and v is farther from w.

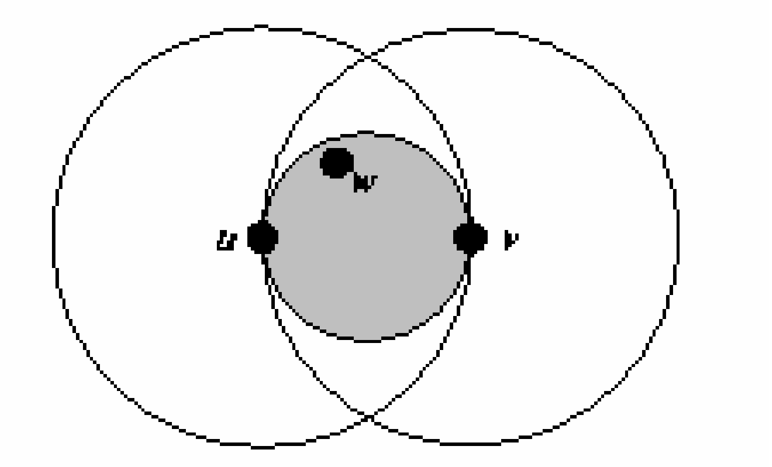
    - $\forall w \neq u, v: d(u,v) \leq \max[d(u,w),d(v,w)]$

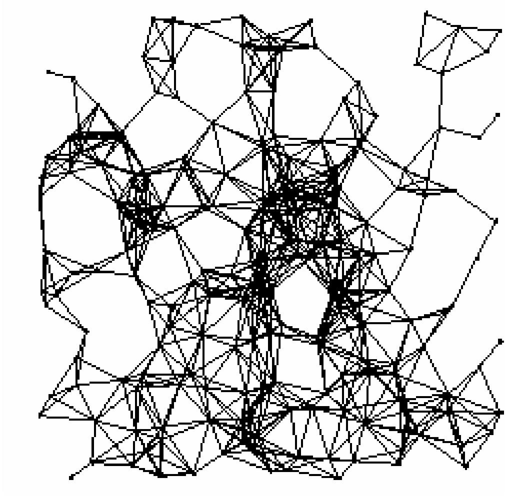


Gabriel Graph

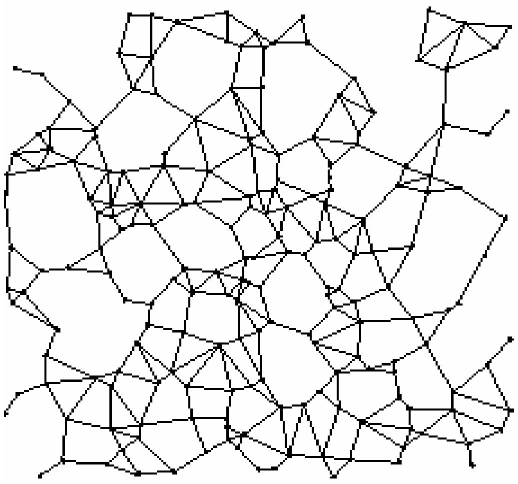
- An edge (u,v) exists between vertices u and v if no other vertex w is present within the circle whose diameter is uv.

    - $\forall w \neq u, v$: d2(u,v) < [d2(u,w) + d2(v,w)]

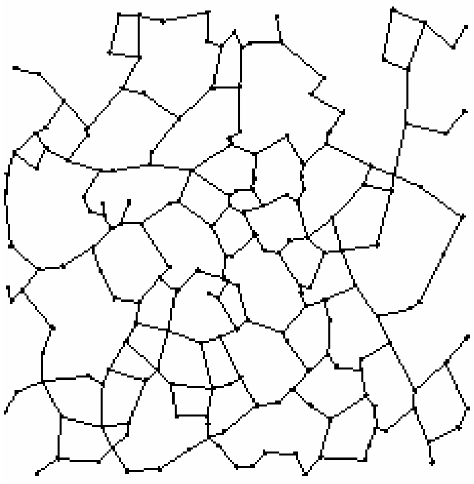




Full graph



GG subset



RNG subset

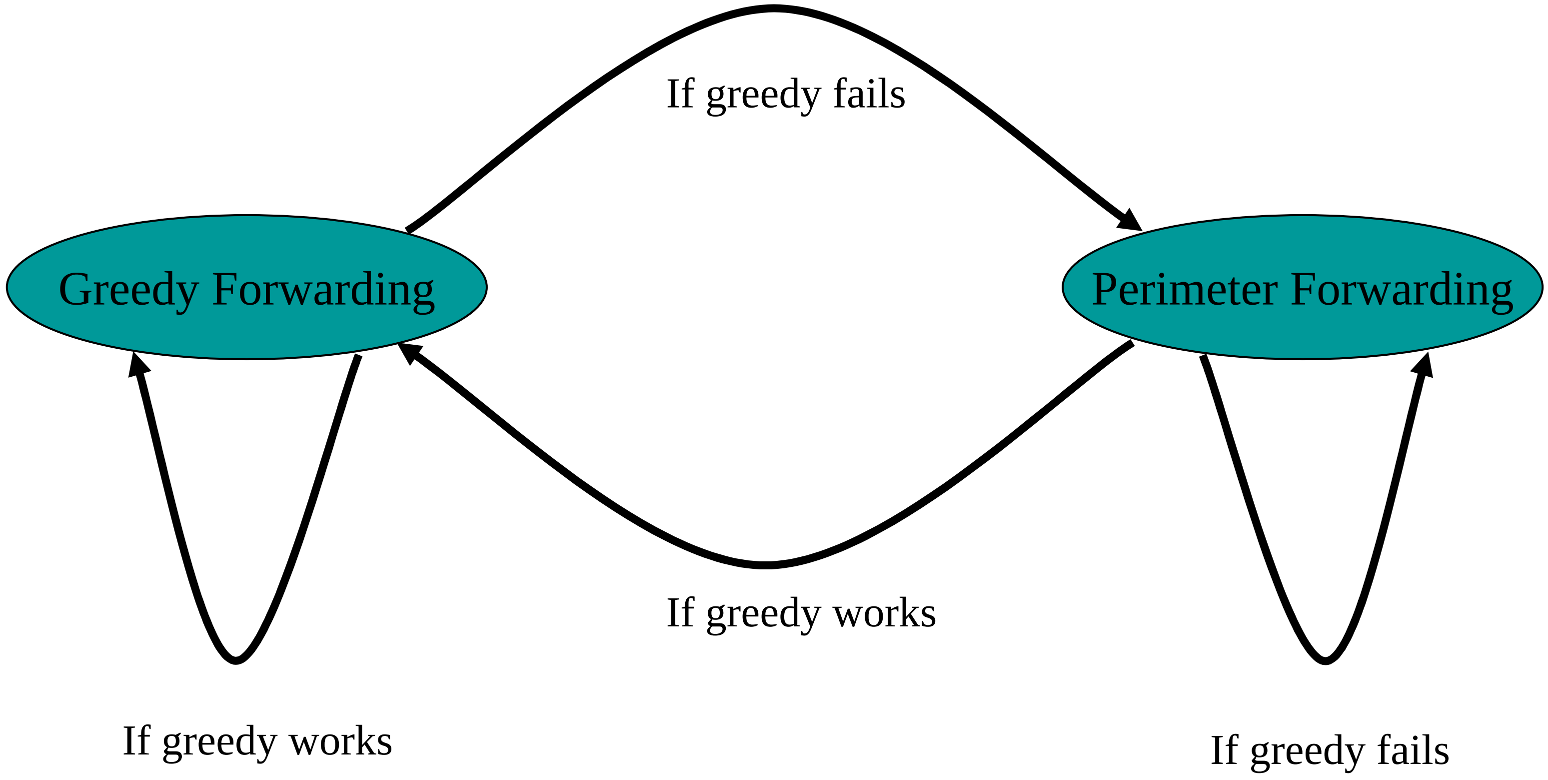
- 200 nodes
- randomly placed on a 2000 x 2000 meter region
- radio range of 250 m

GPSR Algorithm

- All nodes maintain a neighbor table, which stores the address and the locations of their single hop radio neighbors.
- Upon receiving a greedy-mode packet for forwarding, a node searches it's neighbor table for a node geographically closest to the destination.
- If this neighbor is closer to the destination, the node forwards the packet to that neighbor.
- When no neighbor is closer, the node marks the packet into perimeter mode.

GPSR Algorithm

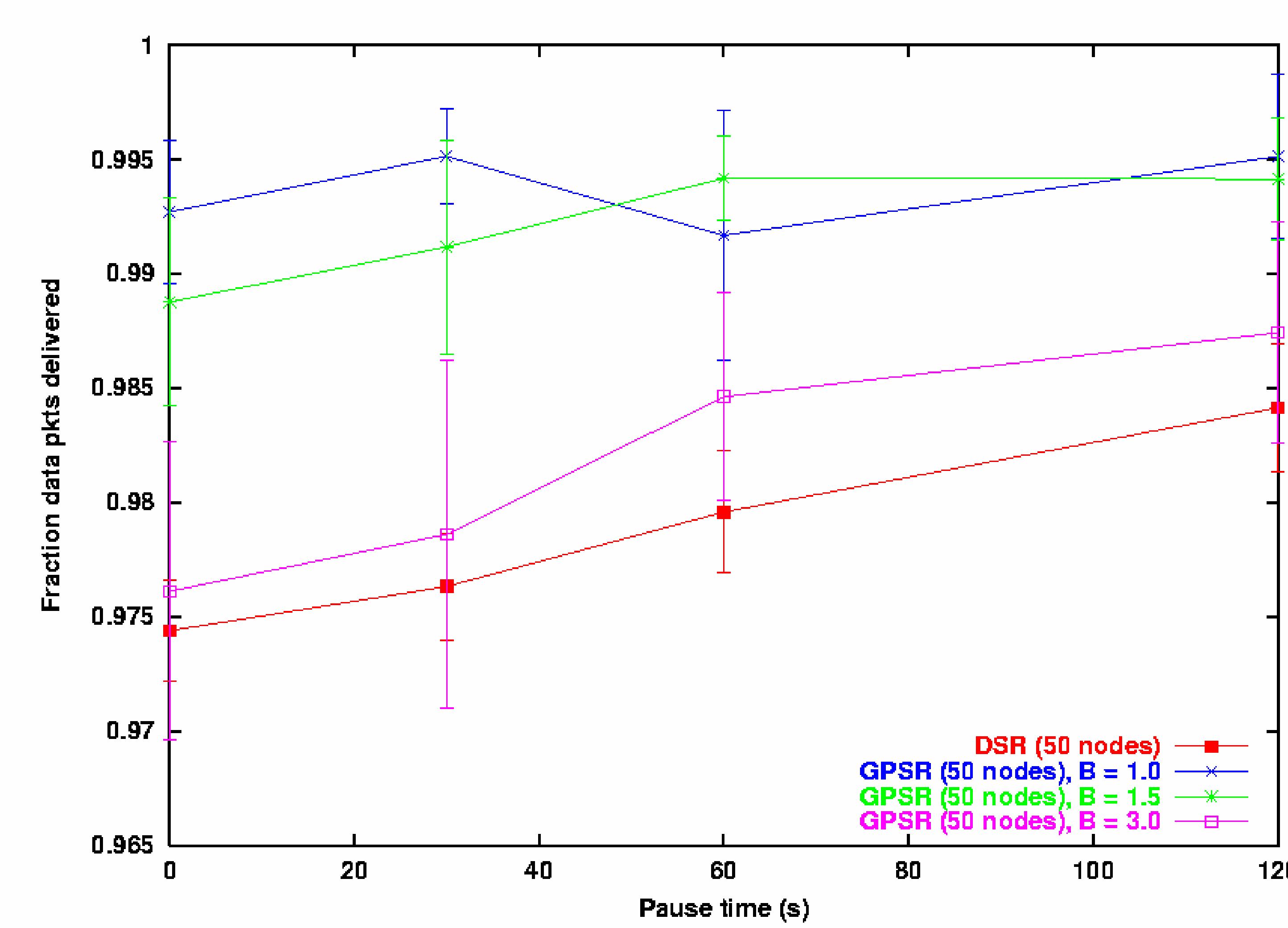
- Perimeter forwarding is only intended to recover from a local maximum.



Simulation Results and Evaluation

- Simulates nodes moving in an unobstructed plane. Motion follows random waypoint model.
- A node
  - chooses a destination at random in the simulated region,
  - chooses a velocity at random from a configurable range,
  - and then moves to that destination at the chosen velocity.
- Upon arriving at the chosen waypoint, the node pauses for a configurable period before repeating the same process.

Packet Delivery Success Rate



Routing Protocol Overhead