Mobile and Sensor Systems

Lecture 5: Sensor Network Routing

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In this lecture

- We will introduce sensor network routing protocols, in particular:
  - Directed diffusion
  - MINT routing
  - GPSR

What's in this Lecture

- We will discuss network layer protocols for sensor networks.
- Also we will illustrate aspects of data gathering and aggregation.

Network Protocols

- Can we apply ad hoc networks protocols?
- Yes protocols like epidemic can be applied but overhead is an issue.
- Aims are usually different: not communication but data reporting to single or multiple source.
- Specific protocols have been devised.
- Specific nodes are interested in specific events:
  - Sink interested in all results;
  - Sink interested in a sensor reading change.

Protocols for Repeated interactions

- Subscribe once, events happen multiple times:
  - Exploring the network topology might actually pay off. But: unknown which node can provide data, multiple nodes might ask for data.

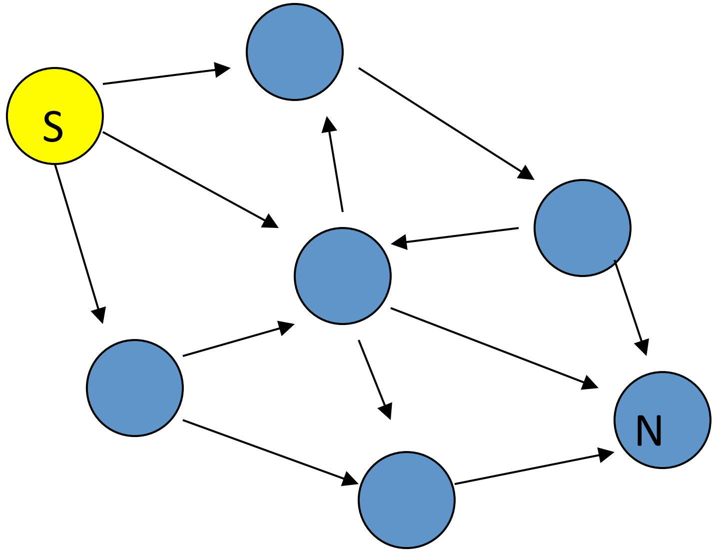
  ! How to map this onto a "routing" problem?
- Put enough information into the network: publications and subscriptions can be mapped onto each other. But try to avoid using unique identifiers: might not be available, might require too big a state size in intermediate nodes.

Directed Diffusion

- ***Directed diffusion*** as one option for implementation:
  - Try to rely only on ***local interactions.***
  - Data-centric approach.
- Nodes send "interests" for data which are diffused in the network.
- Sensors produce data which is routed according to interests.
- Intermediate nodes can filter/aggregate data.

Interest Propagation

- Each sink sends expression of interests to neighbours.
- Each node will store interests and disseminate those further to their neighbours.
  - Cache of interest is checked not to repeat disseminations.
- Interests need refreshing from the sink (they time out).
- Interests have a "rate of events" which is defined as **"gradient".**



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Data delivery

- Sensor data sources emit events which are sent to neighbours according to interest (ie if there is a gradient).
- Each intermediate node sends back data at a rate which depends on the gradient.
  - Ie if gradient is 1 event per second and 2 events per second are received send either the first or a combination of the two (aggregation).

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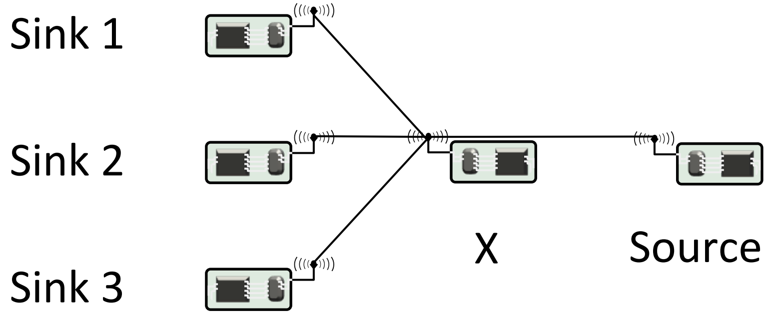
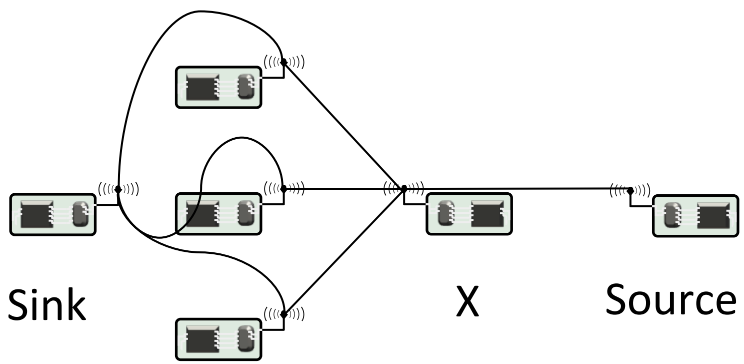
Gradients Reinforcement

- Events are stored to avoid cycles (check if same event received before).
- Data can reach a node through different paths. *Gradient reinforcement needed.*
- When gradients are established the rate is defined provisionally (usually low). Sinks will 'reinforce' good paths which will be followed with higher rate.
- A path expires after a timeout so if not reinforced it will cease to exist. This allows adaptation to changes and failures.

Directed diffusion – Two-phase pull

- **Phase 1**: nodes distribute ***interests*** in certain kinds of named data:
  - Specified as attribute-value pairs
- Interests are flooded in the network.
  - Apparently obvious solution: remember from where interests came, set up a "tree".
  - Problem: Node X cannot distinguish, in absence of unique identifiers, between the two situations on the right – set up only one or three trees?





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Direction diffusion
Gradients in two-phase pull

- Option 1: Node X forwarding received data to all "parents" in a "tree": Not attractive, many needless packet repetitions over multiple routes.
- Option 2: node X only forwards to one parent. Not acceptable, data sinks might miss events.
- Option 3: Only provisionally send data to all parents, but ask data sinks to help in selecting which paths are redundant, which are needed.
  - Information from where an interest came is called ***gradient.***
  - Forward all published data along all existing gradients

Directed diffusion – extensions

- Problem: Interests are flooded through the network.
- Geographic scoping & directed diffusion: Interest in data from specific areas should be sent to sources in specific geo locations only.
- Push diffusion – few senders, many receivers: Same interface/naming concept, but different routing protocol. Here: do not flood interests, but flood the (relatively few) data. Interested nodes will start reinforcing the gradients.

Issues

- Purely theoretical work.
- Apart from the flooding of the interests…No consideration of real world issues such as link stability or link load and load dependence.
- Mac Layer issues (assume nodes are awake…or does not discuss it).
- More recent approaches have considered link capabilities more explicitly as part of the routing decision making.

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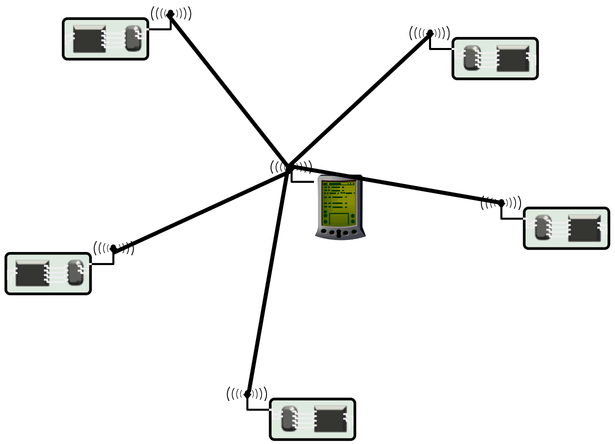
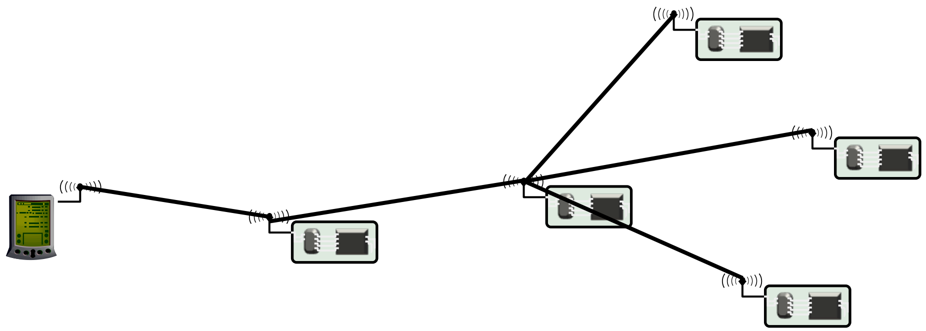
Data aggregation

- Less packets transmitted -> less energy used
- To still transmit data, packets need to combine their data into fewer packets ! ***aggregation*** is needed
- Depending on network, aggregation can be useful or pointless
- Directed diffusion gradient might require some data aggregation





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Metrics for data aggregation

- ***Accuracy***: Difference between value(s) the sink obtains from aggregated packets and from the actual value (obtained in case no aggregation/no faults occur)
- ***Completeness***: Percentage of all readings included in computing the final aggregate at the sink
- ***Latency***
- ***Message overhead***

Link quality based routing

- Directed diffusion uses some sort of implicit ways to indicate which are the good links.
  - Through the gradient.
- Ad hoc routing protocols for mobile networks route messages based on shorter path in terms of number of hops.
- The essence of the next protocol we present: "number of hops might not be the best performance indication in wireless sensor network".

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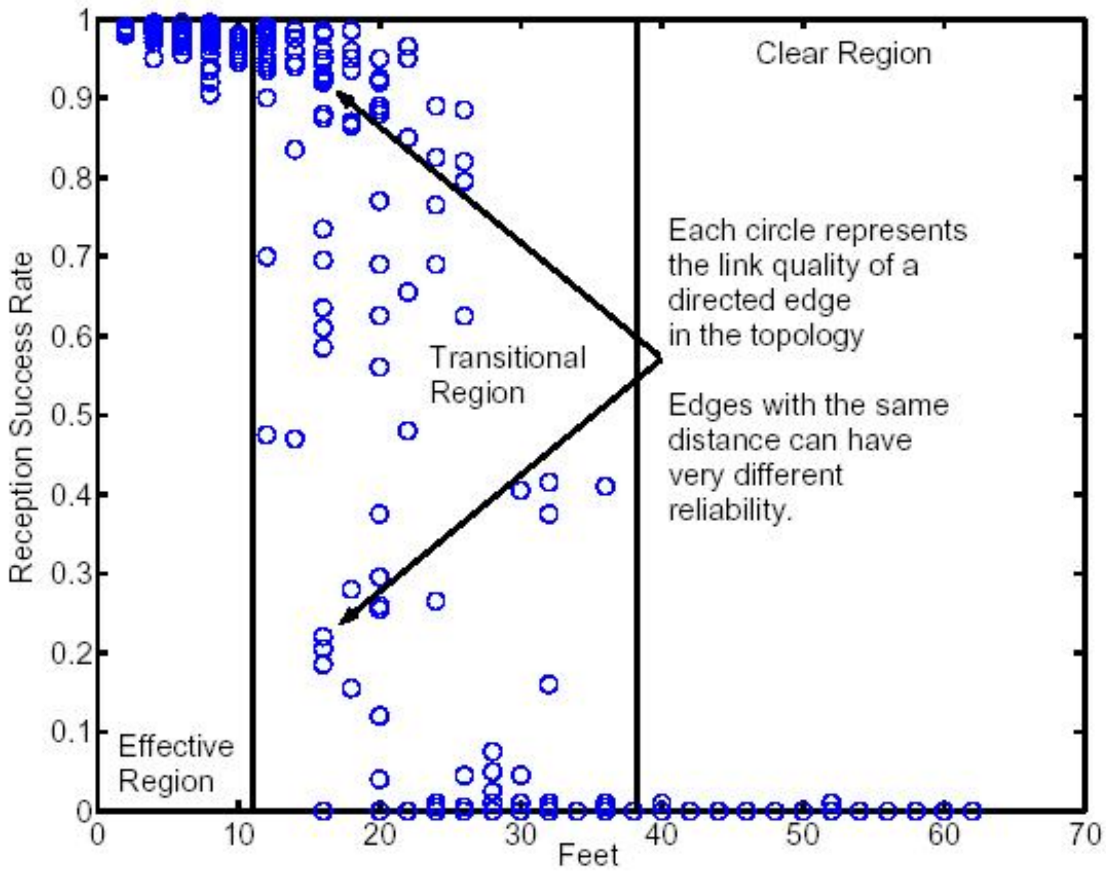
Routing based on Link Estimation

- Routing algorithms should take into account underlying network factors and under realistic loads.
- Link connectivity in reality is not spherical as often assumed.



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Link Estimation

- A good estimator in this setting must:
  - Be stable.
  - Be simple to compute and have a low memory footprint.
  - React quickly to large changes in quality.

  - Neighbour broadcast can be used to passively estimate.

WMEWMA

- Snooping
  - Track the sequence numbers of the packets from each source to infer losses
- Window mean with EWMA
  - $EWMA(t_x)=a\ (MA(t_x)) + (1\text{-}a)EWMA(t_{(x-1)})$
  - t_x : last time interval; a: weight

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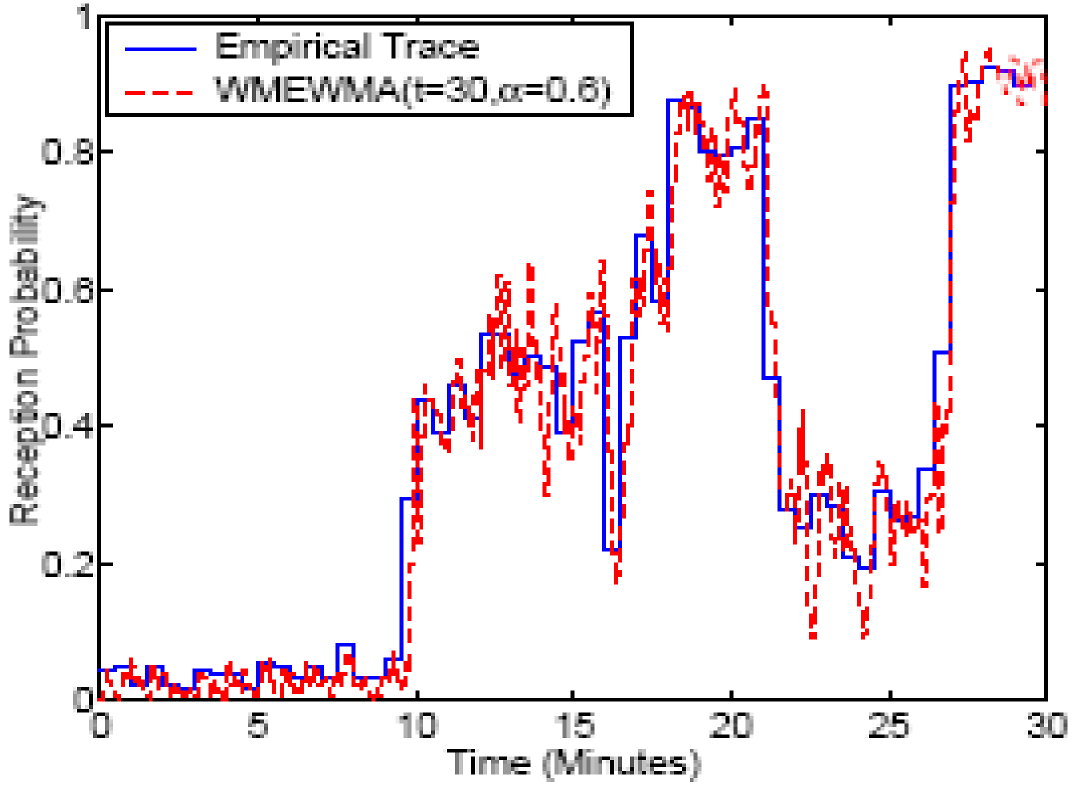
WMEWA (t =30, a =0.6)



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Neighborhood Management

- Neighborhood table:
  - Record information about nodes from which it receives packets (also through snooping).
- If network is dense, how does a node determine which nodes it should keep in the table?
- Keep a sufficient number of good neighbours in the table.

Link Estimation based Routing

- Focus on "many to one" routing model:
  - Information flows one way.
- Estimates of inbound links are maintained, however outbound links need to be used!
  - Propagation back to neighbours.
- Each node selects a parent (using the link estimation table).
  - Changes when link deteriorates (periodically).

Distance vector routing: cost metrics

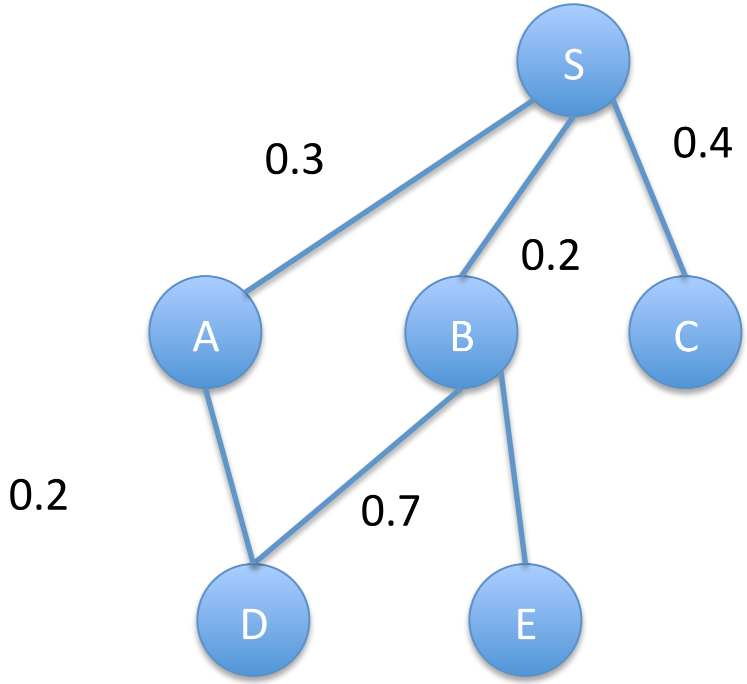
- Routing works as a standard distance vector routing.
- The DVR cost metric is usually the hop count.
- In lossy networks hop count might underestimate costs.
  - Retransmissions on bad links: shortest path with bad links might be worse than longer path with good links.
  - Solution: consider the cost of retransmission on the whole path.

MIN-T Route

- MT (Minimum Transmission) metric:
  - Expected number of transmissions along the path.
  - For each link, MT cost is estimated by

    1/(Forward link quality) * 1/(Backward link quality).
    - backward links are important for acks.
- Use DVR with the usual hop counts and MT weights on links.

An Example



Routing Table on D:

Id	Cost	NextHop
A	0.2	A
B	0.7	B
S	0.5	A

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Greedy Perimeter Stateless Routing (GPSR)

- Another possible routing protocol with different applications is geographical: it assumes the node knows their geographical position and that of the other nodes.

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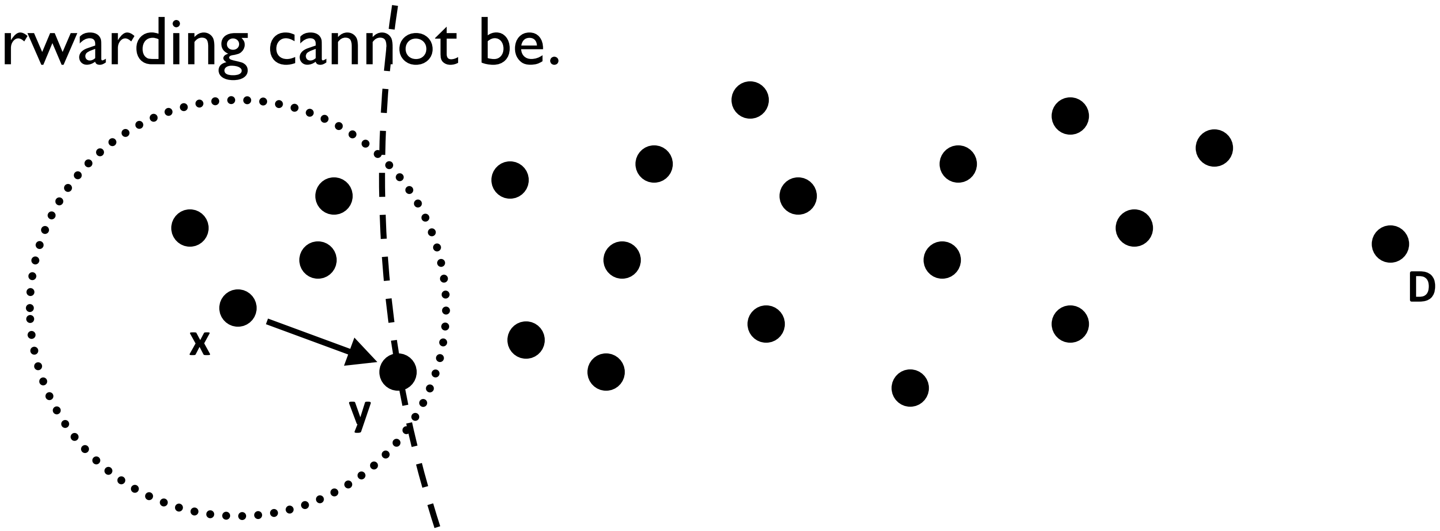
Greedy Perimeter Stateless Routing (GPSR)

- The algorithm consists of two methods for forwarding packets:
- *greedy forwarding*, which is used wherever possible, and
- *perimeter forwarding*, which is used in the regions greedy forwarding cannot be.



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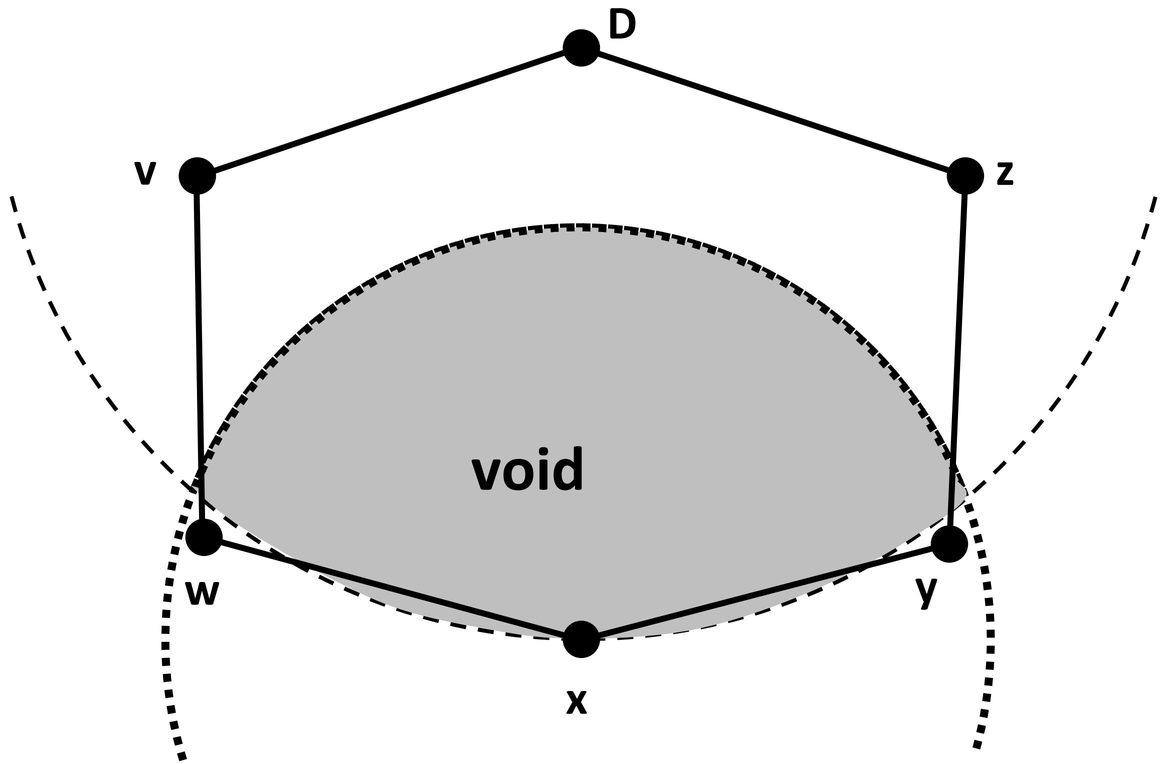
Greedy Forwarding

- Under GPSR, packets are marked by their originator with their destinations' locations.
- A forwarding node can make a locally optimal, greedy choice in choosing a packet's next hop.
- Specifically, if a node knows its neighbors' positions, the locally optimal choice of next hop is the neighbor geographically closest to the packet's destination.
- Forwarding in this regime follows successively closer geographic hops, until the destination is reached.

Greedy Forwarding Failure

Greedy forwarding not always possible! Consider:



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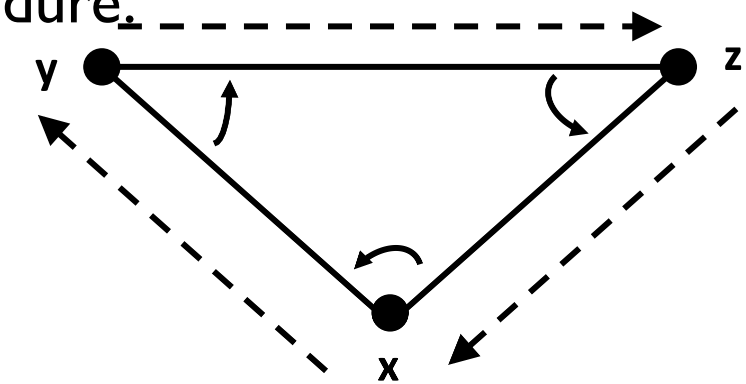
Void Traversal: The Right-hand Rule

Well-known graph traversal: **right-hand rule**

Requires **only neighbors' positions**

- Mapping perimeters by sending packets on tours of them, using the right-hand rule.
- This approach requires the no-crossing heuristic, to force the right-hand rule to find perimeters that enclose voids in regions where edges of the graph cross.
- Caveat: if the graph has cross cutting edges:
  – Remove those with a specific procedure.



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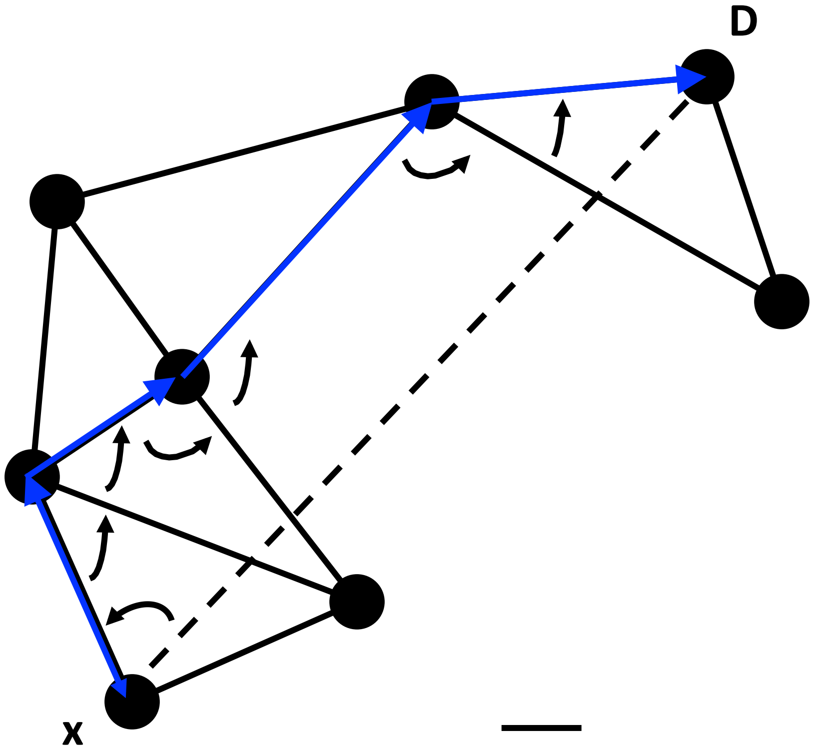
GPSR

- All packets begin in greedy mode. Upon greedy failure, node marks its location in packet, marks packet in perimeter mode.
- Perimeter mode: follow planar graph traversal.
  - Forward along successively closer faces by right-hand rule, until reaching destination.
  - Packets return to greedy mode upon reaching node closer to destination than perimeter mode entry point.

Perimeter Mode



- Traverse <u>face</u> closer to *D* along $\overline{xD}$ by right-hand rule, until crossing *xD*.
- Repeat with next-closer face etc.

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GPSR comments

- No consideration for 3D terrain
- It needs to be augmented with power efficient MAC layers.
- Knowing position is not common in all applications and may require expensive sensors.

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