Virtual Localization in Wireless Sensor Networks

for Robust Geographic Routing

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Outline

Wireless Sensor Networks

- Networks of large numbers of sensor nodes
- *Mesh networks* — nodes participate in routing
- Nodes are cheap, resource-limited
  - Battery-powered — must conserve *energy*
  - Limited computational power and memory
  - Wireless medium is *shared* — limited communication between nodes
- Routing must be *scalable* — independent of network size

Geographic Routing

- Uses *locations* to address nodes
- Routing tables no longer required
- Only *local* information is used
  - Completely scalable
- Requires node locations to be known

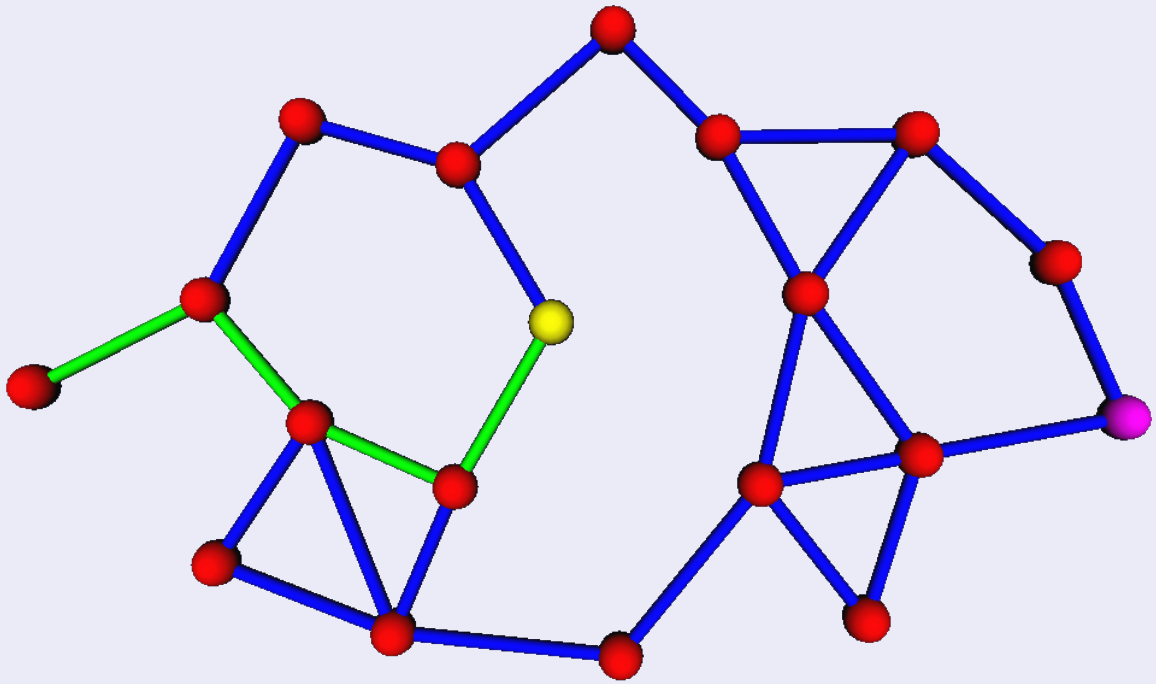
Geographic Routing Schemes

- Greedy routing
  - Simple and efficient
  - Packets do not always reach destination
- Face routing
  - Guaranteed packet delivery for planar networks
  - Not very efficient — long routing paths

- Performance evaluated using two metrics
  - *Reachability* — proportion of packets that are delivered
  - *Stretch* — length of discovered path relative to shortest path

Greedy Routing

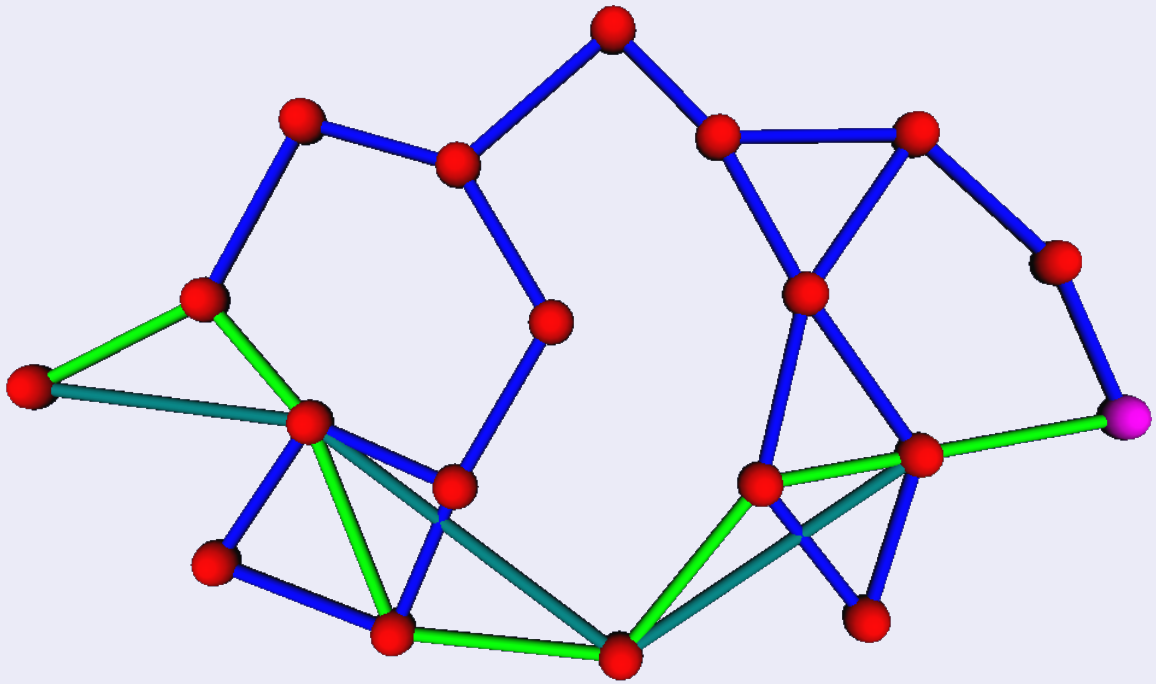
- Simple rule — forward packet to neighbour *closest* to destination



- Paths are not always optimal
- Packets can get stuck in *voids*

Two-hop Greedy Routing

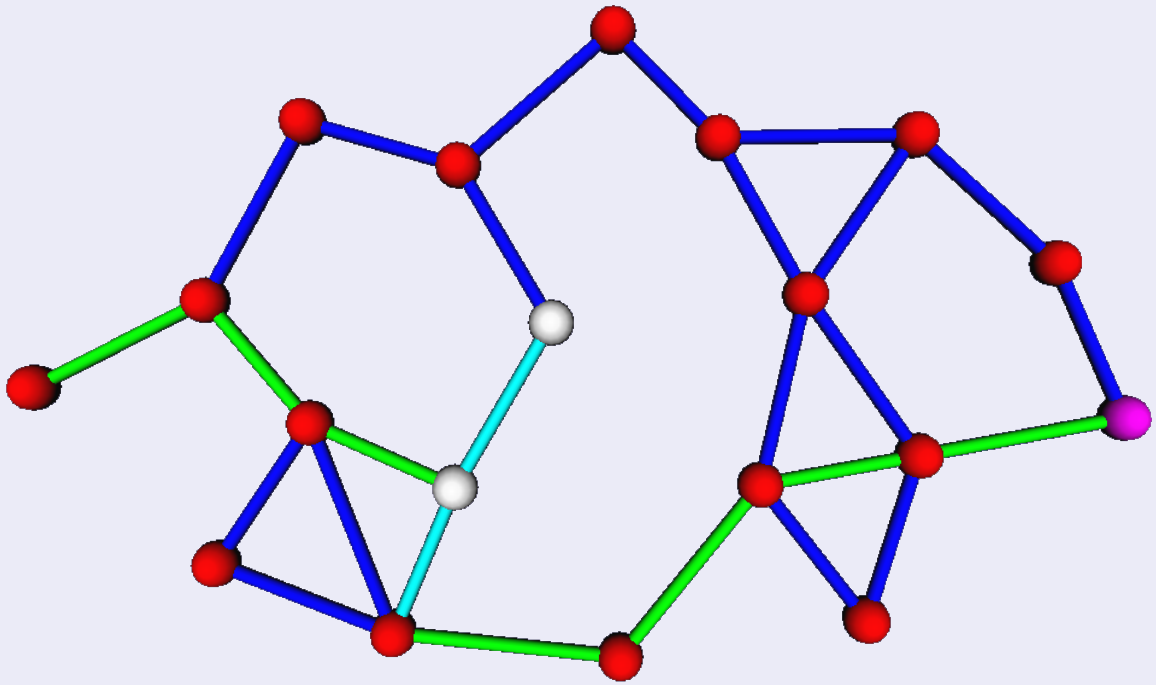
- Choose closest node from the *2-hop neighbourhood*
  - If choice is a 2-neighbour, send via a 1-neighbour



- Improves performance
- Requires 2-hop information

Void Avoidance

- Used for recovery when greedy routing fails
- Nodes marked as *voids* when packet would have been dropped
- Other nodes ignore void nodes when choosing closest neighbour



- Cannot guarantee delivery, but always improves reachability
- Void list is stored in the packet, which increases overhead slightly

Virtual Localisation

- Enables geographic routing functionality *without* location information
- Nodes "place" themselves in a *virtual* coordinate system
  - Routing is performed over the virtual locations
- Locations generated using local connectivity information
  - Nodes are attracted to their neighbours
  - Nodes are repelled from their 2-neighbours
- Equivalent to minimising an energy function:

$$E(a) = k_a \sum_{b \in N} \|a - b\|^2 + k_r \sum_{b \in M} \frac{1}{1 + \|a - b\|}$$

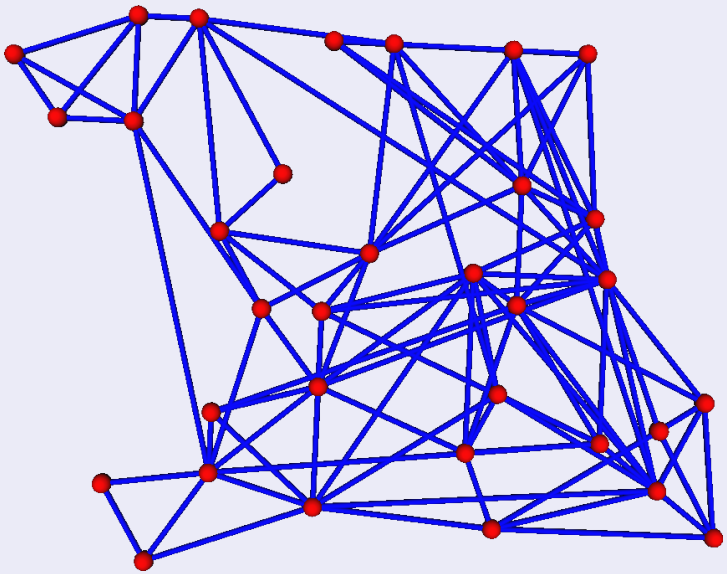
- 1- and 2-neighbours' virtual locations obtained from beacons
  - Each node sends broadcast beacons containing its neighbours' locations
- Very scalable — uses only local information

Packet Radio Network

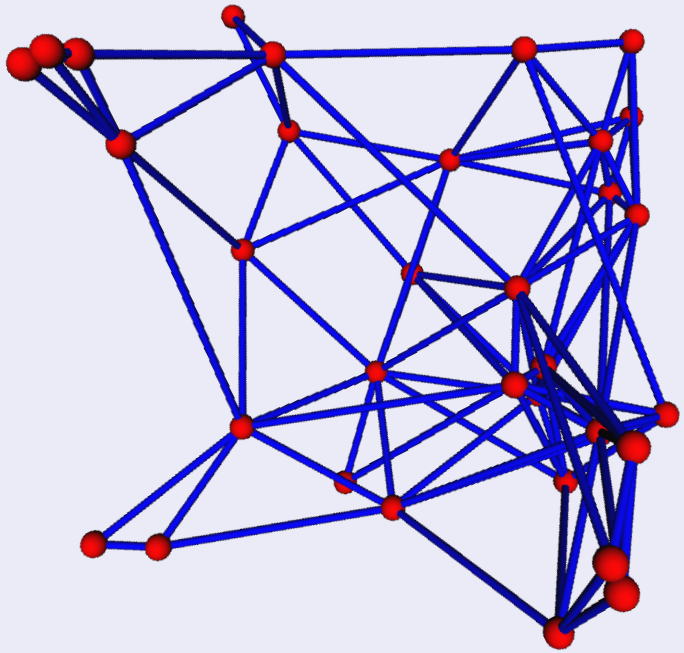
- Initially implemented in a packet radio network
  - Part of a summer research project (2010–2011)
  - Basic virtual localisation in 3 dimensions
- Virtual locations mimicked network structure

Virtual localisation in a real network

Physical Locations



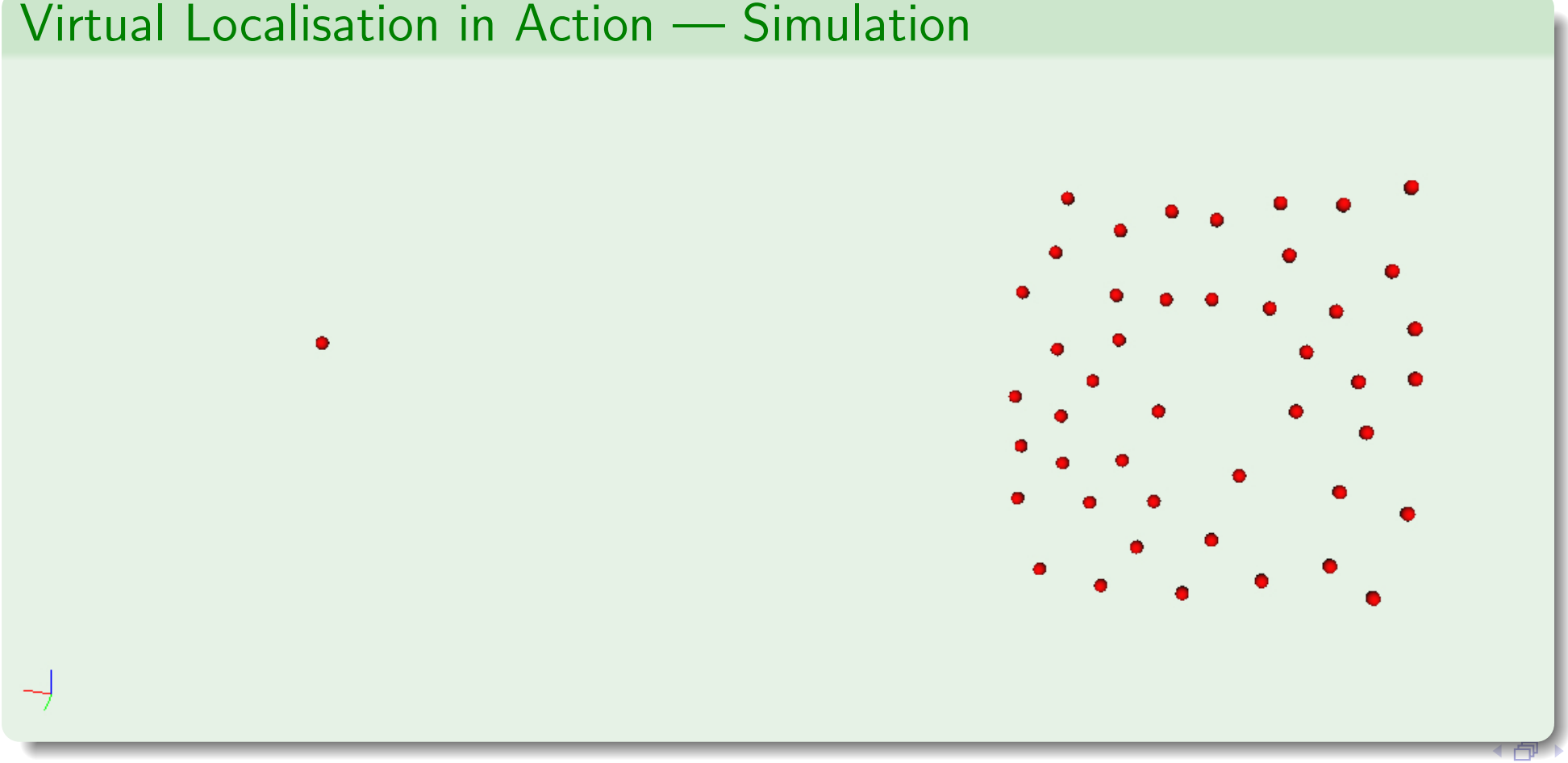
Virtual Locations



Simulation of Algorithm

- Virtual localisation was implemented in OMNeT++
- Results were visualised in 3D using OpenGL
  - Allows direct comparison between physical and virtual locations

Virtual Localisation in Action — Simulation



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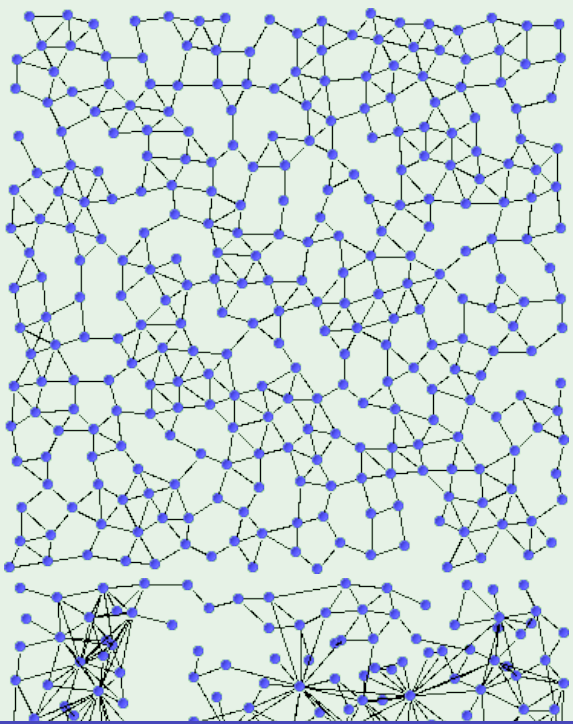
Virtual Localisation in Action — Simulation

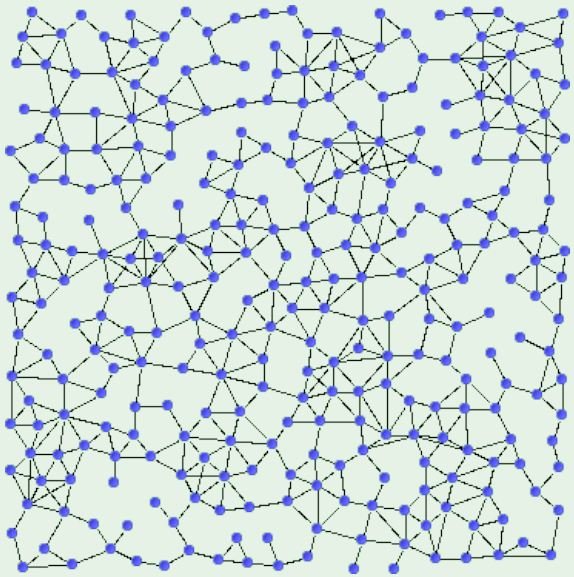
`virtloc_video.flv`

Topology Generation

- Unit-disk graph (UDG) model most commonly used
  - Nodes have a fixed transmission radius
  - Creates unrealistic uniformly dense topologies
- Topology generator with variable range was created
  - Transmission power and receive sensitivity is varied node to node
  - Results in large variation in the length of links

300 Node Network

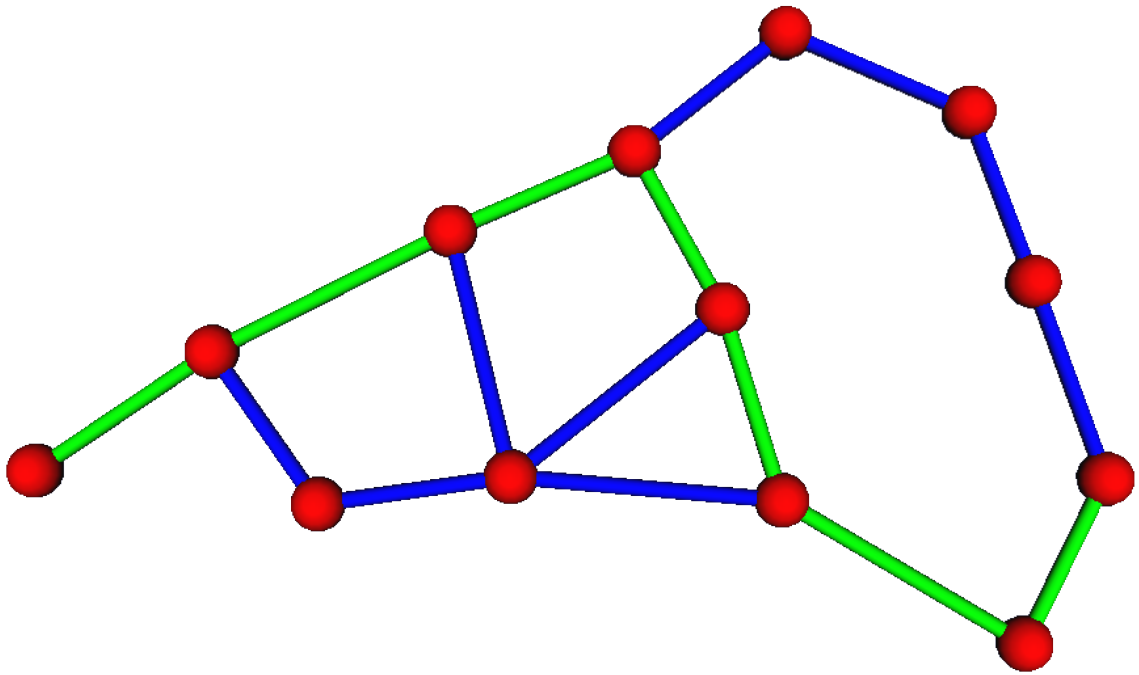




Summary

- Routing in wireless sensor networks must be simple and *scalable*
- *Geographic routing* is the best option for this purpose
  - It requires knowledge of node locations
  - Greedy routing — simplest, good performance
  - Two-hop greedy — better performance
  - Void avoidance — much better reachability
- *Virtual localisation* constructs a virtual coordinate system
  - Location information not necessary
  - Algorithm is very scalable
  - Generated locations can be in almost any metric space
- Algorithms implemented in *OMNeT++* simulator
- *Realistic* topologies generated by varying range
- Results obtained for many configurations
  - Routing over virtual locations more robust to network irregularities
  - Void avoidance improves reachability at the expense of stretch

Greedy Routing in WSNs



- If the locations of nodes are known, *greedy routing* is considered as the best approach (in general).
- How can one discover the locations?

Physical Vs Virtual Locations in WSNs

Physical Locations

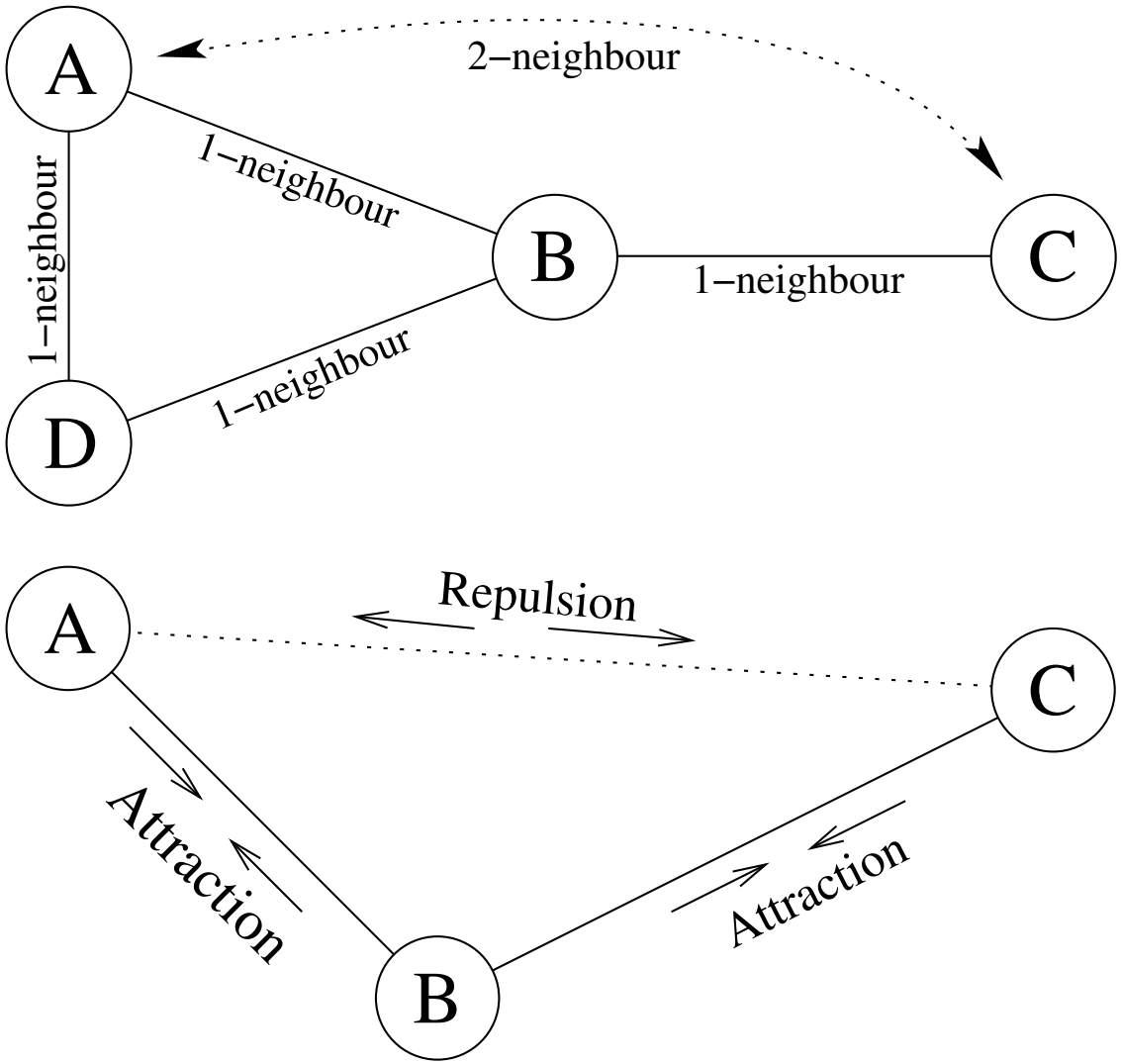
- Naïve solution: GPS
- 'Anchor' nodes (up to 20% of the total number of nodes)
- Radio distance-finding

Virtual Locations

- Location relative to other nodes
- Axes do not correspond to real directions
- Geometries may not correspond either
- Internally consistent
- Generally only useful for routing purposes

n-neighbours, Attraction and Repulsion Forces

Spring Models



Forces and Potentials - Equations

- A node i attempts to minimize the total "potential energy" by iteratively recalculating its "position"

$$U_i = \sum_{j \in N} A_{ij} + \sum_{k \in N} R_{ik}$$

where

- A_{ij} is a springlike "attraction force" to 1-neighbours

$$A_{ij} = k_{att} \cdot d_{ij}^2 \quad ; \quad k_{att} = 1$$

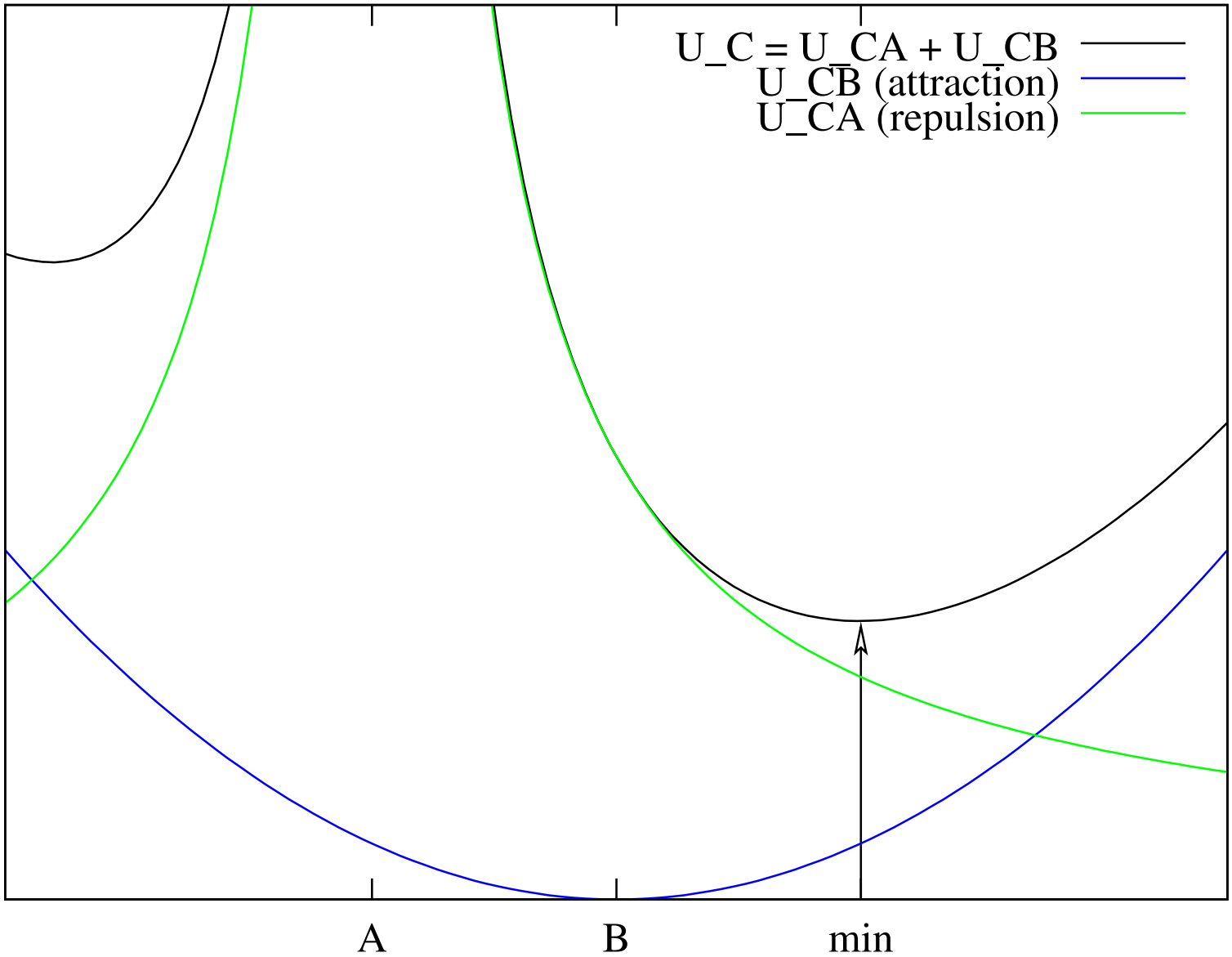
and

- R_{ik} is an electrostatic-like "repulsion force" from 2-neighbours (with a small offset to prevent infinities)

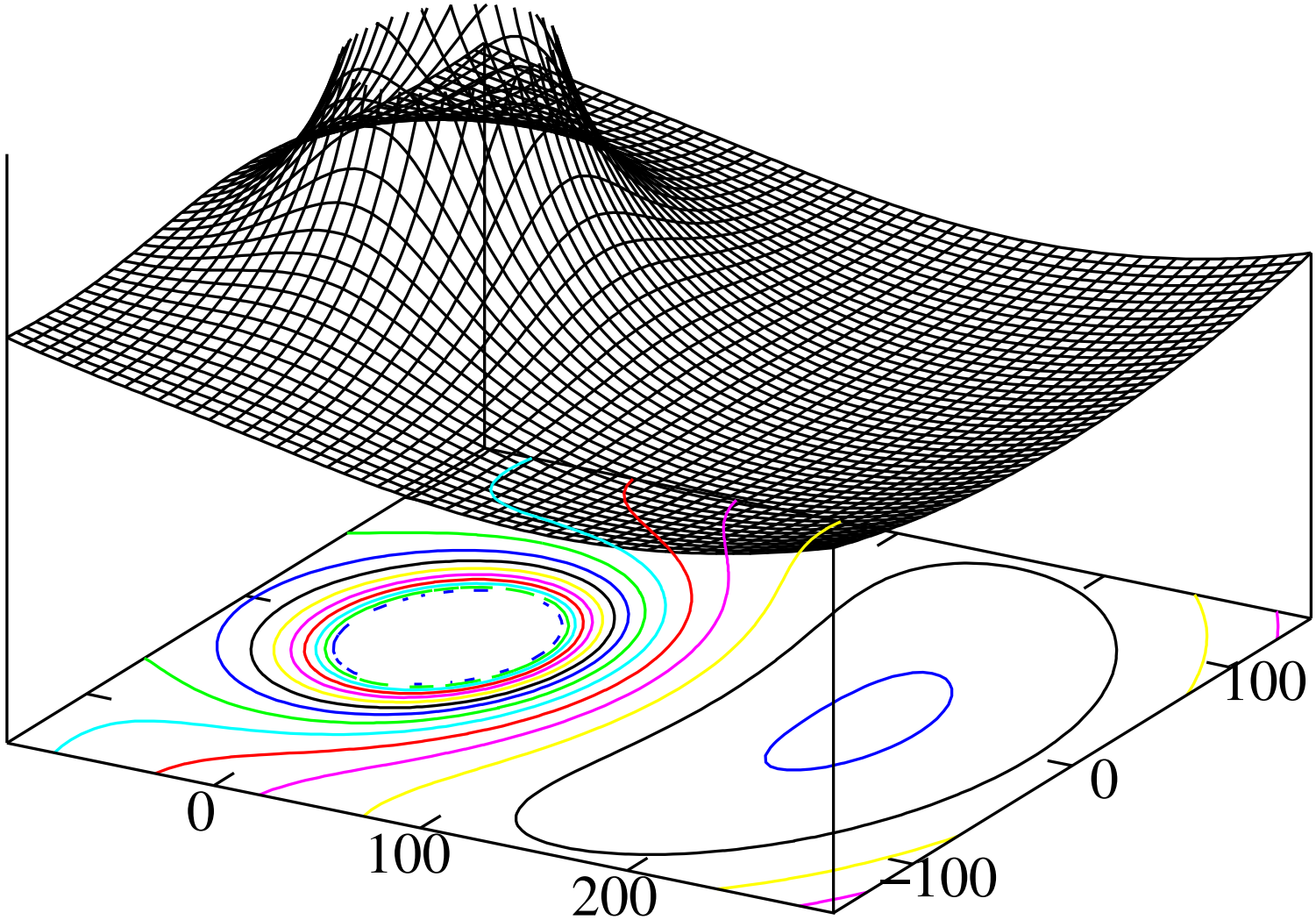
$$R_{ik} = k_{rep} \cdot \frac{1}{d_{ik} + 1} \quad ; \quad k_{rep} = 8 \times 10^6$$

Forces and Potentials - View in a 1D Universe

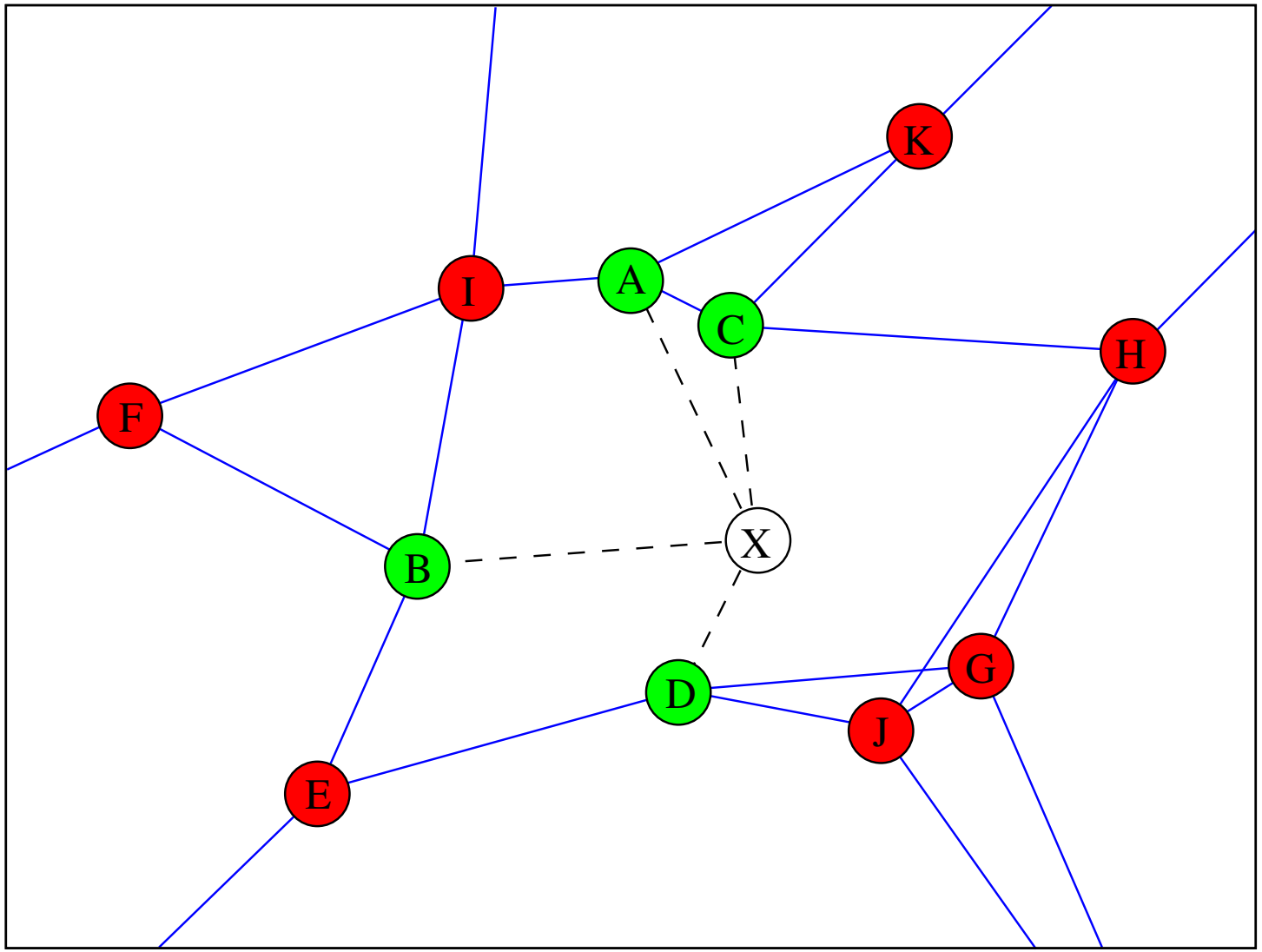
Where is the stable location for node C?



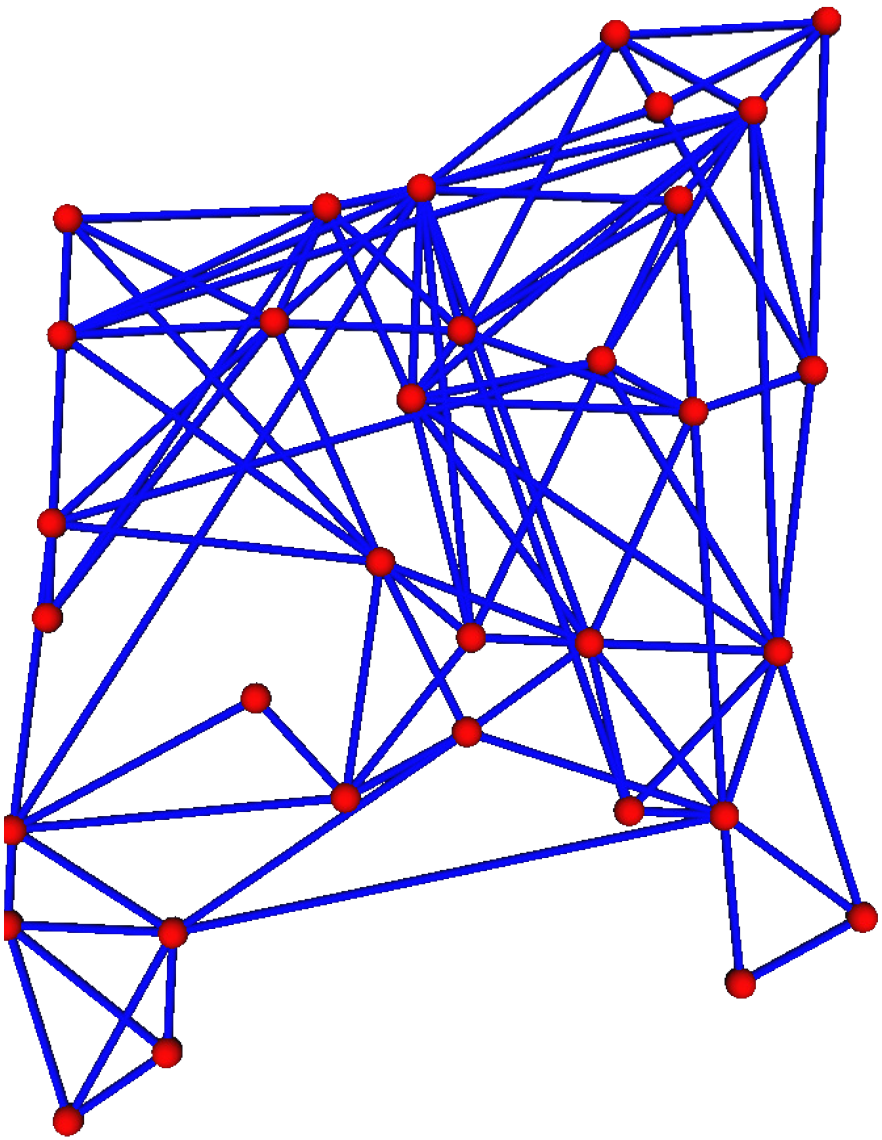
Forces and Potentials - View in a 2D Universe

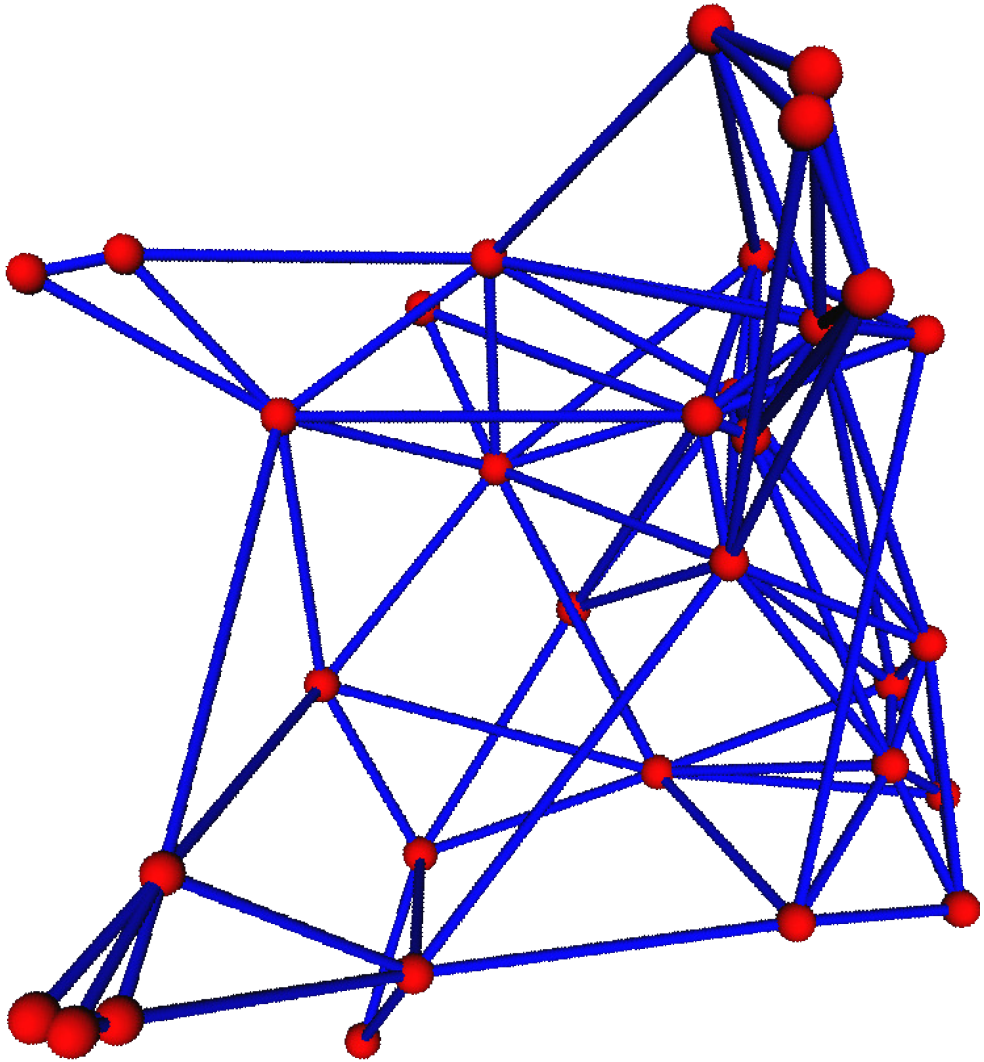


Multiple Neighbours



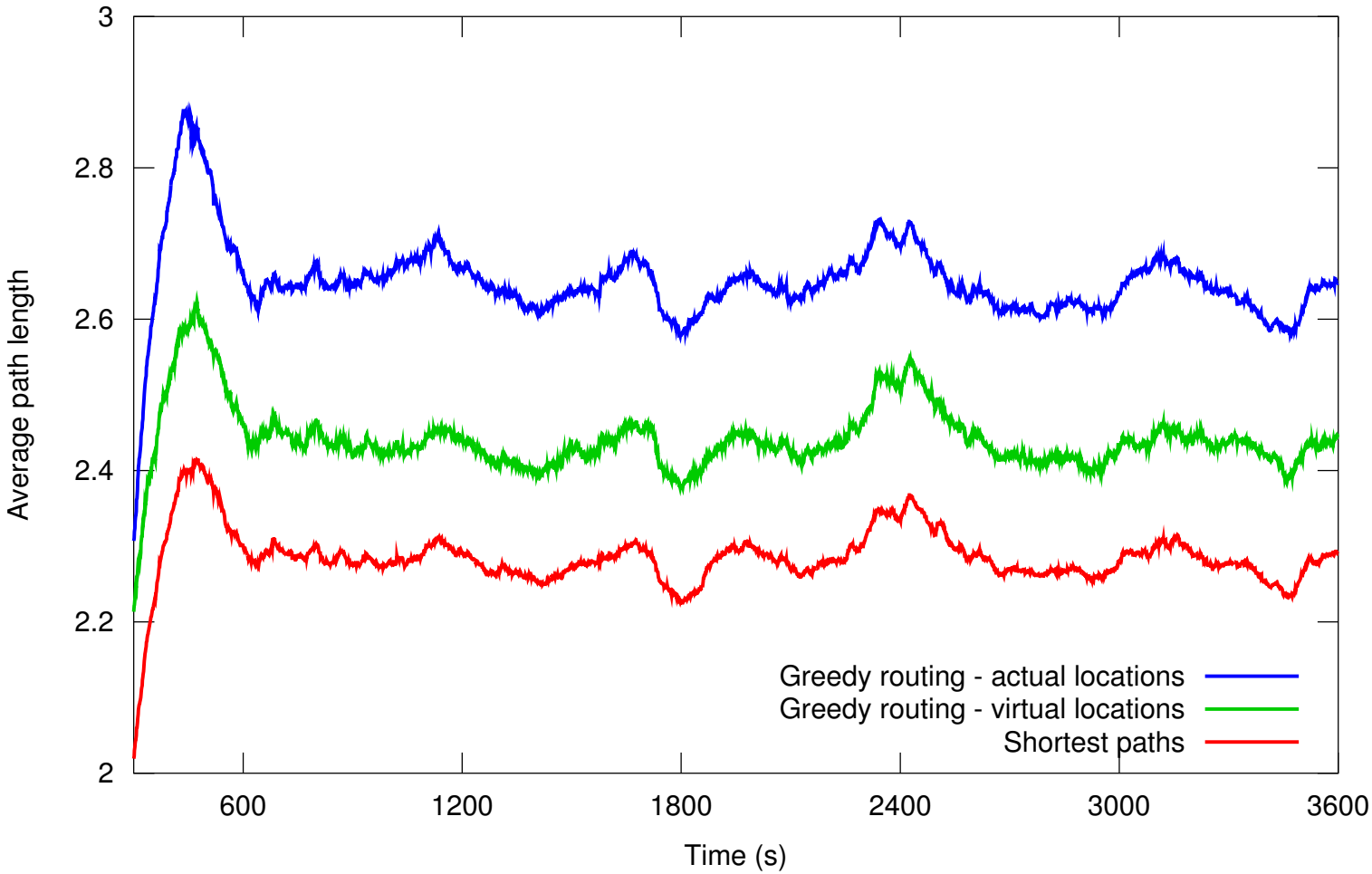
Packet Radio Testbed: Physical Vs. Virtual Locations





Greedy Routing Over Physical Vs. Virtual Locations

Average Number of Hops to Sink



Greedy Routing Over Physical Vs. Virtual Locations

Source to Sink Reachability