This lecture is being recorded

# 18-452/18-750
# Wireless Networks and Applications
## Lecture 12: Ad Hoc Networks

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**http://www.cs.cmu.edu/~prs/wirelessS21/**

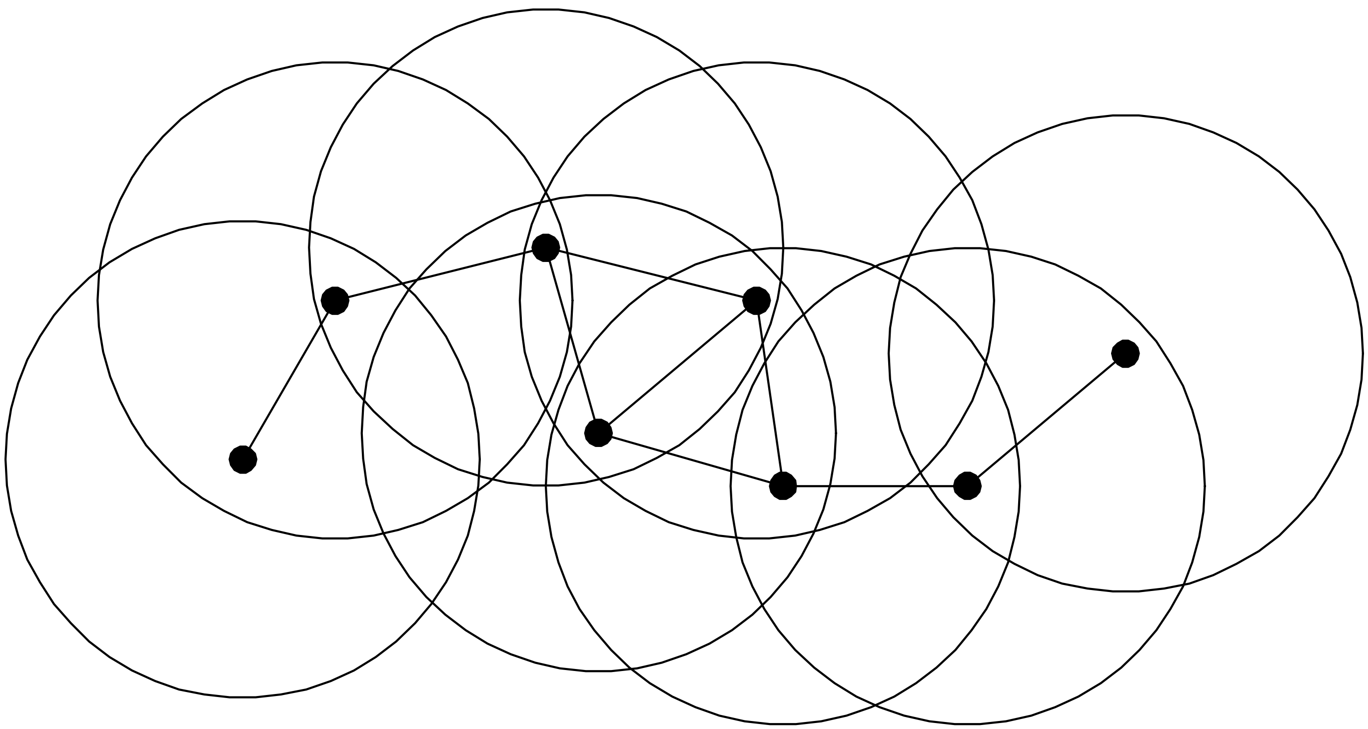
# Ad Hoc Routing

- Definition and challenges
- Routing:
  - Classes: proactive versus reactive routing
  - Proactive, table based routing: DSDV
  - Reactive routing DSR
  - Geographic routing: GPSR
- Discussion

- Structured as a survey
  - But a bit longer since it covers more material

# Ad Hoc Networking

- **Goal:  Communication between wireless nodes**
  - » **No infrastructure – network must be self-configuring**
- **It may require multiple hops to reach a destination**
  - » **Nodes are traffic sources, sinks and forwarders**

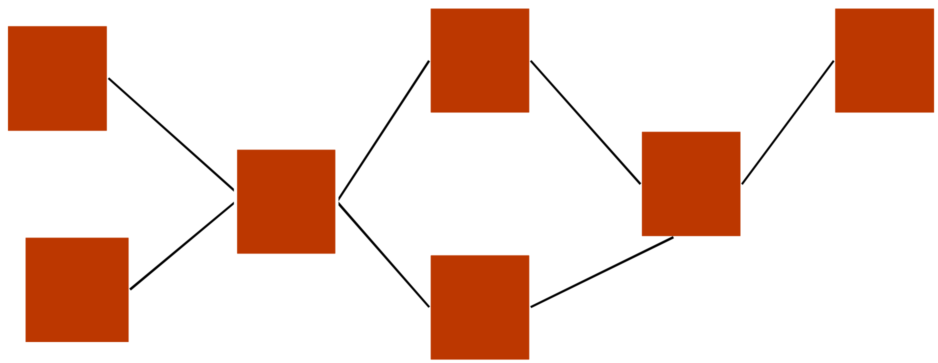


# Ad Hoc Networking Challenging

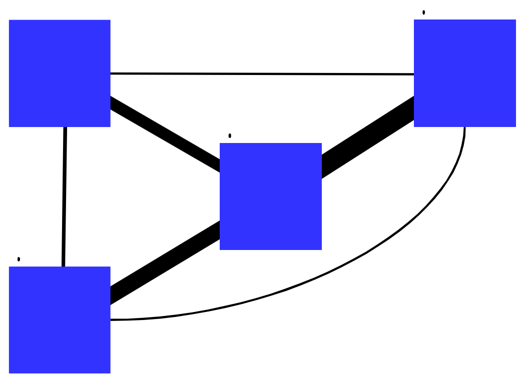
- **All the challenges of wireless, and more:**
  - » **Decentralized: nobody is in charge – no planning!**
  - » **No fixed infrastructure, random network design**
  - » **Generic ad hoc can be arbitrarily bad: limited batteries, malicious nodes, high mobility, low density, ..**
- **Precise challenges depend on the application domain, e.g., vehicular networks versus first-responder networks versus sensor networks**
  - » **Domain focus typically simplifies the problem**
  - » **Most research papers address the complex general case**
- **The big challenge: Routing**

# Traditional Routing vs Ad Hoc

- **Traditional wired network:**
  - » Well-structured
  - » ~O(N) nodes & links
  - » All links work equally well
  - » Sensible topology
  - » Links are independent



- **Ad Hoc wireless network**
  - » N^2 links - but many stink!
  - » Topology may be really weird
  - » Links interfere with each other
  - » Dynamic link conditions affect link quality unpredictably
    - – So the topology also changes constantly!

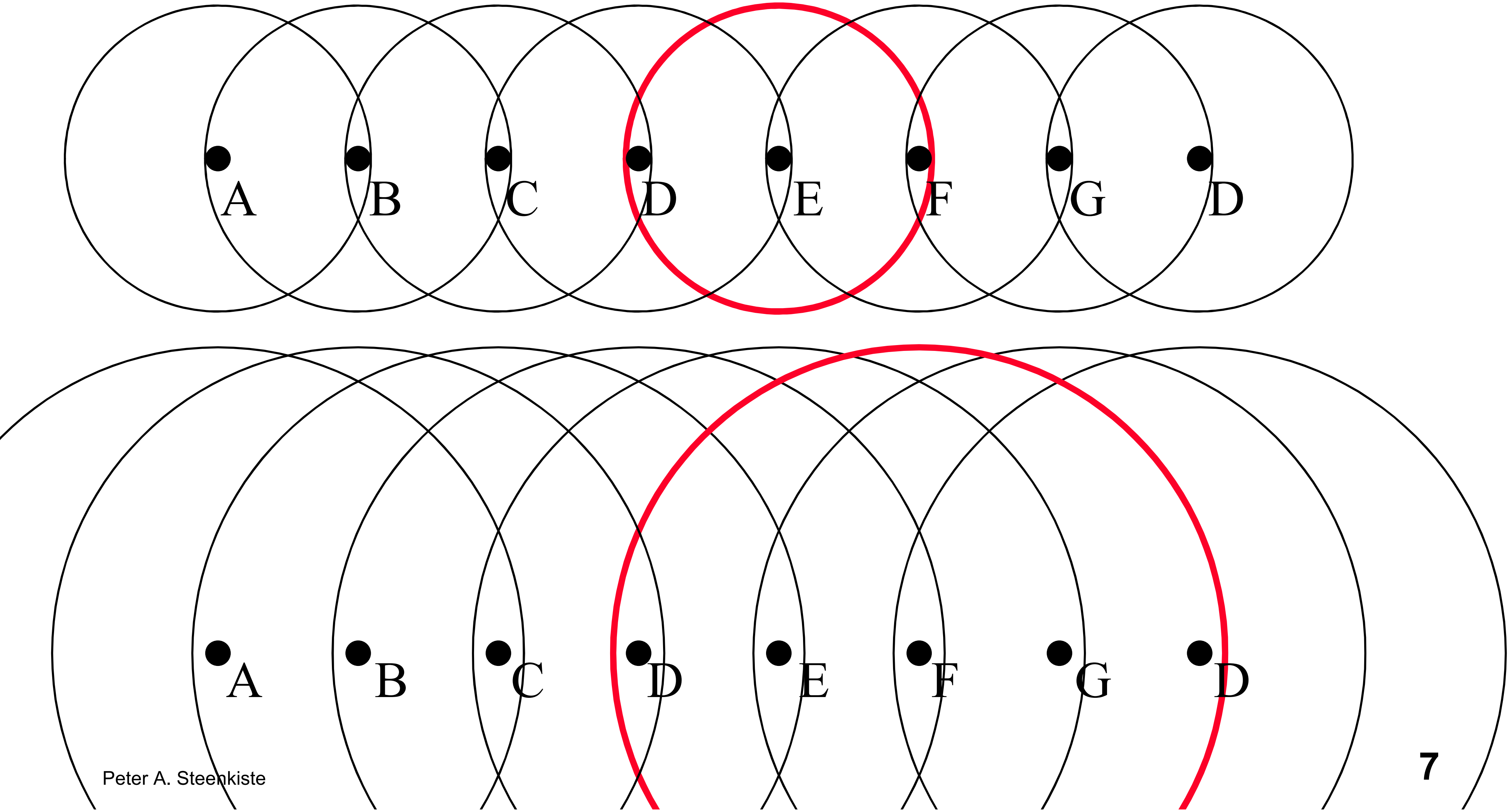


# Forwarding Packets is expensive

- Assume link throughput is X
  - » X depends on the WiFi version, distance, fading, …
- What is the throughput of a chain?
  - » Basic: A → B → C
  - » Or: A → B → C → D
  - » Or: A → B → C → D → E …
- Considering:
  - » Wired versus wireless
  - » Assume minimum power for radios.
  - » Now assume a dense network, i.e., all radios can hear each other
  - » Now assume dynamic link conditions, mobility, ..

# 2 Simple Examples

A → B → C → D → E → F → G → D



# Ad Hoc Routing

- Proactive routing: each router maintains a forwarding table listing all destinations
  - » Uses routing algorithms similar to those in the Internet
  - » Example: DSDV
- Reactive routing: only find a path when you need it
  - » Avoids the overhead of periodically executing a routing protocols but can introduce high packet delay
  - » Example: DSR
- Geographic routing: find a path based on geographic coordinates
  - » Does not require any topology information
  - » Does not maintain forwarding tables
  - » Example: GPSR

# Proactive or Table-based Protocols

- Proactive: routers maintain routes independently of the need for communication
  - Similar to wired networking – uses forwarding table
- Route update messages are sent periodically or when network topology changes
- Low latency – forwarding information is always readily available
- Bandwidth might get wasted due to periodic updates

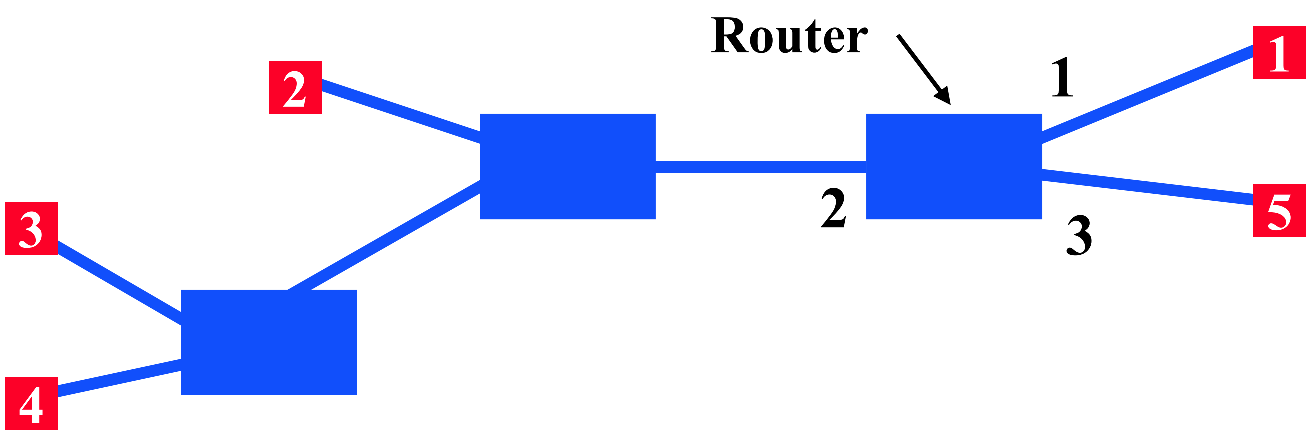
# Reactive or On-Demand Routing

- Routers discover a route only when there is data to be sent
- Saves energy and bandwidth during periods of inactivity or low activity
- Route discovery introduces significant delay for the first packet of a new transfer
- Bad if many nodes send packets to many destinations at random times or in unstable networks

# Ad Hoc Routing

- Classes: proactive versus reactive routing
- Proactive, table based routing: DSDV
- Reactive routing DSR
- Geographic routing: GPSR

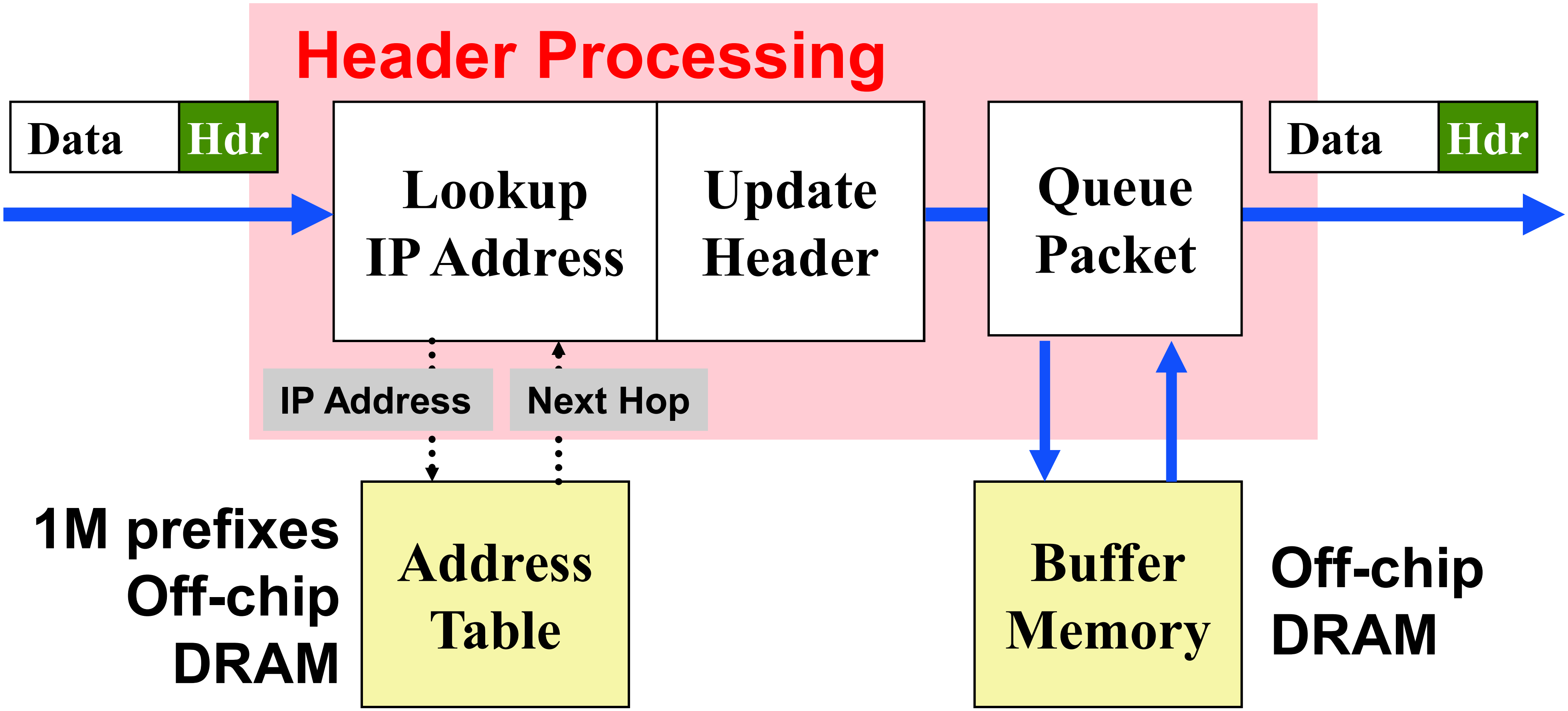
# Packet Forwarding versus Routing




| Destination Address | Port |
|---|---|
| IP1 | 1 |
| IP2 | 2 |
| IP3 | 2 |
| IP4 | 2 |
| IP5 | 3 |

- Routing finds a path between two end-points
- Forwarding receives a packet and decides which egress port to send it out on
- Most networks use a routing protocol to pre-calculate paths between every pair of nodes
  - » Routers put the result in a forwarding table
- Forwarding only requires a lookup in the forwarding table – fast!

# Generic Router Architecture

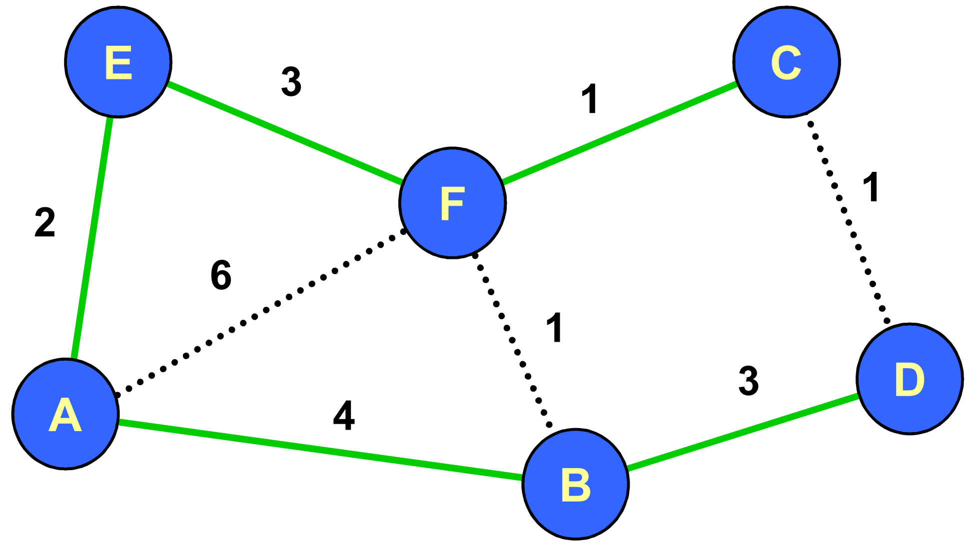


# Traditional Routing Solutions

- **Link state routing**
  - » Each router obtains a full topology of the network by having nodes periodically flood connectivity information
  - » Each router then uses Dijkstra's algorithm to locally calculate its forwarding table
  - » Bad fit for ad hoc: LS flooding creates a lot of traffic and relies on all routers having a consistent view of network
- **Distance vector**
  - » Each router tells its neighbors its shortest path to each destination
  - » Routers then use the "best" option provided to them
  - » Based on the Bellman-Ford algorithm
  - » More promising for ad hoc: has lower routing overhead
  - » Challenge is how to avoid routing loops (details omitted)

# Routes from Node A

| Forwarding Table for A | | |
|---|---|---|
| Dest | Cost | Next Hop |
| A | 0 | A |
| B | 4 | B |
| C | 6 | E |
| D | 7 | B |
| E | 2 | E |
| F | 5 | E |



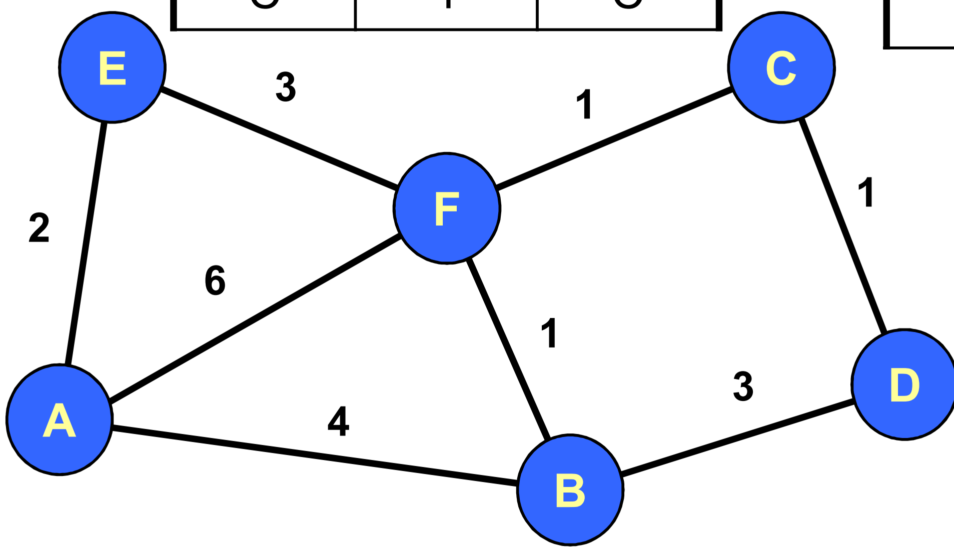

- **Set of shortest paths forms tree**
  - » **Shortest path spanning tree**
- **Solution is not unique**
  - » **E.g., A-E-F-C-D also has cost 7**

# Different View: How to Get to Node C

| Forwarding Table for E | | |
|---|---|---|
| Dest | Cost | Next Hop |
| C | 4 | F |

| Forwarding Table for F | | |
|---|---|---|
| Dest | Cost | Next Hop |
| C | 1 | C |

| Forwarding Table for C | | |
|---|---|---|
| Dest | Cost | Next Hop |
| C | - | - |



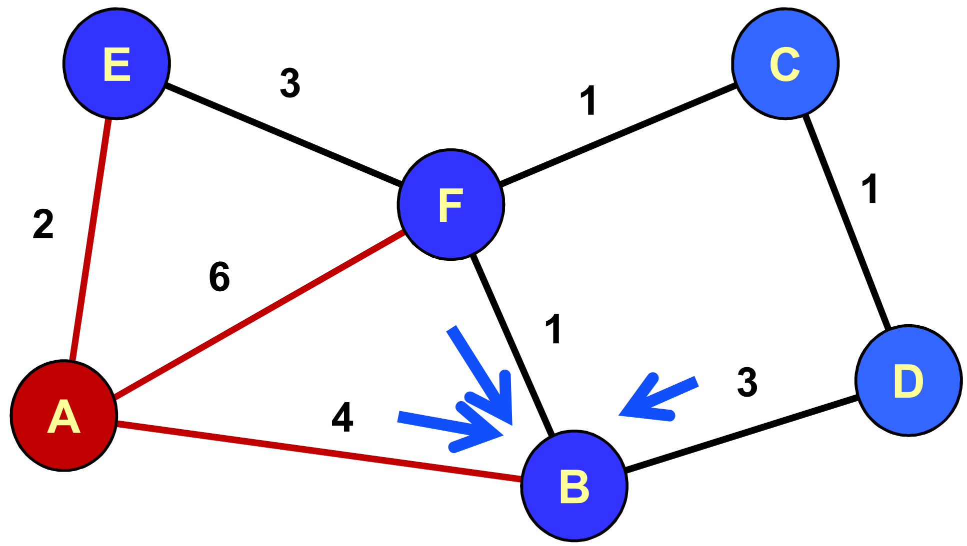

| Forwarding Table for A | | |
|---|---|---|
| Dest | Cost | Next Hop |
| C | 6 | E |

| Forwarding Table for B | | |
|---|---|---|
| Dest | Cost | Next Hop |
| C | 2 | F |

| Forwarding Table for D | | |
|---|---|---|
| Dest | Cost | Next Hop |
| C | 1 | C |

# Distance-Vector Method

| Initial Table for A | | |
|---|---|---|
| Dest | Cost | Next Hop |
| A | 0 | A |
| B | 4 | B |
| C | ∞ | – |
| D | ∞ | – |
| E | 2 | E |
| F | 6 | F |




- **Router periodically exchanges tables with neighbors**
  - » **Contains the cost and next hop of best known path to all destination**
- **Routers pick the best of the candidates paths**
  - » **May be the path it is currently using already**

# Destination-Sequenced Distance Vector (DSDV)

- By Perkins and Bhagvat
- DV protocol specifically designed for wireless
  - » Exchange of routing tables
  - » Routing table: the way to the destination, plus the cost
- Each node advertises its presence and tables
  - » Maintains fresh routes by periodically sending updates to neighbors
  - » Update for each destination: hop count, sequence number
- Uses sequence number to avoid loops
  - » Advertisements for each destination include sequence number that is incremented for each update
  - » Since loops are created by advertisements based on old routing information, they can be detected

# DSDV Properties

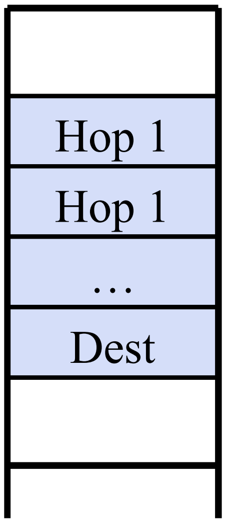
- Keep the simplicity of Distance Vector
- Guarantees Loop Freeness
  - » While adding minimal overhead
- Allow fast reaction to topology changes
  - » Make immediate route advertisement on significant changes in routing table
- Drawbacks:
  - » Overhead can be significant under dynamic conditions and mobility
  - » Many ad hoc networking scenarios do not require all-all connectivity, so some effort is wasted

Based on: cone.informatik.uni-freiburg.de/teaching/vorlesung/manet-s07/exercises/DSDV.ppt

# Overview

- Ad hoc networking concept
- Proactive versus reactive routing
- Proactive, table based routing: DSDV
- Reactive routing DSR
- Geographic routing: GPSR
- Wireless link metrics
- Ad hoc networking examples

# Dynamic Source Routing (DSR) Key Features

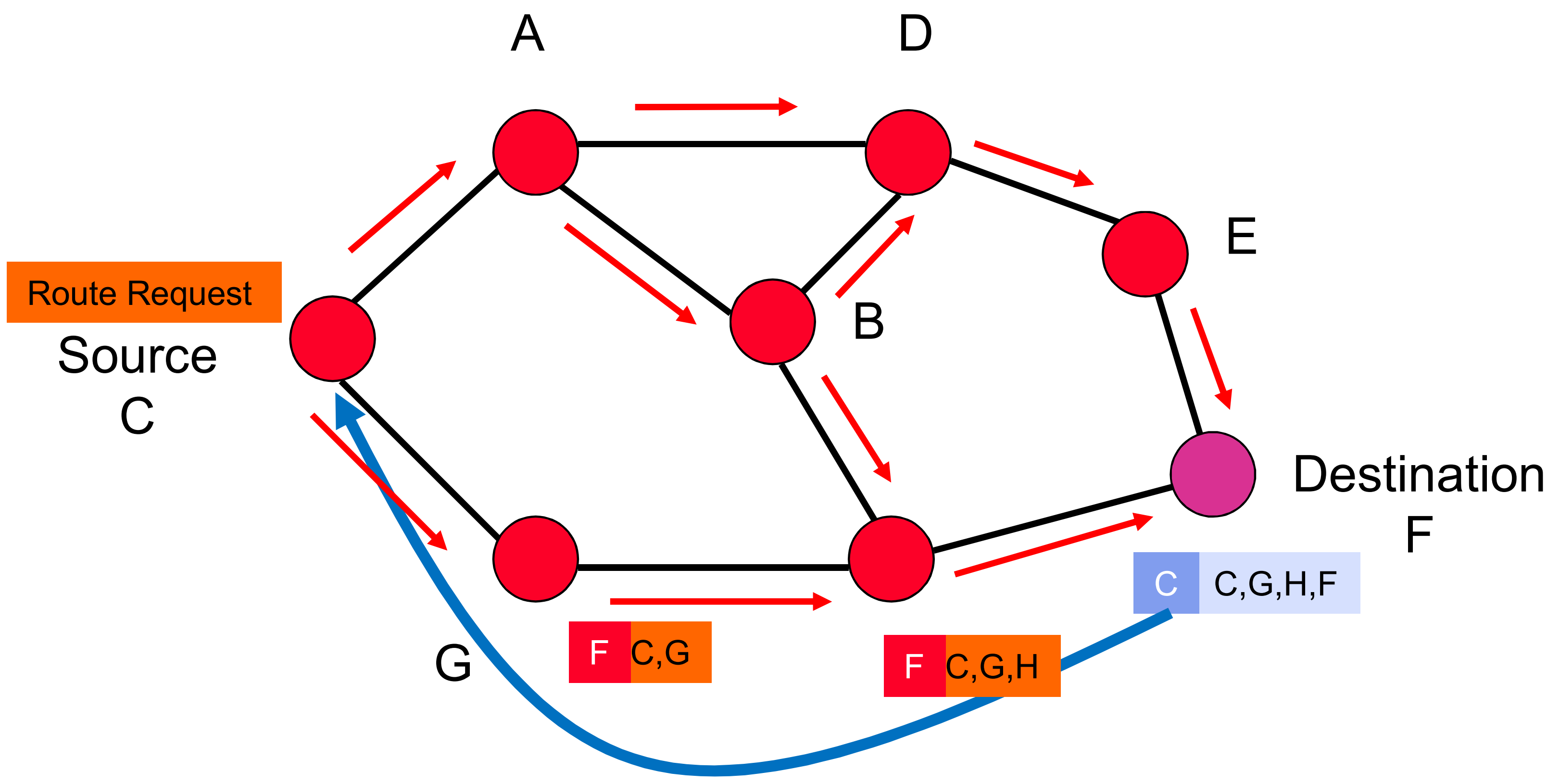



- On-demand route discovery finds route only when it is needed
  - » Avoid overhead of periodic route advertisements
- Uses source routing: path information is stored in the packet header
- DSR control functions:
  - » Route discovery: senders obtain route to destination
  - » Route maintenance: detect changes in topology and update routes that are affected
  - » Route caching: nodes cache route information to avoid route discovery for every packet
    - – Caching can be done on sender and intermediate routers
    - – Flush broken routes from cache

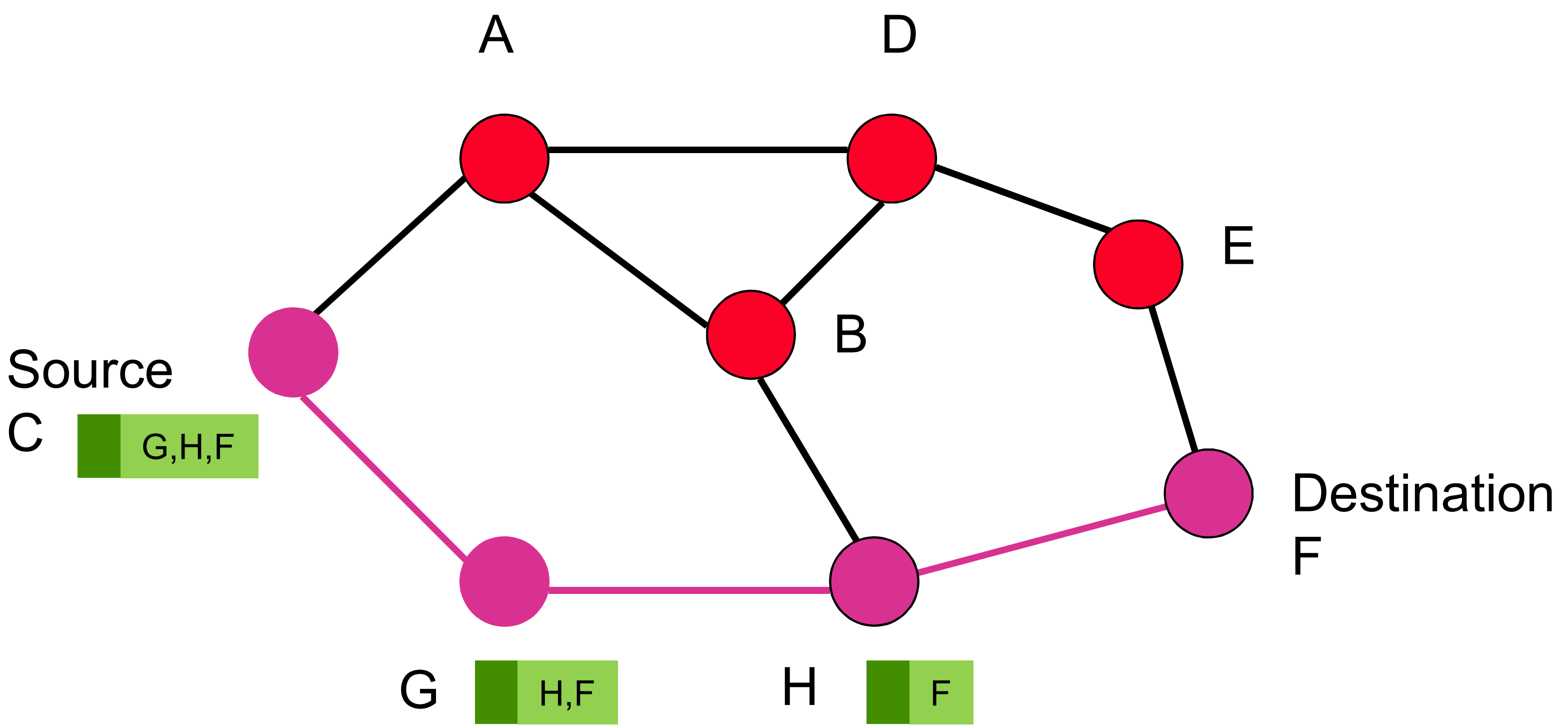
# DSR Route Discovery

- Source broadcasts a route-request towards the destination
  - » The request includes a (partial) path from source to destination
- Each node forwards the request by adding own address to the path and re-broadcasting
- Requests propagate outward until:
  - » The destination is found, or
  - » A node that has a route to the destination is found

# Route Request is Re-Broadcasted until Destination is Reached



# C Transmits a Packet to F



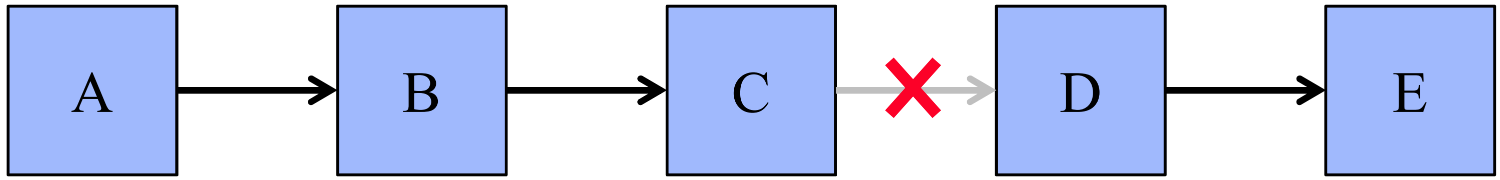
# Forwarding Route Requests

- A request is forwarded by a node if:
  - » Node is not the destination
  - » Node not already listed in recorded source route
  - » Node has not seen request with same sequence number
  - » IP TTL field may be used to limit scope
- Destination copies selected route into a Route-reply packet and sends it back to Source
  - » I.e., route reply uses reverse path of the route selected by the destination
  - » Destination can choose one of the paths, e.g., first path (with shortest delay)

# Route Cache

- All source routes learned by a node are kept in a Route Cache
  - » Routes are learned by overhearing route requests/responses
  - » Reduces cost of route discovery
- If an intermediate node receives a route request for a destination and has an entry for the destination in its route cache, it
  - » Responds to the request using the cached information
  - » Does not propagate the request any further
- Nodes use their local route cache when asked to send a data packet
  - » If route is missing, they initiate a route request

# Basic Route Maintenance




- **When forwarding a packet, each sender must get an acknowledgement from the next hop**
  - » **Will retransmit the packet up to a limit if needed**
- **If no ACK is received it drops the packet and notifies the sender A of the broken link**
- **A removes the route from its route cache and ..**
  - » **Intermediate nodes also remove any cached entries to E**
- **Will do a new route discovery when it sends another packet to E**
  - » **It is left up to TCP to recover from the packet loss**

# Discussion

- Source routing is good for certain types of networks and traffic loads
  - For example, stable traffic flows and/or a small number of sender-receiver pairs
  - Stable network topologies, e.g., with limited mobility
- Periodic messages are avoided
- Significant delay for the first packet to a destination
  - Also, need to buffer packets

# Overview

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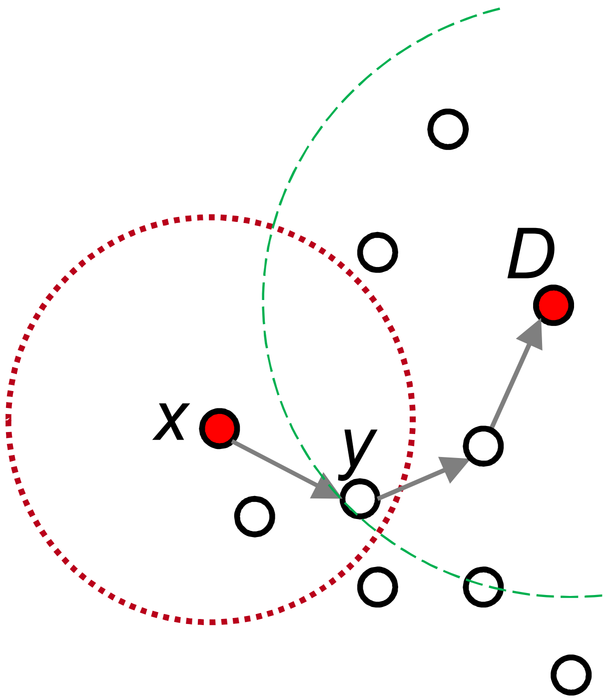
# Greedy Perimeter Stateless Routing (GPSR)

- Use *positions* of neighboring nodes and packet destination to forward packets
  - No connectivity or global topology is assumed – no forwarding or path information anywhere!
  - Nodes are assumed to know their location
  - Need a mechanism for address-to-location look up
- Two forwarding techniques is used
  - *Greedy forwarding*, if possible
  - *Perimeter forwarding*, otherwise

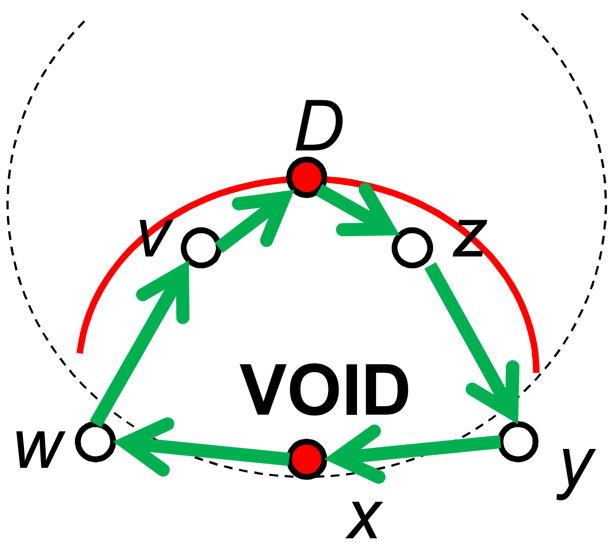
# GPSR – Greedy forwarding

- A sender/forwarder *x* chooses to forward to a neighbor *y* such that $\{d_{xy} + d_{yD}\}$ is minimum



# GPSR – Perimeter forwarding

- **What happens if a node does not have a neighbor that is closer to the destination?**
- **Right Hand Rule: you forward the packet to your first neighbor clockwise around yourself**
  - **Traverse an interior region in *clockwise* edge order**
  - **Guaranteed to reach a (reachable) destination for planar graph**




This sequence of edges traversed is called a *PERIMETER*

# Discussion

- Many variants:
  - » Hybrid approaches mix different solutions
  - » Hierarchical: create a hierarchy of clusters
- Many proposals for optimizations
  - » Links use different frequencies, multiple radios, etc.
  - » Link metrics that consider interference level, …
- Best solutions is highly context dependent: density, traffic load, degree of mobility, …
- Practical applications are rare by exist:
  - » Mesh networking: wireless, last mile Internet access
  - » Challenging conditions: first responders, military, ..
  - » In the future maybe vehicular, drones, …

# Summary

- Ad hoc networks face many challenges
  - » Bad links, interference, mobility, …
  - » Makes routing very challenging
  - » Limited support: hardware and driver limitations
- Many proposals!
  - » Proactive routing: variants of "wired" routing protocols
  - » Reactive routing: only establish a path when it is needed
  - » Geographic routing: use destination location info only
  - » Many variants and extensions
- Specific challenges depend on the application domains
  - » Mesh versus vehicular
  - » Active area of research

# Some References

- **DSR:**
  - » www.cs.rice.edu/~dbj/pubs/aw-dsr.pdf
- **DSDV:**
  - » www.cs.jhu.edu/~cs647/class-papers/Routing/p234-perkins.pdf
- **GPSR:**
  - » www.eecs.harvard.edu/~htk/publication/2000-mobi-karp-kung.pdf
- **ETX:**
  - » pdos.csail.mit.edu/papers/grid:mobicom03/paper.pdf
- **ETT**
  - » http://www.cs.jhu.edu/~cs647/class-papers/Routing/p114-draves.pdf