Wireless Networks
Lecture 14:
Mesh and Ad Hoc Networks

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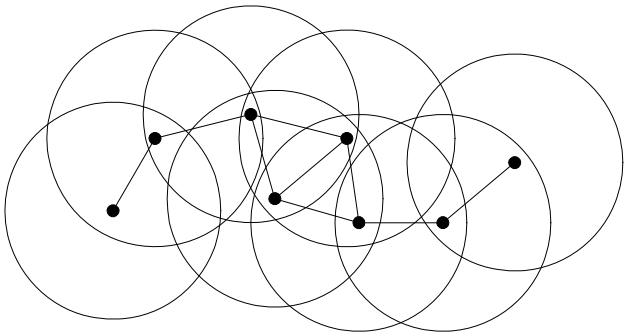
Overview

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

Ad Hoc Networking

- Goal: Communication between wireless nodes
  - » No infrastructure – network must be self-configuring
  - » It may require multiple hops to reach a destination



Ad Hoc Networking Challenging

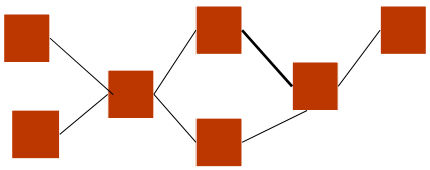
- All the challenges of wireless, plus some of:
  - » No fixed infrastructure
  - » Mobility and multi-hop!
  - » Ad hoc – no rational "network design" – random!
  - » Decentralized – nobody is in charge!
  - » Can be arbitrarily bad: limited batteries, malicious nodes, high mobility, low density, ..
- Precise challenges depend on the application domain, e.g., vehicular networks versus first-responder networks versus sensor networks
- Nodes are traffic sources, sinks and forwarders
- The big challenge: Routing

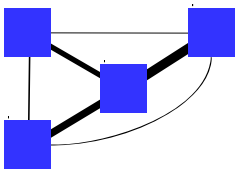
Ad Hoc Routing Requirements

- Find multi-hop paths through the network
- Low resource consumption
  - » Bandwidth, memory, CPU cycles, ..
- Adapt to new routes in response to movement and environment changes
- Deal with interference
  - » Many co-located wireless nodes
- Scale well with the number of nodes
  - » Localize effects of link changes

Traditional Routing vs Ad Hoc

- Traditional network:
  - » Well-structured
  - » ~O(N) nodes & links
  - » All links work ~= well
  - » Sensible topology
- Ad Hoc network
  - » N^2 links - but many stink!
  - » Topology may be really weird
  - » Reflections, multi-path and interference affect link quality unpredictably
    - – May affect both link throughput and topology





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Proactive or Table-based Protocols

- Proactive: routers maintain routes independently of the need for communication
  - » Similar to wired networking – uses forwarding table
- 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
- Routers maintain O(N) state per node, N = #nodes

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
- Traffic can be bursty → can cause congestion during periods of high activity
  - » Due to overhead caused by on-demand route discovery
- Route discovery introduces significant delay for the first packet of a new transfer
- Good for light loads, but the network can collapse under high loads

Many Other Variants

- Geographic routing: forward packet based on the geographic coordinates of the device
  - » No route discovery overhead and no network state stored on the device
- Hybrid approaches: used different algorithms in different parts of the network
- Hierarchical approaches: create a hierarchy of clusters
  - » Improve scalability be reducing routing overhead
- Best solutions is highly context dependent: density, traffic load, degree of mobility, …

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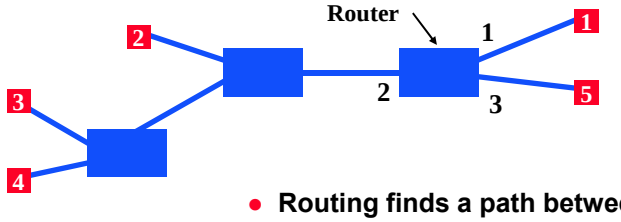
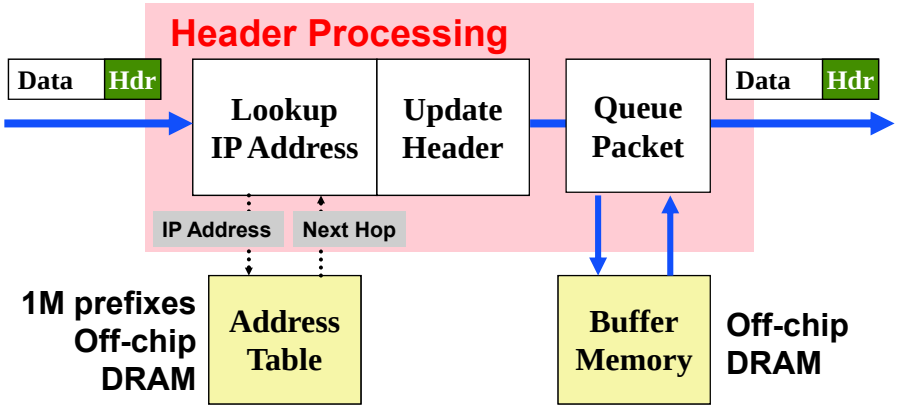
Packet Forwarding versus Routing



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

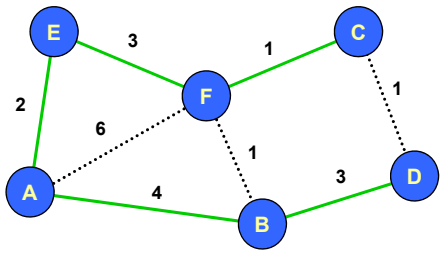
- Routing finds a path between two end-points
- Forwarding receives a packet and decides which egress port to send it out on
- Most networks use a routing protocol to pre-calculate paths between every pair of nodes
  - » The result is put in a forwarding table in every router
- Forwarding only requires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

Generic Router Architecture



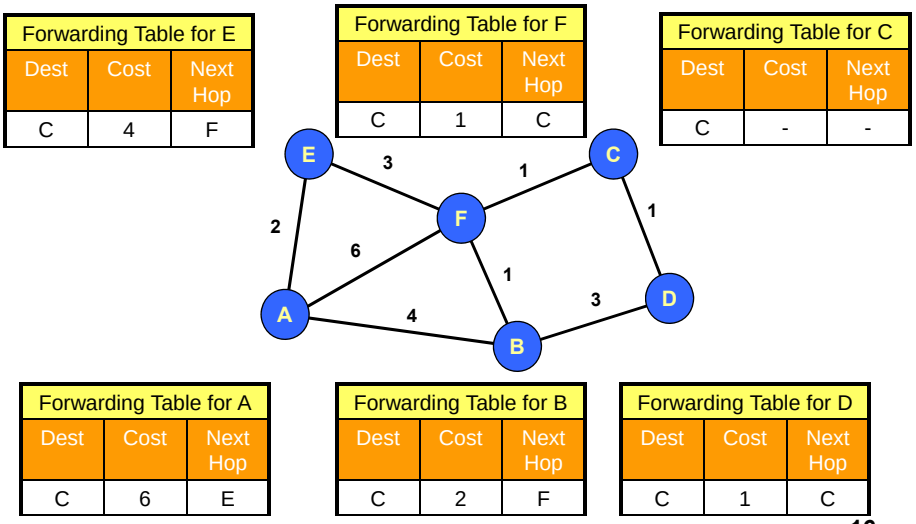
Routes from Node A

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

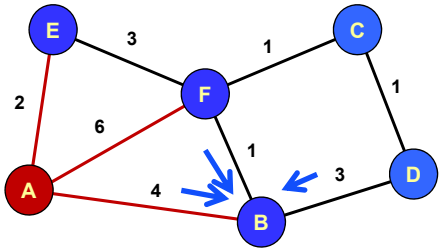


Traditional Routing Solutions

- **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)

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



- Each router periodically exchanges tables with its neighbors
  - » Contains the cost/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, cost
- Each node advertises its position
  - » Maintains fresh routes by periodically sending updates to neighbors
  - » Update for each destination: hop count, sequence number
- Uses sequence number to avoid loops
  - » Destinations include sequence number that is incremented for each update
  - » Is used to flush old information from the network

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DSR

- On-demand route discovery
  - » Only discover a route when you need it
  - » Avoid the overhead of periodic route advertisements
- Source routing: path information is stored in the packet header by the sender
  - » Intermediate nodes can have out of date information

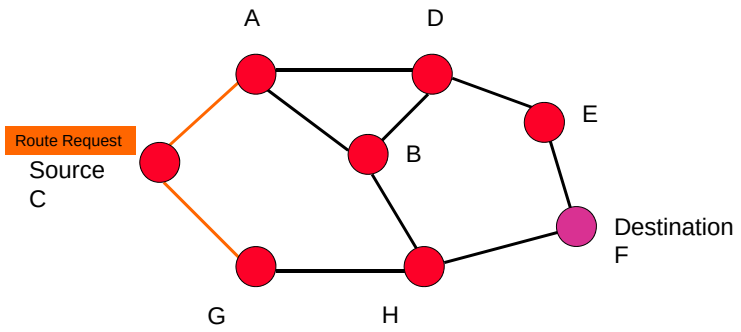
DSR Components

- Route discovery
  - The mechanism by which a sending node obtains a route to destination
- Route maintenance
  - The mechanism by which a sending node detects that the network topology has changed and its route to destination is no longer valid

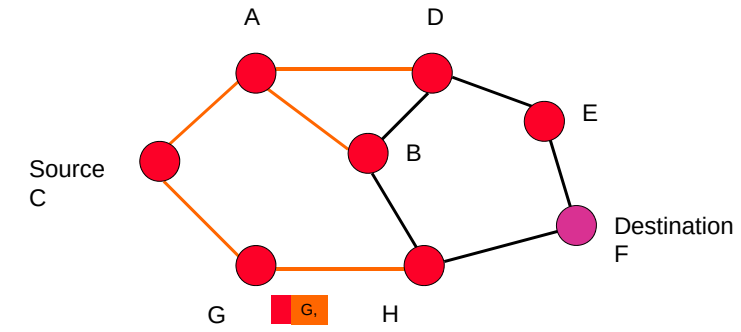
DSR Route Discovery

- 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

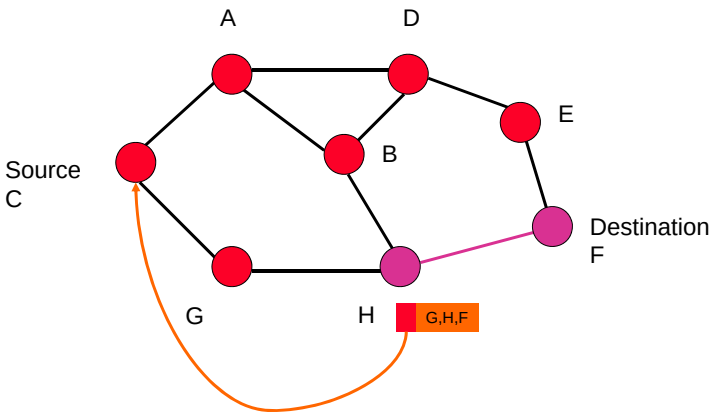
C Broadcasts Route Request to F



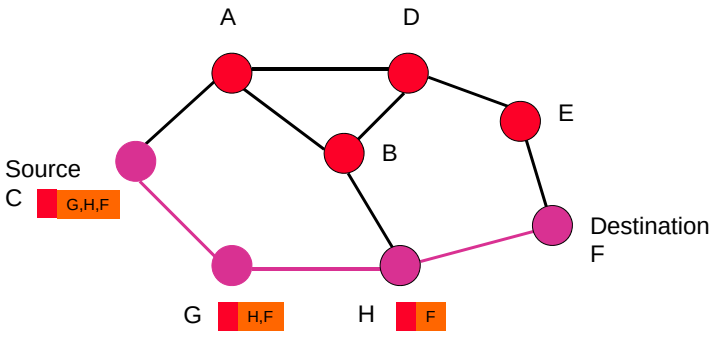
G Rebroadcasts Route Request



H Responds to Route Request



C Transmits a Packet to F



Forwarding Route Requests

- A request is forwarded 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 route into a Route-reply packet and sends it back to Source

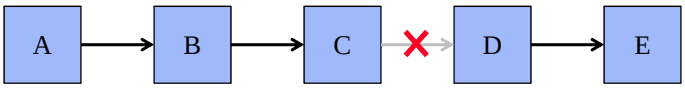
Route Cache

- All source routes learned by a node are kept in Route Cache
  - Reduces cost of route discovery
- If an intermediate node receives RR for a destination and has an entry for the destination in its route cache, it responds to RR and does not propagate RR further
- Nodes overhearing RR/RP may insert routes in their cache

Sending Data

- Check cache for route to destination
- If route exists then
  - » If reachable in one hop, send packet
  - » Else insert a routing header to the destination and send
- If no route exists, buffer the packet and initiate route discovery

Basic Route Maintenance



- 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 will remove the route from its route cache and ..
- 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
  - » If A has alternative paths in its route cache, it can use those instead

Discussion

- Source routing is good for certain types of networks and traffic loads
  - » For example, stable traffic flows or networks with limited mobility
- Route discovery protocol used to obtain routes on demand
  - » Caching used to minimize use of discovery
- Periodic messages avoided
- But need to buffer packets
- How do you decide between candidate paths?