18-452/18-750
Wireless Networks and Applications
Lecture 11:
Mesh and Ad Hoc Networks

Peter Steenkiste

Spring Semester 2017

http://www.cs.cmu.edu/~prs/wirelessS17/

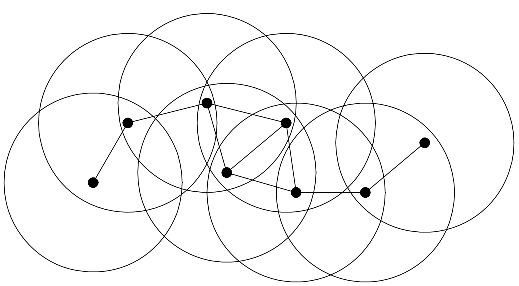
Overview

Context: ad hoc routing course project

- 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

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

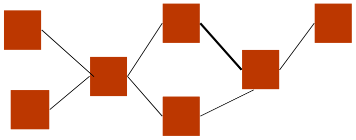
- All the challenges of wireless, plus some of:
  - » No fixed infrastructure
  - » Mobility and multi-hop!
  - » Ad hoc – no rational "network design" – random!
  - » Decentralized – nobody is in charge!
  - » Can be arbitrarily bad: limited batteries, malicious nodes, high mobility, low density, ..
- 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

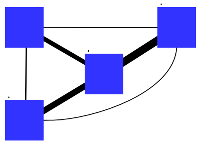
Ad Hoc Routing Requirements

- 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





Forwarding Packets is expensive

- Assume link throughput is X
  - » X depends on the WiFi version
  - » Distance, obstacles and fading reduce capacity
- What is throughput of a chain?
  - » A -> B -> C ?
  - » A -> B -> C -> D ?
  - » Assume minimum power for radios.
  - » Now assume a dense network, i.e., all radios can hear each other
- Routing metric should take this into account

Overview

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

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

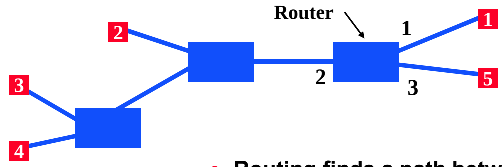
Many Other Variants

- 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, …

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

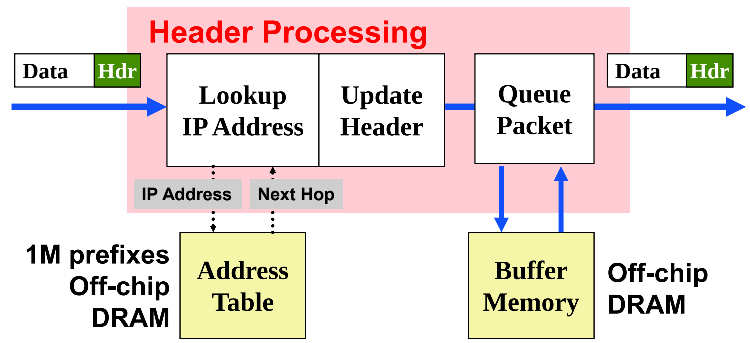
Packet Forwarding versus Routing



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

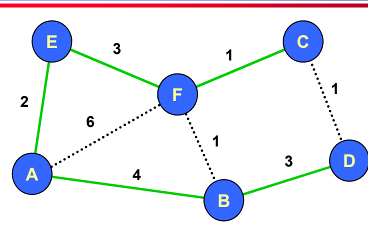
- Routing finds a path between two end-points
- Forwarding receives a packet and decides which egress port to send it out on
- Most networks use a routing protocol to pre-calculate paths between every pair of nodes
  - » The result is put in a forwarding table in every router
- Forwarding only requires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



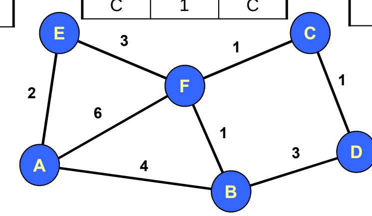
- Set of shortest paths forms tree
  - » Shortest path spanning tree
- Solution is not unique
  - » E.g., A-E-F-C-D also has cost 7

Different View: How to Get to Node C

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

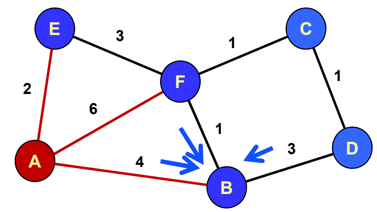
Forwarding Table for D		
Dest	Cost	Next Hop
C	1	C

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 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
  - » Destinations include sequence number that is incremented for each update
  - » Is used to flush old information from the network

DSDV Properties

- Keep the simplicity of Distance Vector
- Guarantee Loop Freeness
  - » New Table Entry for Destination Sequence Number
- Allow fast reaction to topology changes
  - » Make immediate route advertisement on significant changes in routing table
  - » but wait with advertising of unstable routes (damping fluctuations)

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

DSDV Table Format

Destination	Next	Metric	Seq. Nr	Install Time	Stable Data
A	A	0	A-550	001000	Ptr_A
B	B	1	B-102	001200	Ptr_B
C	B	3	C-588	001200	Ptr_C
D	B	4	D-312	001200	Ptr_D

- Sequence number originated from destination
  - » Ensures loop freeness
- Install Time when entry was made
  - » Used to delete stale entries from table
- Stable Data Pointer to a table holding information on how stable a route is
  - » Used to damp fluctuations in network

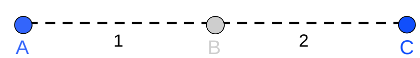
DSDV Advertisements

- Advertise to each neighbor own routing information
  - » Destination Address
  - » Metric = Number of Hops to Destination
  - » Destination Sequence Number
- Rules to set sequence number information
  - » On each advertisement increase own destination sequence number (use only even numbers)
  - » If a node is no more reachable (timeout) increase sequence number of this node by 1 (odd sequence number) and set metric = ∞

DSDV Route Selection

- Information in advertisements is compared to content of routing table
  1. Select route with higher destination sequence number (This ensure to use always newest information from destination)
  2. Select the route with better metric when sequence numbers are equal.
     – Routing metrics can be path length in hops, or metrics that capture link quality

DSDV Example

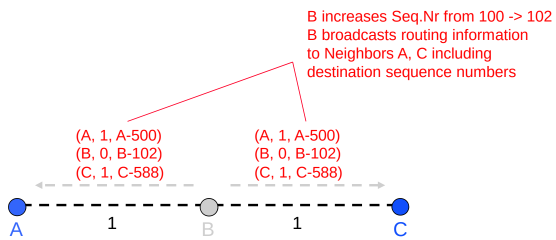


Dest.	Next	Metric	Seq
A	A	0	A-550
B	B	1	B-100
C	B	3	C-586

Dest.	Next	Metric	Seq
A	A	1	A-550
B	B	0	B-100
C	C	2	C-588

Dest.	Next	Metric	Seq.
A	B	1	A-550
B	B	2	B-100
C	C	0	C-588

DSDV Advertisement



Dest.	Next	Metric	Seq
A	A	0	A-550
B	B	1	B-102
C	B	2	C-588

Dest.	Next	Metric	Seq
A	A	1	A-550
B	B	0	B-102
C	C	1	C-588

Dest.	Next	Metric	Seq.
A	B	2	A-550
B	B	1	B-102
C	C	0	C-588

DSDV Dealing with Topology Changes

- Immediate advertisements
  - » Information on new Routes, broken Links, metric change is immediately propagated to neighbors.
- Full/Incremental Update:
  - » Full Update: Send all routing information from own table.
  - » Incremental Update: Send only entries that has changed. (Make it fit into one single packet)

Other DSDV Features

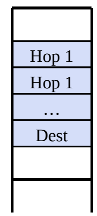
- Sequence number is used to recover from failures quickly and to avoid loops
  - » When a link failure is detected, increment sequence number by one and advertise
  - » This effectively “poisons” all stale routing entries
  - » New even sequence number used for new routes
- Stability information can be used to avoid rapid fluctuations in routing tables
  - » E.g., oscillating between two paths of similar quaility
  - » Give preference to the more stable path

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

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



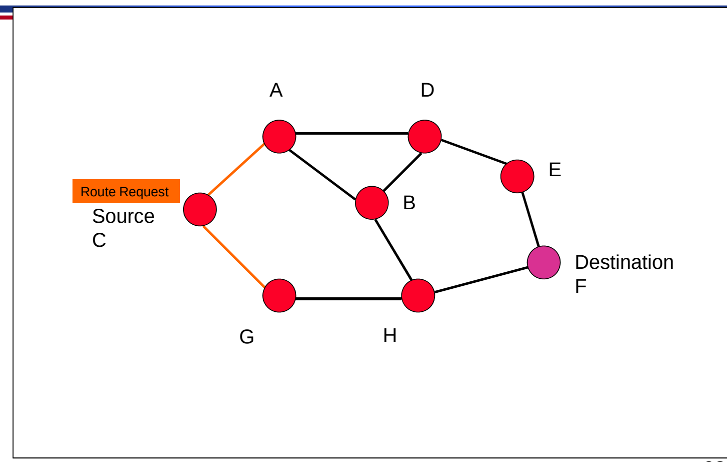
DSR Components

- 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

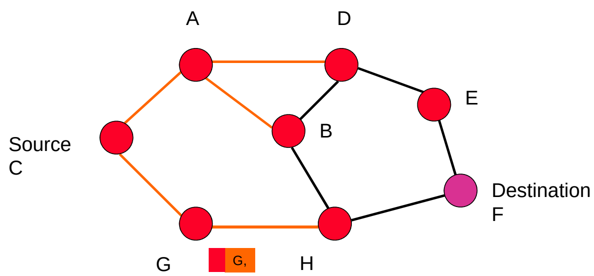
DSR Route Discovery

- 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

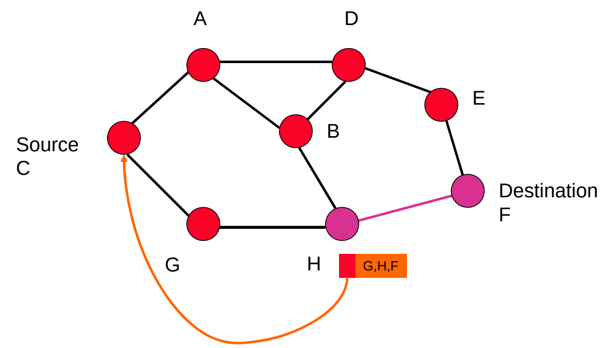
C Broadcasts Route Request to F



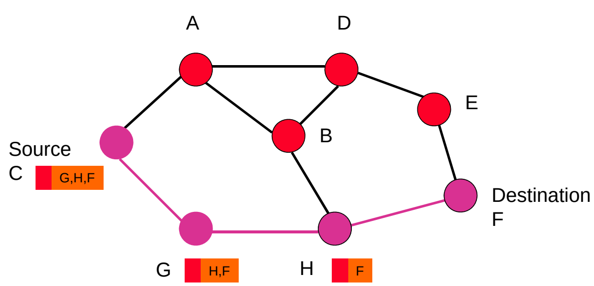
G Rebroadcasts Route Request



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**

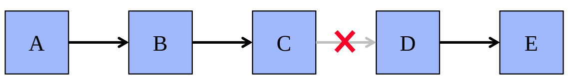
Route Cache

- 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?

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