EEC 687/787 Mobile Computing (Spring 2007)

Routing in Mobile Ad Hoc Networks

Chansu Yu

Cleveland State University

Contents

Network layer solutions in infrastructure-less networks

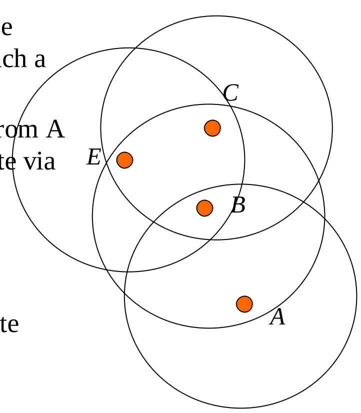
- What is MANET: Mobile ad hoc (multihop) networks?
- Routing algorithms for MANETs
  - Dynamic Source Routing (DSR)
  - Routing in Fixed Networks
    - Distance Vector (DV) Algorithm
    - Link State (LS) Algorithm
  - Destination Sequence Distance Vector (DSDV) & Ad-hoc On-Demand Distance Vector (AODV)

Mobile Ad Hoc Networks (MANETs)

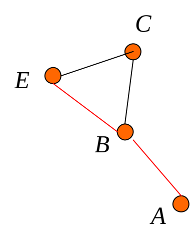
- A collection of mobile hosts may form a temporary network without the aid of any established infrastructure or centralized administration (base station)
- Routes between nodes may potentially contain multiple hops, thus also called multihop networks
- Better space utilization than direct communication
  - Requires a longer latency as for a single communication pair due to more number of hops
  - But the overall performance improves because simultaneous transmissions are allowed as long as they are separated in space
- Better energy utilization than direct communication

Mobile Ad Hoc Networks

- Multihop communication
  - May need to traverse multiple links to reach a destination
  - C is not reachable from A but can communicate via B
- Major difficulty
  - Mobility causes route changes



A graph can be used to model a MANET



Why Ad Hoc Networks ?

- Advantages
  - Ease of deployment
  - Speed of deployment
  - Decreased dependence on infrastructure
- Applications
  - Personal area networking
    - cell phone, laptop, ear phone, wrist watch
  - Military environments
    - soldiers, tanks, planes
  - Civilian environments
    - taxi cab network
    - meeting rooms
    - sports stadiums
    - boats, small aircraft
  - Emergency operations
    - search-and-rescue
    - policing and fire fighting

Characteristics of MANET

- Characteristics
  - Dynamic topology
  - Broadcast transmission: overhearing is possible
  - Bidirectional connection
  - Limited resources: bandwidth, CPU, battery
  - Higher link error rate
- Assumptions
  - Moderate movement with respect to packet transmission latency
  - Promiscuous receive mode
  - Enough number of mobile hosts: no network partitioning

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Dynamic Source Routing (DSR)

- Source determines the entire path to the destination when it has data packet to send
  - On-demand or reactive protocols
  - No periodic advertisements
- Three control packets: RREQ, RREP, RERR
- Procedures

  (1) Route discovery procedure

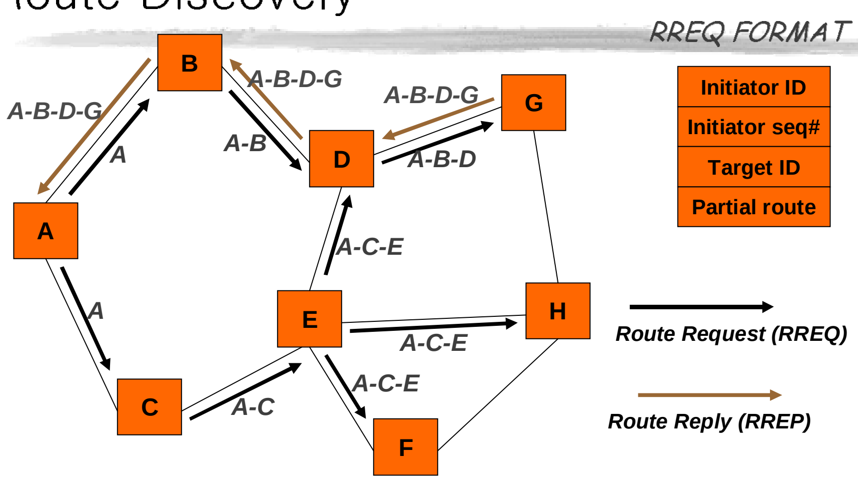
  (2) Route maintenance procedure

  (3) DSR Optimizations (Route cache)

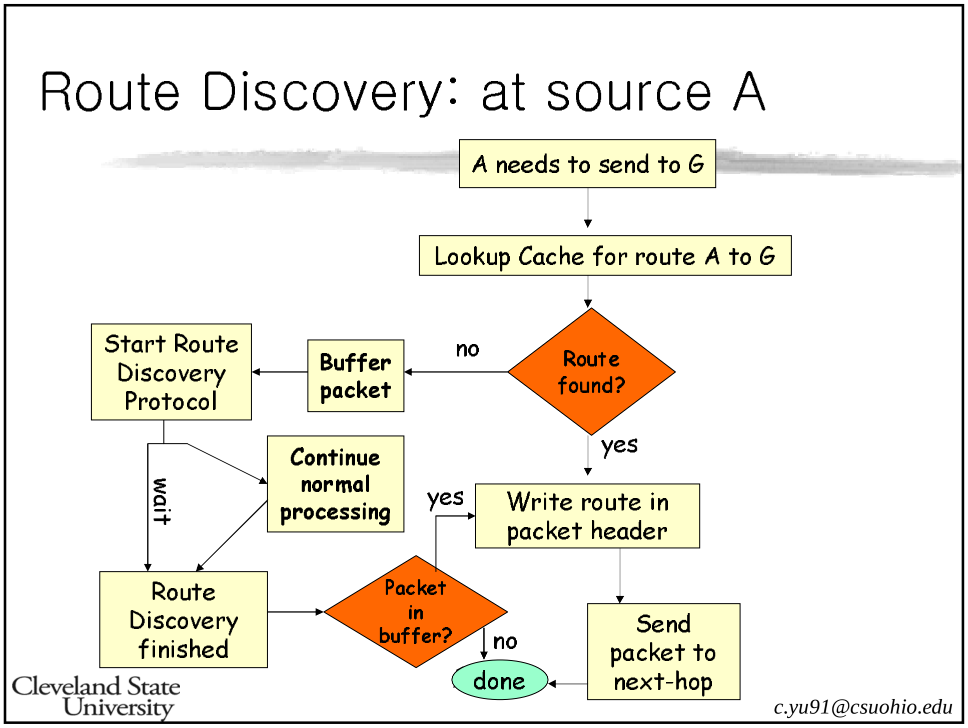
Assumption:

- Cooperative nodes
- Relatively small network diameter (5-10 hops)
- Detectable packet error
- Unidirectional or bidirectional link
- Promiscuous mode (optional)

Route Discovery



- Each node appends own identifier when forwarding RREQ
- RREQ is broadcast, while RREP is unicast


Route Discovery: at source A
A needs to send to G
Lookup Cache for route A to G
Route found?
no
Buffer packet
Start Route Discovery Protocol
wait
Continue normal processing
yes
Write route in packet header
yes
Route Discovery finished
Packet in buffer?
no
done
Send packet to next-hop
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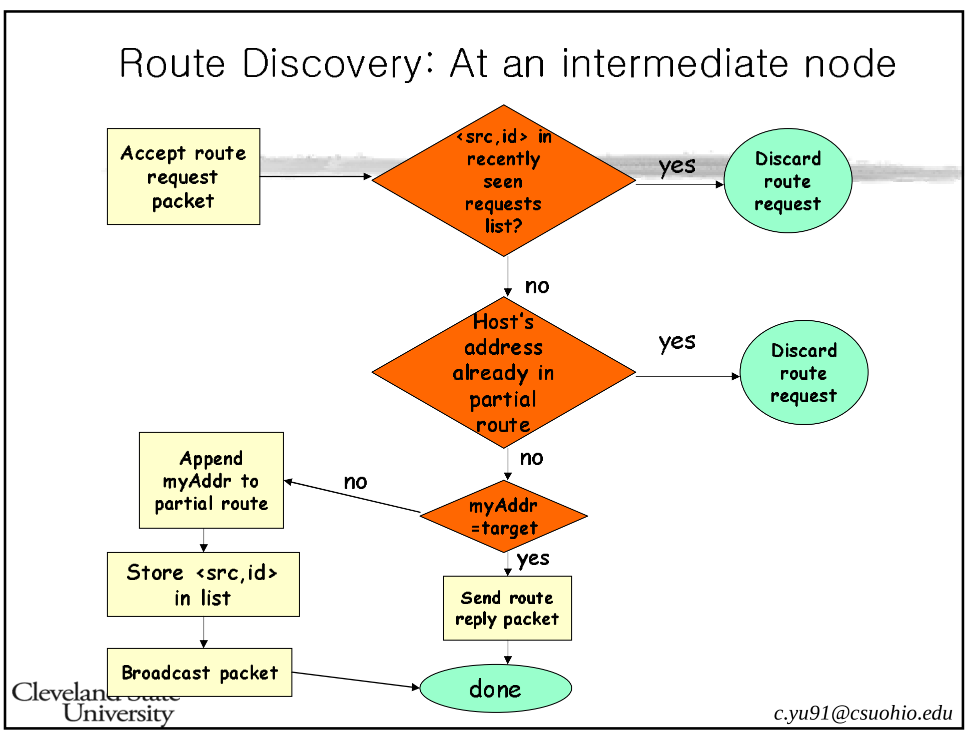
c.yu91@csuohio.edu


Route Discovery: At an intermediate node
Accept route request packet
<src,id> in recently seen requests list?
yes
Discard route request
no
Host's address already in partial route
yes
Discard route request
no
myAddr =target
no
Append myAddr to partial route
Store <src,id> in list
Broadcast packet
yes
Send route reply packet
done
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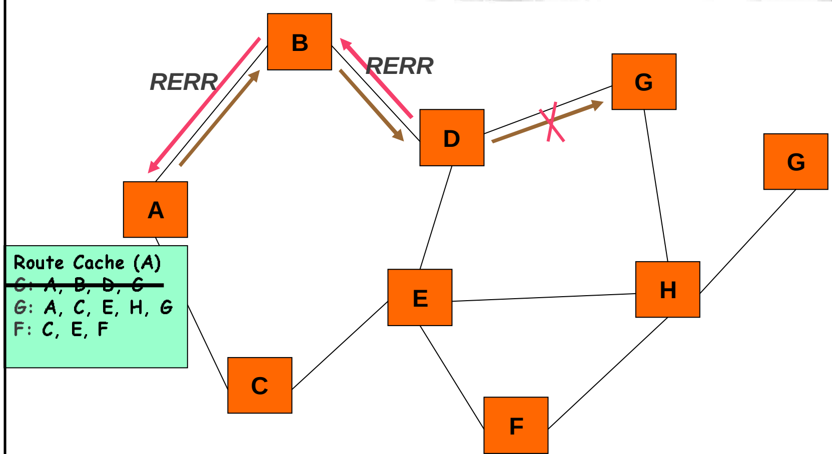
Route Reply in DSR

- ❑ **Route Reply can be sent by reversing the route in Route Request (RREQ) only if links are guaranteed to be bi-directional**
  - ➢ **To ensure this, RREQ should be forwarded only if it received on a link that is known to be bi-directional**
- ❑ **If unidirectional (asymmetric) links are allowed, then RREP may need a route discovery for S from node D**
  - ➢ **Unless node D already knows a route to node S**
  - ➢ **If a route discovery is initiated by D for a route to S, then the Route Reply is piggybacked on the Route Request from D.**
- ❑ **If IEEE 802.11 MAC is used to send data, then links have to be bi-directional (since Ack is used)**

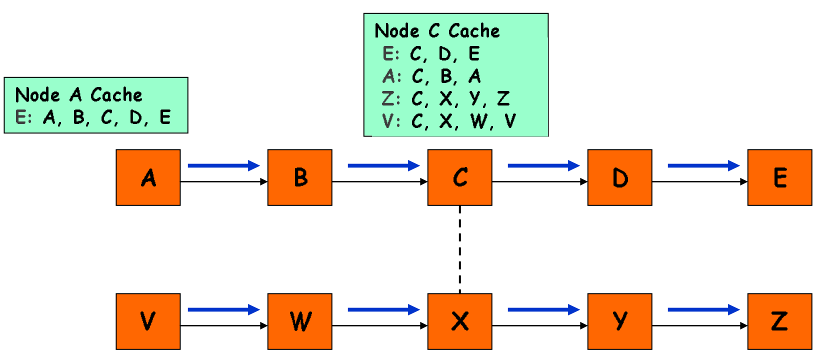
Now, Route is Discovered

- ❑ **Node S on receiving RREP, caches the route included in the RREP**
- ❑ **When node S sends a data packet to D, the entire route is included in the packet header**
  - ➢ **hence the name source routing**
- ❑ **Intermediate nodes use the source route included in a packet to determine to whom a packet should be forwarded**

Route Maintenance



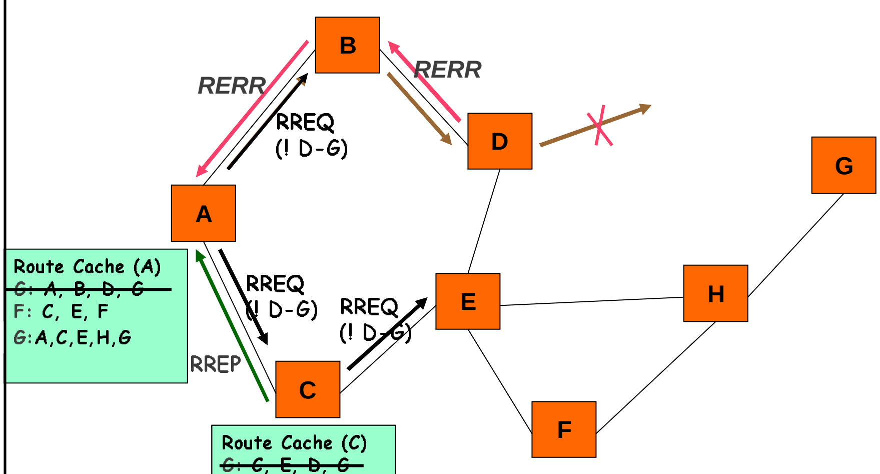
Additional feature #1: Caching Overheard Routes



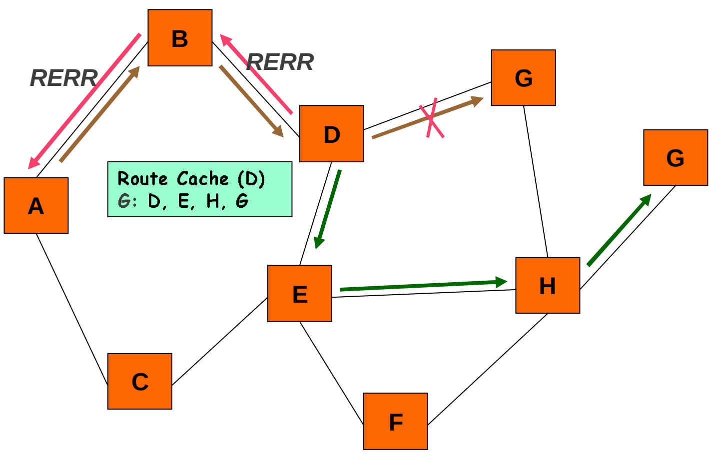
Route Caching: Beware!

- When sending a RREQ
  - Send first with TTL=1 hoping that nearby hosts have an entry: non-propagating route request
  - If no reply for some time, send RREQ with maximum TTL
  - This is called “Expand Ring Search”
- Beware
  - Stale caches can adversely affect performance
  - With passage of time and host mobility, cached routes may become invalid
  - A sender host may try several stale routes (obtained from local cache, or replied from cache by other nodes), before finding a good route
  - Adverse impact on TCP

Additional feature #2: RREP with Cached Routes



Additional feature #3: Packet Salvage



Caution: No double salvage allowed !!!

A Summary of DSR

- **Entirely on-demand, potentially zero control message overhead**
- **Trivially loop-free with source routing**
- **Conceptually supports unidirectional links as well as bidirectional links**

- **High packet delays/jitters associated with on-demand routing**
- **Space overhead in packets and route caches**
- **Promiscuous mode operations consume excessive amount of power**
- **Network partition problem - Message explosion problem (large number of route request packets)**
  - **Use exponential backoff to limit the rate at which new route discoveries may be initiated for the same target**

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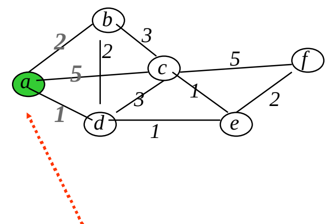
Unicast Routing in Fixed Networks

- Packet-switched fixed (wired) network
  - Packets are stored and forwarded (store-and-forward) toward destinations
  - Key issues
    - Routing : static (topology) and dynamic (traffic) factors
    - Congestion control
    - Error control
- Adaptive routing
  - Isolated adaptive
  - Centralized adaptive
  - Distributed adaptive : Distance vector or Link state

Unicast Routing in Fixed Networks



Node of interest

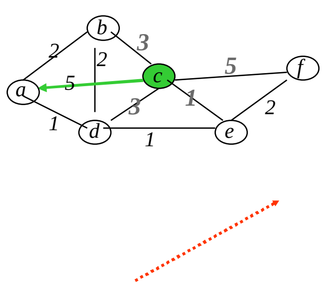
Node "a" keeps track of the shortest route to each destination.

Without any further information than from its direct neighbors,
node 'a' takes cost of 2 to reach b,
5 to reach c,
1 to reach d,
∞ to reach e and
∞ to reach f.

Thus, **Distance vector**=(2, 5, 1, ∞, ∞)
Next node vector=(b, c, d, ?, ?)

Cleveland State University
c.yu91@csuohio.edu

Unicast Routing in Fixed Networks



Distance vector algorithm

-Periodic info from neighbors
-Update routing table (vectors)

DV is updated when node "a" receives information from its neighbors b, c and d

For example, node "c" gives information on its cost to nodes b, d, e, and f.
With that information, nodes "a" has an updated DV
2 to b (via b),
4 to c (via d),
1 to d (via d),
6 to e (via c), and
10 to f (via c).
Thus, DV=(2, 4, 1, 6, 10)
Next node vector=(b, d, d, c, c)

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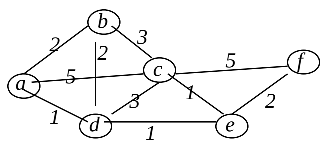
Unicast Routing in Fixed Networks



Every node updates its distance and next node vectors.

For example, the route “a” – “c” has been updated
“5” (directly)
=> “4” (via d)
=> “3” (via d and e)

Finally, at node “a”
DV = (2,3,1,2,4)
Next node vector = (b,d,d,d,d)

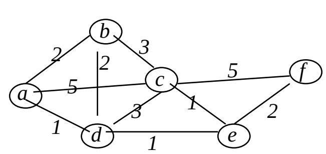
Unicast Routing in Fixed Networks

- Distance vector algorithm (Bellman-Ford)
  - Each node periodically broadcasts to its neighbors with the costs to all other nodes
  - Cost is measured by hop count or delay
  - ARPANET (1969): 128ms period
  - No knowledge of complete topology but simpler

Unicast Routing in Fixed Networks

- Link state algorithm (Dijkstra)
  - Each node periodically broadcasts to all other nodes with the costs to its neighbors
  - Cost is measured by queue length
  - New ARPANET (1979): 10s period
  - Complete knowledge of total topology but much overhead
- Each node
  - Computes the shortest path to all other nodes
  - Knows the overall topology ?

Unicast Routing in Fixed Networks



Node "a" got information from all nodes about their cost (LS or link state) to their neighbors

	a	b	c	d	e	f
a	-	2	5	1	∞	∞
b	2	-	3	2	∞	∞
c	5	3	-	3	1	5
d	1	2	3	-	1	∞
e	∞	∞	1	1	-	2
f	∞	∞	5	∞	2	-

And, then it can calculate the smallest cost to every other node using this set of information
- Cost vector & next hop vector

Does node "a" has the knowledge of overall topology?

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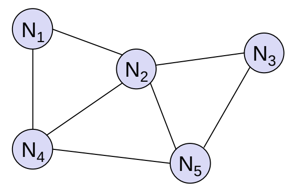
Destination-Sequenced Distance-Vector (DSDV)

- ❑ Each node maintains a routing table which stores
  - ➢ next hop towards each destination
  - ➢ a cost metric for the path to each destination
  - ➢ a destination sequence number that is created by the destination itself
  - ➢ Sequence numbers used to avoid formation of loops
- ❑ Each node periodically forwards the routing table to its neighbors
  - ➢ Each node increments and appends its sequence number when sending its local routing table
  - ➢ This sequence number will be attached to route entries created for this node

DSDV – Example

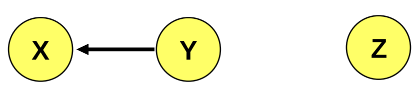
- At node N_1

Destination	Next hop	Metric	Sequence no.
N2	N2	1	S2-321
N3	N2	2	S3-218
N4	N4	1	S4-043
N5	N4	2	S5-092



DSDV – Route Maintenance

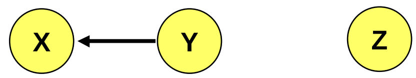
- Assume that node X receives routing information from Y about a route to node Z



- Let S(X) and S(Y) denote the destination sequence number for node Z as stored at node X, and as sent by node Y with its routing table to node X, respectively

DSDV – Route Maintenance

- Node X takes the following steps:



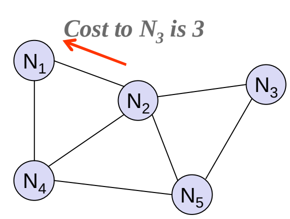
  - If S(X) > S(Y), then X ignores the routing information received from Y
  - If S(X) = S(Y), and cost of going through Y is smaller than the route known to X, then X sets Y as the next hop to Z
  - If S(X) < S(Y), then X sets Y as the next hop to Z, and S(X) is updated to equal S(Y)

DSDV – Example

- At node N_1

Destination	Next hop	Metric	Sequence no.
N2	N2	1	S2-321
N3	N2	2	S3-218
N4	N4	1	S4-043
N5	N4	2	S5-092

- If node N1 got info from N2
  - N1-N3 cost becomes 4
  - Should N1 take this or not?
    - If Seq#<218, ignore
    - If Seq#>218, take
    - If Seq#=218, compare cost

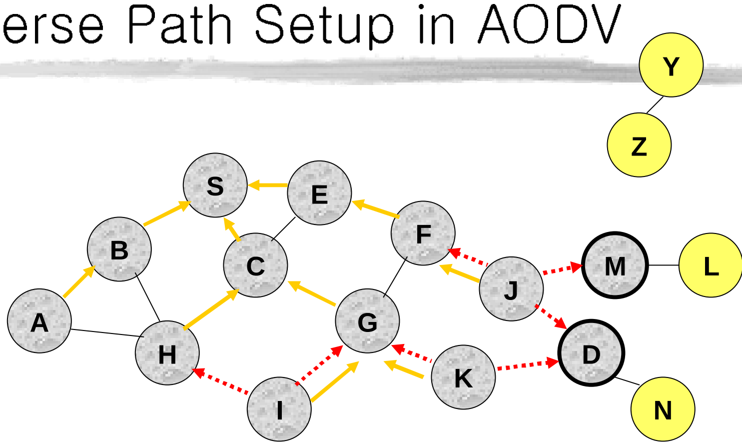


Ad Hoc On-Demand Distance Vector Routing (AODV)

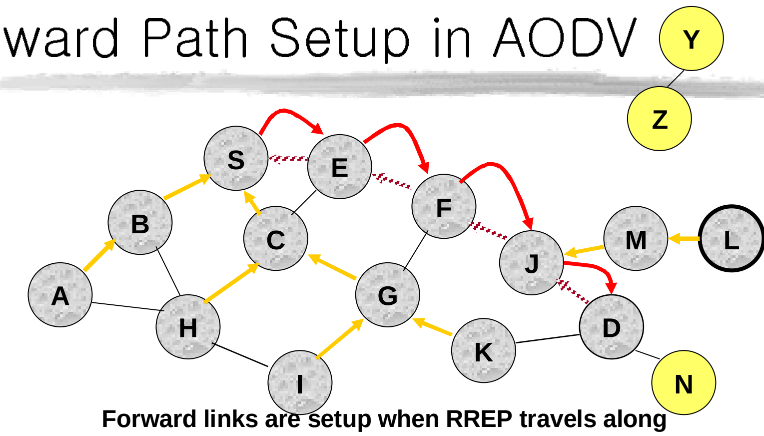
* Explained very well in C.E.Perkins' Ad Hoc Networking book

- DSR includes source routes in packet headers
- Resulting large headers can sometimes degrade performance
  - particularly when data contents of a packet are small
- AODV attempts to improve on DSR by maintaining routing tables at the nodes, so that data packets do not have to contain routes
- AODV retains the desirable feature of DSR that routes are maintained only between nodes which need to communicate

Reverse Path Setup in AODV



Forward Path Setup in AODV



Forward links are setup when RREP travels along the reverse path

Those paths are not included in the header of each data packet but stored in each node as a routing table or DV

Routing in MANET (Unicast)

- Many protocols have been proposed
  - Some have been invented specifically for MANET
  - Others are adapted from previously proposed protocols for wired networks
- No single protocol works well in all environments
  - some attempts made to develop adaptive protocols

- Proactive protocols (or called "Table-based")
  - Determine routes independent of traffic pattern
  - Traditional LS and DV routing protocols are proactive
- Reactive protocols (or called "On-demand")
  - Maintain routes only if needed (DSR)
- Hybrid protocols

Reactive Routing Protocols

- ❑ Flooding
  - ➢ Data packets are flooded to the destination
  - ➢ But also to all other nodes => much overhead but more reliable
- ❑ DSR (Dynamic Source Routing)
  - ➢ First, small control packet is flooded to discover a route
  - ➢ Then, unicast data packets along the discovered route
  - ➢ But each data packet includes the information on the entire path in its packet header => larger packet size
- ❑ AODV (Ad-hoc On-demand Distance Vector)
  - ➢ Route discovery as in DSR but each node keeps a routing table as in proactive algorithm to reduce the packet size
  - ➢ Reactive + Proactive

Trade-Off between Proactive and Reactive Protocols

- ❑ Latency of route discovery
  - ➢ Proactive protocols may have lower latency since routes are maintained at all times
  - ➢ Reactive protocols may have higher latency because a route from X to Y will be found only when X attempts to send to Y
- ❑ Overhead of route discovery/maintenance
  - ➢ Reactive protocols may have lower overhead since routes are determined only if needed
  - ➢ Proactive protocols can (but not necessarily) result in higher overhead due to continuous route updating
- ❑ Which approach achieves a better trade-off depends on the traffic and mobility patterns