EEC 687 Mobile Computing (Spring 2008)

Routing in Mobile Ad Hoc Networks

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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)

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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

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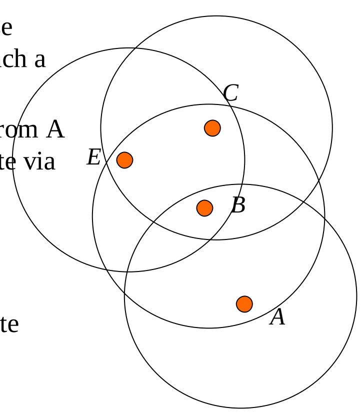
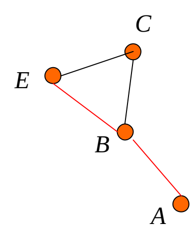
Mobile Ad Hoc Networks

- 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



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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

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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)

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Assumption:

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

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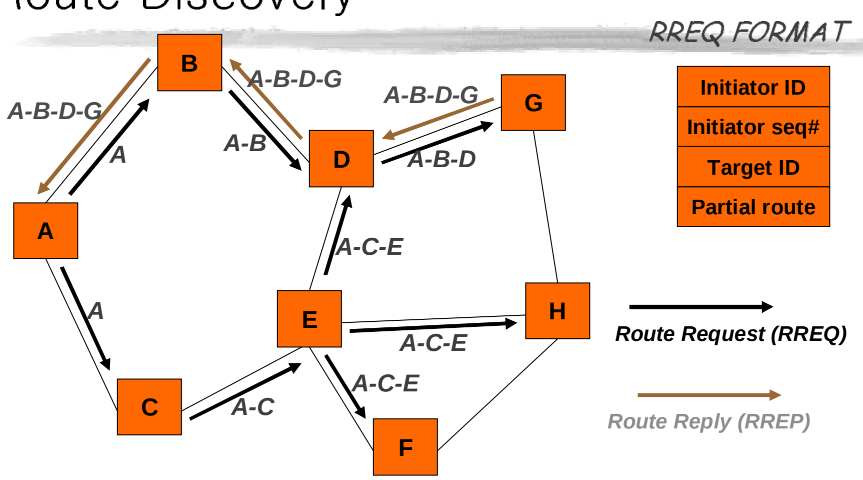
Route Discovery



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

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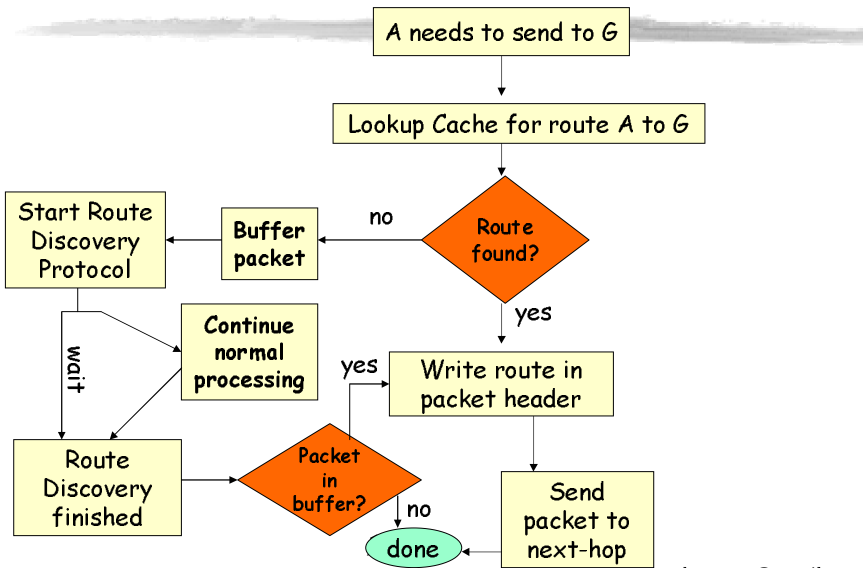
Route Discovery: at source A



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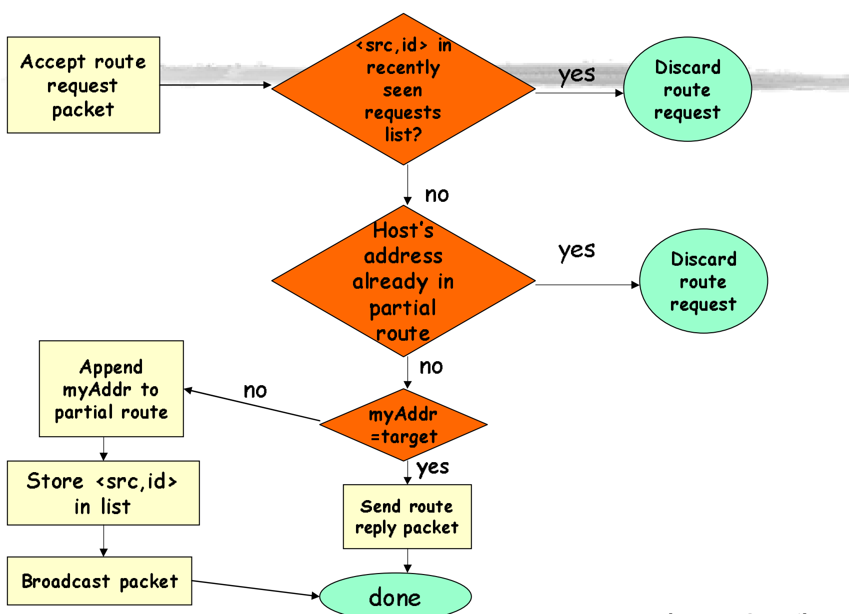
Route Discovery: At an intermediate node



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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 A from node G
  - Unless node G already knows a route to node A
  - If a route discovery is initiated by G for a route to A, then the Route Reply is piggybacked on the Route Request from G.
- If IEEE 802.11 MAC is used to send data, then links have to be bi-directional (since Ack is used)

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Now, Route is Discovered

- Node A on receiving RREP, caches the route included in the RREP
- When node A sends a data packet to G, 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

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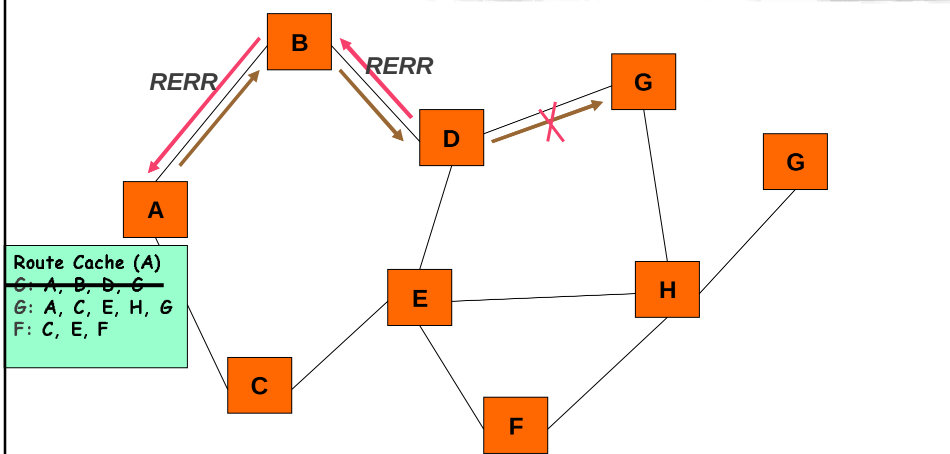
Route Maintenance



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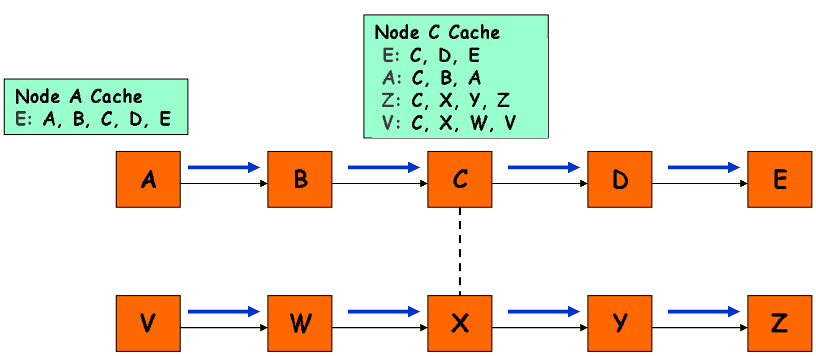
Additional feature #1: Caching Overheard Routes



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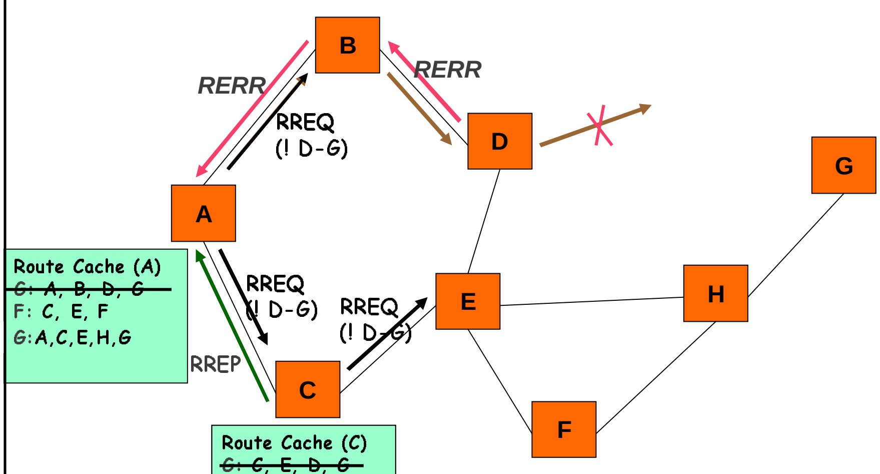
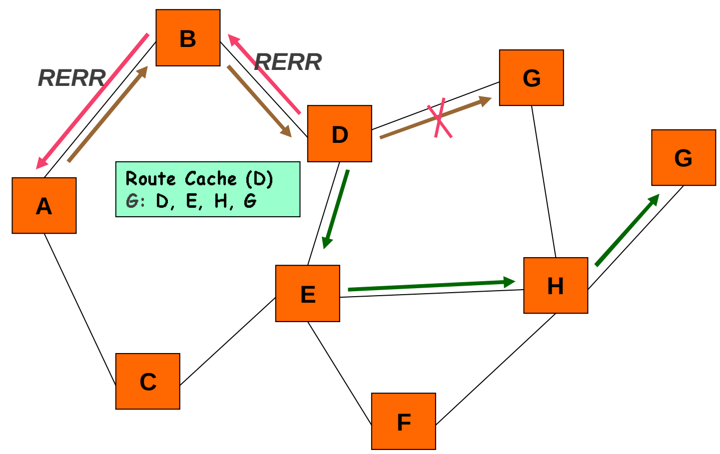
Route Caching: Beware!

- **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 !!!

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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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*With DSR, "**CMUPriQueue**" msut be used instead of "**Queue/DropTail/PriQueue**" for interface queue*

DSR in ns-2

- Use in ns-2

```
…
set val(rp)          DSR                    ;# routing protocol
…
 $ns_ node-config -adhocRouting $val(rp)
…                   -routerTrace ON
```

- Code is in $NS/dsr/dsragent.cc
- ns defaults - $NS/tcl/lib/ns-default.tcl
- Trace
  - s 128.014398266 _0_ RTR --- 3 DSR 24 [0 0 0 0] ------- [0:255 2:255 32 0] 1 [1 2] [0 2 0 0->0] [0 0 0 0->0]
  - Send, Time, Node, Router or agent, Packet (event) id, Packet type, Size

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DSR traces using DSR code

- Make changes in dsragent.cc and recompile ns
  - `static const int verbose = 1;`
  - `static const int verbose_srr = 1;`
- Verbose output
  - `S$miss 127.93668 _0_ 0 -> 2`
  - `Sdebug 127.93668 _0_ stuck into send buff 0 -> 2`
  - `S$hit 135.40639 _0_ 0 -> 2 [(0) 1 2 ]`
- Trace file analysis
  - Using grep and awk to get times of all cache misses:

```
$ cat file.tr > awk '$1=="S$miss"{print $2, $3}'
```

  - Using grep and awk to get times of all drops:

```
$ cat file.tr > awk '$1=="SRR" && $4=="dropped"{print $2, $3}'
```

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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

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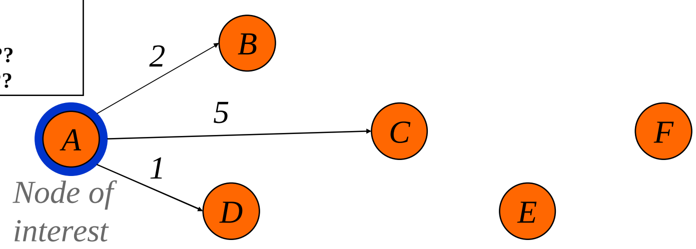
Unicast Routing in Fixed Networks

To get	Cost	Via
B	2	
C	5	
D	1	
E	???	
F	???	



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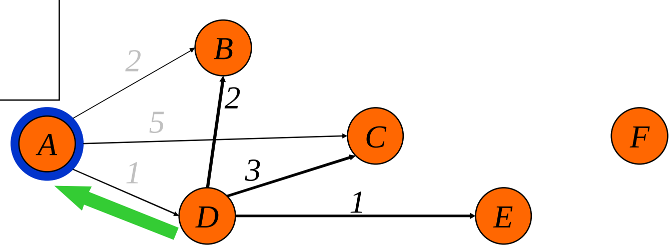
Unicast Routing in Fixed Networks

To get	Cost	Via
B	2	
C	5	
D	1	
E	???	
F	???	



To get	Cost	Via
A	1	
B	2	
C	3	
E	1	
F	???	

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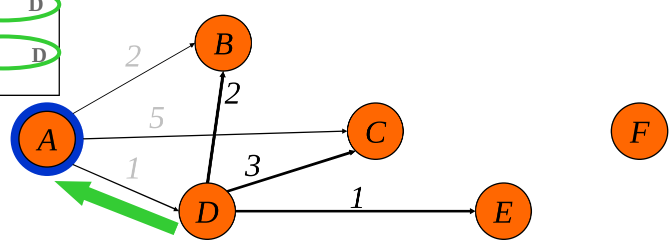
Unicast Routing in Fixed Networks

To get	Cost	Via
B	2	
C	4	D
D	1	
E	2	D
F	???	



To get	Cost	Via
A	1	
B	2	
C	3	
E	1	
F	???	

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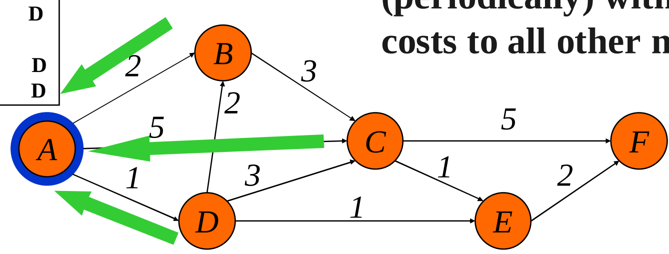
Unicast Routing in Fixed Networks

Each neighbor gives information (periodically) with the costs to all other nodes

To get	Cost	Via
B	2	
C	4	D
D	1	
E	2	D
F	4	D



Distance vector at A
= (2, 4, 1, 2, 4)
Next node vector at A
= (B, D, D, D, D)

Distance vector algorithm

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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

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Destination-Sequenced Distance-Vector (DSDV)

- Each node maintains a routing table which stores
  - next node towards each destination
  - a cost metric for the path to each destination
  - a 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

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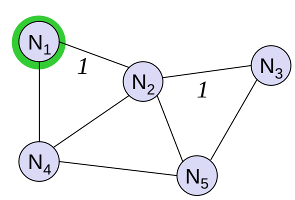
DSDV - Example

- 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



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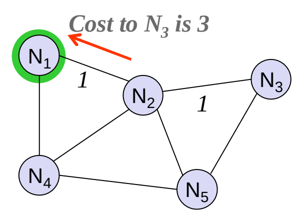
DSDV – Example

- 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

- Node N1 gets info from N2
  - N1-N3 cost becomes 4
  - Should N1 take this or not?



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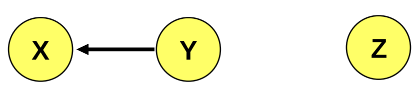
DSDV – Route Maintenance

- 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

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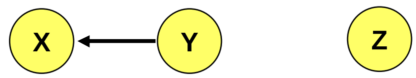
DSDV – Route Maintenance

- 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)

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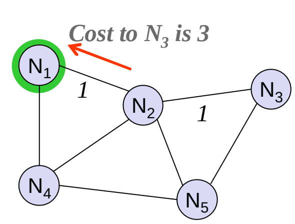
DSDV – Example

- 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

- Node N1 gets 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



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Ad Hoc On-Demand Distance Vector Routing (AODV)

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

- ❑ DSR vs DSDV
  - ➢ DSR typically outperforms DSDV because periodic control messages are not needed
  - ➢ A main drawback of DSR is the large packet header (entire route information)

- ❑ AODV = DSR + DSDV
  - ➢ Routes are discovered only when there are packets (on-demand) as in DSR
  - ➢ Nodes main distance and next node vectors as in DSDV to reduce the header size

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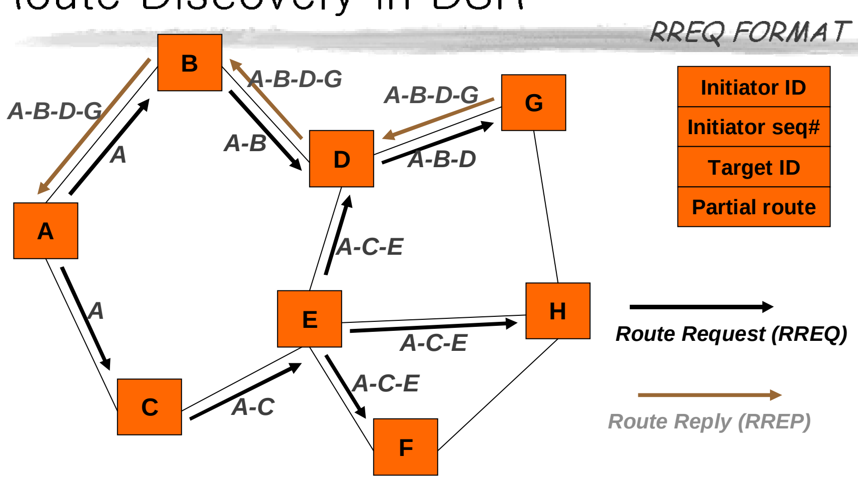
Route Discovery in DSR



- Each node appends own identifier when forwarding RREQ

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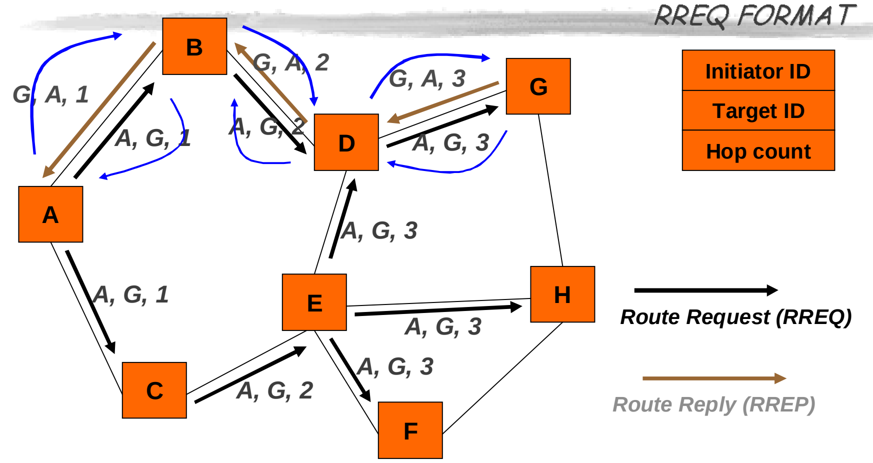
Route Discovery in AODV



- **Each node remembers** where the packet came from (reverse path) **during RREQ.**
- **It set up** forward path **during RREP.**

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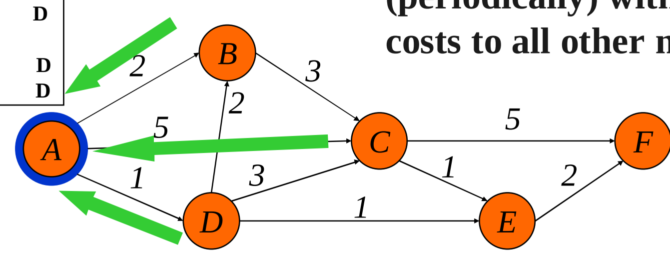
Unicast Routing in Fixed Networks (revisited)

To get	Cost	Via
B	2	
C	4	D
D	1	
E	2	D
F	4	D

Each neighbor gives information (periodically) with the costs to all other nodes



Distance vector at A
= (2, 4, 1, 2, 4)
Next node vector at A
= (B, D, D, D, D)

Distance vector algorithm

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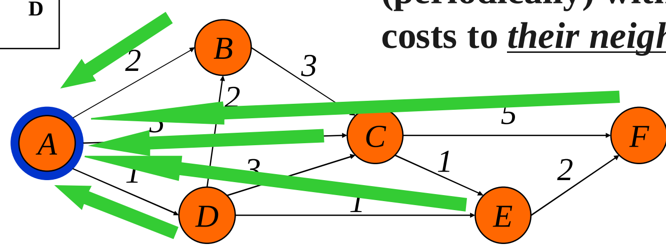
Unicast Routing in Fixed Networks

To get	Cost	Via
B	2	
C	4	D
D	1	

All other nodes **gives information (periodically) with the costs to *their neighbors***



Link state algorithm

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Unicast Routing in Fixed Networks (revisited)

- 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

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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 ?

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Link State Routing

- LSR
  - Each node periodically floods status of its links
  - Each node re-broadcasts link state information received from its neighbor
  - Each node keeps track of link state information received from other nodes
  - Each node uses above information to determine next hop to each destination
- Direct application of LSR in a MANET is difficult due to a large control overhead
  - Due to mobility, broadcast period cannot be reduced as in wired network

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Optimized Link State Routing (OLSR)

- The overhead of flooding link state information is reduced by requiring fewer nodes to forward the information
- A broadcast from node X is only forwarded by its *multipoint relays*
- Multipoint relays of node X are its neighbors such that each two-hop neighbor of X is a one-hop neighbor of at least one multipoint relay of X
  - Each node transmits its neighbor list in periodic beacons, so that all nodes can know their 2-hop neighbors, in order to choose the multipoint relays

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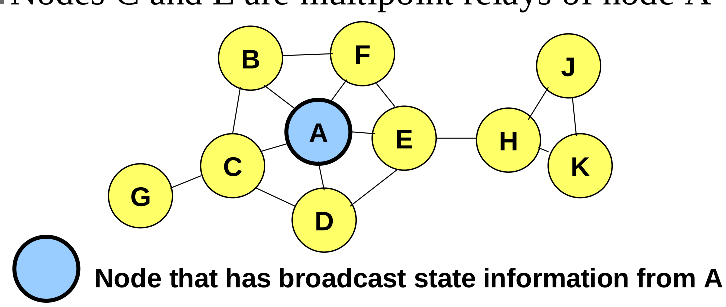
Optimized Link State Routing (OLSR)

- Nodes C and E are multipoint relays of node A



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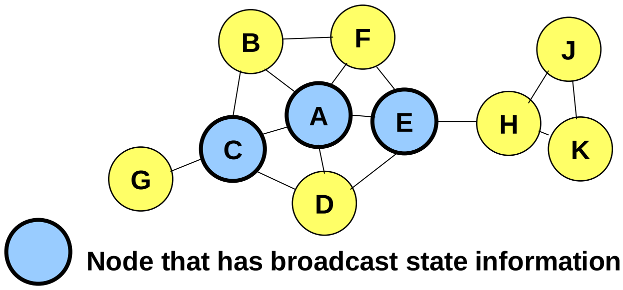
Optimized Link State Routing (OLSR)

- Nodes C and E forward information received from A



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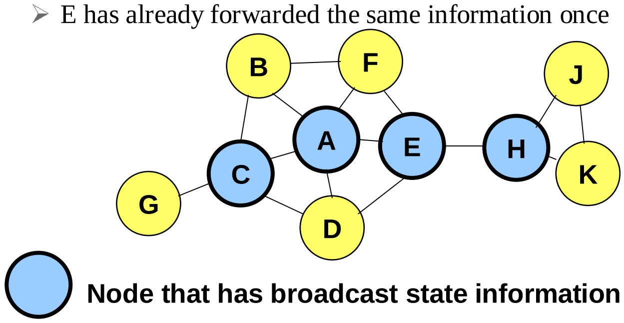
Optimized Link State Routing (OLSR)

- Nodes E and K are multipoint relays for node H
- Node K forwards information received from H
  - E has already forwarded the same information once



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Flooding of Control Packets

- How to reduce the scope of the route request flood ?
  - LAR (Localized Area Routing)
  - Query localization
- How to reduce redundant broadcasts ?
  - The Broadcast Storm Problem

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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

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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

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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

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