Ad Hoc On-Demand Distance Vector Routing (AODV)

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Unicasting

- The routing we have discussed so far is mainly point-to-point routing.
- A source node wants to send a message to a destination node.

Multicasting

- However, in many situations a node wants to send a message to a group of nodes in the network.
- This is called multicasting and the group is called a multicast group.

Broadcasting

- Broadcasting is a special case of multicasting when all the nodes in the network is in the multicast group.

Multicasting Support

- DSDV and DSR mainly support unicast routing.
- If multicasting is required, a node must establish unicast routes to each node in the multicast group.
- A more efficient approach will maintain multicast routing trees for each multicast group.

Non-uniform Packet Size in DSR

- Though DSR is a reactive or on-demand routing protocol, a major problem with DSR is its non-uniform packet size.

- When a source node S sends a packet to a destination node D, S should send the entire route to D along with the packet.

- This is necessary for the intermediate nodes to forward the packet.

Problem with Non-uniform Packet Size

- Usually all media support packets of uniform size. If a packet is large, it has to be split into smaller packets.
- This may cause problems in the wireless medium as packets that are split into smaller parts may not arrive in correct order.
- Intermediate nodes may not be able to forward packets correctly.

Main Features of the AODV Protocol (I)

- The Ad hoc On-Demand Distance Vector protocol is both an on-demand and a table-driven protocol.
- The packet size in AODV is uniform unlike DSR. Unlike DSDV, there is no need for system-wide broadcasts due to local changes.
- AODV supports multicasting and unicasting within a uniform framework.

Main Features of the AODV Protocol (II)

- Each route has a lifetime after which the route expires if it is not used.
- A route is maintained only when it is used and hence old and expired routes are never used.
- Unlike DSR, AODV maintains only one route between a source-destination pair.

Continued

- 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.

Unicast Route Establishment

- Unicast route is a route from a source node to a destination node.
- Like DSR, this protocols uses two types of messages, route request (RREQ) and route reply (RREP).
- Like DSDV, we use sequence numbers to keep track of recent routes. Every time a node sends a new message, it uses a new sequence number which increases monotonically.

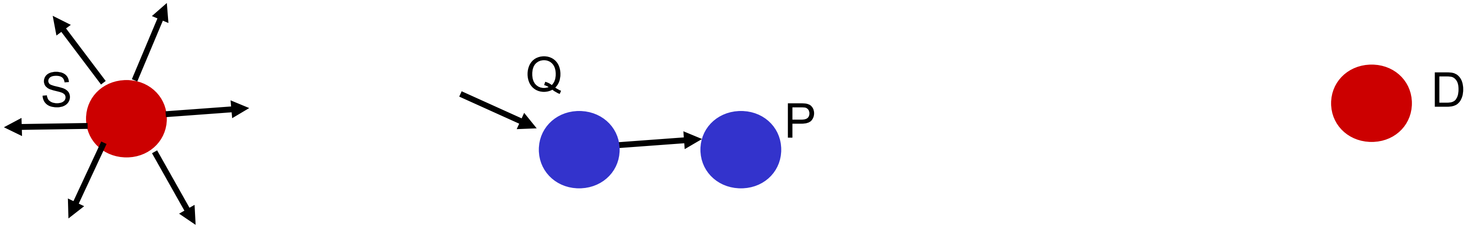
Route Request (RREQ) Message

- When node S wants to send a message to node D, S searches its route table for a route to D.
- If there is no route, S initiates a RREQ message with the following components :
  - The IP addresses of S and D
  - The current sequence number of S and the last known sequence number of D
  - A broadcast ID from S. This broadcast ID is incremented each time S sends a RREQ message.

Processing a RREQ Message (I)

- The <broadcast ID, IP address> pair of the source S forms a unique identifier for the RREQ.
- Suppose a node P receives the RREQ from S. P first checks whether it has received this RREQ before.
- Each node stores the <broadcast ID, IPaddress> pairs for all the recent RREQs it has received.

Processing a RREQ Message (II)

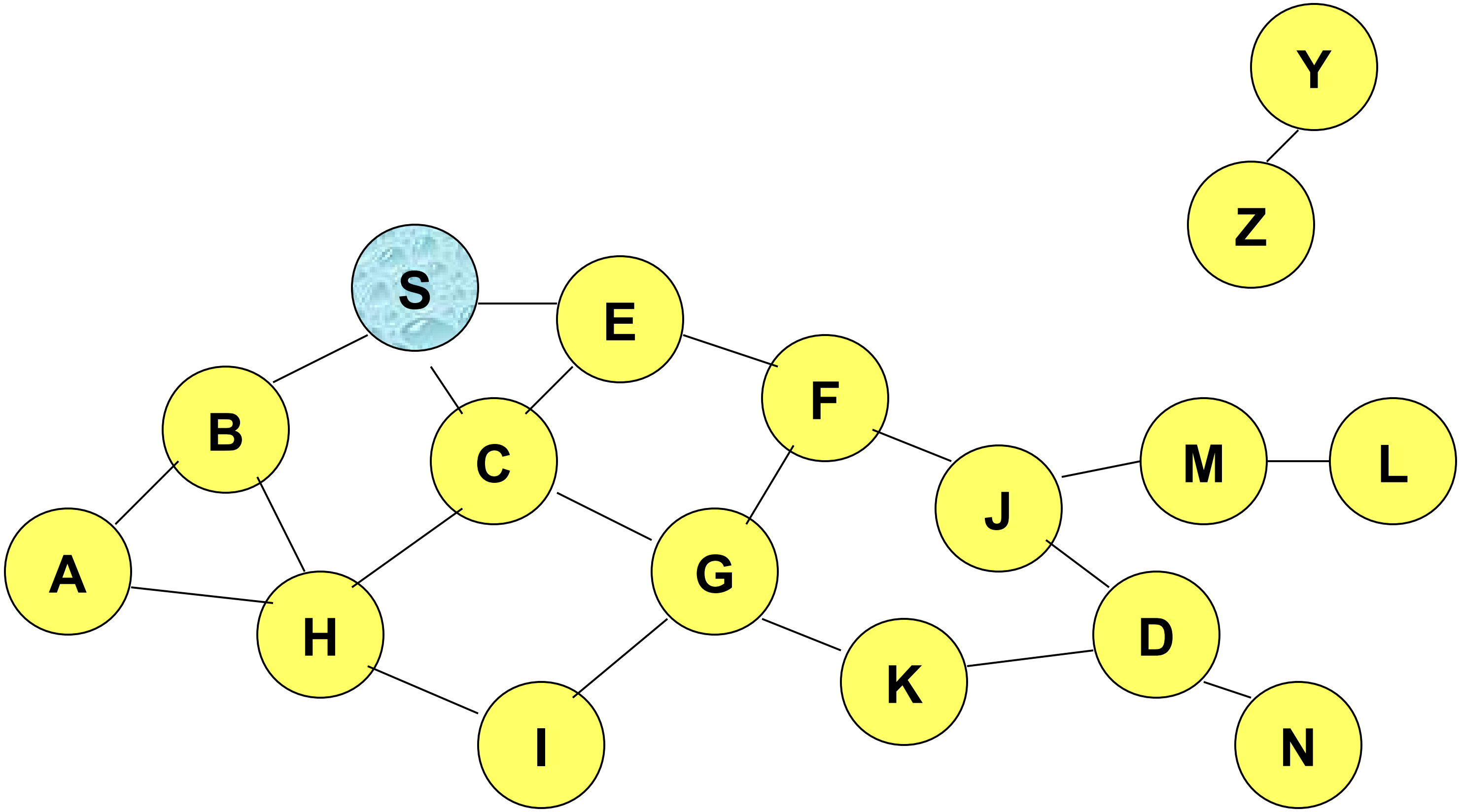


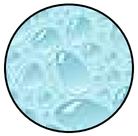
- If P has seen this RREQ from S already, P discards the RREQ. Otherwise, P processes the RREQ :
- P sets up a reverse route entry in its route table for the source S.
- This entry contains the IP address and current sequence number of S, number of hops to S and the address of the neighbour from whom P got the RREQ.

Lifetime of a Route-Table Entry

- A lifetime is associated with the entry in the route table.
- This is an important feature of AODV. If a route entry is not used within the specified lifetime, it is deleted.
- A route is maintained only when it is used. A route that is unused for a long time is assumed to be stale.

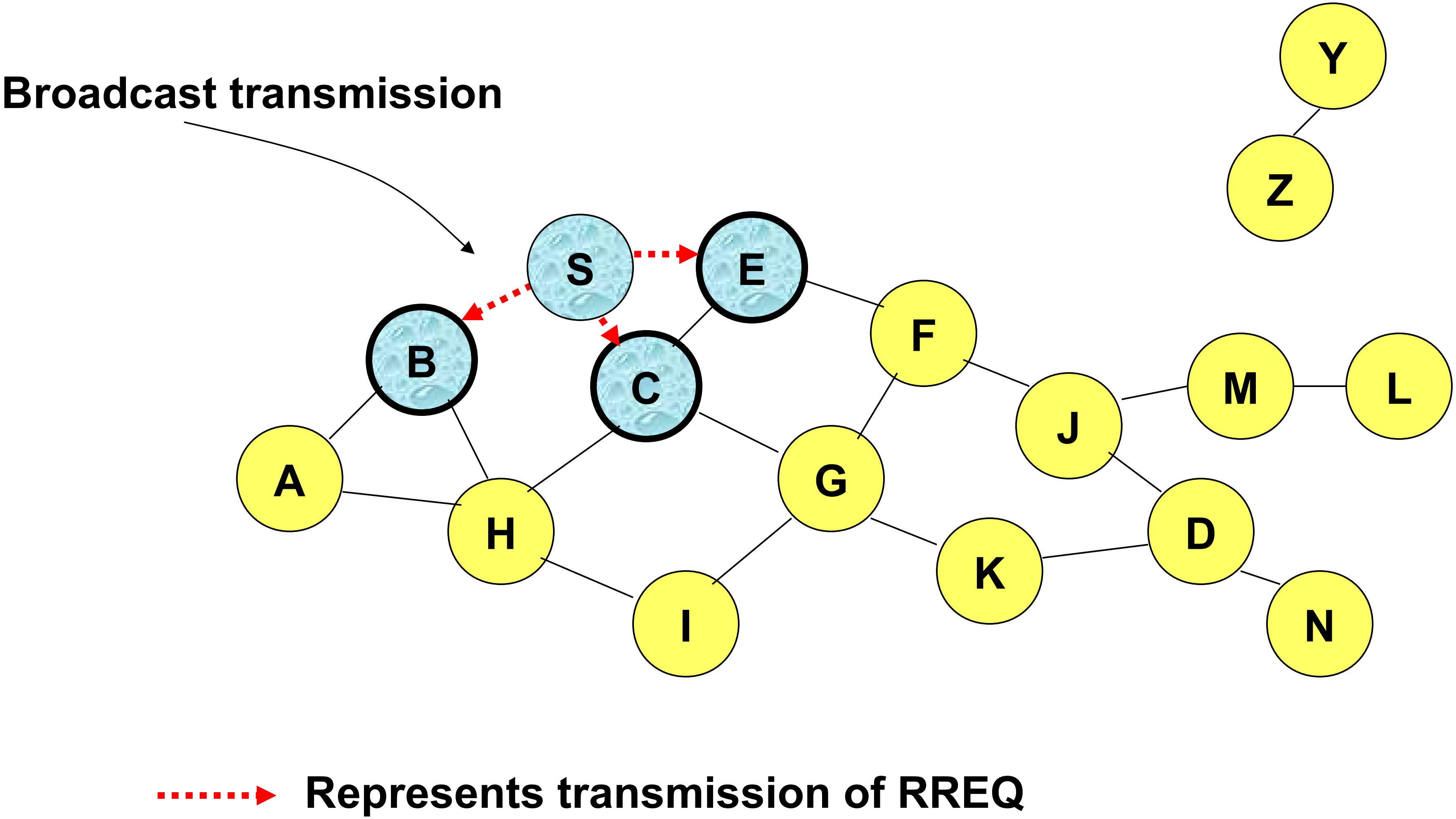
Route Requests in AODV





Represents a node that has received RREQ for D from S

Route Requests in AODV



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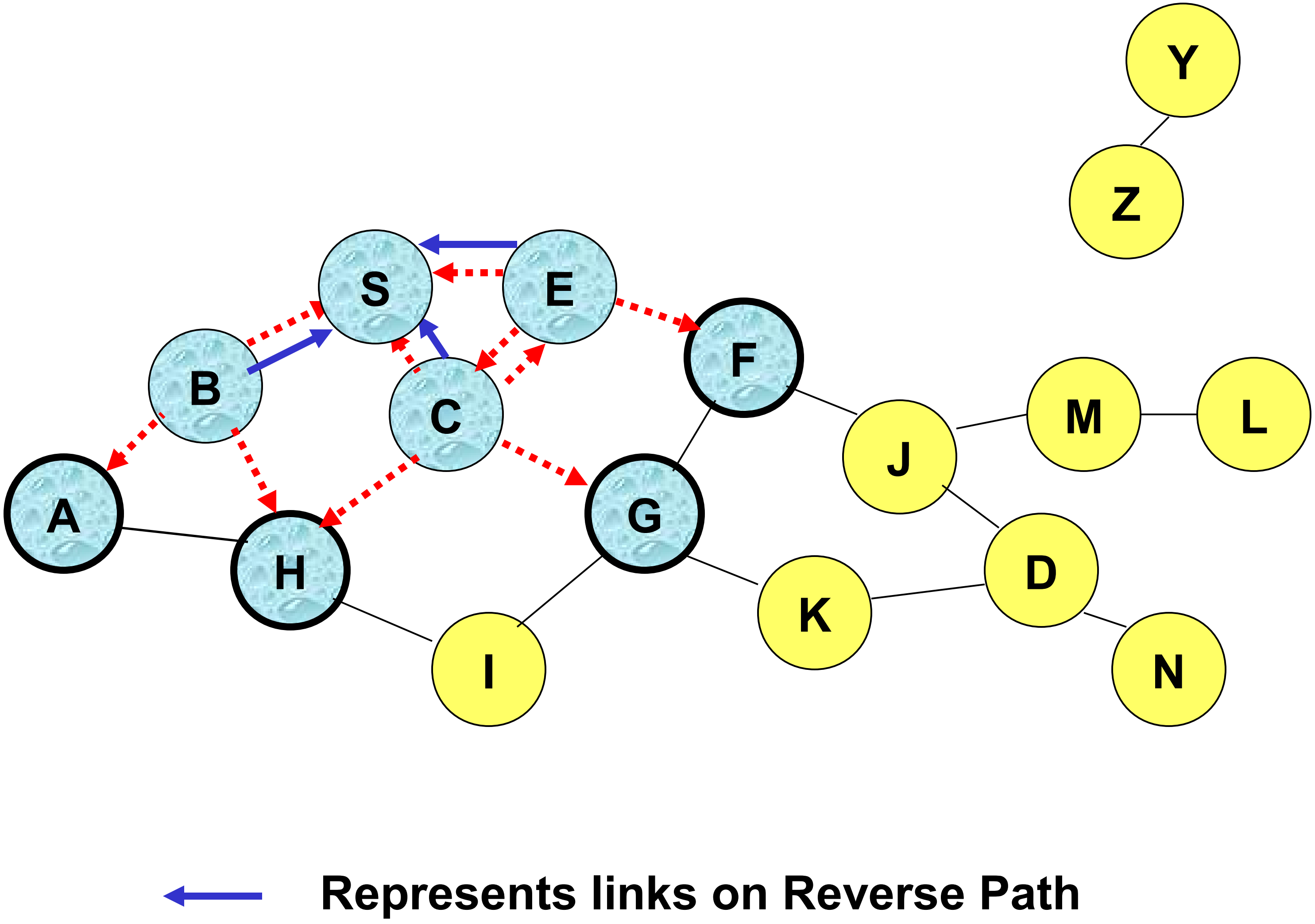
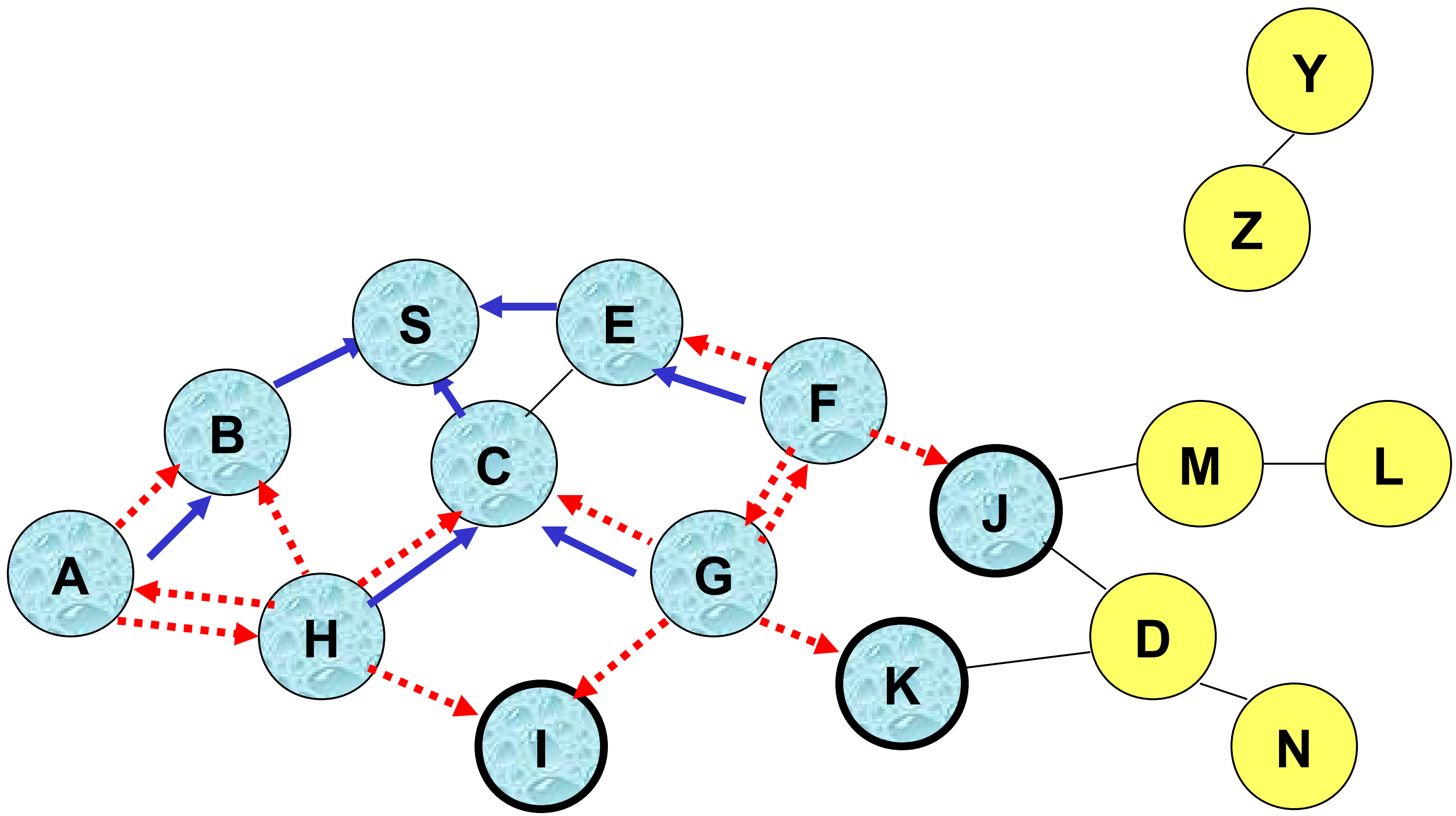
Route Requests in AODV

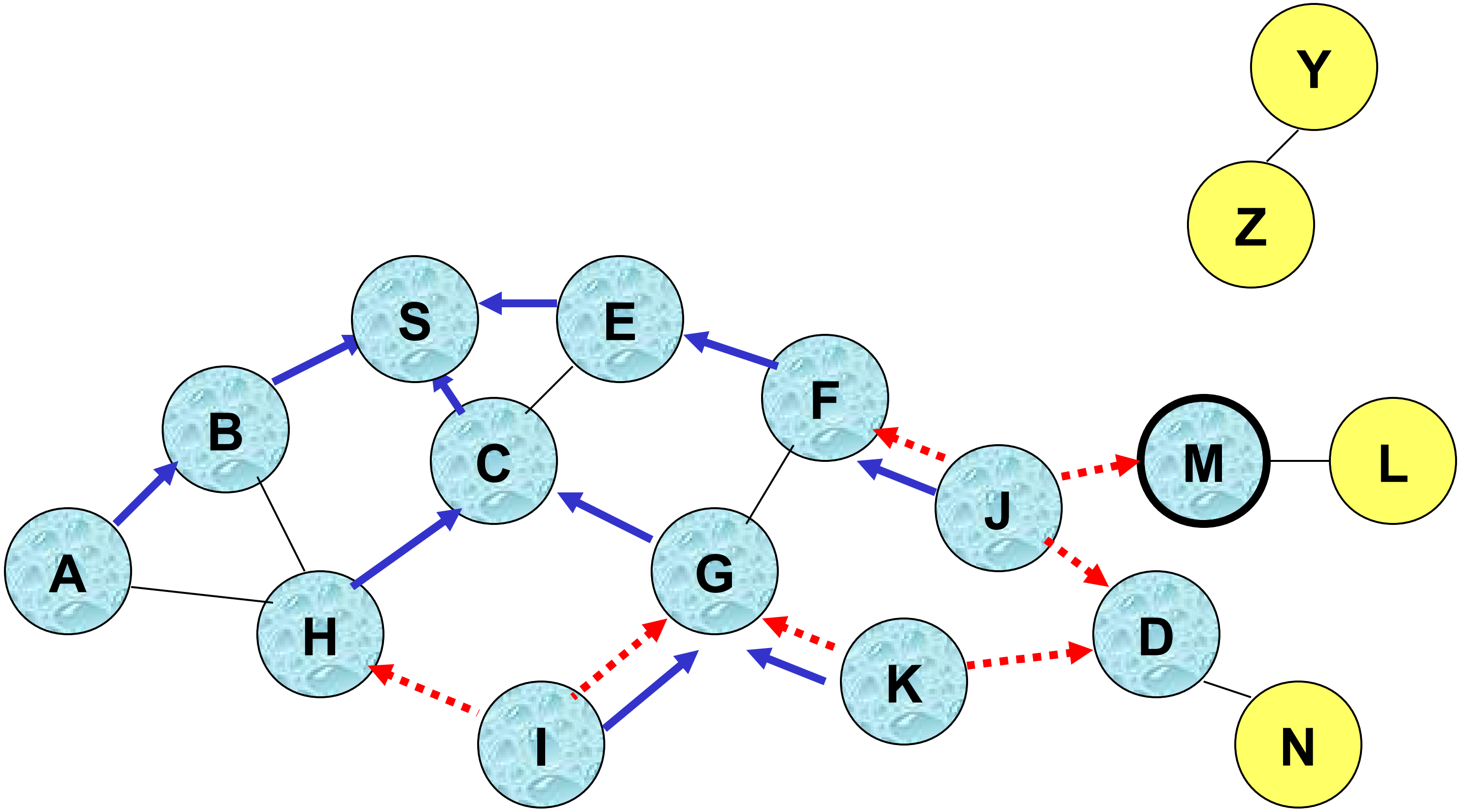


Reverse Path Setup in AODV

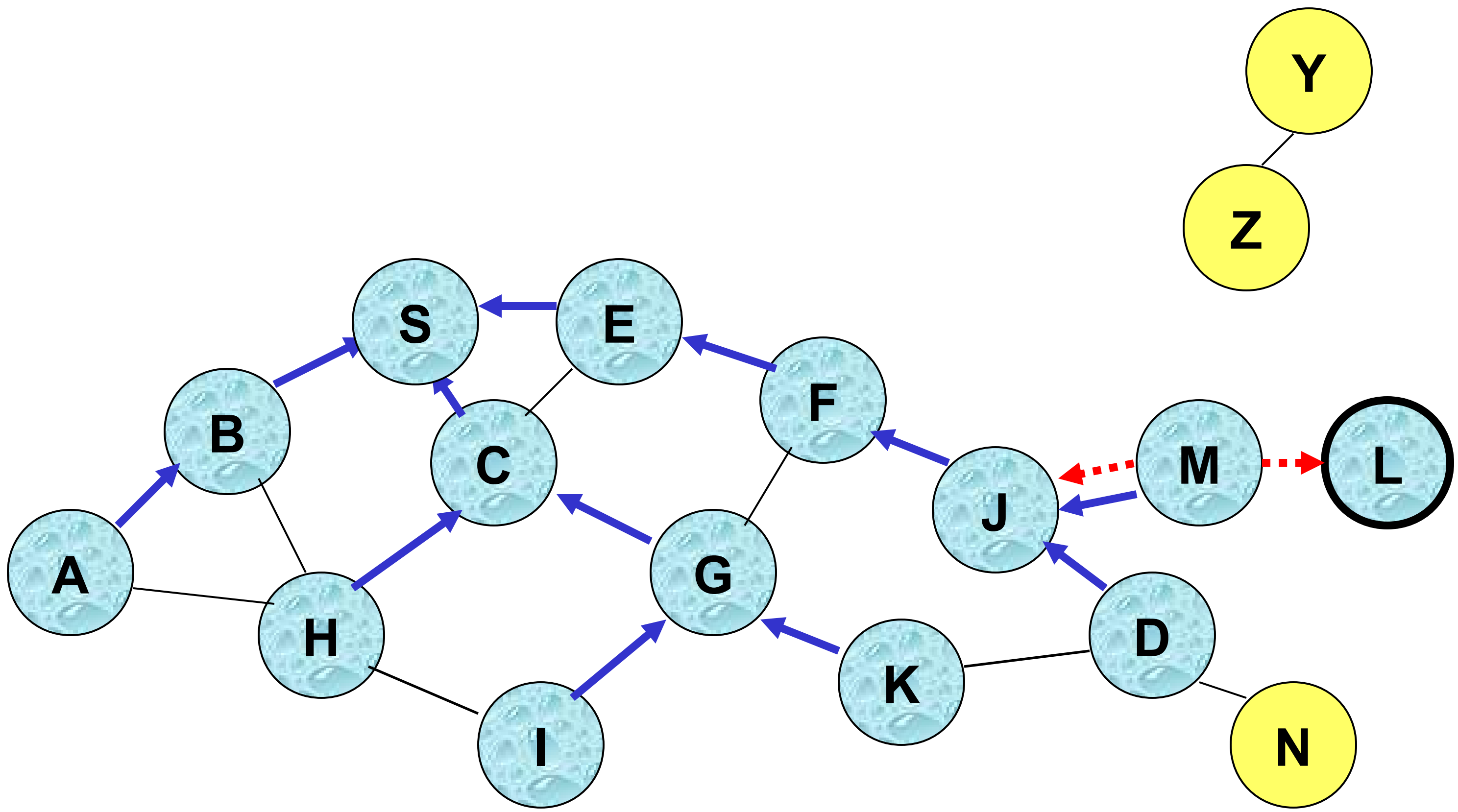


- **Node C receives RREQ from G and H, but does not forward it again, because node C has already forwarded RREQ once**

Reverse Path Setup in AODV

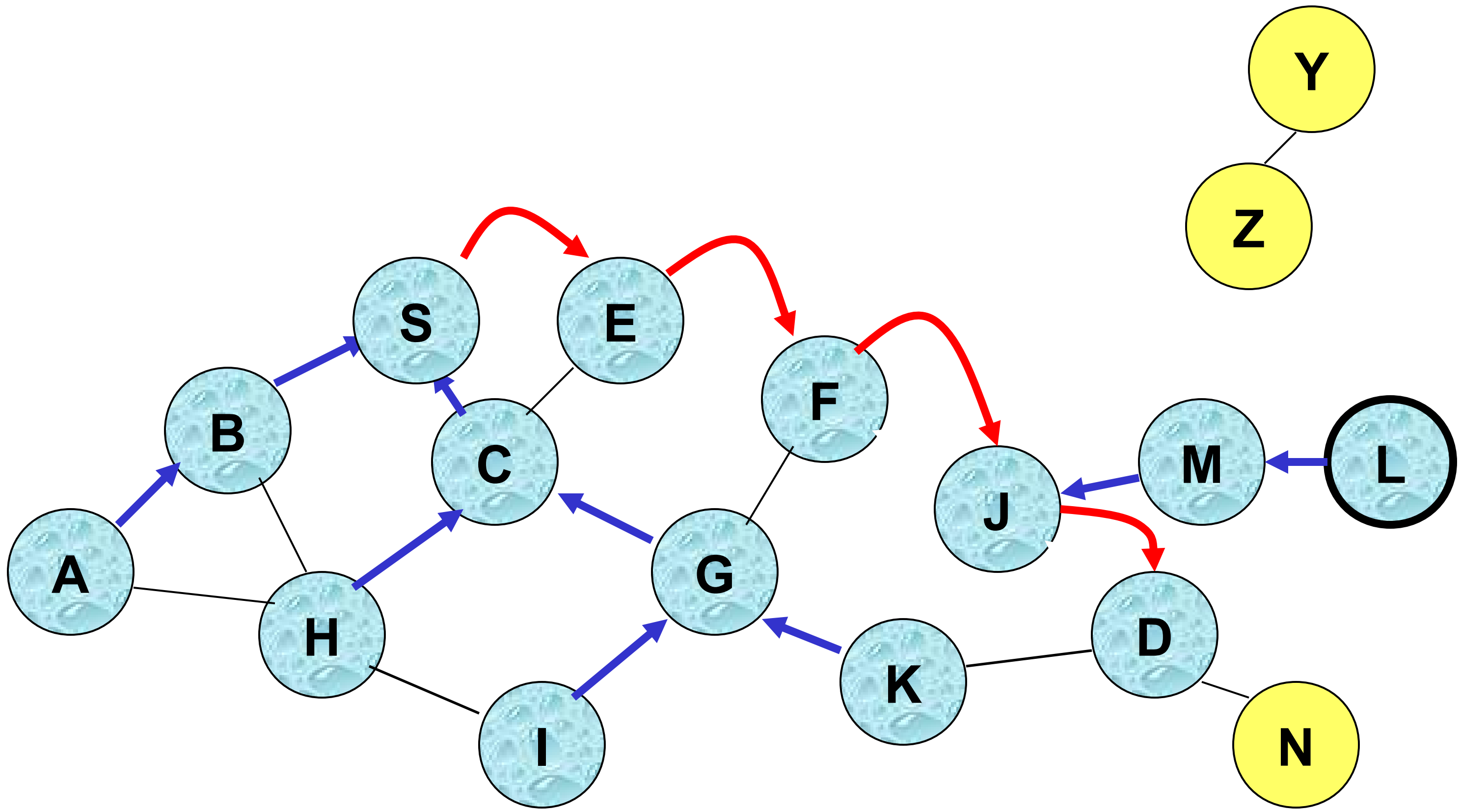


Reverse Path Setup in AODV

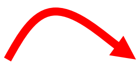


- Node D **does not forward** RREQ, because node D is the **intended target** of the RREQ

Forward Path Setup in AODV



Forward links are setup when RREP travels along the reverse path


Represents a link on the forward path

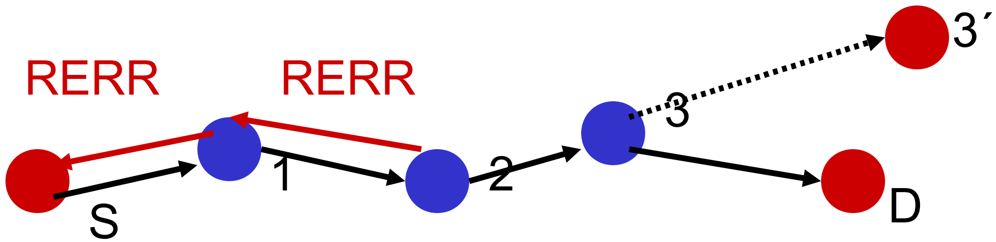
Handling More than one RREP

- An intermediate node P may receive more than one RREP for the same RREQ.
- P forwards the first RREP it receives and forwards a second RREP later only if :
  - The later RREP contains a greater sequence number for the destination, or
  - The hop-count to the destination is smaller in the later RREP
  - Otherwise, it does not forward the later RREPs. This reduces the number of RREPs propagating towards the source.

Route Maintenance

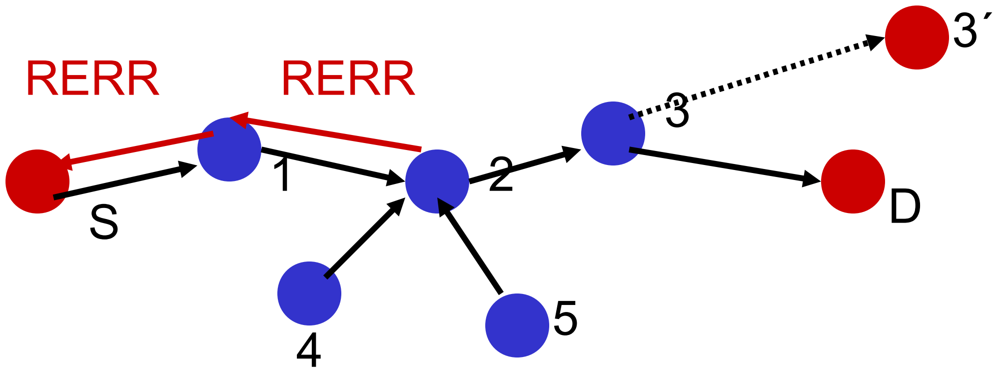
- Once a unicast route has been established between two nodes S and D, it is maintained as long as S (source node) needs the route.
- If S moves during an active session, it can reinitiate route discovery to establish a new route to D.
- When D or an intermediate node moves, a route error (RERR) message is sent to S.

Route Maintenance



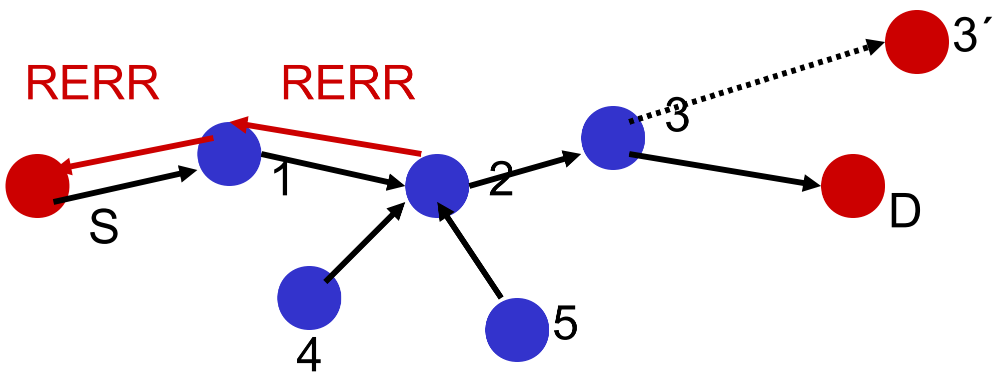
- The link from node 3 to D is broken as 3 has moved away to a position 3´.
- Node 2 sends a RERR message to 1 and 1 sends the message in turn to S.
- S initiates a route discovery if it still needs the route to D.

Updating Route Tables



- Suppose neighbours 4 and 5 route through 2 to reach D. Node 2 broadcasts RERR to all such neighbours.
- Each neighbour marks its route table entry to D as invalid by setting the distance to infinity.

Updating Route Tables



- Each neighbour in turn propagates the RERR message.
- Route entries with an infinity metric are not rejected immediately as they contain useful routing information for the neighbourhood.

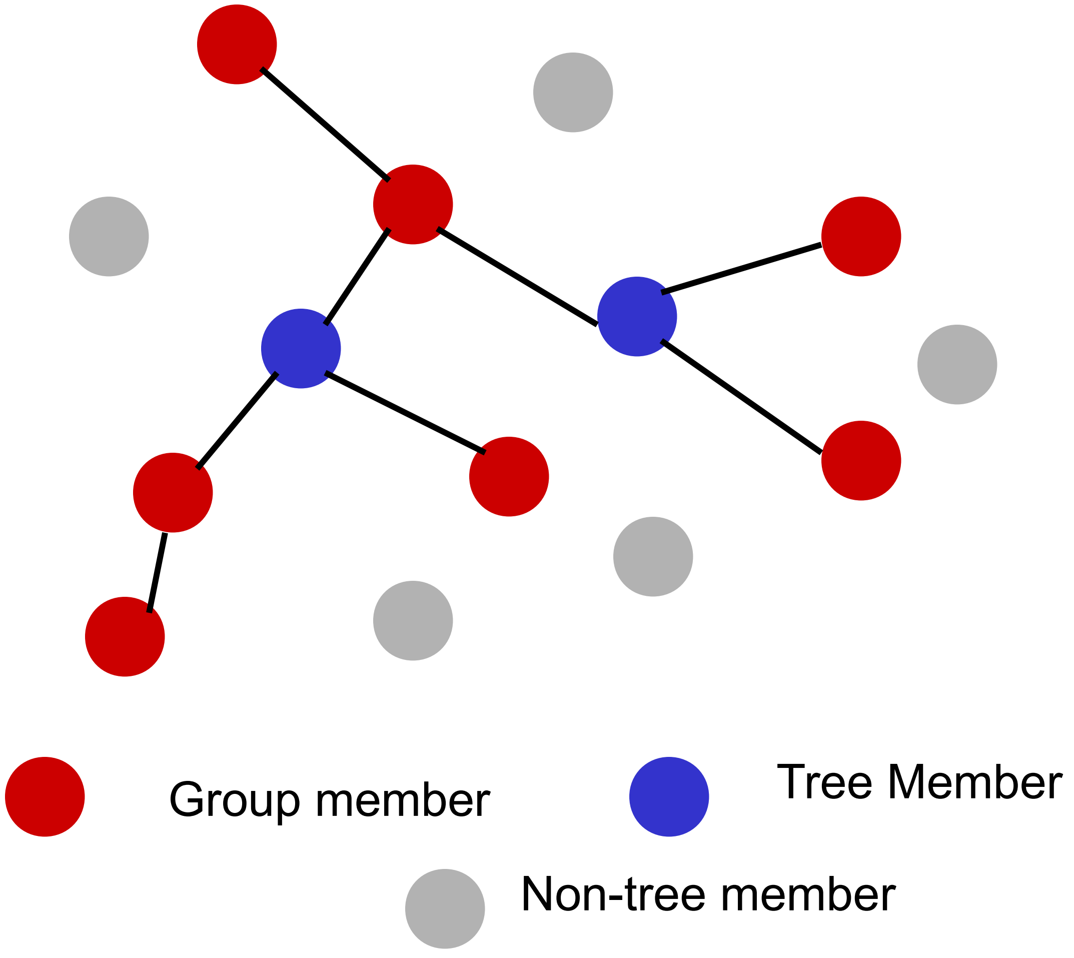
Local Connectivity

- Neighbourhood information is obtained through hello messages. Each node broadcasts a hello message to its neighbours at a regular hello-interval.
- When a node M receives a hello message from a neighbour N, node M updates the lifetime associated with N in its route table.
- Hello messages propagate only for one hop, in the neighbourhood of a node.

Multicast Route Establishment

- RREQ and RREP messages are used for multicast route establishment.
- A multicast tree has two kinds of members.
- A group member is a node that is part of the multicast group.
- A tree member is not part of the multicast group, but used to connect the multicast tree.

An Example Multicast Tree



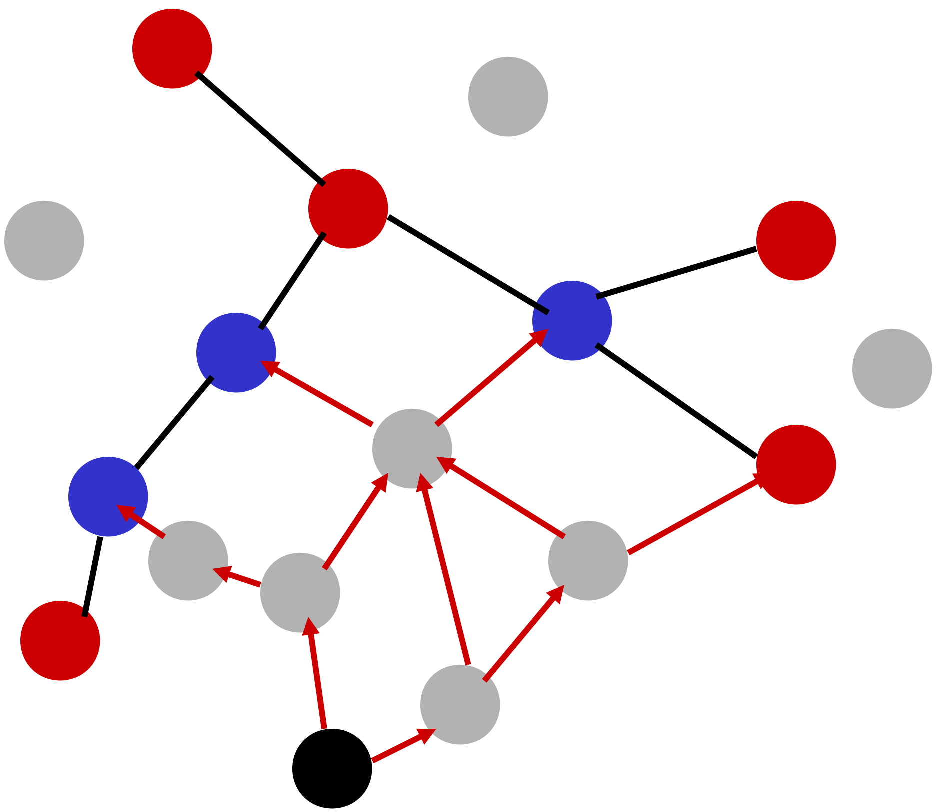
Multicast Route Discovery

- Multicast route discovery begins when either
  - A node S wishes to join a multicast group
  - A node S has data to send to a multicast group and does not have a current route to it
- S sends a RREQ with the destination address set to the IP address of the multicast group and the last known sequence number of the group. These could be for any node from the multicast group known to S.

Multicast Route Discovery

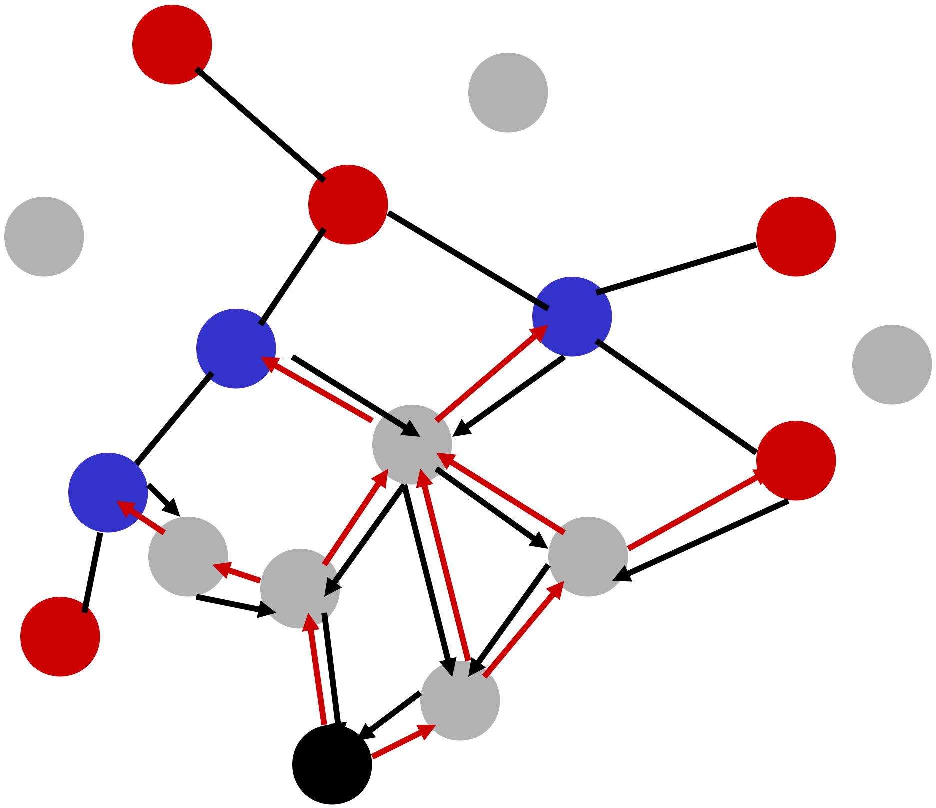
- S also indicates whether it wants to join the multicast group by setting a join flag.
- S then broadcasts this RREQ to its neighbours.
- If the RREQ is a join request, only a node that is a member of the multicast group may reply.
- Otherwise, any node with a current route to the multicast group may reply.

Joining a Multicast Group



Sending RREQ

Joining a Multicast Group



RREP back

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Forward Path for RREP

- The forward path for a RREP is set up in the same way as for unicast path set up.
- A member of the multicast group may send a RREP for a RREQ if it has a greater sequence number for the multicast group than the sequence number in the RREQ.
- The RREP is unicast back to the sender of the RREQ and all route tables along the path are updated.

Multicast Route Activation

- The node S sending a RREQ will generally receive multiple RREPs. These RREPs set up potential branches for S to join the multicast tree.
- S chooses the path with the greatest sequence number and smallest hop count.
- S activates this route by sending a multicast activation (MACT) message to the next hop of this route. This message is forwarded by the other nodes along the route.

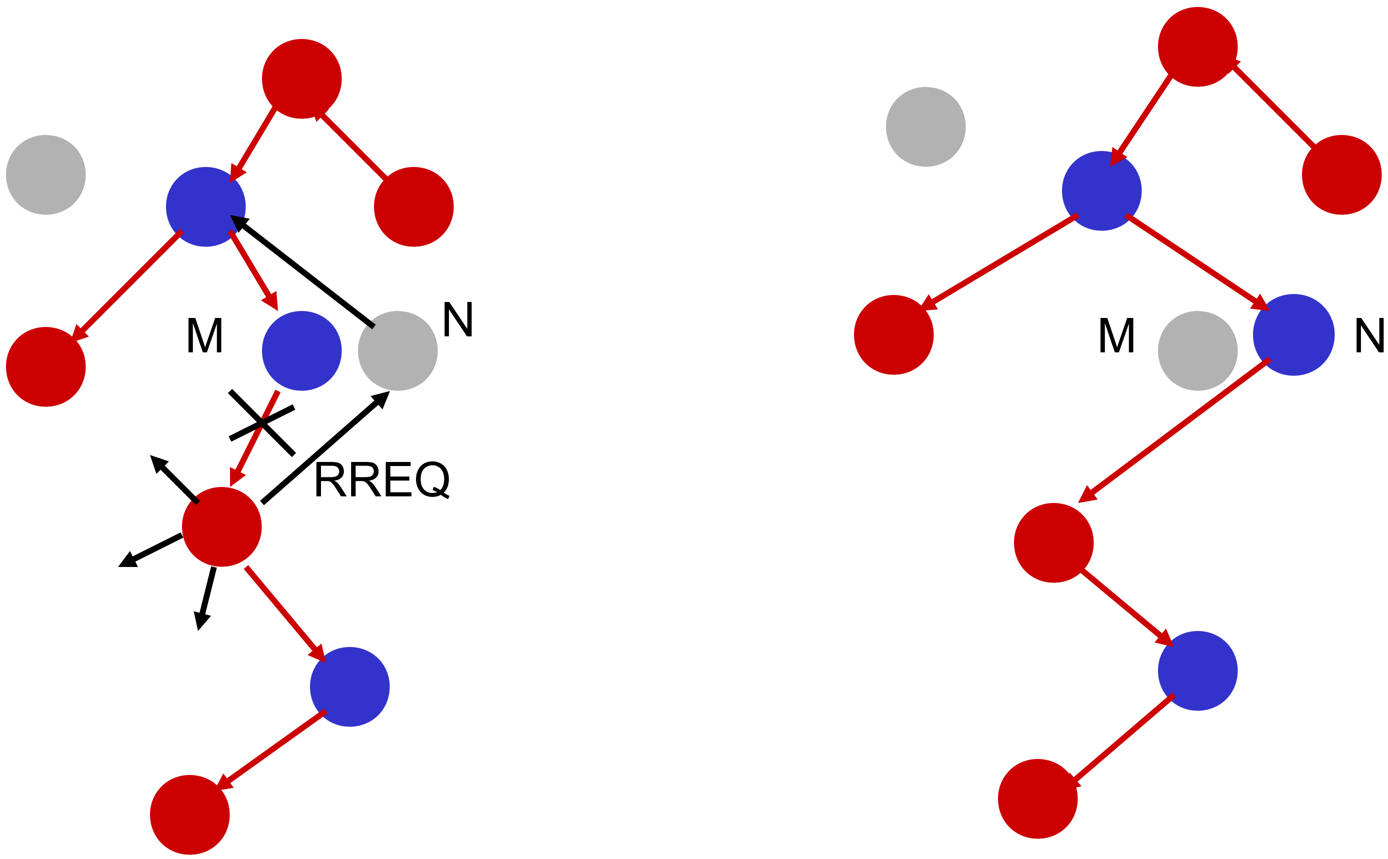
Multicast Tree Deactivation

- A leaf node may leave a multicast tree by following a similar procedure, by sending an MACT message and deleting the multicast group information from its route table.
- However, a non-leaf node cannot remove itself from a tree as that partitions the tree.
- A non-leaf node continues to act as a router for the multicast group even when it leaves the group.

Link Breaks

- A member or a tree-node in a multicast tree may notice a link break when :
  - No hello-message has been received from the next hop node for sometime
  - Or, when the node cannot send a packet to the next hop node (the next hop node has moved away)
- It is the responsibility of a node nearer to the source S to repair this link break.
- This is done through sending a RREQ message.

Repairing Link Breaks



Repairing Link Breaks

- A node discovering the link break broadcasts a RREQ message to its neighbours. This RREQ message requests a route to the multicast group.
- Once RREP messages are recieved, the node chooses a new route to the multicast group by sending an MACT message.

Performance of AODV

- AODV does not retransmit data packets that are lost and hence does not guarantee packet delivery.
- However, the packet delivery percentage is close to 100 with relatively small number of nodes.
- The packet delivery percentage drops with increased moility.

Control Overheads

- The overhead packets in AODV are due to RREQ, RREP and RERR messages.
- AODV needs much less number of overhead packets compared to DSDV.
- The number of overhead packets increases with increased mobility, since this gives rise to frequent link breaks and route discovery.

Latency in Route Discovery

- The route discovery latency in AODV is low compared to DSR and DSDV.

- The latency is almost constant even with increased mobility if the concentration of the nodes remain similar.

- The average path length for discovered routes is also quite low.

Route Request and Route Reply

- Route Request (RREQ) includes the last known sequence number for the destination
- An intermediate node may also send a Route Reply (RREP) provided that it knows a more recent path than the one previously known to sender
- Intermediate nodes that forward the RREP, also record the next hop to destination
- A routing table entry maintaining a reverse path is purged after a timeout interval
- A routing table entry maintaining a forward path is purged if *not used* for a *active_route_timeout* interval

Link Failure

- A neighbor of node X is considered active for a routing table entry if the neighbor sent a packet within *active_route_timeout* interval which was forwarded using that entry
- Neighboring nodes periodically exchange hello message
- When the next hop link in a routing table entry breaks, all active neighbors are informed
- Link failures are propagated by means of Route Error (RERR) messages, which also update destination sequence numbers

Route Error

- When node X is unable to forward packet P (from node S to node D) on link (X,Y), it generates a RERR message
- Node X increments the destination sequence number for D cached at node X
- The incremented sequence number *N* is included in the RERR
- When node S receives the RERR, it initiates a new route discovery for D using destination sequence number at least as large as *N*
- When node D receives the route request with destination sequence number N, node D will set its sequence number to N, unless it is already larger than N

AODV: Summary

- Routes need not be included in packet headers
- Nodes maintain routing tables containing entries only for routes that are in active use
- At most one next-hop per destination maintained at each node
  - DSR may maintain several routes for a single destination
- Sequence numbers are used to avoid old/broken routes
- Sequence numbers prevent formation of routing loops
- Unused routes expire even if topology does not change

Questions???

Thank You