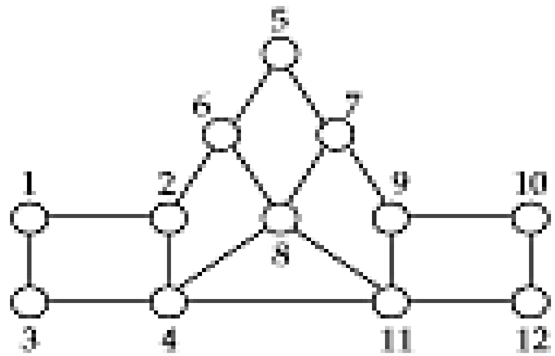
Routing Protocols

Traditional Routing

- A *routing protocol* sets up a *routing table* in *routers*



ROUTING TABLE AT 1

Destination	Next hop	Destination	Next hop
1	—	7	2
2	2□	8□	2□
3	3□	9□	2□
4	3□	10□	2□
5	2□	11□	3□
6	2	12	3

- A node makes a *local* choice depending on *global* topology

Routing and Mobility

- Finding a path from a source to a destination

- Issues
  - Frequent route changes
    - amount of data transferred between route changes may be much smaller than traditional networks
  - Route changes may be related to host movement
  - Low bandwidth links

- Goal of routing protocols
  - decrease routing-related overhead
  - find short routes
  - find "stable" routes (despite mobility)

Routing in MANET

Unicast Routing Protocols

- Many protocols have been proposed
- Some specifically invented for MANET
- Others adapted from protocols for wired networks
- No single protocol works well in all environments
  - some attempts made to develop adaptive/hybrid protocols
- Standardization efforts in IETF
  - MANET, MobileIP working groups
  - **http://www.ietf.org**

Routing Protocols

- Proactive protocols
  - Traditional distributed shortest-path protocols
  - Maintain routes between every host pair at all times
  - Based on periodic updates; High routing overhead
  - Example: DSDV (destination sequenced distance vector)
- Reactive protocols
  - Determine route if and when needed
  - Source initiates route discovery
  - Example: DSR (dynamic source routing)
- Hybrid protocols
  - Adaptive; Combination of proactive and reactive
  - Example : ZRP (zone routing protocol)

Protocol Trade-offs

- Proactive protocols
  - Always maintain routes
  - Little or no delay for route determination
  - Consume bandwidth to keep routes up-to-date
  - Maintain routes which may never be used

- Reactive protocols
  - Lower overhead since routes are determined on demand
  - Significant delay in route determination
  - Employ flooding (global search)
  - Control traffic may be bursty

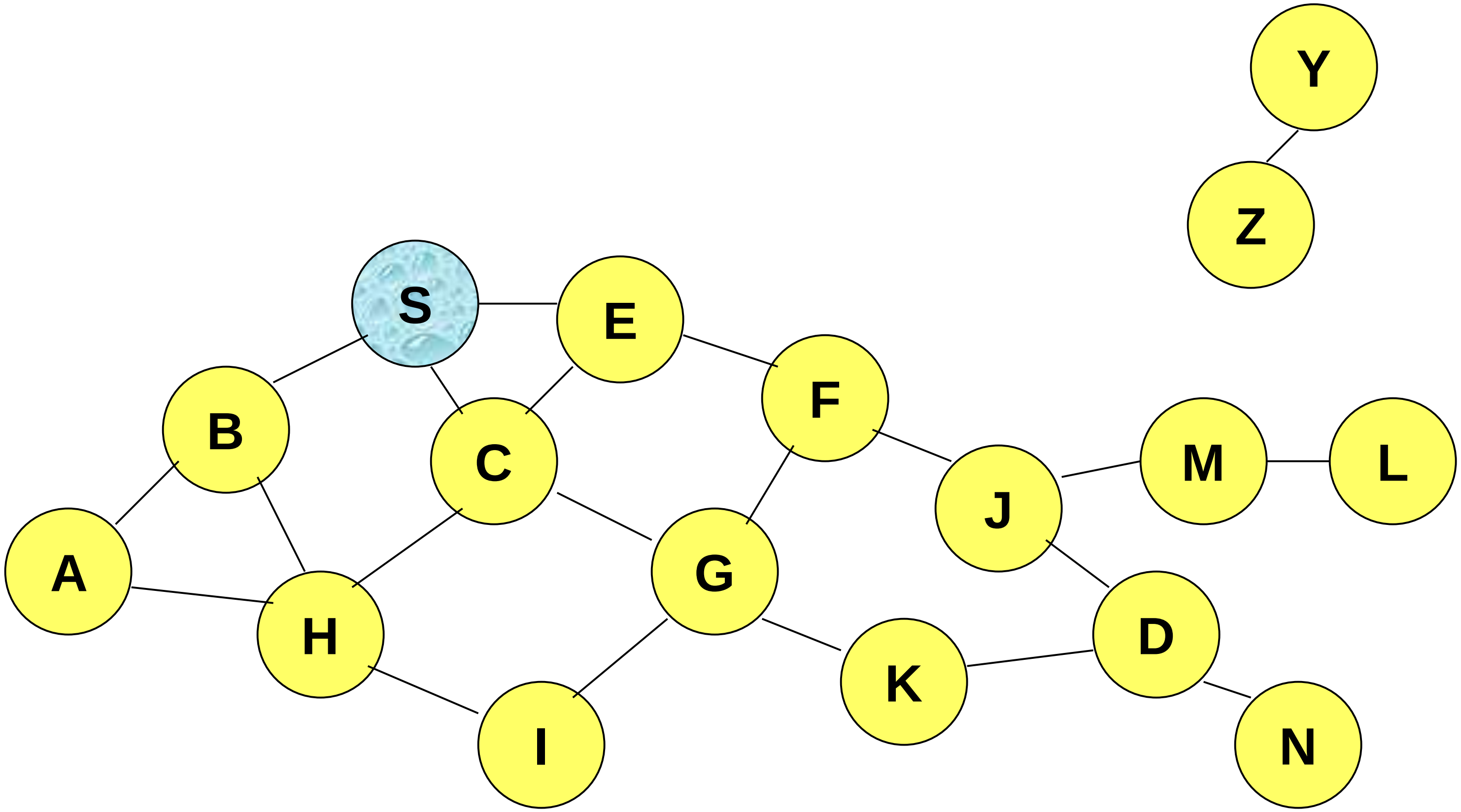
- Which approach achieves a better trade-off depends on the traffic and mobility patterns

Reactive Routing Protocols

Dynamic Source Routing (DSR)

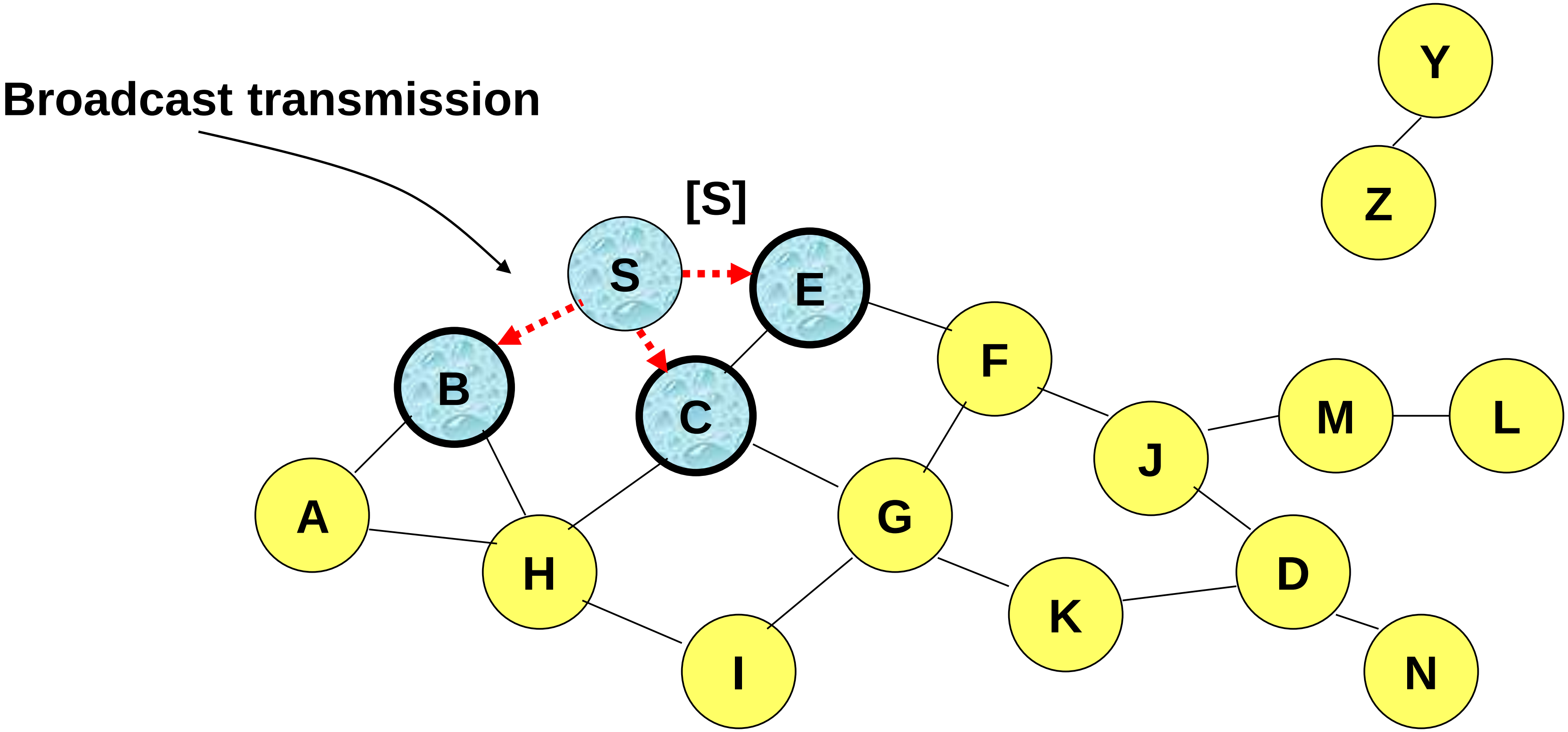
- When node S wants to send a packet to node D, but does not know a route to D, node S initiates a route discovery
- Source node S floods Route Request (RREQ)
- Each node *appends own identifier* when forwarding RREQ

Route Discovery in DSR



Represents a node that has received RREQ for D from S

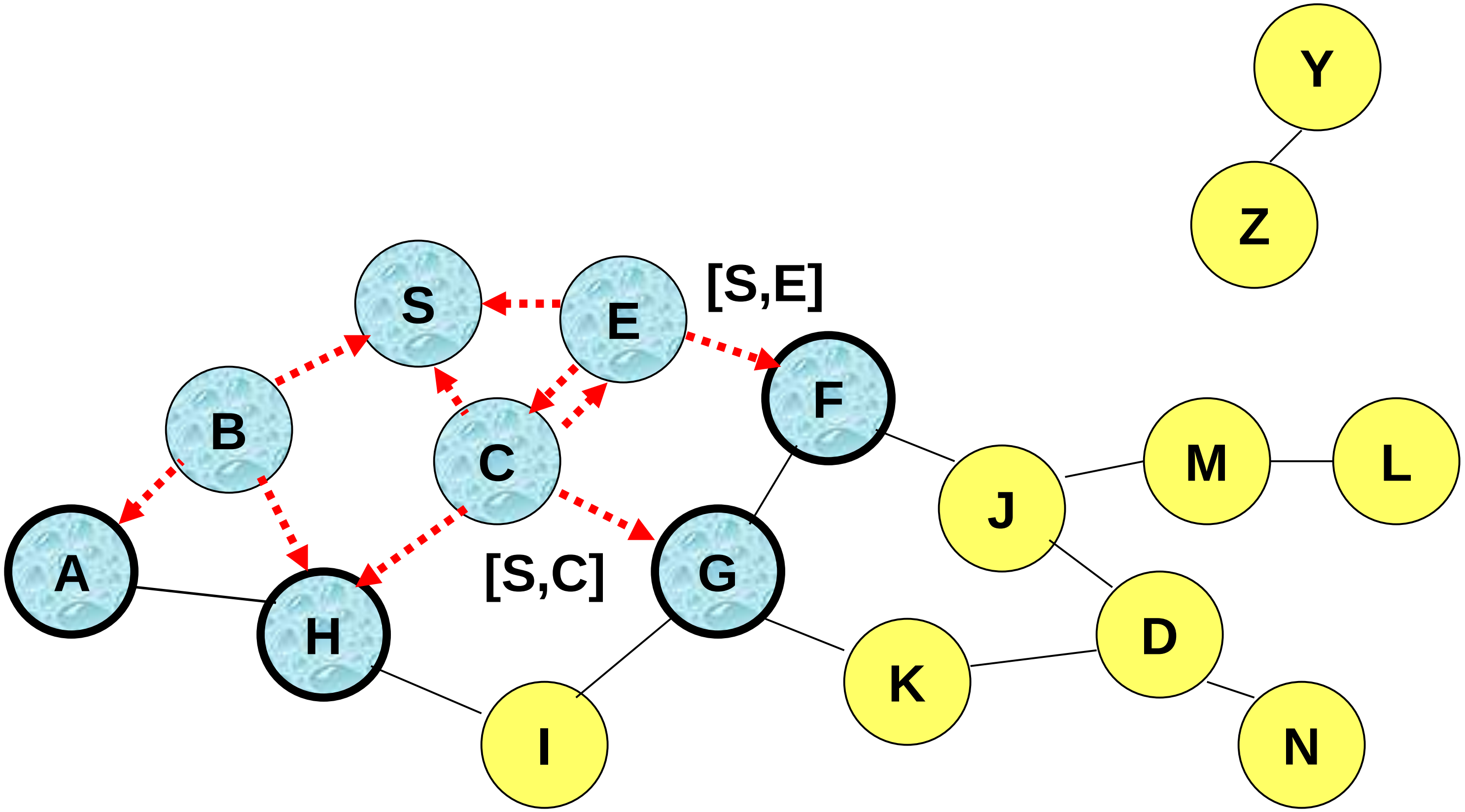
Route Discovery in DSR



Represents transmission of RREQ

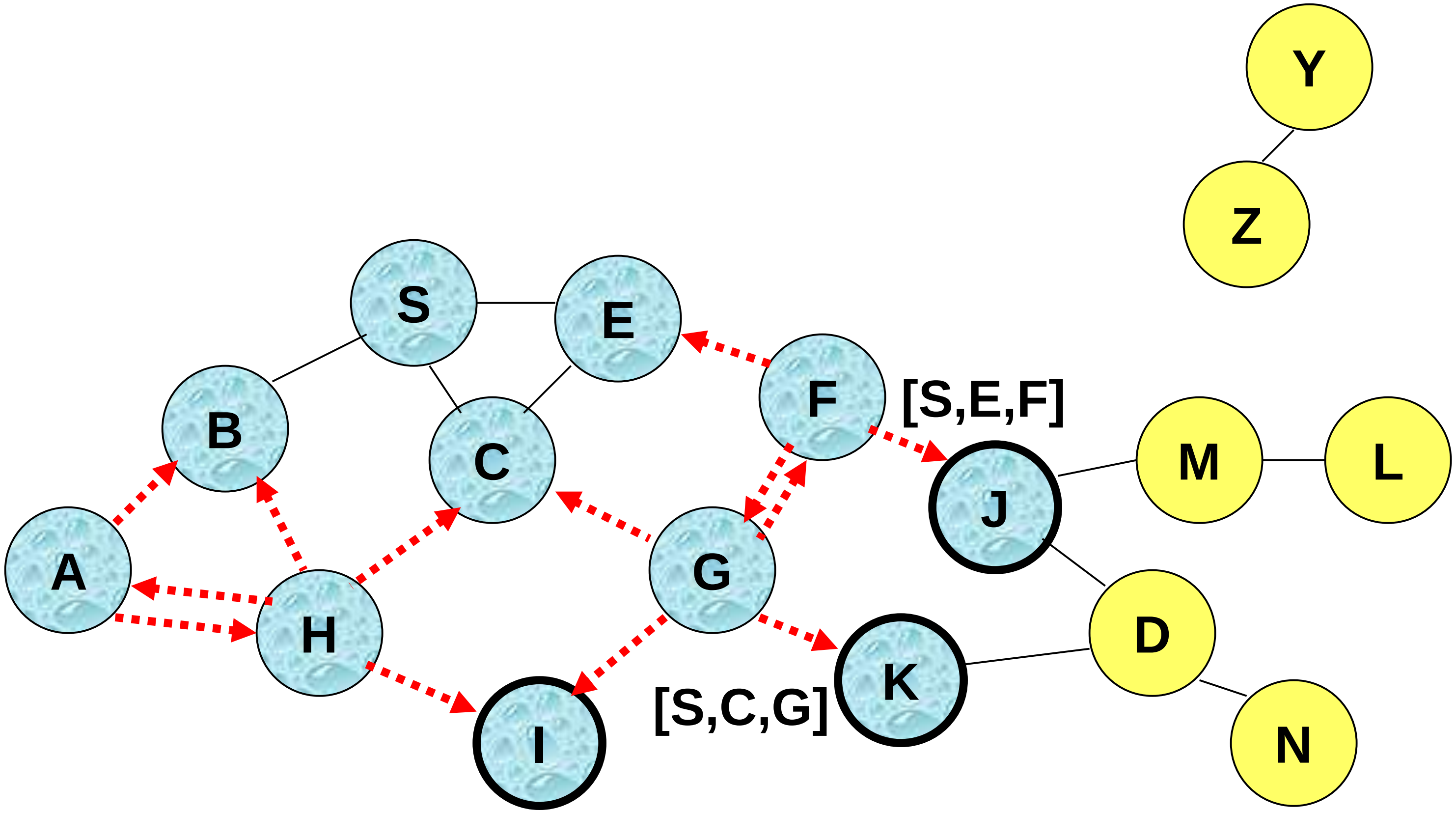
[X,Y] Represents list of identifiers appended to RREQ

Route Discovery in DSR



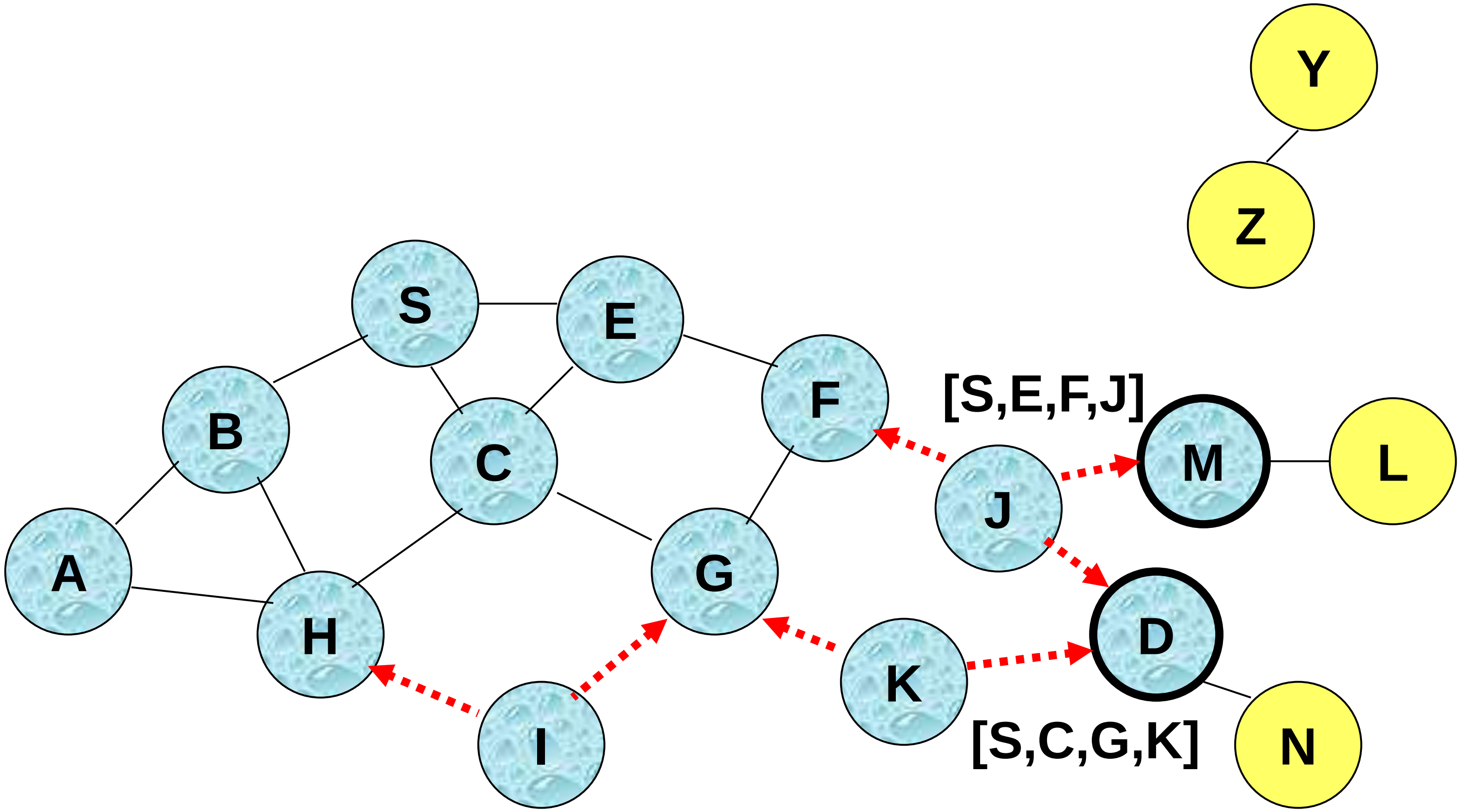
- **Node H receives packet RREQ from two neighbors: potential for collision**

Route Discovery in DSR



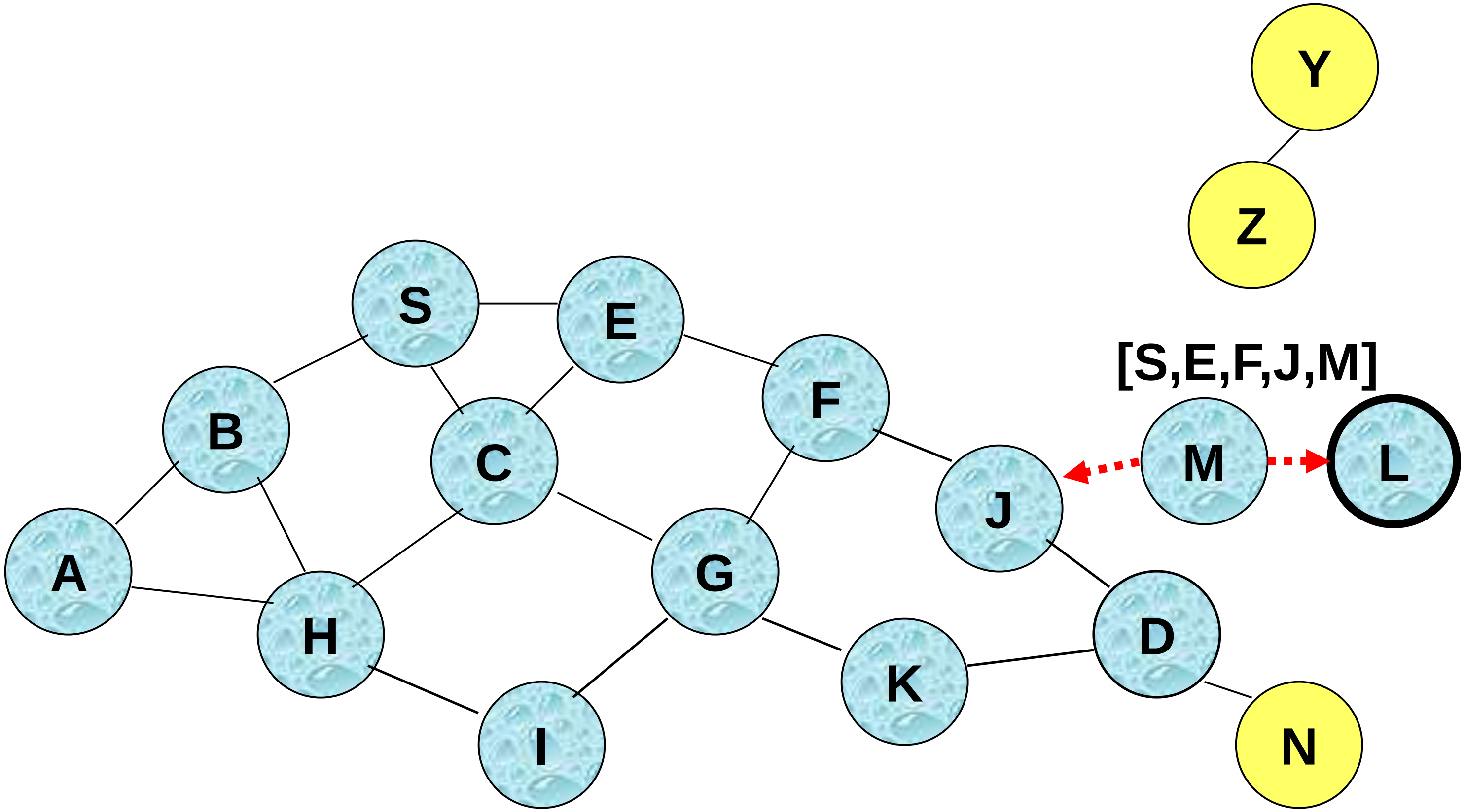
- Node C receives RREQ from G and H, but does not forward it again, because node C has already forwarded RREQ once

Route Discovery in DSR



- Nodes J and K both broadcast RREQ to node D
- Since nodes J and K are hidden from each other, their transmissions may collide

Route Discovery in DSR



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

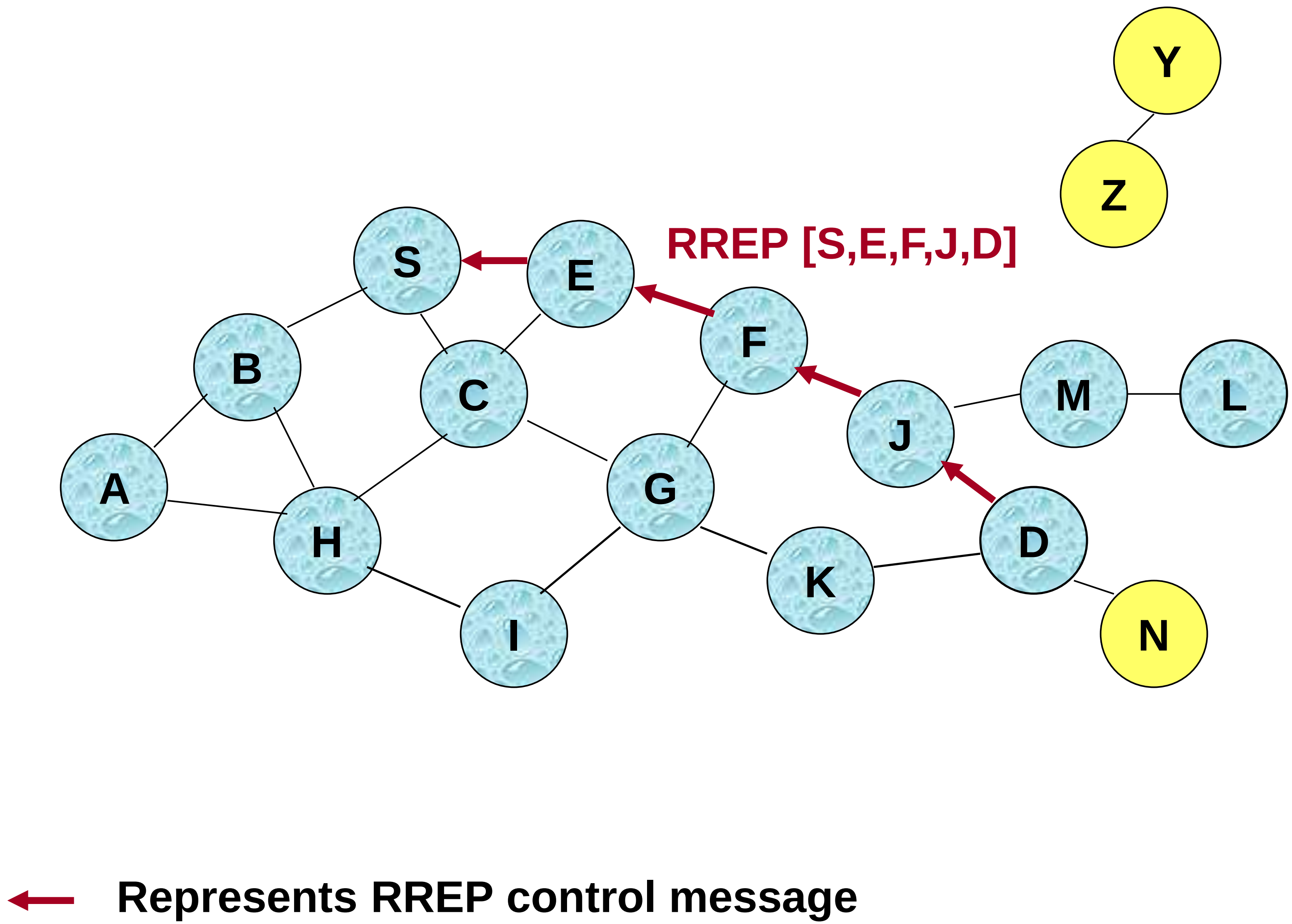
Route Discovery in DSR

- Destination D on receiving the first RREQ, sends a Route Reply (RREP)

- RREP is sent on a route obtained by reversing the route appended to received RREQ

- RREP includes the route from S to D on which RREQ was received by node D

Route Reply in DSR



Represents RREP control message

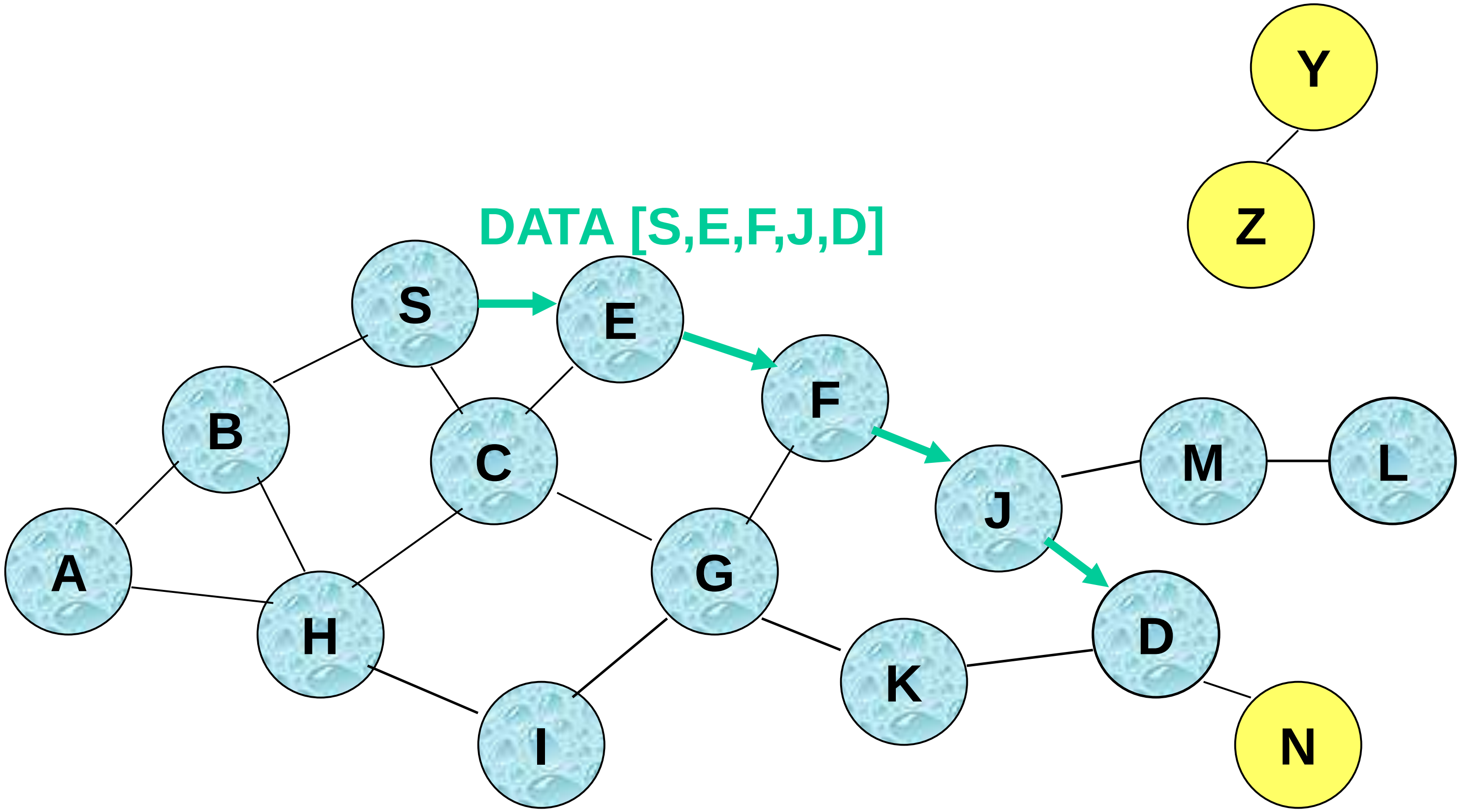
Dynamic Source Routing (DSR)

- 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

Data Delivery in DSR



Packet header size grows with route length

DSR Optimization: Route Caching

- Each node caches a new route it learns by *any means*
- When node S finds route [S,E,F,J,D] to node D, node S also learns route [S,E,F] to node F
- When node K receives Route Request [S,C,G] destined for node, node K learns route [K,G,C,S] to node S
- When node F forwards Route Reply RREP [S,E,F,J,D], node F learns route [F,J,D] to node D
- When node E forwards Data [S,E,F,J,D] it learns route [E,F,J,D] to node D
- A node may also learn a route when it overhears Data
- Problem: Stale caches may increase overheads

Dynamic Source Routing: Advantages

- Routes maintained only between nodes who need to communicate
  - reduces overhead of route maintenance
- Route caching can further reduce route discovery overhead
- A single route discovery may yield many routes to the destination, due to intermediate nodes replying from local caches

Dynamic Source Routing: Disadvantages

- Packet header size grows with route length due to source routing
- Flood of route requests may potentially reach all nodes in the network
- Potential collisions between route requests propagated by neighboring nodes
  - insertion of random delays before forwarding RREQ
- Increased contention if too many route replies come back due to nodes replying using their local cache
  - Route Reply *Storm* problem
- Stale caches will lead to increased overhead

Ad Hoc On-Demand Distance Vector Routing (AODV)

- 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

AODV

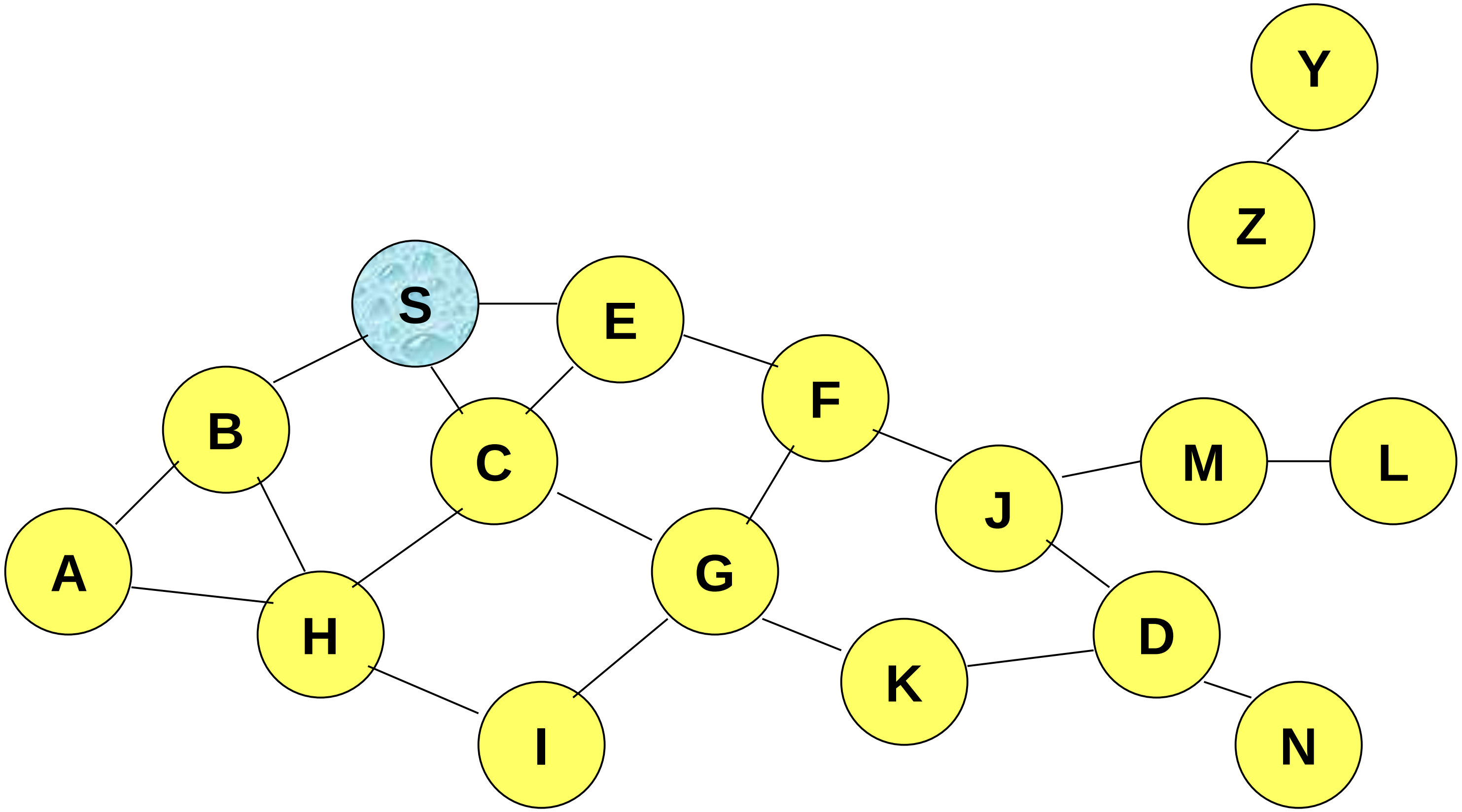
- Route Requests (RREQ) are forwarded in a manner similar to DSR

- When a node re-broadcasts a Route Request, it sets up a reverse path pointing towards the source
  - AODV assumes symmetric (bi-directional) links

- When the intended destination receives a Route Request, it replies by sending a Route Reply (RREP)

- Route Reply travels along the reverse path set-up when Route Request is forwarded

Route Requests in AODV



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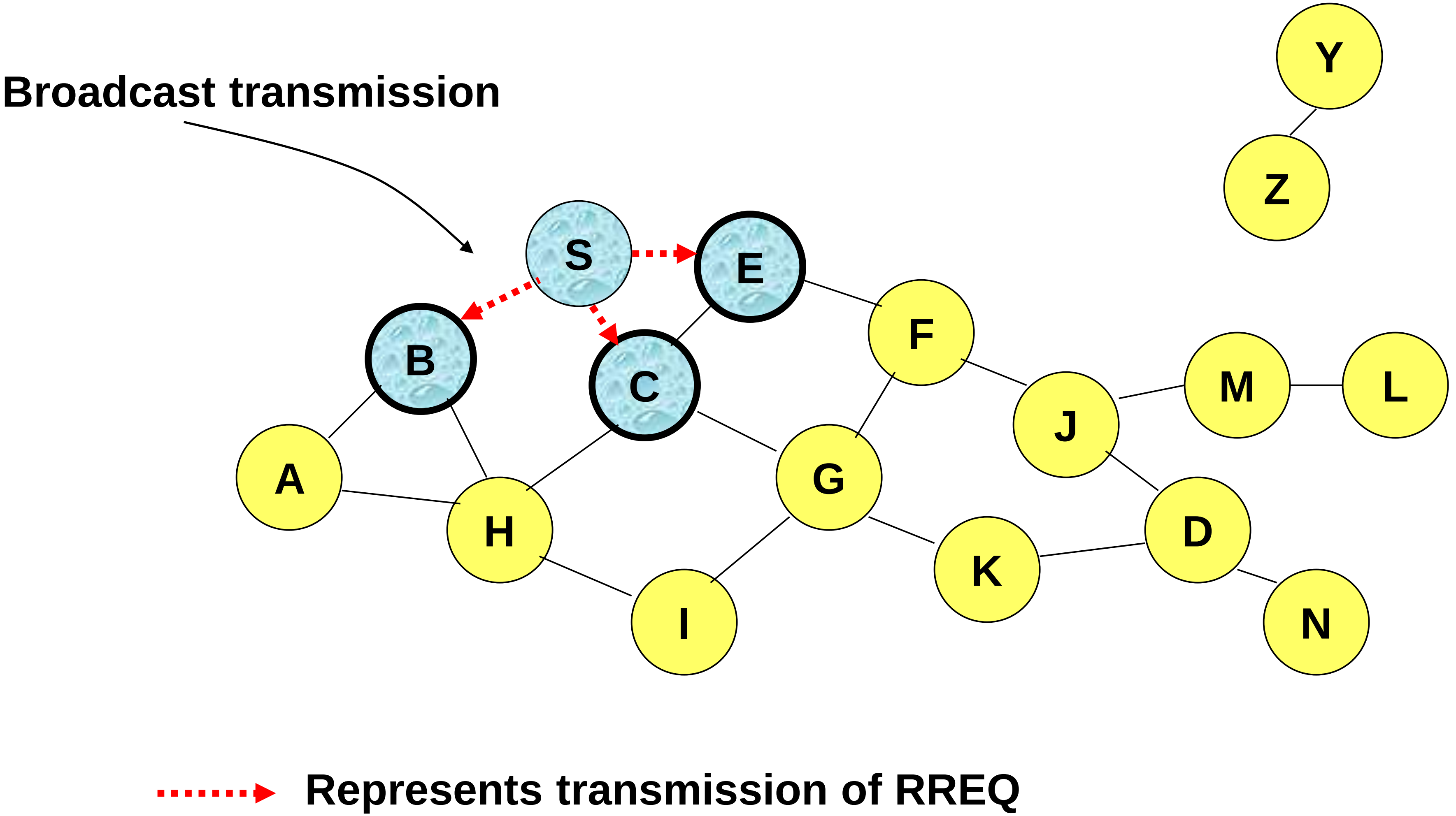
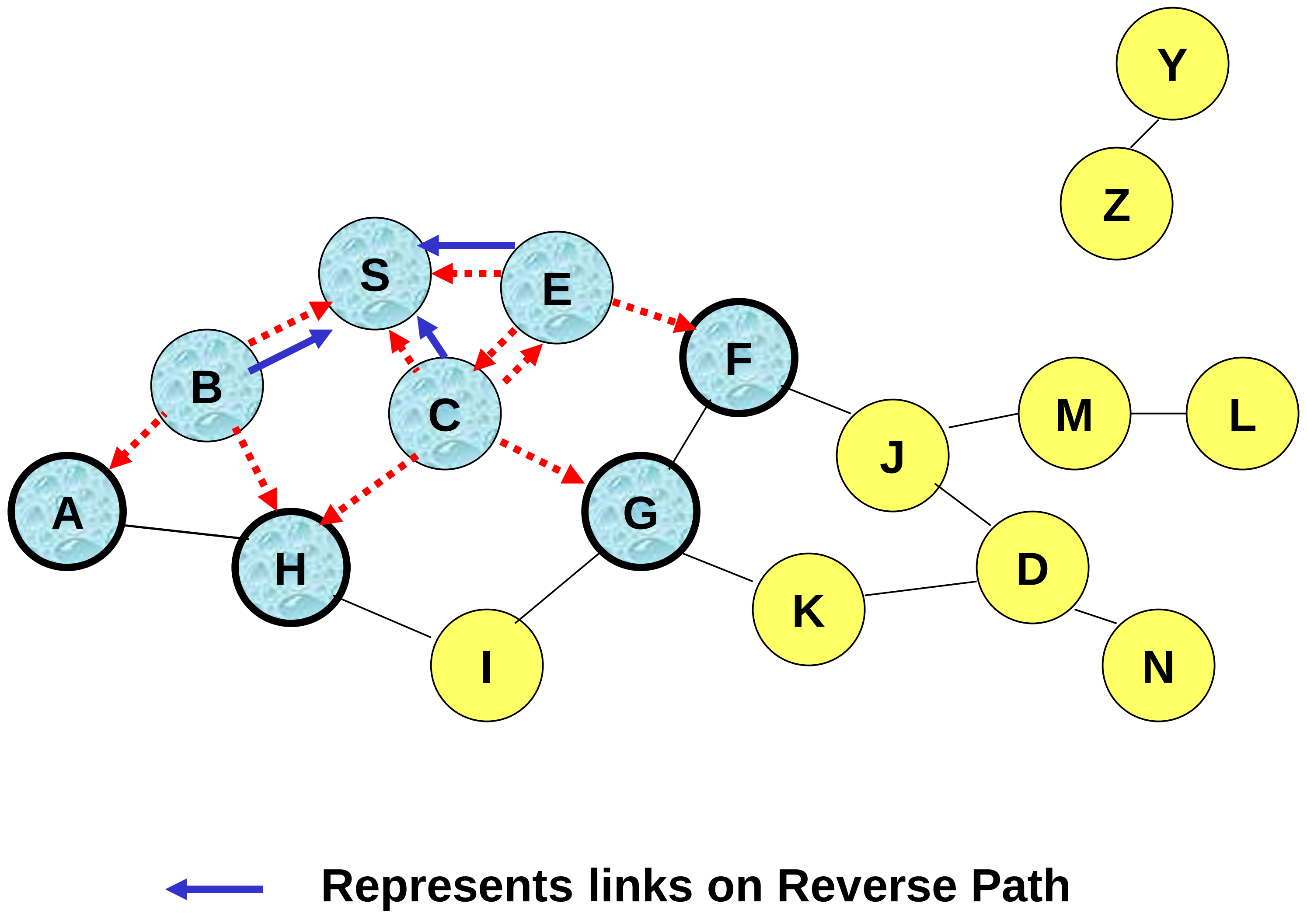
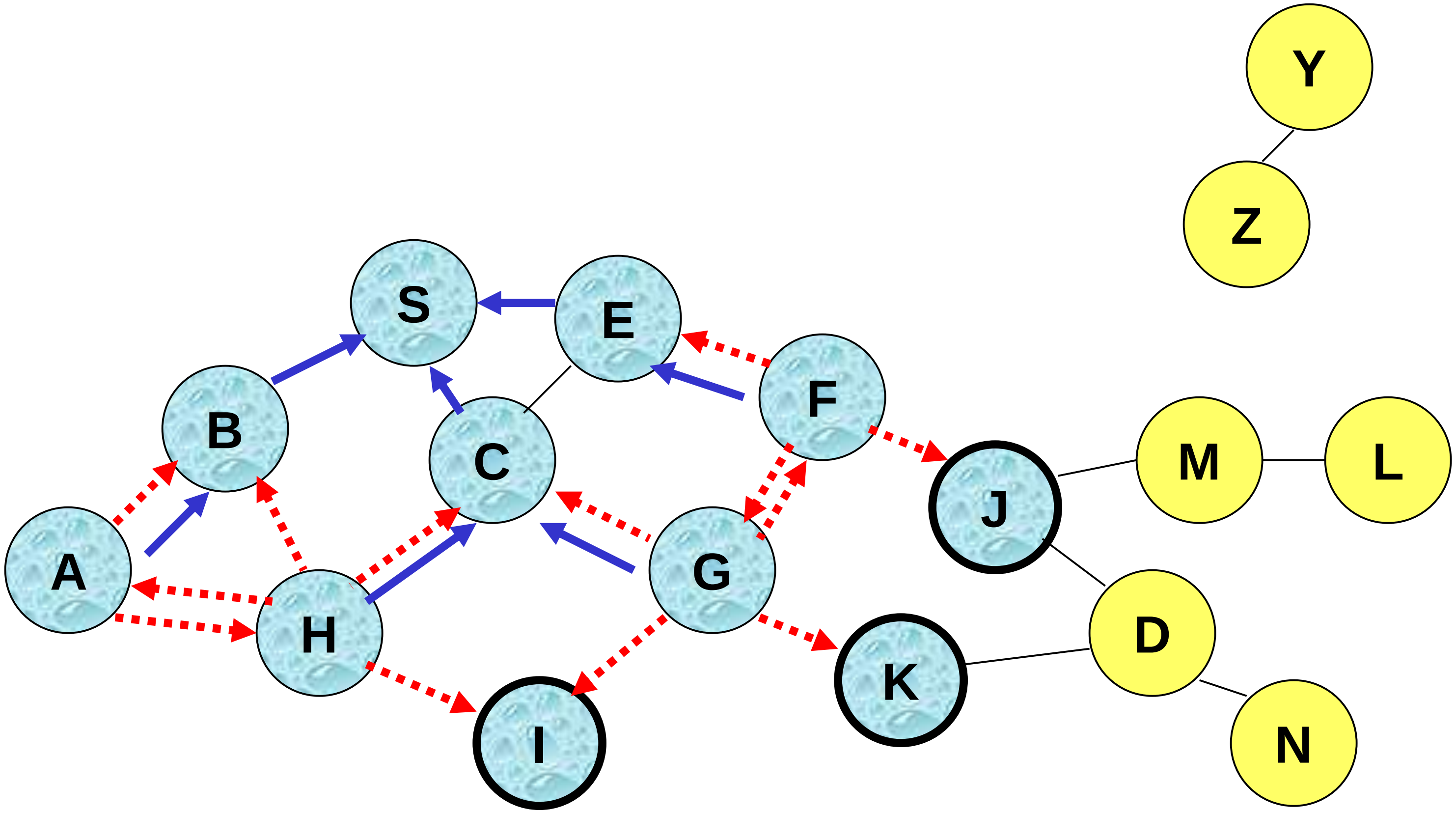
Route Requests in AODV



Route Requests in AODV



Reverse Path Setup in AODV



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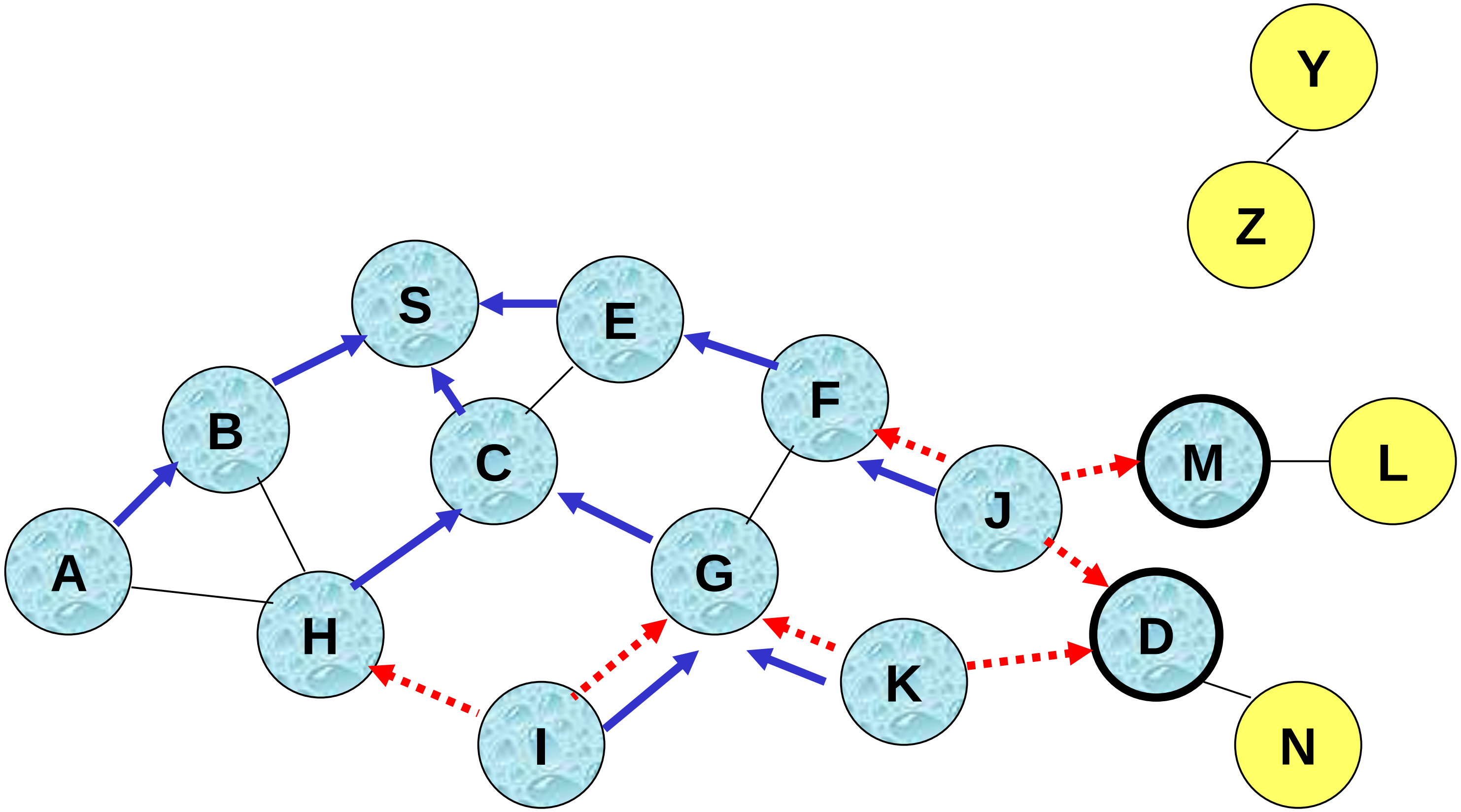
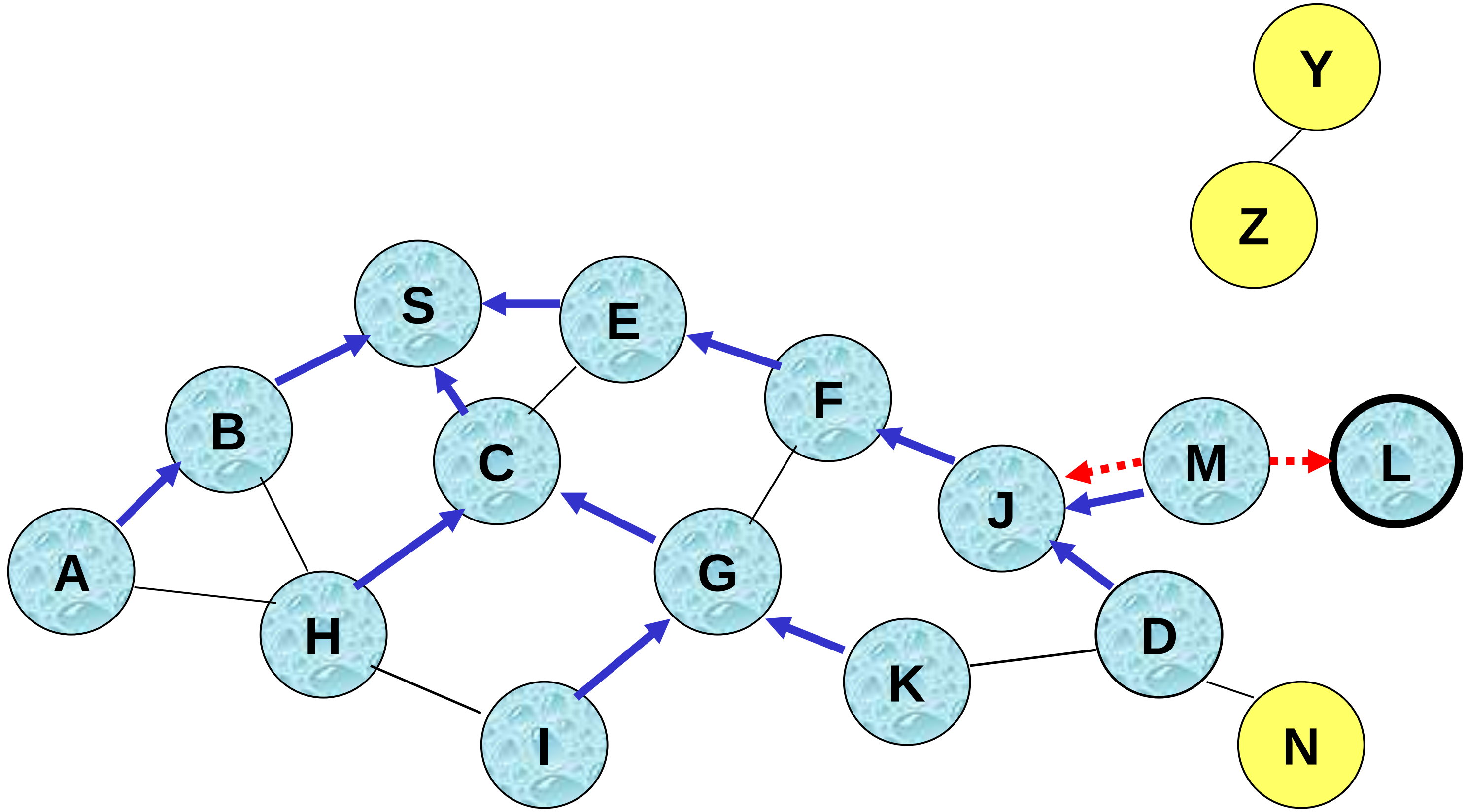
Reverse Path Setup in AODV

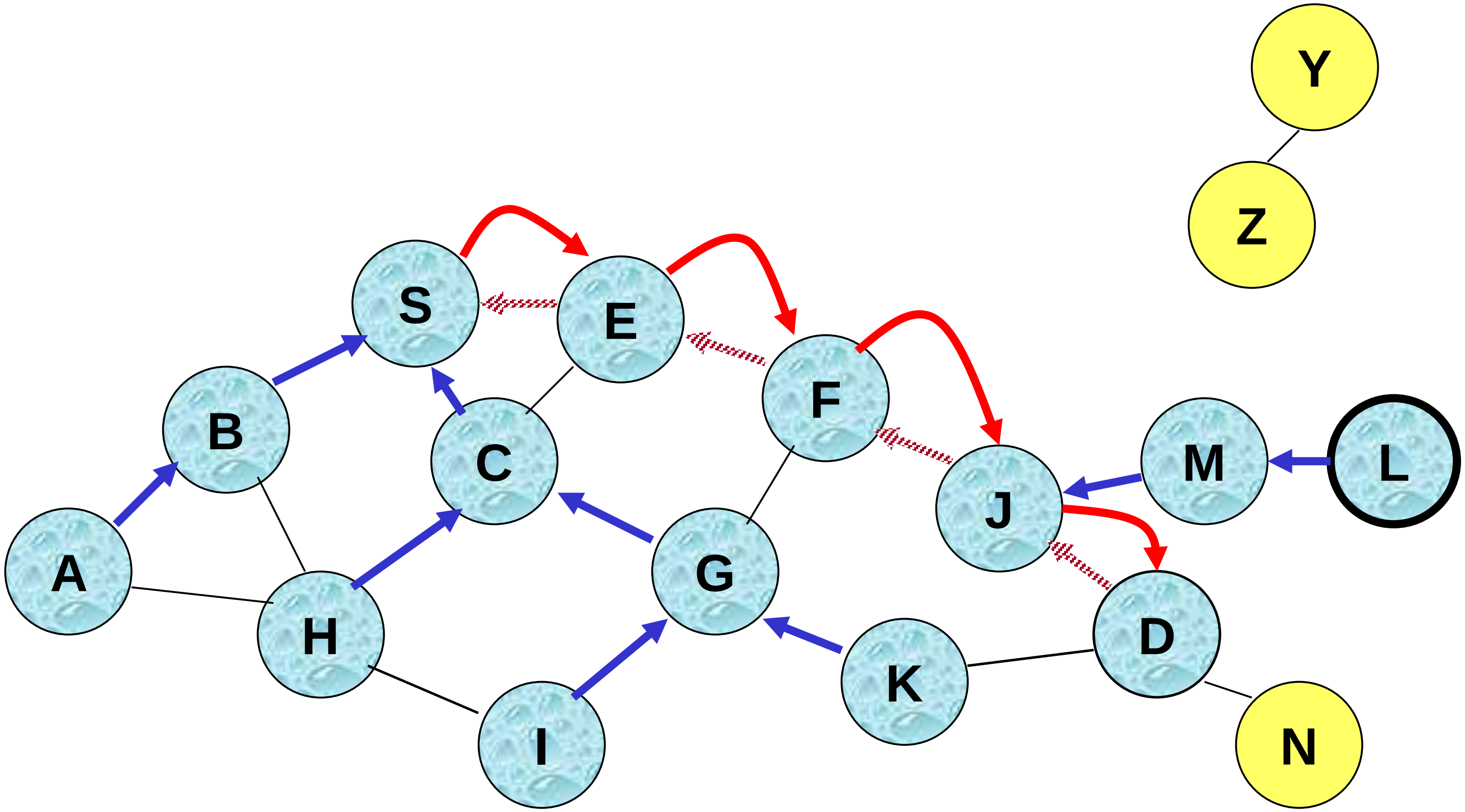


Reverse Path Setup in AODV



- 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

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

TERMS	AODV	DSR
Protocol Type	Hop by Hop routing	Source routing
Route maintained in	Routing table	Routing Cache
Route Discovery	On Demand	On Demand
Multiple route discovery	No	Yes
Multicast	Yes	No
Broadcast	Yes	Yes
Reuse of routing information	No	No
Route reconfiguration	Erase route, than source notification or local route repair	Erase route the source information
Limited overhead	No	Concept of route cache
Advantage	Reduced control overhead	Multiple route reduced bandwidth overhead

Disadvantage	Scalability problem, large delay caused by route discovery process	Scalability problem due to source routing and flooding, large delay
Route Storage Space	Low Storage Space	High Storage Space
Routes in routing table	Deletion of valid link	Usage of invalid link
Bandwidth usage	Efficient bandwidth usage	Waste bandwidth
MAC Overhead	AODV has less normalized MAC overhead	DSR have MAC overhead
Performance in AD hoc network	AODV has better performance in high mobility scenario	DSR have poor performance in high mobility scenario
Route discovery frequency	AODV have very frequent route discovery	DSR have less frequent route discovery
Utilization	Route discovery is on demand, which is more efficient in dynamic nature of mobile ad-hoc network.	Route is only created when required and node utilizes the route cache information efficiently to reduce the overhead and collision.

Temporally-Ordered Routing Algorithm (TORA)

- Route optimality is considered of secondary importance; longer routes may be used

- At each node, a logically separate copy of TORA is run for each destination, that computes the height of the node with respect to the destination
- Height captures number of hops and next hop
- Route discovery is by using query and update packets

- TORA modifies the partial link reversal method to be able to detect partitions
- When a partition is detected, all nodes in the partition are informed, and link reversals in that partition cease

Proactive Routing Protocols

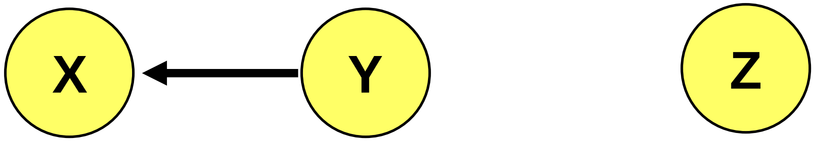
Destination-Sequenced Distance-Vector (DSDV)

- Each node maintains a routing table which stores
  - next hop, cost metric towards each destination
  - a sequence number that is created by the destination itself
- Each node periodically forwards routing table to neighbors
  - Each node increments and appends its sequence number when sending its local routing table
- Each route is tagged with a sequence number; routes with greater sequence numbers are preferred

- Each node advertises a monotonically increasing even sequence number for itself
- When a node decides that a route is broken, it increments the sequence number of the route and advertises it with infinite metric
- Destination advertises new sequence number

Destination-Sequenced Distance-Vector (DSDV)

- When X receives information from Y about a route to Z
  - Let destination sequence number for Z at X be S(X), S(Y) is sent from Y



  - 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)