MANET - Routing

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AP/CSE

Routing MANET vs Traditional N/ws

- 3 important differences
- MANET
  - All nodes act as routers
  - Dynamic Topology (Routing Table expire quickly)
  - IP address encapsulated in the subnet structure does not work
- Traditional N/ws
  - Nodes do not participate in routing
  - Static Topology
  - IP addressing scheme

Types of Communications

- Unicast
- Multicast
- Broadcast
  - Unrestricted broadcast communication can choke MANET.
  - Therefore applications usually do not use broadcast communication.

Unicast MANET Routing Protocols

- Classification of Unicast MANET Routing Protocols
  - Proactive Protocols (Table Driven)
  - Reactive Protocols (On - Demand)
  - Hybrid Routing Protocols

Proactive Protocols (Table Driven)

- Each node maintains routing table (Information about the routes to every other node in the network)
- The node itself finds the shortest path to reach the destination.
- Periodic Updation happens.
- As topology changes frequently, large number of control messages are used.
- More bandwidth is used by control messages.
- This protocol not suitable for large networks as the routing table will be large. (Communication overhead, Memory overhead)
- DSDV – Destination Sequenced Distance Vector Routing

Reactive Protocols (On - Demand)

- No up-to-date routing table maintenance.
- New routes are discovered only when required.
  - ie Routing table also updated on demand.
- Uses flooding technique to determine the route
- Reduces the overhead incurred by proactive protocols
- DSR – Dynamic Source Routing
- AODV – Ad-hoc On-demand Distance Vector Routing

Hybrid Routing Protocols

- Have the characteristics of both Proactive and Reactive protocols.
- Combine the good features of both.
- Consider a small Geographical area as a zone
- Routing within a zone is proactive (Table driven)
- Destination outside a zone is reactive (on-demand)
- ZRP – Zone Routing Protocol

Features of MANET Routing Protocols

- Identification of network topology after changes due to mobility
- Topology maintenance
- Transmission scheduling and channel assignment

Popular MANET Routing Protocols

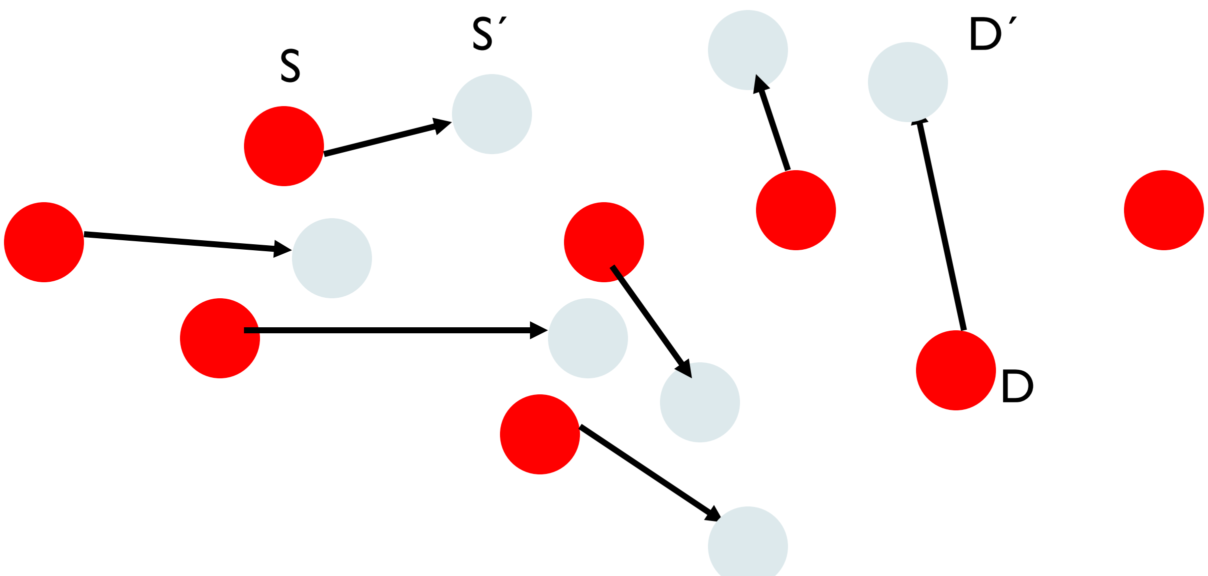
- Unicast Routing Protocols
  - DSDV – Destination Sequenced Distance Vector Routing
  - DSR – Dynamic Source Routing
  - AODV – Ad-hoc On-demand Distance Vector Routing
  - ZRP – Zone Routing Protocol
- Multicast Routing Protocols
  - Tree - Based Protocol
  - Mesh - Based Protocol

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 each node
- Each node periodically forwards routing table to its 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 finds that a route is broken, it increments the sequence number of the route and advertises it with infinite metric.

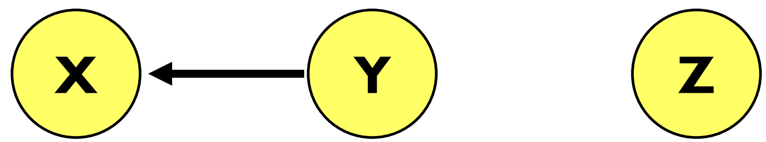
DSDV Cont…

- Consider a source node S and a destination node D.
- Each routing table entry in S is tagged with a sequence number that is originated by the destination node.
- For example, the entry for D is tagged with a sequence number that S received from D (may be through other nodes).



DSDV Cont…

- 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)

DSDV Cont…

- The nodes perform routing in the same way as the Distributed Bellman-Ford algorithm.
- Packets are transmitted between the nodes using routing tables stored at each node.
- Each routing table lists all available destinations and the number of hops to each destination.
- Each node knows which of its neighbours leads to the shortest path to the destination.

DSDV Cont…

- The consistency of the routing tables should be maintained in a dynamically varying topology.
- Each node periodically transmits updates. This is done by each node when significant new information is available.
- Do not assume any clock synchronization among the mobile nodes.
- The route-update messages indicate which nodes are accessible from each node and the number of hops to reach them.
- Consider the hop-count as the distance between two nodes.
- However, the DSDV protocol can be modified for other metrics as well.

DSDV Cont…

- A neighbour in turn checks the best route from its own table and forwards the message to its appropriate neighbour.

- There are two issues in this protocol :
  - How to maintain the local routing tables
  - How to collect enough information for maintaining the local routing tables

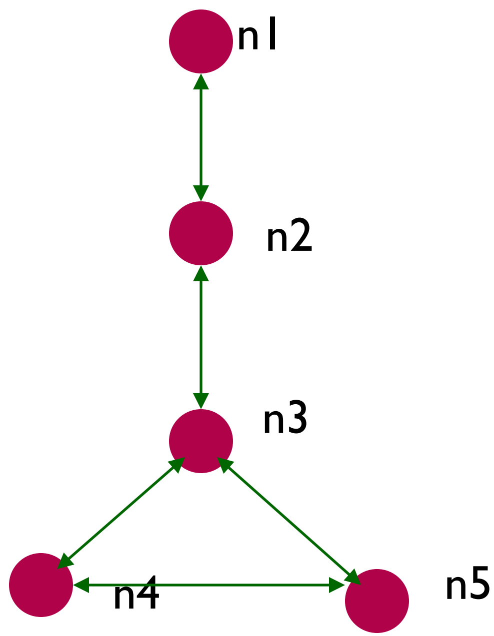
Route Advertisements

- The DSDV protocol requires each mobile node to advertise its own routing table to all of its current neighbours.
- Since the nodes are mobile, the entries can change dynamically over time.
- The route advertisements should be made whenever there is any change in the neighbourhood or periodically.
- Each mobile node agrees to forward route advertising messages from other mobile nodes.
- This forwarding is necessary to send the advertisement messages all over the network.
- In other words, route advertisement messages help mobile nodes to get an overall picture of the topology of the network.

Route Advertisements

- The route advertisement broadcast by each mobile node has the following information for each new route :
  - The destination's address
  - The number of hops to the destination
  - The sequence number of the information received from that destination. This is the original sequence number assigned by the destination.

An Example of Route Update

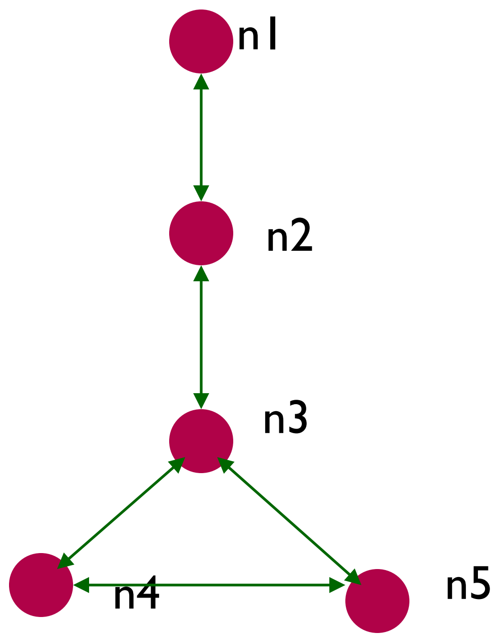


- At the start, each node gets route updates only from its neighbour.
- For n4, the distances to the other nodes are :

  n5=1, n3=1, n2= ∞

  n1 = ∞
- All nodes broadcast with a sequence number 1

Continued…

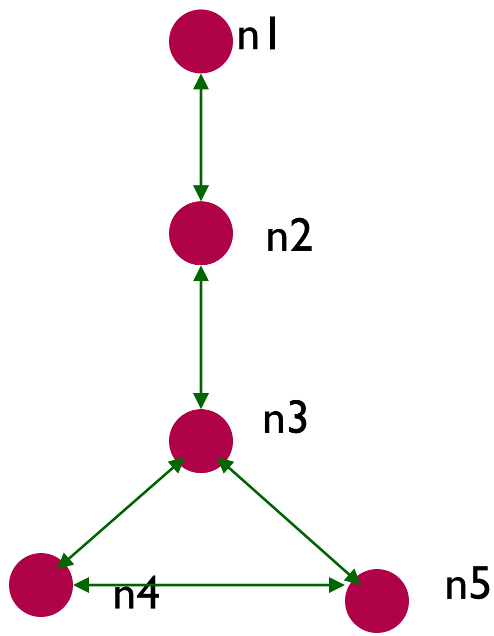


- After this, nodes forward messages that they have received earlier.
- n2 forwards RT to n3 and n3 to n4
- For n4, the distances are now

  n5=1, n3=1, n2=2, n1=∞

All messages have sequence number 1

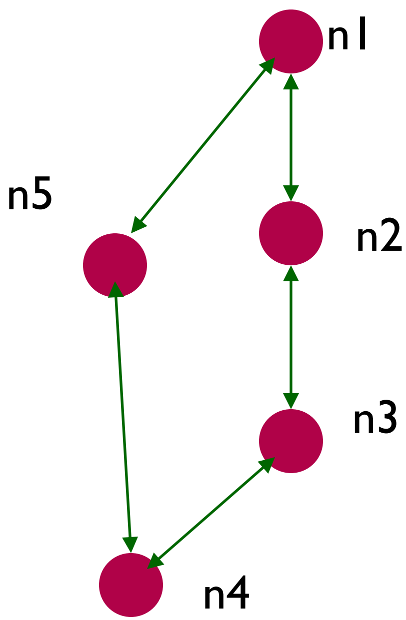
Continued…



- Finally, after second round of forwarding, n4 gets the following distances :

n5=1, n3=1, n2=2, n1=3

Continued…



- Suppose n5 has moved to its new location.
- Also, n5 receives a new message from n1 with a sequence number 2
- This message is forwarded by n5 to n4
- Two distances to n1 in n4
  - Distance 3 with seqence number 1
  - Distance 2 with sequence number 2
- Since the latter message has a more recent sequence number, n4 will update the distance to n1 as 2

Route Advertisements

- For example, a node n may receive two different messages originating from another node m.
- However, node n will forward the most recent message from m to its neighbours.
- Usually n will add one extra hop to the routes in the message received from m as the destination is one more hop away.

Responding to Topology Changes

- Some of the links in a mobile network may be broken when the nodes move.
- A broken link is described by a distance
- When a link to a next hop is broken, any route through that next hop is given a distance
- This is considered as a major change in the routing table and immediately broadcast.
- The number of routing updates may be quite high in a large network with high level of mobility.
- It is necessary to avoid excessive control traffic (route update information) in such networks. Otherwise, the bandwidth will be taken up by control traffic.
- The solution is to broadcast two types of updates.

Responding to Topology Changes

- A full dump carries complete routing table. A node broadcasts a full dump infrequently.
- An incremental dump carries minor changes in the routing table. This information contains changes since the last full dump.
- When the size of an incremental dump becomes too large, a full dump is preferred.

Route Selection Criteria

- When a node i receives incremental dump or full dump from another node j, the following actions are taken :
  - The sequence number of the current dump from j is compared with previous dumps from j
  - If the sequence number is new, the route table at i is updated with this new information.
  - Node i now broadcasts its new route table as an incremental or a full dump.

How frequently should a node broadcast?

- A node decides on a new route based on one of the two criteria :
  - If a route has a smaller metric (distance) to a destination
  - Or, if an update from the destination with a new sequence number has been received.

- However, it is not desirable that a node broadcasts an update every time it has updated its routing table.

Routing Table

Destination	Next	Cost	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.

Advantages of DSDV

- DSDV is an efficient protocol for route discovery.
- Whenever a route to a new destination is required, it already exists at the source.
- Hence, latency for route discovery is very low.
- DSDV also guarantees loop-free paths.

Disadvantages

- However, DSDV needs to send a lot of control messages. These messages are important for maintaining the network topology at each node.
- This may generate high volume of traffic for high-density and highly mobile networks.
- Special care should be taken to reduce the number of control messages.

Dynamic Source Routing

- Split routing into discovering a path and maintaining a path
- Route discovery
  - Only if a route for sending packets to a certain destination is needed and no route is currently available
- Route Maintenance
  - Only while the route is in use one has to make sure that it can be used continuously
- No periodic updates needed!

Dynamic Source Routing

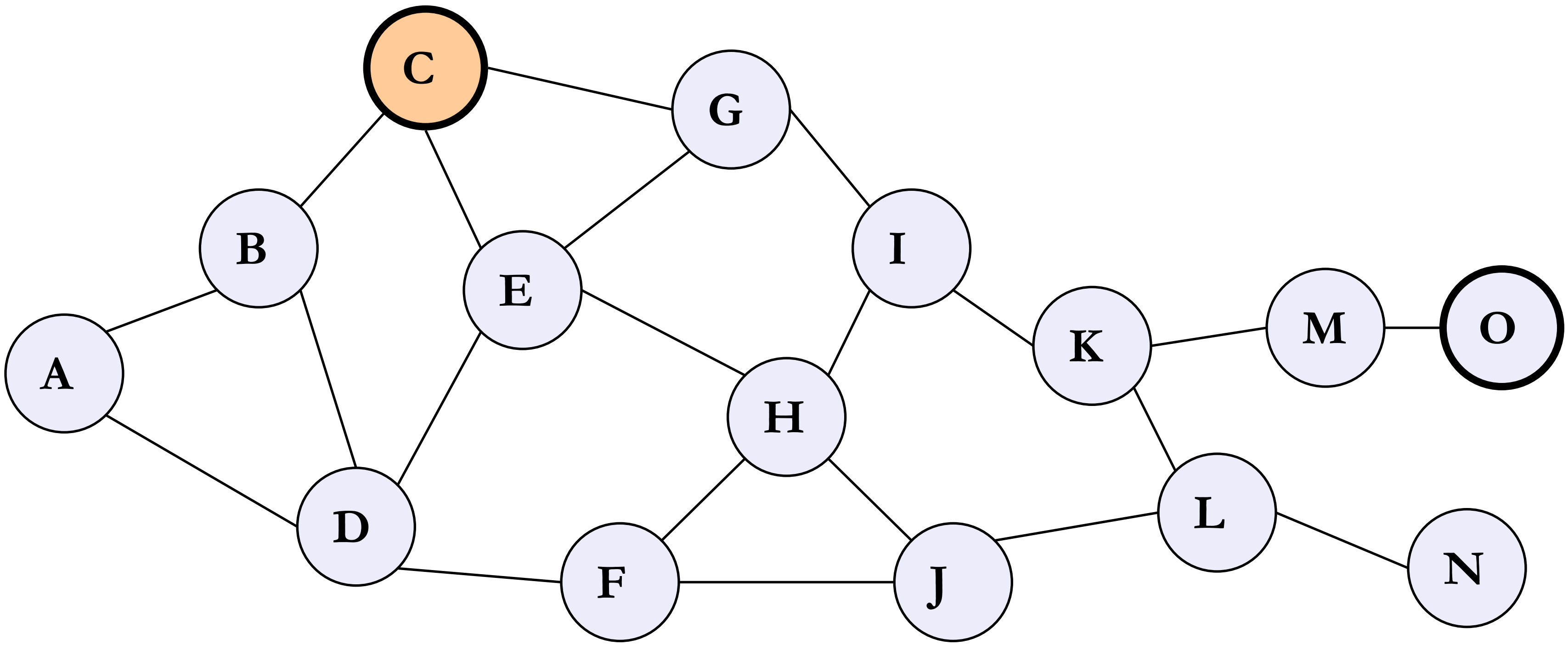
- Route discovery
  - Broadcast a packet with destination address and unique ID
  - If a station receives a broadcast packet
    - If the station is the receiver (i.e., has the correct destination address) then return the packet to the sender (path was collected in the packet)
    - If the packet has already been received earlier (identified via ID) then discard the packet
    - Otherwise, append own address and broadcast packet
  - Sender receives packet with the current path (address list)

Route discovery

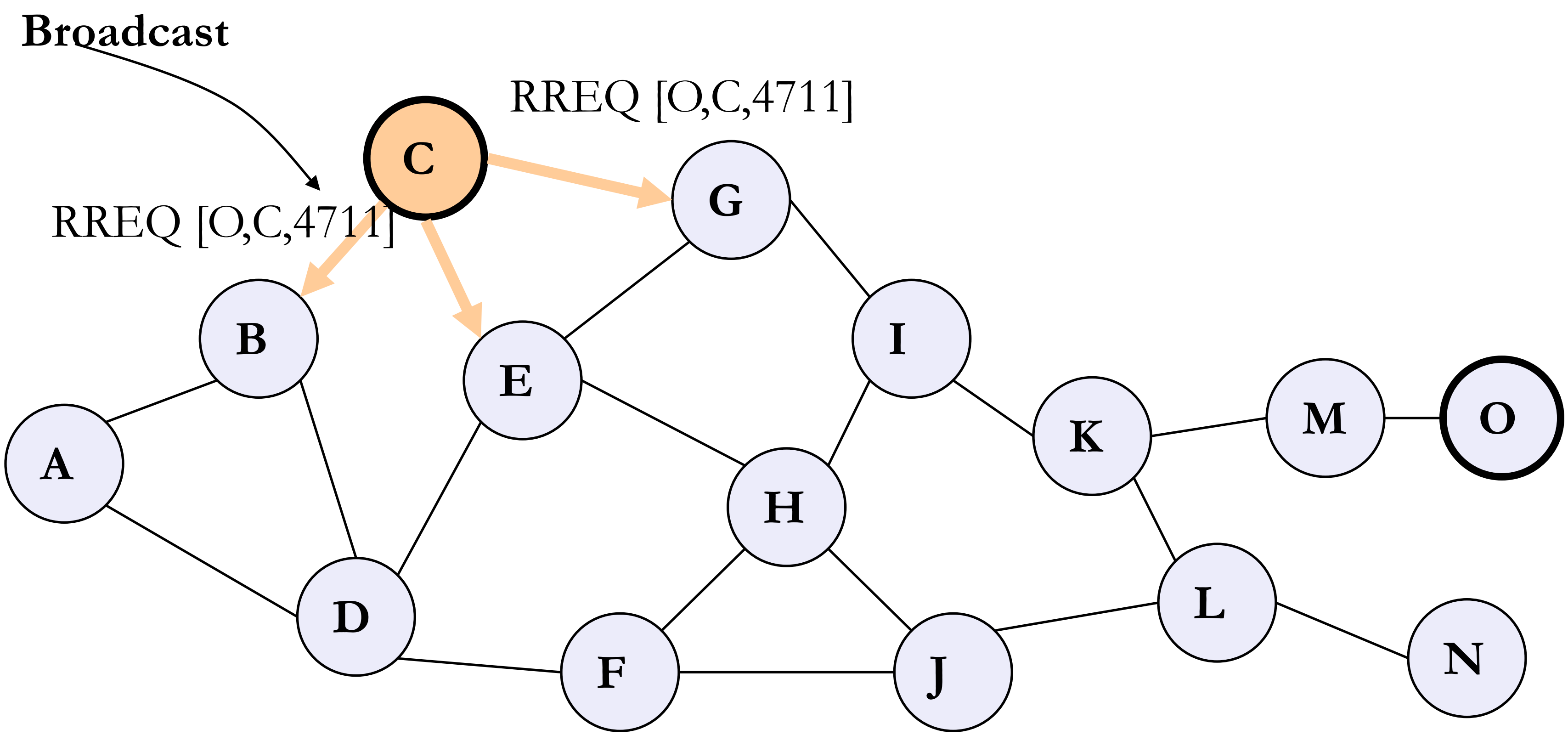
- When node C wants to send a packet to node O, but does not know a route to O, node C initiates a route discovery
- Source node C floods Route Request (RREQ)
- Each node appends own identifier when forwarding RREQ

DSR: Route Discovery

Sending from C to O



DSR: Route Discovery



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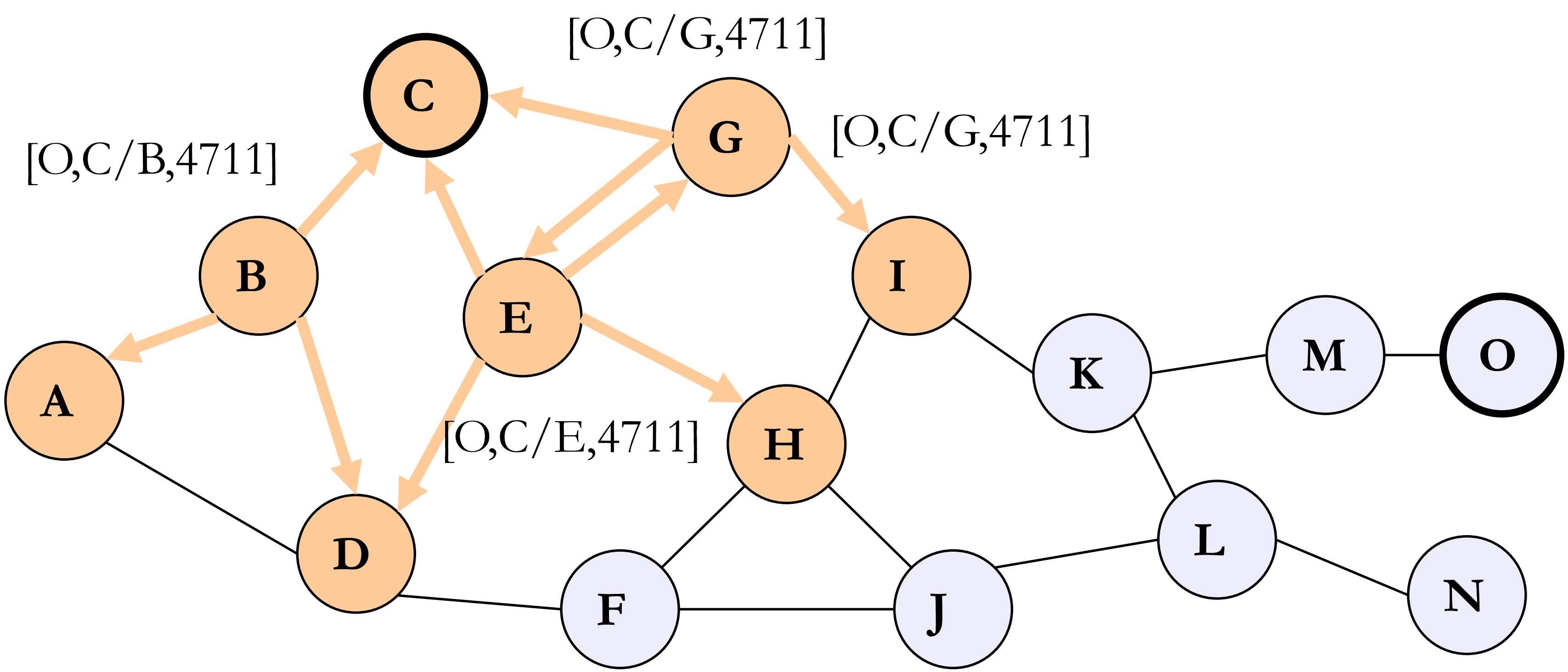

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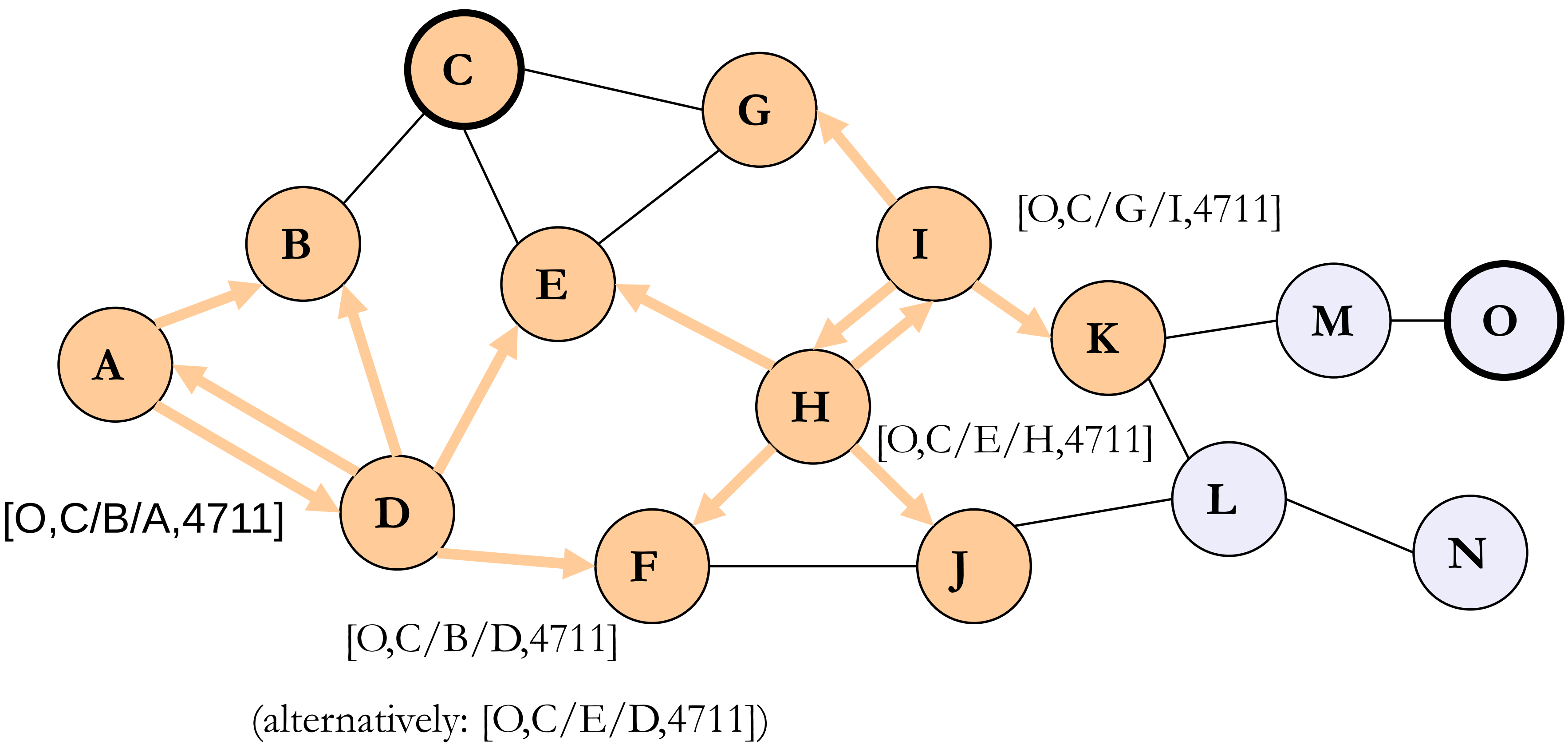

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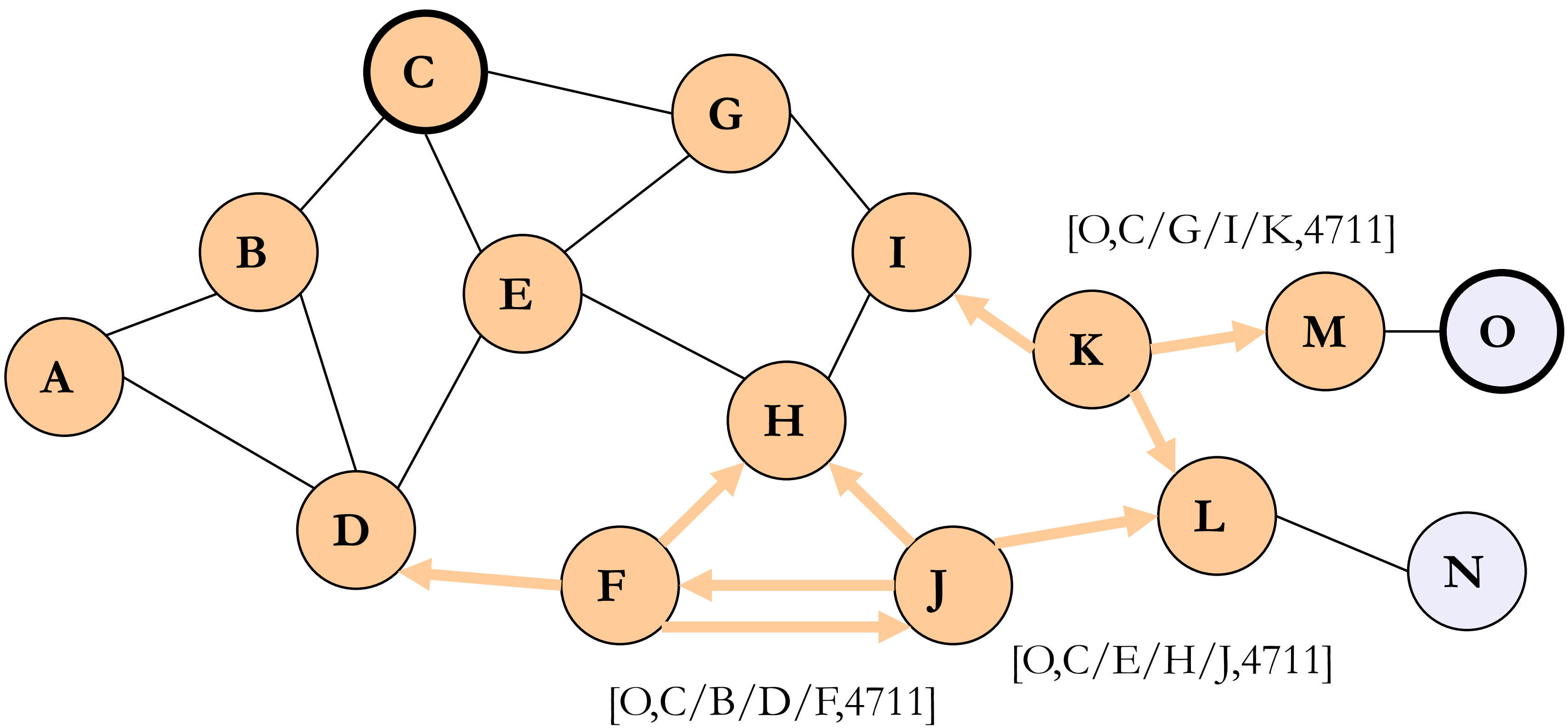

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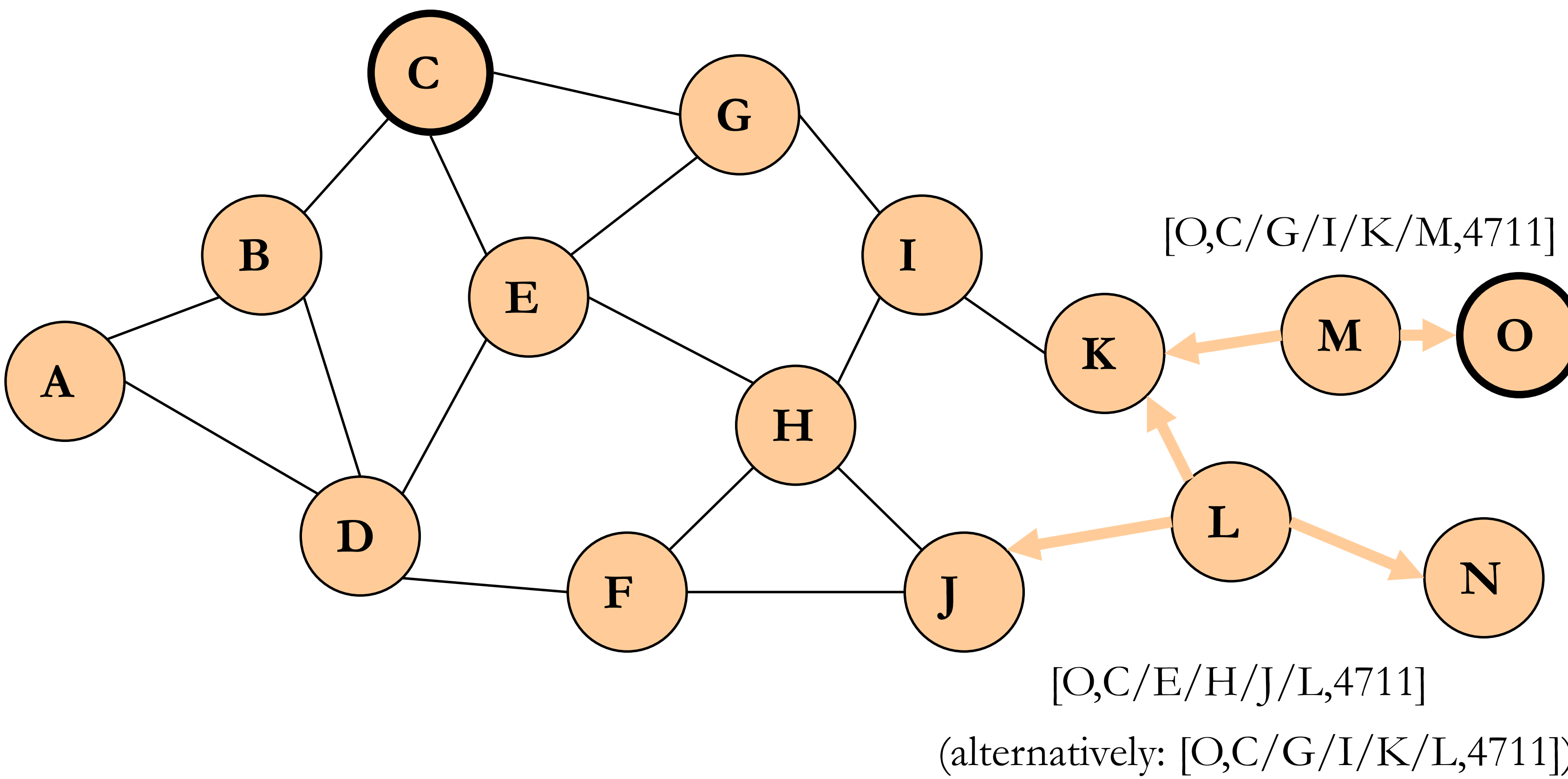

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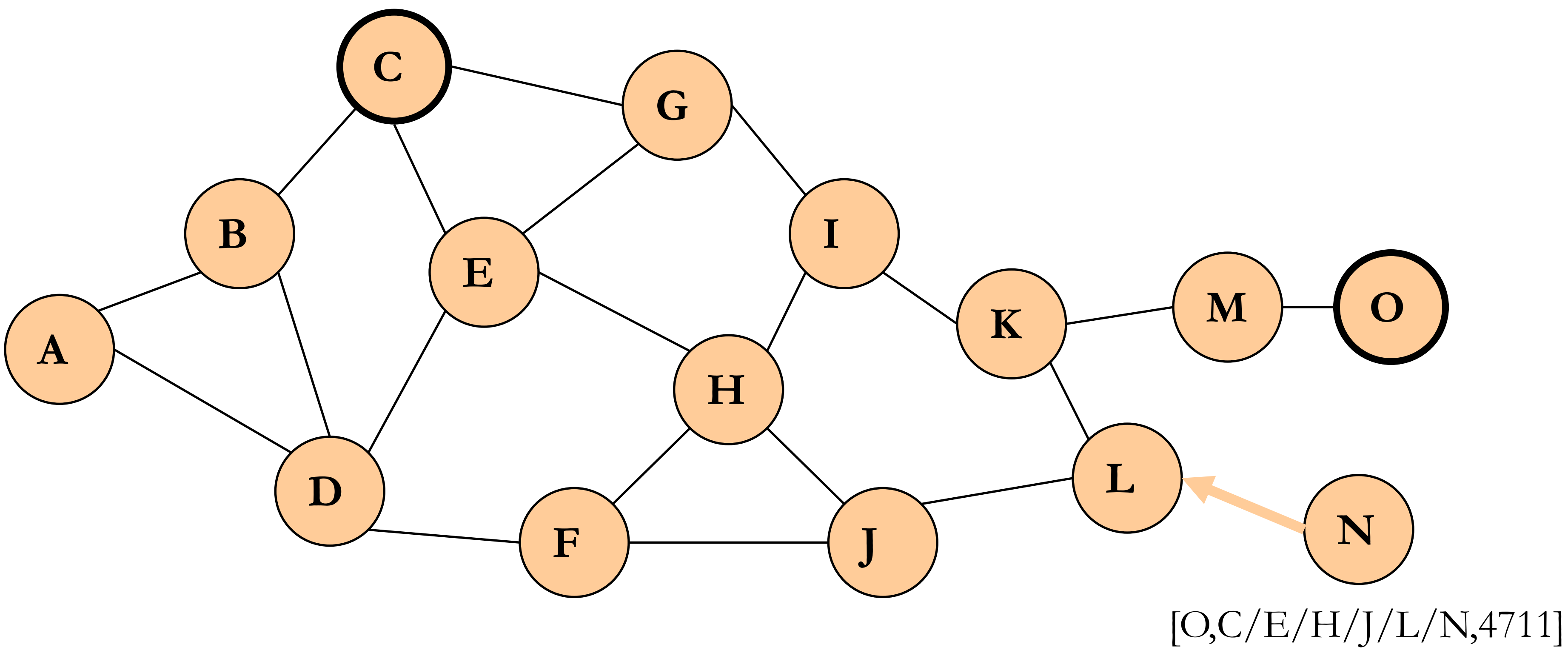

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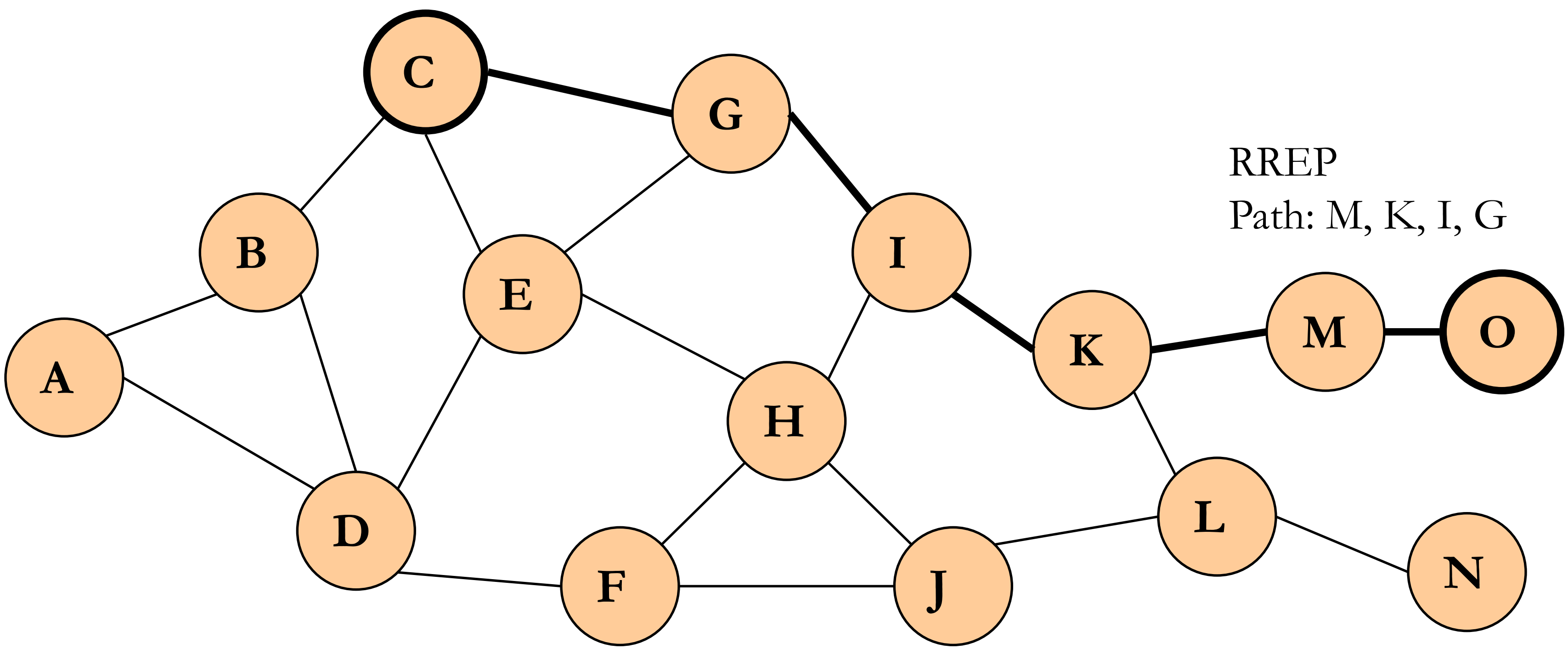
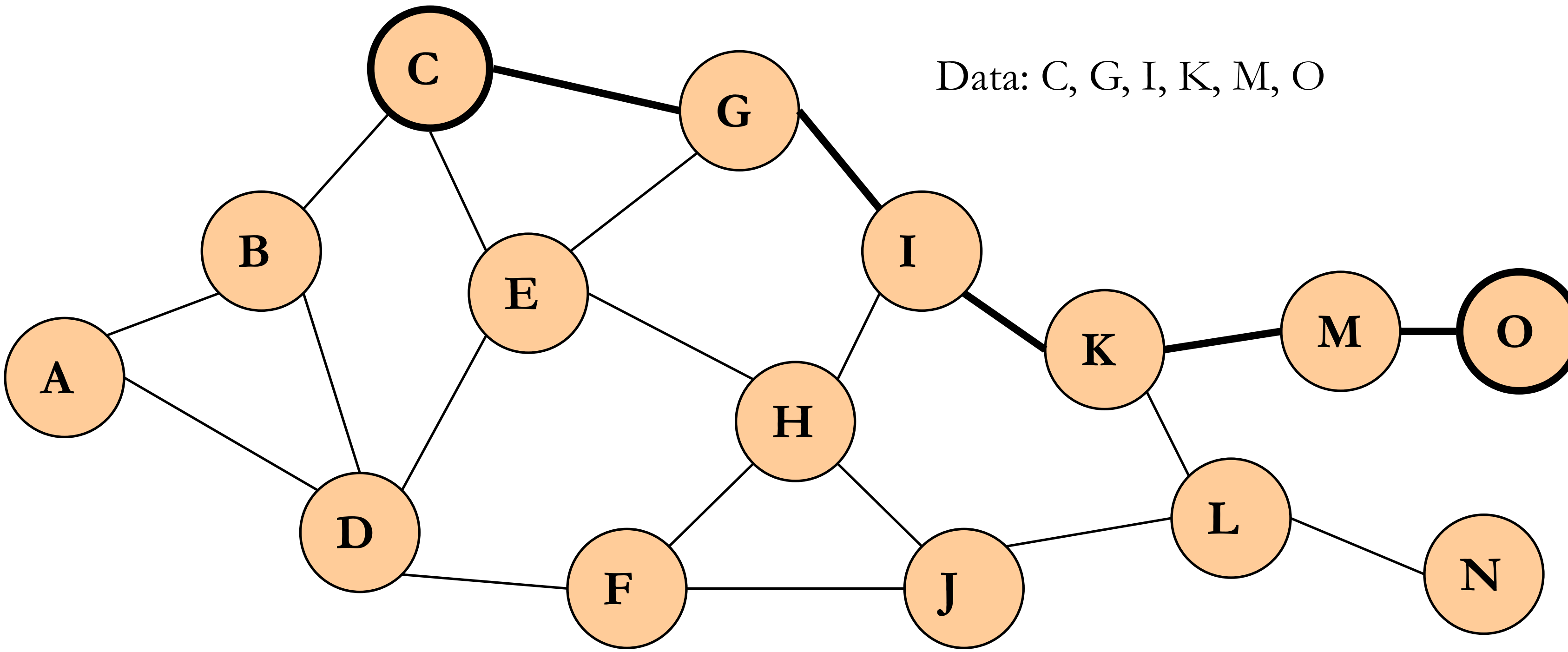


Route Discovery

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

DSR: Route Discovery



Dynamic Source Routing

- Optimizations
  - Limit broadcasting if maximum diameter of the network is known
  - Caching of address lists (i.e. paths) with help of passing packets (Route Caching)
    - Stations can use the cached information for path discovery (own paths or paths for other hosts)

Route Caching

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

Dynamic Source Routing

- Route Maintenance
  - After sending a packet
    - Wait for a layer 2 acknowledgement (if applicable)
    - Listen into the medium to detect if other stations forward the packet (if possible)
    - Request an explicit acknowledgement
  - If a station encounters problems it can inform the sender of a packet or look-up a new path locally

DSR : 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

DSR : 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

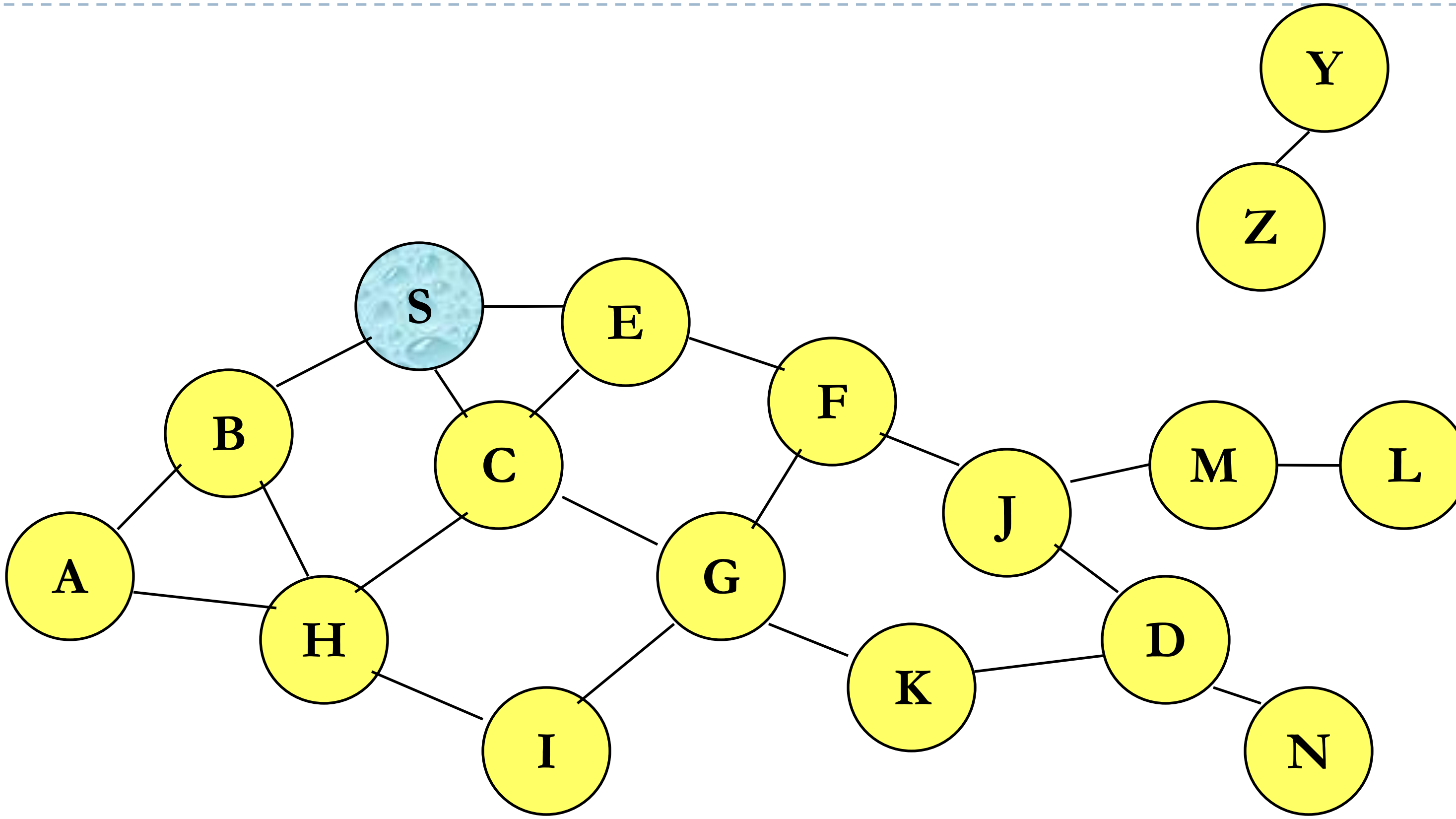
Ad Hoc On-Demand Distance Vector Routing

- 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

Ad Hoc On-Demand Distance Vector Routing

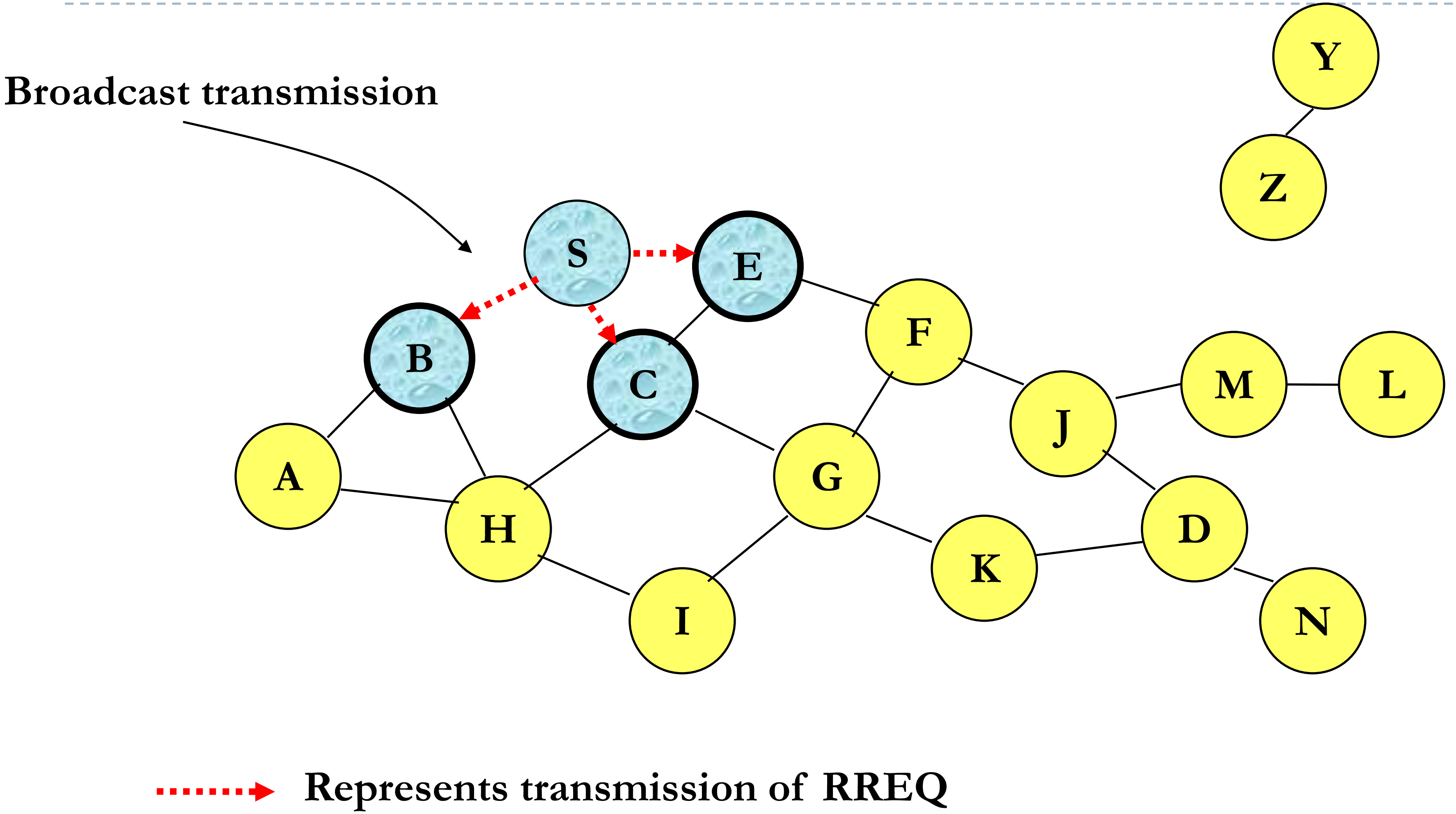
- Route Requests (RREQ) are forwarded in a manner similar to DSR
- When a node re-broadcasts a Route Request, it sets up a reverse path pointing towards the source
  - AODV assumes symmetric (bi-directional) links
- When the intended destination receives a Route Request, it replies by sending a Route Reply (RREP)
- Route Reply travels along the reverse path set-up when Route Request is forwarded

Route Requests in AODV

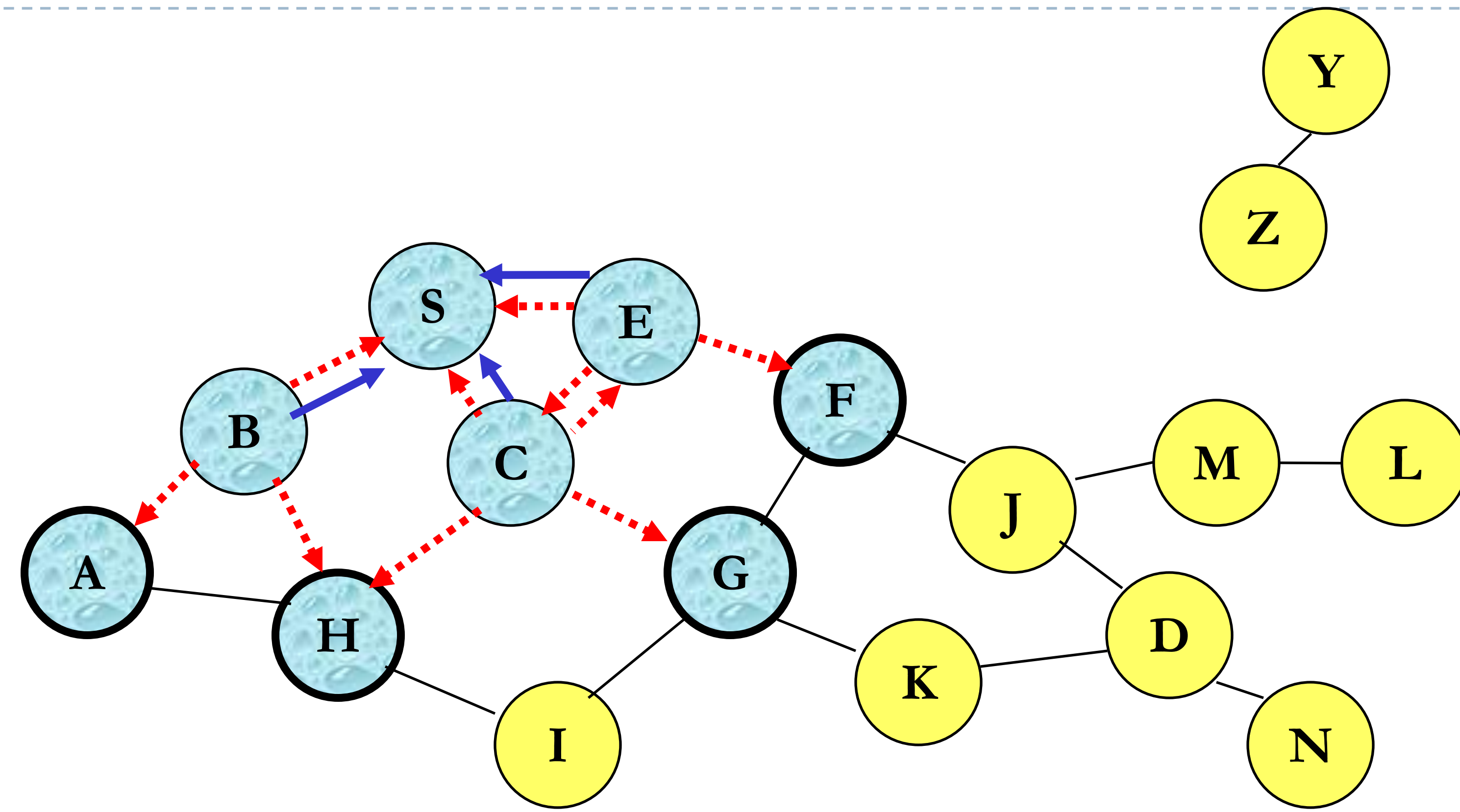


Represents a node that has received RREQ for D from S

Route Requests in AODV

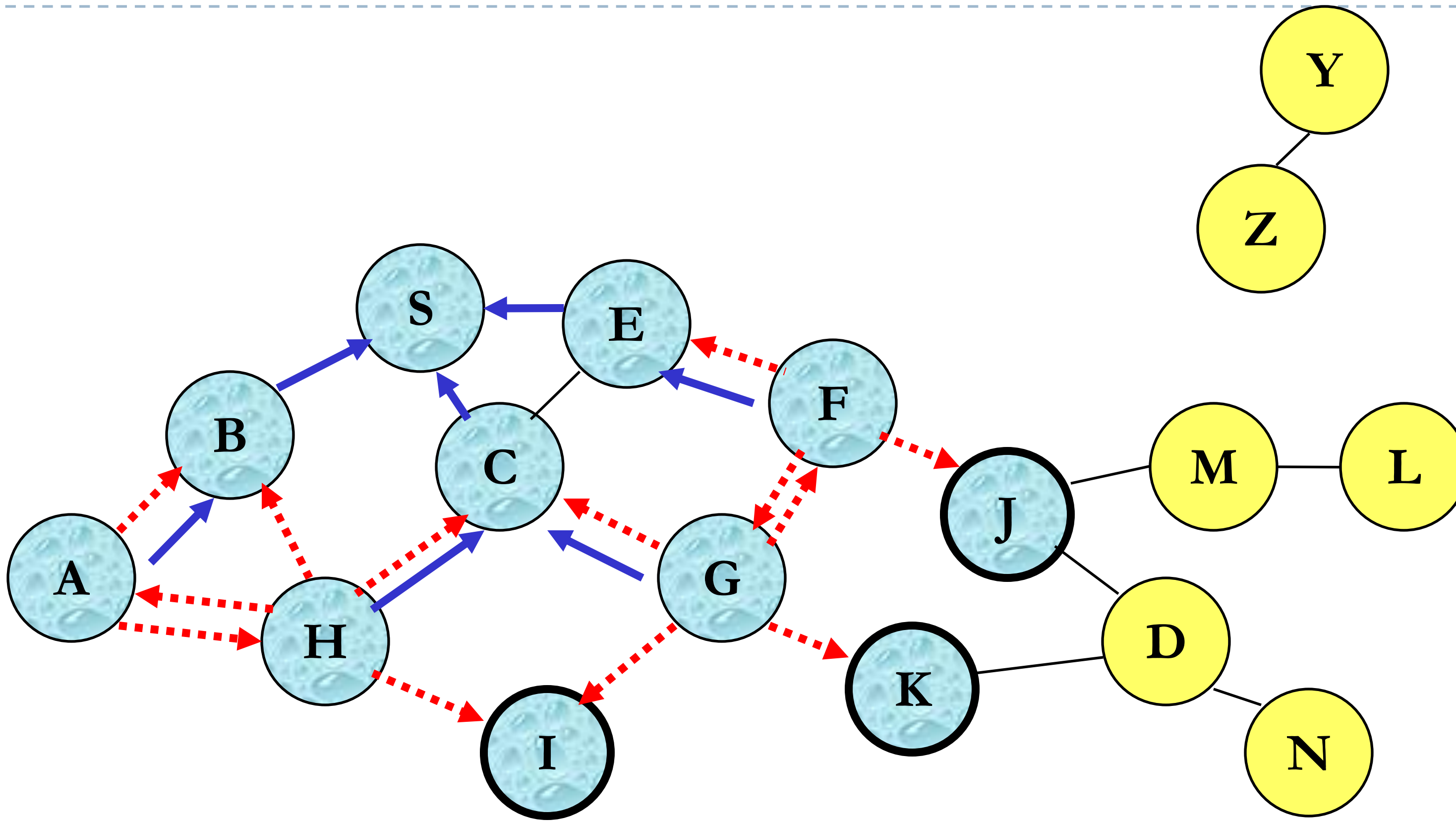


Route Requests in AODV



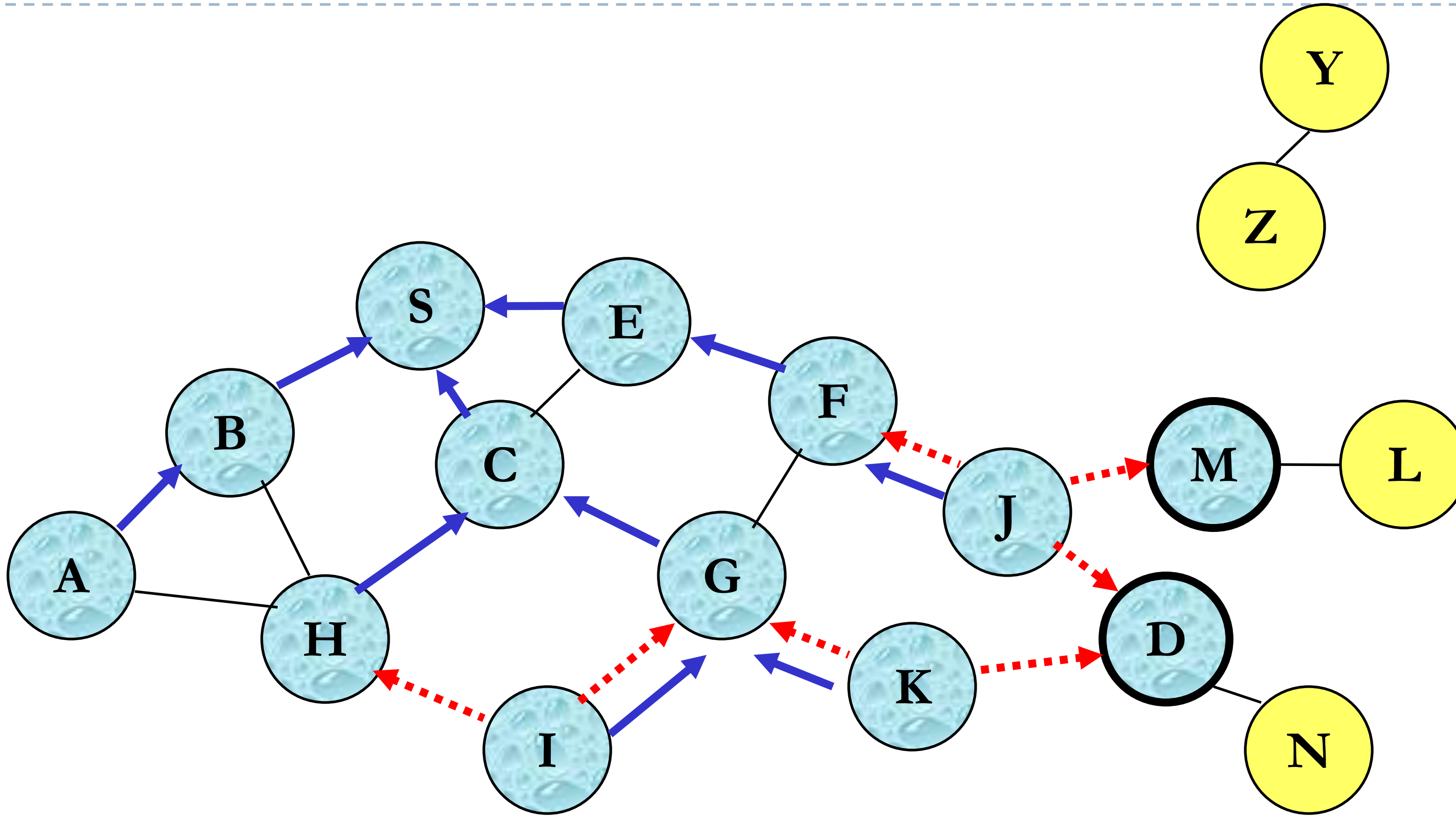
Represents links on Reverse Path

Route Requests in AODV

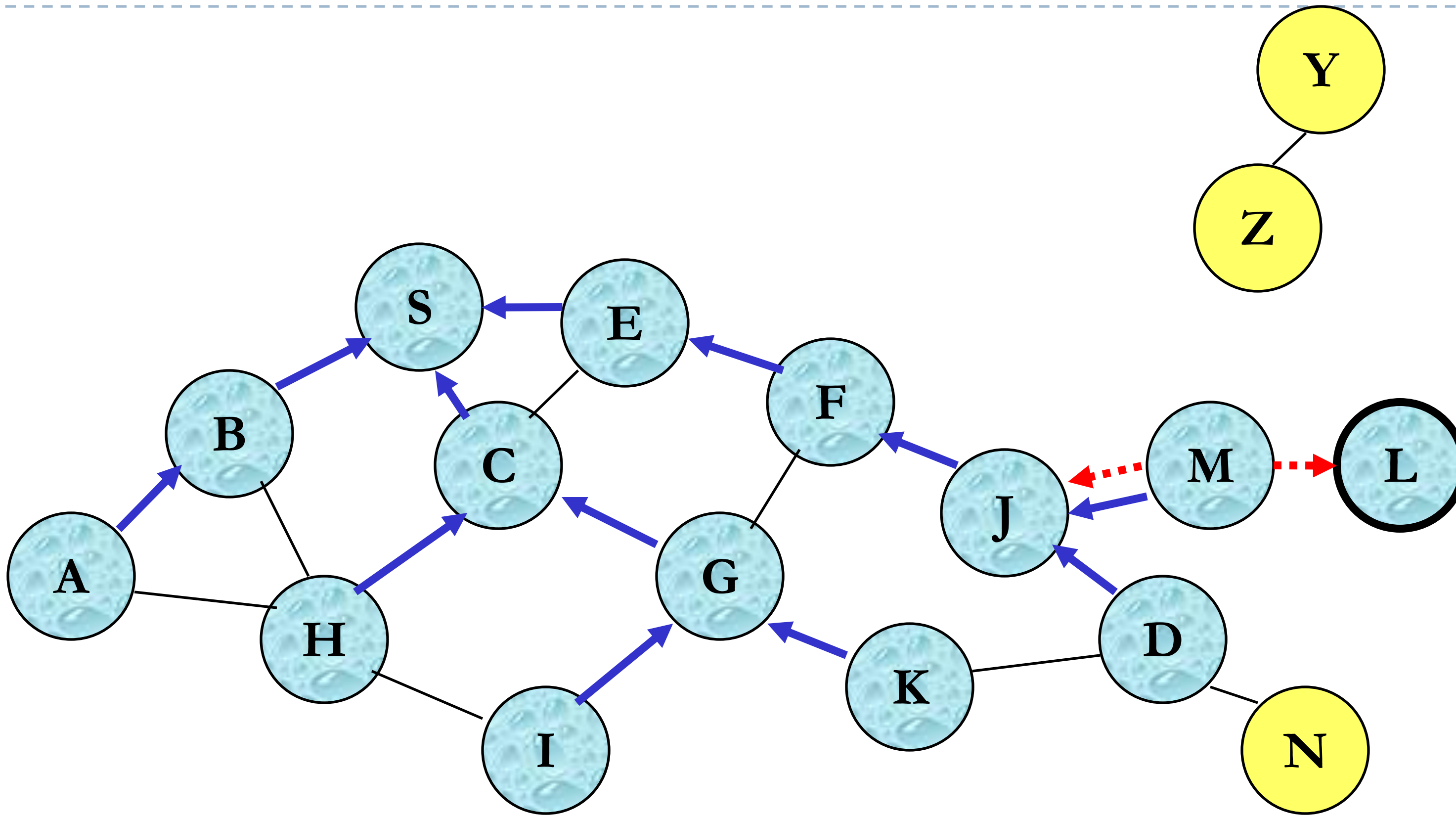


- Node C receives RREQ from G and H, but does not forward it again, because node C has already forwarded RREQ once

Route Requests in AODV

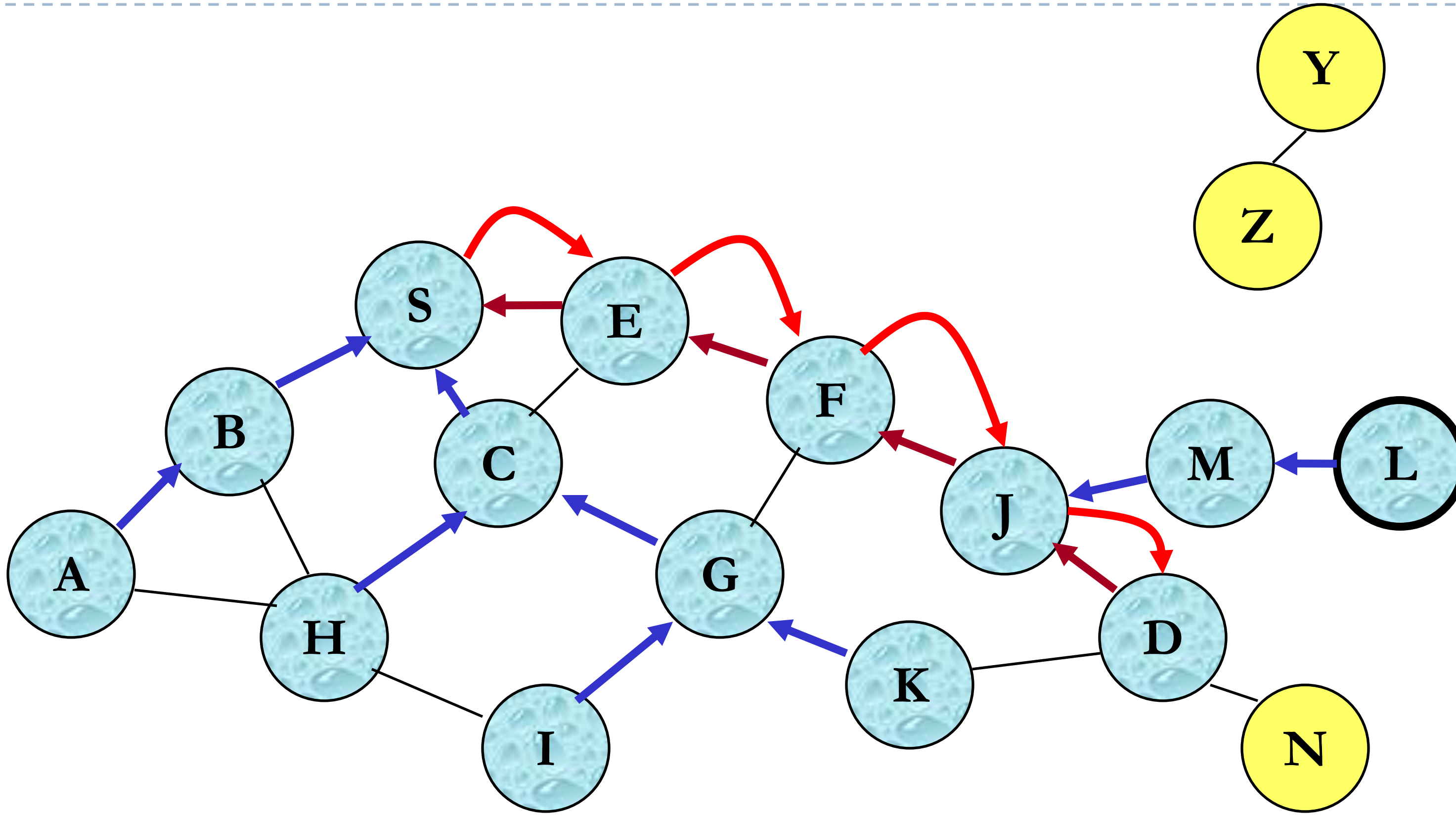


Route Requests in AODV

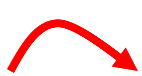


- **Node D does not forward RREQ, because node D is the intended target of the RREQ**

Route Requests in AODV



Forward links are setup when RREP travels along the reverse path

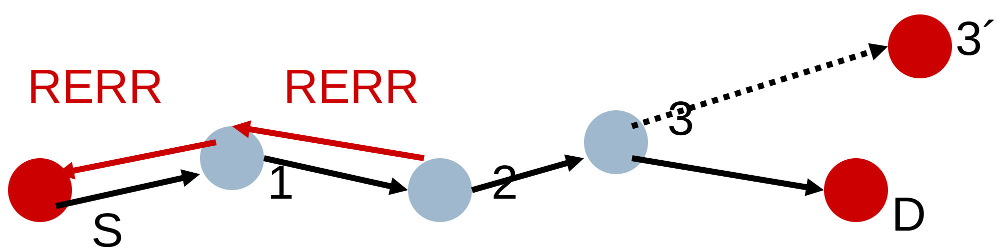
 **Represents a link on the forward path**

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 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.
- 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.



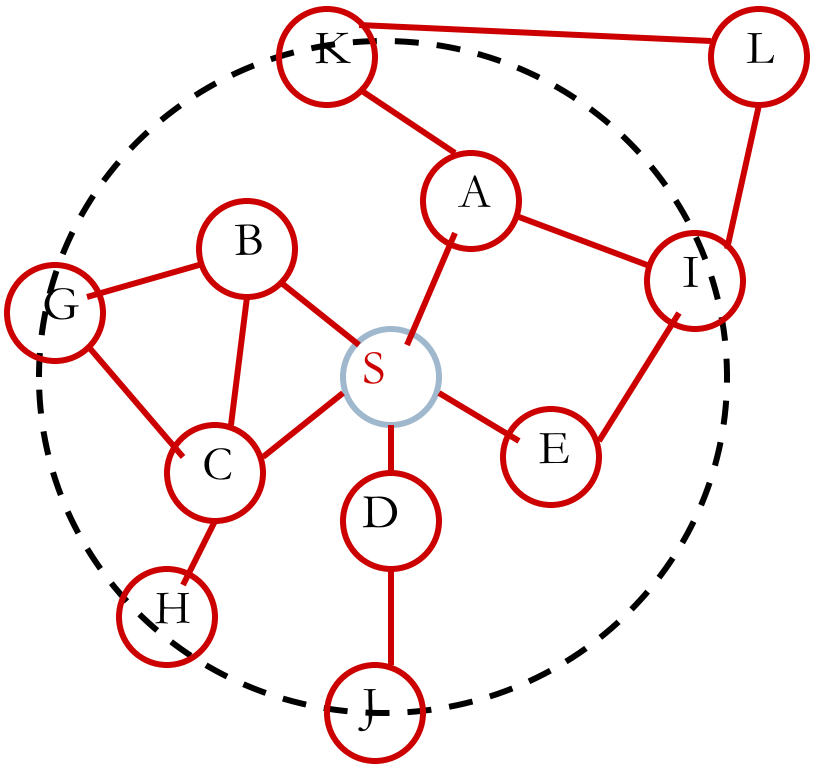
Zone Routing Protocol

- It is possible to exploit the good features of both reactive and proactive protcols and the Zone routing protocol does that.
- The proactive part of the protocol is restricted to a small neighbourhood of a node and the reactive part is used for routing across the network.
- This reduces latency in route discovery and reduces the number of control messages as well.

Routing Zones

- Each node S in the network has a routing zone. This is the proactive zone for S as S collects information about its routing zone in the manner of the DSDV protocol.
- If the radius of the routing zone is k, each node in the zone can be reached within k hops from S.
- The minimum distance of a peripheral node from S is k (the radius).

Routing Zones



- All nodes except L are in the routing zone of S with radius 2.

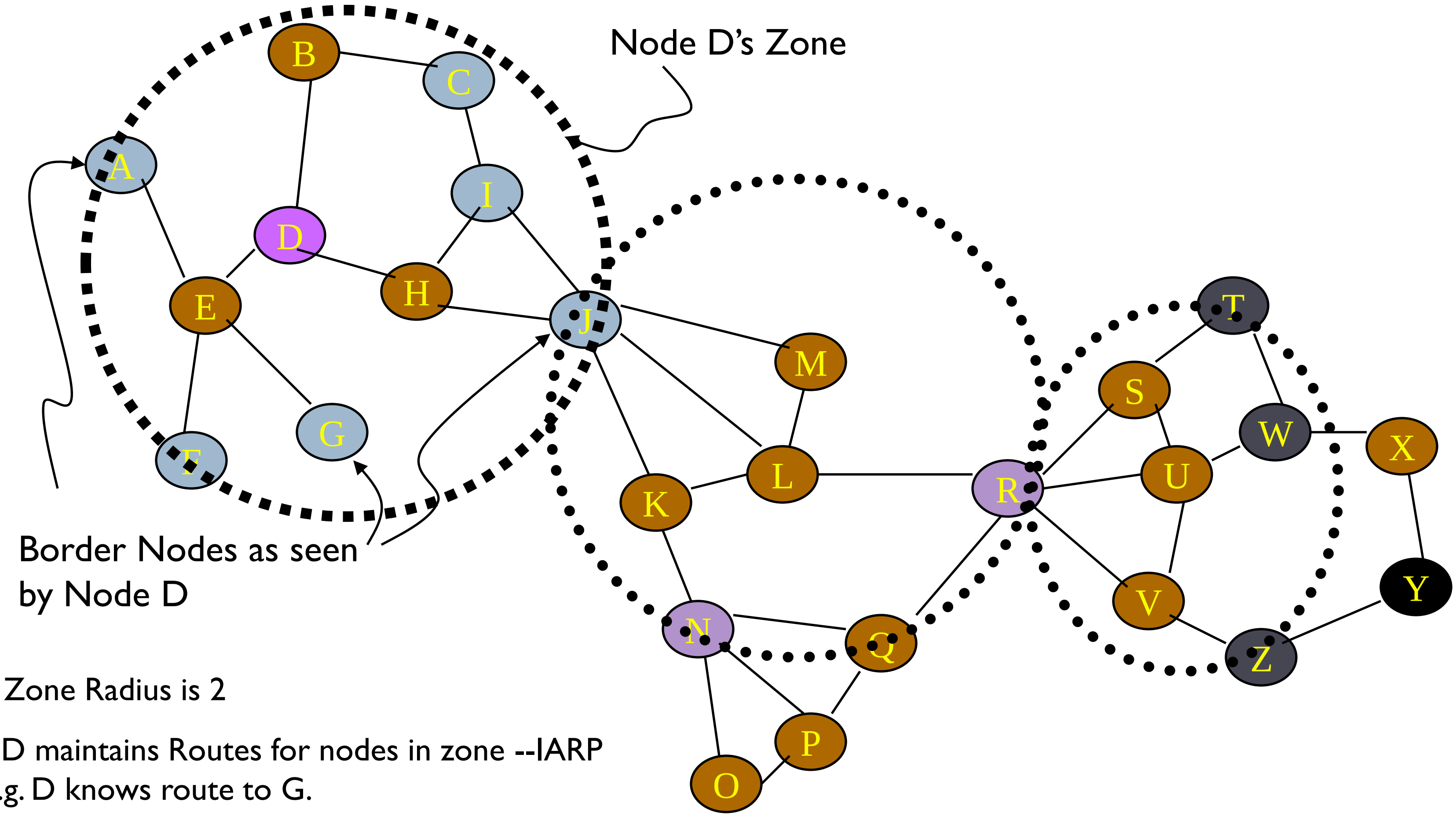
Routing Zones

- The coverage of a node´s trasmitter is the set of nodes in direct communication with the node. These are also called neighbours.
- In other words, the neighbours of a node are the nodes which are one hop away.
- For S, if the radius of the routing zone is k, the zone includes all the nodes which are k-hops away.
- The routing in ZRP is divided into two parts
  - Intrazone routing : Proactively maintain routes to all nodes within the source node's own zone.
  - Interzone routing : Use an on-demand protocol (similar to DSR or AODV) to determine routes to outside zone..

Intrazone Routing Protocol (IARP)

- Each node collects information about all the nodes in its routing zone proactively. This strategy is similar to a proactive protocol like DSDV.
- Each node maintains a routing table for its routing zone, so that it can find a route to any node in the routing zone from this table.

Intrazone Routing Protocol (IARP)



- Zone Radius is 2
- D maintains Routes for nodes in zone --IARP e.g. D knows route to G.
- If node not found, resort to Inter zone search.

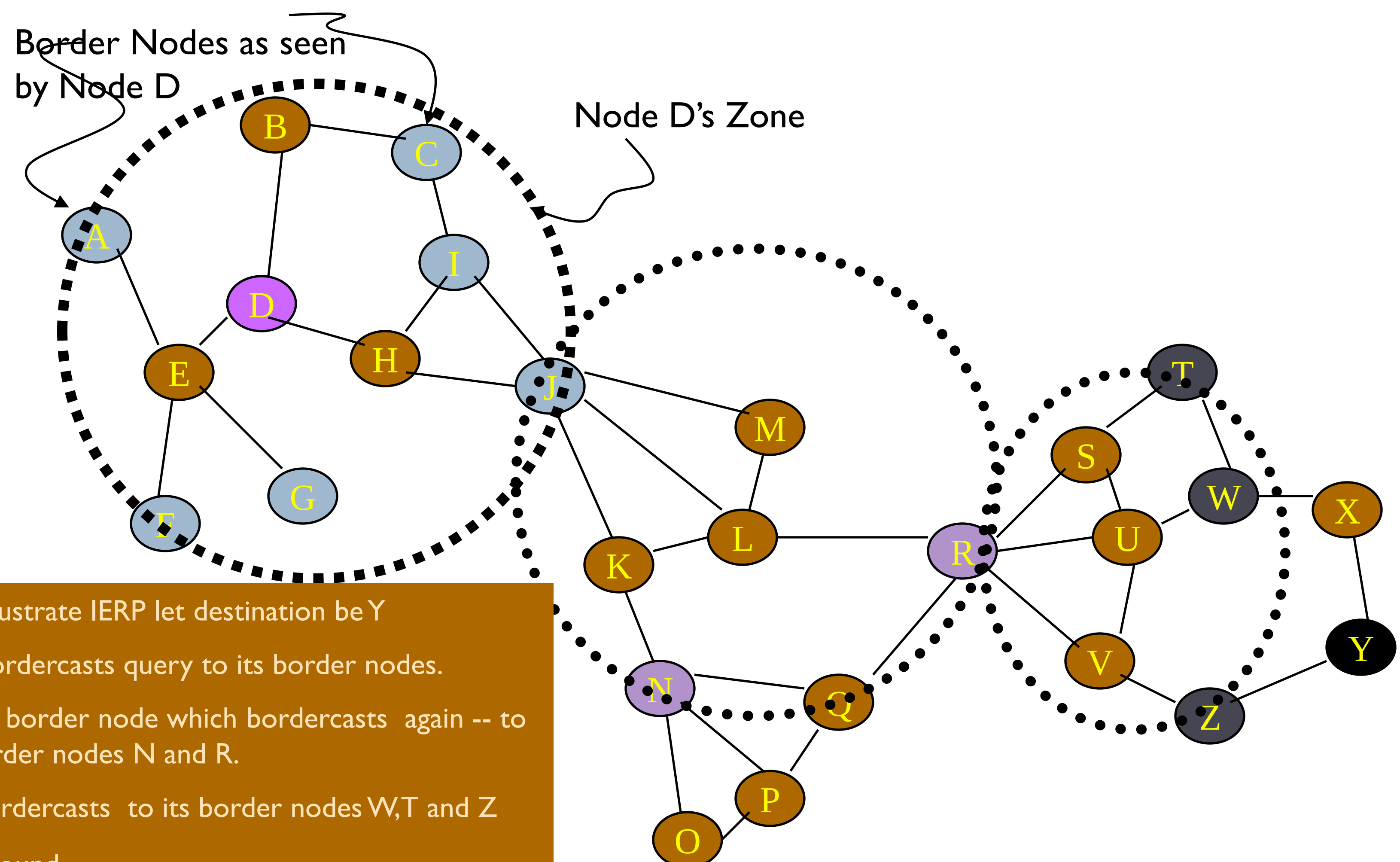
Interzone Routing Protocol (IERP)

- The interzone routing discovers routes to the destination reactively.
- Consider a source (S) and a destination (D). If D is within the routing zone of S, the routing is completed in the intrazone routing phase.
- Otherwise, S sends the packet to the peripheral nodes of its zone through bordercasting.

Bordercasting

- The node would direct the query message out only to its peripheral nodes.
- These nodes would execute the same algorithm that the primary node executed which is:
  - Check to see if the destination can be found within its zone. (How ?).
  - If yes, send a route-reply back to the source, indicating the route to the destination.
  - If not, forward the route-request to its peripheral nodes which execute the same procedure.

Interzone Routing Protocol (IERP)



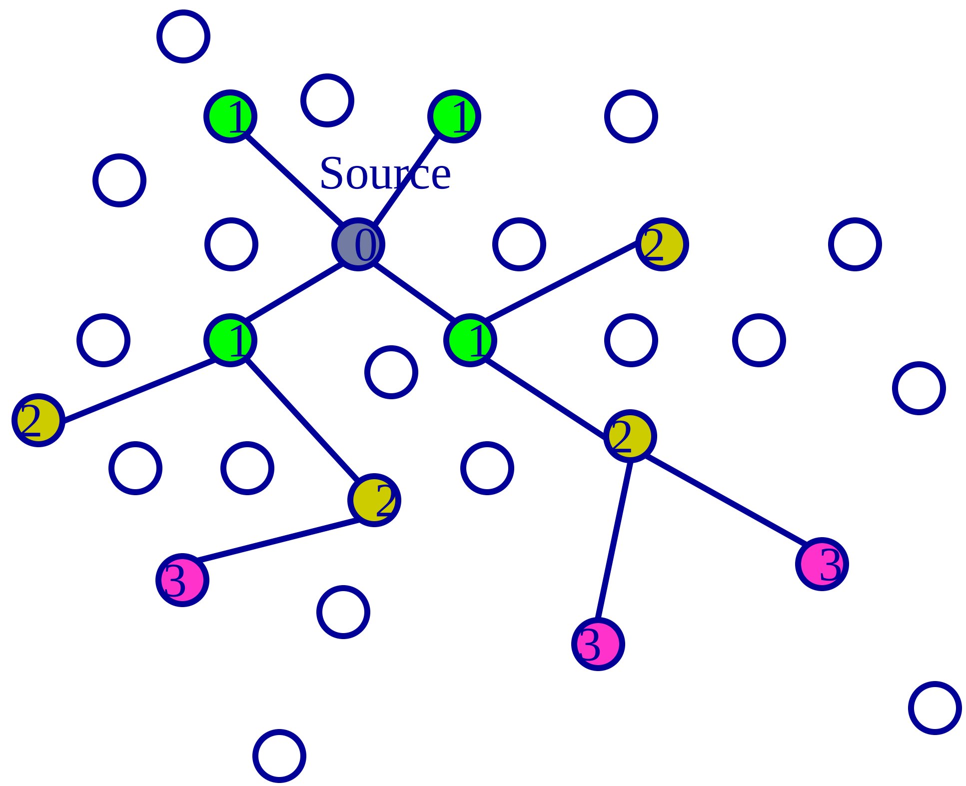
- To illustrate IERP let destination be Y
- D bordercasts query to its border nodes.
- J is a border node which bordercasts again -- to its border nodes N and R.
- R bordercasts to its border nodes W,T and Z
- Y is found.

Multicast Routing Protocols for MANET

- Multicast → group transmission
- Efficient operation → Minimize unnecessary packet transmission – which minimizes energy consumption

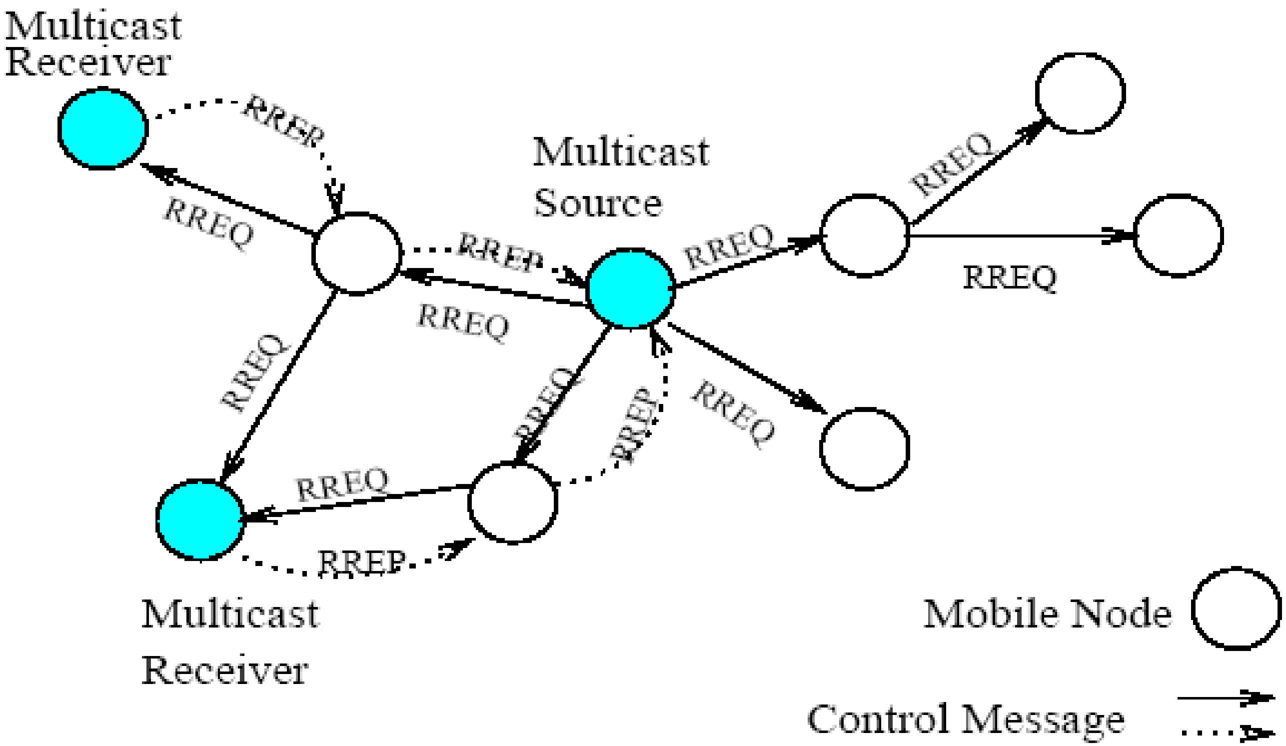
Tree – Based Protocol

- A packet traverses each hop and node in a tree at most once
- Tree structure built representing shortest paths amongst nodes, and a loop-free data distribution structure
- Even a link failure could mean reconfiguration of entire tree structure, could be a major drawback



Tree – Based Protocol

- Multicast Ad hoc On-Demand Distance Vector Protocol
  - Follows directly from the unicast AODV



Mesh Based Protocol

- Mesh-based multicast protocols may have multiple paths between any source and receiver pairs
- Mesh-based protocols seem to outperform tree-based proposals due to availability of alternative paths
- A mesh has increased data-forwarding overhead
- The redundant forwarding consumes more bandwidth
- The probability of collisions is higher when a larger number of packets are generated