

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

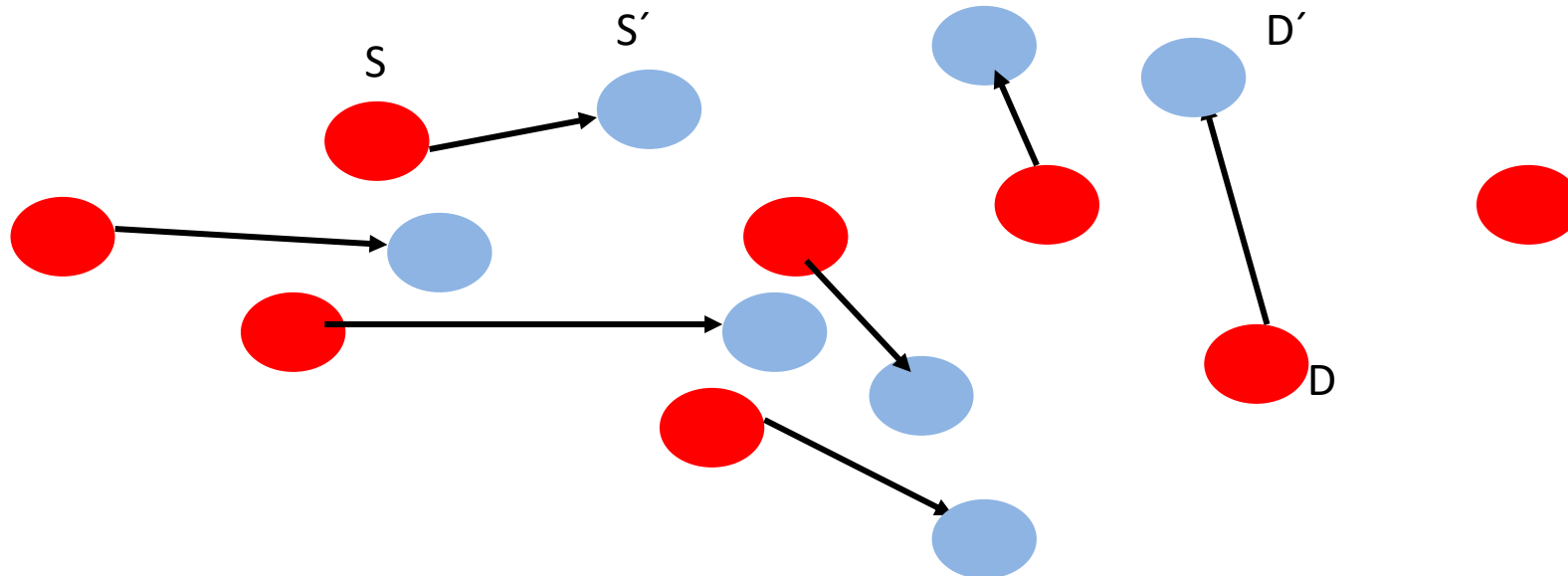
- Unicast Routing Protocols
 - DSDV – Destination Sequenced Distance Vector Routing
 - DSR – Dynamic Source Routing
 - AODV – Ad-hoc On-demand Distance Vector Routing
 - ZRP – Zone Routing Protocol
- Multicast Routing Protocols
 - Tree - Based Protocol
 - Mesh - Based Protocol

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.

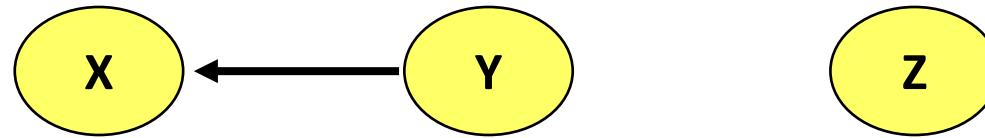
DSDV Cont...

- 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

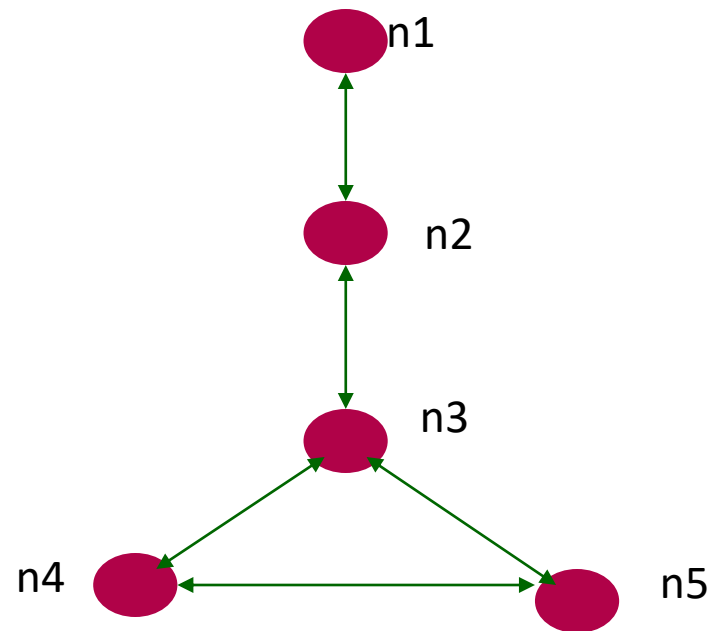
Route Advertisements

- 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

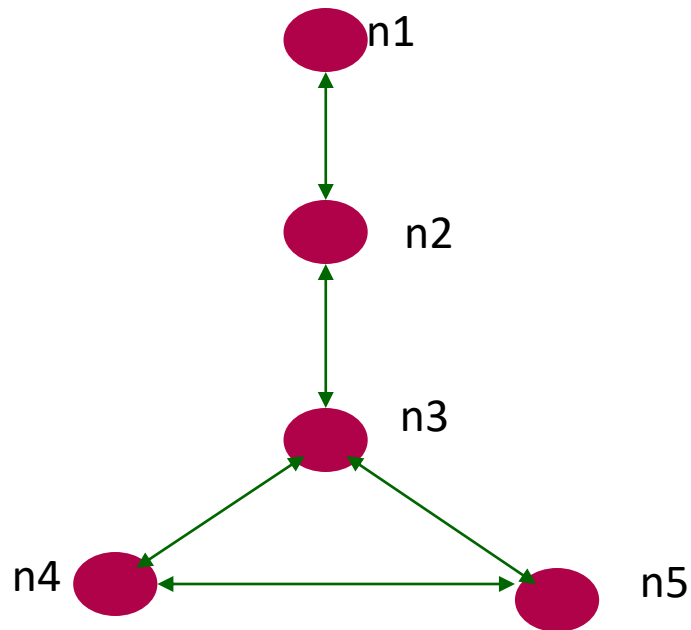
- The route advertisement broadcast by each mobile node has the following information for each new route :
 - The destination's address
 - The number of hops to the destination
 - The sequence number of the information received from that destination. This is the original sequence number assigned by the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

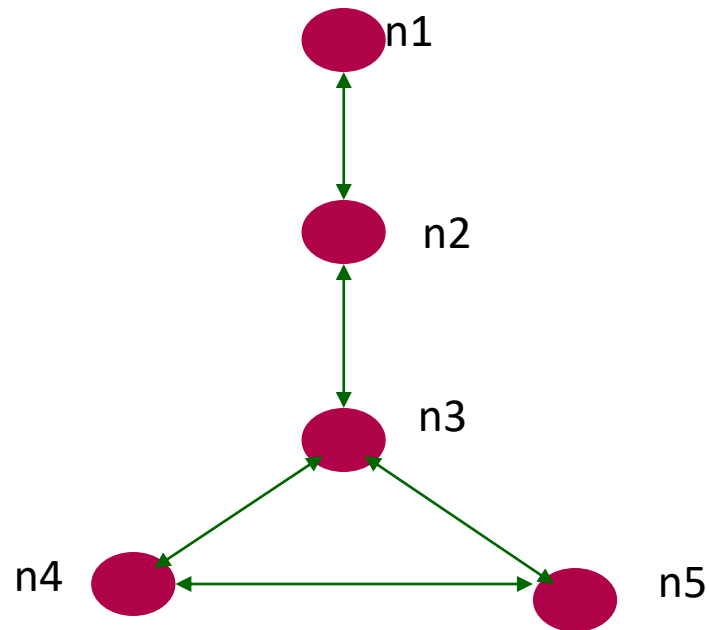
An Example of Route Update



- 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**

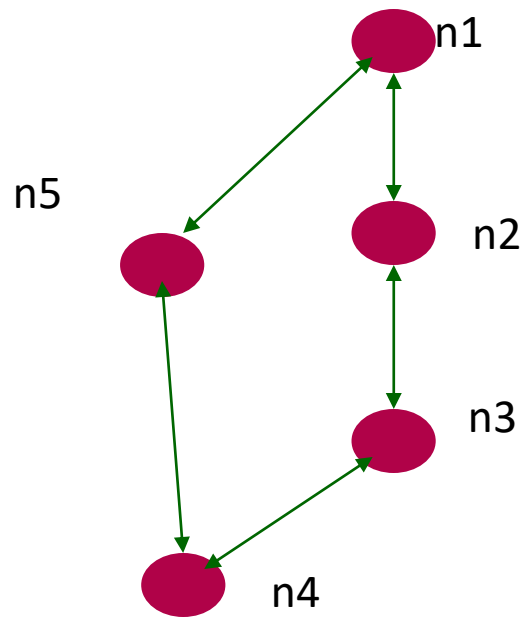
An Example of Route Update



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

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

An Example of Route Update



- 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 sequence 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

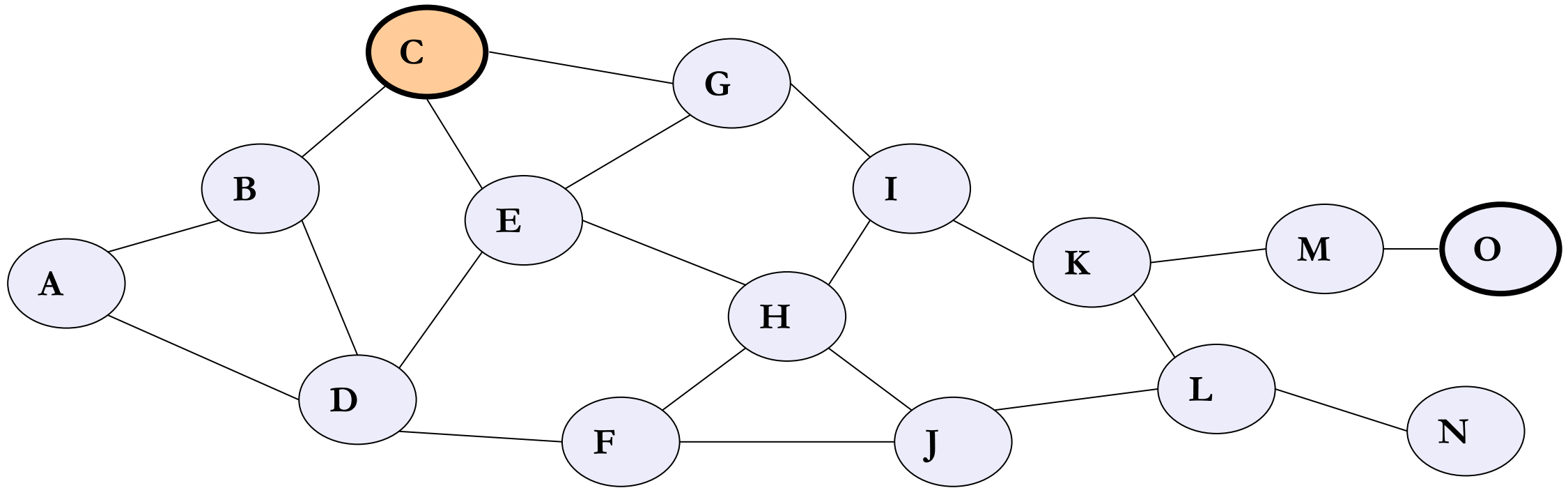
- Route discovery
 - Broadcast a packet with destination address and unique ID
 - If a station receives a broadcast packet
 - If the station is the receiver (i.e., has the correct destination address) then return the packet to the sender (path was collected in the packet)
 - If the packet has already 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

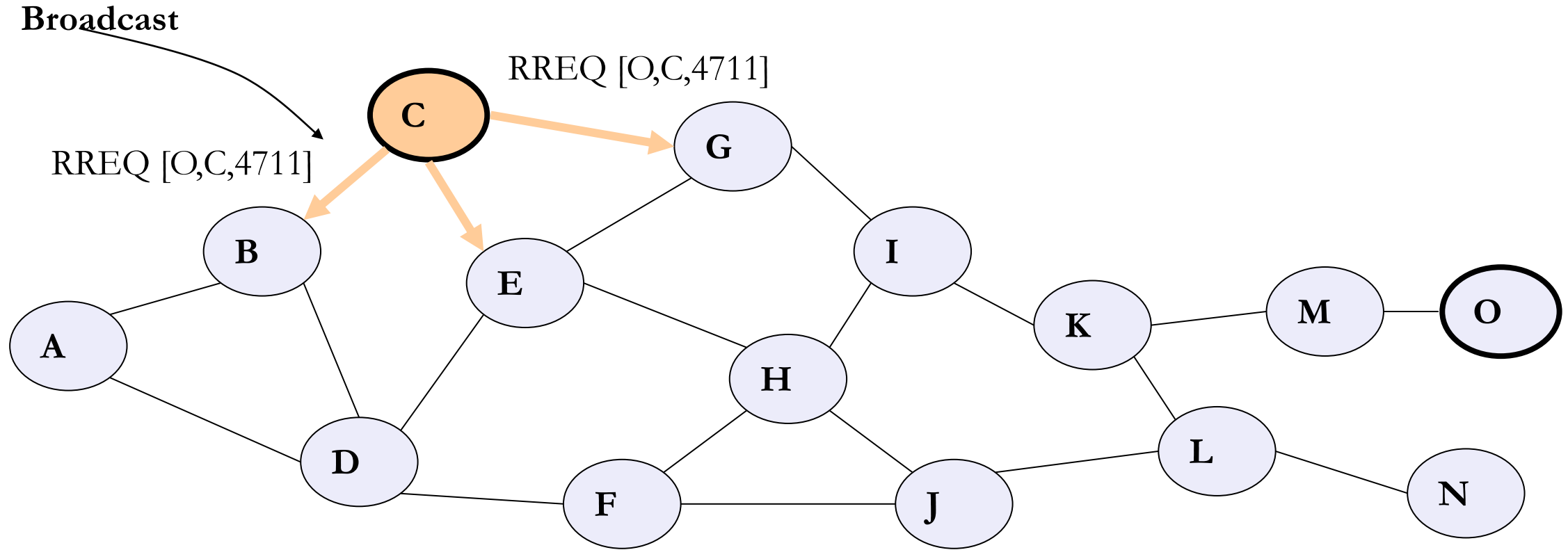
- When node C wants to send a packet to node O, but does not know a route to O, node C initiates a route discovery
- Source node C floods Route Request (RREQ)
- Each node appends own identifier when forwarding RREQ

DSR: Route Discovery

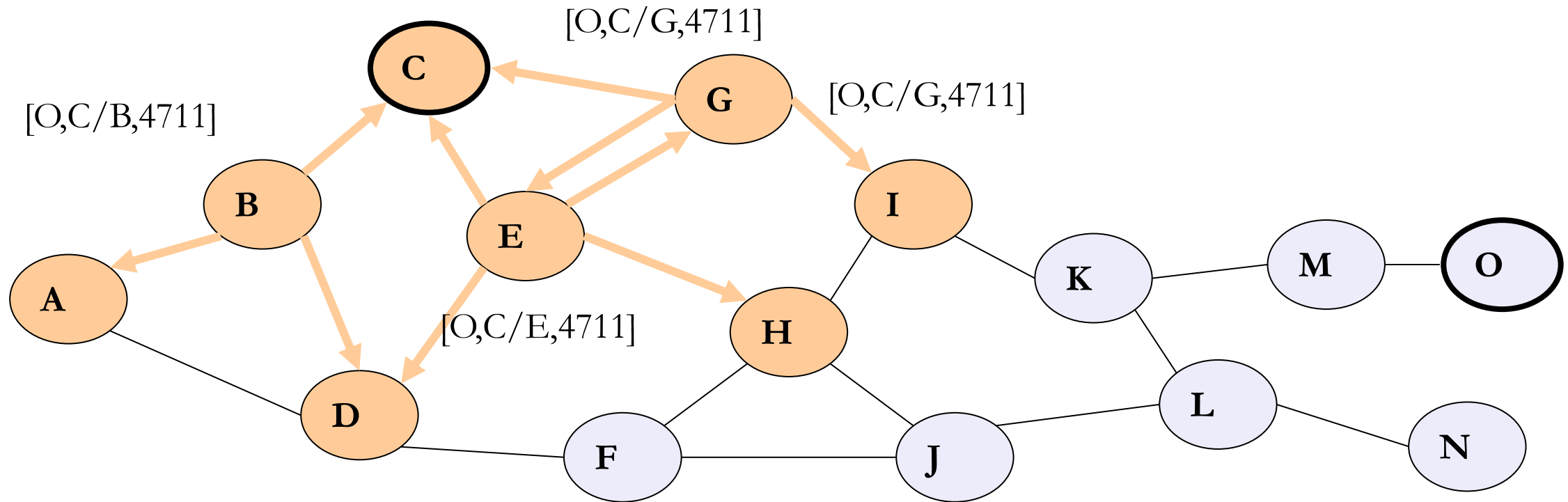
Sending from C to O



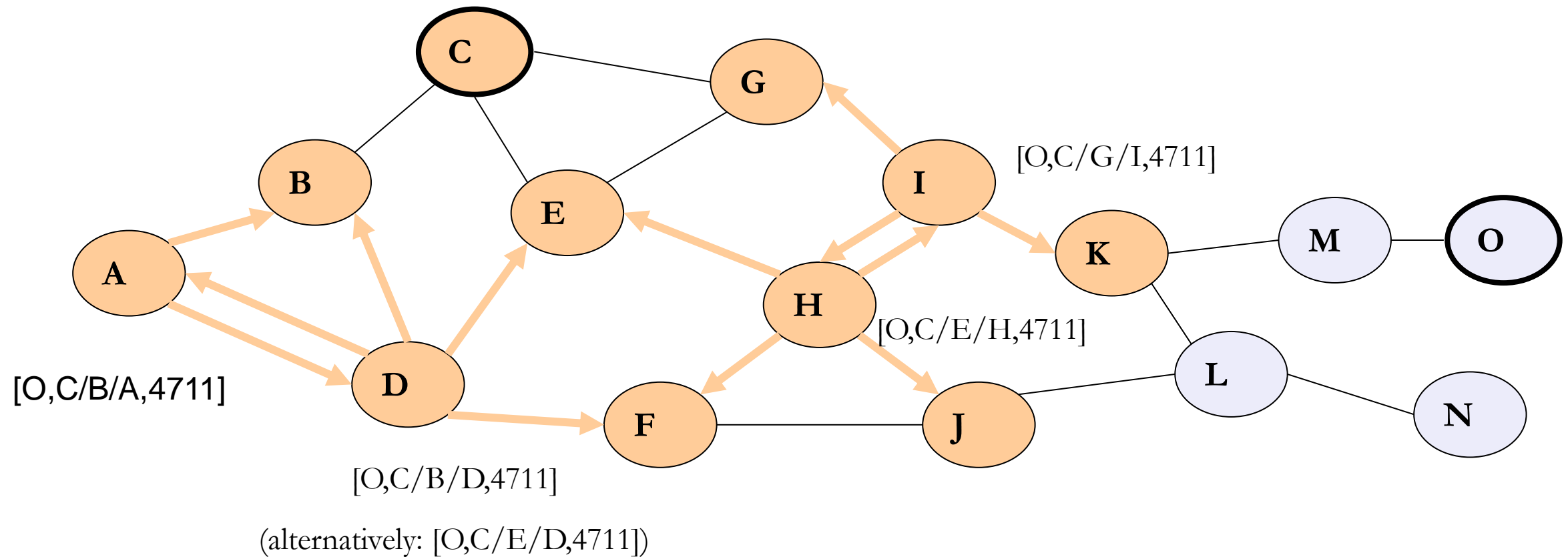
DSR: Route Discovery



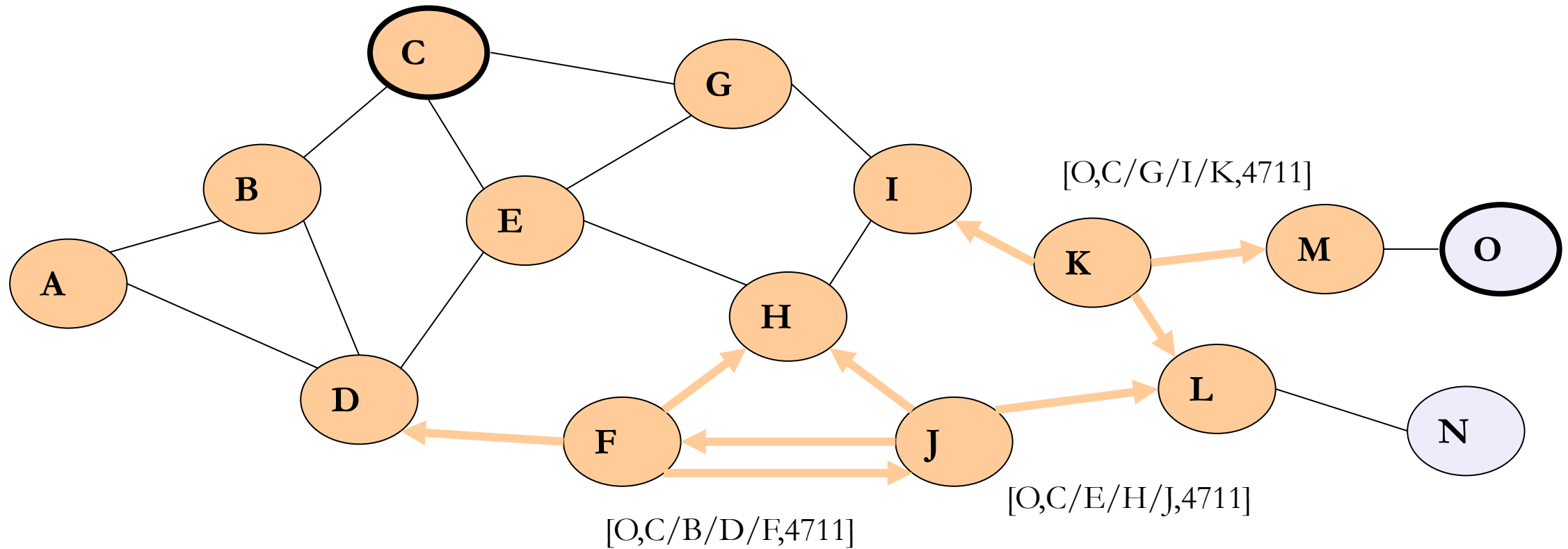
DSR: Route Discovery



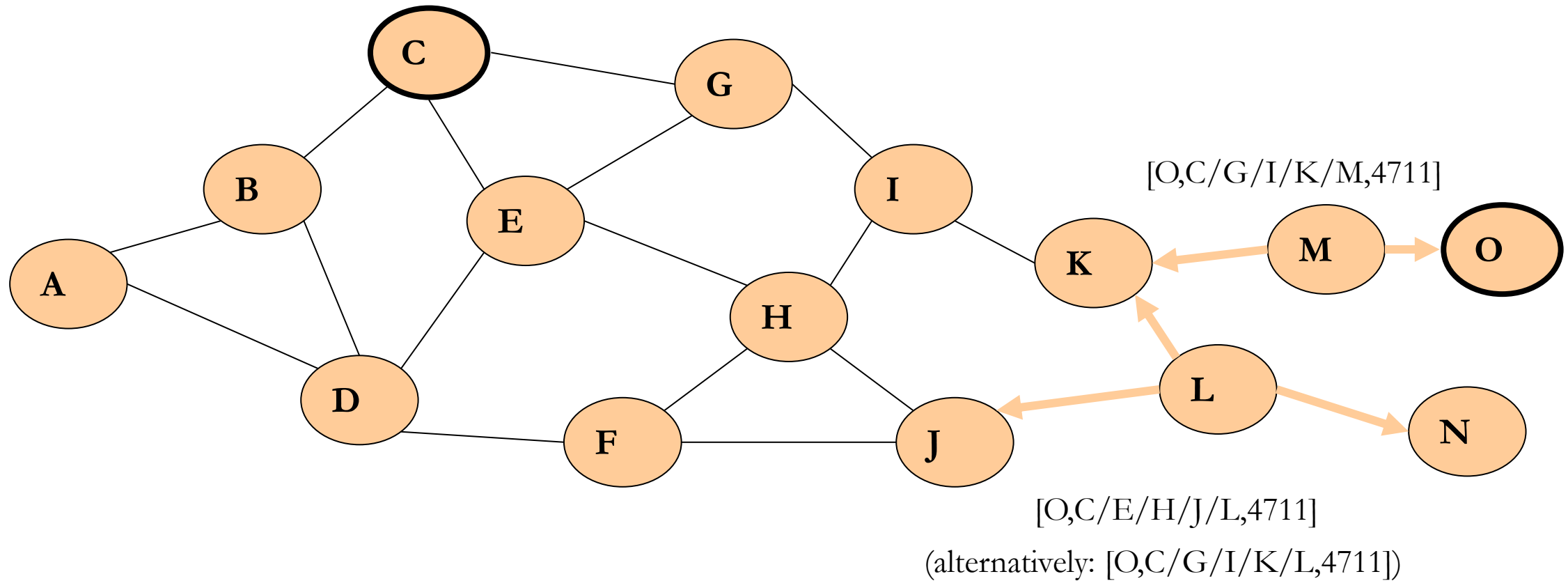
DSR: Route Discovery



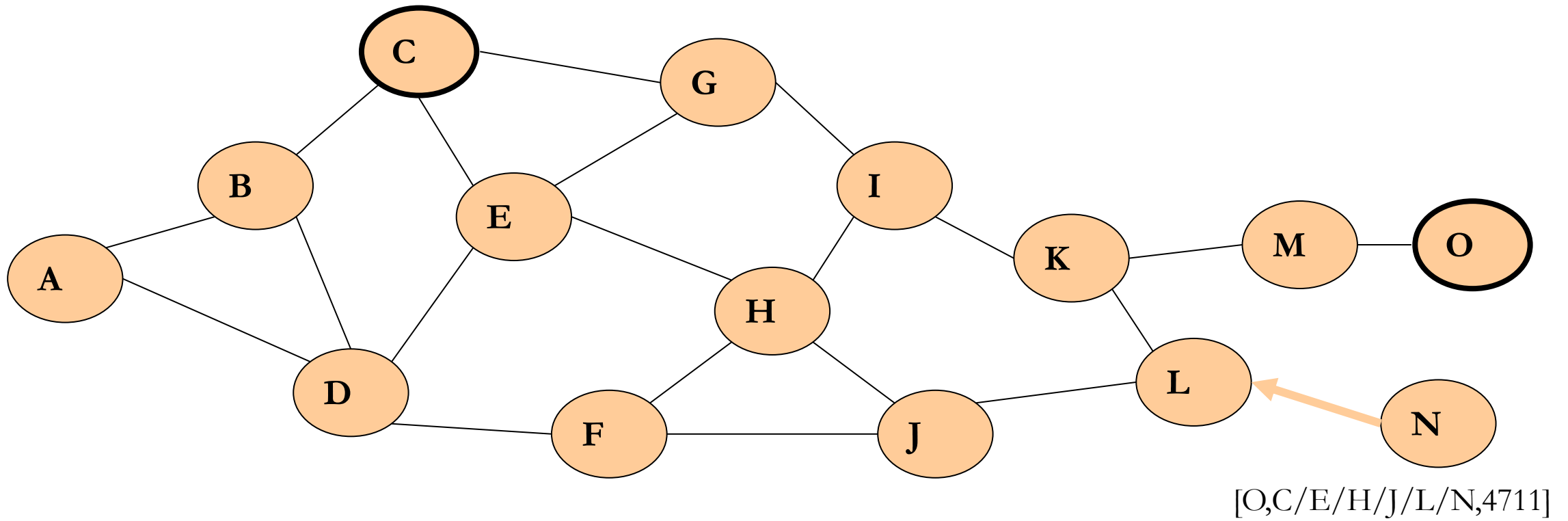
DSR: Route Discovery



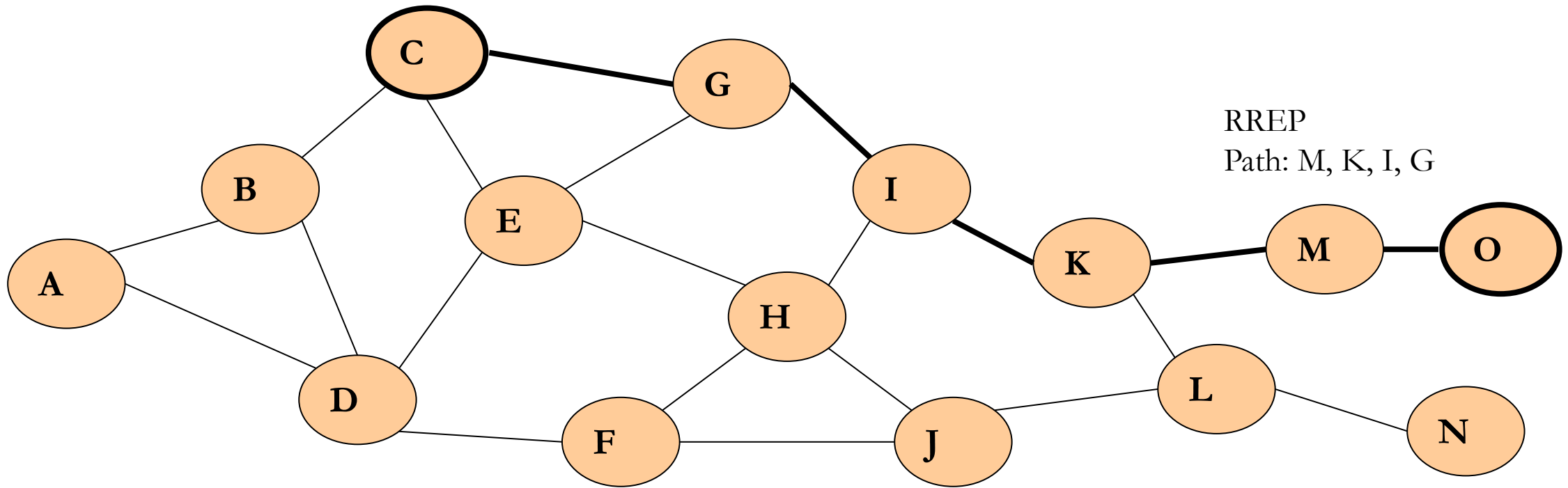
DSR: Route Discovery



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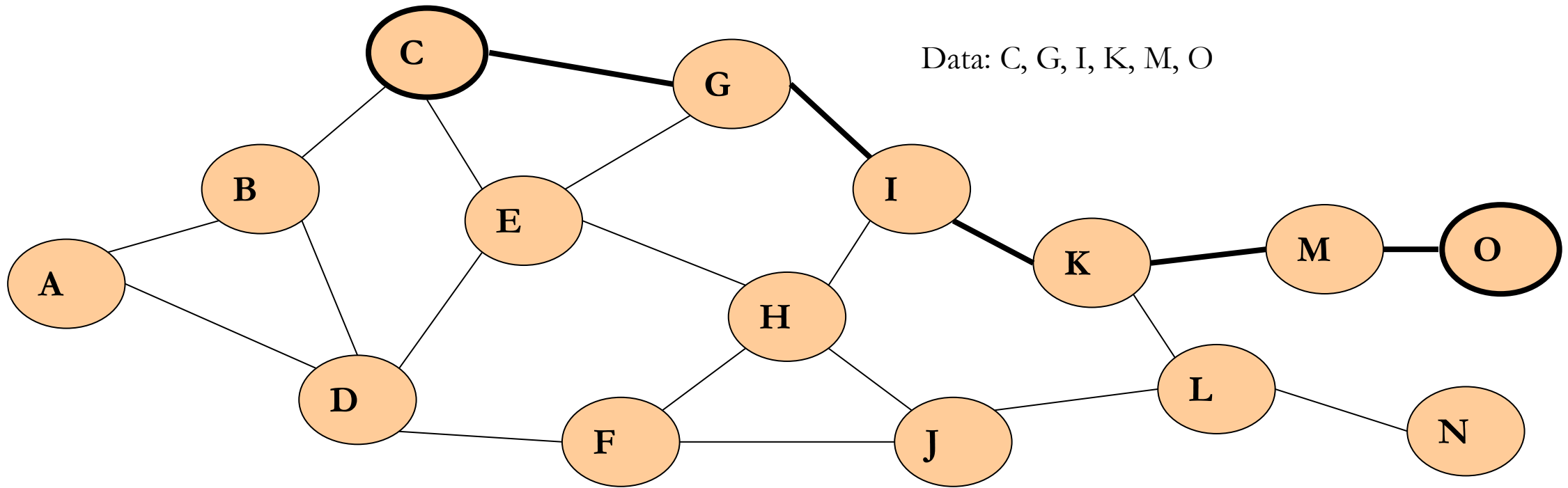
DSR: Route Discovery



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

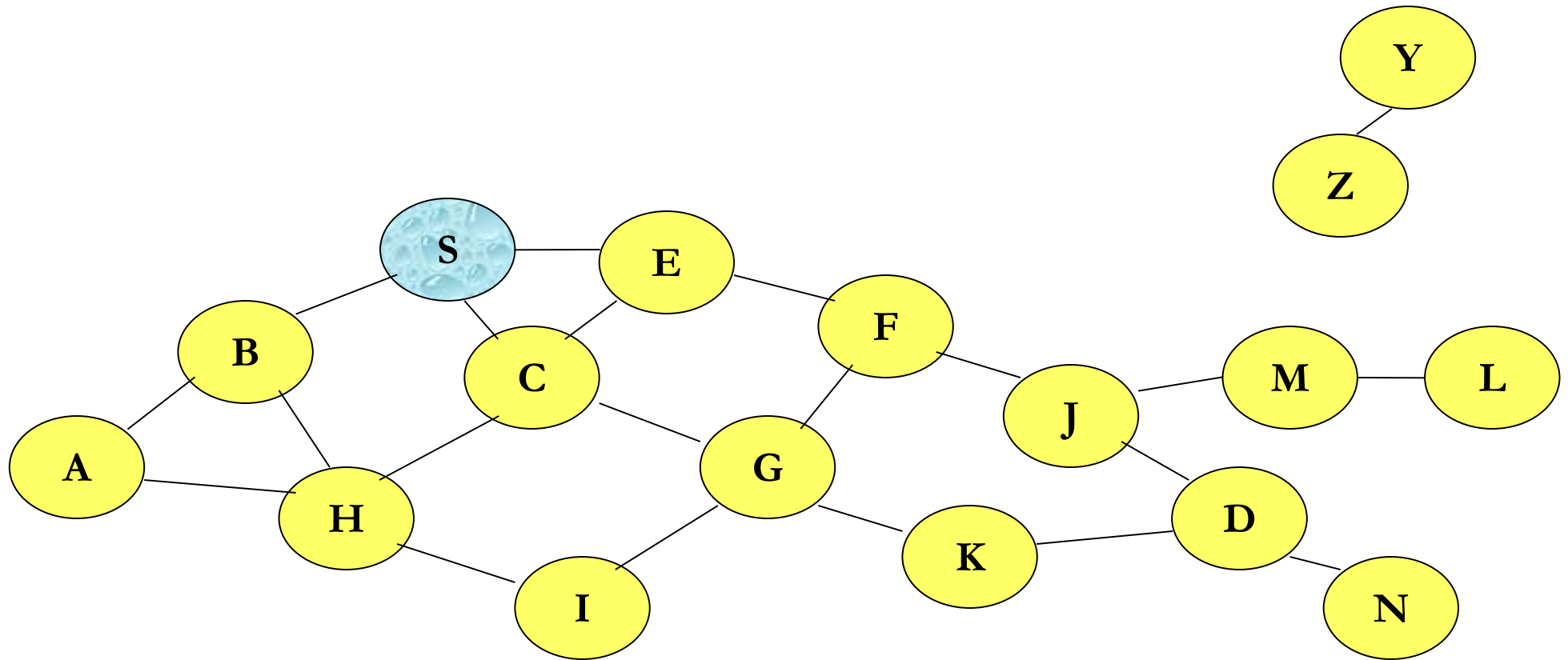
AdHoc On-Demand Distance Vector Routing

- 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

AdHoc 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

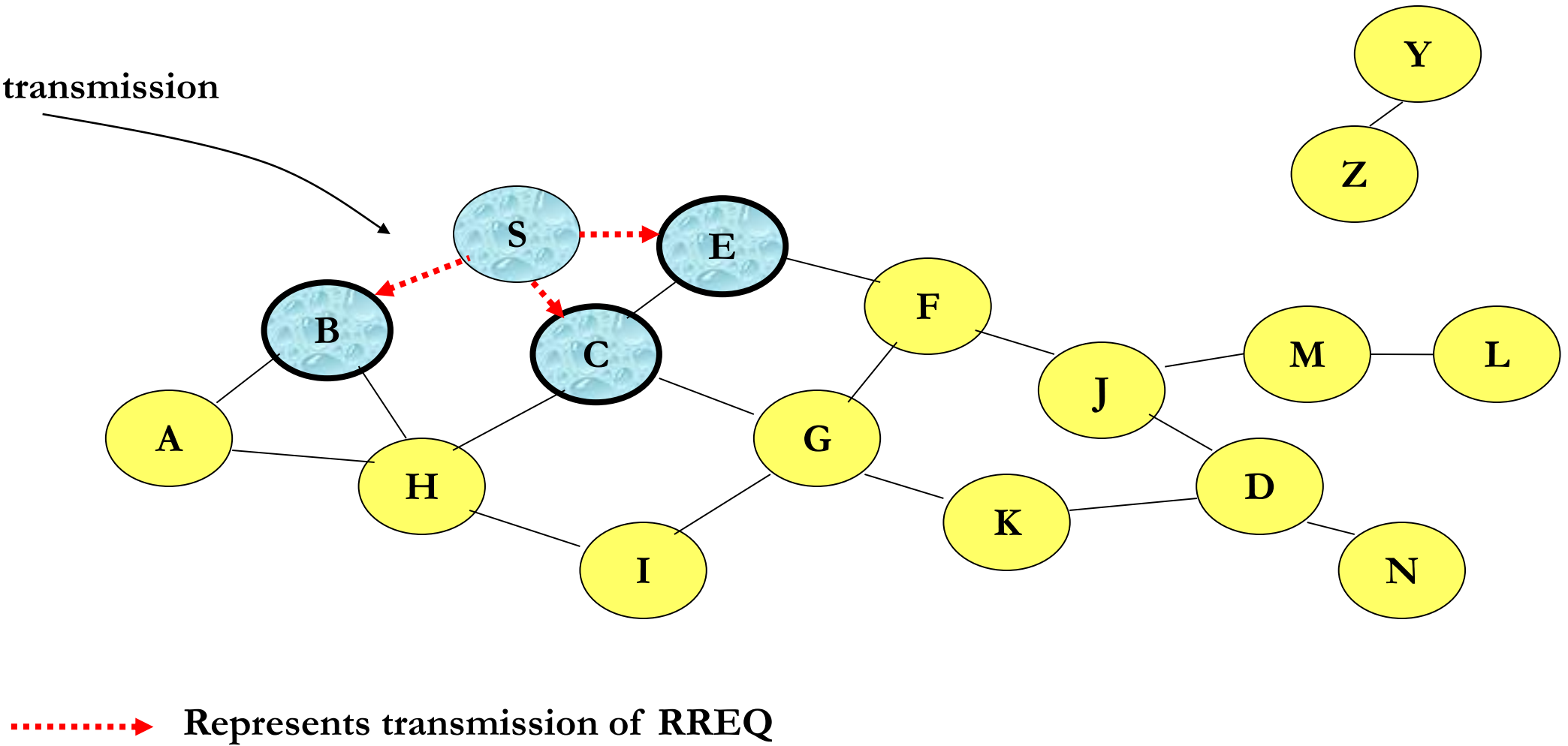
Route Requests in AODV



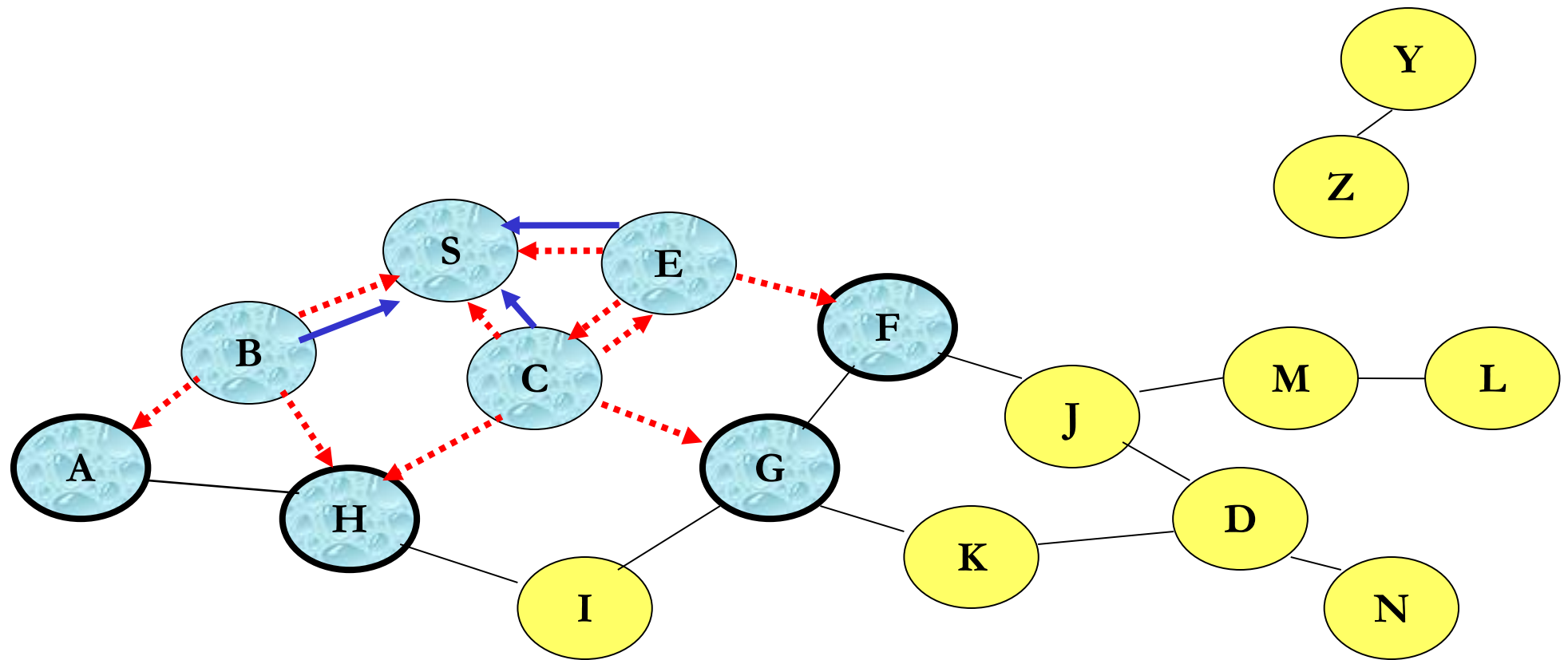
Represents a node that has received RREQ for D from S

Route Requests in AODV

Broadcast transmission

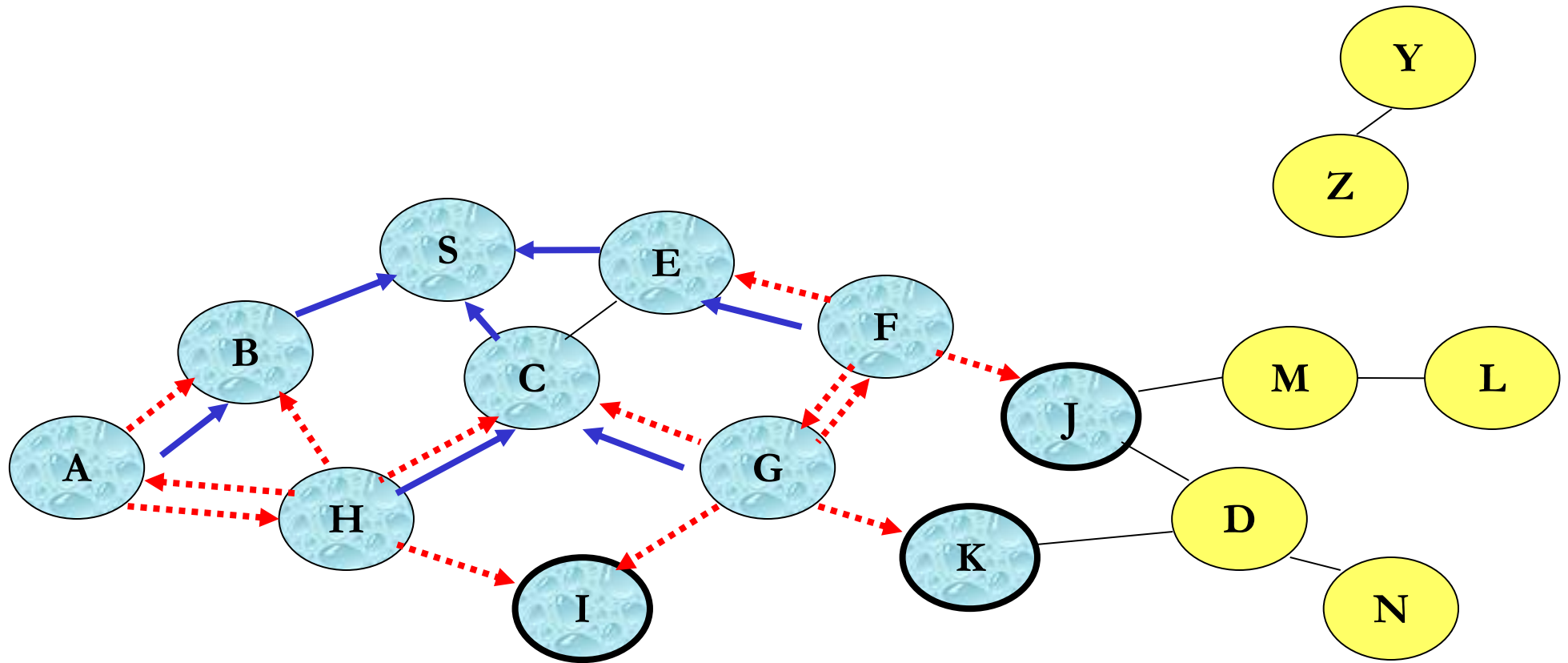


Route Requests in AODV



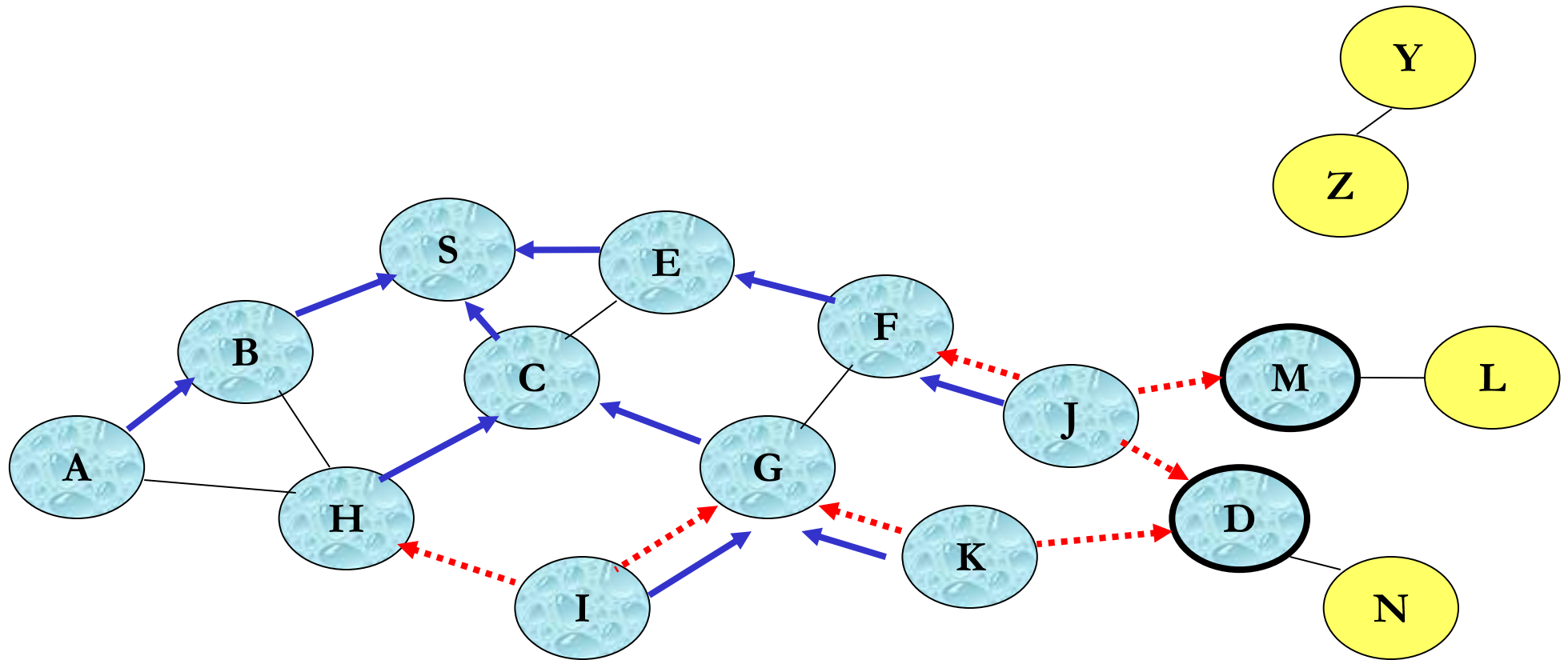
← Represents links on Reverse Path

Route Requests in AODV

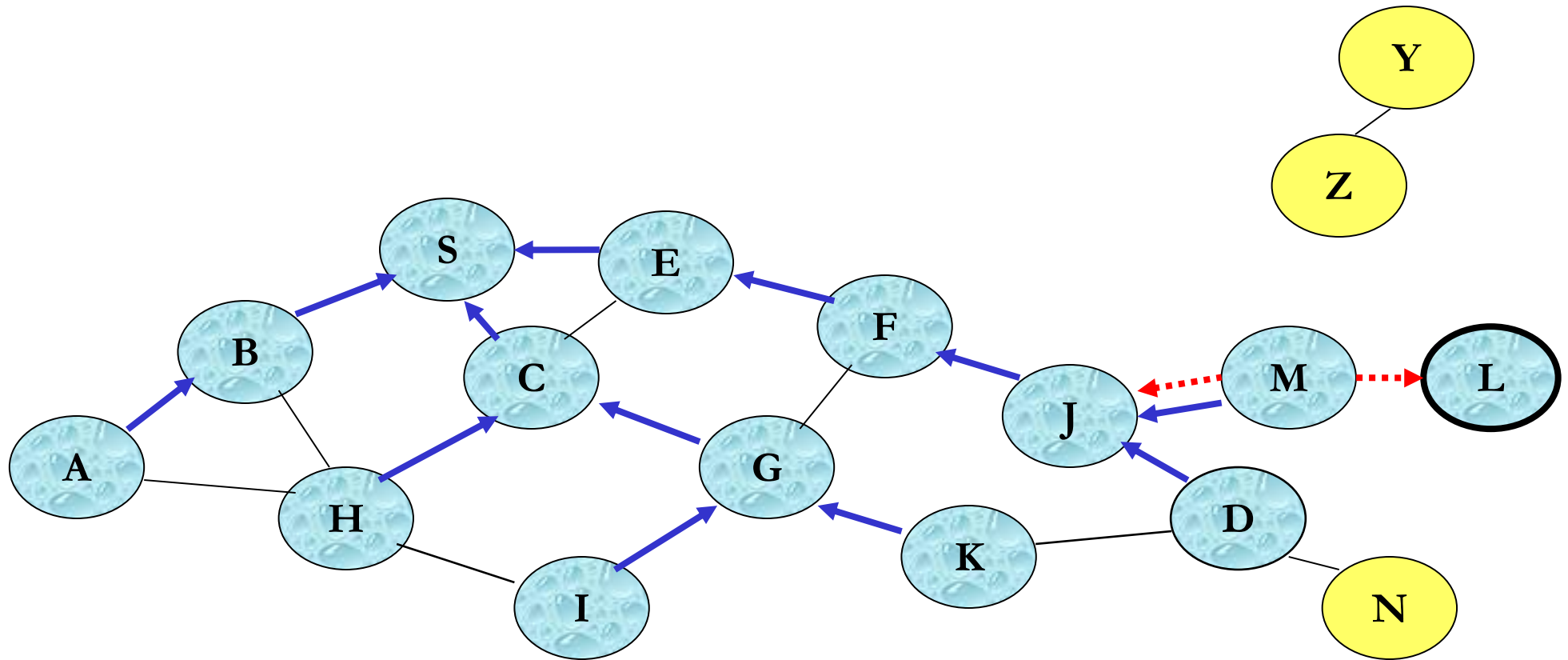


- **Node C** receives **RREQ** from **G** and **H**, but does not forward it again, because node **C** has already forwarded **RREQ** once

Route Requests in AODV

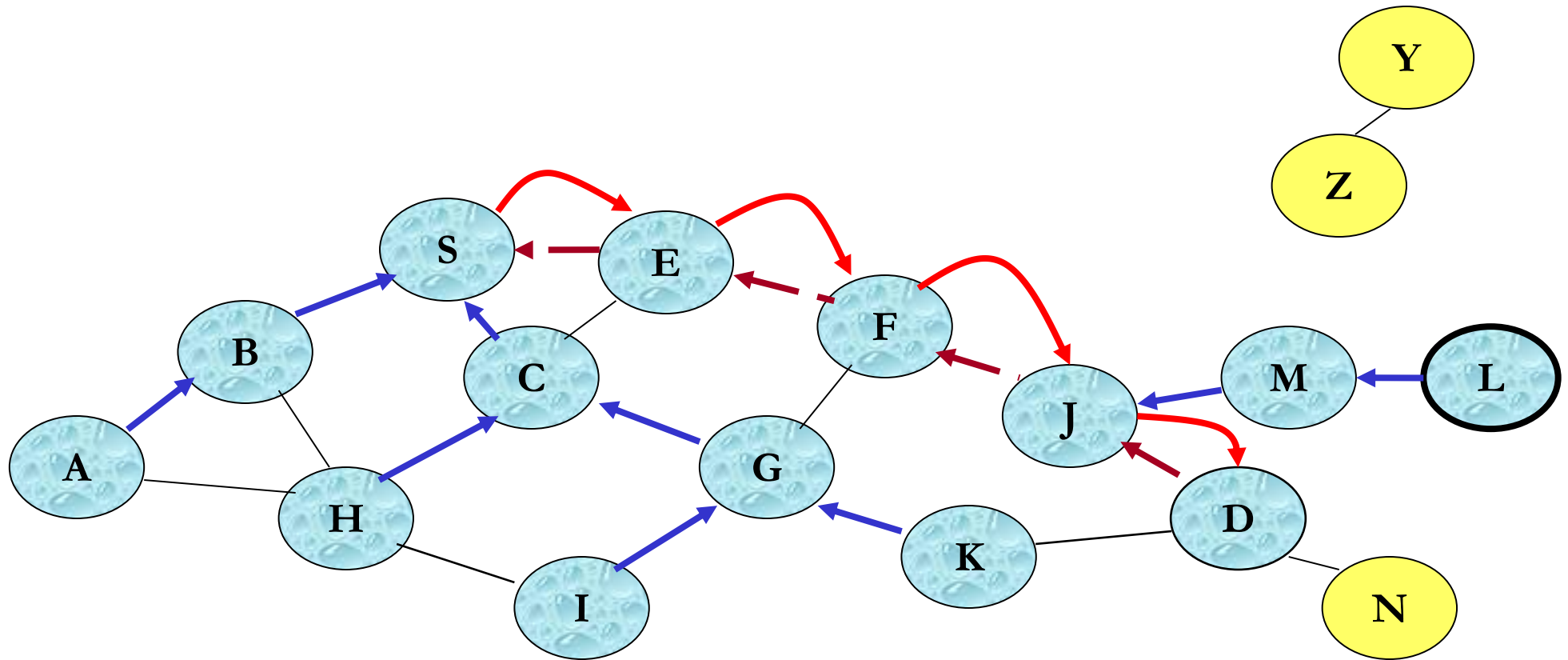


Route Requests in AODV



- **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



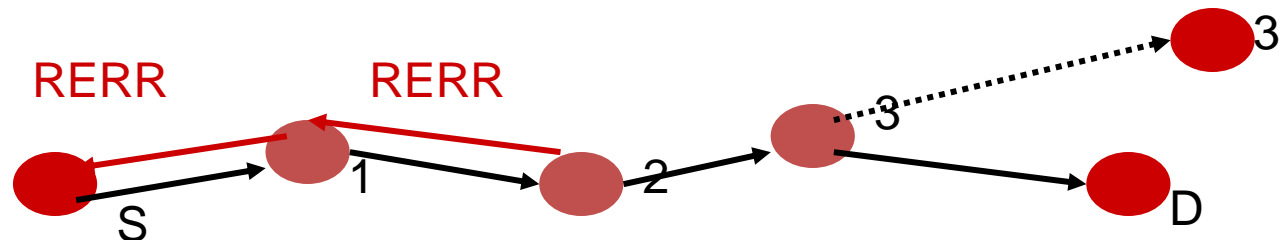
Represents a link on the forward path

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.



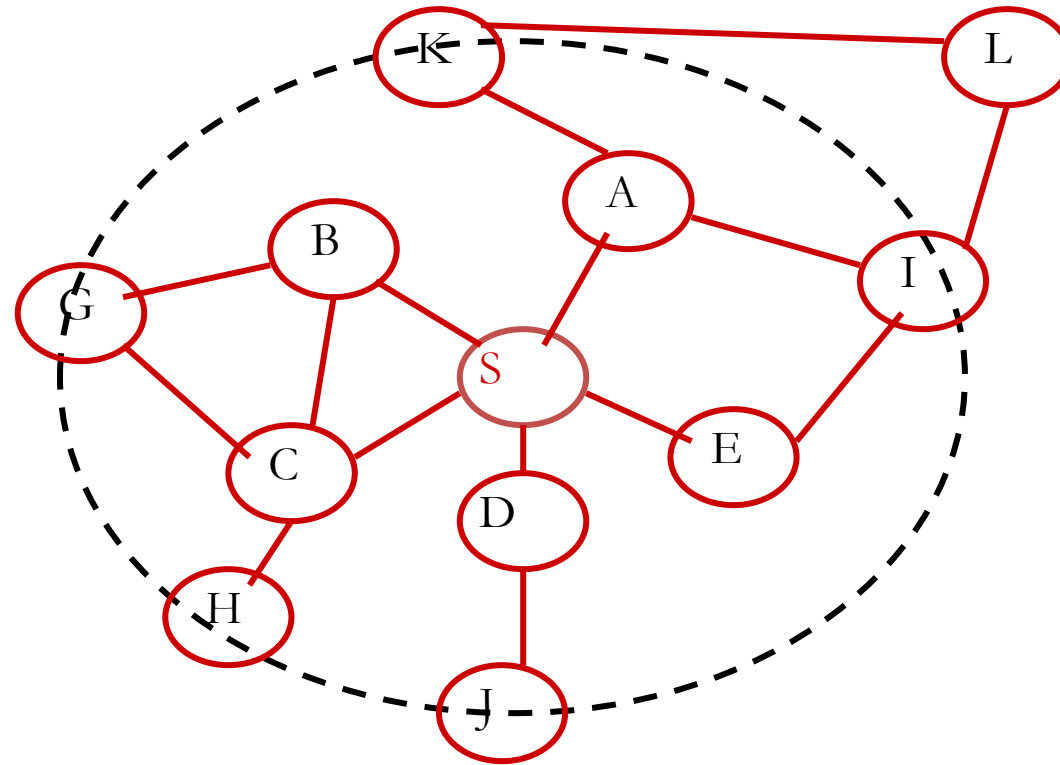
Zone Routing Protocol

- It is possible to exploit the good features of both reactive and proactive protocols 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.

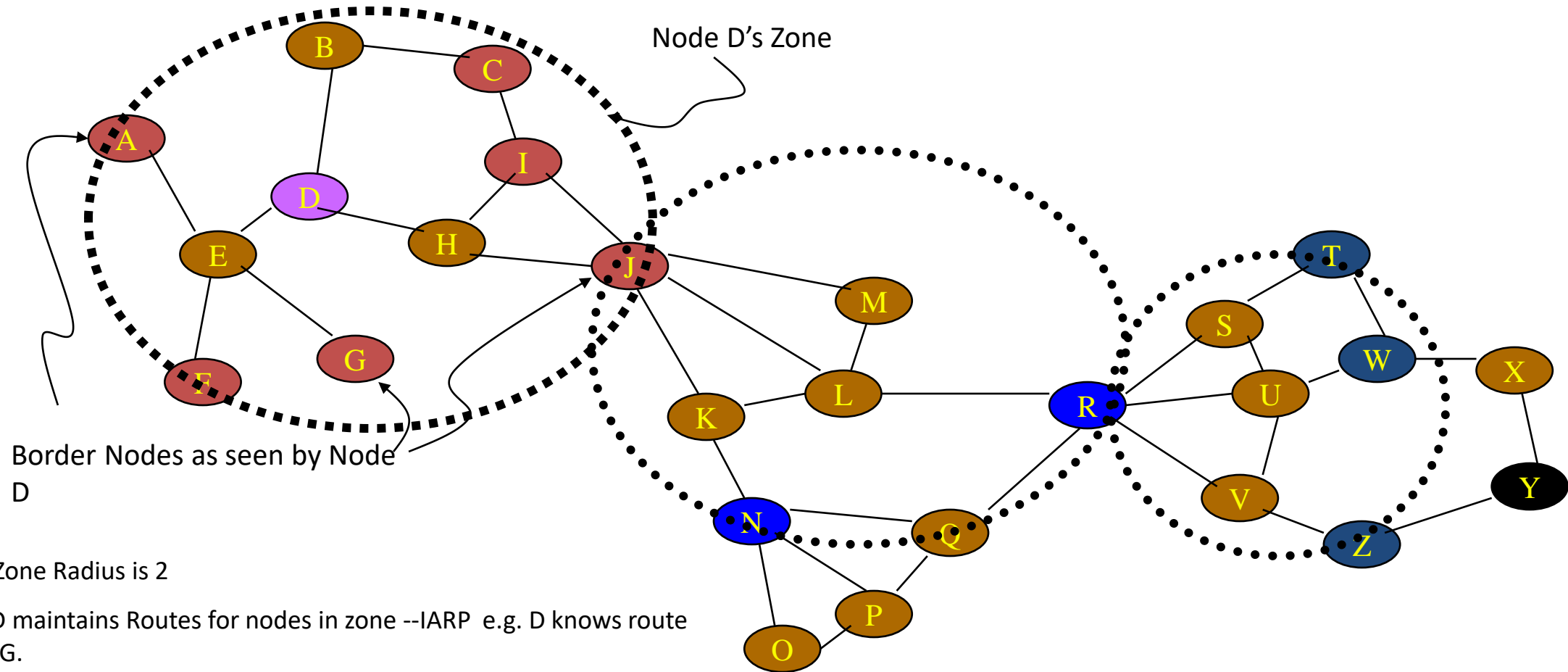
Routing Zones

- The coverage of a node's transmitter 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.

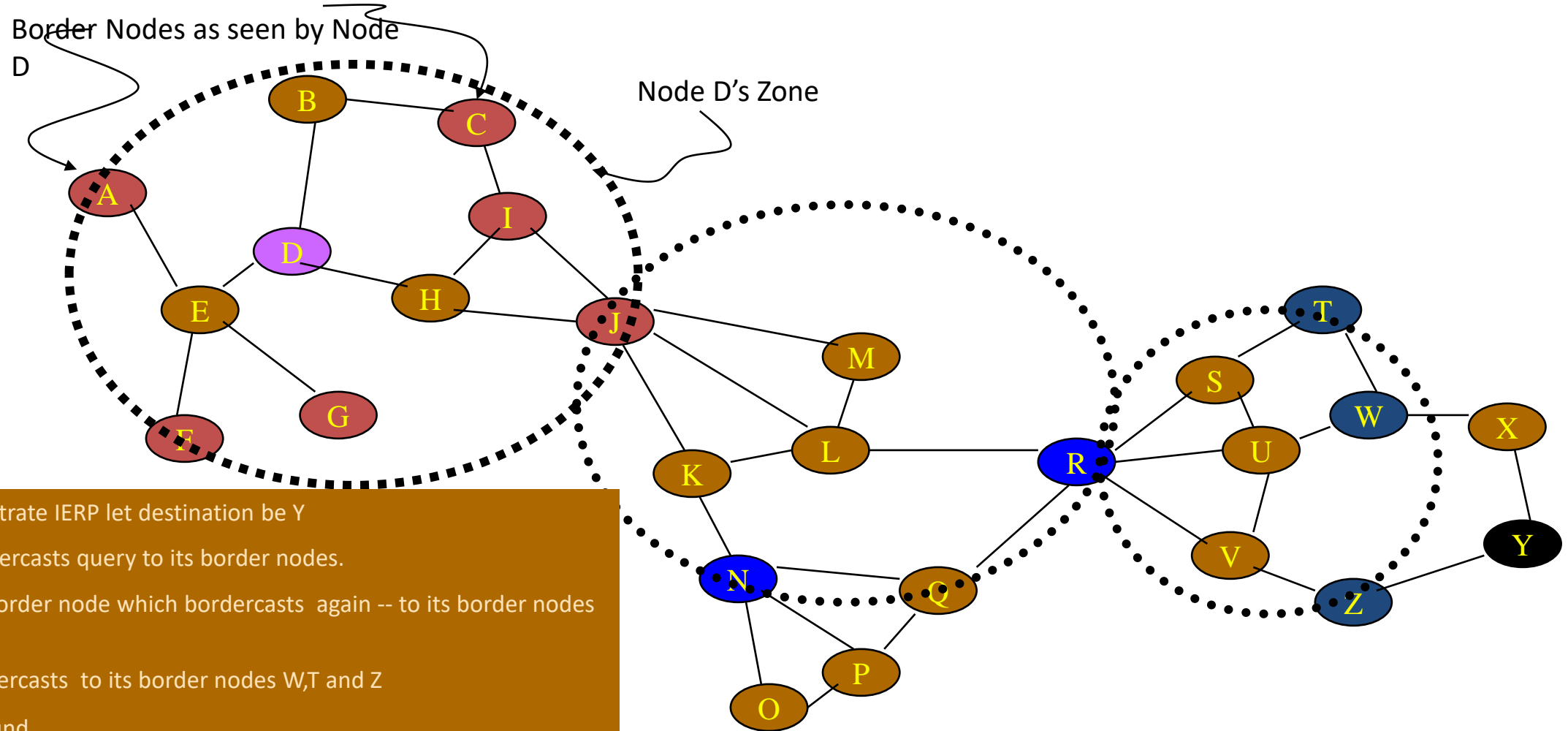
Interzone Routing Protocol (IERP)

- 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)



Multicast Routing Protocols for MANET

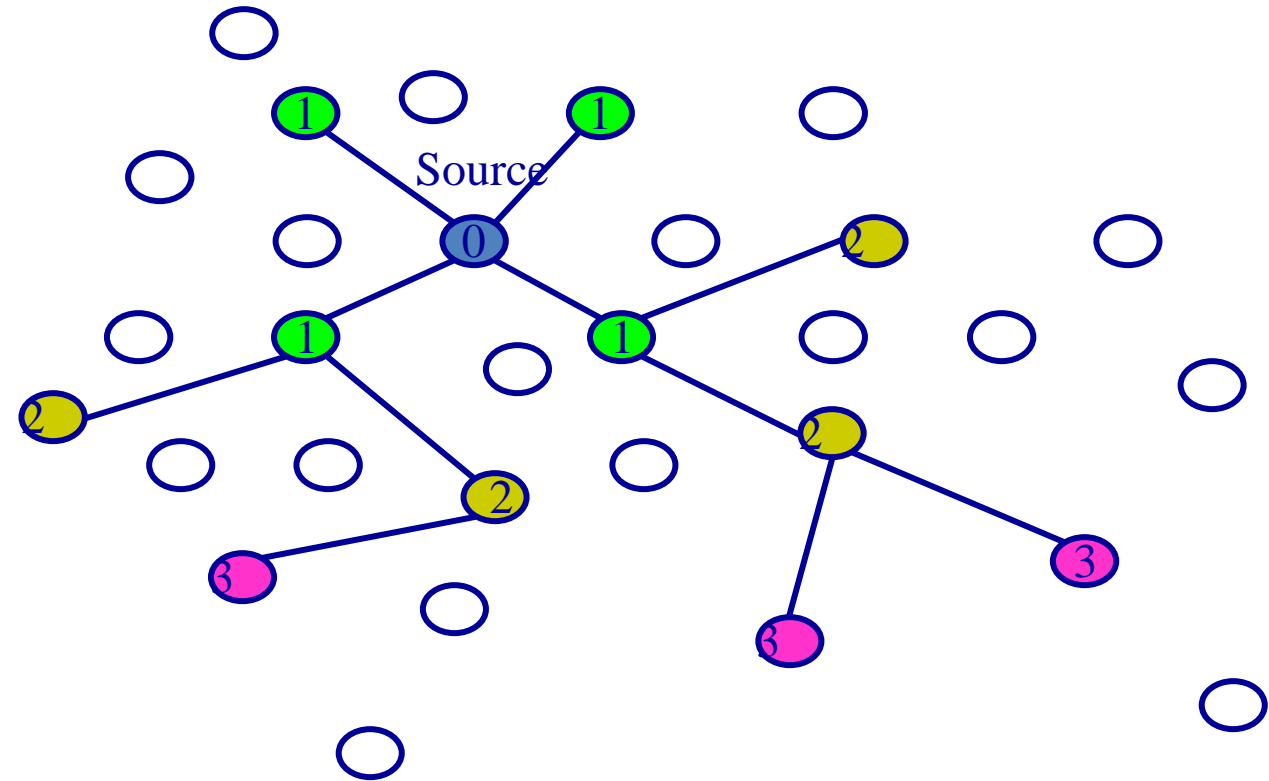
- Multicast → group transmission
- Efficient operation → Minimize unnecessary packet transmission – which minimizes energy consumption

Types of Multicast Routing

- Tree-based
 - One path between a source-receiver pair
 - AMRoute -Ad hoc Multicast Routing protocol
 - AMRIS- Ad Hoc Multicast Routing Protocol Utilizing Increasing ID Numbers
 - MAODV - Multicast Ad hoc On-Demand Distance Vector
- Mesh-based
 - Multiple paths between a source-receiver pair
 - ODMRP - On-demand Multicasting Routing Protocol
 - CAMP - Core Assisted *Mesh* protocol

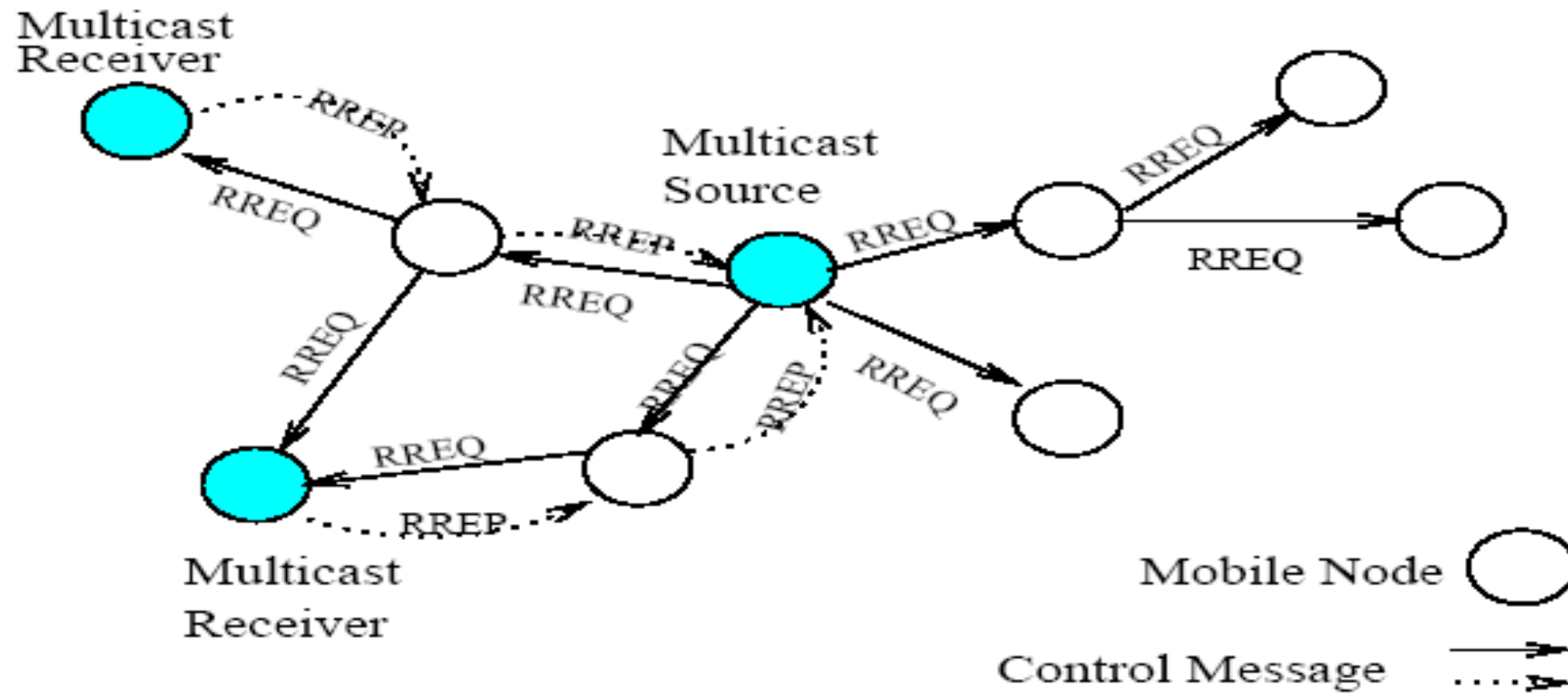
Tree – Based Protocol

- 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

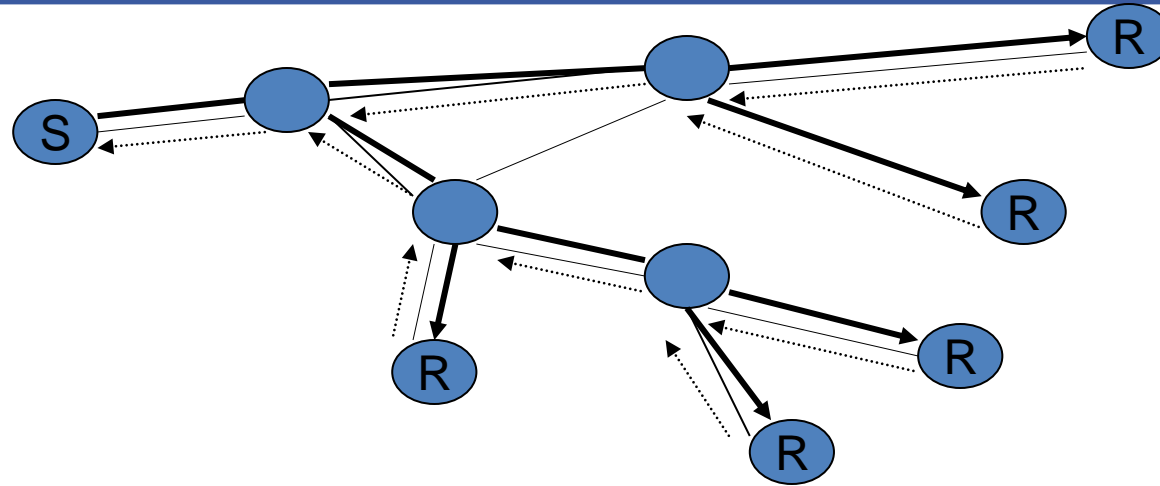
On-demand Multicasting Routing Protocol - ODMRP

- Multicast Messages:
 - JOIN-QUERY (J-Q);
 - JOIN-REPLY (J-R);
- Similar to Route Request and Route Reply in AODV and DSR

Basic Operation of ODMRP

On Demand Route and Mesh Creation

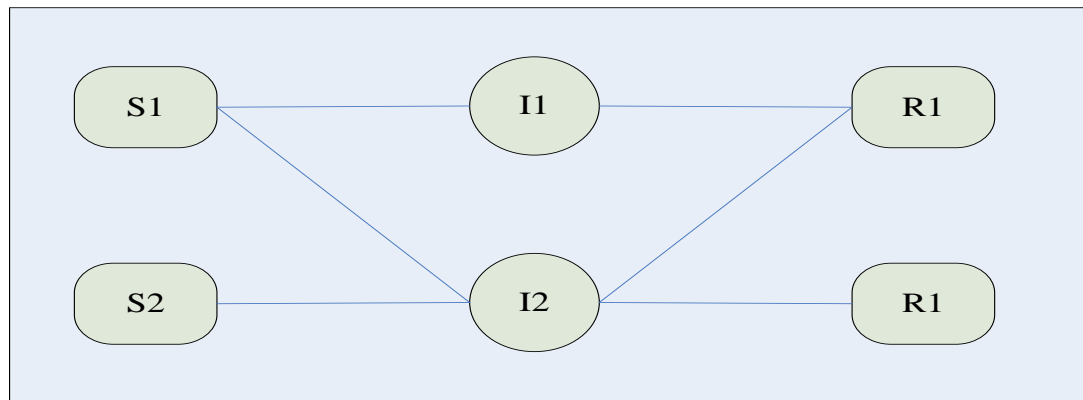
Join Query \longrightarrow
Join Reply \longleftarrow



- S floods a Join Query to entire network to refresh membership.
- Receiving node stores the backward learning into routing table and rebroadcasts the packet.
- Finally when query reaches a receiver creates a Join Reply and broadcasts to its neighbors.
- Node receiving the Join Reply checks whether the next node id in Join Reply matches its own. If yes, it is a part of the forwarding group, sets its FG_FLAG and broadcasts its join reply built upon matched entries.
- Join Reply is propagated by each forwarding group member until it reaches source via a shortest path.
- Routes from sources to receivers build a mesh of nodes called “**forwarding group**”.

ODMRP: Join Reply

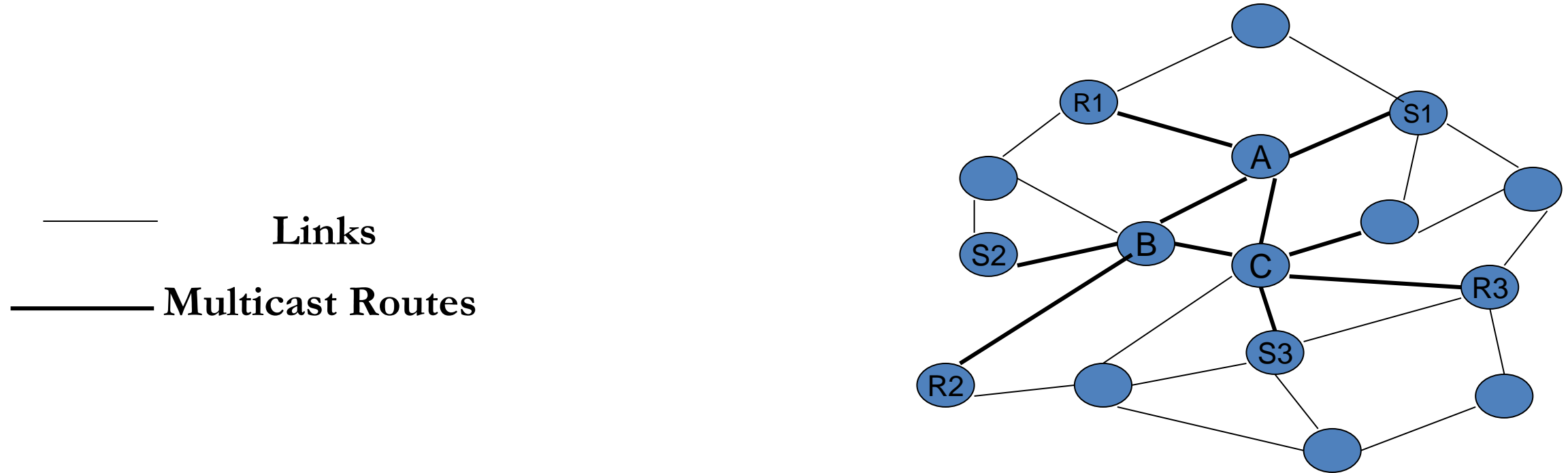
- JOIN-REPLY message



Sender	Next Node
S1	I1
S2	I2

Sender	Next Node
S1	S1

Why a mesh?



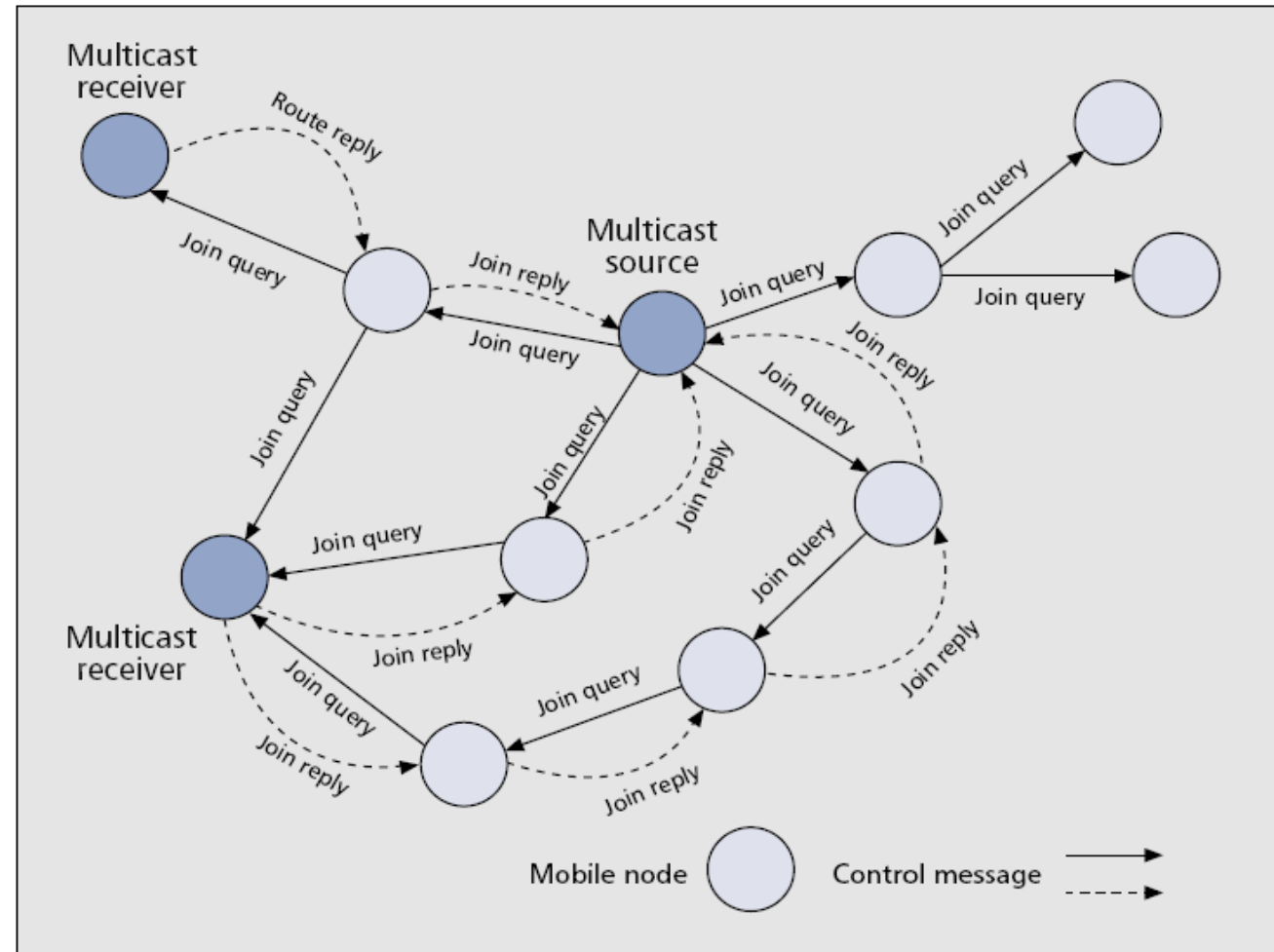
Initial Route from S1 to R2 is $\langle S1 - A - B - R2 \rangle$

Redundant Route $\langle S1 - A - C - B - R2 \rangle$

ODMRP: Sender Actions

Sender actions:

- Downstream
 - Generate J-Q message;
 - Broadcast J-Q ;
- Upstream
 - Receive J-R (include the path info);



■ Figure 4. Mesh creation in ODMRP.

ODMRP: Intermediate Nodes (downstream)

Intermediate node actions: (downstream)

- Receive J-Q, omit duplicated ones (use cached sequence numbers);
- Store upstream node info;
- Re-broadcast J-Q;

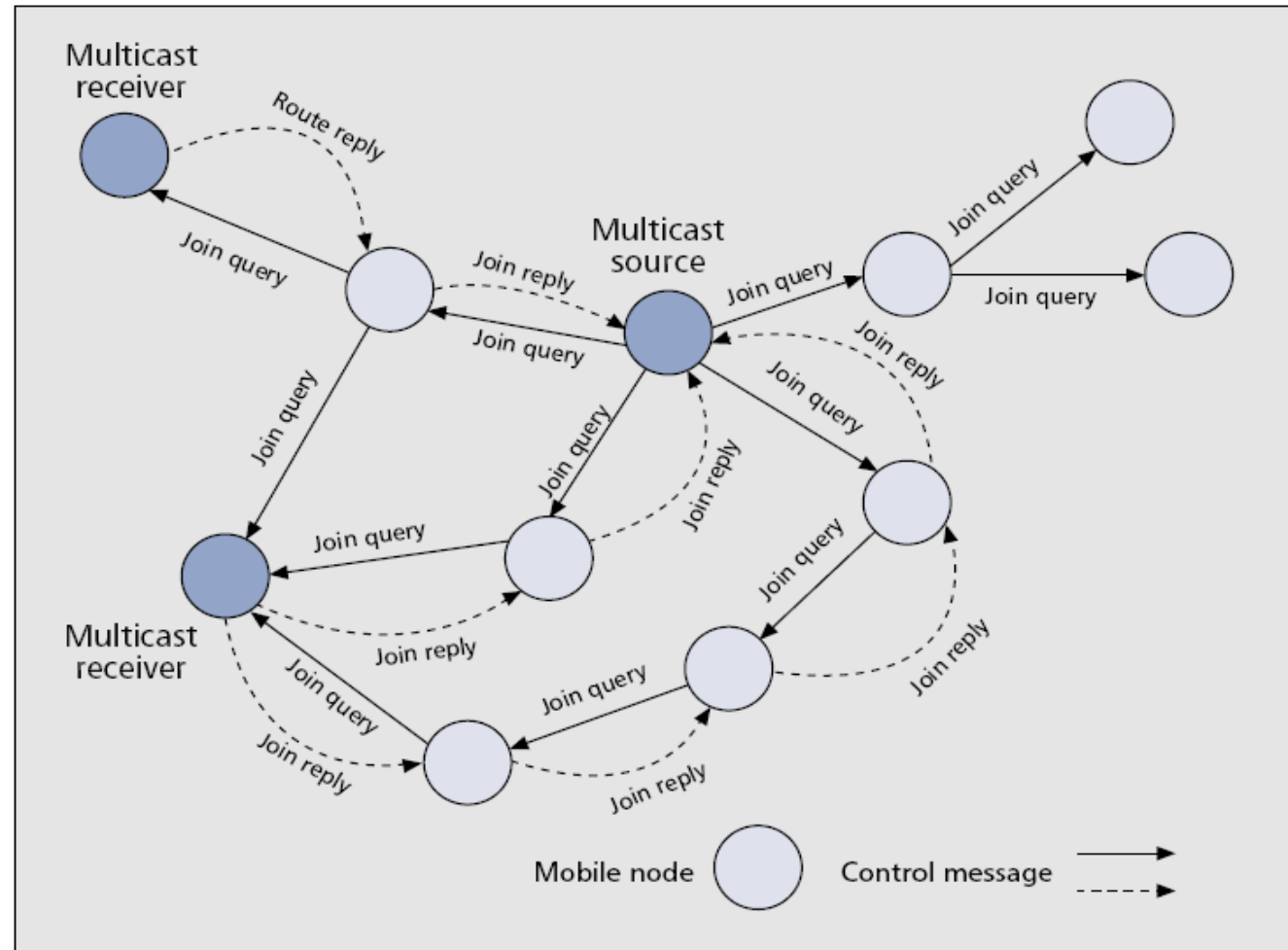
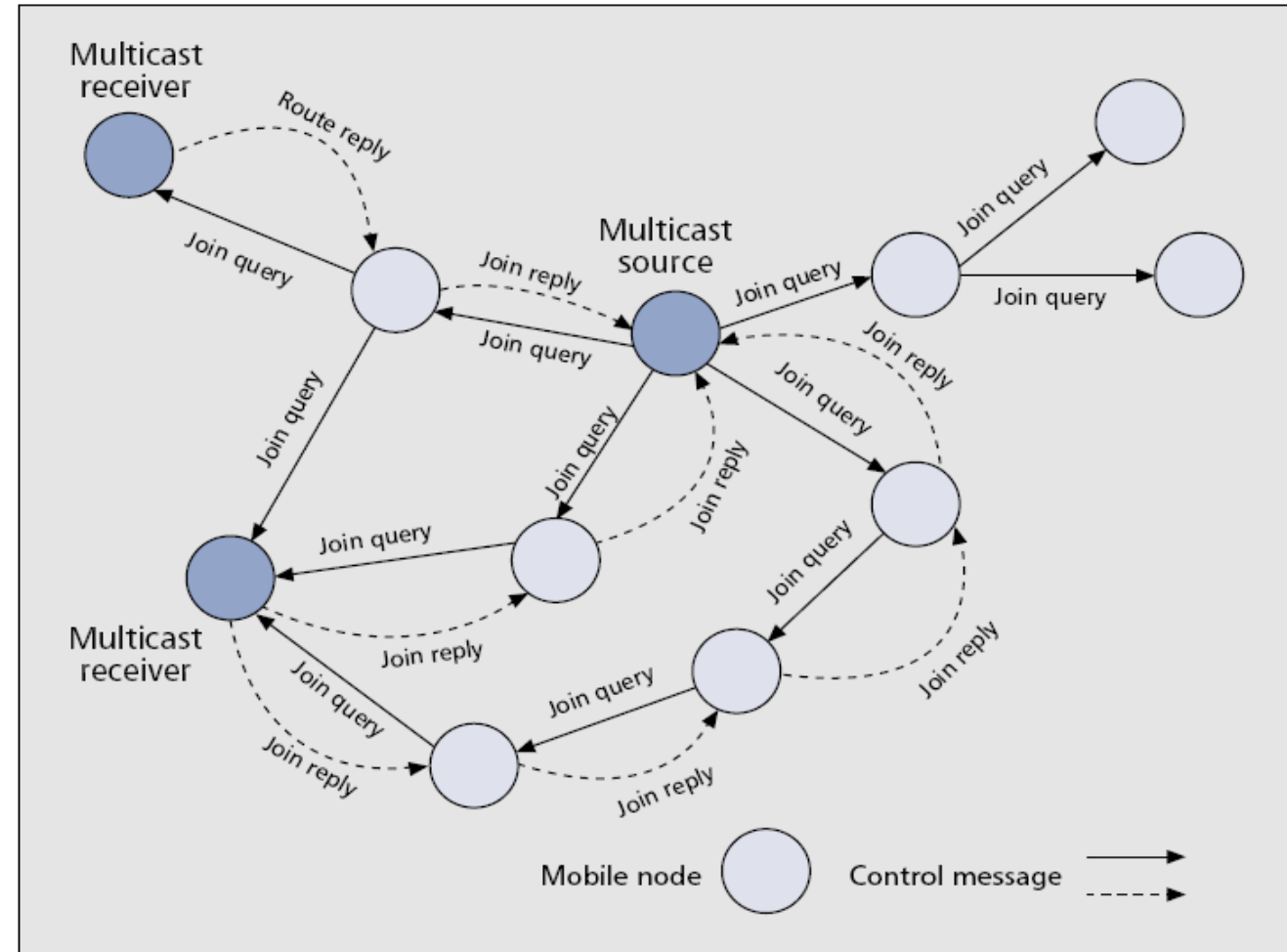


Figure 4. Mesh creation in ODMRP.

ODMRP: Intermediate Nodes (upstream)

Intermediate node actions: (upstream)

- Received J-R;
- If node is on the path
 - Generate new J-R with node info and broadcast, route **established!**

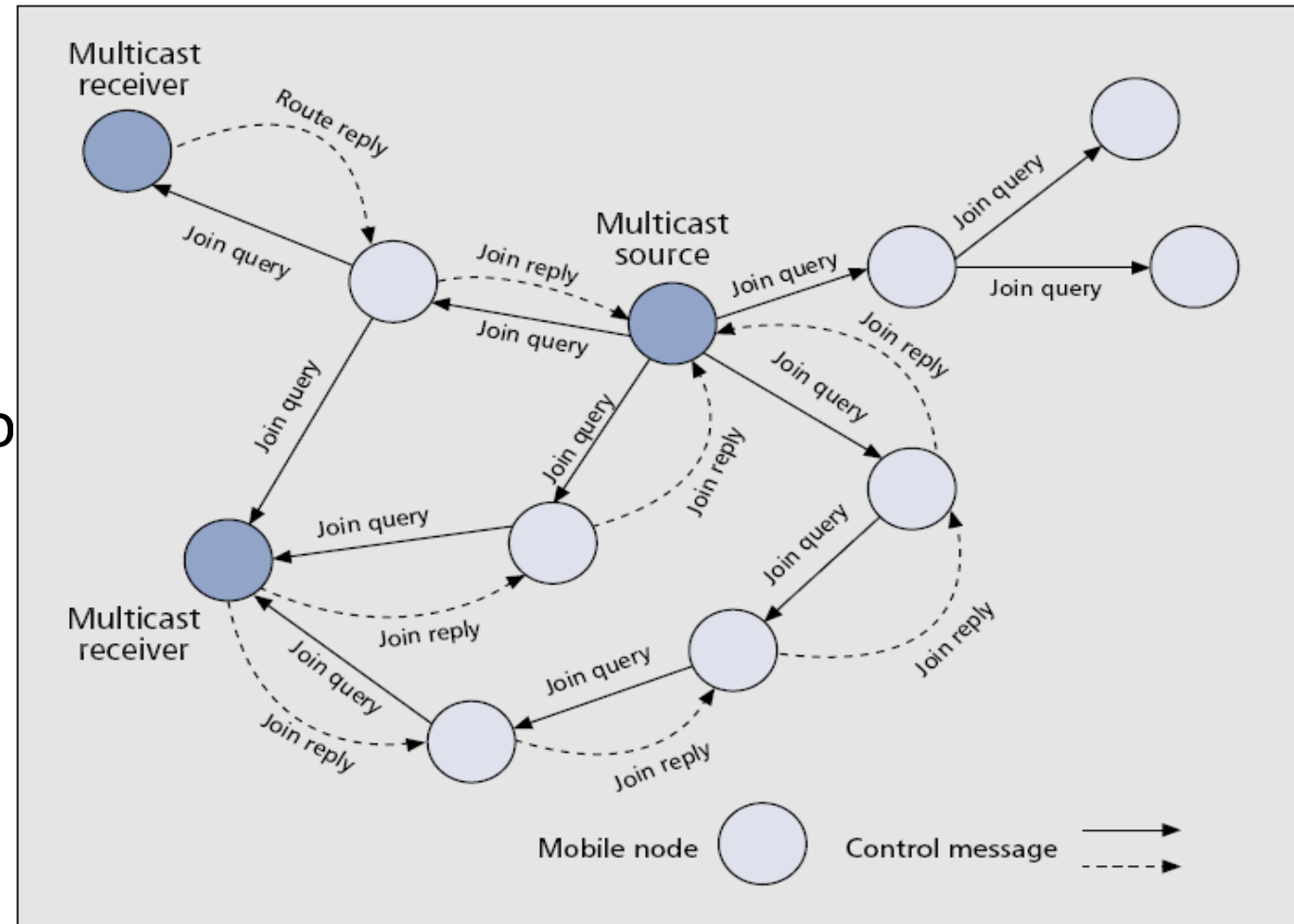


■ Figure 4. Mesh creation in ODMRP.

ODMRP: Receiver Actions

Receiver actions:

- Downstream
 - Received J-Q;
 - Generate J-R with path info
- Upstream
 - Broadcast J-R;



■ Figure 4. Mesh creation in ODMRP.

ODMRP: Maintenance phase

Soft state approach

- Sender repeat J-R periodically to maintain mesh.
- Node joins
 - Sending J-R as discusses before.
- Node leaves
 - Sender: stops sending J-Q;
 - Receiver: stops sending J-R;
- Links break
 - Receiver: receives new J-Q and replies with J-R;

Test your Knowledge

- Explain how DHCP can be used when the size of the block assigned to an organization is less than the number of hosts in the organization.

Summary

	MAODV	ODMRP
Big difference		
Topology	Shared (Core-based) Tree	Mesh of Nodes
Main Similarity		
Mobility support	Yes, based on MANET	
Driven mode	On-demand, do not store whole network topology	
Advantages	simple topology low overheads	mobility robustness
Disadvantages	sensitive to mobility (low delivery ratio)	complex topology high overheads

References

Jochen H. Schller, “Mobile Communications”, Second Edition, Pearson Education, New Delhi, 2007.