Mobility and MANET

Intelligent Transportation Systems

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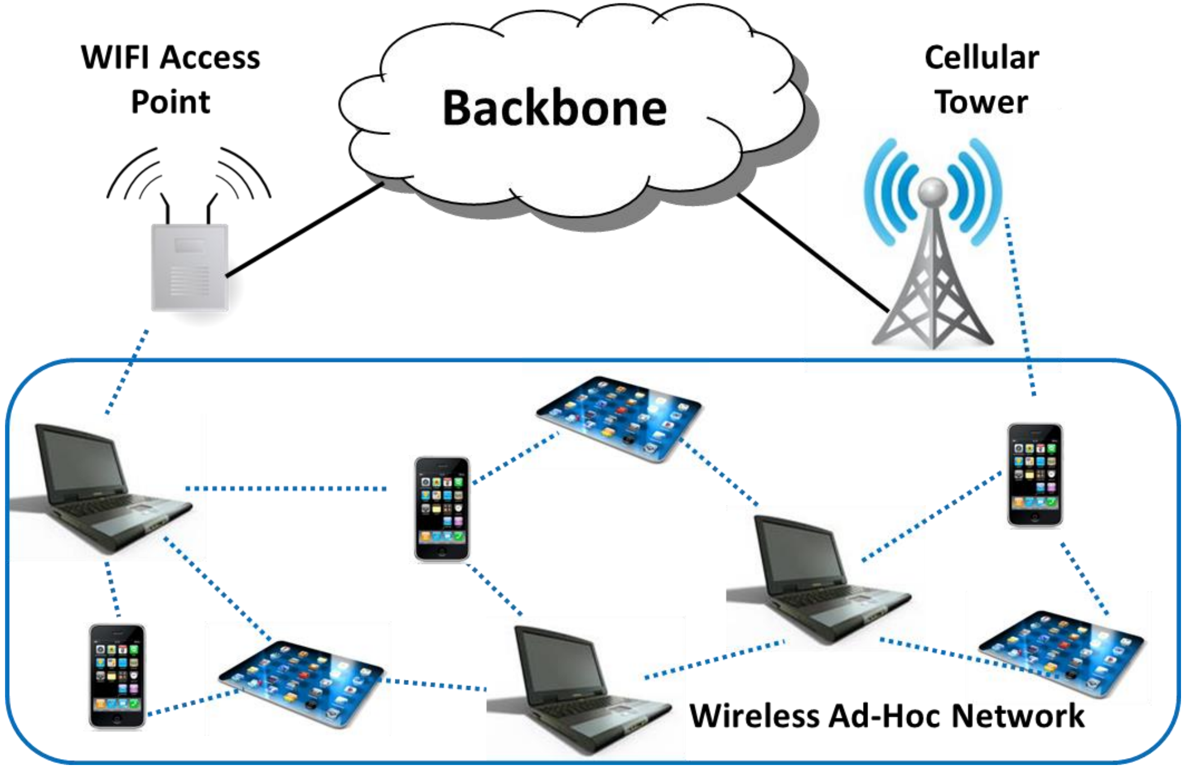
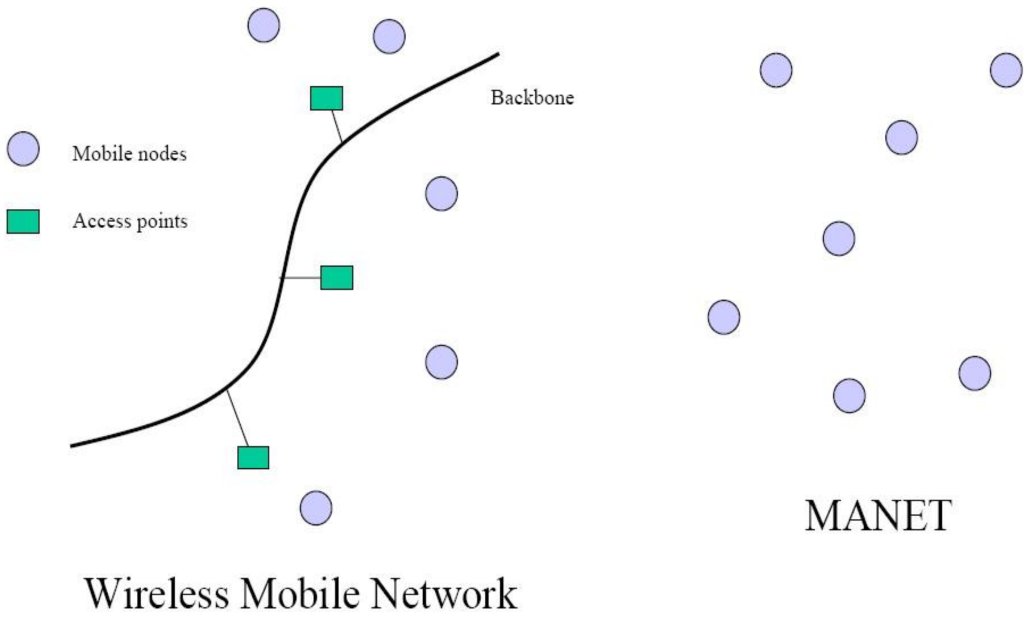
Overview

- MANET – Mobile Ad Hoc Networks

- Meaning of **„Ad Hoc”**
  - Immediate, provisional, without preparation



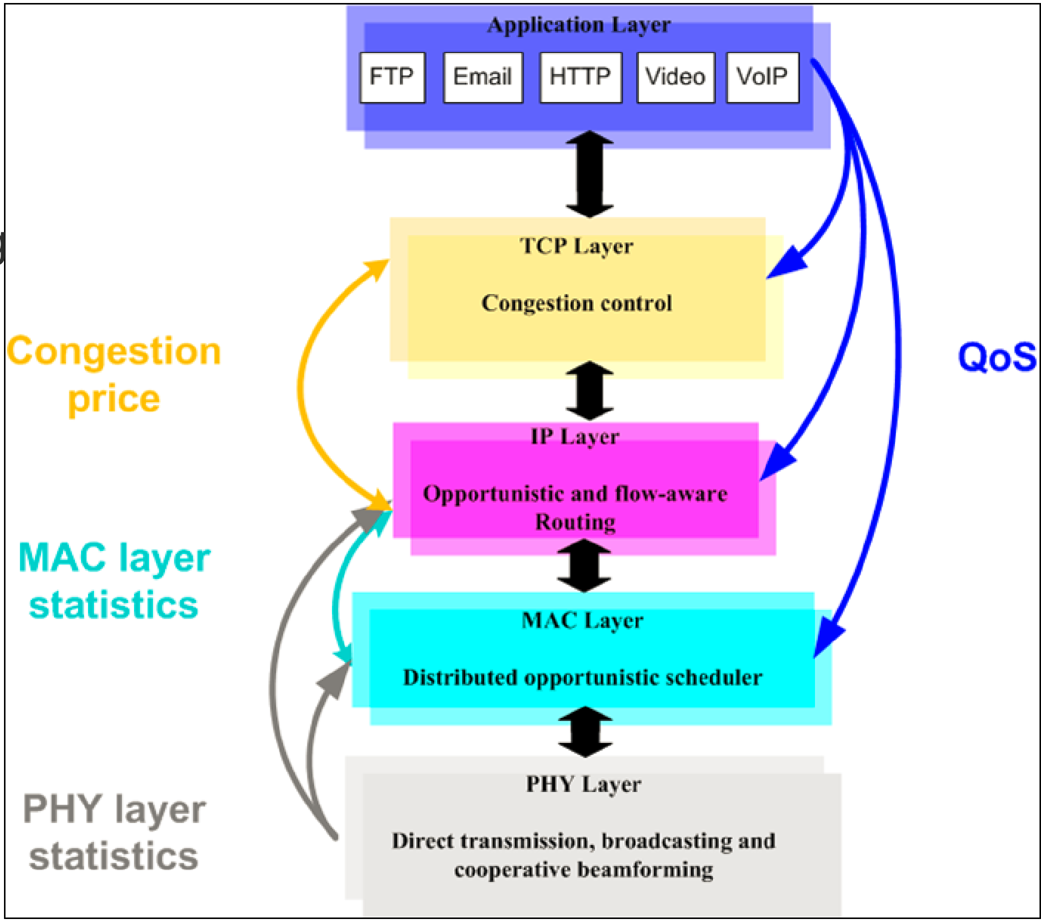
Ad hoc networks



- **No available infrastructure**
  - No internet connections, gateways, access points
  - No dedicated, deployed servers (AAA, DHCP, etc.), or services
- **No addressing based on IP subnets**
  - A problem for „classical” routing protocols
- **No reliable (stable) network devices**
  - Services provided by neighbors, fellow peer nodes
  - The status of my neighbor can change at any time – depleted battery, increased distance, etc.
  - I do not know my neighbors, I do not know if I can trust them
- **Self-organization**
  - Peer-to-peer paradigm (on the networking layer)
- **Multihop**
  - Communication (routing) over several hops (devices)

MANET research topics

- Physical layer -> „*mobility models*"
  - Energy-efficient operation – adjusting radio power, sleep scheduling
  - Mobility-aware radio technologies
- **Data-link layer**
  - MAC (shared medium access, efficiency, decreasing the chance of collisions)
- **Networking layer**
  - Routing (dynamically changing topology, prefix-based routing not working)
- Upper layers
  - Packet retransmissions, TCP (packet loss, unreliable transmission medium)
  - Security (can be extended to any of the layers)
- Cross-layer optimization
  - The parallel optimization of several layers in the ISO/OSI model
  - Each layer might have its own influence over mobility

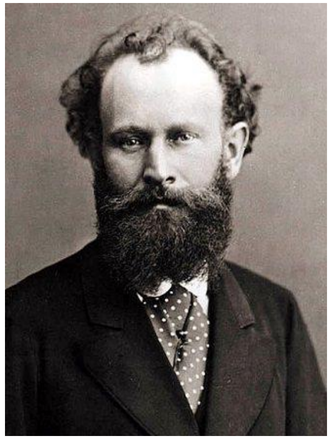


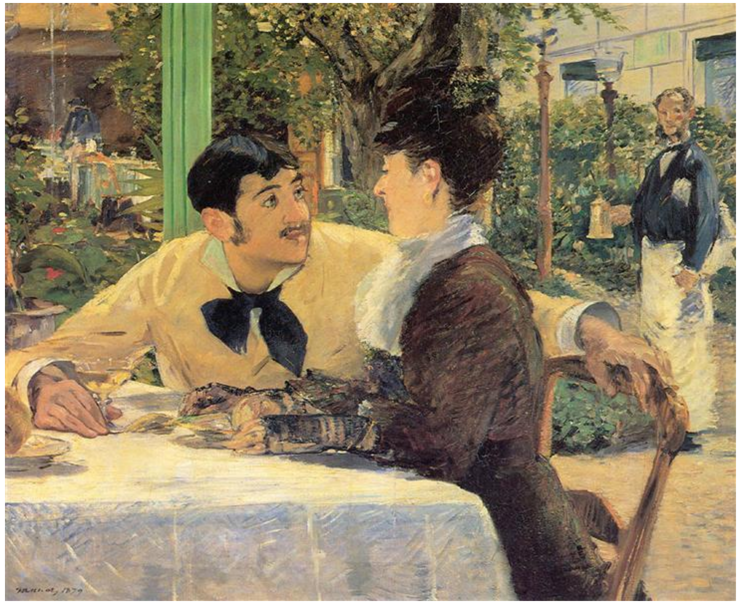
Mobility types

- Nomadic mobility (nomadicity)
  - No communication while moving – device turned off
  - When restarting, new IP address, rebuilding the interrupted connections
- Slow mobility
  - E.g., people walking around in a building
  - University campus – students walking, biking
- Fast mobility
  - Cars, bikes, …
- Moving networks…

MANET vs. MONET

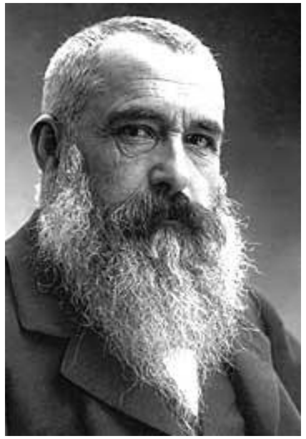
Edouard MANET





Mobile **A**d Hoc **Ne**twork

Claude MONET

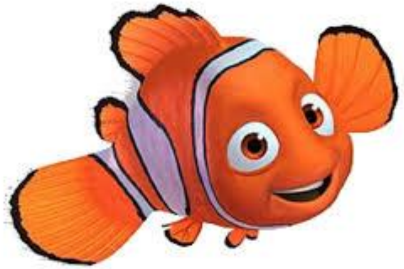


Moving **Net**works

- Networking devices moving together
  - E.g., passengers in a train, metro, bus, airplane
- Alternative name
  - **Networks in Motion – NEMO**

NEMO – Networks in Motion

- Many MNs moving together
  - If they move together, let's handle their mobility together
- MR (mobile router) – default gateway
  - Provides the connection between NEMO-members and the outside world
  - Dedicated device, or one among the others assuming this role (periodic role changes)
    - Usually the biggest battery, the largest bandwidth, etc.
- The MNs have to register at the MR
  - They belong to the subnetwork of the MR
  - "Fixed" nodes in the network (relatively to the MR), their relative position does not change
    - Called also Fixed Local Nodes (FLN) because of that

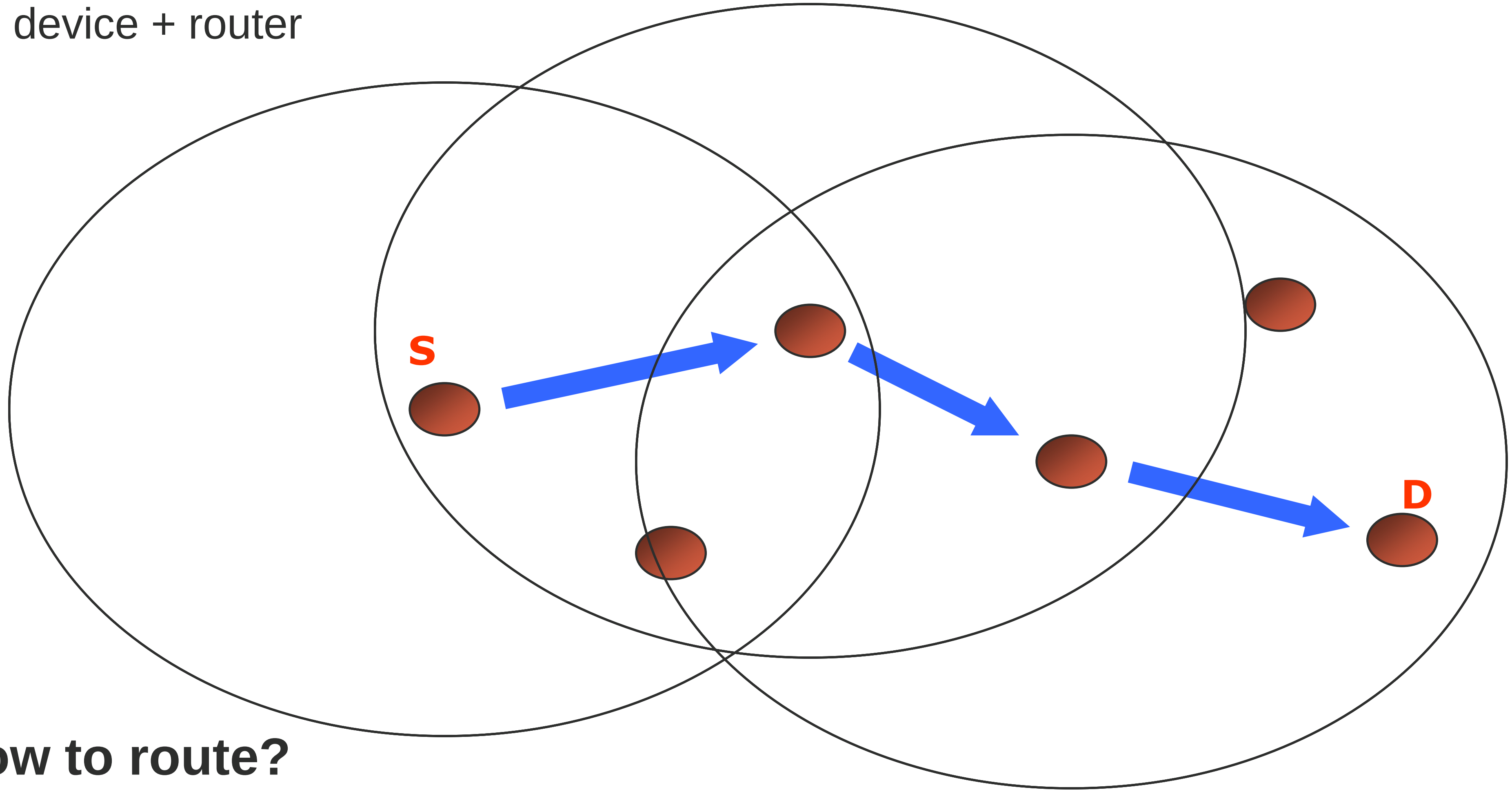


NEMO efficiency depends on the environment

- (Possible) drawbacks:
  - Case of 100 MNs with 3G/4G mobile internet access in a city
  - If the MNs do not join the NEMO
    - - personal mobility management needed for all the 100 MNs
    - + Any one of them receives the bandwidth provided by the given technology
  - If all the MNs join the same NEMO
    - The MR link capacity becomes a bottleneck
    - In the worst case, the MNs receive only 1/100 of the bandwidth provided in the previous case
- (Possible) advantage:
  - If 100 MNs on an airplane want to connect to the internet
    - The dedicated MR is the only node being able to connect
  - Mobility management is optimal
    - Only the mobility of the MR has to be handled

MANET routing

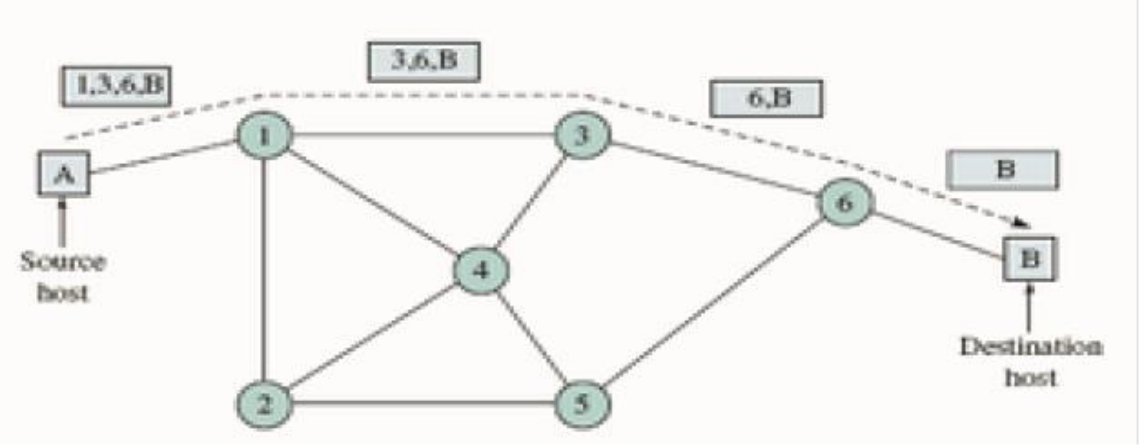
- Point-to-point
- Mobile node = end device + router

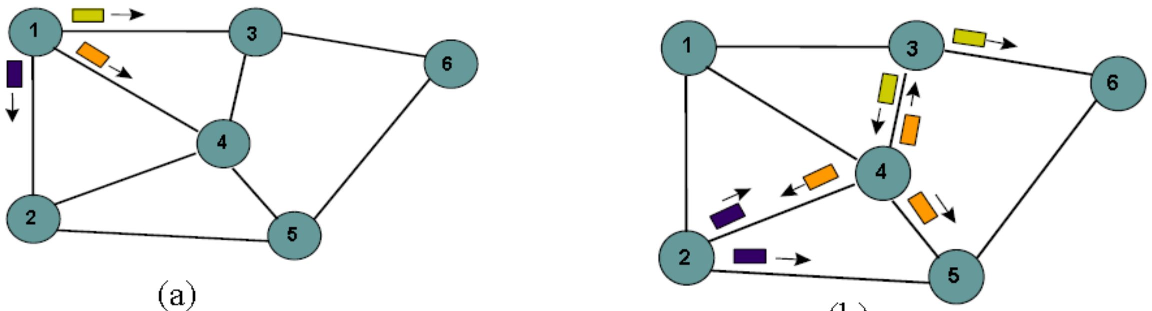


- **Who knows how to route?**

Where to send the packet?

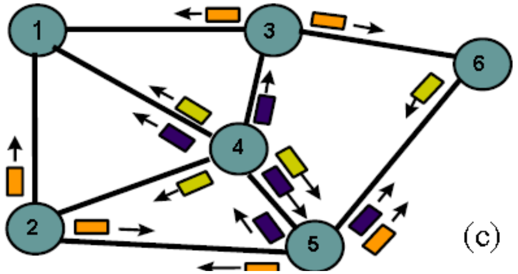
- **Sometimes only the source knows**
  - All the route is stored in the header
    - Packet is routed based on the header
  - **Source routing,** as the entire route is decided by the source
    - **E.g., Dynamic Source Routing (DSR)**
  - Header can grow large
    - Fragmentation, low efficiency
    - Especially if long routes and not much data





(a) (b)

- **Sometimes nobody knows**
  - **Flooding** solutions
    - Everyone rebroadcasts the received packet
    - Hopefully it will reach the destination
  - High burden on the wireless network, where resources are limited



(c)

About routing in general

- Many routing protocols were developed
  - Some specific to MANETs
  - Some others adapted from the wired networks
- There is no one-size-fits-all protocol, which performs well in all circumstances

- Desired features for a MANET routing protocol
  - Distributed operation
  - Loop-free
  - Operation on demand
  - Security
  - Support for „sleeping” cycles
  - Support for one-directional links

MANET routing

- **Proactive routing**
  - The routing table is continuously maintained
    - No matter if there is traffic or not
  - Relatively stable networks
  - DSDV – based on the Bellman-Ford algorithm
- **On demand, reactive routing**
  - Builds a route only if needed, if a packet has to be sent to the destination
  - The routes are temporary, are dismantled if not used
  - AODV
- Hybrid protocols
  - Combining the previous two
- Position-based protocols
  - Makes use of geographical position information for routing

Constraints

- Delay
  - Proactive protocols provide lower delay, as routes are prepared in advance, and always up to date, ready to use
  - Reactive protocols provide large delay, as the route from A to B has to be found, when needed
- Overhead
  - Proactive protocols have a large overhead, too much signaling traffic to build and maintain the routes, even if no real data to send
  - Reactive protocols have lower overhead, useless routes are not maintained
- Each application will choose the best protocol
  - Low mobility -> Proactive protocols
  - High mobility -> Reactive protocols

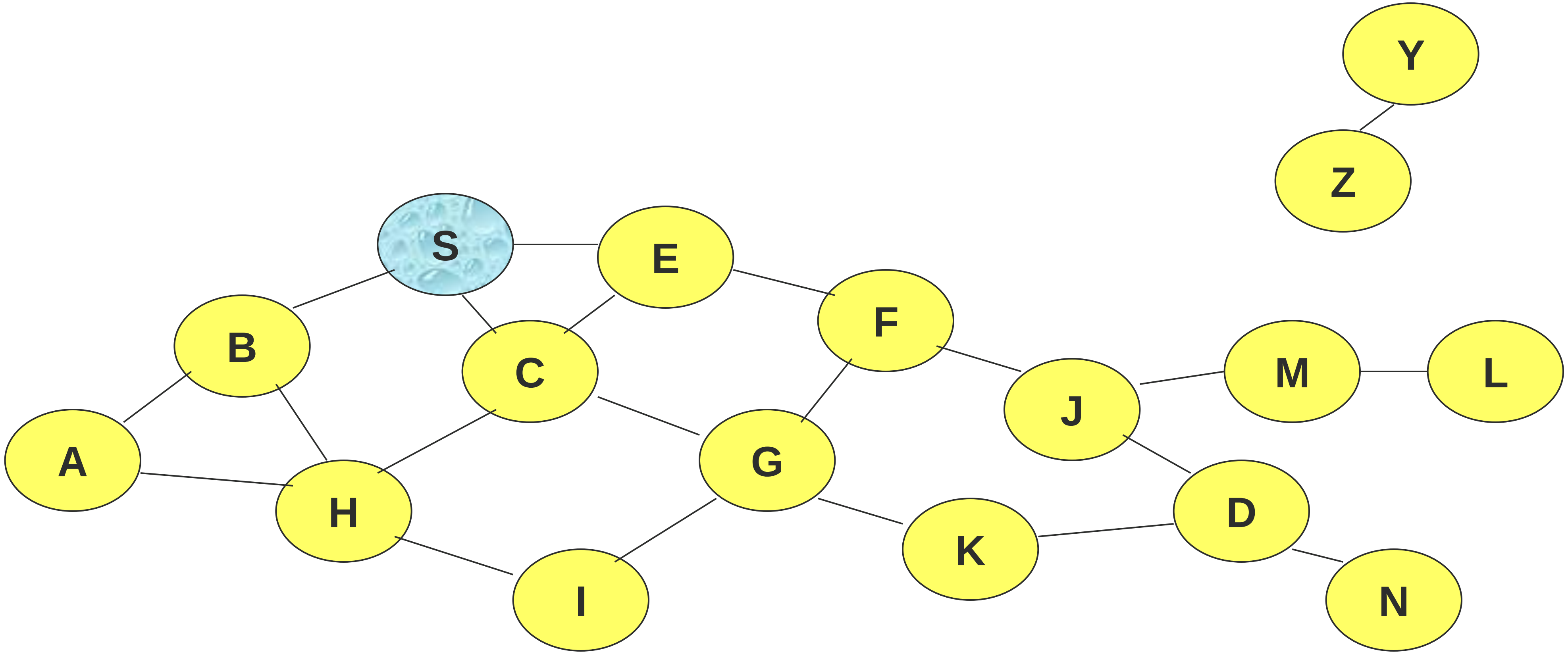
Ad Hoc On-Demand Distance Vector Routing (AODV)

- Reactive protocol
  - Maintains a routing table in each node, no need to store the route in the packet header
  - The route is built and maintained only if it is „active”

AODV

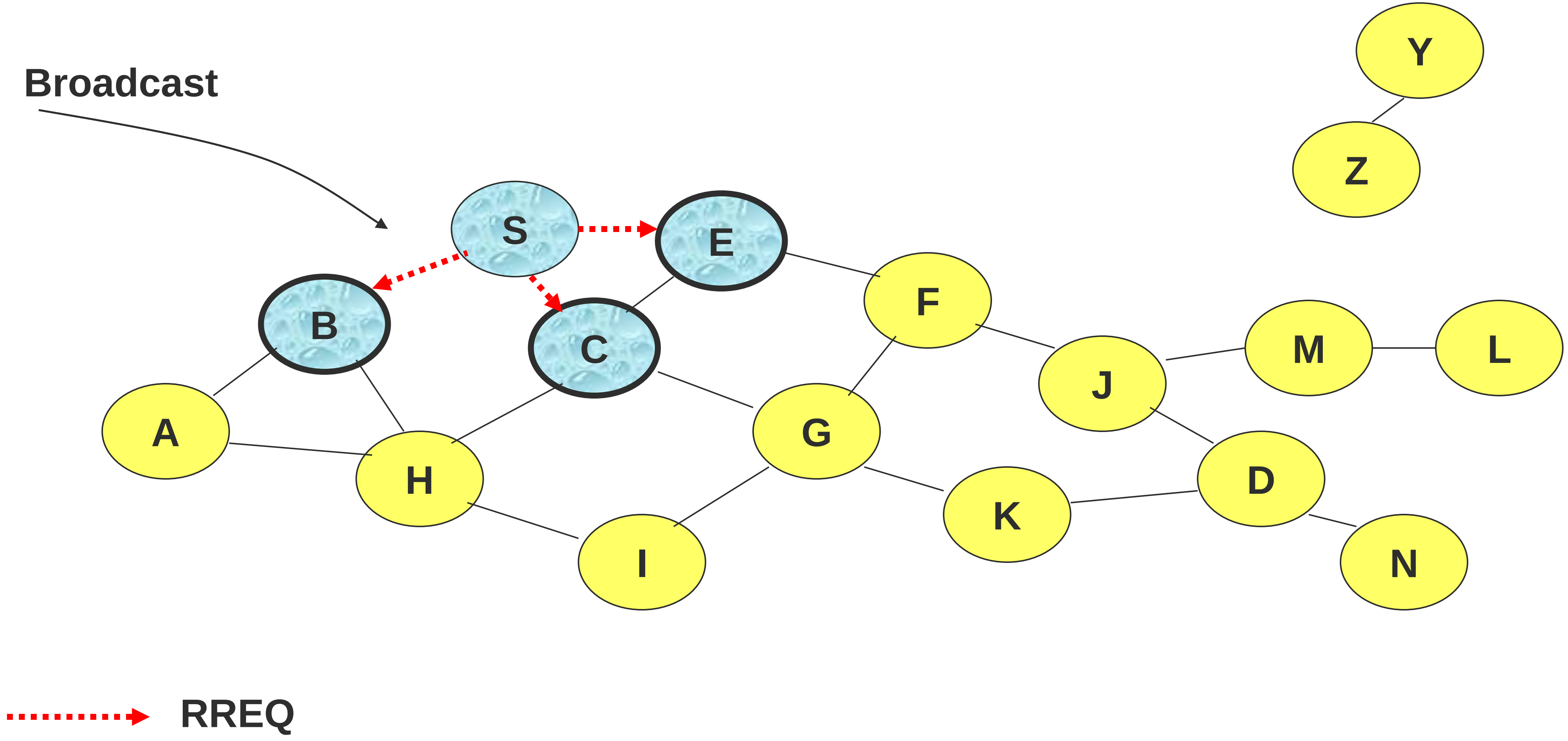
- To discover the route, the source broadcasts a **Route Request (RREQ) message**
- Those who receive it, rebroadcast it
- When a node rebroadcasts a Route Request message, it stores a **reverse path pointer** towards the node from where the request came
  - AODV symmetric (bi-directional) links
  - A small timer ensures that these records time out after a while
- If the RREQ arrives to the destination D, a **Route Reply (RREP)** message is sent back
- It will propagate along the path built from the reverse path pointers

Route Request - AODV

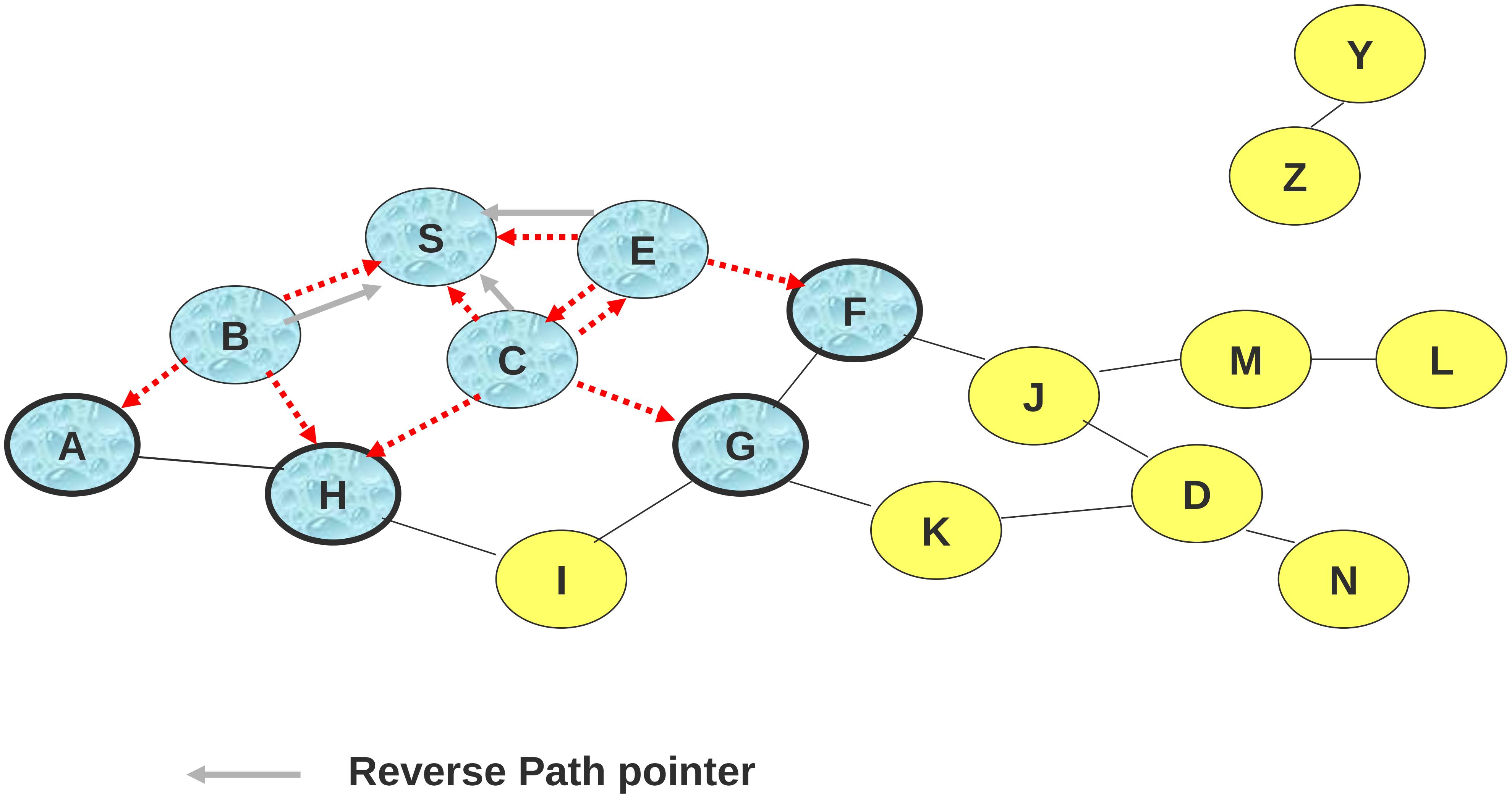


Node that already received a RREQ for D initiated by S

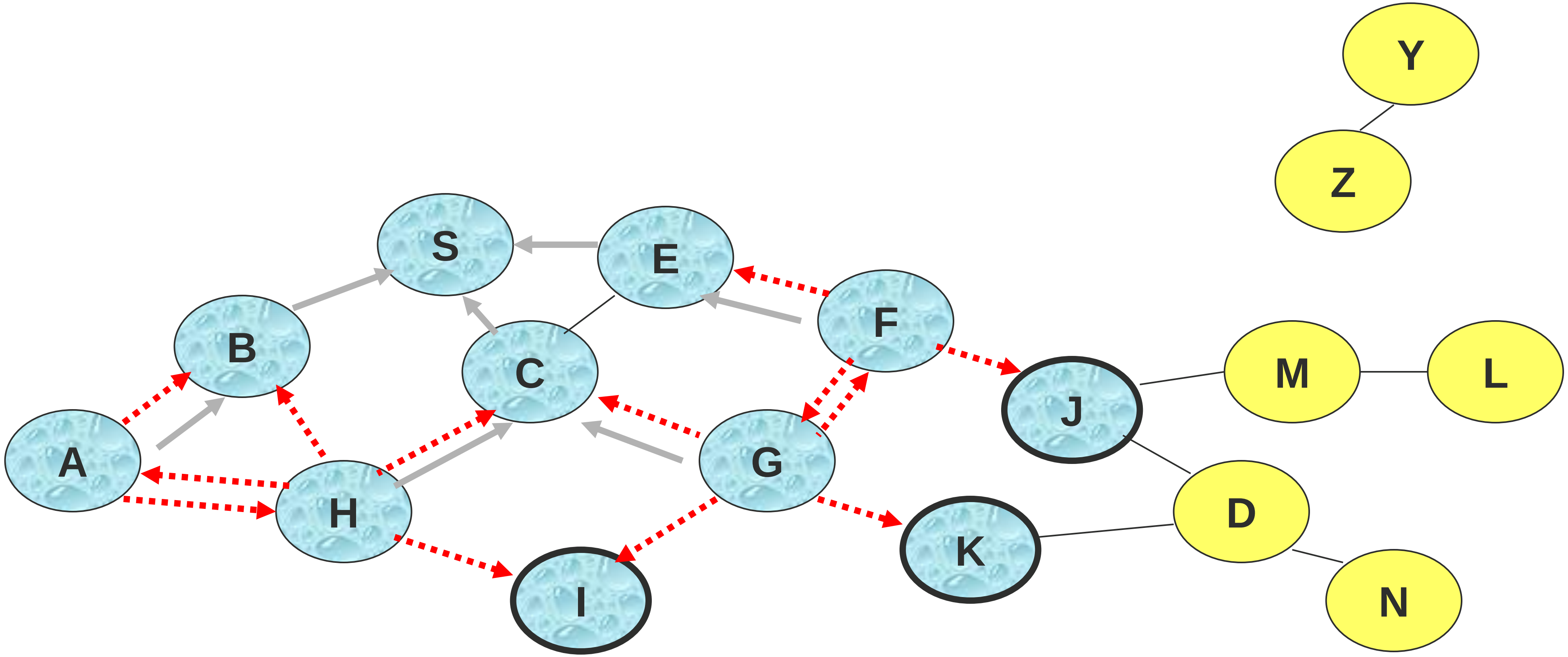
Route Request - AODV



Route Requests - AODV

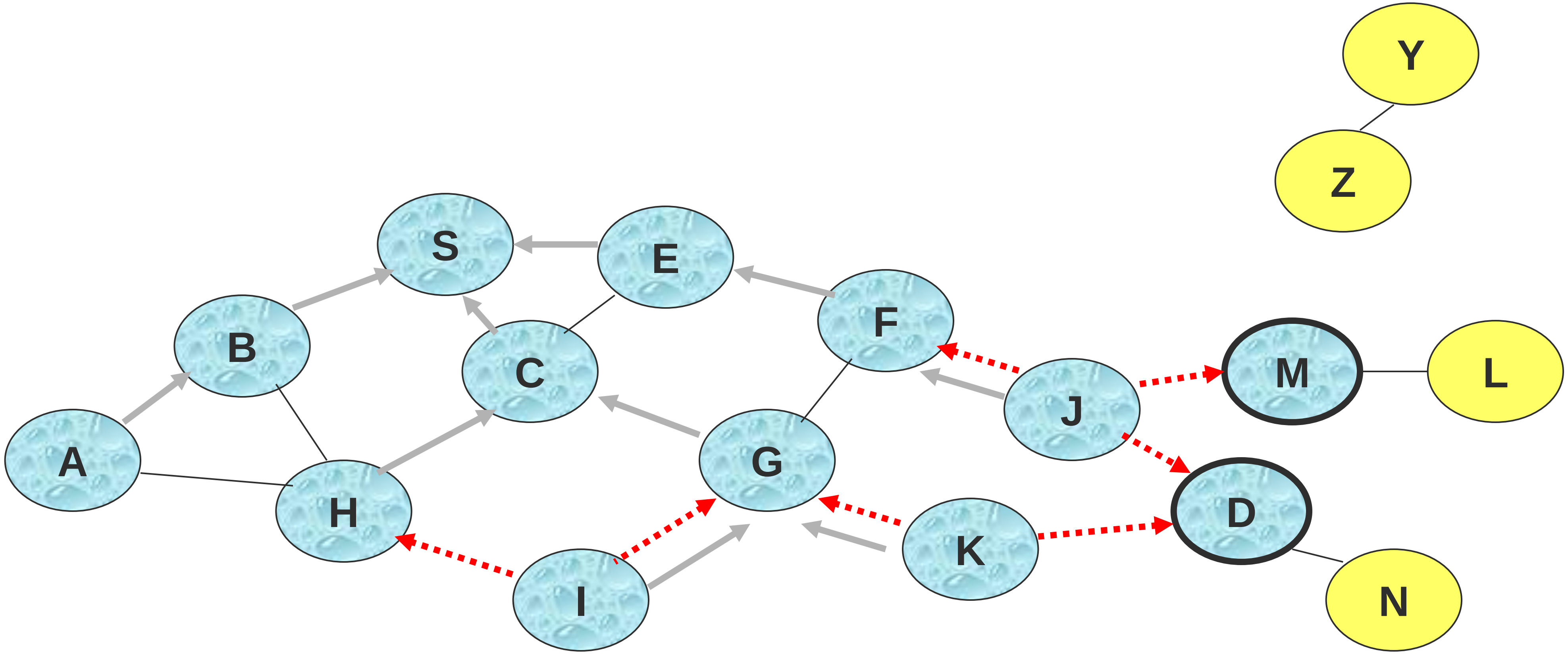


Reverse Path - AODV

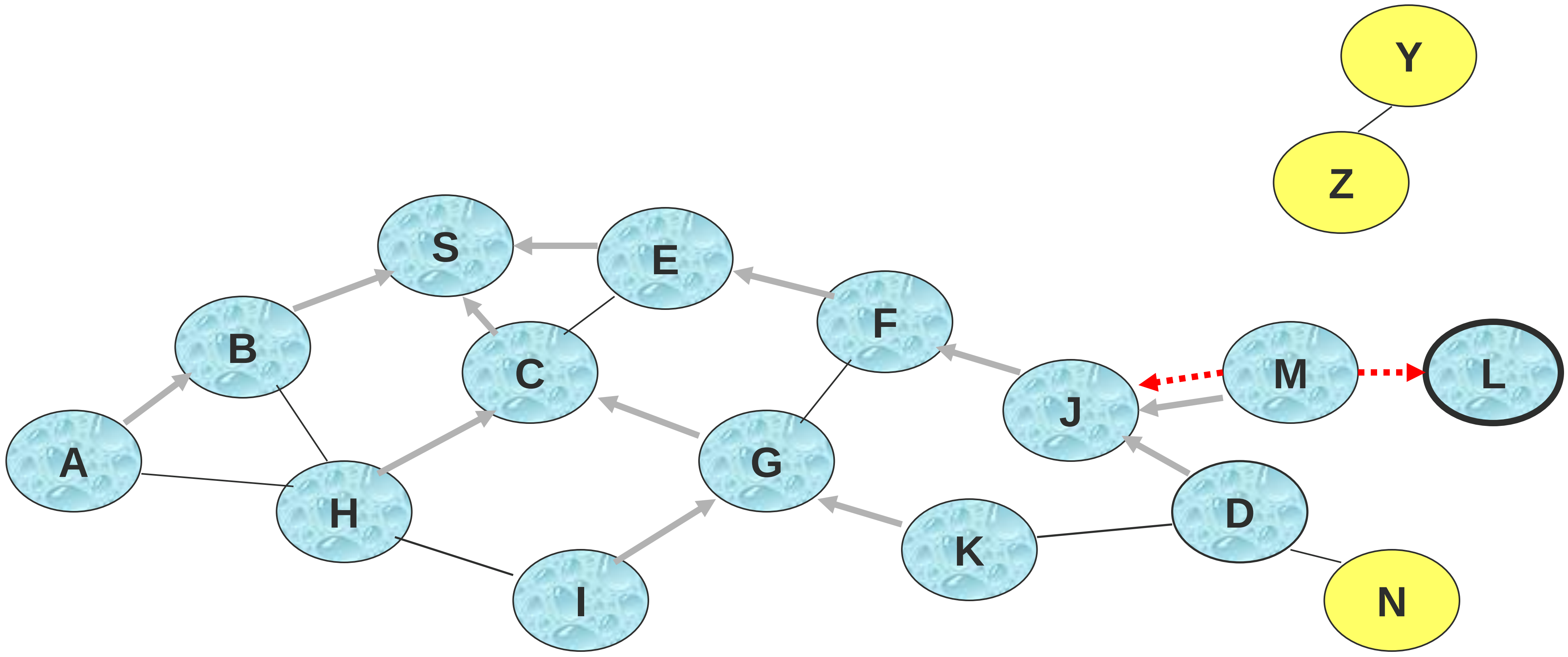


• C receives a RREQ from neighbors (G and H)
But does not rebroadcast it again

Reverse Path - AODV

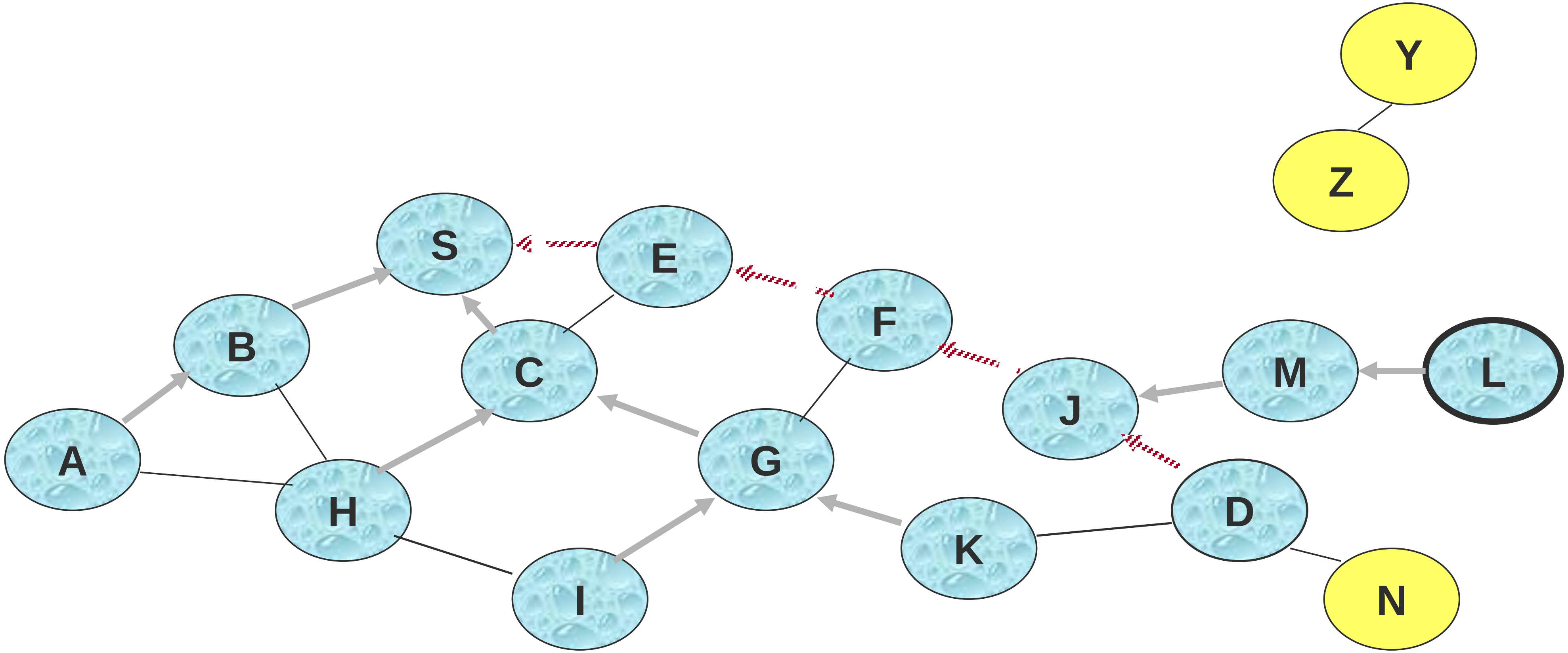


Reverse Path - AODV



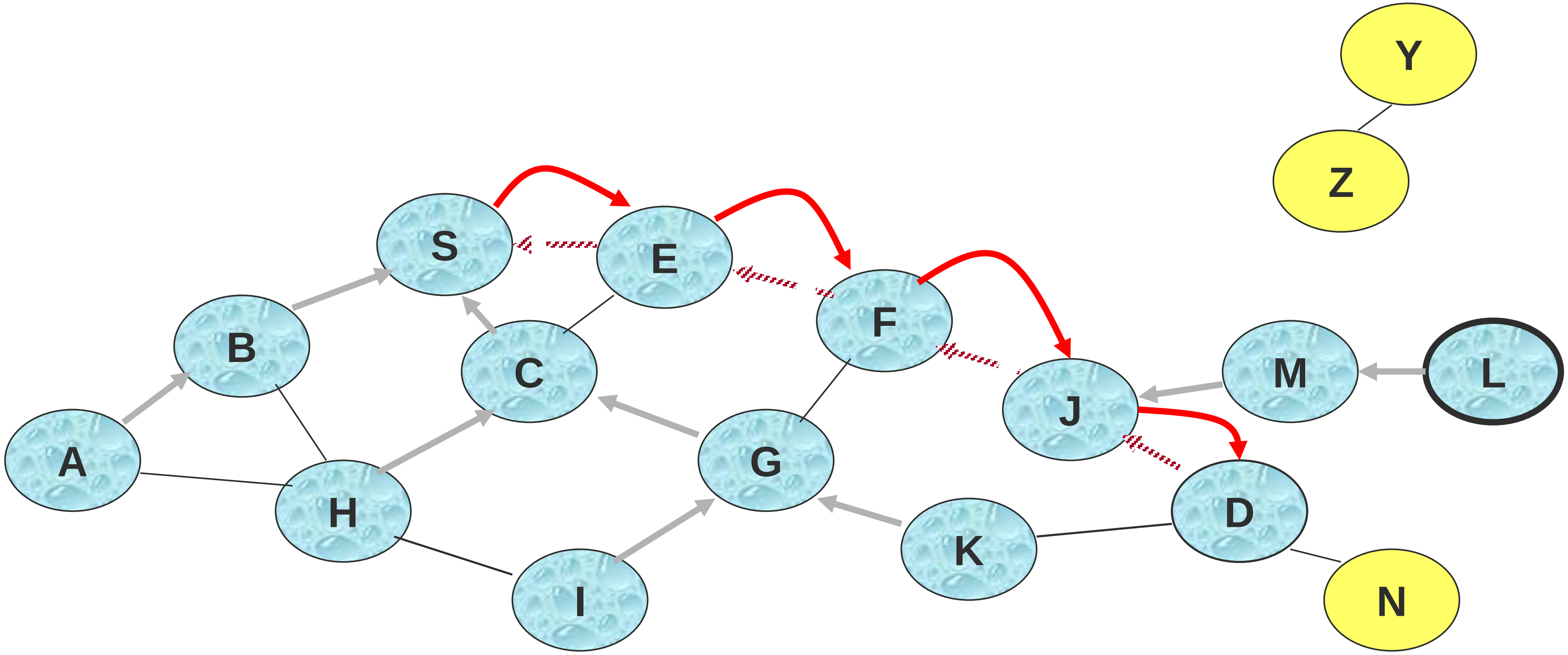
- node D does not forward anymore the RREQ message, as he is the destination

Route Reply - AODV



Path of the RREP message

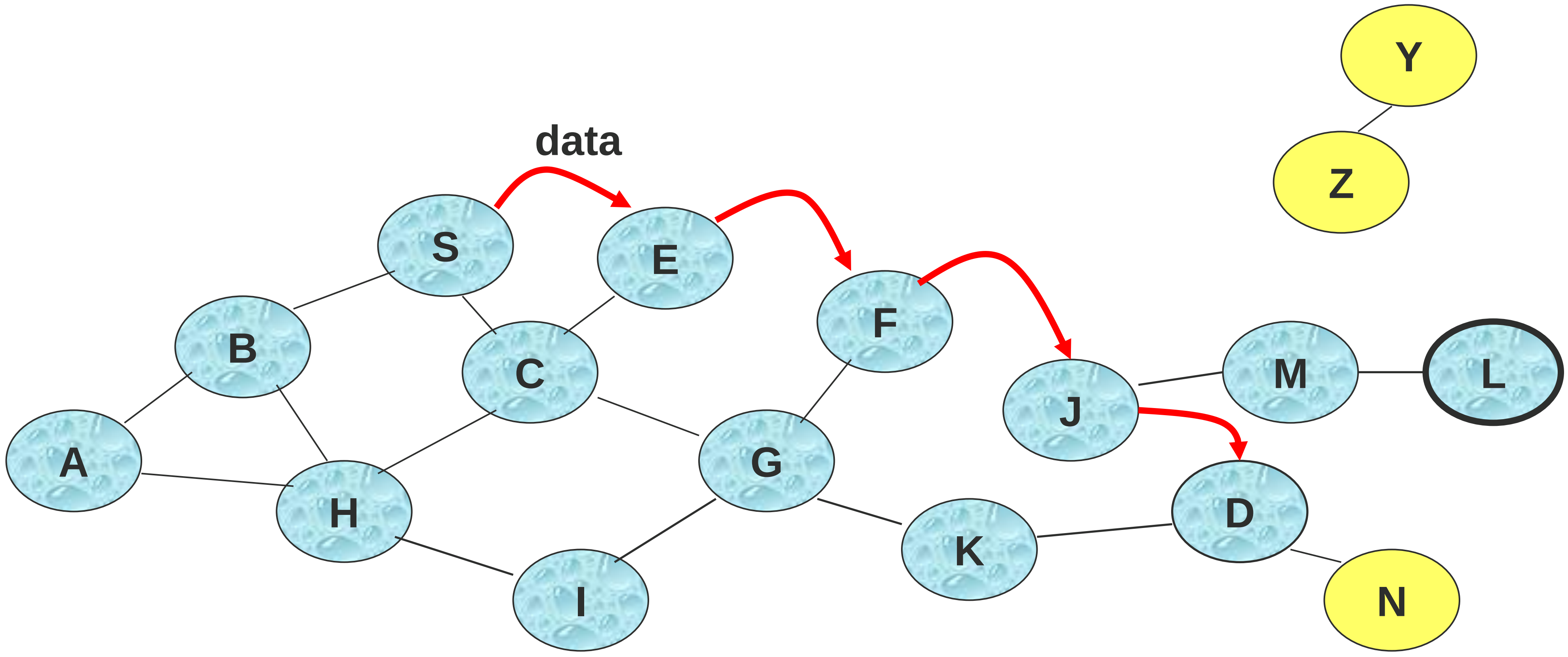
Forward Path - AODV



As the RREP message travels from D to S, forward path pointers are stored in the intermediate nodes

Forward path pointer

Data sending - AODV



For sending the useful data, these forward path pointers are used

The path is not included in the header

Timers

- The reverse path records are deleted after a while from the routing tables
  - We should take into account the specificities of the wireless domain and the size of the network, leave time for the RREP message to propagate back before deleting the record
- The forward path pointer is deleted if it becomes inactive – no traffic
  - *active_route_timeout*
  - If no traffic, the record is deleted, even if the path is still valid

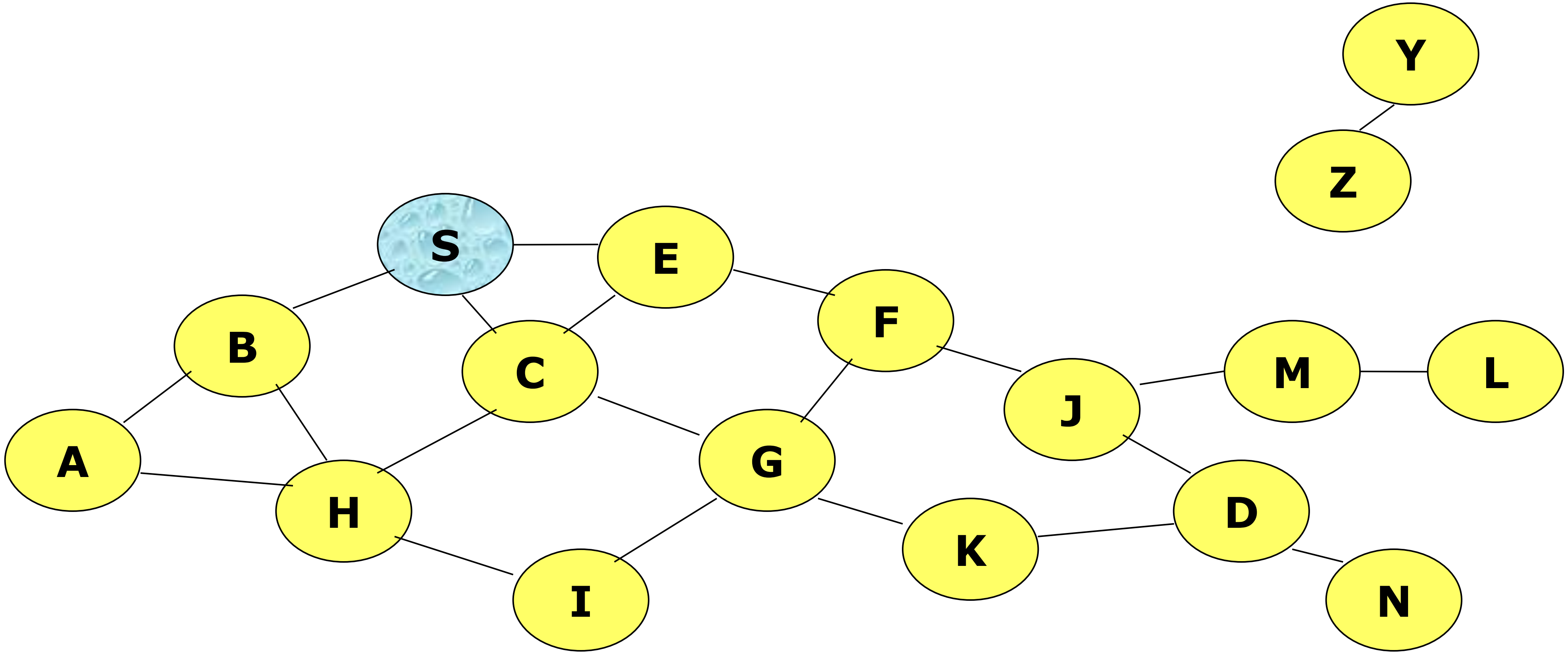
Optimization: Expanding Ring Search

- Searching an expanding territory
- The RREQ messages are first sent out with a small Time-to-Live (TTL) value
  - After each hop the TTL value is decreased
  - If 0, the message is dropped
  - Used in many protocols that are based on flooding
- If no Route Reply until a timer expires, the value of the TTL is increased
  - After a few steps the search will cover the entire topology

Dynamic Source Routing (DSR)

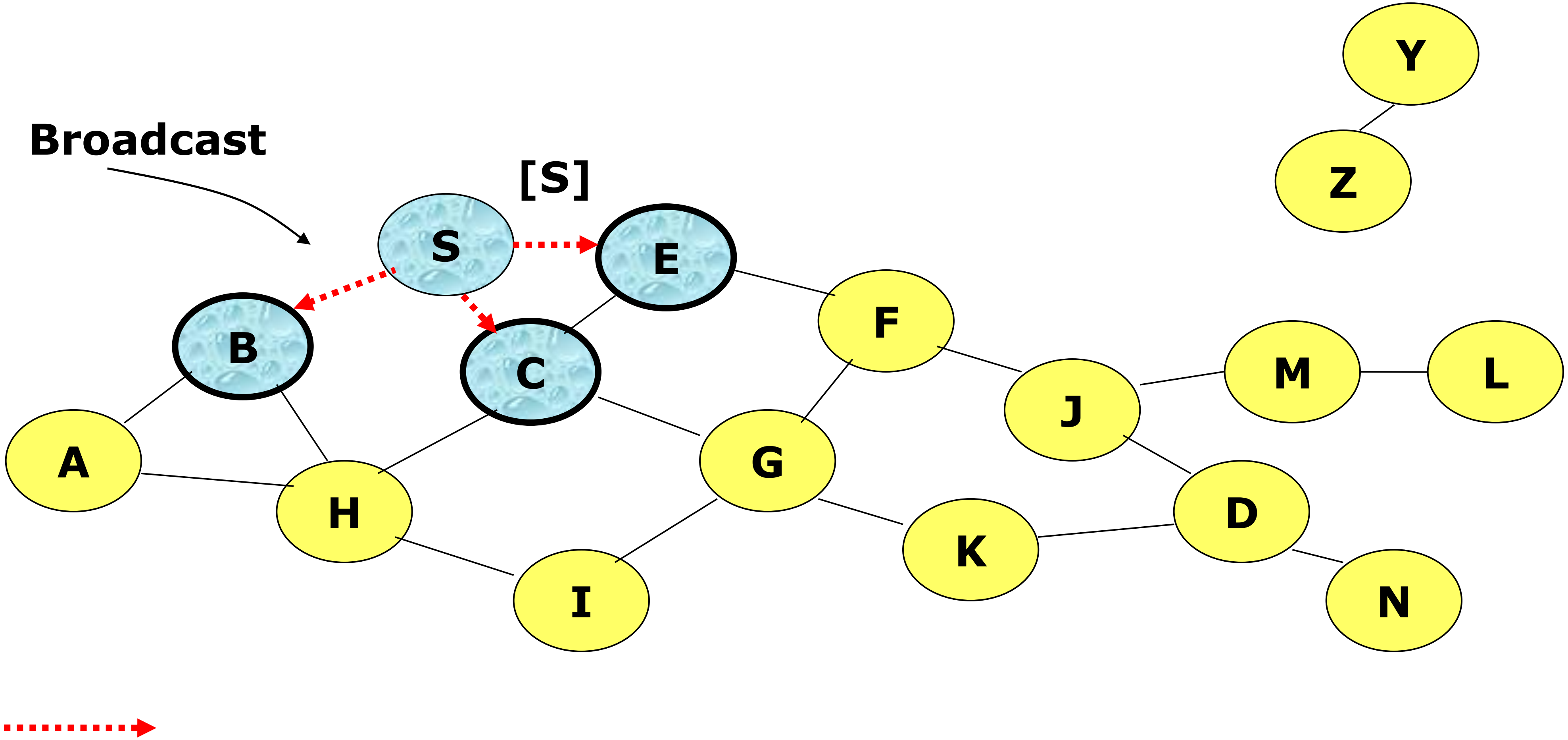
- If the source **S** wants to send something to destination **D,** it initiates route discovery
- **S** floods the network with Route Request (**RREQ**) messages
- Each intermediate node adds his ID to the RREQ before forwarding it

DSR Route Discovery



Nodes that already received the RREQ from S, regarding D

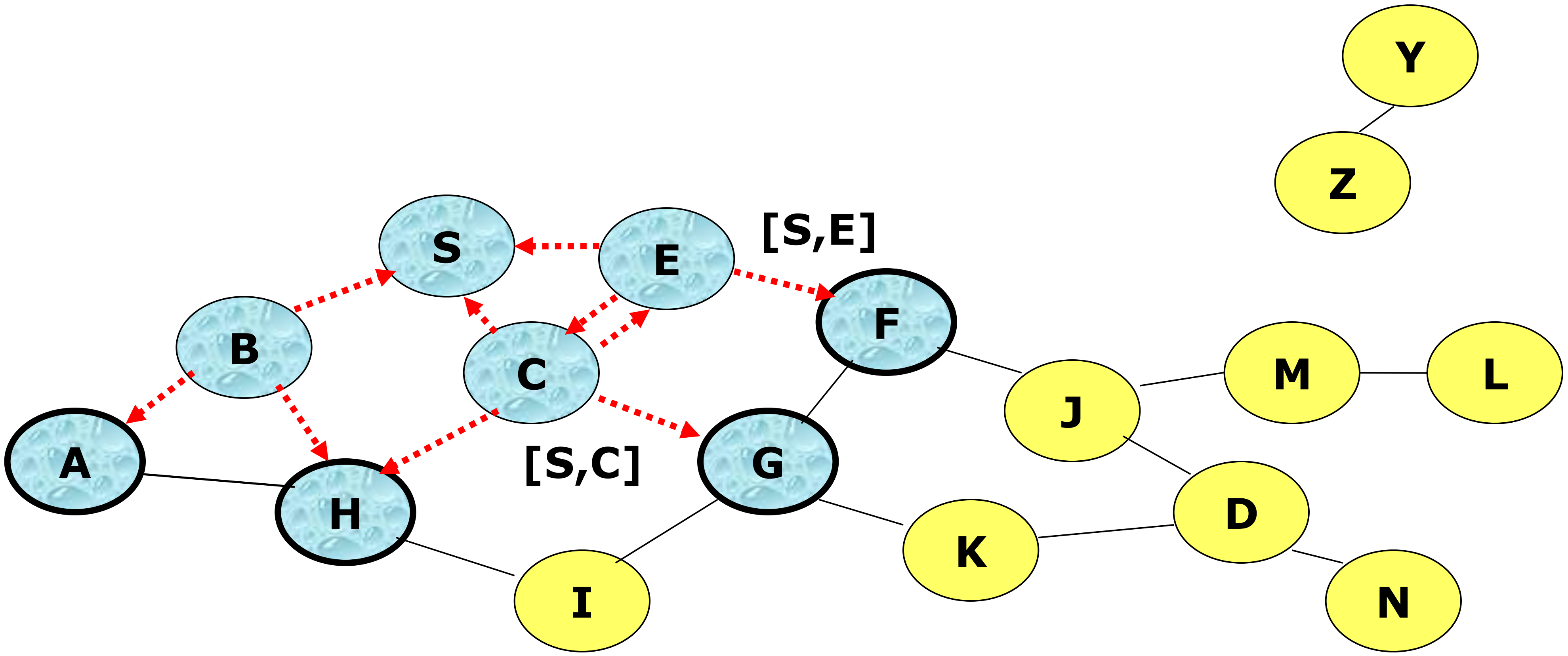
DSR Route Discovery



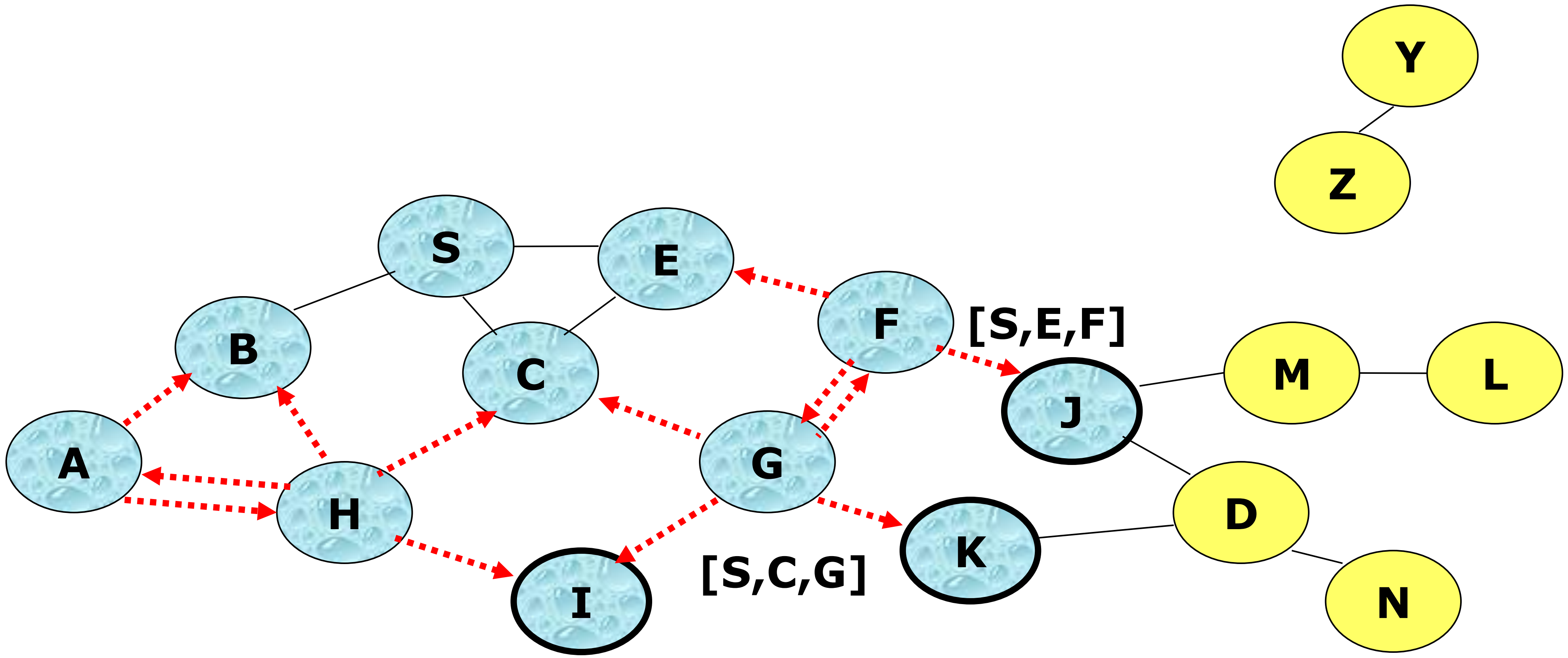
RREQ

[X, ...] intermediate nodes already added to the path

DSR Route Discovery

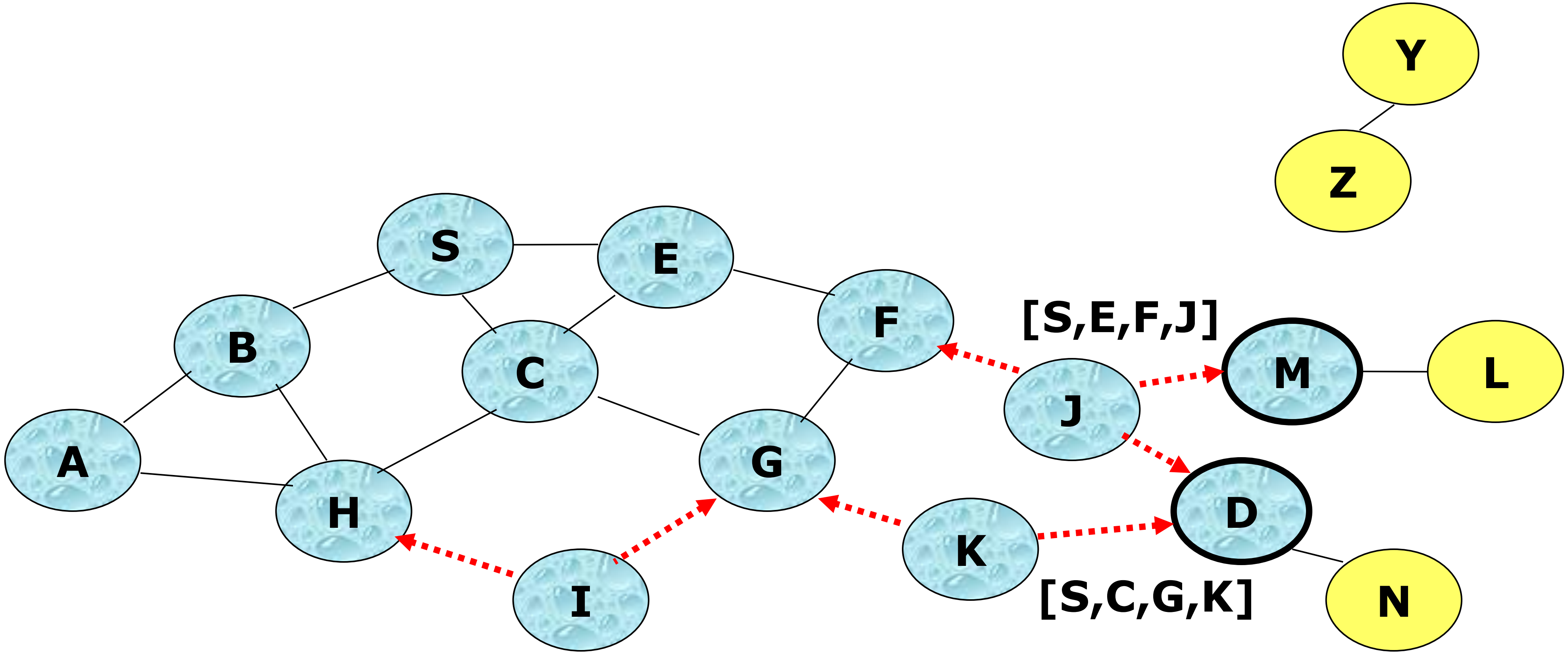


DSR Route Discovery

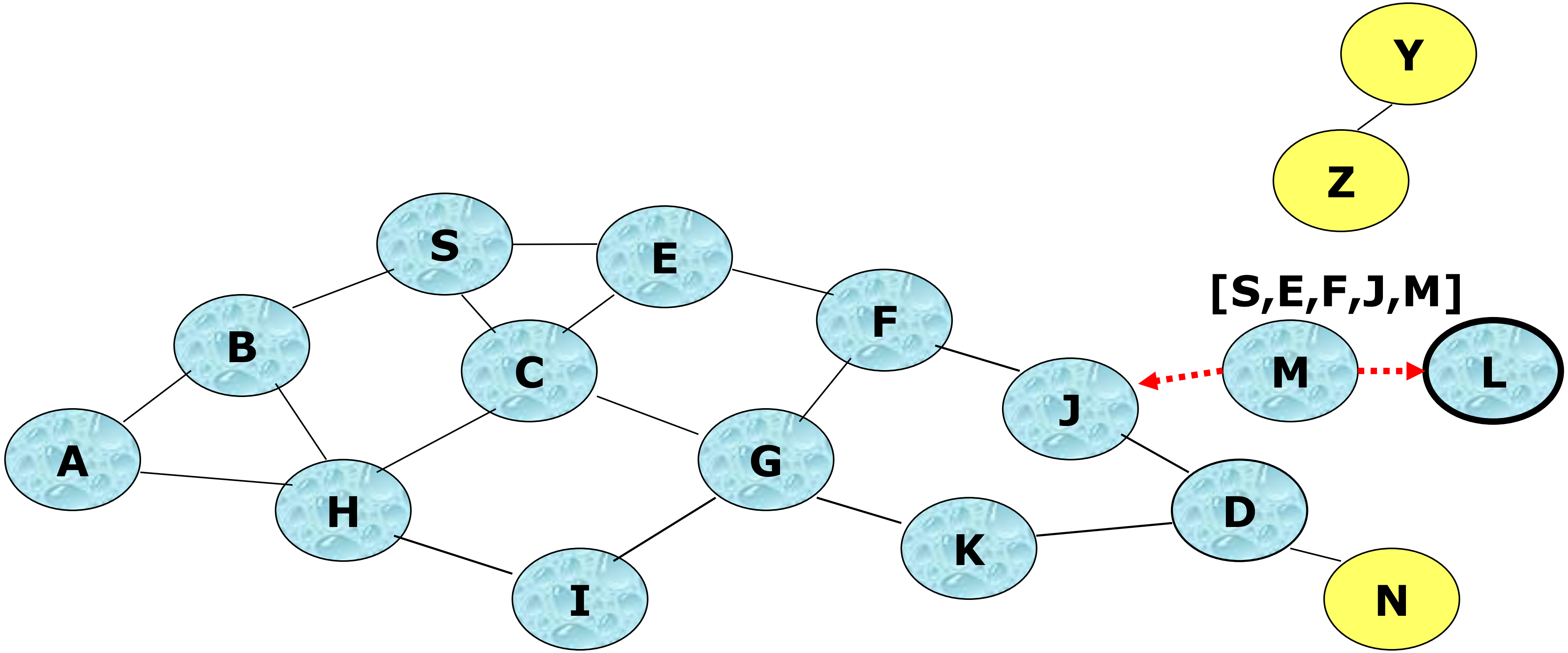


Restricting the flooding (like in AODV):
C receives the RREQ again from G and H, but does not forward it again

DSR Route Discovery



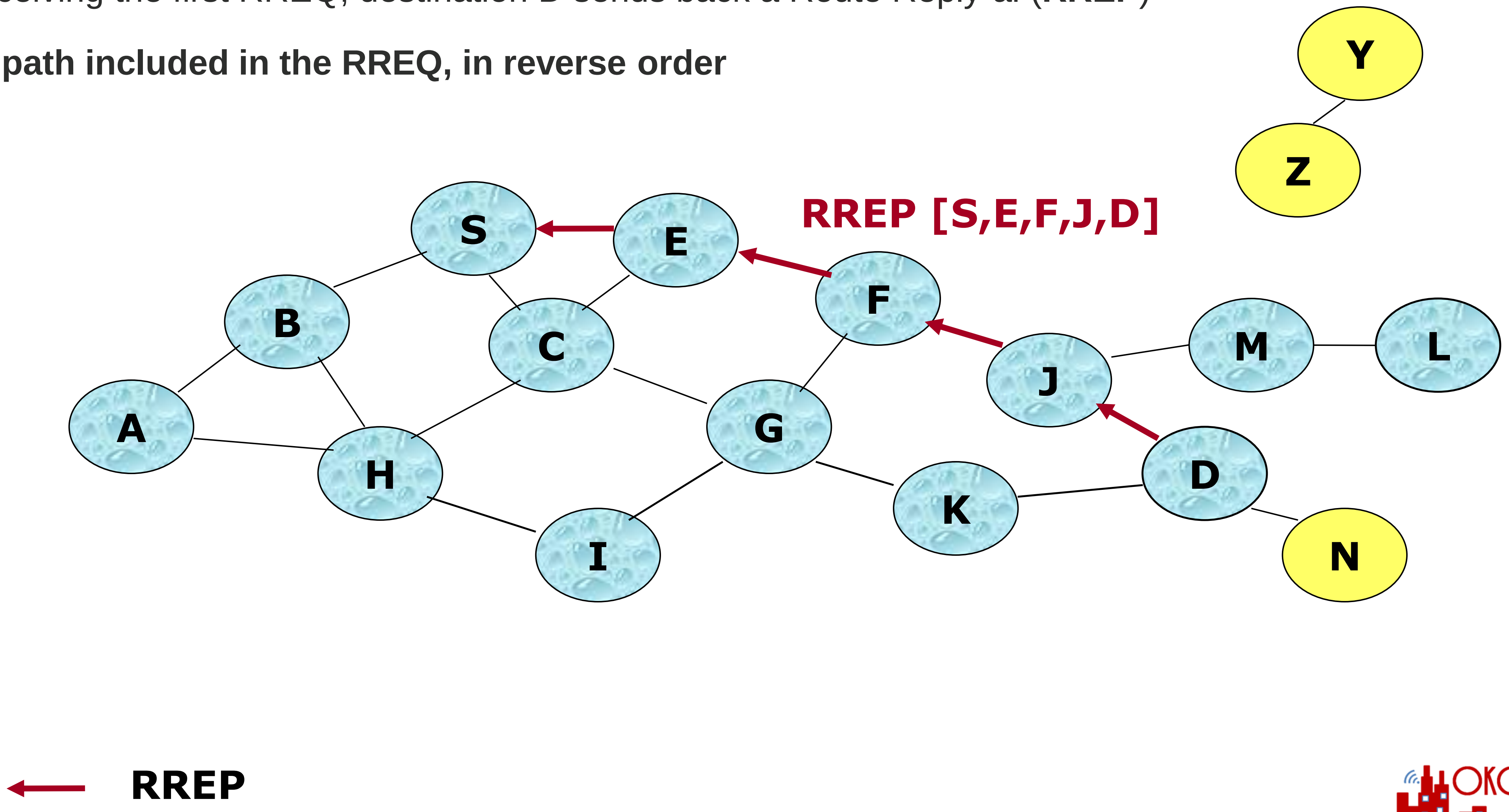
DSR Route Discovery



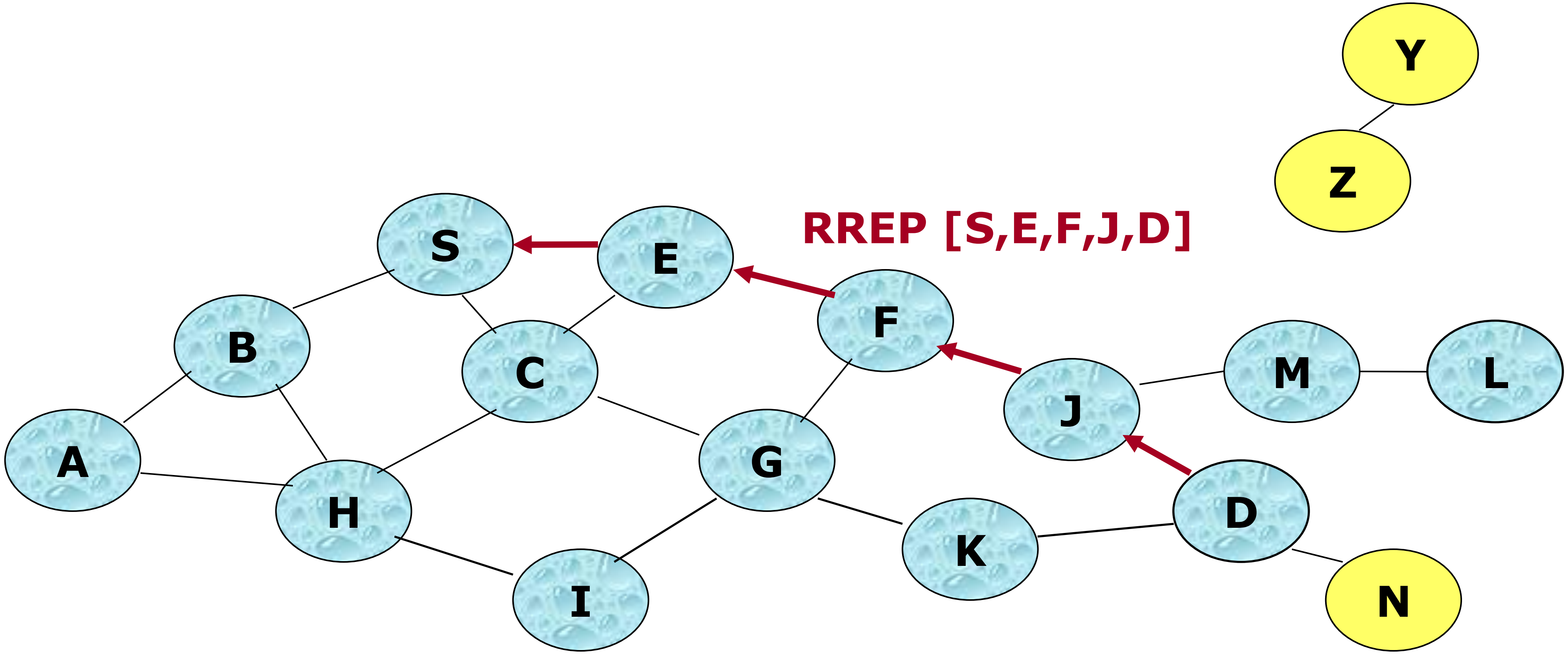
D stops the broadcast of RREQ, as it is the destination

DSR Route Discovery

- After receiving the first RREQ, destination D sends back a Route Reply-al (**RREP**)
- **On the path included in the RREQ, in reverse order**

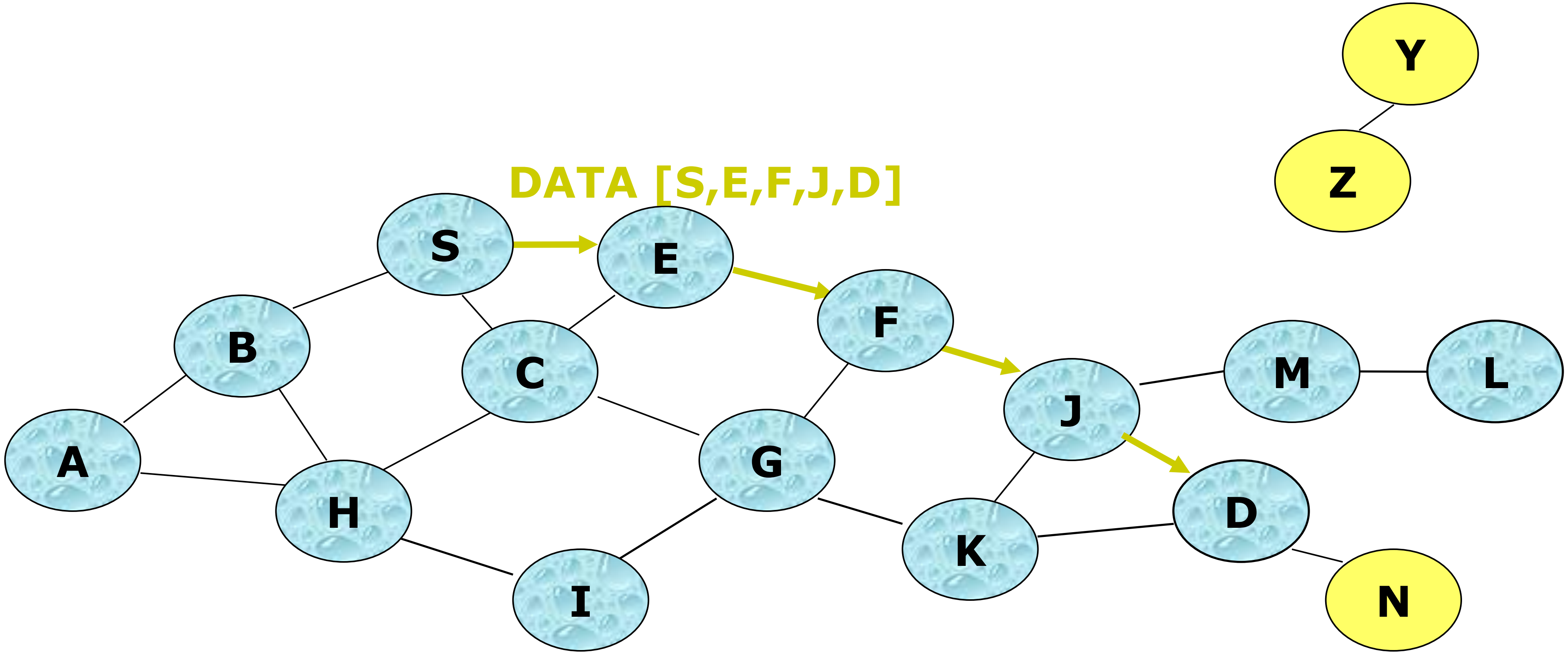


DSR Route Reply



RREP routing message

Data Delivery in DSR



The header increases with the path length

Position-based routing

- Eliminate some drawbacks of the topology-based routing algorithms

- The source makes use of some **localization service**, and finds out the geographical position of the destination.

- If we know the position of the destination, there is no need to build and maintain routes in advance
  - Instead of building the routes, we need a **forwarding strategy**
  - At each node, we select the next hop based on the position of the destination and the position of the neighbors

Localization service

- **Localization service**
  - Helps a node to determine its position
  - In an ad hoc network a localization server is not always available

- The localization service can be provided by one or several nodes:
  - „some/all to some/all”
  - „Chicken-egg” problem: but how do we know the position of the localization server?

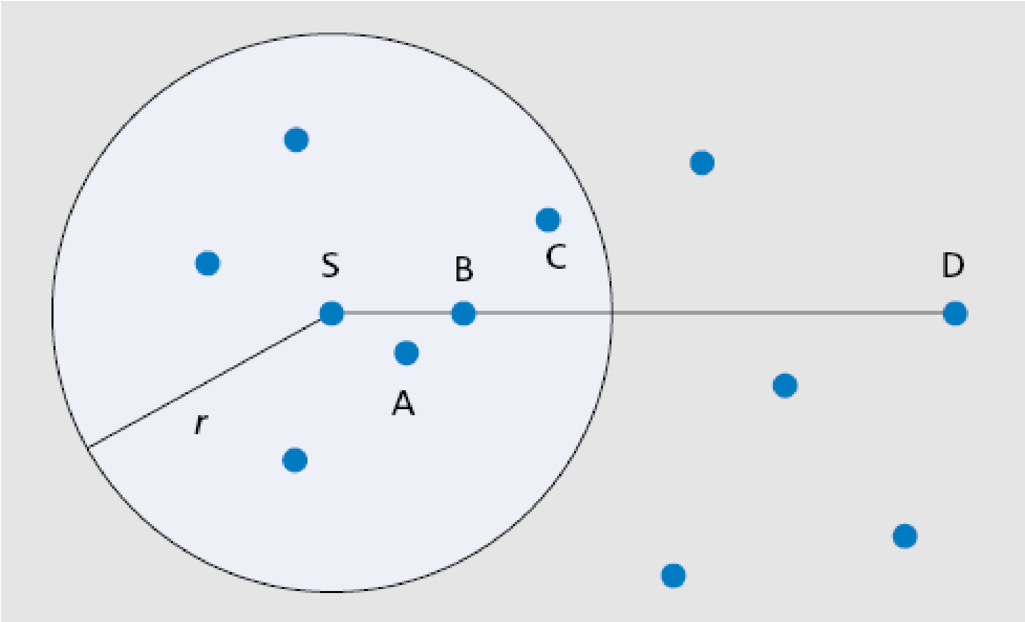
- If a source does not know the position of the destination, makes use of such a localization service
  - In case of a cellular (mobile) network, localization is centralized, and at cell level
  - It cannot be applied in ad hoc systems

Forwarding strategies

- The forwarding decision of an intermediate node:
  - Based on the position information of the destination, embedded in the packet
  - Based on the position of one-hop neighbors
- Positions of the neighbors: known from periodic Hello messages
- Forwarding strategies:
  - Greedy forwarding
    - E.g. MFR, NFP, compass routing
  - Restricted directional flooding
    - E.g., LAR, DREAM
  - Hierarchic solutions

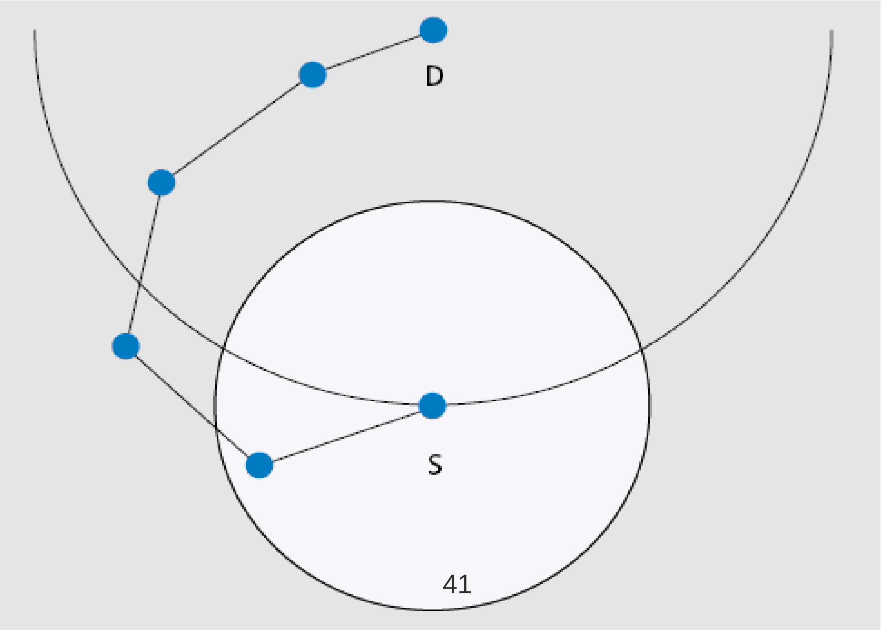
Greedy forwarding

- Which strategy should be used to select the next hop?
- **Most forward within *r* (MFR)**
  - Choose the node that is closest to the destination **D** (Node **C** in the figure)
  - The number of hops is minimized
  - Good strategy if the radio power cannot be changed
- **Nearest with forward progress (NFP)** (node **A**)
  - If the radio power can be adapted
  - Decreases the probability of collisions
- **Compass routing** (node **B**)
  - The smallest angle compared to the SD line
- **Random** choice of a neighbor in the good direction
  - No precise position information needed about neighbors
  - Lower overhead



Greedy forwarding

- Problems:
  - **S** might be closer to the destination **D** than any other node
  - Forwarding might arrive to a local maximum, where there is no way forward
  - **Recovery** mode:
    - If the greedy forwarding stops, we switch to recovery mode
    - If a neighbor can be found again, we switch back to the greedy mode



Restricted directional flooding

Location-Aided Routing (LAR)

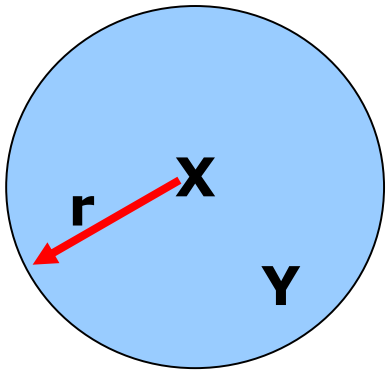
- Use the position information of the destination node to limit the flooding
- Introduces the notion of **Expected Zone**
  - The zone where the destination is expected to be
  - Estimation, based on the previous location of the destination, its speed and direction information
- RREQ messages forwarded only inside a **Request Zone**
  - The Request Zone includes the Expected Zone, together with the area linking the source with the Expected Zone

LAR Expected Zone, Request Zone

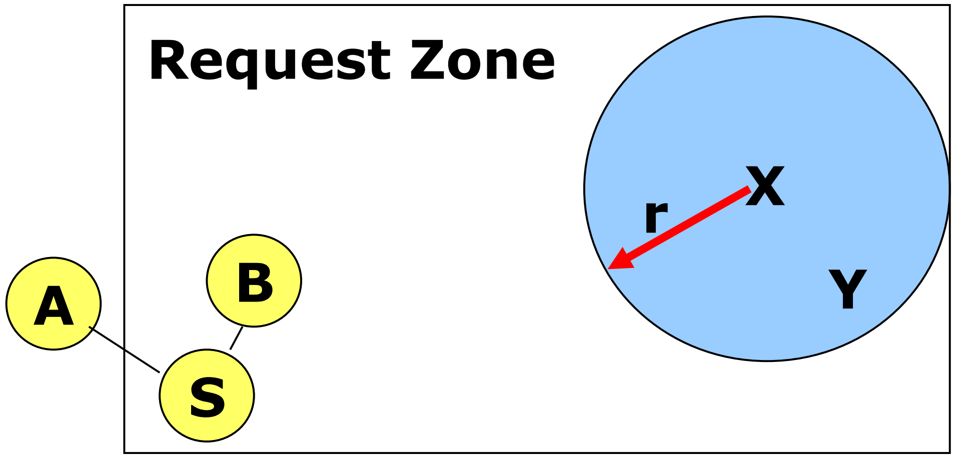
X = the last known position of the destination **D,** at time t_0

Y = the current position of the destination node **D** at time t_1 (S is not aware of it)

r = $(t_1 - t_0)$ * [estimated speed of **D**]



Expected Zone



LAR Request Zone (2)

- RREQ messages forwarded only inside the Request Zone
  - The Request Zone **might be** the smallest rectangle including the source and the Expected Zone
  - E.g., in the example, B forwards the RREQ, but A does not
- The Request Zone explicitly defines whether the RREQ message should be dropped or not
- Each node knows its own position, knows if it is inside the Request Zone or not

LAR Request Zone (3)

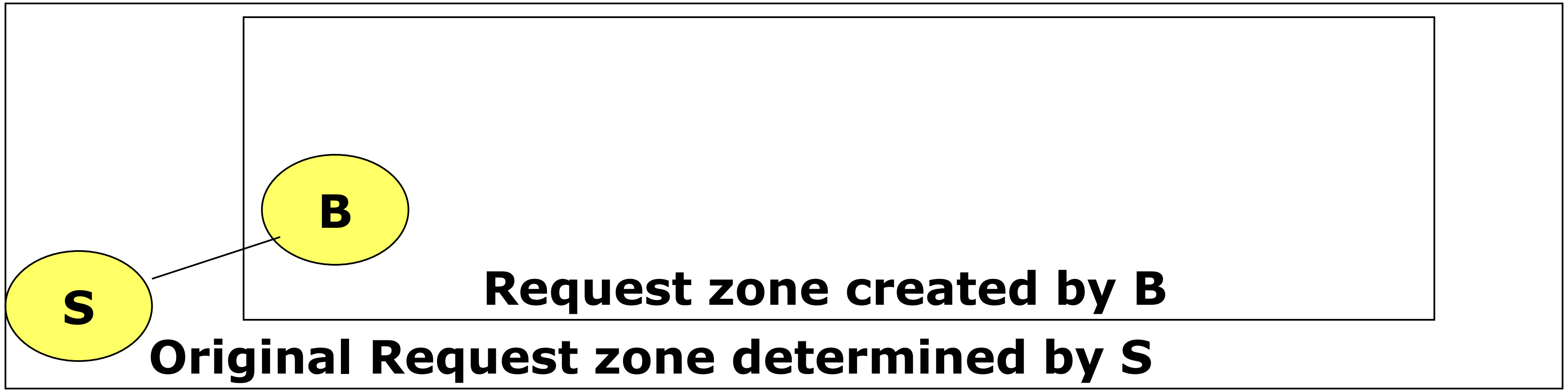
- If the source did not estimate well the position of the destination, the Request Zone might not contain it
→ the route discovery will fail*!*

- After a timeout, the source starts a new search…
  - Increases the size of the Request Zone;
  - If needed, the entire network is included in the Request Zone

- The following steps of LAR are similar to **DSR**
  - In the RREQ message we include the path, step by step
  - The destination sends back a RREP, following this path
  - The path is then included in the header of the data packet
  - Routes have to be refreshed from time to time

LAR versions: Adaptive Request Zone

- The Request Zone stored in the RREQ can be modified by each internal node, if
  - It has fresher information about the destination
  - **AND** the resulting Request Zone is included in the original one



LAR overview

- Advantages
  - The area of spreading of the RREQ message is limited
  - Smaller overhead for route discovery

- Drawbacks
  - Nodes have to know their location
  - Doesn’t take into account possible problems in the radio transmission

Distance Routing Effect Algorithm for Mobility (DREAM)

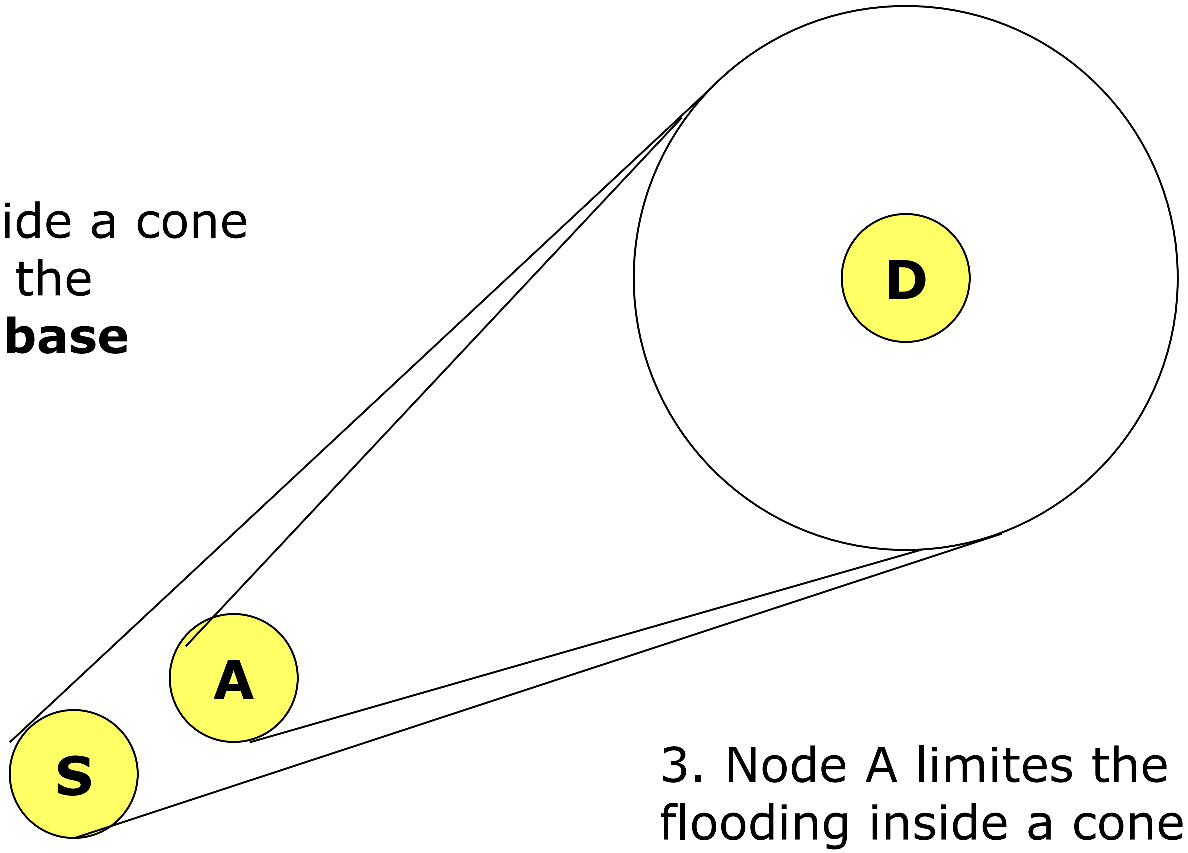
- Uses information about position and speed (as in LAR) for reducing the area flooded with **data packets**

- Data is distributed by flooding, as opposed to LAR, where we only use flooding to discover the best route

DREAM localization

1. Expected zone („as in LAR")

2. Data is flooded inside a cone where S is the **apex,** the expected zone is the **base**

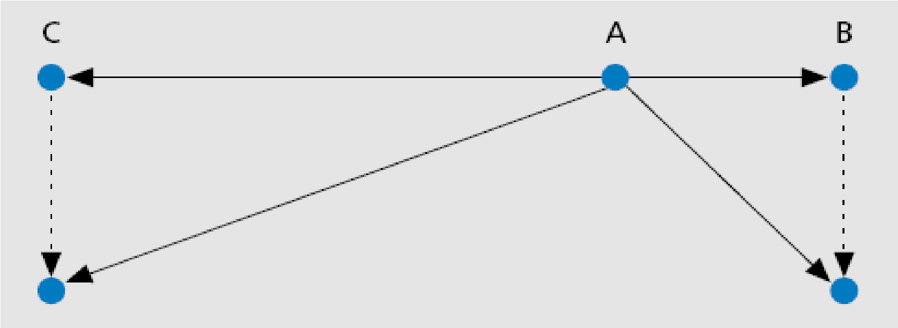


3. Node A limites the flooding inside a cone where A is the apex

DREAM distance effect

- Nodes periodically broadcast their position

- „Distance effect” = Remote nodes move with a smaller angular speed.



→ *Close nodes should refresh their data more often*

- Playing with the *time-to-live* (TTL) field
- Adaptive TTL

CBF (Contention Based Forwarding)

- In position-based routing solutions a node learns about the position of its neighbors via periodic beacon messages
  - Mobility and energy-efficiency should be taken into account when calculating the frequency of beaconing
- Proposal **CBF (Contention Based Forwarding)**
  - **Greedy forwarding, without any knowledge on the position of the neighbors**
  - Distributed next hop selection, hop-by-hop
  - Advantages:
    - Each node has to know only its own position
    - No burden on the network because of the beacon (hello) messages
- Comment: In some cases, if local maximum is reached, recovery mode might have to be activated, but this is a different problem.

Contention Based Forwarding

- How it works:
  - The next hop is selected based on a **contest**
  - **Suppression**: lowers the probability of collisions, as normally just one node is selected as next hop
- Steps:
  1. The source broadcasts the message to its neighbors.
  2. Each node sets a timer for its own retransmission
     - The timer inversely proportional to the distance form the source
  3. The timer of the furthest away node will expire first
  4. He retransmits, all the others hear it, and cancel their own retransmission
- Decentralized selection of the next hop

Vehicle-to-vehicle communication

- „Traditional” ad hoc protocols:
  - Reactive: AODV, DSR
    - High signaling load for topology discovery, slow discovery
    - Not efficient for cars, as they move faster
  - Position-based: LAR, DREAM
    - Needs localization service
    - In some cases it leads to local maximums, needs a recovery mode
    - In urban scenarios there is a high chance for such local maximums, the physical distance is not so relevant when many buildings obstructing the communication

- New solutions needed for vehicle-to-vehicle (V2V) communication

AODV versions for VANETs

- **AOMDV: Multipath**
  - Not only one path is stored, but all those that were discovered
    - This can be done without extra burden, as the path discovery is anyhow based on flooding
  - If the primary path is broken, we can switch rapidly to a back-up path
    - We need to search for new paths only if all the previously known paths are broken (or their number is getting very low)
- **SD-AOMDV: Speed and Direction**
  - The speed and direction of nodes is taken into account when selecting the best path out of the discovered ones
  - A node can be next hop only if it goes in the same direction, with roughly the same speed
- **R-AOMDV: Retransmission count**
  - Takes into account the quality of the links, besides the hop count
    - Link quality: number of retransmissions at MAC layer, until a successful retransmission
  - **Problem:** link quality changes rapidly
  - Cross-layer optimization – information from lower layers is used for routing at networking layer

AODV versions for VANETs

- **AODV+PGB: Preferred Broadcast Group**
  - If the next hop is too close, the message does not advance rapidly
  - If the next hop is too far, there is a high chance for the link to break
  - **Proposal**: select as next hop nodes which are at a medium distance (the signal strength is average), they will form the Preferred Group

- **BAODV: Bus-AODV**
- **P-AODV**
- **I-AODV**
- **Improved-AODV**
- **AODV-BD**
- **AODV-VANET**
- **etc.**

Link-stability based routing

- **Movement Prediction based Routing (MOPR)**
  - Takes into account the position, speed and direction of the cars
  - Builds routes with nodes that move in similar ways