MANET Routing

- Introduction to MANETs
- Fundamentals of Wireless Ad Hoc Networks
- Routing in MANETs
- Properties of MANETs

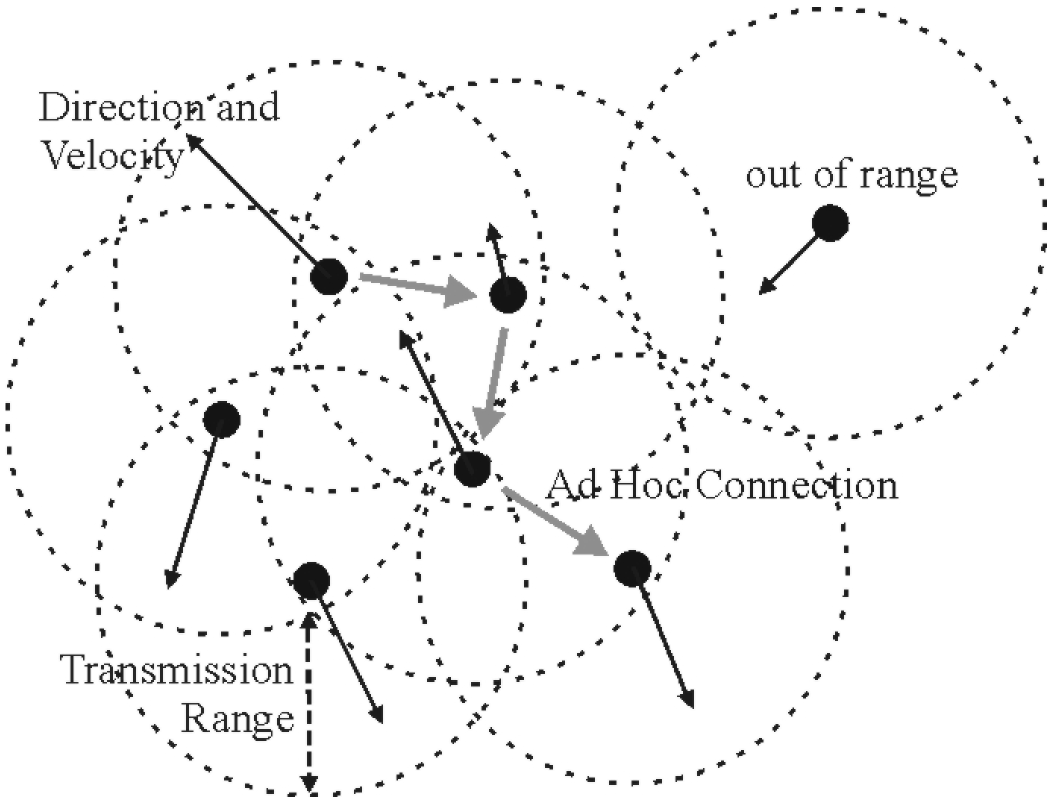
Graphics on MANET routing taken from: Nitin H. Vaidya

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Distributed Systems in Mobile Environments

- Scenario 1: Mobile Overlay Members
  - Walking user at roaming devices ...
  - Issues: Transfer personal context,
    location based context
  - Networking solution: application transparency of Mobile IP(v6)
- Scenario 2: Spontaneous Overlays in Mobile Ad-Hoc Networks
  - Collaborative application in local, mobile environments
  - Issues: Adapt to efficiency & proximity needed in Manets,
    cope with unreliable, mobile underlay networks
  - P2P Systems and Manets both void infrastructure

Ad Hoc Networks (WLAN, Bluetooth)

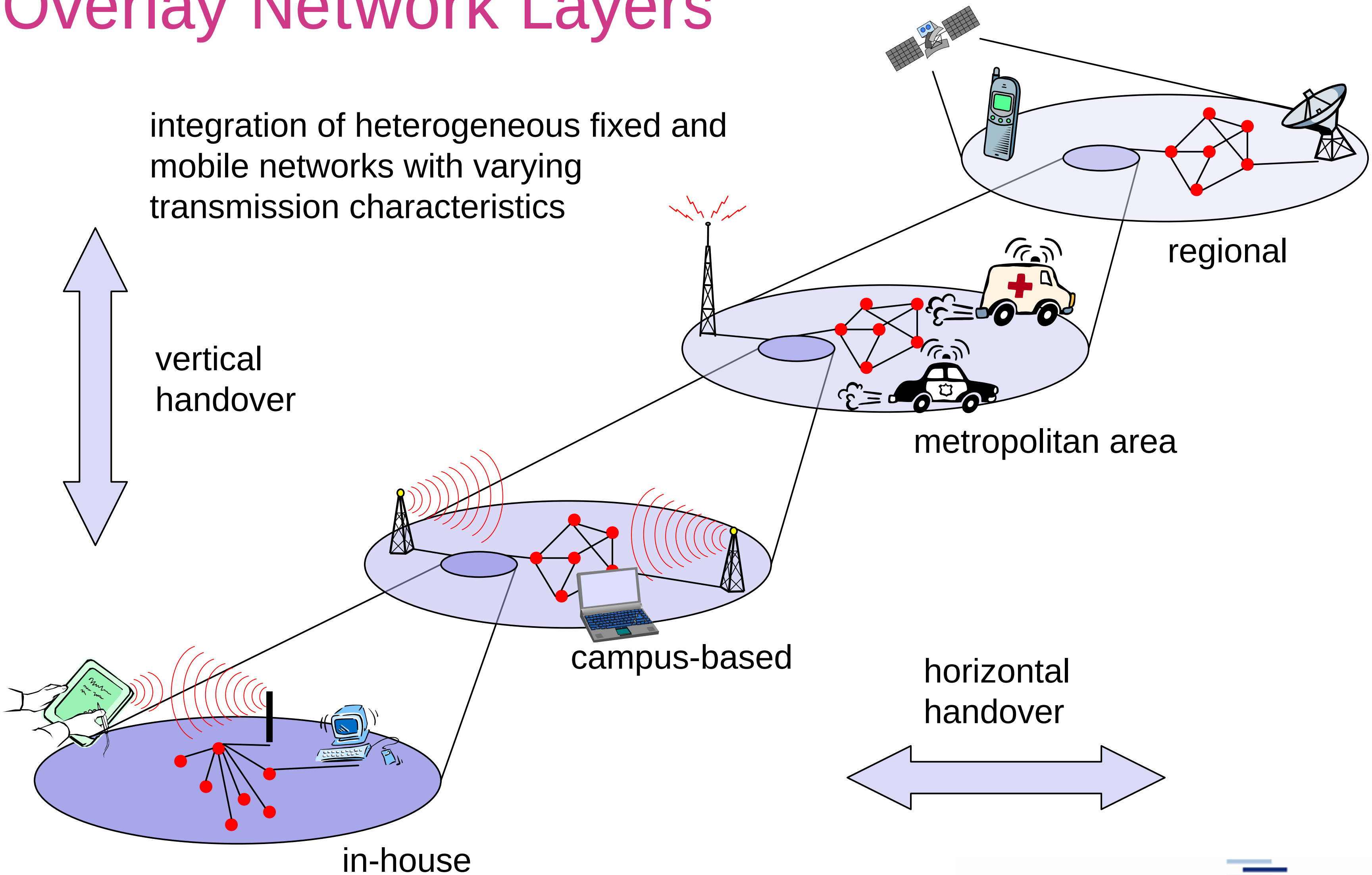


Characteristics:

- Self configuring
- Infrastructure free
- Wireless
- Unpredictable terminal mobility
- Limited radio transmission range
- Goal: provide communication between nodes

The Global View: Overlay Network Layers

integration of heterogeneous fixed and mobile networks with varying transmission characteristics



Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Application Examples

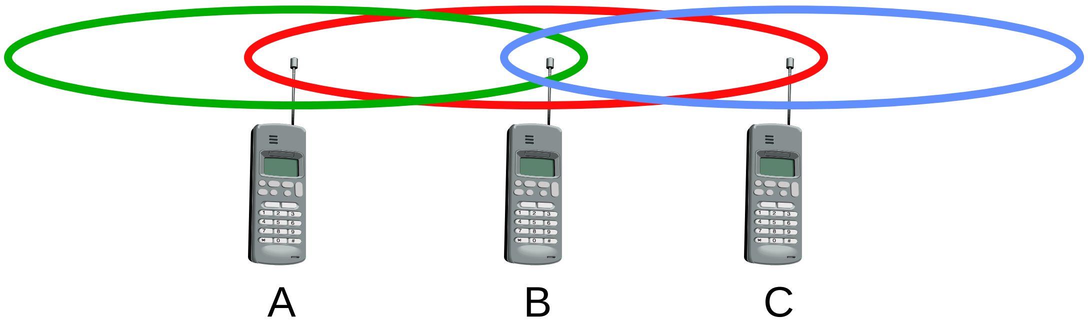
- Active Collaboration & Passive Information Dissemination
- Single & Multiple Dedications of Nodes
- Common Examples:
  - Military
  - Rescue Services
  - Regional Mesh Networks
  - Collaborative Inter-Vehicular Communication
  - Sensor Networks
  - Personal Area Networking / Local Device Networks
  - Gaming, Edu-/Info-/Sociotainment

Mobile Ad Hoc Networks

- Formed by wireless hosts which may be mobile
- Without (necessarily) using a pre-existing infrastructure
- Routes between nodes may potentially contain multiple hops
- Motivations:
  - Ease of deployment, low costs
  - Speed of deployment
  - Decreased dependence on infrastructure

Hidden and exposed terminals

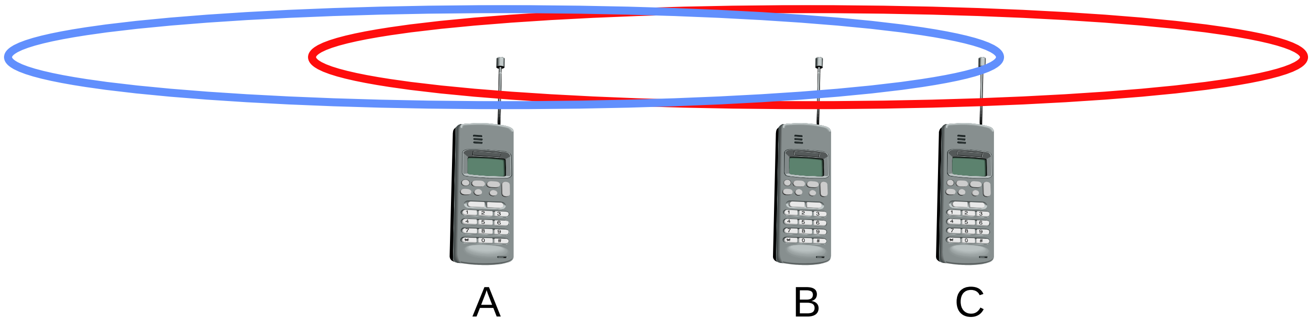
- Hidden terminals
  - A sends to B, C cannot receive A
  - C wants to send to B, C senses a “free” medium (CS fails)
  - collision at B, A cannot receive the collision (CD fails)
  - A is “hidden” for C



- Exposed terminals
  - B sends to A, C wants to send to another terminal (not A or B)
  - C has to wait, CS signals a medium in use
  - but A is outside the radio range of C, therefore waiting is not necessary
  - C is “exposed” to B

Near and far terminals

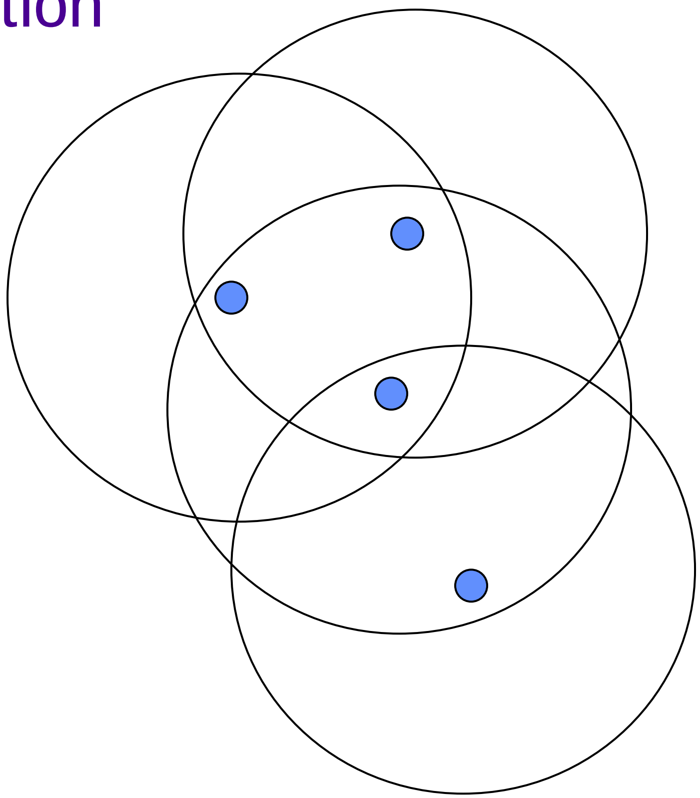
- Terminals A and B send, C receives
  - signal strength decreases proportional to the square of the distance
  - the signal of terminal B therefore drowns out A's signal
  - C cannot receive A

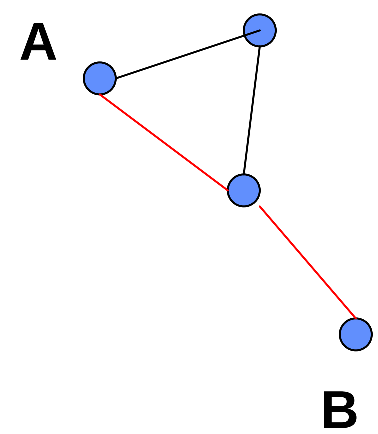


- If C for example was an arbiter for sending rights, terminal B would drown out terminal A already on the physical layer
- Also severe problem for CDMA-networks - precise power control needed!

Mobile Ad Hoc Networks

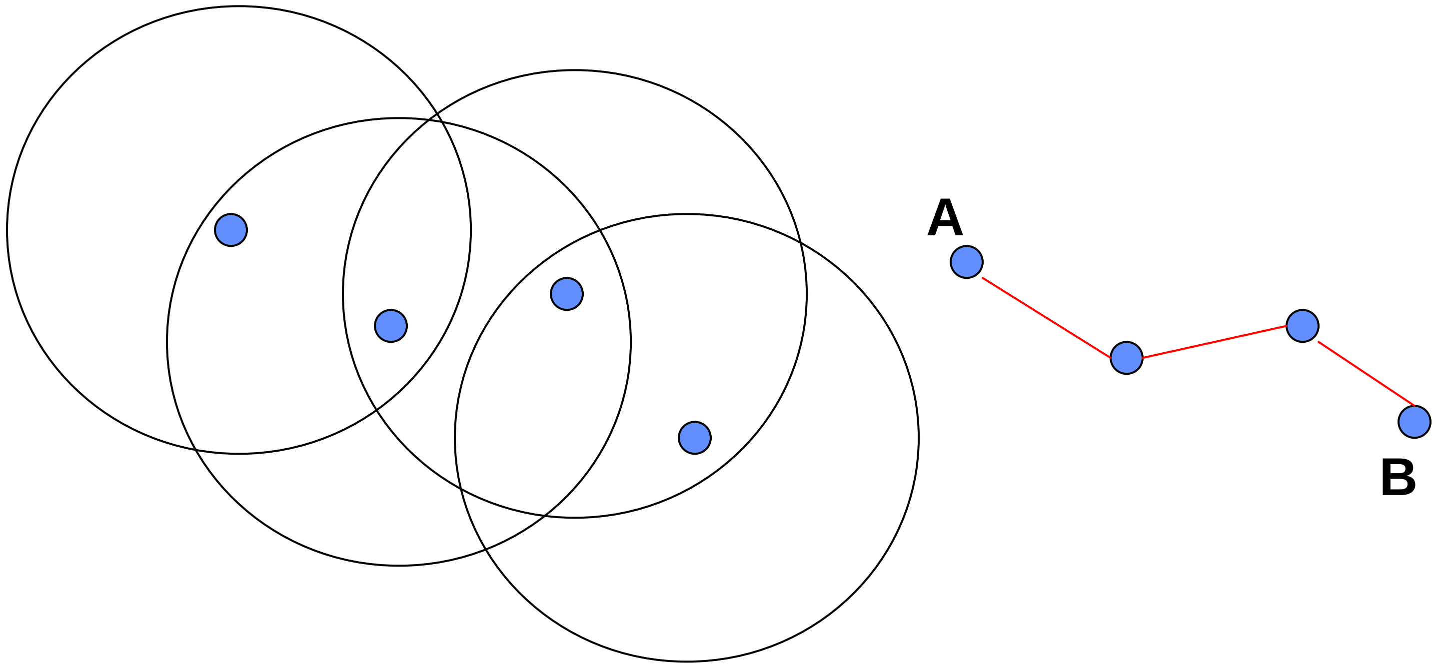
- May need to traverse multiple links to reach a destination





Mobile Ad Hoc Networks (MANET)

- Mobility causes route changes



Many Variations

- Fully Symmetric Environment
  - all nodes have identical capabilities and responsibilities
- Asymmetric Capabilities
  - transmission ranges and radios may differ (→ asymmetric links)
  - battery life at different nodes may differ
  - processing capacity may be different at different nodes
  - speed of movement
- Asymmetric Responsibilities
  - only some nodes may route packets
  - some nodes may act as leaders of nearby nodes (e.g., cluster head)
- Varying Traffic Characteristics

Unicast Routing in MANETs - Why is it different ?

- Host mobility
  - link failure/repair due to mobility may have different characteristics than those due to other causes
- Rate of link failure/repair may be high when nodes move fast
- New performance criteria may be used
  - route stability despite mobility
  - energy consumption
- Many routing protocols proposed – no universal solution

Routing Protocols

- Proactive protocols
  - Determine routes independent of traffic pattern
  - Traditional link-state and distance-vector routing protocols are proactive
- Reactive protocols
  - Maintain routes only if needed
- Hybrid protocols

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

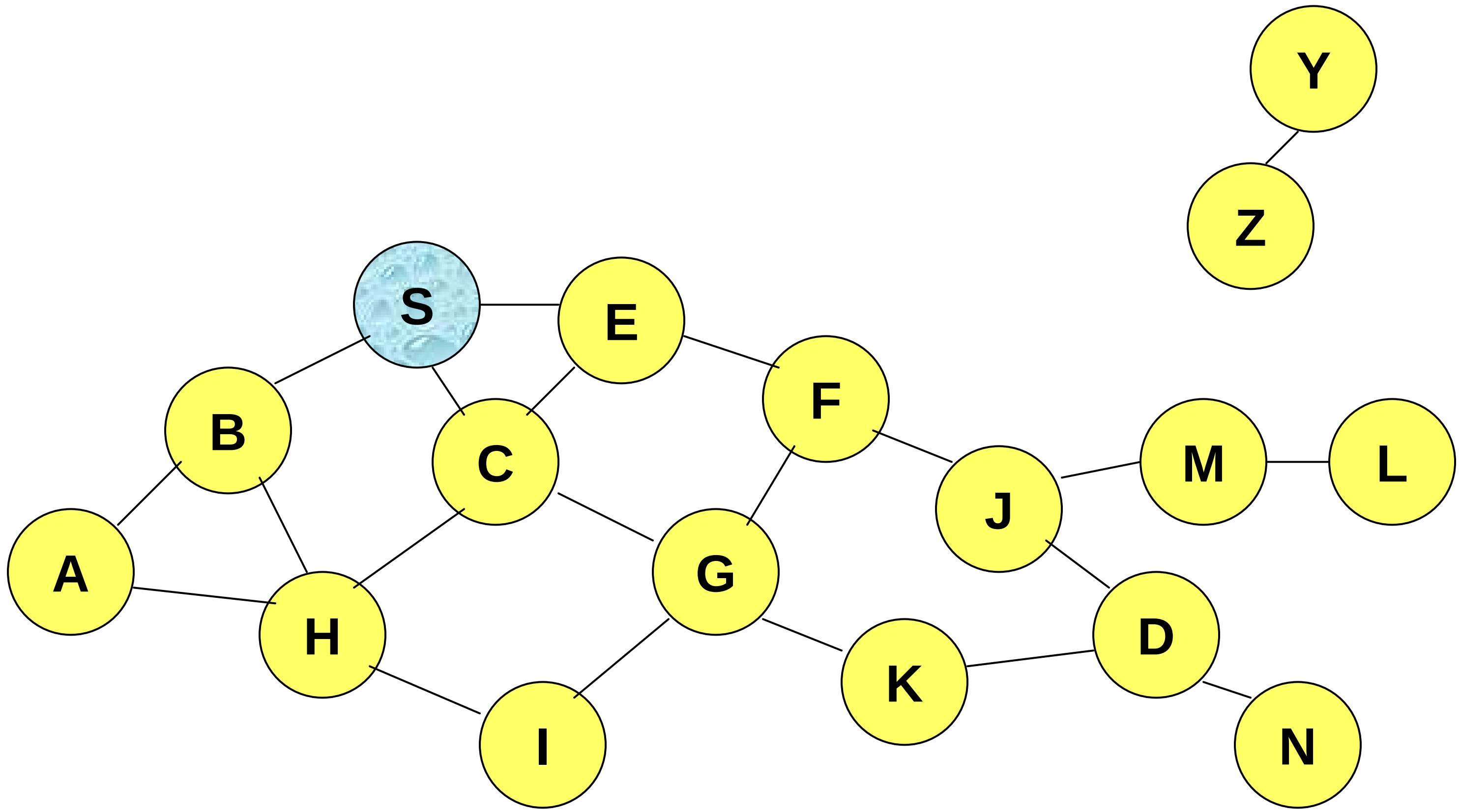
Trade-Off

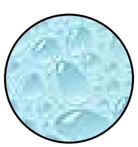
- Latency of route discovery
  - Proactive protocols may have lower latency since routes are maintained at all times
  - Reactive protocols may have higher latency because a route from X to Y will be found only when X attempts to send to Y
- Overhead of route discovery/maintenance
  - Reactive protocols may have lower overhead since routes are determined only if needed
  - Proactive protocols can (but not necessarily) result in higher overhead due to continuous route updating
- Which approach achieves a better trade-off depends on the traffic and mobility patterns

Flooding for Data Delivery

- Sender S broadcasts data packet P to all its neighbors
- Each node receiving P forwards P to its neighbors
- Sequence numbers used to avoid the possibility of forwarding the same packet more than once
- Packet P reaches destination D provided that D is reachable from sender S
- Node D does not forward the packet

Flooding for Data Delivery



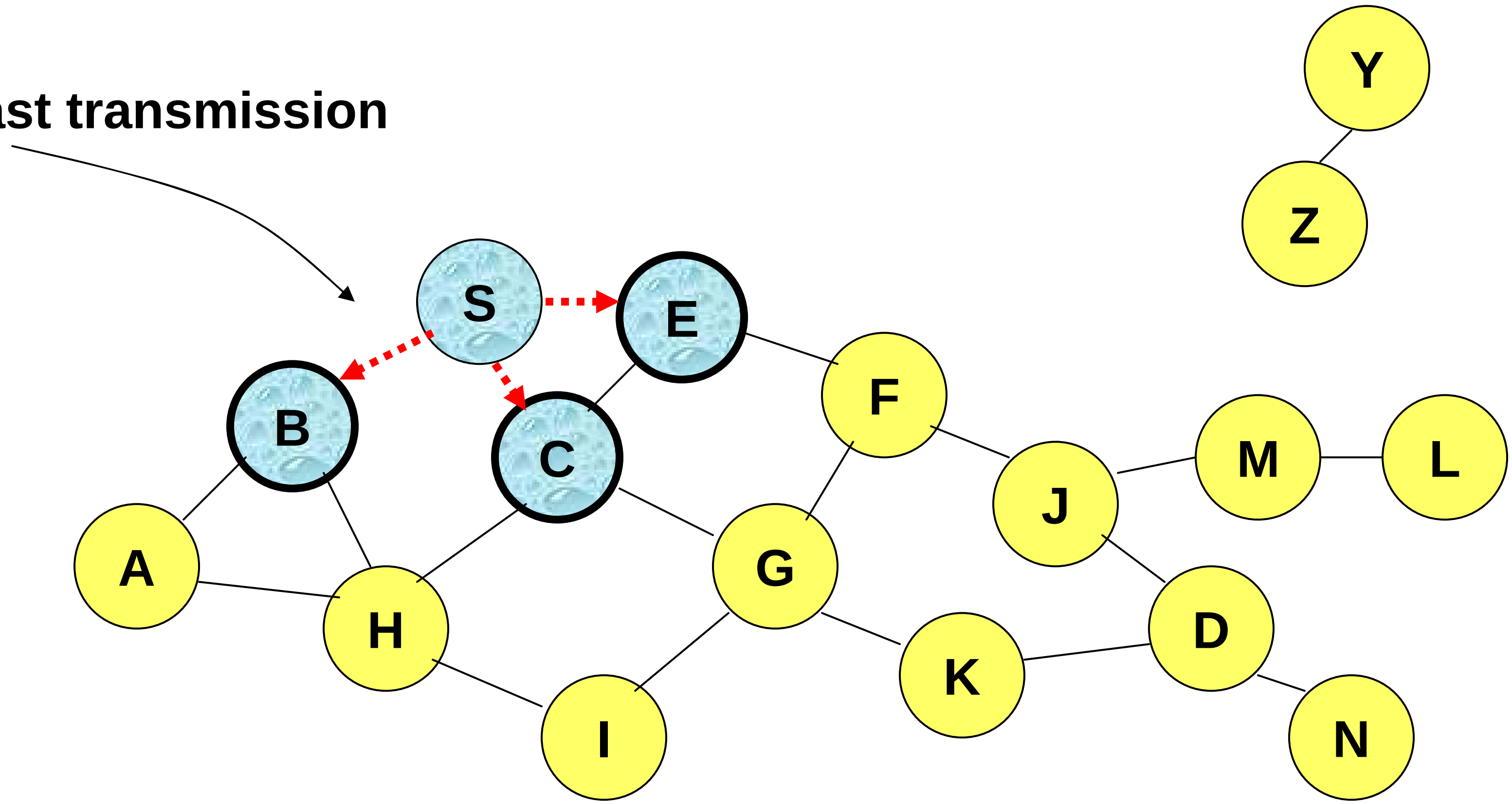


Represents a node that has received packet P

Represents that connected nodes are within each other's transmission range

Flooding for Data Delivery

Broadcast transmission

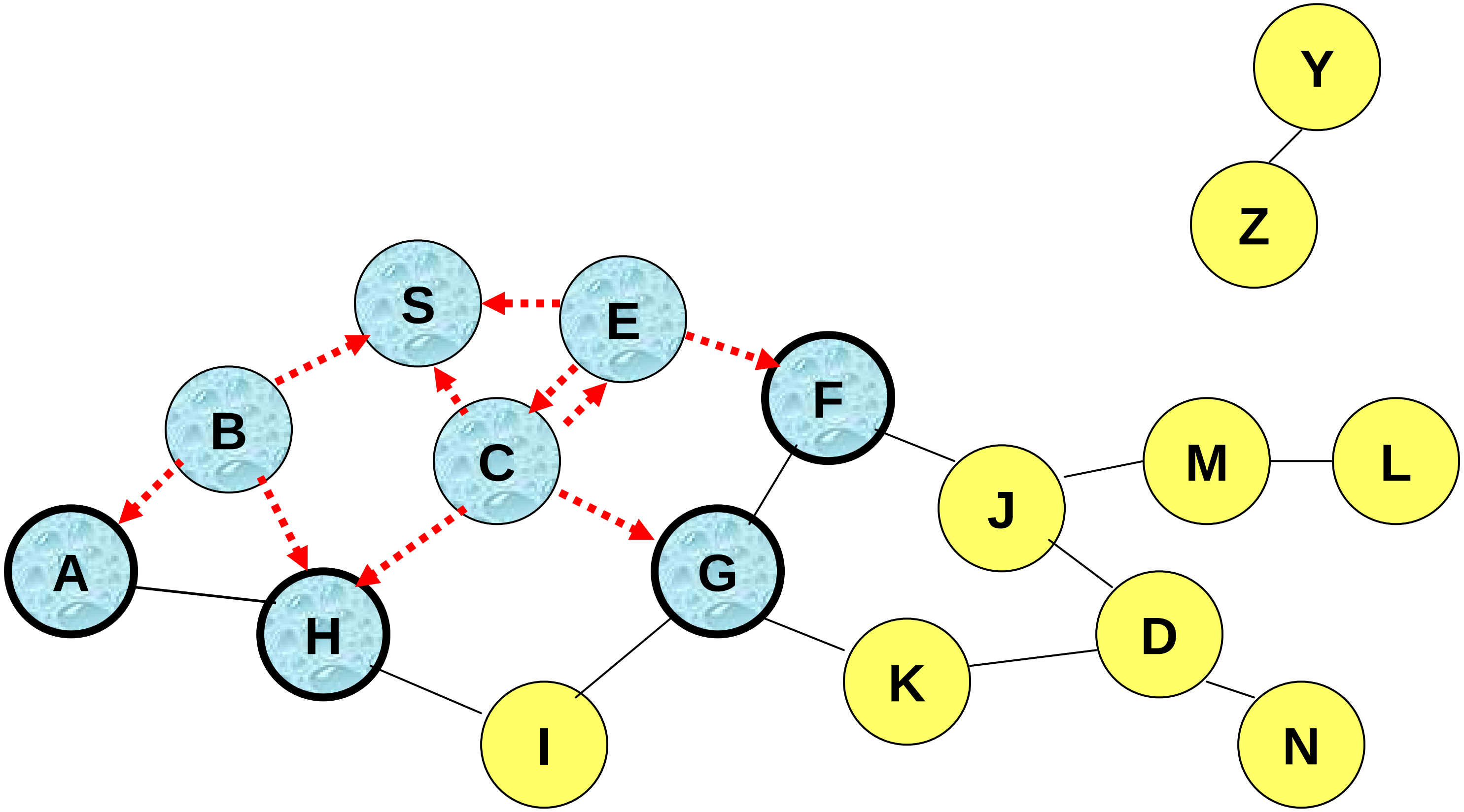


Represents a node that receives packet P for the first time

Represents transmission of packet P

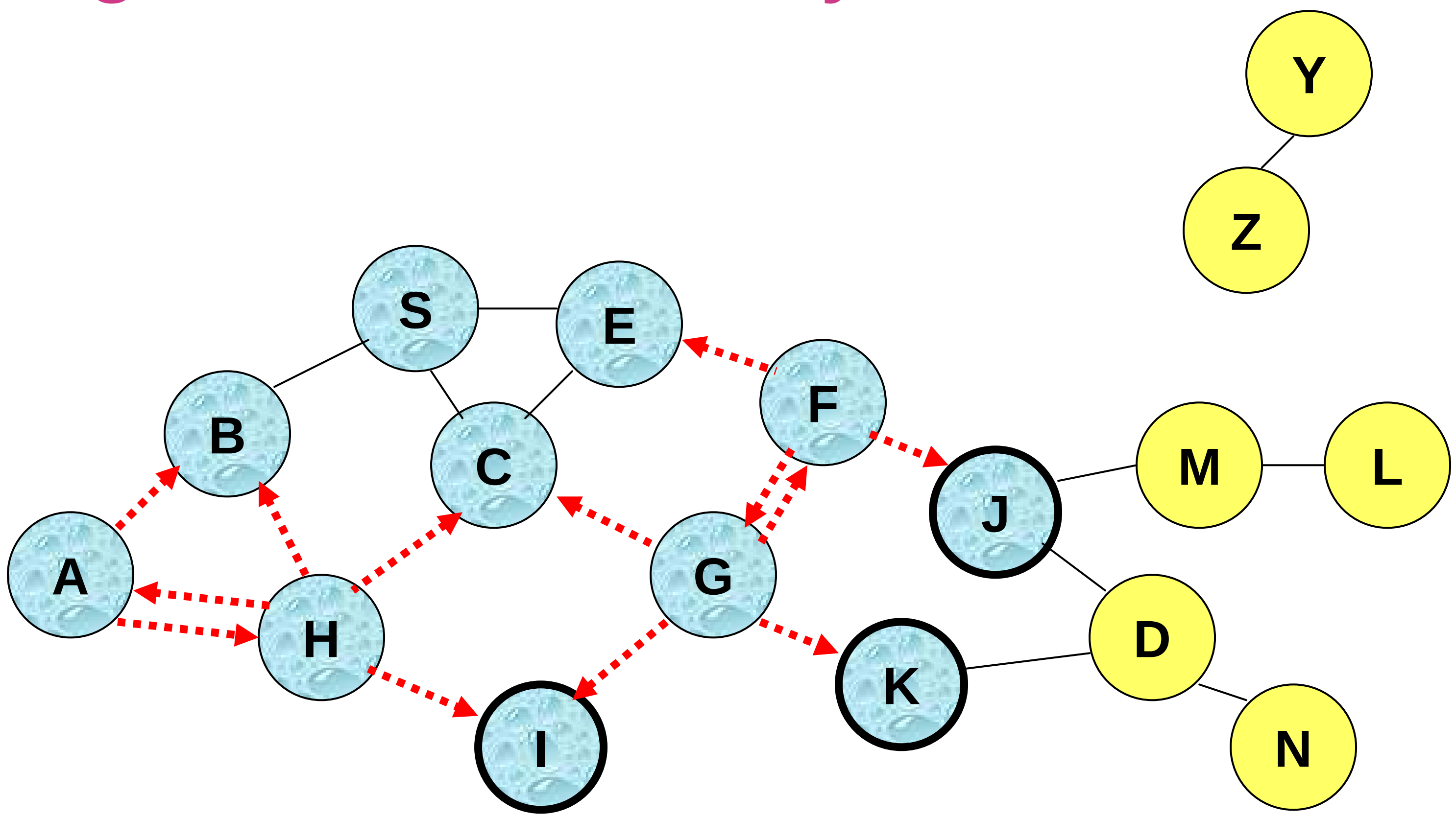
Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Flooding for Data Delivery



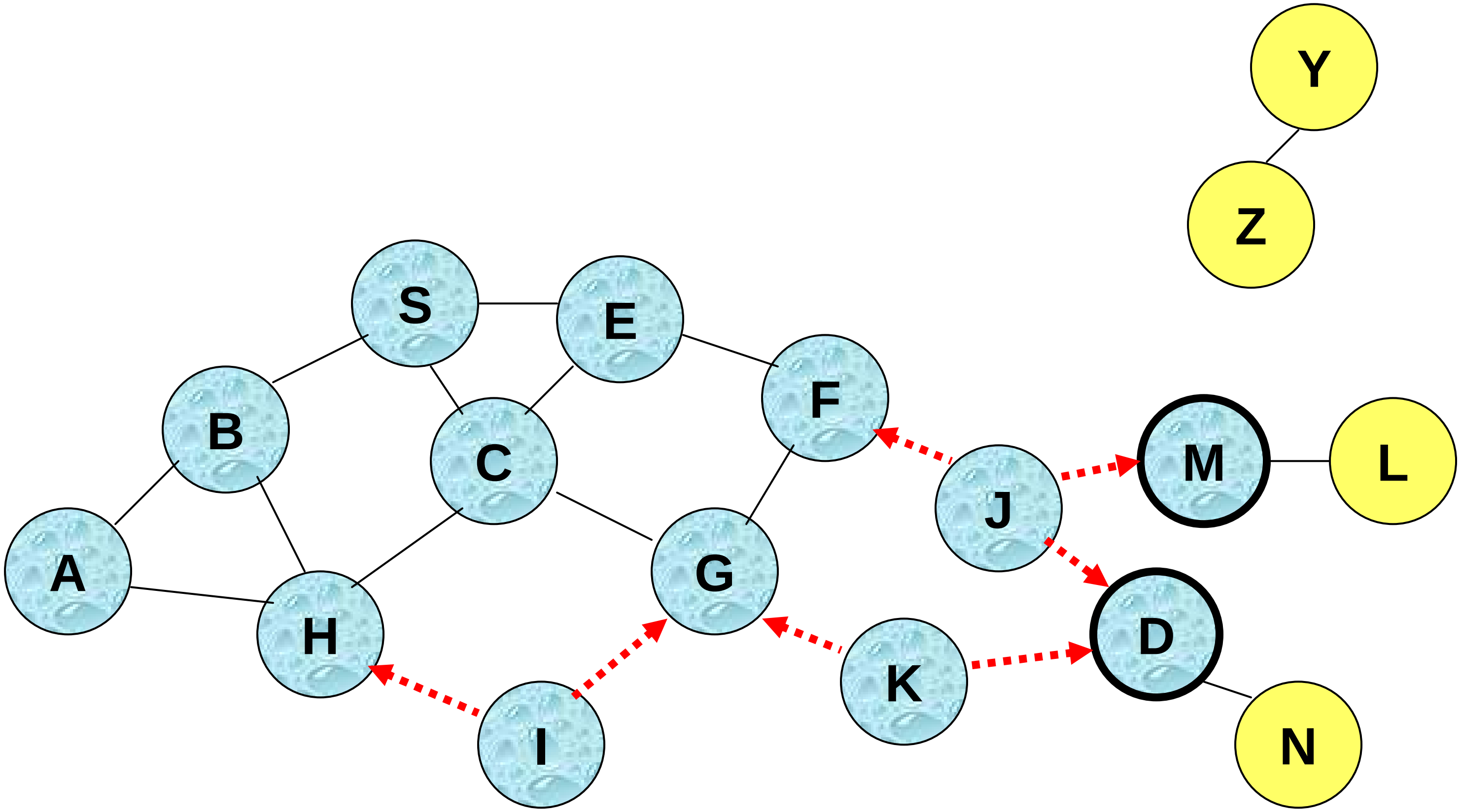
- **Node H receives packet P from two neighbors:**
  potential for collision

Flooding for Data Delivery



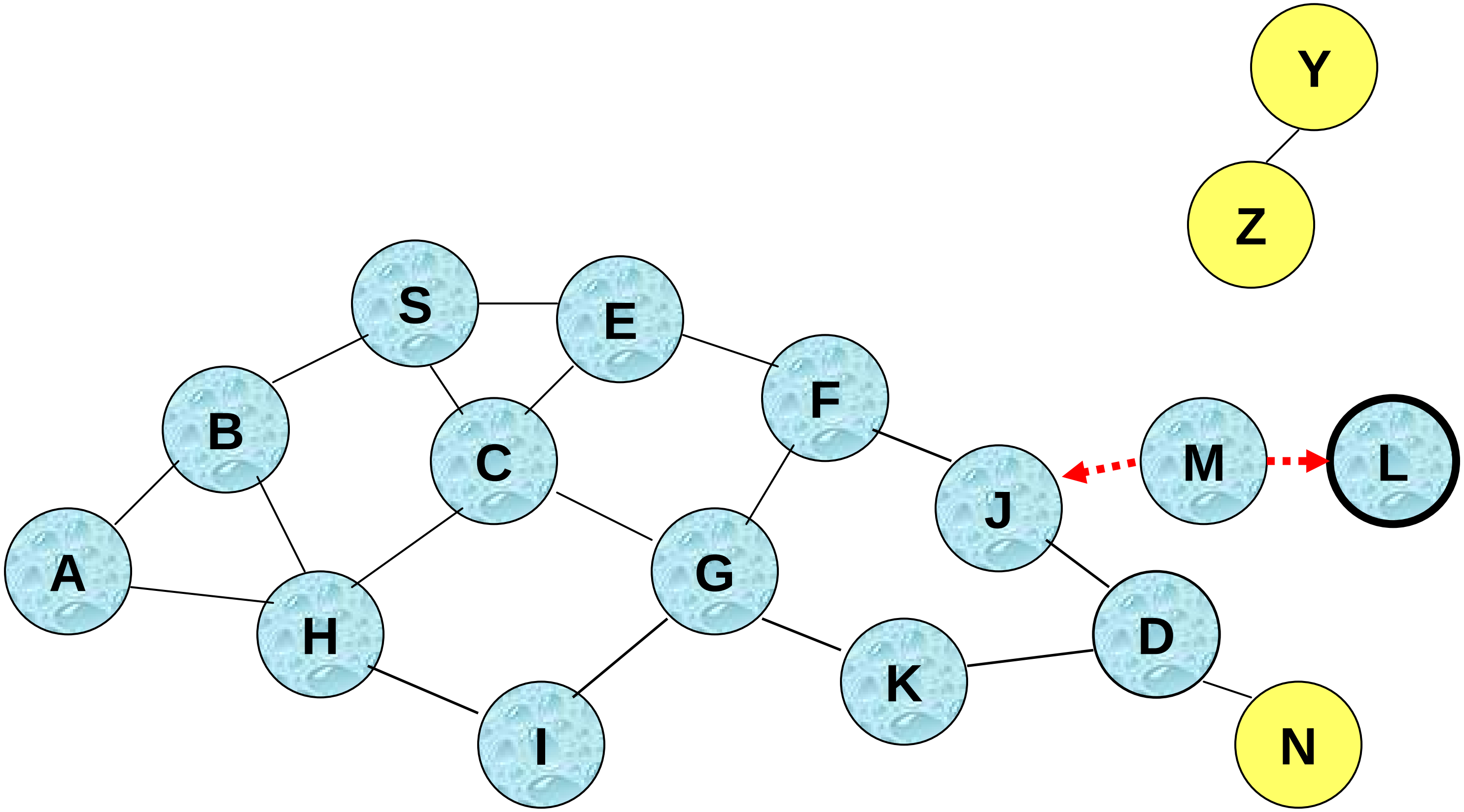
- Node C receives packet P from G and H, but does not forward it again, because node C has already forwarded packet P once

Flooding for Data Delivery



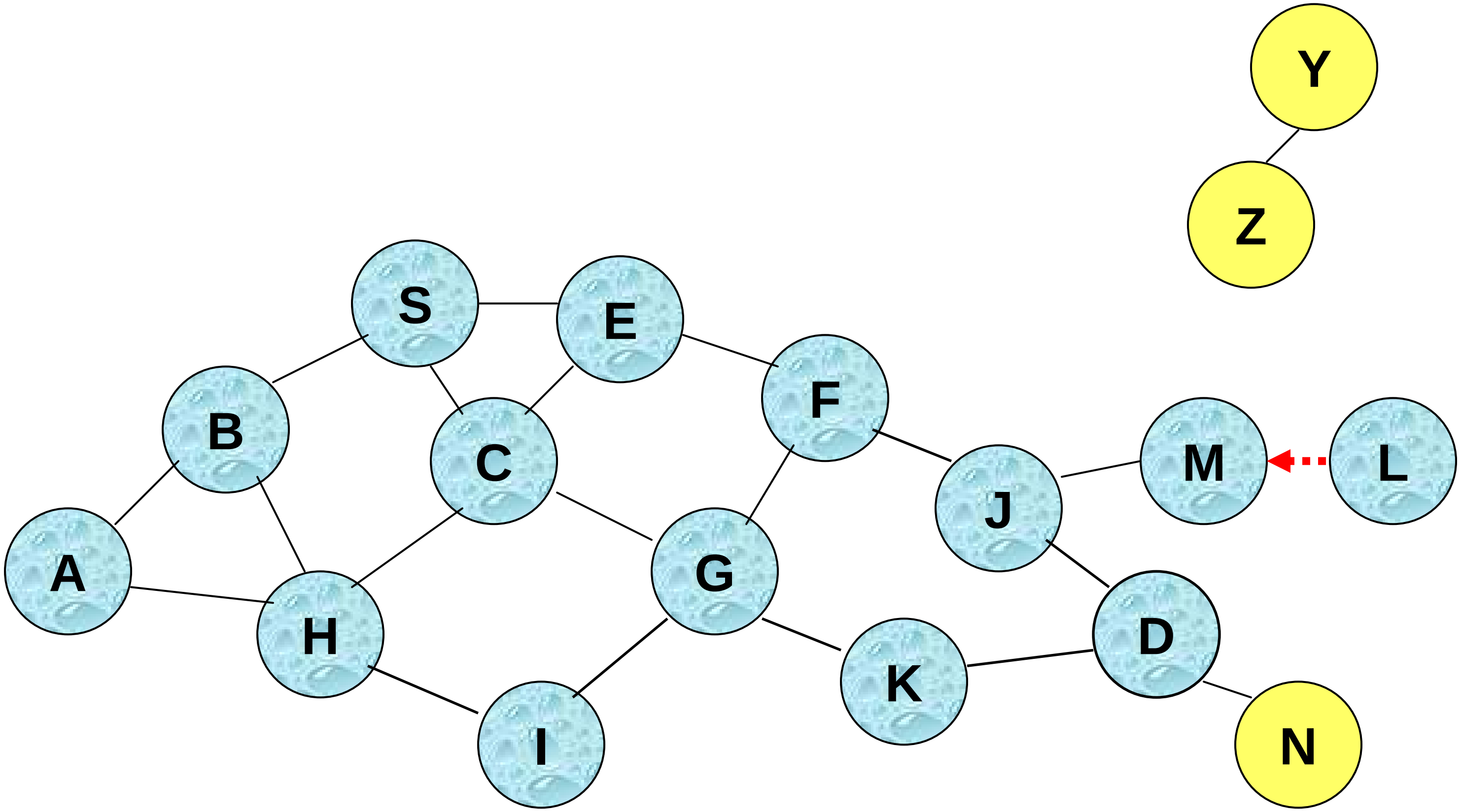
- Nodes J and K both broadcast packet P to node D
- Since nodes J and K are hidden from each other, their transmissions may collide
  => Packet P may not be delivered to node D at all, despite the use of flooding

Flooding for Data Delivery



- **Node D does not forward packet P, because node D is the intended destination of packet P**

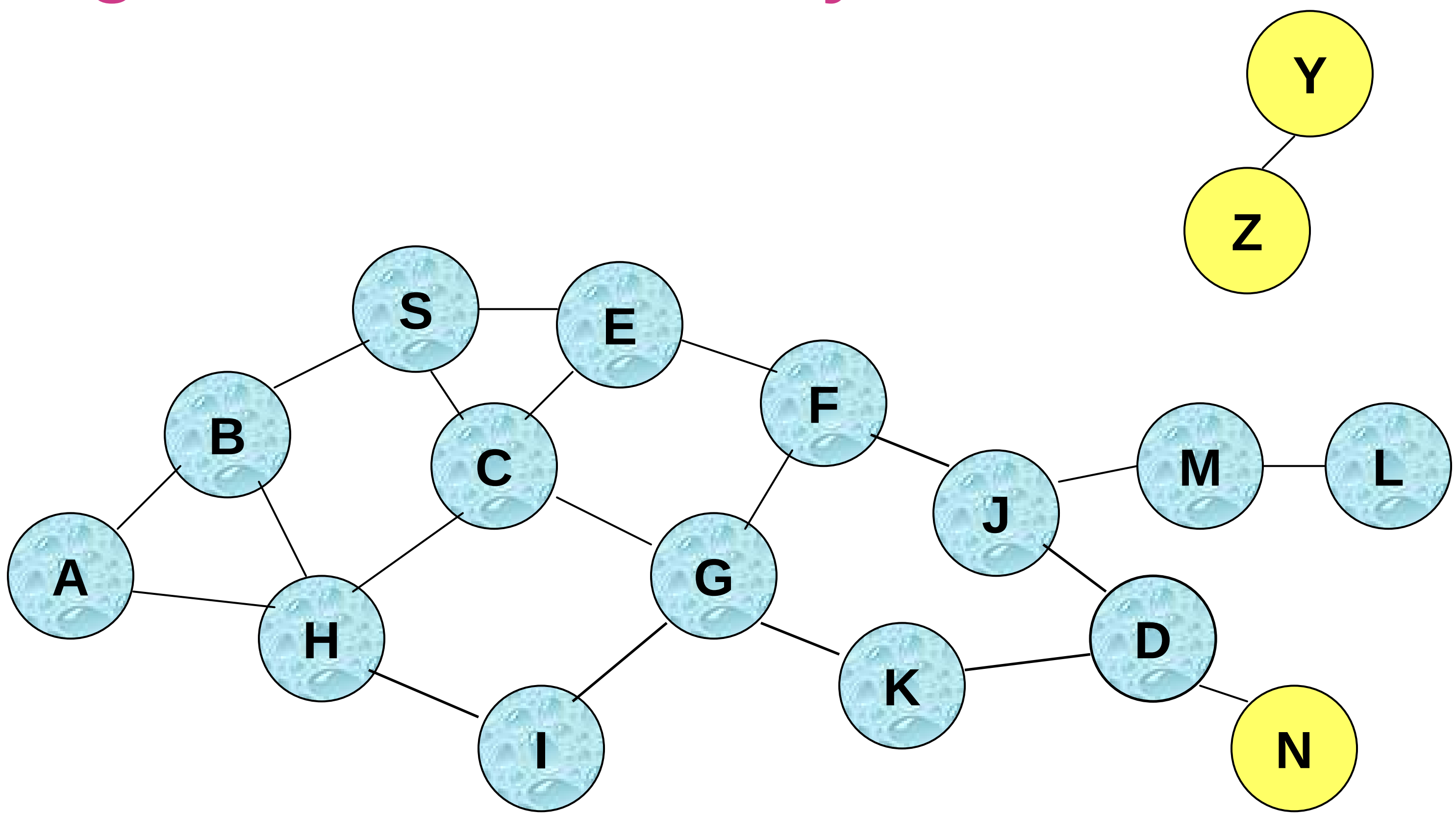
Flooding for Data Delivery



- Flooding completed
- Nodes unreachable from S do not receive packet P (e.g., node Z)
- Nodes for which all paths from S go through the destination D also do not receive packet P (example: node N)

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Flooding for Data Delivery



- **Flooding may deliver packets to too many nodes (in the worst case, all nodes reachable from sender may receive the packet)**

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Flooding for Data Delivery: Advantages

- Simplicity
- May be more efficient than other protocols when rate of information transmission is low enough that the overhead of explicit route discovery/maintenance incurred by other protocols is relatively higher
  - this scenario may occur, for instance, when nodes transmit small data packets relatively infrequently, and many topology changes occur between consecutive packet transmissions
- Potentially higher reliability of data delivery
  - Because packets may be delivered to the destination on multiple paths

Flooding for Data Delivery: Disadvantages

- Potentially, very high overhead
  - Data packets may be delivered to too many nodes who do not need to receive them
- Potentially lower reliability of data delivery
  - Flooding uses broadcasting -- hard to implement reliable broadcast delivery without significantly increasing overhead
    - Broadcasting in IEEE 802.11 MAC is unreliable
  - In our example, nodes J and K may transmit to node D simultaneously, resulting in loss of the packet
    - in this case, destination would not receive the packet at all

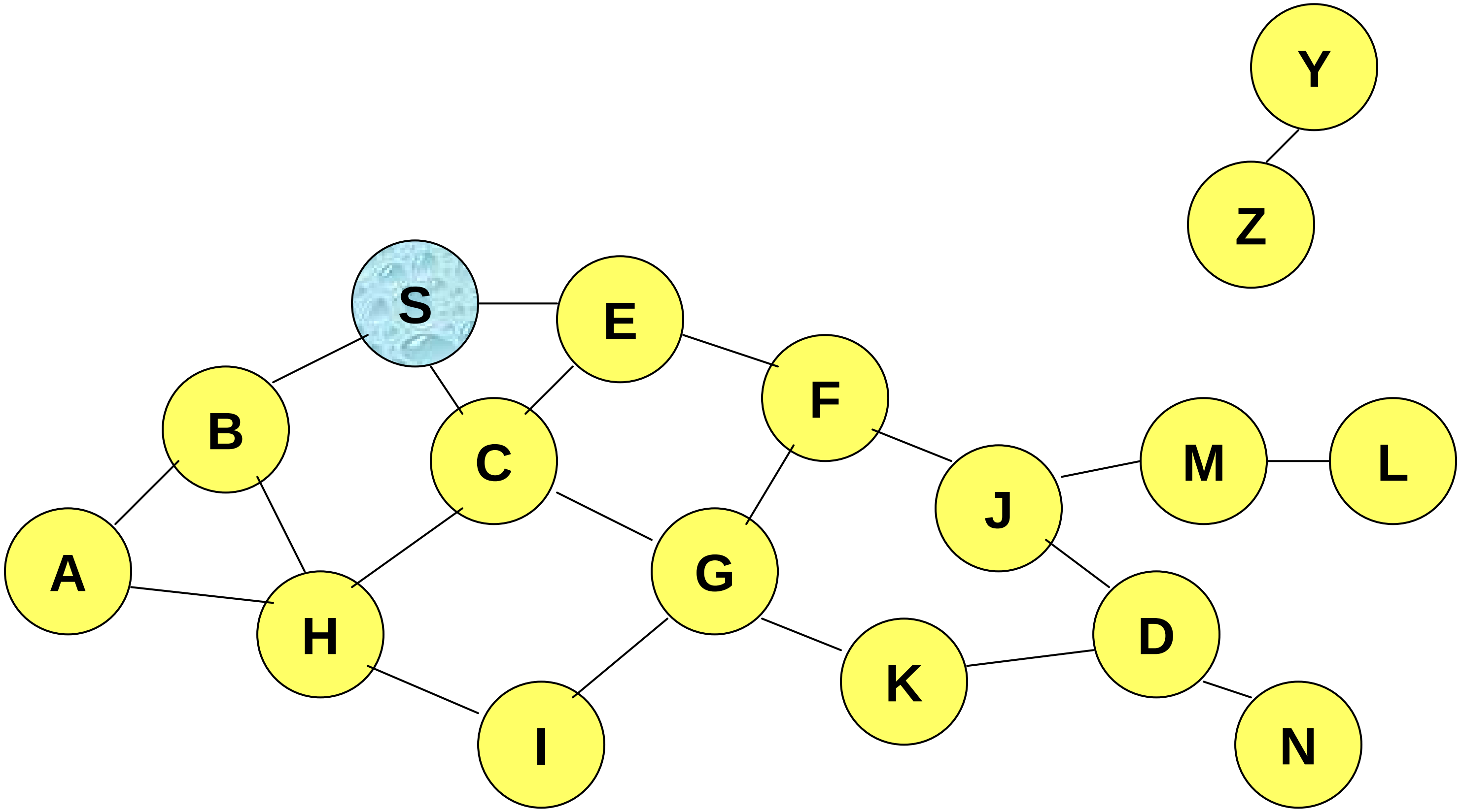
Flooding of Control Packets

- Many protocols perform (potentially *limited*) flooding of control packets, instead of data packets
- The control packets are used to discover routes
- Discovered routes are subsequently used to send data packet(s)
- Overhead of control packet flooding is amortized over data packets transmitted between consecutive control packet floods

Dynamic Source Routing (DSR) [Johnson96]

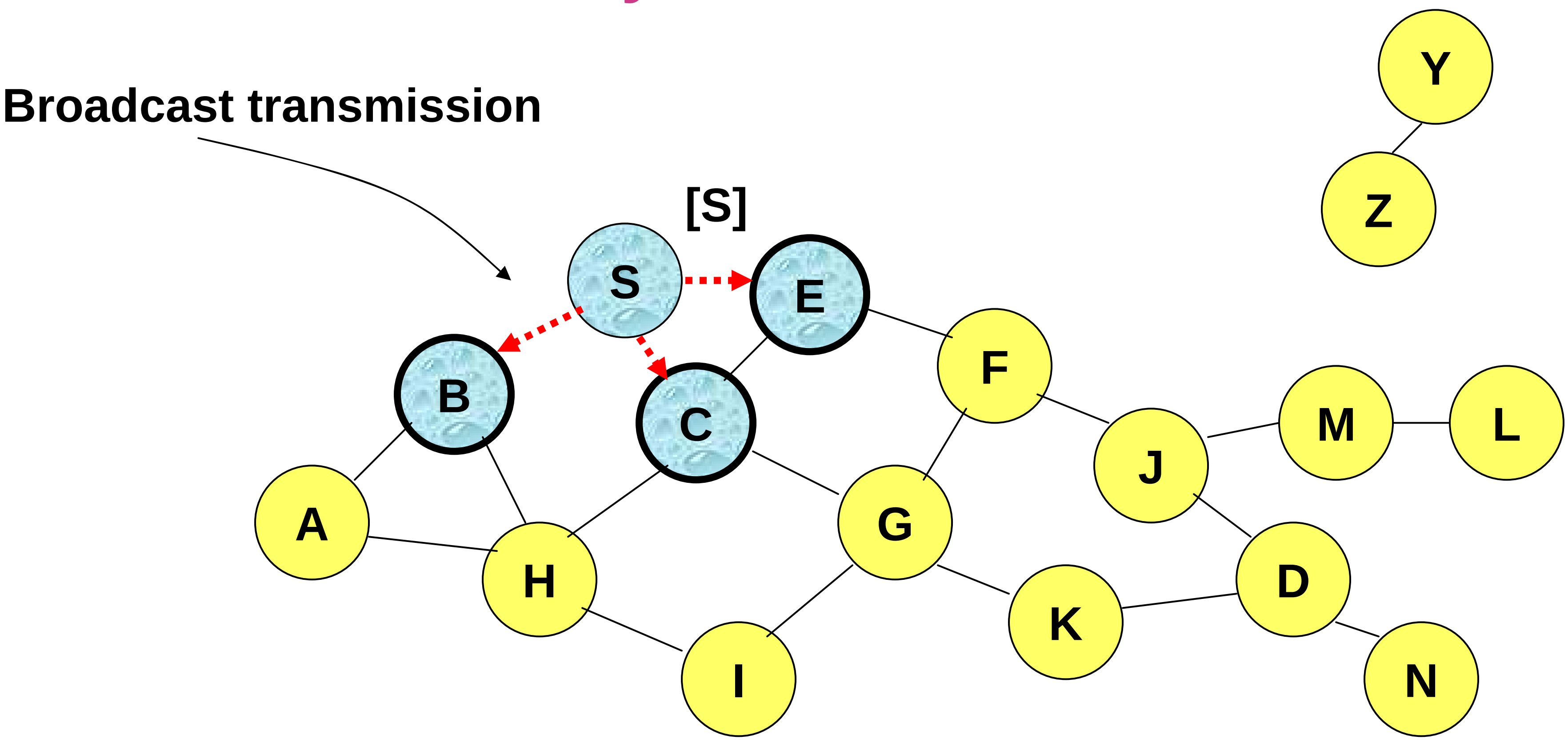
- When node S wants to send a packet to node D, but does not know a route to D, node S initiates a route discovery
- Source node S floods Route Request (RREQ)
- Each node appends own identifier when forwarding RREQ

Route Discovery in DSR



Represents a node that has received RREQ for D from S

Route Discovery in DSR

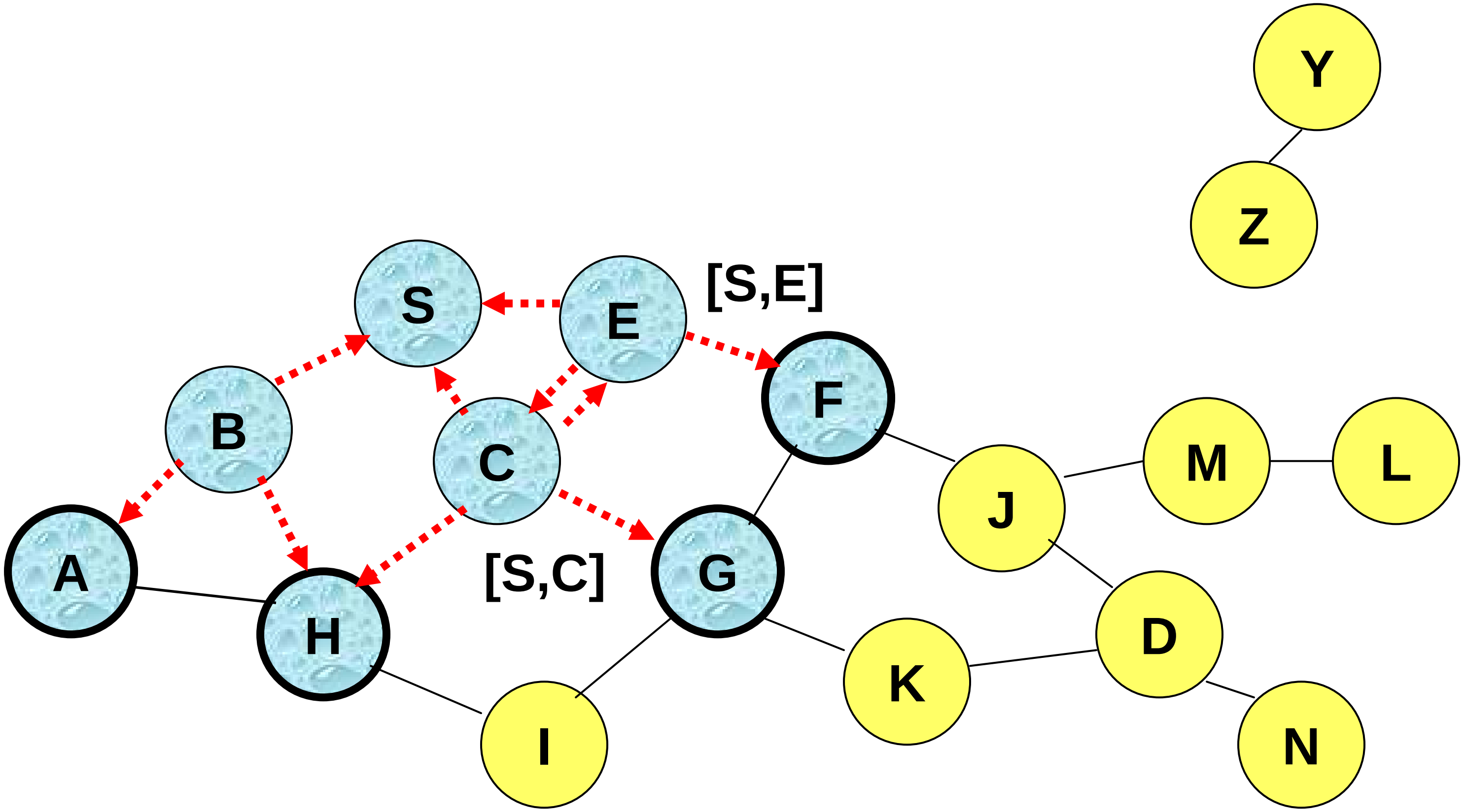


Represents transmission of RREQ

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

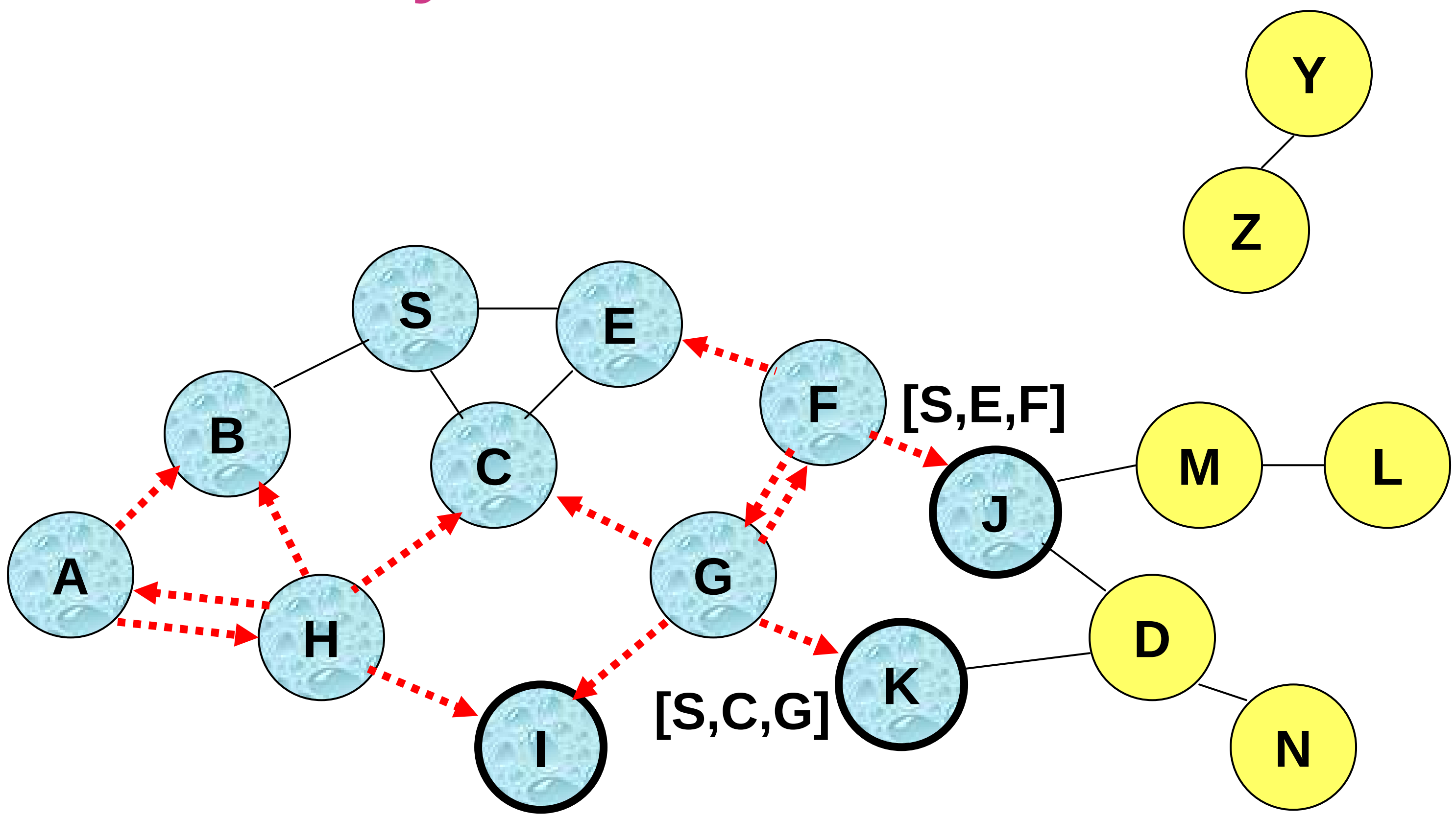
Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Route Discovery in DSR



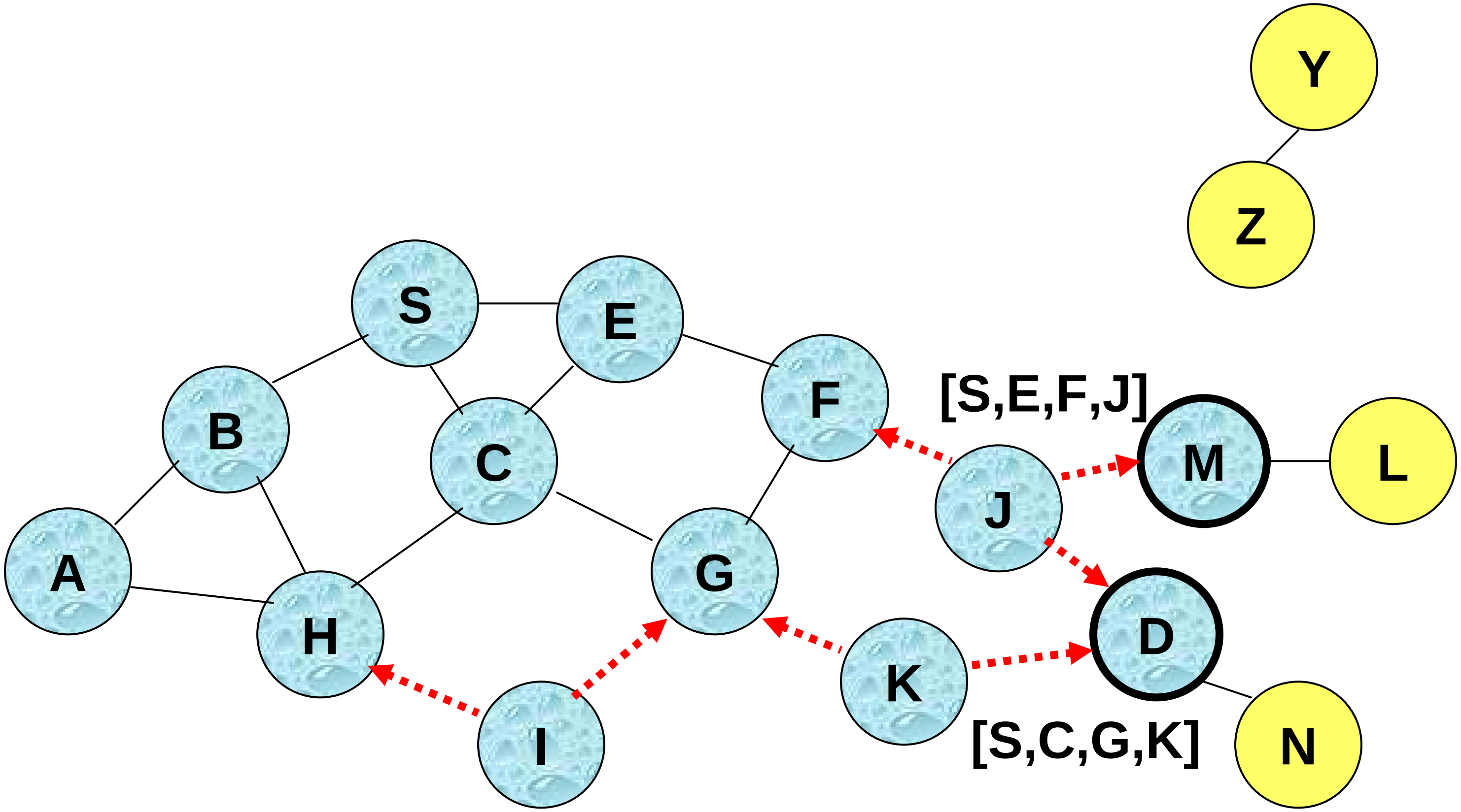
- **Node H receives packet RREQ from two neighbors:** **potential for collision**

Route Discovery in DSR



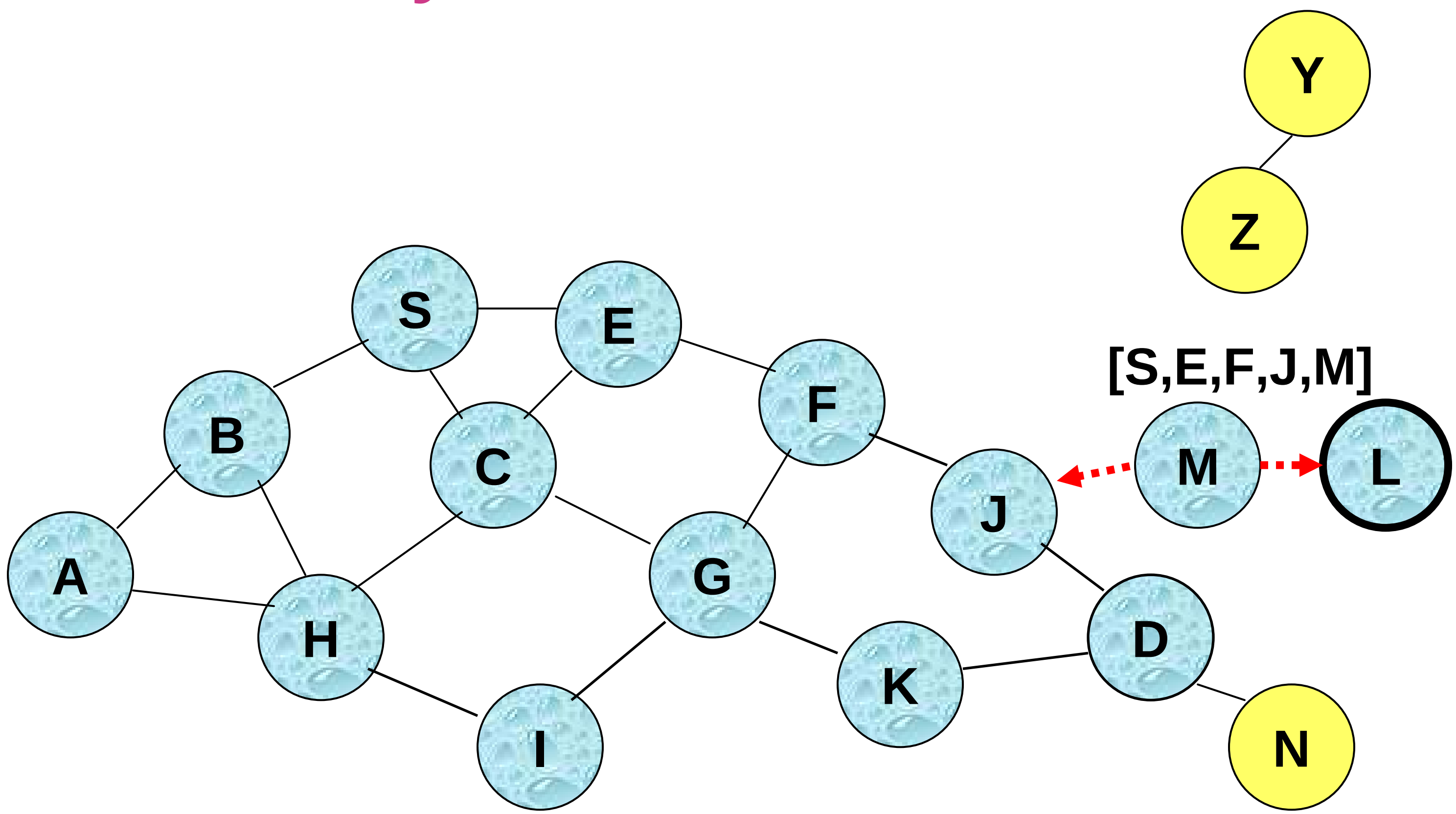
- Node C receives RREQ from G and H, but does not forward it again, because node C has already forwarded RREQ once

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**

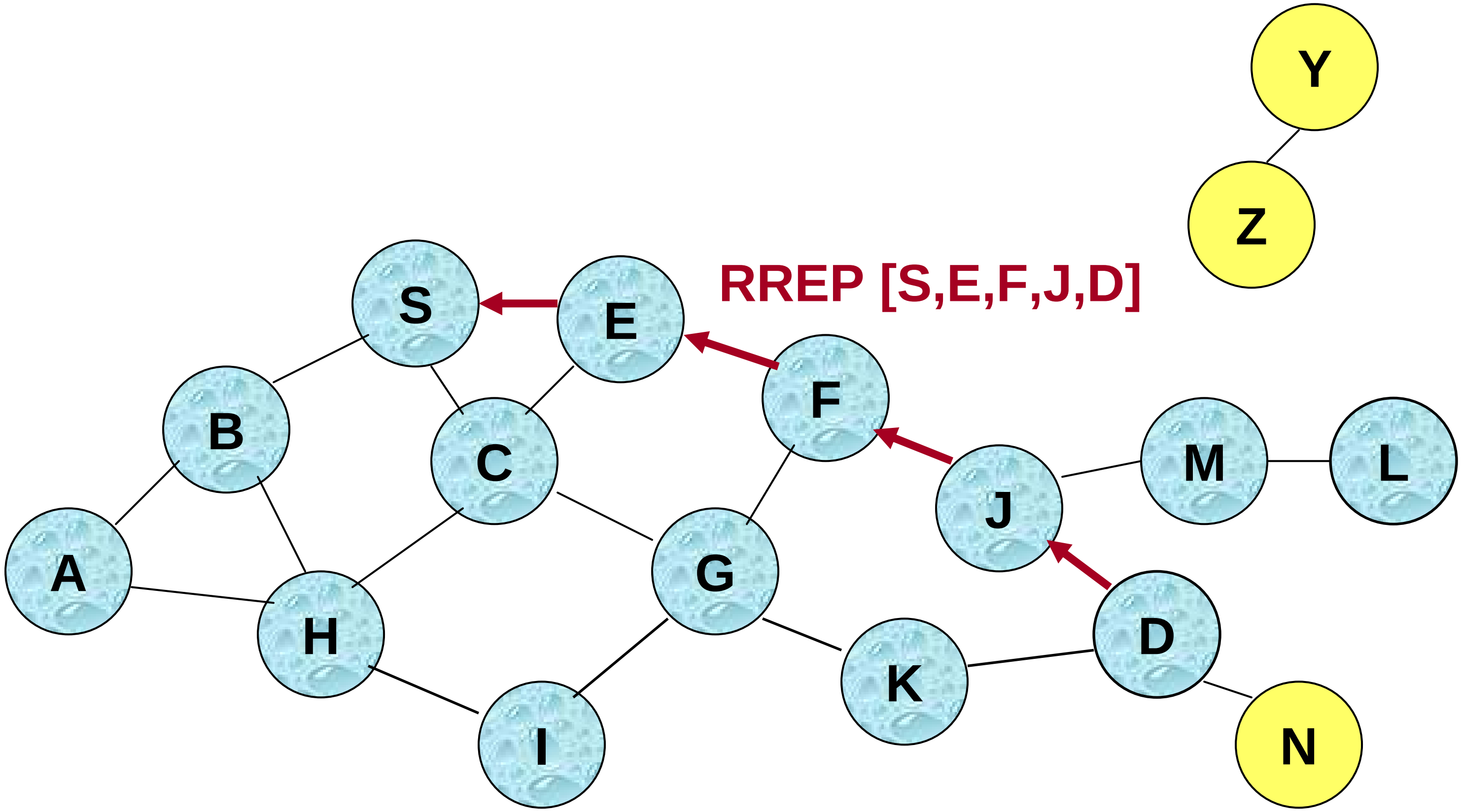
Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

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

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Route Reply in DSR



Represents RREP control message

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

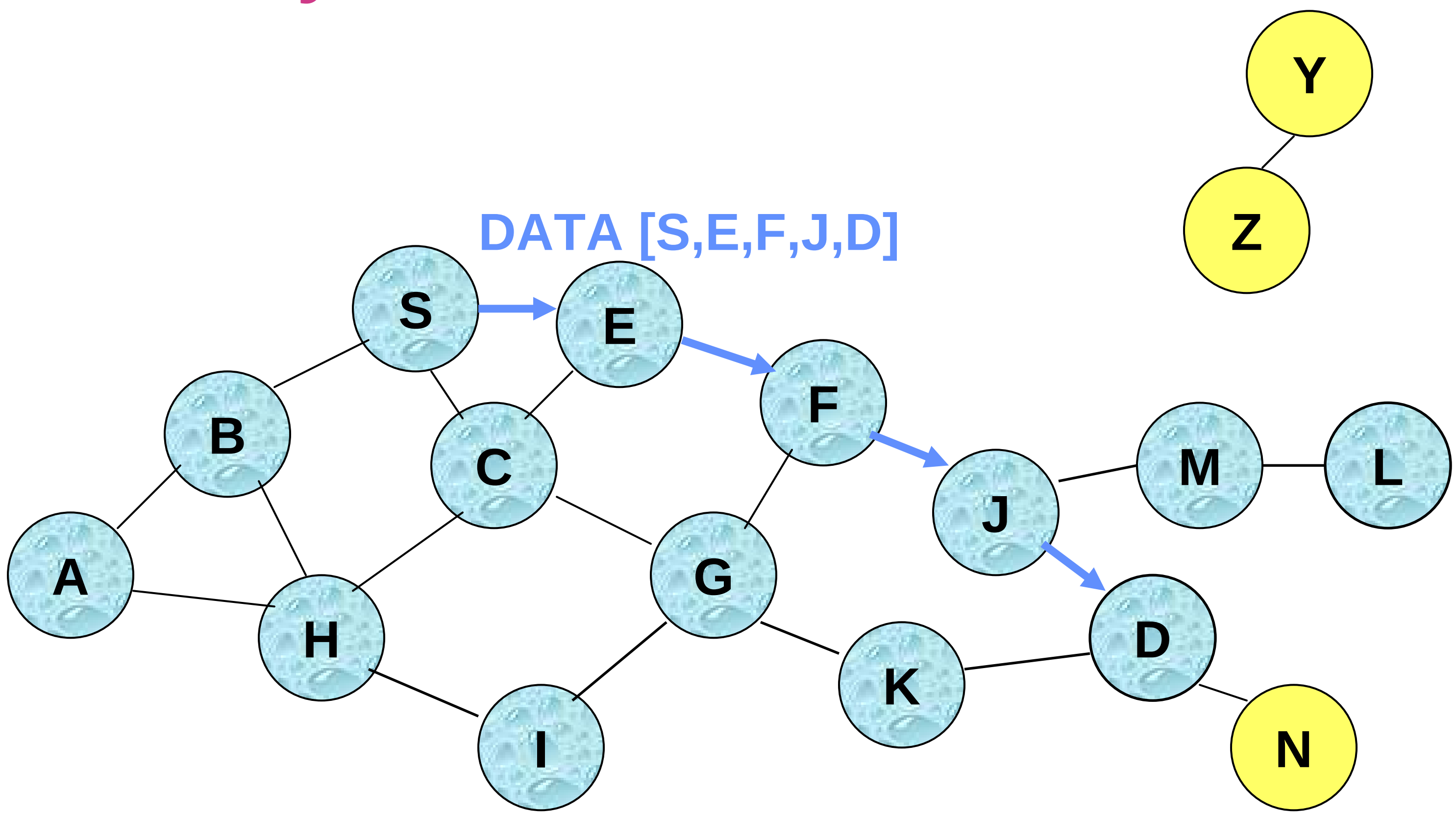
Route Reply in DSR

- Route Reply can be sent by reversing the route in Route Request (RREQ) only if links are guaranteed to be bi-directional
  - To ensure this, RREQ should be forwarded only if it received on a link that is known to be bi-directional
- If unidirectional (asymmetric) links are allowed, then RREP may need a route discovery for S from node D
  - Unless node D already knows a route to node S
  - If a route discovery is initiated by D for a route to S, then the Route Reply is piggybacked on the Route Request from D.
- If IEEE 802.11 MAC is used to send data, then links have to be bi-directional (since Ack is used)

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

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
- Care must be taken to avoid 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
  - Reply storm may be eased by preventing a node from sending RREP if it hears another RREP with a shorter route

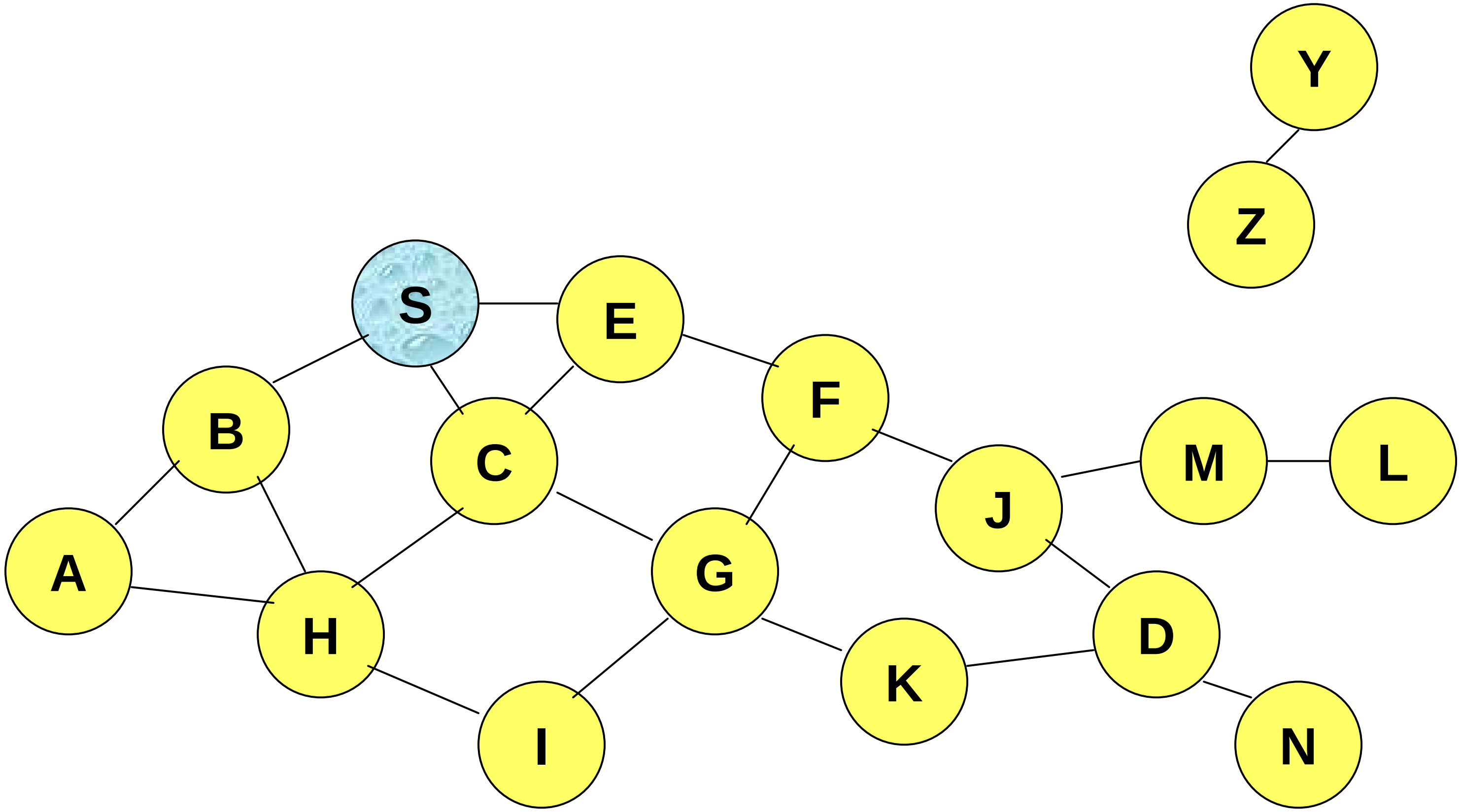
Ad Hoc On-Demand Distance Vector Routing (AODV) [Perkins99Wmcsa]

- 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

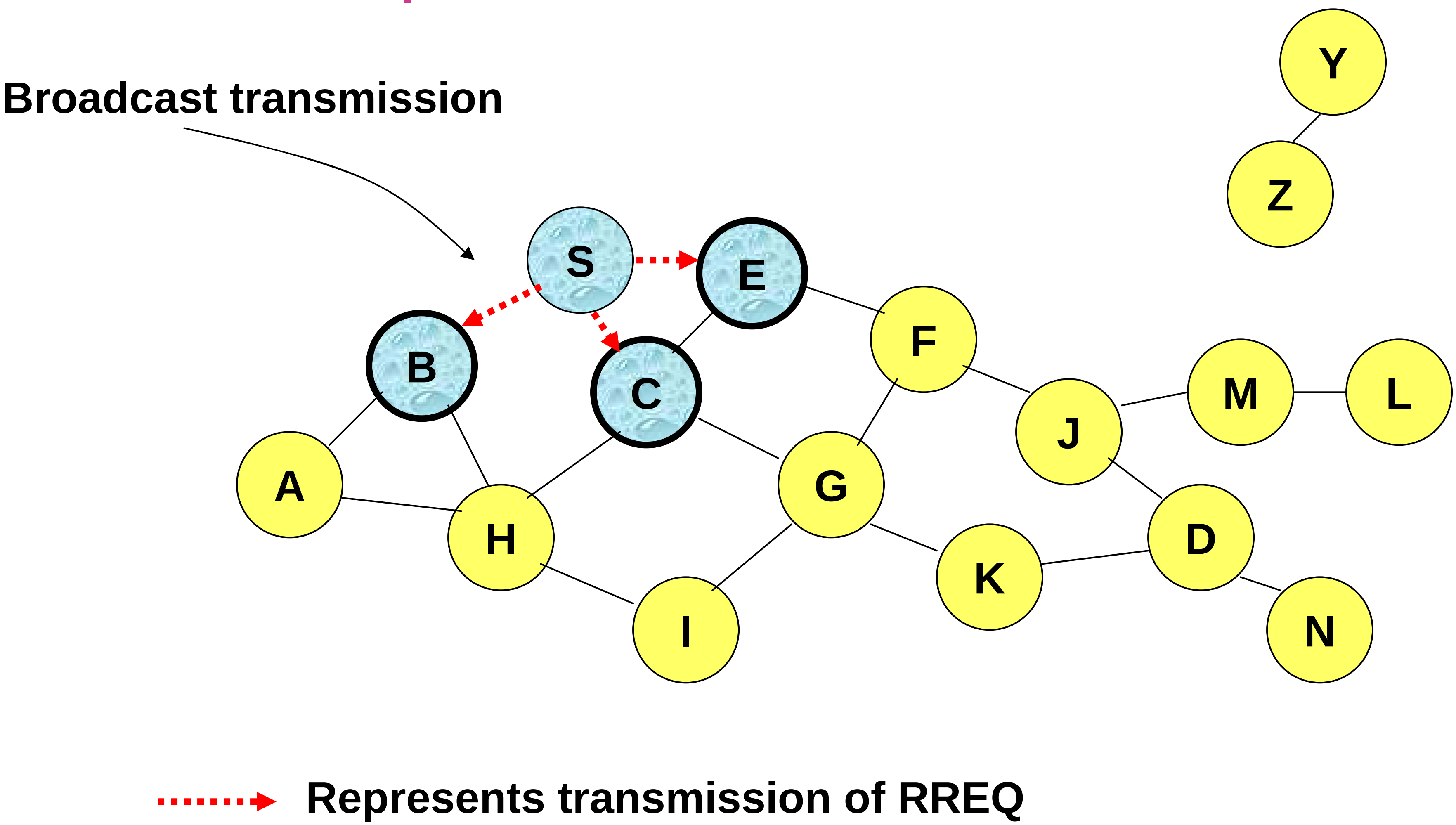
- Route Requests (RREQ) are forwarded in a manner similar to DSR
- When a node re-broadcasts a Route Request, it sets up a reverse path pointing towards the source
  - AODV assumes symmetric (bi-directional) links
- When the intended destination receives a Route Request, it replies by sending a Route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

Route Requests in AODV

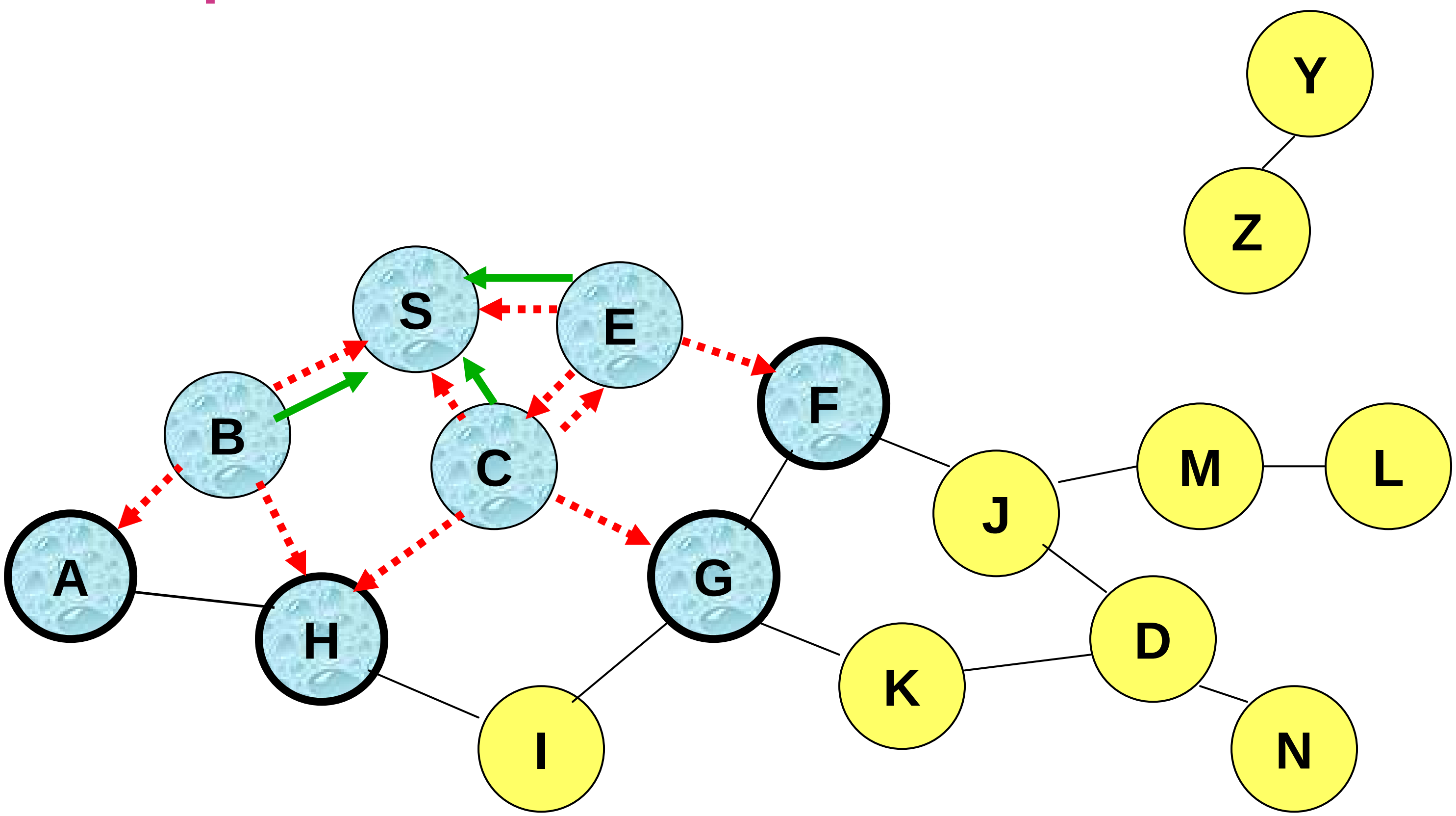


Represents a node that has received RREQ for D from S

Route Requests in AODV



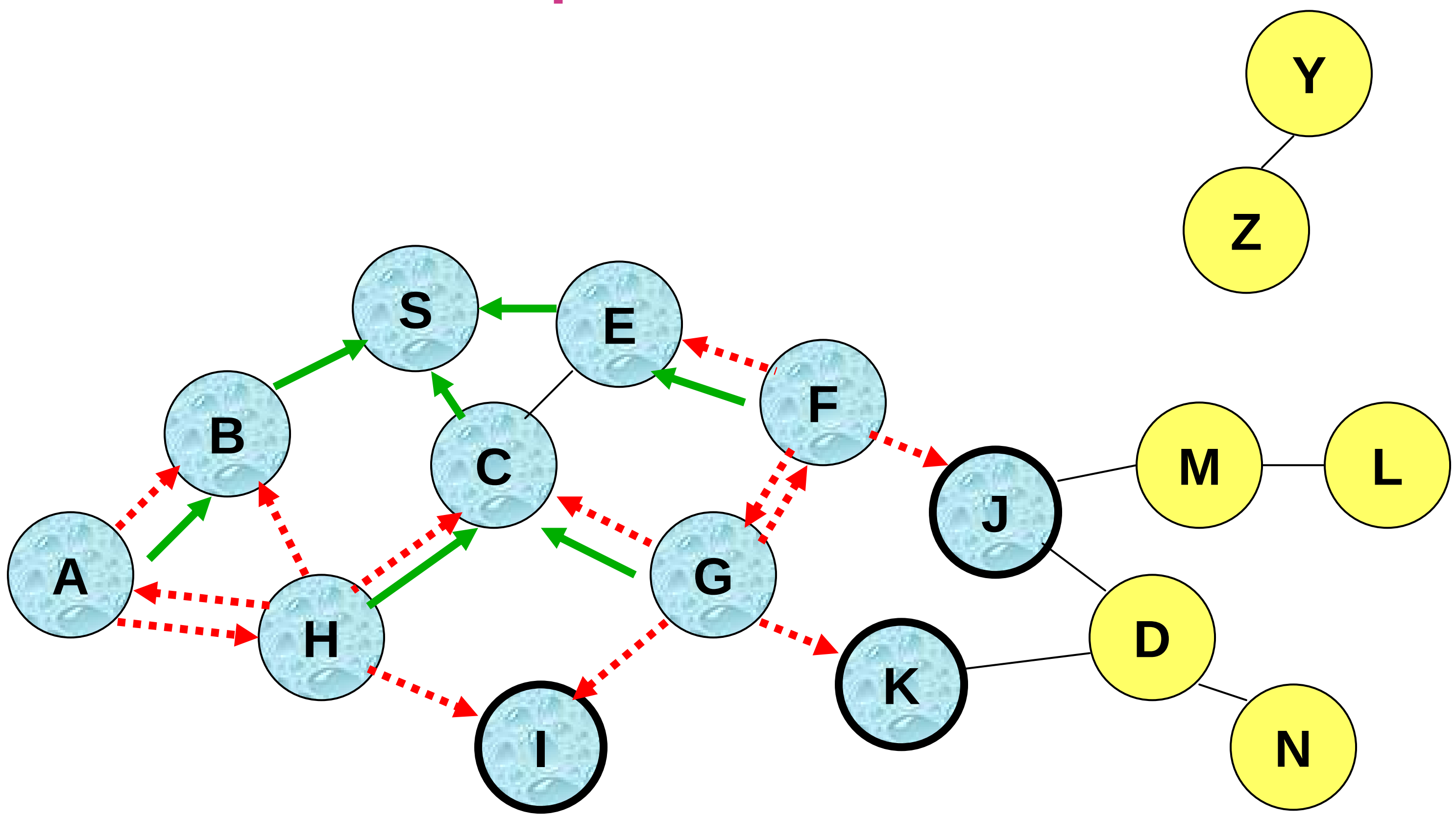
Route Requests in AODV



Represents links on Reverse Path

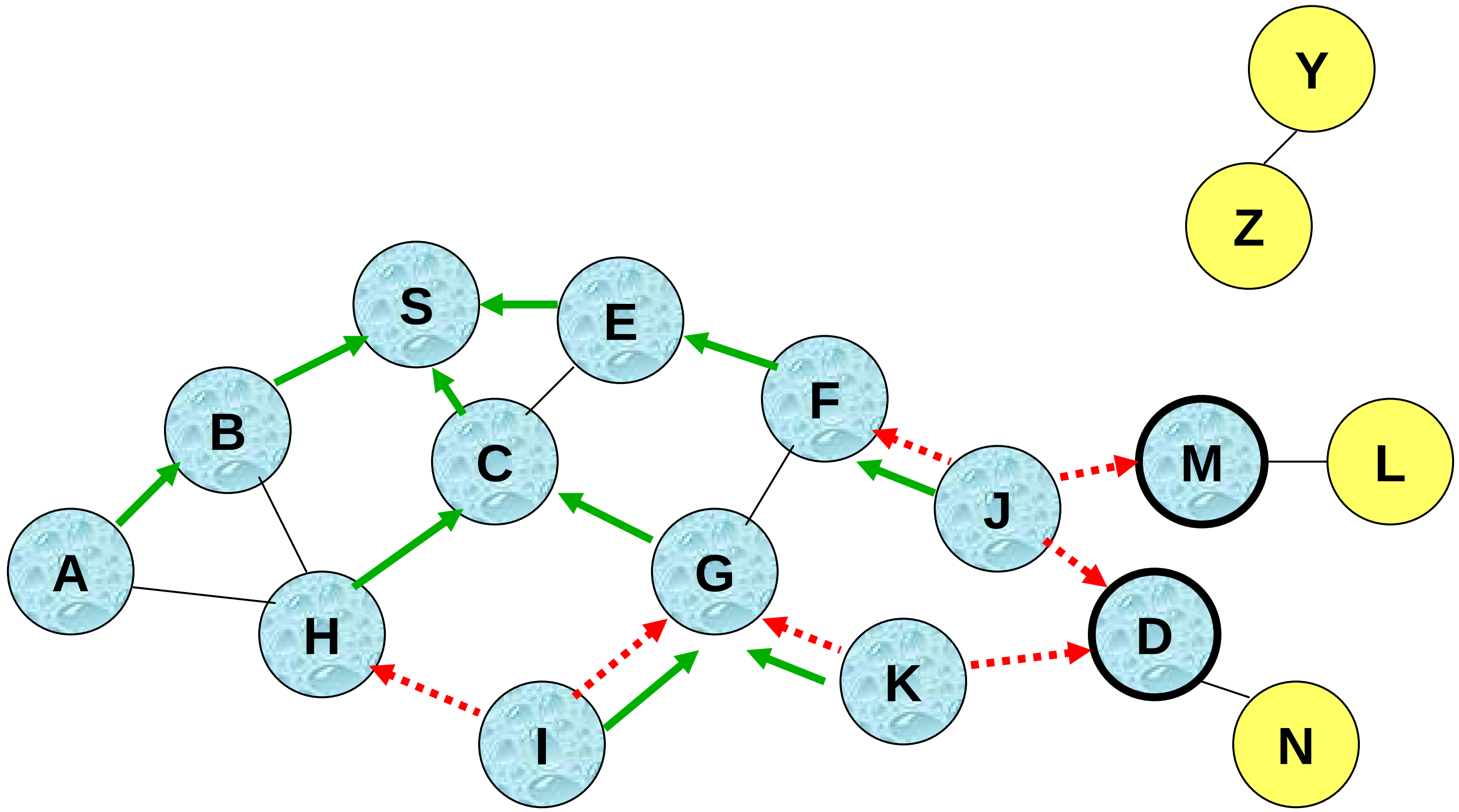
Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Reverse Path Setup in AODV



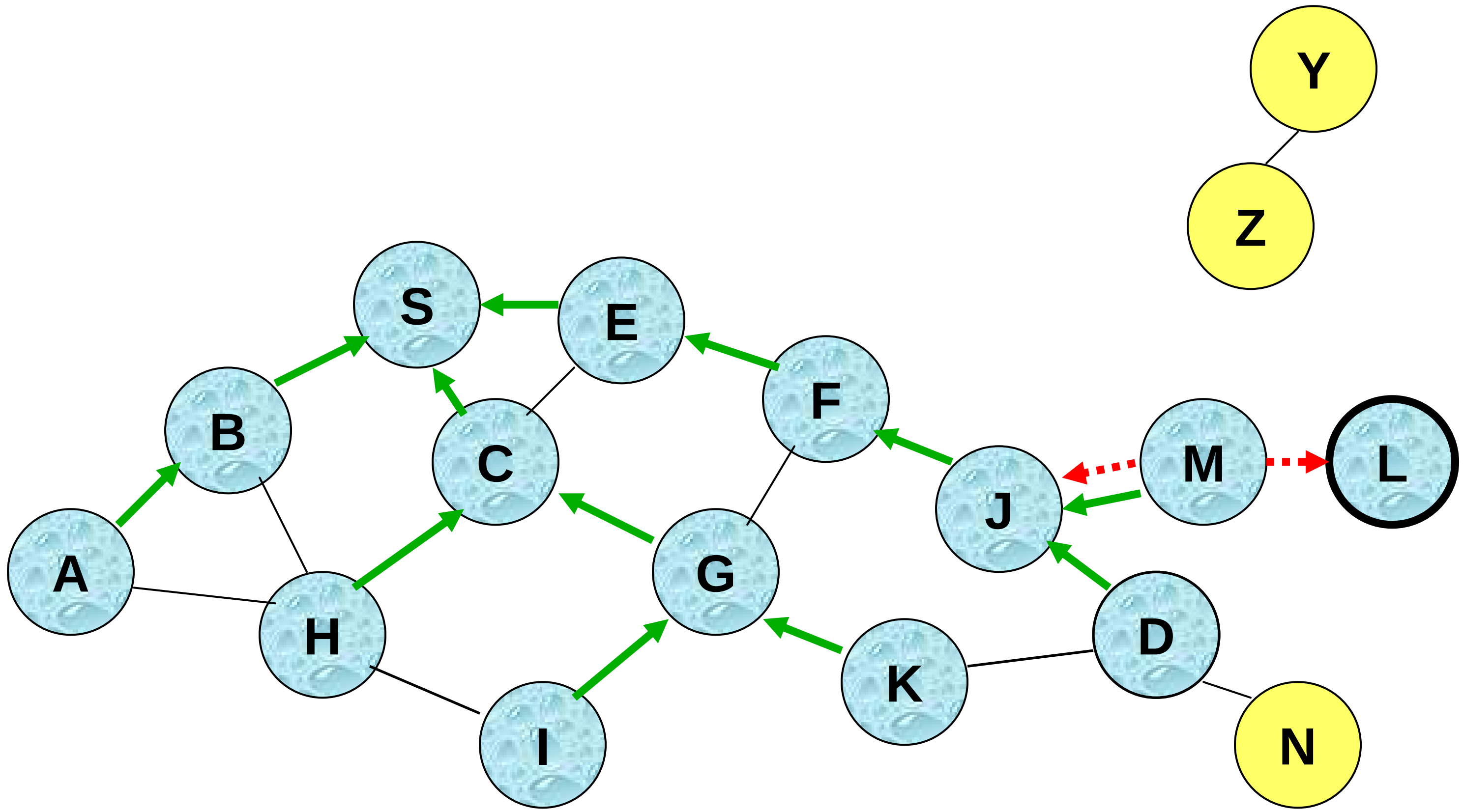
- **Node C receives RREQ from G and H, but does not forward it again, because node C has already forwarded RREQ once**

Reverse Path Setup in AODV



Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

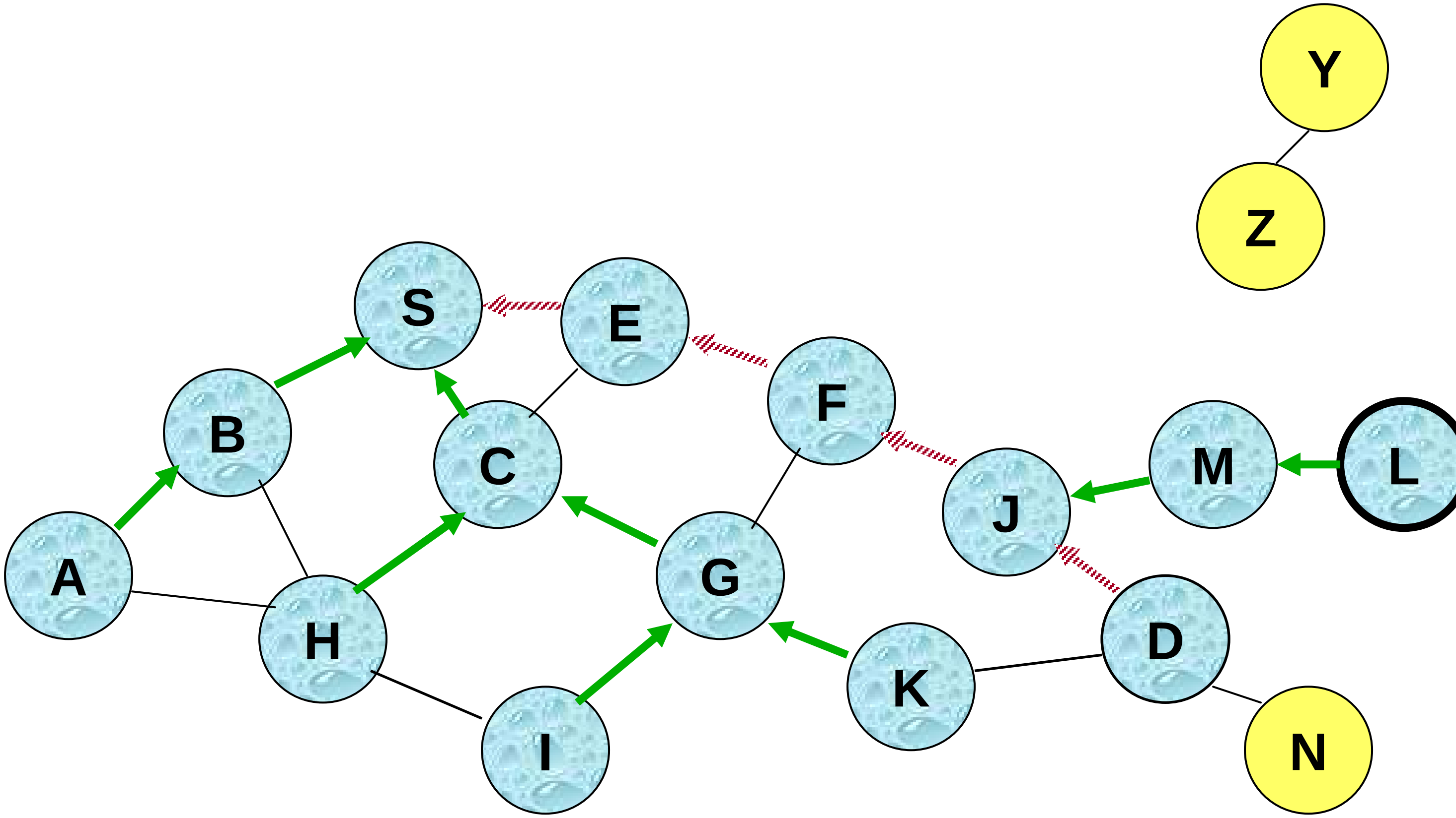
Reverse Path Setup in AODV



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

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Route Reply in AODV

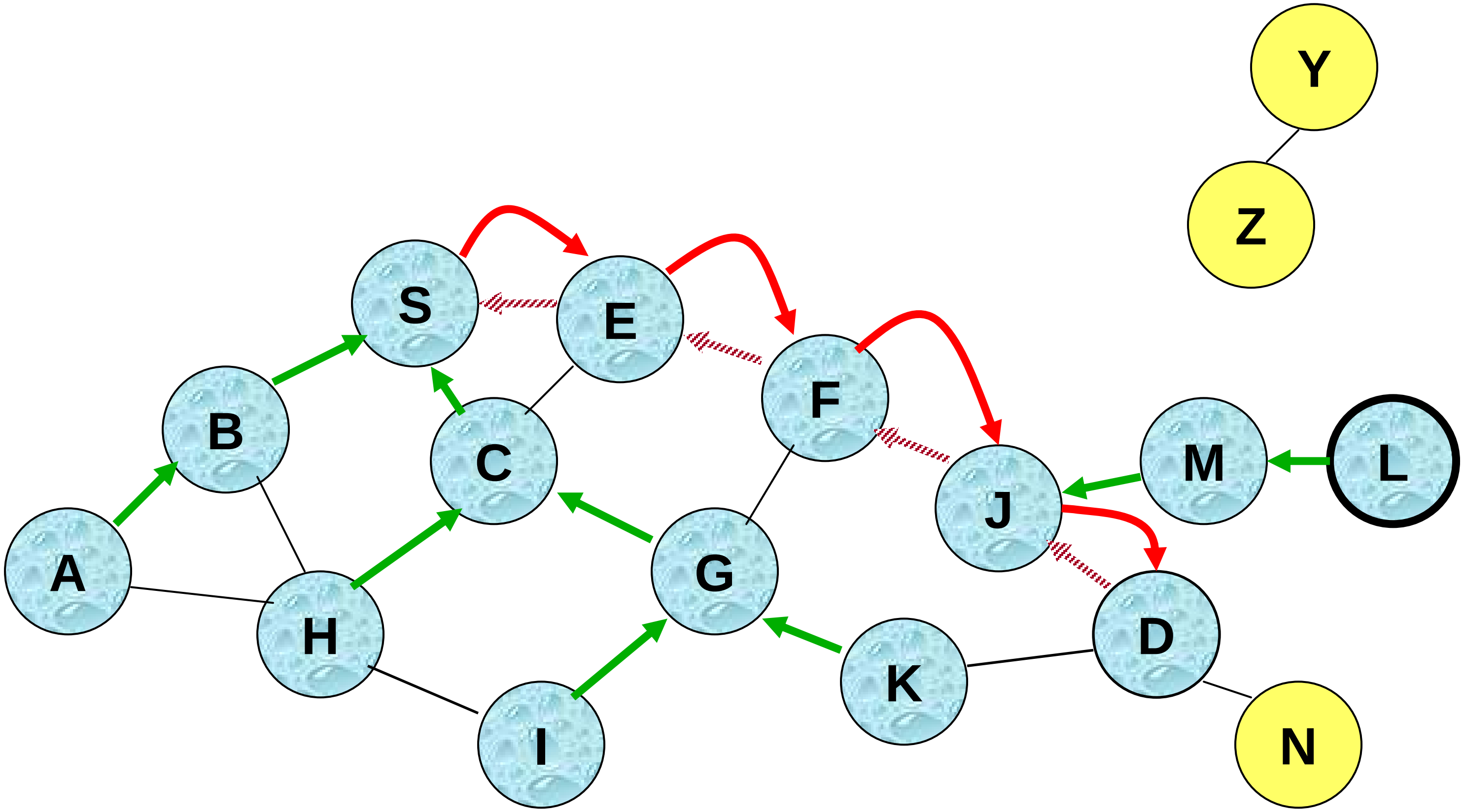


Represents links on path taken by RREP

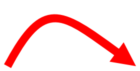
Route Reply in AODV

- An intermediate node (not the destination) may also send a Route Reply (RREP) provided that it knows a more recent path than the one previously known to sender S
- To determine whether the path known to an intermediate node is more recent, *destination sequence numbers* are used
- The likelihood that an intermediate node will send a Route Reply when using AODV is not as high as DSR
  - A new Route Request by node S for a destination is assigned a higher destination sequence number. An intermediate node, which knows a route, but with a smaller sequence number, cannot send Route Reply

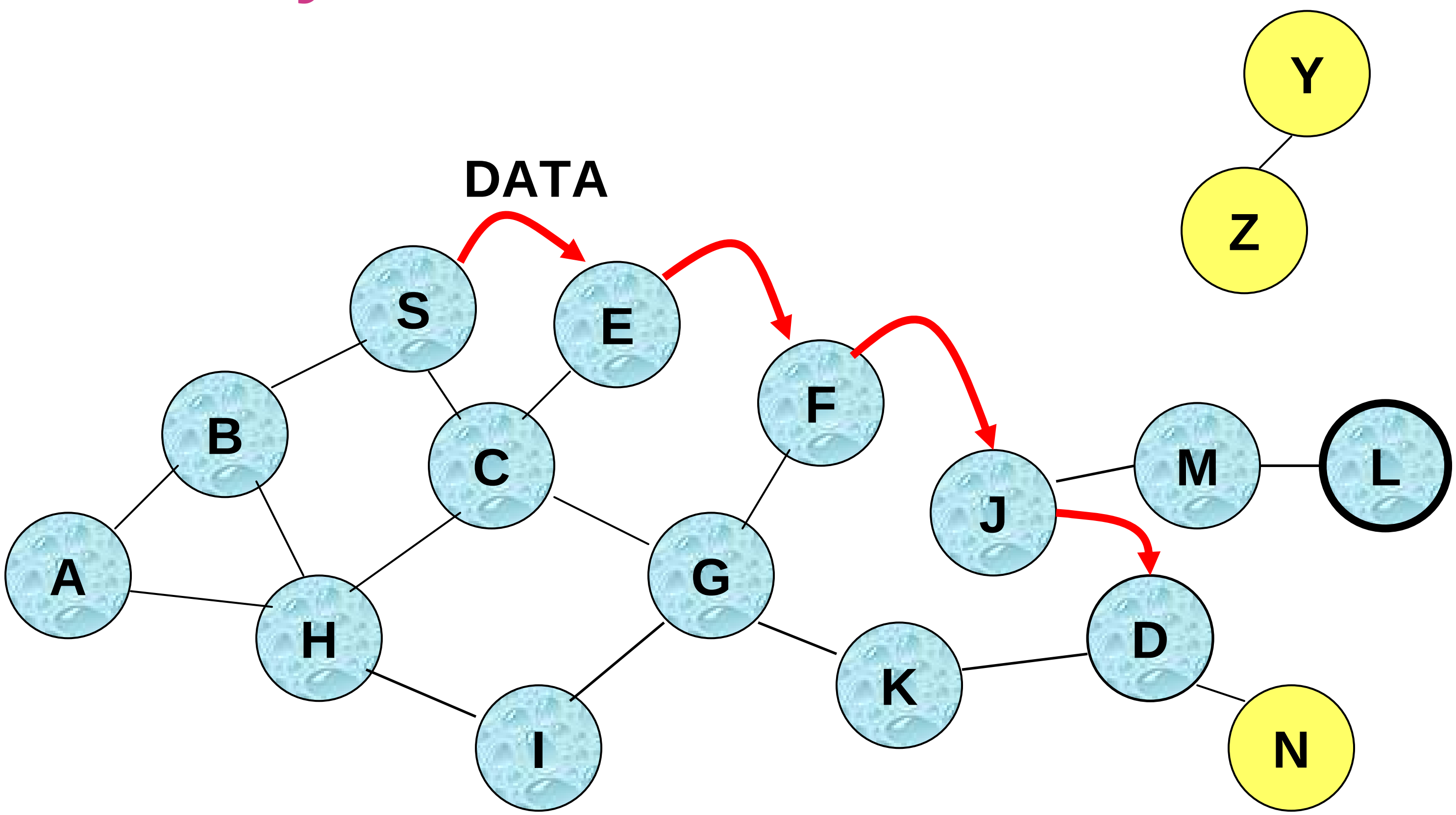
Forward Path Setup in AODV



Forward links are setup when RREP travels along the reverse path

 **Represents a link on the forward path**

Data Delivery in AODV



Routing table entries used to forward data packet.
Route is *not* included in packet header.

Summary: AODV

- 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
  - Multi-path extensions can be designed
  - DSR may maintain several routes for a single destination
- Unused routes expire even if topology does not change

Link State Routing [Huitema95]

- Each node periodically floods status of its links
- Each node re-broadcasts link state information received from its neighbor
- Each node keeps track of link state information received from other nodes
- Each node uses above information to determine next hop to each destination

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

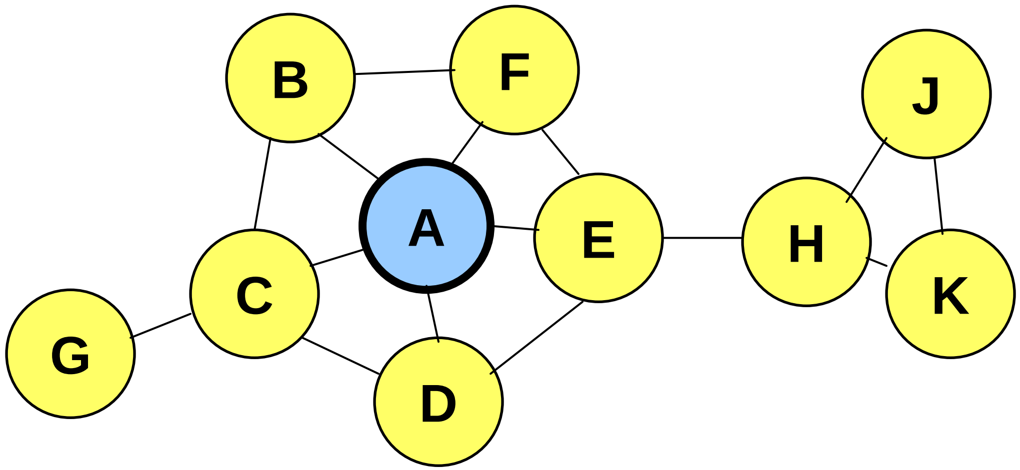
Optimized Link State Routing (OLSR)

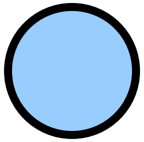
- The overhead of flooding link state information is reduced by requiring fewer nodes to forward the information
- A broadcast from node X is only forwarded by its *multipoint relays*
- Multipoint relays of node X are its neighbors such that each two-hop neighbor of X is a one-hop neighbor of at least one multipoint relay of X
  - Each node transmits its neighbor list in periodic beacons, so that all nodes can know their 2-hop neighbors, in order to choose the multipoint relays

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Optimized Link State Routing (OLSR)

- Nodes C and E are multipoint relays of node A



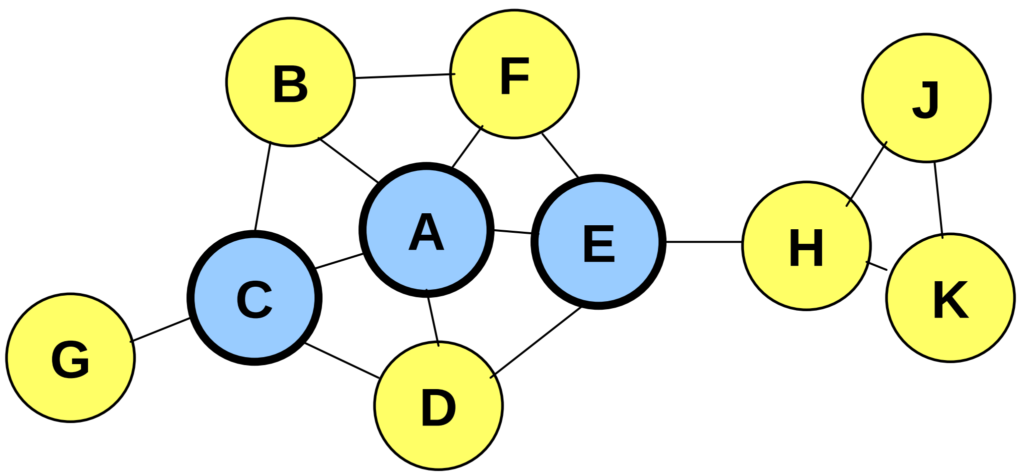


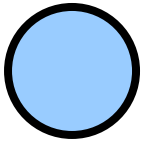
Node that has broadcast state information from A

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Optimized Link State Routing (OLSR)

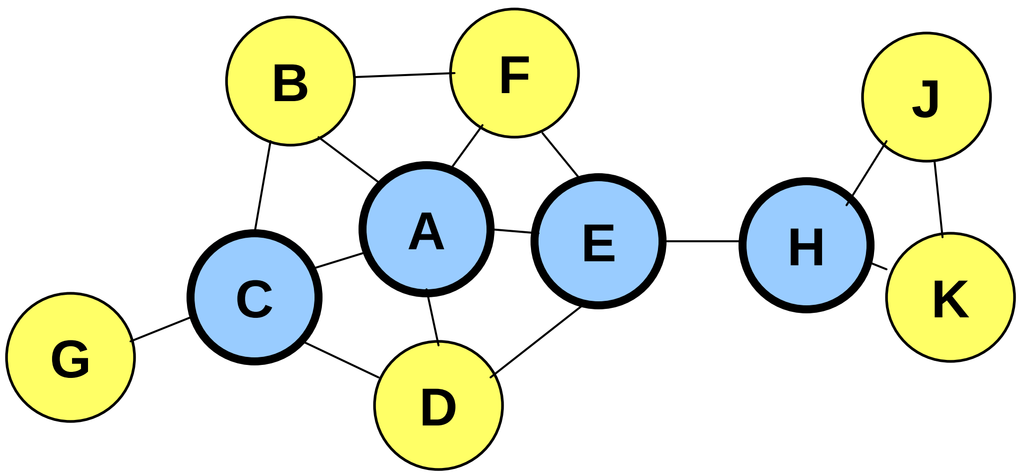
- Nodes C and E forward information received from A




Node that has broadcast state information from A

Optimized Link State Routing (OLSR)

- Nodes E and K are multipoint relays for node H
- Node K forwards information received from H
  - E has already forwarded the same information once



Node that has broadcast state information from A

Summary: OLSR

- OLSR floods information through the multipoint relays
- The flooded information itself is for links connecting nodes to respective multipoint relays
- Routes used by OLSR only include multipoint relays as intermediate nodes

Further Routing Approaches

- Improvements & Optimisations of Previous Protocols
- Location Aided Routing
- Clustering after Landmarking
- Hierarchic / Anchored Routing
- Power-Aware Routing
- ...

Performance Properties of MANETs

- One-Hop Capacity:
  Consider MANET of *n* equal nodes, each acting as router, with constant node density. Then the One-Hop Capacity grows linearly → v *(n)*
- Total Capacity surprisingly low:
  - Consider MANET of *n* equal nodes, each acting as router in an *optimal* set-up, then the Node Capacity to reach an arbitrary destination reads → v *(1/ô n)*
  - Node Capacity further decreases under wireless transmission → v *(1/ô (n ln(n))*

Aspects in P2P over MANETs

- Manets consist of moving, unstable components
  ➔ unsuitable for client-server, but P2P applications
- P2P applications built for failure tolerance
  ➔ potential for compensating Manet drop-outs
- P2P and Manets cope with member mobility
  ➔ provide capabilities of self-restructuring
- But: P2P routing (mainly) regardless of underlay capacities
  ➔ Manet limitations require optimising adaptation
- P2P and Manet changes may amplify
  ➔ Issues of cross-layer synchronisation

References

- C. Murthy and B. Manoj: *Ad Hoc Wireless Networks*, Pearson Prentice Hall, 2004.
- Charles Perkins: *Ad Hoc Networking*, Addison-Wesley, 2001.
- S. Sarkar, T. Basavaraju, C. Puttamadappa: *Ad Hoc Mobile Wireless Networks*, Auerbach Publications, 2008.
- Nitin H. Vaidya: *Mobile Ad Hoc Networks,* Tutorial at InfoCom 2006*,* http://www.crhc.uiuc.edu/wireless/talks/2006.Infocom.ppt.
- P. Gupta and P. R. Kumar, “The capacity of wireless networks,” IEEE Transactions on Information Theory, vol. 46, no. 2, pp. 388–404, 2000.