Mobile Ad Hoc Networks

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MOBILE NETWORK PERVASIVE COMPUTING

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Outline

- Introduction
- Medium Access Control
- Routing (unicast)
  - Reactive Protocols ✓
  - Proactive Protocols ✓
  - Hybrid Protocols
- Transport Issues
- Summary and Conclusions

Wireless Networks

- Need: Access computing and communication services

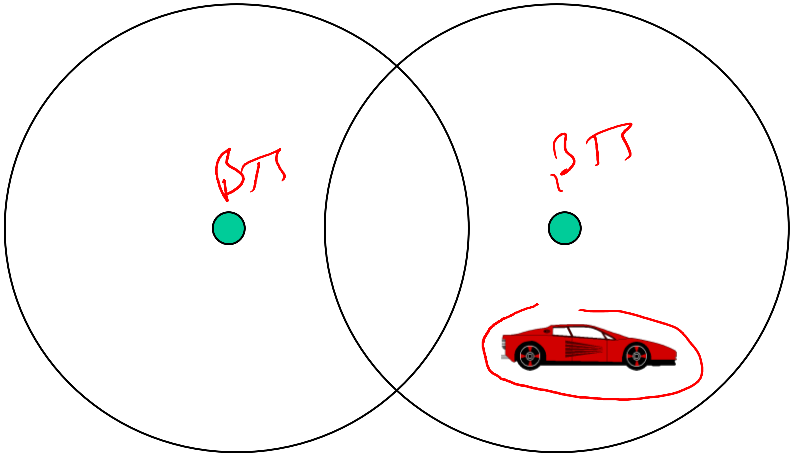
- Infrastructure-based Networks
  - traditional cellular systems (base station infrastructure)

- Wireless LANs
  - Infrared (IrDA) or radio links (Wavelan)
  - very flexible within the reception area; ad-hoc networks possible
  - low bandwidth compared to wired networks (1-10 Mbit/s)

- Ad hoc Networks
  - useful when infrastructure not available, impractical, or expensive
  - military applications, rescue, home networking

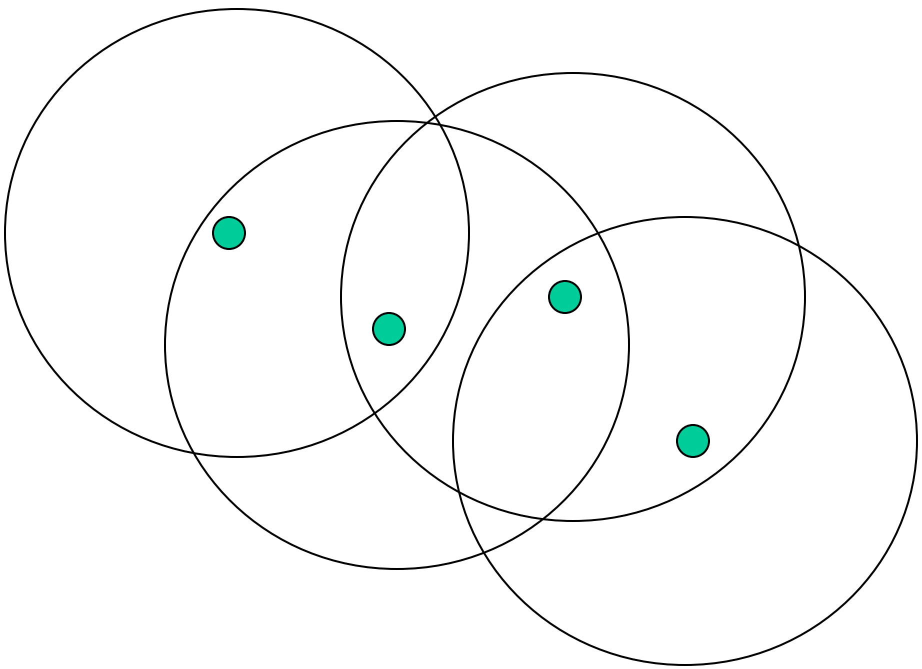
Cellular Wireless

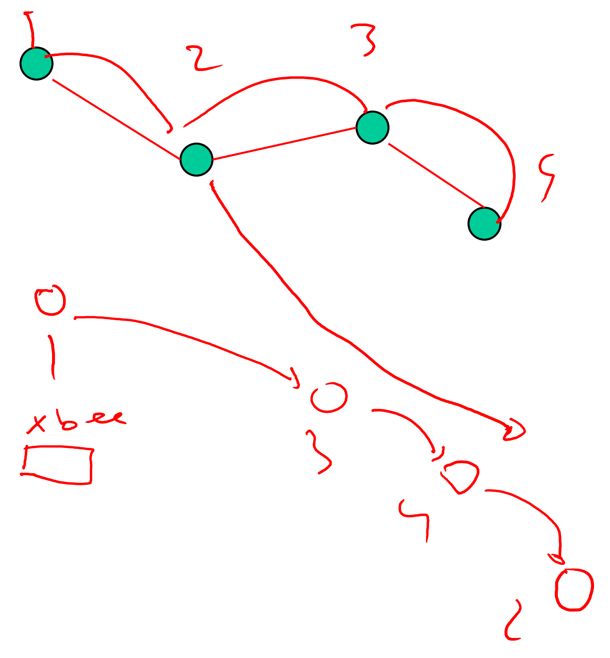
- Single hop wireless connectivity to the wired world
  - Space divided into cells
  - A base station is responsible to communicate with hosts in its cell
  - Mobile hosts can change cells while communicating
  - Hand-off occurs when a mobile host starts communicating via a new base station



Multi-Hop Wireless

- May need to traverse multiple links to reach destination

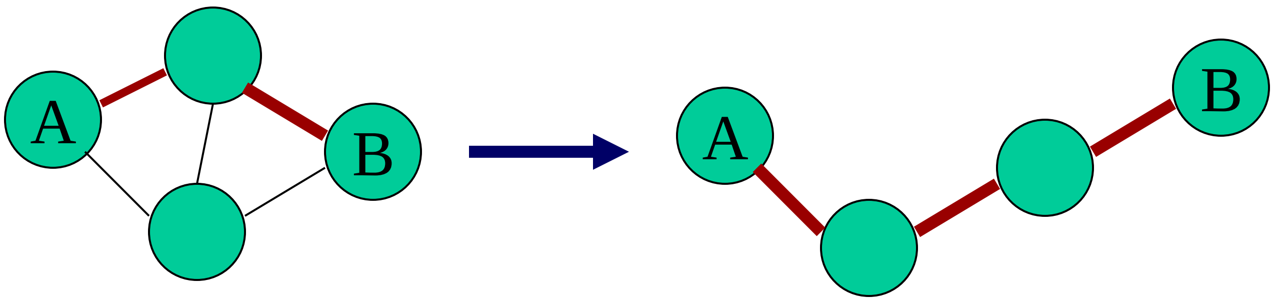




- Mobility causes route changes

Mobile Ad Hoc Networks (MANET)

- Host movement frequent
- Topology change frequent



- No cellular infrastructure. Multi-hop wireless links.
- Data must be routed via intermediate nodes.

Why Ad Hoc Networks ?

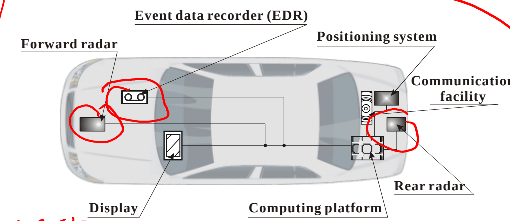
- Setting up of fixed access points and backbone infrastructure is not always viable
  - Infrastructure may not be present in a disaster area or war zone
  - Infrastructure may not be practical for short-range radios; Bluetooth (range ~ 10m)

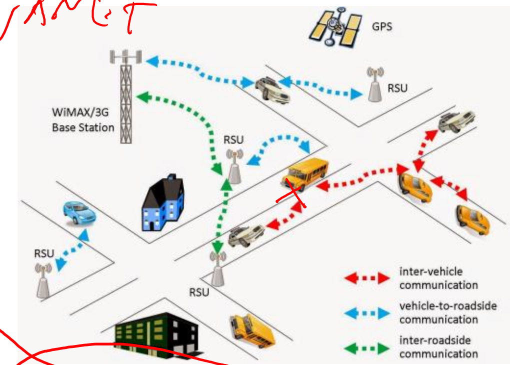
BLE ~100m

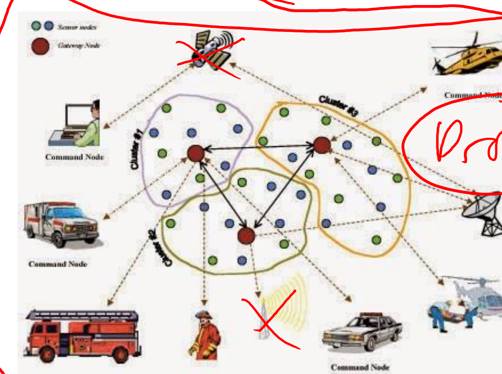
- Ad hoc networks:
  - Do not need backbone infrastructure support
  - Are easy to deploy
  - Useful when infrastructure is absent, destroyed or impractical

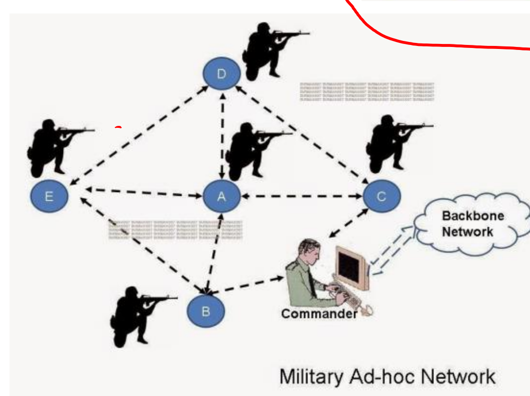
Many Applications

- Personal area networking
  - cell phone, laptop, ear phone, wrist watch
- Military environments
  - soldiers, tanks, planes
- Civilian environments
  - taxi cab network
  - meeting rooms
  - sports stadiums
  - boats, small aircraft
- Emergency operations
  - search-and-rescue
  - policing and fire fighting



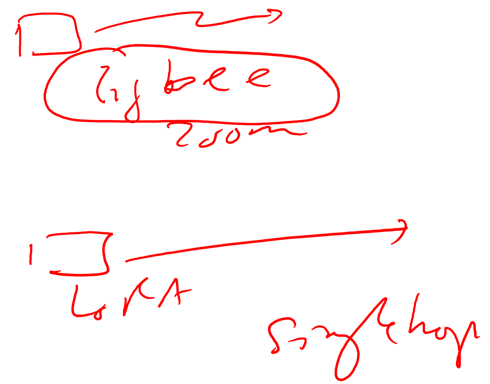






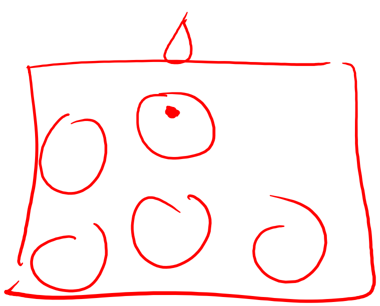
Challenges in Mobile Environments

- Limitations of the Wireless Network
  - packet loss due to transmission errors
  - variable capacity links
  - frequent disconnections/partitions
  - limited communication bandwidth
  - Broadcast nature of the communications



- Limitations Imposed by Mobility
  - dynamically changing topologies/routes
  - lack of mobility awareness by system/applications

- Limitations of the Mobile Computer
  - short battery lifetime
  - limited capacities



Effect of mobility on the protocol stack

- Application
  - new applications and adaptations
- Transport
  - congestion and flow control
- Network
  - addressing and routing
- Link
  - media access and handoff
- Physical
  - transmission errors and interference

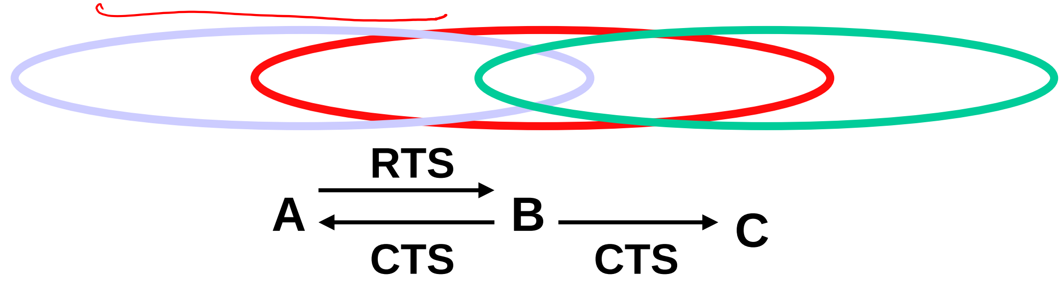
Medium Access Control in MANET

Multiple Access with Collision Avoidance (MACA) [Karn90]

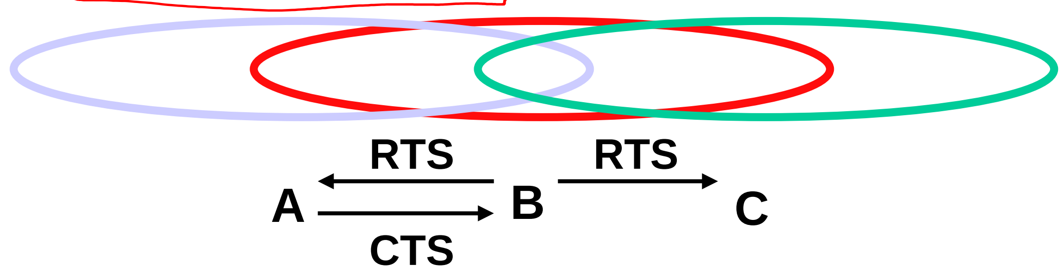
- MACA uses signaling packets for collision avoidance
  - RTS (request to send)
    - sender request the right to send from a receiver with a short RTS packet before it sends a data packet
  - CTS (clear to send)
    - receiver grants the right to send as soon as it is ready to receive
- Signaling packets contain
  - sender address
  - receiver address
  - packet size
- Variants of this method are used in IEEE 802.11

MACA Solutions [Karn90]

- MACA avoids the problem of hidden terminals
  - A and C want to send to B
  - A sends RTS first
  - C waits after receiving CTS from B



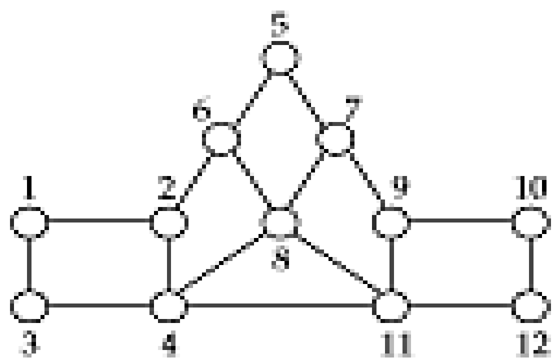
- MACA avoids the problem of exposed terminals
  - B wants to send to A, C to another terminal
  - now C does not have to wait, as it cannot receive CTS from A



Routing Protocols

Traditional Routing

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



ROUTING TABLE AT 1

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

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

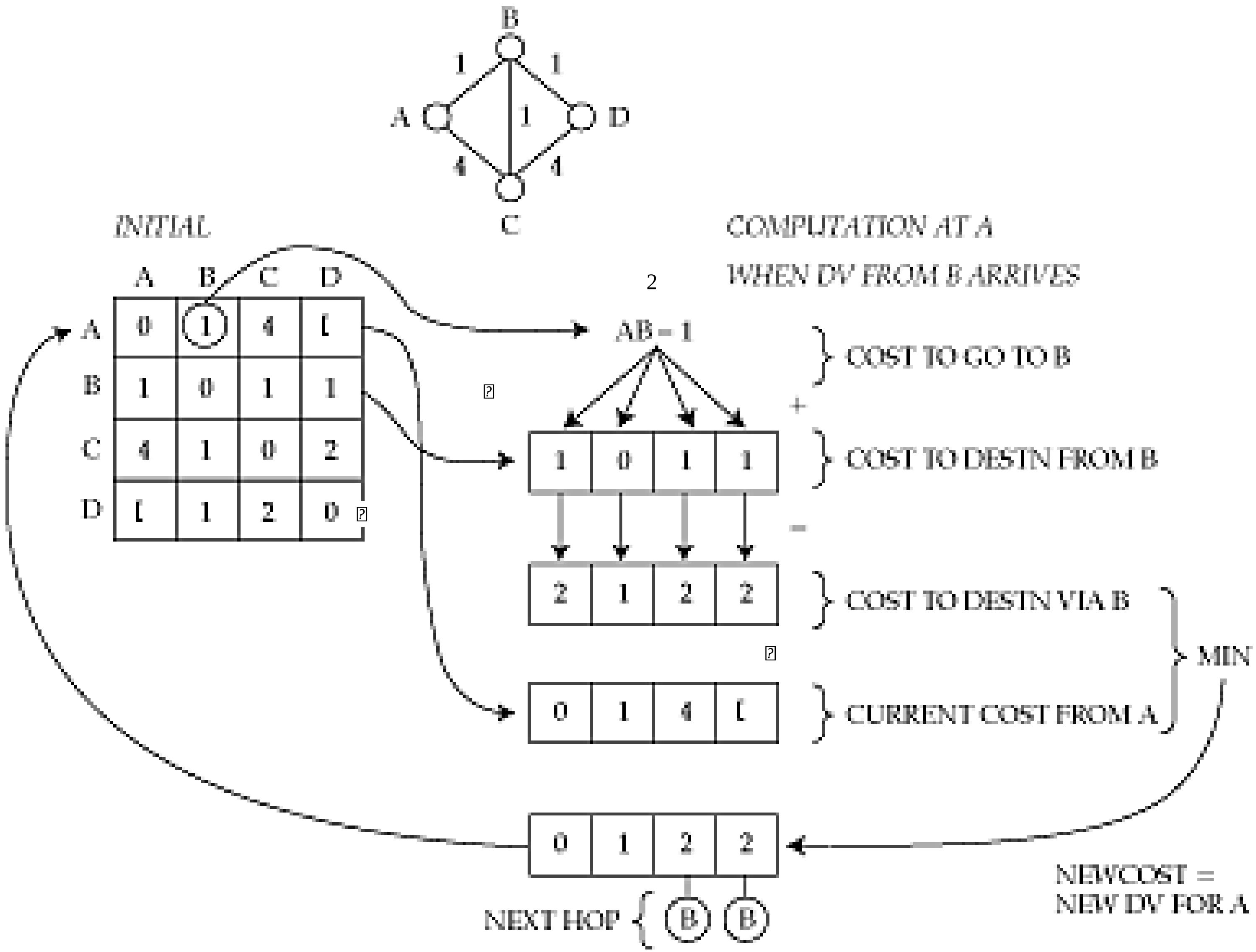
Distance-vector & Link-state Routing

- Both assume router knows
  - address of each neighbor
  - cost of reaching each neighbor
- Both allow a router to determine global routing information by talking to its neighbors

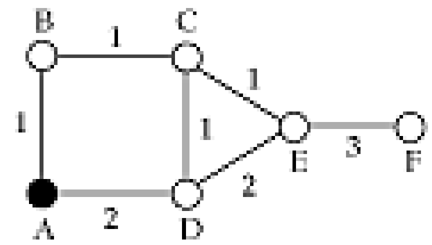
- Distance vector - router knows cost to each destination

- Link state - router knows entire network topology and computes shortest path

Distance Vector Routing: Example

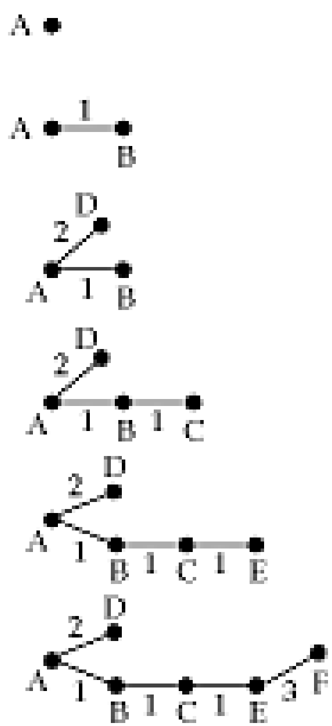


Link State Routing: Example



B(A,1) means B was reached by A, cost 1

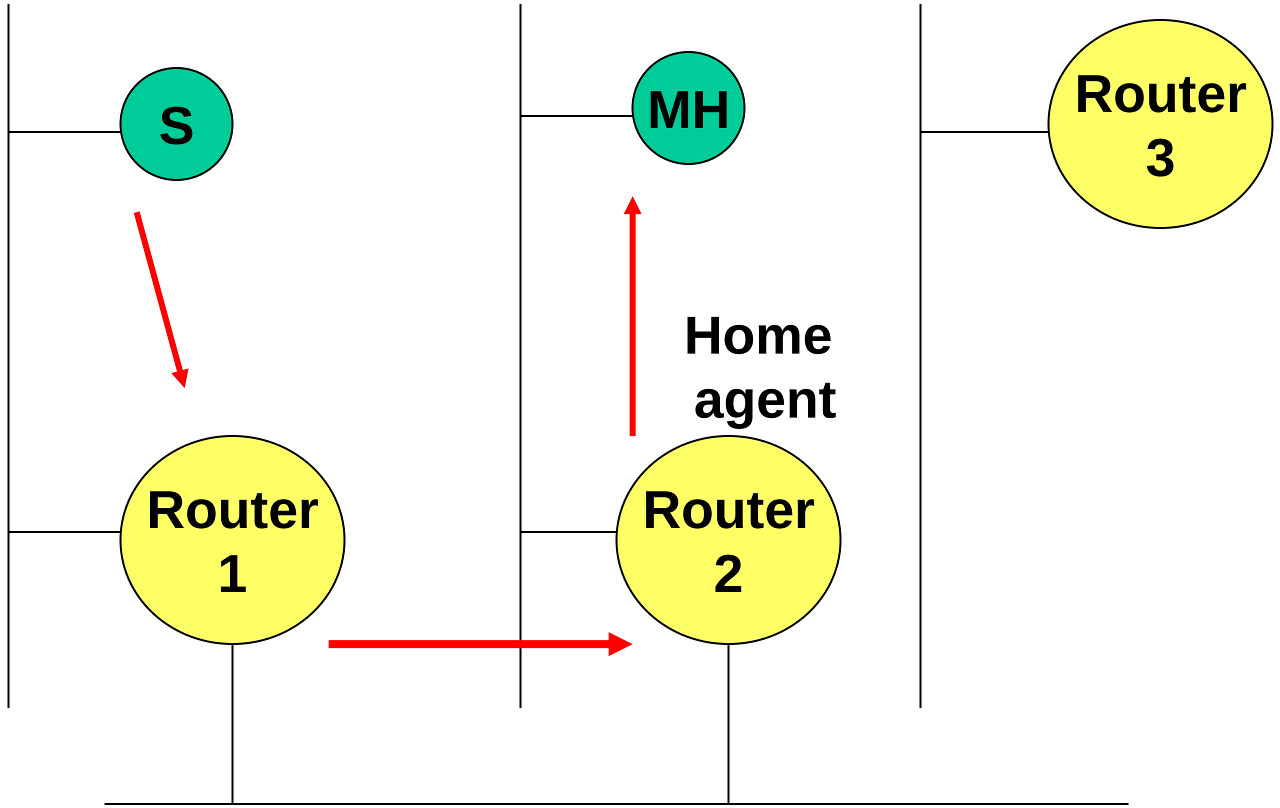
PERMANENT	TEMPORARY	COMMENTS
A	B(A,1), D(A,2)	ROOT AND ITS NEIGHBORS
A, B(A,1)	D(A,2), C(B,2)	ADD C(B,2)
A, B(A,1) D(A,2)	E(D,4), C(B,2)	C(D,3) DIDN'T MAKE IT
A, B(A,1) D(A,2), C(B,2)	E(C,3)	E(D,4) TOO LONG
A, B(A,1) D(A,2), C(B,2) E(C,3)	F(E,6)	
A, B(A,1) C(B,2), D(A,2) E(C,3), F(E,6)	NULL	STOP



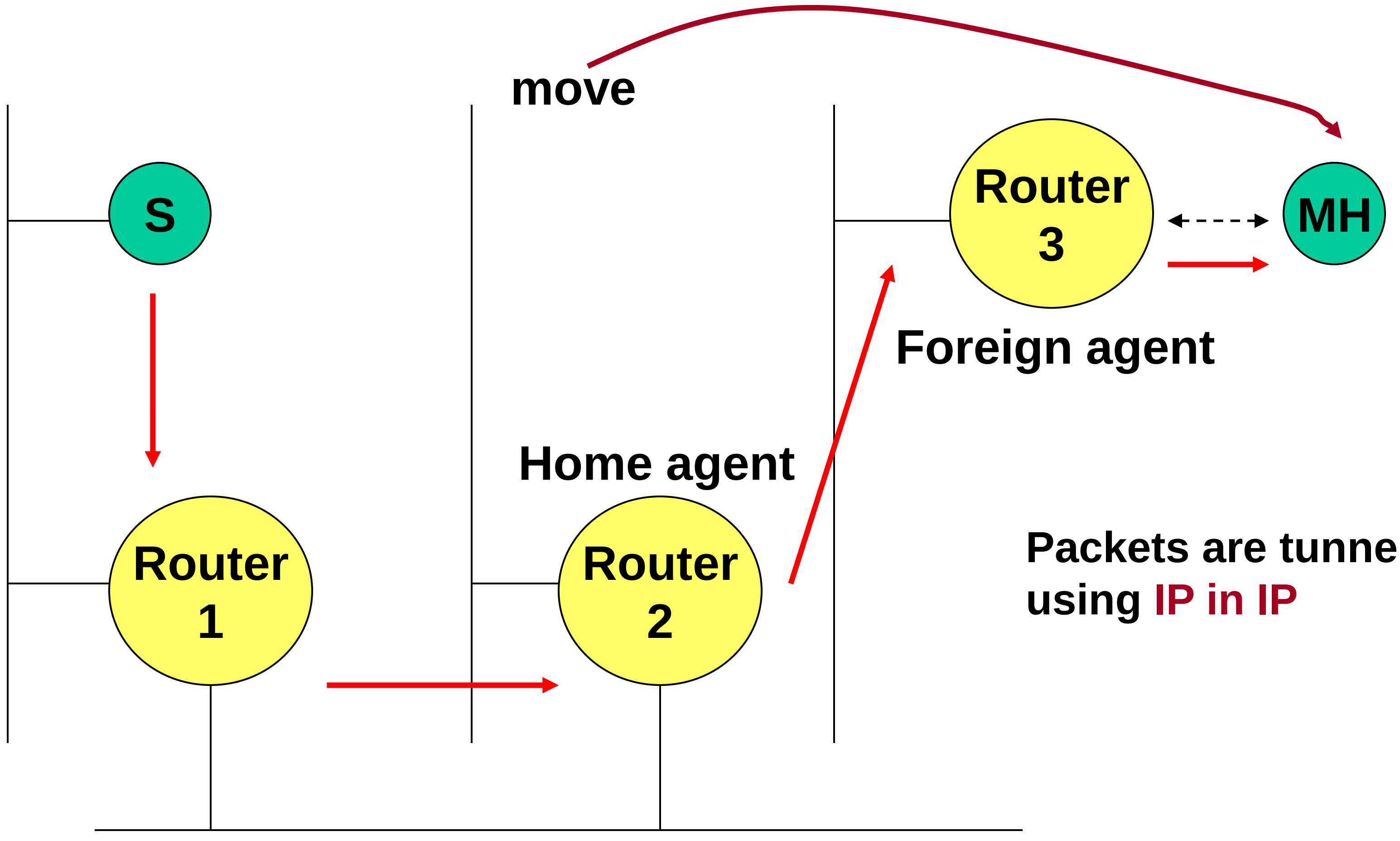
Routing and Mobility

- Finding a path from a source to a destination
- Issues
  - Frequent route changes
    - amount of data transferred between route changes may be much smaller than traditional networks
  - Route changes may be related to host movement
  - Low bandwidth links
- Goal of routing protocols
  - decrease routing-related overhead
  - find short routes
  - find "stable" routes (despite mobility)

Mobile IP



Mobile IP



Packets are tunneled using IP in IP

Routing in MANET

Unicast Routing Protocols

- Many protocols have been proposed

- Some specifically invented for MANET
- Others adapted from protocols for wired networks

- No single protocol works well in all environments
  - some attempts made to develop adaptive/hybrid protocols

- Standardization efforts in IETF
  - MANET, MobileIP working groups
  - **http://www.ietf.org**

Routing Protocols

- Proactive protocols
  - Traditional distributed shortest-path protocols
  - Maintain routes between every host pair at all times
  - Based on periodic updates; High routing overhead
  - Examples:
    - DSDV (Dynamic sequenced distance-vector)
    - OLSR (Optimized Link State Routing)
- Reactive protocols
  - Determine route if and when needed
  - Source initiates route discovery
  - Examples:
    - DSR (Dynamic source routing)
    - AODV (on-demand distance vector)
- Hybrid protocols
  - Adaptive; Combination of proactive and reactive
  - Example: Zone Routing Protocol (intra-zone: proactive; inter-zone: on-demand), SHARP (proactive near, reactive long distance)

Protocol Trade-offs

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

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

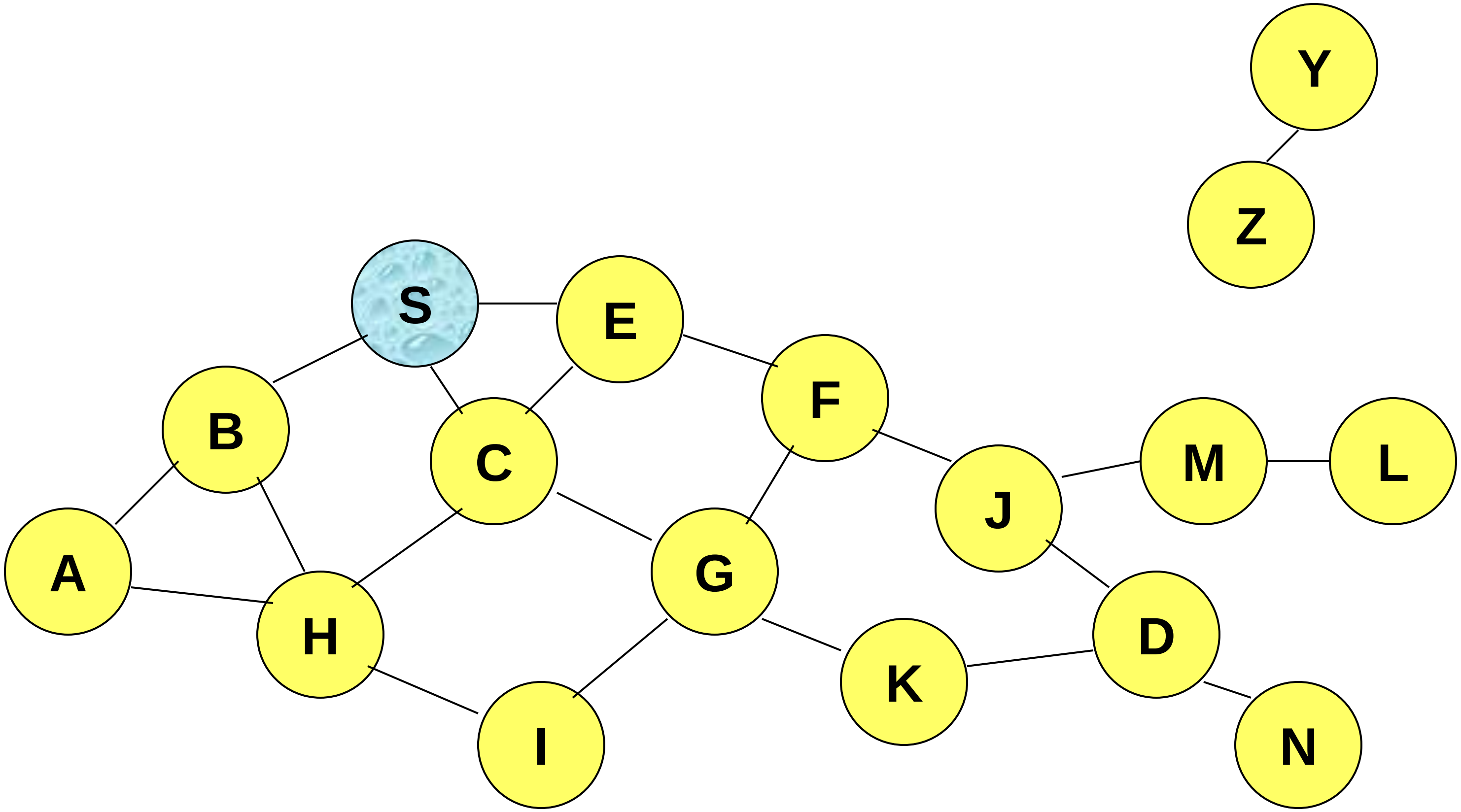
- Which approach achieves a better trade-off depends on the traffic and mobility patterns

Reactive Routing Protocols

Dynamic Source Routing (DSR) [Johnson96]

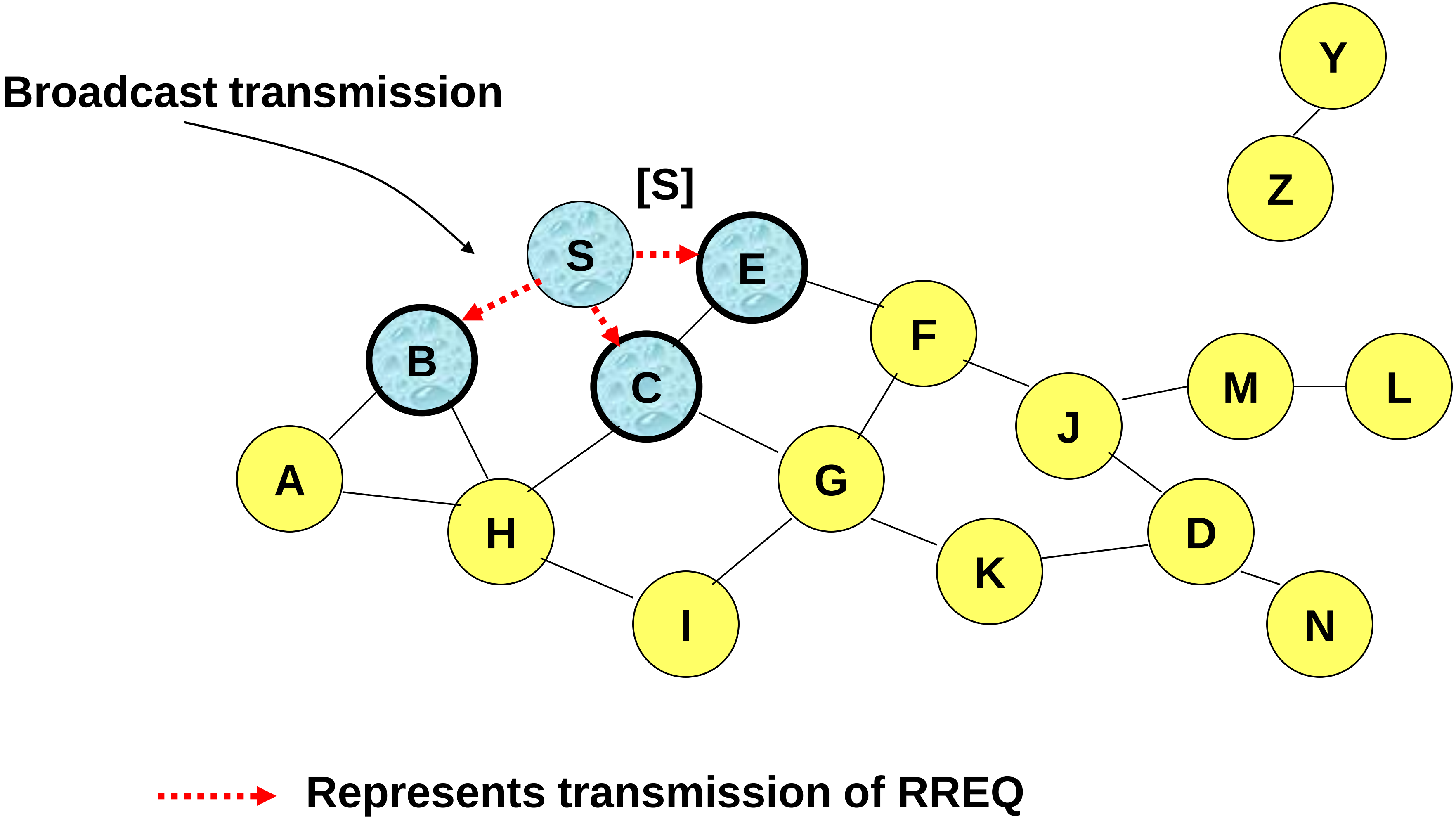
- When node S wants to send a packet to node D, but does not know a route to D, node S initiates a route discovery
- Source node S floods Route Request (RREQ)
- Each node *appends own identifier* when forwarding RREQ

Route Discovery in DSR



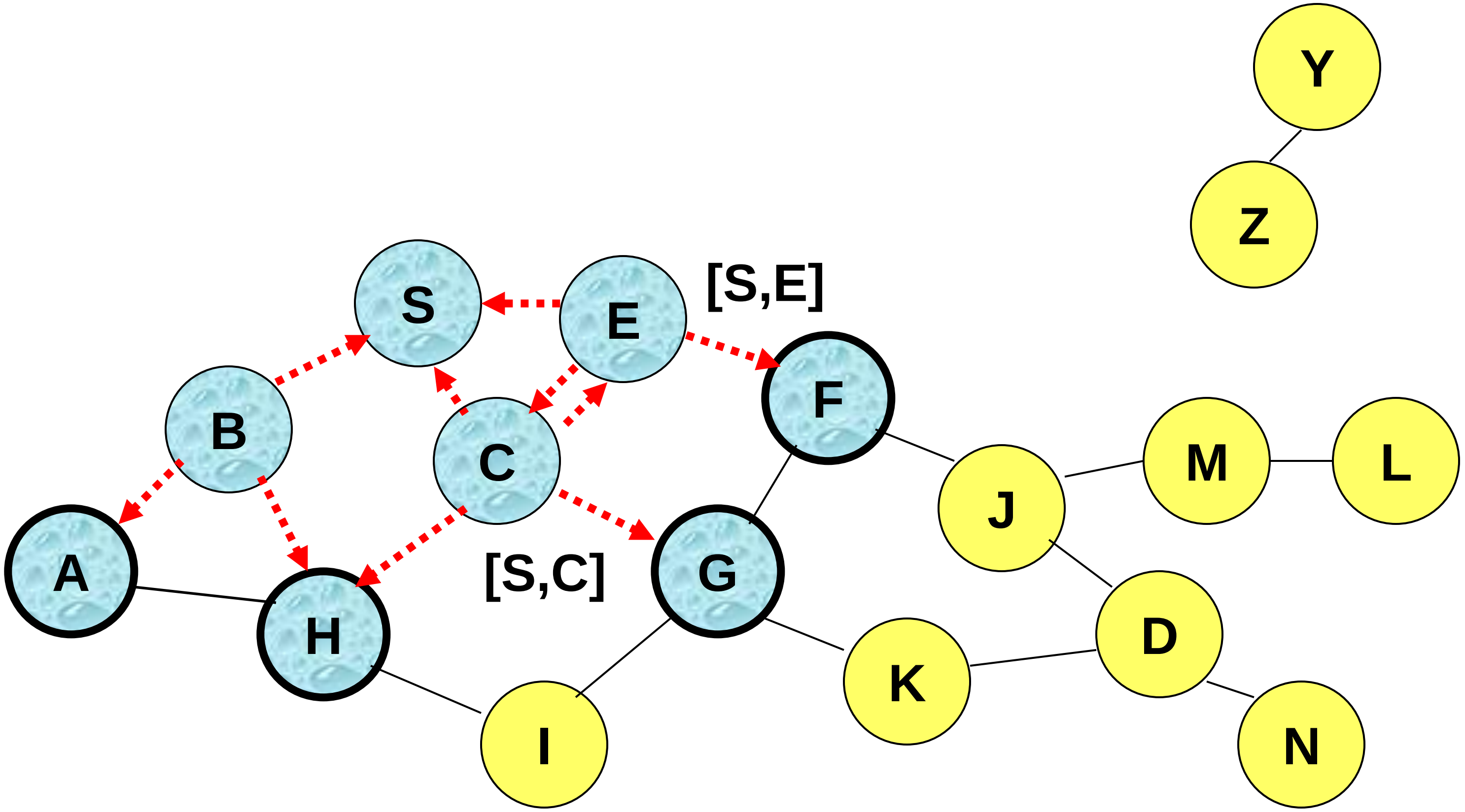
Represents a node that has received RREQ for D from S

Route Discovery in DSR



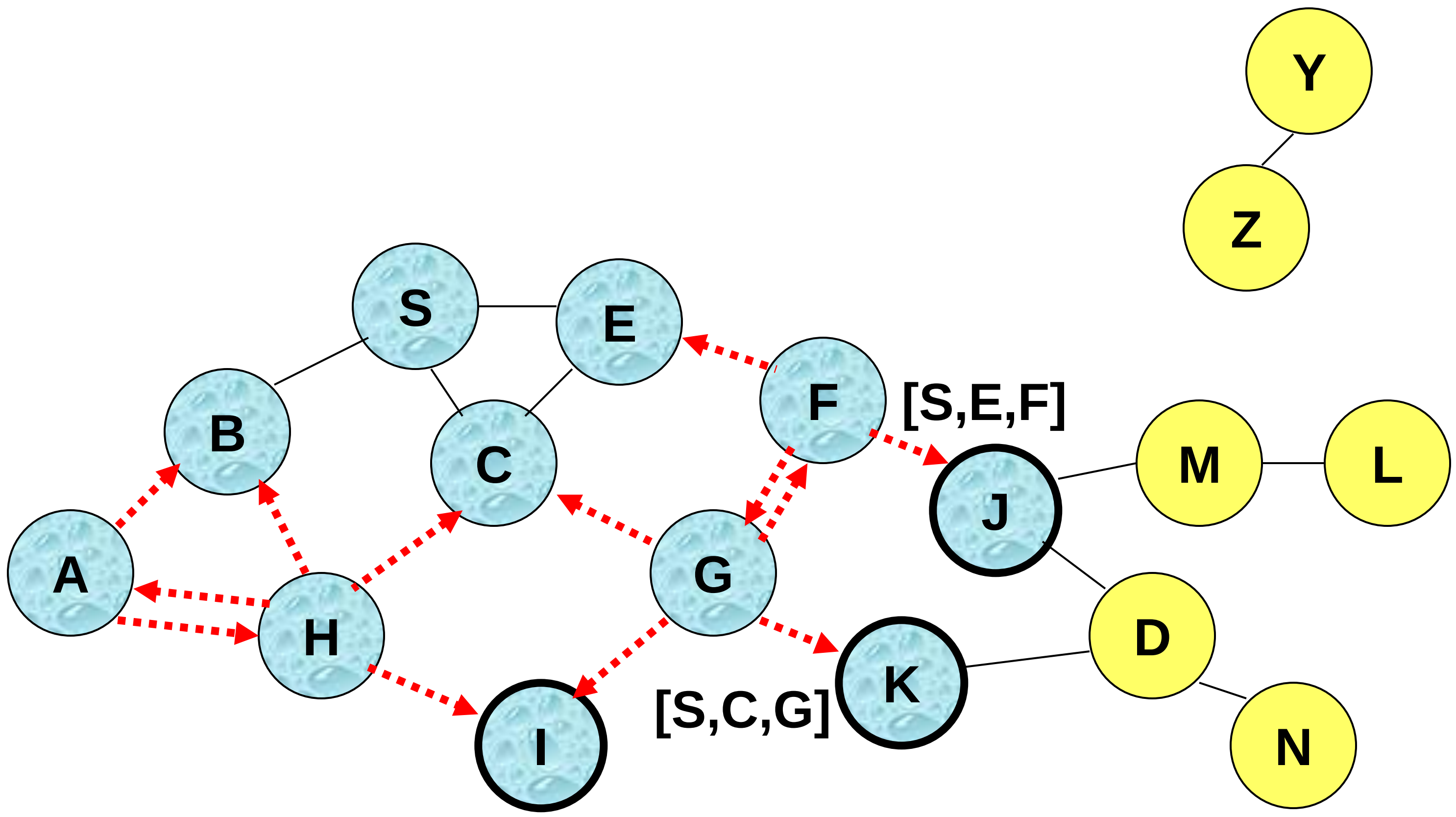
[X,Y] Represents list of identifiers appended to RREQ

Route Discovery in DSR



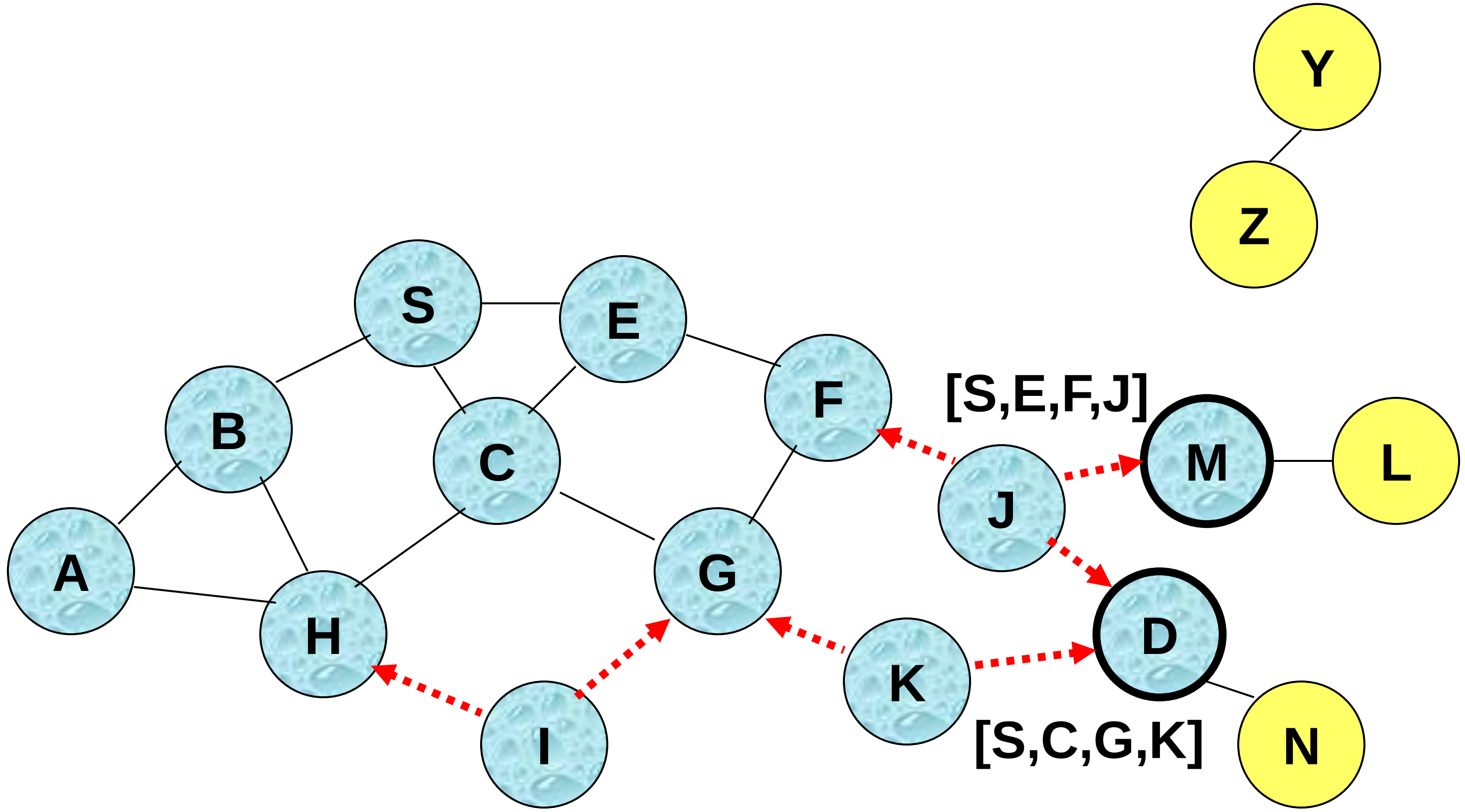
- **Node H receives packet RREQ from two neighbors: potential for collision**

Route Discovery in DSR



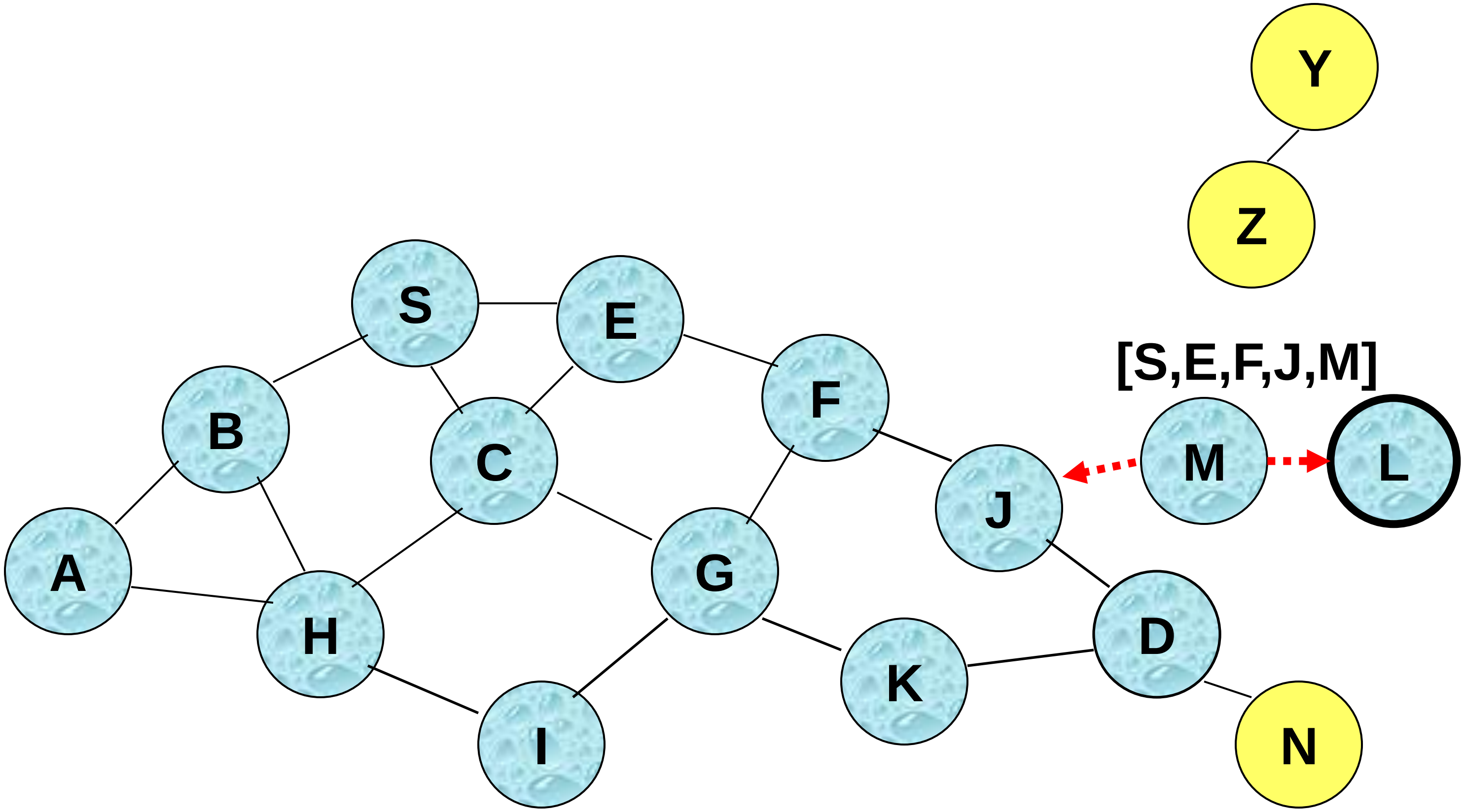
- **Node C receives RREQ from G and H, but does not forward it again, because node C has already forwarded RREQ once**

Route Discovery in DSR



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

Route Discovery in DSR

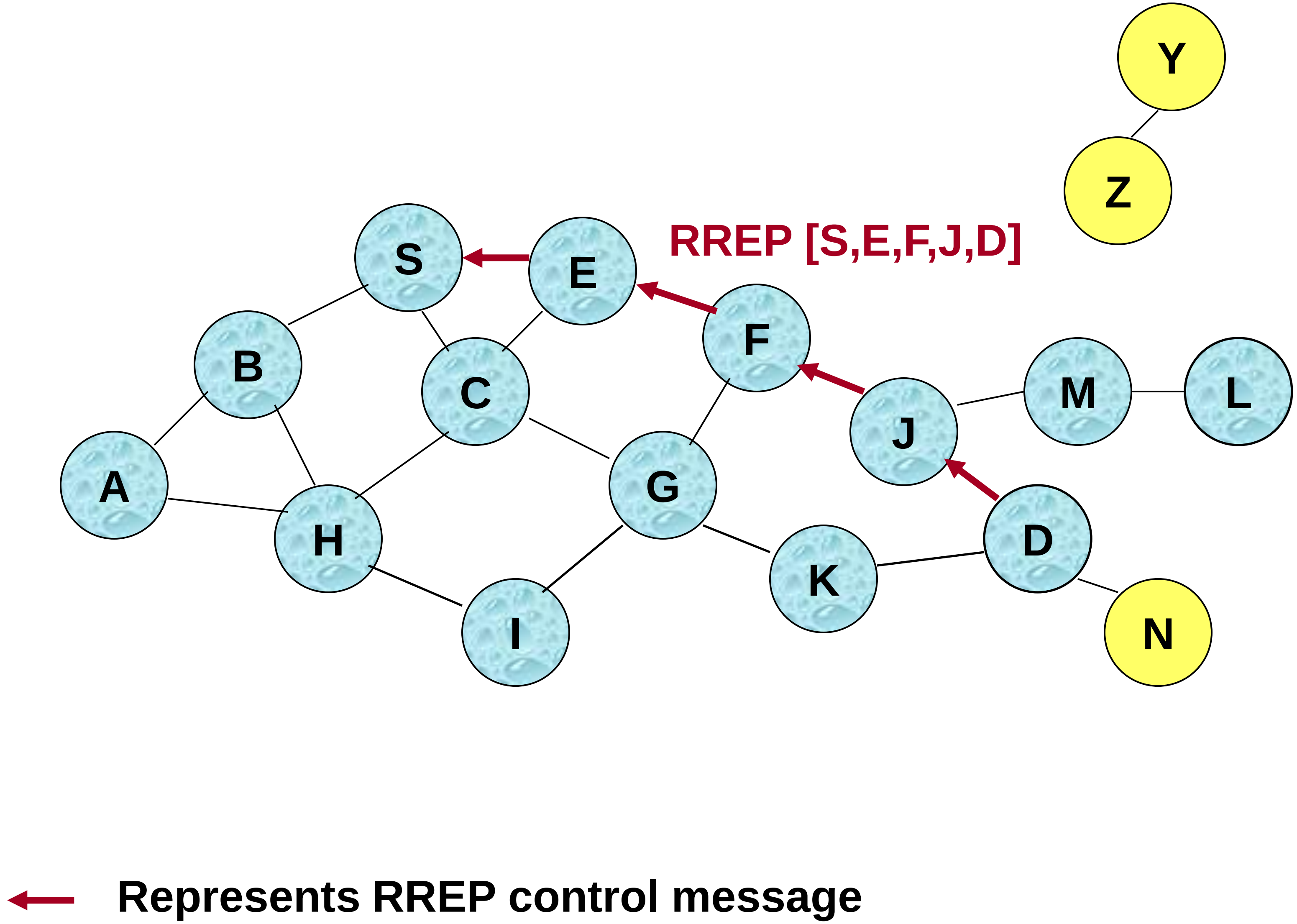


- **Node D** **does not forward** **RREQ, because node D is the** **intended target** **of the route discovery**

Route Discovery in DSR

- Destination D on receiving the first RREQ, sends a Route Reply (RREP)
- RREP is sent on a route obtained by reversing the route appended to received RREQ
- RREP includes the route from S to D on which RREQ was received by node D

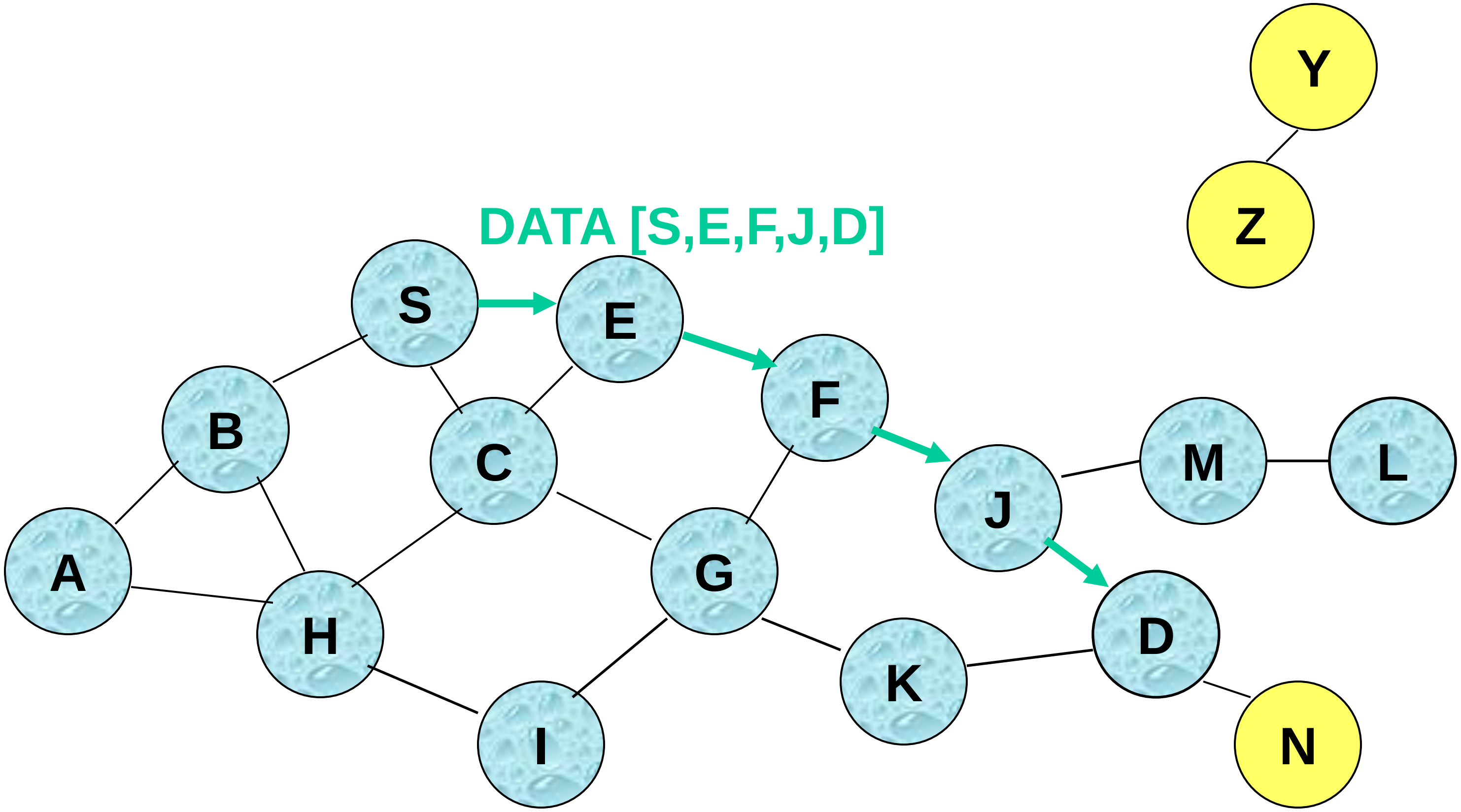
Route Reply in DSR



Dynamic Source Routing (DSR)

- Node S on receiving RREP, caches the route included in the RREP
- When node S sends a data packet to D, the entire route is included in the packet header
  - hence the name source routing
- Intermediate nodes use the source route included in a packet to determine to whom a packet should be forwarded

Data Delivery in DSR



Packet header size grows with route length

DSR Optimization: Route Caching

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

Dynamic Source Routing: Advantages

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

Dynamic Source Routing: Disadvantages

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

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

Proactive Routing Protocols

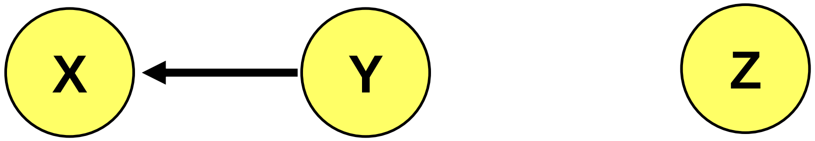
Destination-Sequenced Distance-Vector (DSDV) [Perkins94Sigcomm]

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

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

Destination-Sequenced Distance-Vector (DSDV)

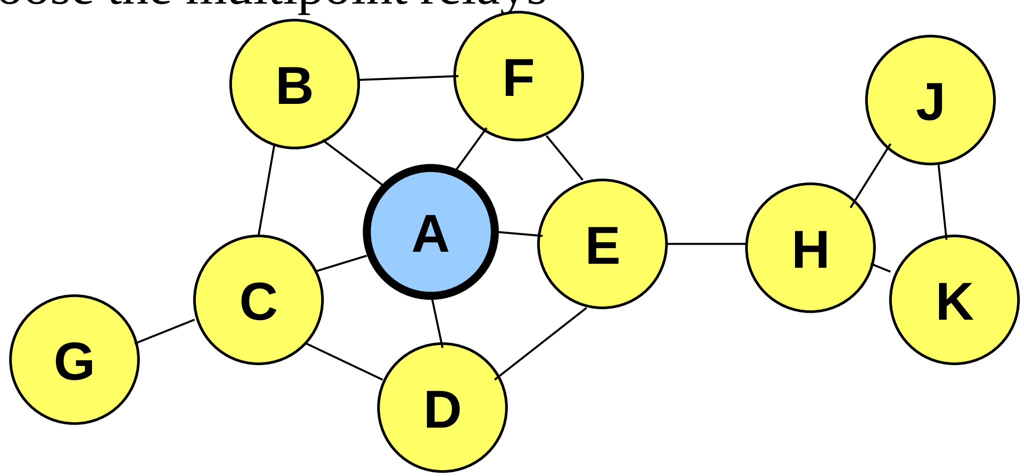
- When X receives information from Y about a route to Z
  - Let destination sequence number for Z at X be S(X), S(Y) is sent from Y

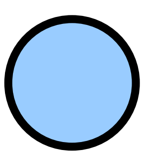


  - If S(X) > S(Y), then X ignores the routing information received from Y
  - If S(X) = S(Y), and cost of going through Y is smaller than the route known to X, then X sets Y as the next hop to Z
  - If S(X) < S(Y), then X sets Y as the next hop to Z, and S(X) is updated to equal S(Y)

Optimized Link State Routing (OLSR) [Jacquet00ietf]

- Nodes C and E are multipoint relays of node A
  - Multipoint relays of A are its neighbors such that each two-hop neighbor of A is a one-hop neighbor of one multipoint relay of A
  - Nodes exchange neighbor lists to know their 2-hop neighbors and choose the multipoint relays

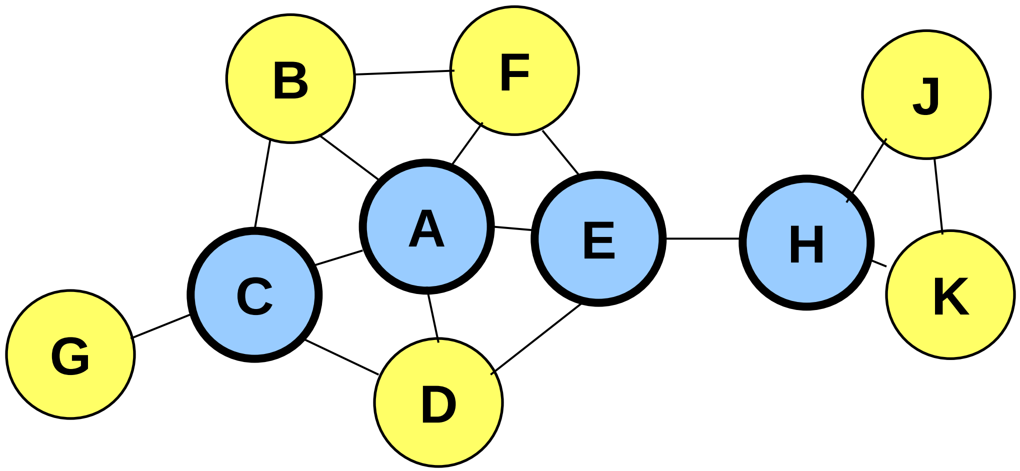


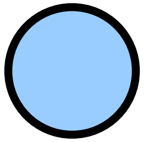


Node that has broadcast state information from A

Optimized Link State Routing (OLSR)

- Nodes C and E forward information received from A
- Nodes E and K are multipoint relays for node H
- Node K forwards information received from H





Node that has broadcast state information from A

Hybrid Routing Protocols

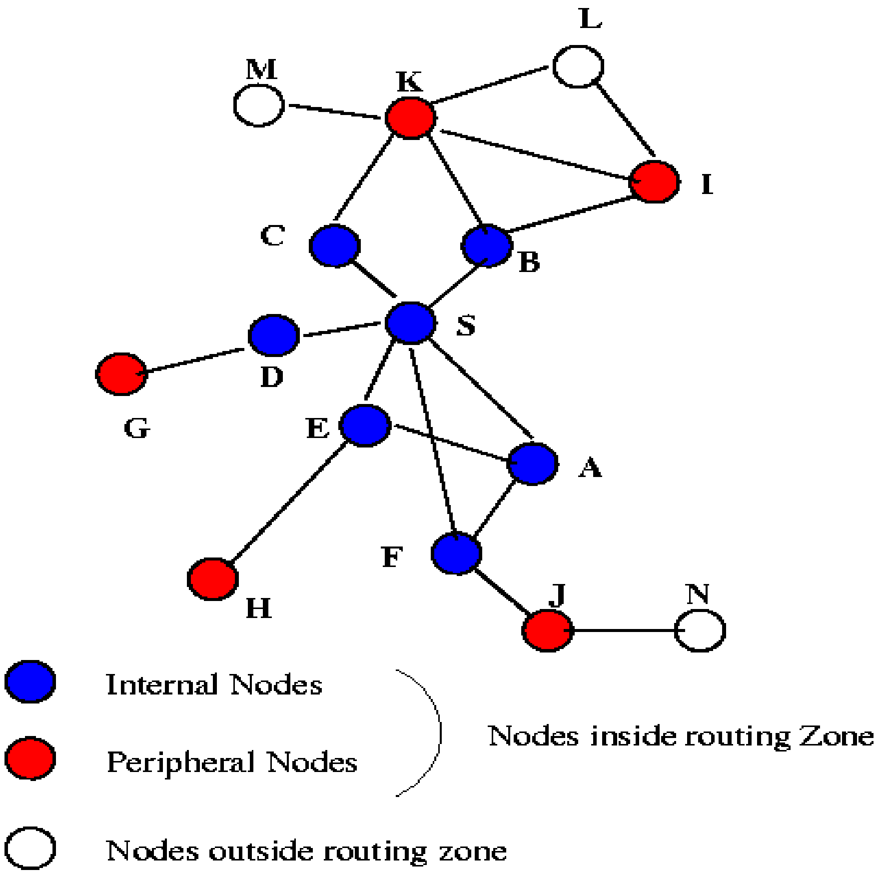
Zone Routing Protocol (ZRP) [Haas98]

- ZRP combines proactive and reactive approaches

- All nodes within hop distance at most *d* from a node X are said to be in the routing zone of node X
- All nodes at hop distance exactly *d* are said to be peripheral nodes of node X's routing zone

- Intra-zone routing: Proactively maintain routes to all nodes within the source node's own zone.
- Inter-zone routing: Use an on-demand protocol (similar to DSR or AODV) to determine routes to outside zone.

Zone Routing Protocol (ZRP)



Radius of routing zone = 2

Routing Summary

- Protocols
  - Typically divided into proactive, reactive and hybrid
  - Plenty of routing protocols. Discussion here is far from exhaustive
- Performance Studies
  - Typically studied by simulations using ns, discrete event simulator
  - Nodes (10-30) remains stationary for pause time seconds (0-900s) and then move to a random destination (1500m X300m space) at a uniform speed (0-20m/s). CBR traffic sources (4-30 packets/sec, 64-1024 bytes/packet)
  - Attempt to estimate latency of route discovery, routing overhead …
- Actual trade-off depends a lot on traffic and mobility patterns
  - Higher traffic diversity (more source-destination pairs) increases overhead in on-demand protocols
  - Higher mobility will always increase overhead in all protocols

References

- http://www.it.iitb.ernet.in.in/~sri
- IEEE 802.11 Wireless LAN
- VANET