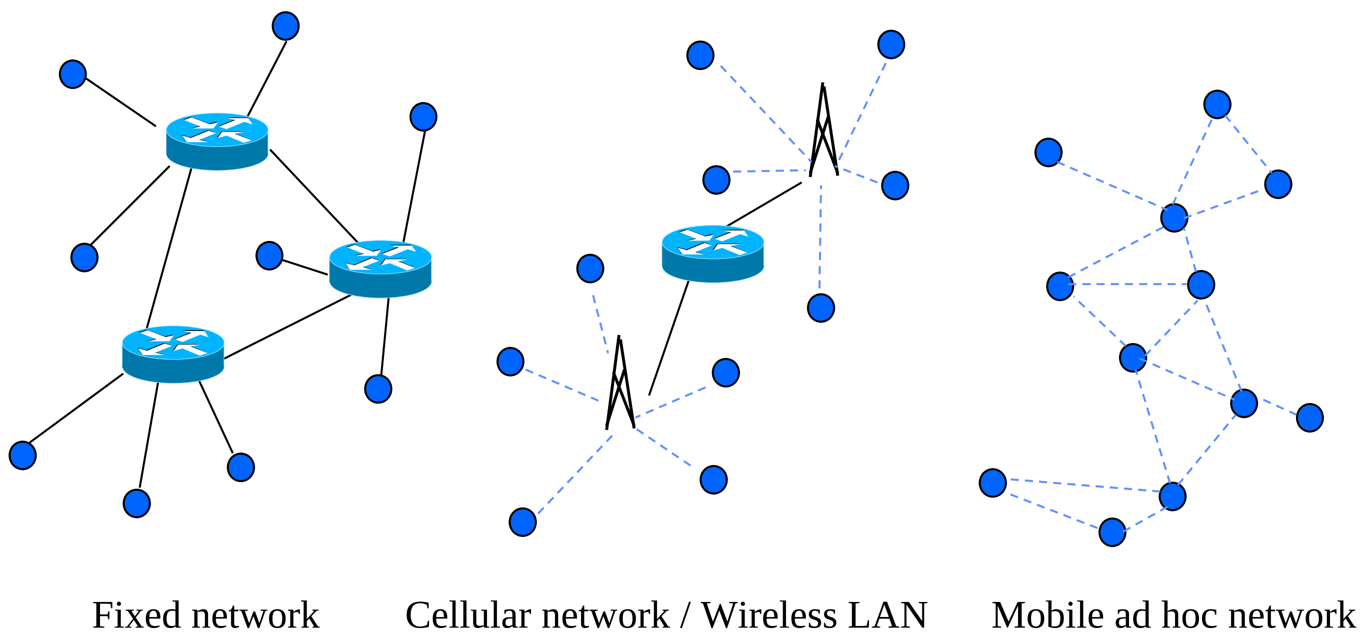
Routing In Ad Hoc Networks

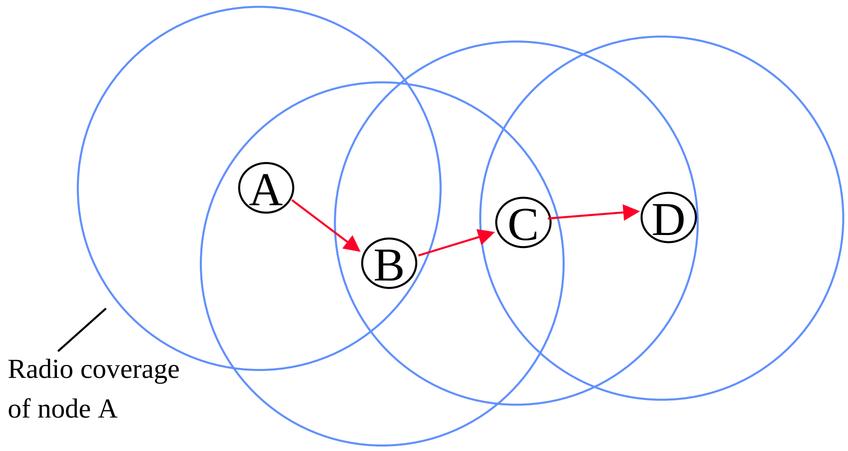
1. Introduction to Ad-hoc networks
2. Routing in Ad-hoc networks
3. Proactive routing protocols
   - DSDV
4. Reactive routing protocols
   - DSR, AODV
5. Non-uniform routing protocols
   - ZRP, CEDAR
6. Other approaches
   - Geographical routing

Introduction – fixed and wireless networks



Mobile Ad Hoc Networks (MANETs)

- Network of mobile *wireless* nodes
  - No infrastructure (e.g. basestations, fixed links, routers, centralized servers)
  - Data can be relayed by intermediate nodes
  - Routing infrastructure created dynamically



Traffic from A → D is relayed by nodes B and C

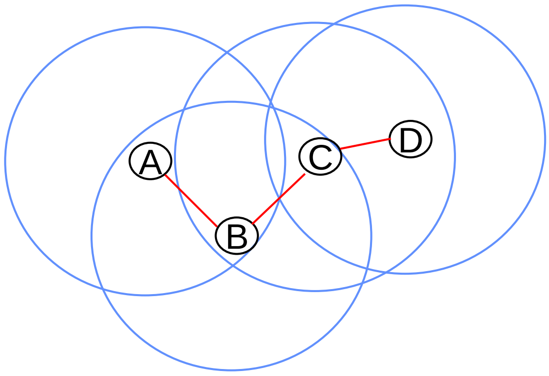
Ad Hoc Networks

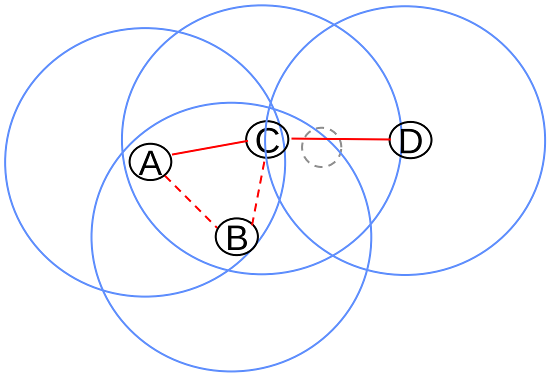
- Characteristics
  - Dynamic topology
  - Links are low bandwidth, variable capacity, sometimes unidirectional
  - Limited battery power and other resources in the nodes
  - More route alternatives (every node is a router)

- Typical applications
  - Military environments (soldiers, tanks, planes)
  - Emergency and rescue operations
  - Meeting rooms
  - Personal area networking, e.g. Bluetooth
  - Wireless home networking
  - Special applications (industrial control, taxis, boats)

Routing in Ad Hoc Networks

- Challenges
  - Dynamic topology
  - Unreliable links
  - Limited resources (battery, processing power)
  - Low link bandwidth
  - Security
  - No default router available
- No physical links
  - Wireless links created and destroyed as nodes move
  - Frequent disconnections and partitions





Traditional routing is proactive

- In proactive routing (table-driven routing), the routing tables are created before packets are sent
  - Link-state (e.g. OSPF)
  - Distance-vector (e.g. RIP)
- Each node knows the routes to all other nodes in the network
- Problems in Ad-Hoc networks
  - Maintenance of routing tables requires much bandwidth
  - Dynamic topology ⇒ much of the routing information is never used
    - ⇒Waste of capacity
  - Flat topology
    - ⇒No aggregation

Reactive routing

- In reactive routing the routes are created when needed
  - Before a packet is sent, a *route discovery* is performed
  - The results are stored in a cache
  - When intermediate nodes move, a *route repair* is required
- Advantages
  - Only required routes are maintained
- Disadvantages
  - Delay before the first packet can be sent
  - Route discovery usually involves flooding

Routing protocols in Ad Hoc Networks

- Many routing protocols have been proposed
  - Both proactive and reactive
  - Some protocols adapted from wired networks, some invented for mobile ad hoc networks
- No single protocol works well in all environment
  - Attempts to combine different solutions, e.g. adaptive and combinations of proactive and reactive protocols
- Standardization in IETF
  - MANET (Mobile Ad hoc Network) working group
    - Currently considered routing protocols: DSR, AODV, OLSR, TBRPF
  - MobileIP

Proactive routing protocols

Destination Sequenced Distance-Vector
(DSDV)

Proactive Ad Hoc routing protocols

- Protocols
  - DSDV (Destination Sequenced Distance-Vector)
  - WRP (Wireless Routing Protocol)
  - GSR (Global State Routing)
  - FSR (Fisheye State Routing)
  - OLSR (Optimized Link State Routing)
- Main principles similar to fixed networks

  ⇒ we will only look at DSDV.

Proactive distance vector protocols

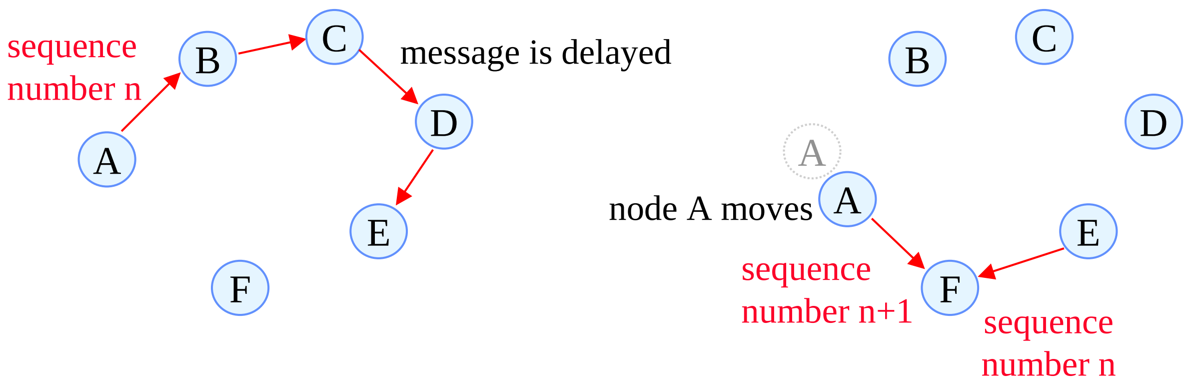
- Problems of distance vector protocols in ad-hoc networks
  - Topology changes are distributed too slowly
  - Moving nodes can create routing loops
    - The connectivity information is not valid at the new place
  - Bandwidth consuming
  - Count-to-infinity problem

Destination Sequenced Distance-Vector (DSDV)

- DSDV is a proactive distance vector protocol
- Improvements for Ad Hoc networks
  - Tagging of distance information
    - Increasing sequence numbers
    - Nodes can discard received old entries and duplicates
  - Delay before sending distance vectors
    - Allows settling
  - Incremental updates are sent instead of full table

Destination Sequenced Distance-Vector (DSDV)

Sequence number example



F can discard message n, although message n+1 reached F before

Reactive routing protocols

Dynamic Source Routing (DSR)

Ad-hoc On-demand Distance Vector Routing (AODV)

Reactive routing – route request

- Also called ”on demand”
- The source must discover a route to the destination
  - The source broadcasts a *route request* message
  - Each node re-broadcasts the route request (flooding), and adds its own address to the path
  - When the destination receives the route request, it generates a *route reply*, which traverses the reverse path back to the source
- Route discovery effectively floods the network with the route request packet

Reactive routing – route maintenance

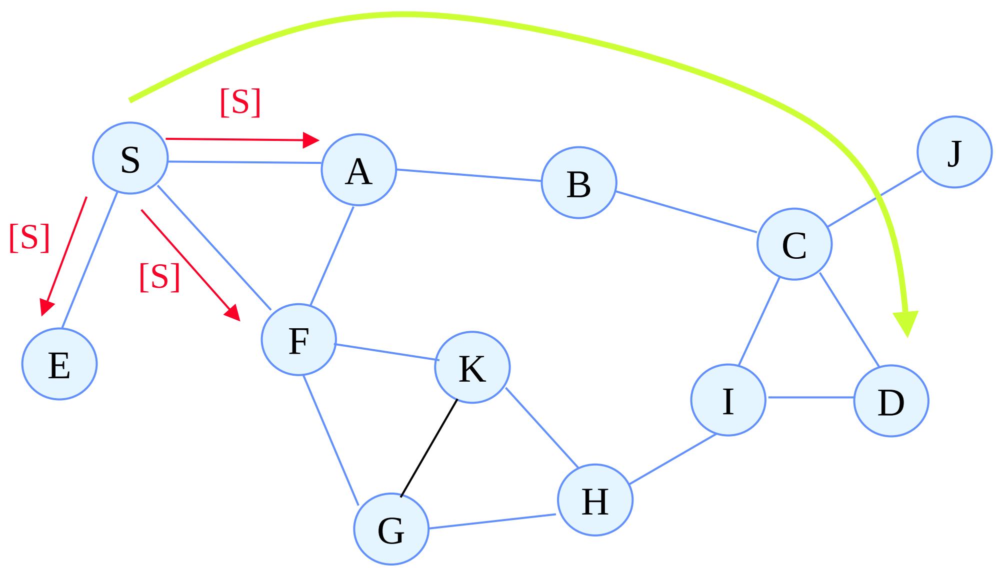
- The source and the intermediate nodes must maintain the route when it is used.
- If the topology changes, the route must be *repaired*
  - The source sends a new route request to the destination
  - Improvement: Intermediate nodes can discover broken links and automatically repair the connection
- Intermediate nodes can remember successful paths
  - If a route request to the destination is received from another node, the intermediate node can answer on behalf of the destination

Reactive routing protocols

- Reactive routing protocols
  - DSR (Dynamic Source Routing)
    - draft-ietf-manet-dsr-09.txt
  - AODV (Ad-hoc On-demand Distance Vector)
    - RFC 3561 (experimental)
  - TORA (Temporally Ordered Routing Algorithm)
  - ABR (Associativity Based Routing)
- We only look at a a few (DSR, AODV)

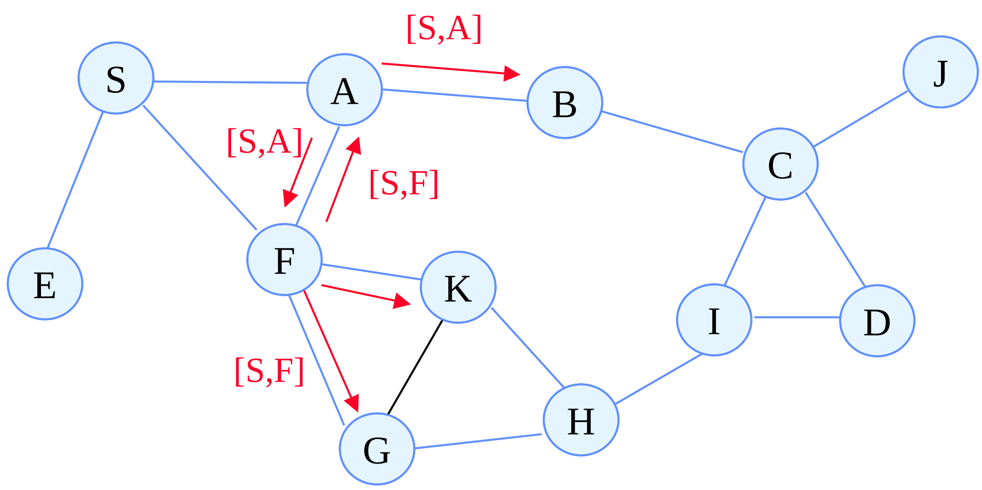
DSR – Dynamic Source Routing Example

Source node S floods a Route Request (RREQ)



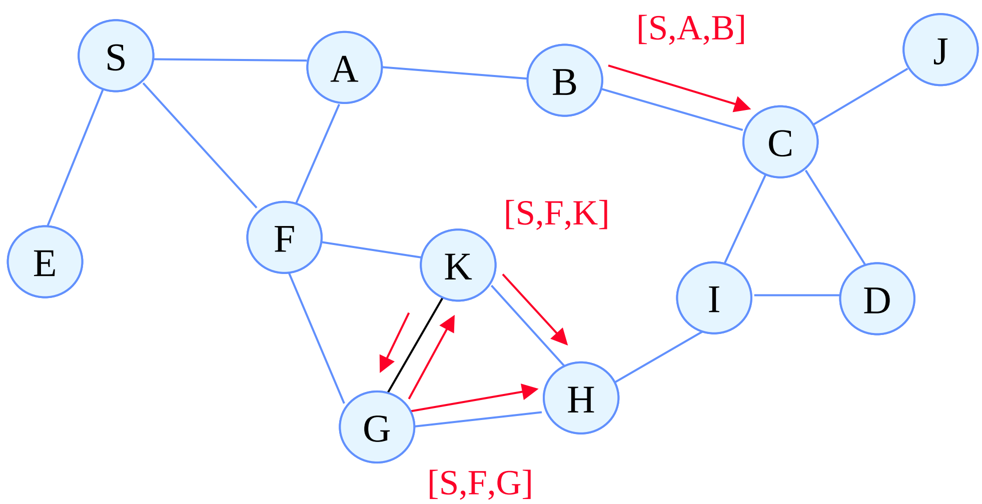
DSR – Dynamic Source Routing Example

Nodes receiving the Route Request forward it to their neighbors



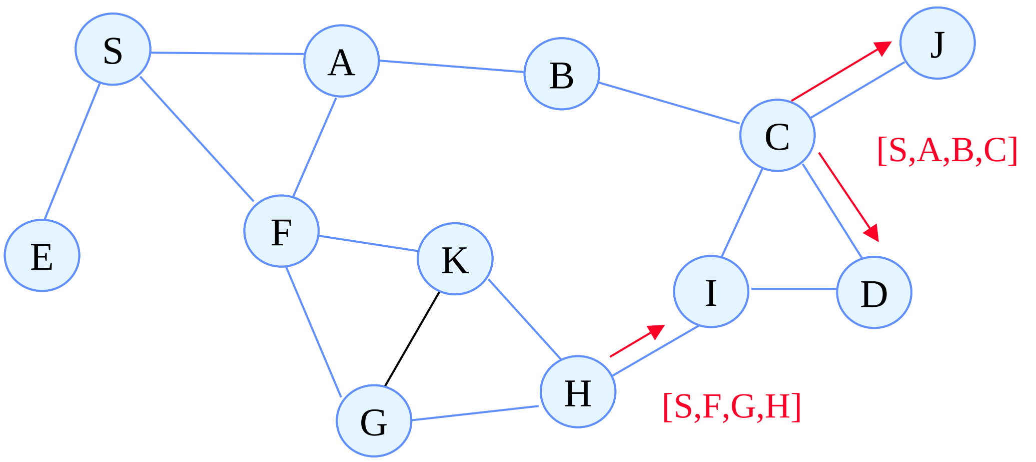
DSR – Dynamic Source Routing Example

The process is repeated



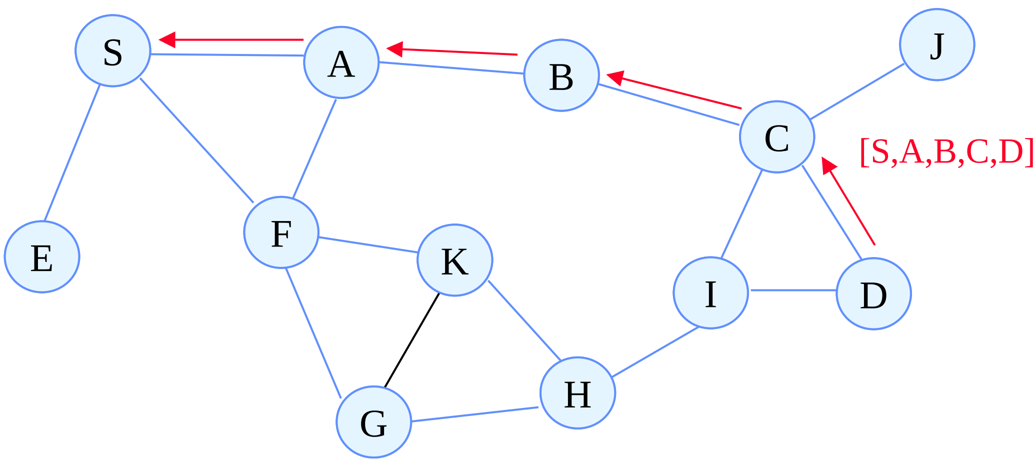
DSR – Dynamic Source Routing Example

The destination node receives the Route Request



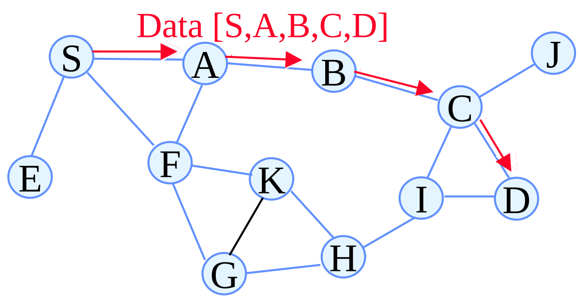
DSR – Dynamic Source Routing Example

The destination generates a Route Reply (RREP), which is forwarded back to the source along the reversed path.



DSR – Dynamic Source Routing

- The source node caches the path received in the RREP
- The entire route is included in packets sent from S
  ⇒ Source routing
- The source node also learns the routes to the intermediate nodes
  – S also learns route to A, B and C
- Intermediate nodes learn routes to nodes in forwarded RREQ and RREP packets
  – Node B learns route to S, A, C and D

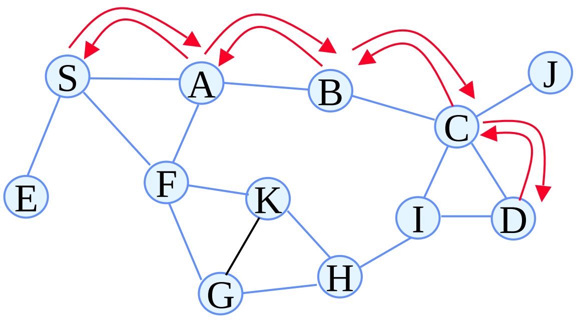


DSR Properties

- Advantages
  – Only the communicating nodes need to maintain the route
  – Several alternative routes to the destination
  – Intermediate nodes can reply to requests using their cache
- Problems
  – Long routes ⇒ Long packets
  (Large overhead in e.g. small voice packets)
  – Route request is flooded to the whole network
  (Can be limited with expanding ring search)
  – Contention if too many nodes reply
  – Stale caches

AODV – Ad-hoc On-demand Distance Vector Routing

- Aims to reduce packet size by maintaining the route in the intermediate nodes as distance vectors
- Route request (RREQ) flooded similarly to DSR
- When the route reply (RREP) is relayed, the intermediate node record the next hop in their forwarding table
- The forwarding table has entries for both directions
- Entries in the forwarding table time out when not used



Destination	Next hop
D	C
S	A

Routing table of B

AODV routing table

For each routing table entry

- Destination IP address
- Destination sequence number
- Interface
- Hop count
- Next hop
- List of precursors
- Lifetime
- Flags
  - valid destination sequence number
  - valid, invalid, repairable, being repaired

The entries are identified with destination sequence numbers

- Sequence number are used to
  - Prevent routing loops
  - Avoid old and broken routes
- The destination generates the sequence number and includes it in the reply
- If two routes are available, the requesting node selects the one with greatest sequence number
- The requesting node gives a minimum sequence number
  - Intermediate nodes can reply only if it has a route with at least the given minimum number

Route requests

- A node sends a route request when it needs a route to a destination and does not have one
- Destination number in RREQ is the last known number for the destination (may be unknown)
- Expanding ring search
- Waiting packets are queued during the route request
- Intermediate nodes
  - Discards duplicate requests
  - Creates an entry towards the requester (sequence number from RREQ)
    - Used for reply
  - Creates an entry to the previous hop (no sequence number)
  - Replies if it has an active route with requested or higher sequence number
  - Otherwise broadcasts the request on all interfaces

Route replies

- If the destination replies
  - The sequence number is first incremented if it is equal to the number in the request
  - RREP contains the current sequence number, hop count = 0, full lifetime
- If an intermediate node replies
  - The sequence number, hop count and lifetime are copied from the routing table to the RREP
  - It may be necessary to unicast a gratuitous RREP to the destination so it learns the path to the requester
- The intermediate nodes update their routing table (this is simplified)
  - The RREP is forwarded to the originator
  - The next hop to the originator is added to the precursor list

Route errors are reported

- Neighboring nodes with active routes periodically exchange Hello messages
- If a next hop link in the routing table fails, the active neighbors are informed
  - A neighbor is considered active for an entry, if the neighbor sent a packet within a timeout interval that was forwarded using the entry.
  - The RERR indicates the unreachable destinations
  - The sequence number for the destinations using the link is increased
- A Route Error (RERR) message is also generated if a node is unable to relay a message
- The source performs a new route request when it receives a RERR
- An intermediate node can perform a local repair

Non-uniform protocols

Zone Routing Protocol (ZRP)

Clustering routing protocols

Non-uniform protocols

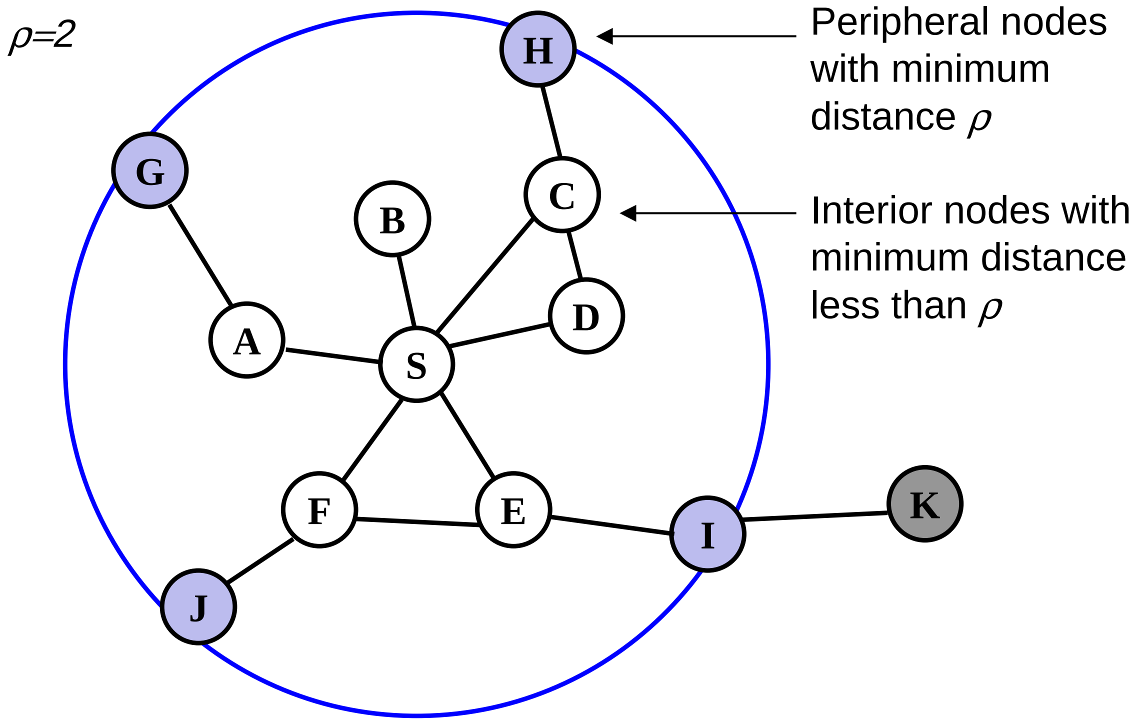
- The previously discussed (uniform) protocols scales to networks with less than 100 nodes
- Larger networks (up to 1000 nodes) require hierarchy
- Two approaches

  1. Neighbor selection
     - Routing activity is focused on a subset of the neighbors
       - Zone Routing Protocol (ZRP)
       - Optimized Link State Routing (OLSR)
       - Fisheye State Routing (FSR)
  2. Partitioning
     - The network is topologically partitioned
       - Core Extraction Distributed Ad-hoc Routing (CEDAR)
       - Cluster Based Routing Protocol (CBRP)

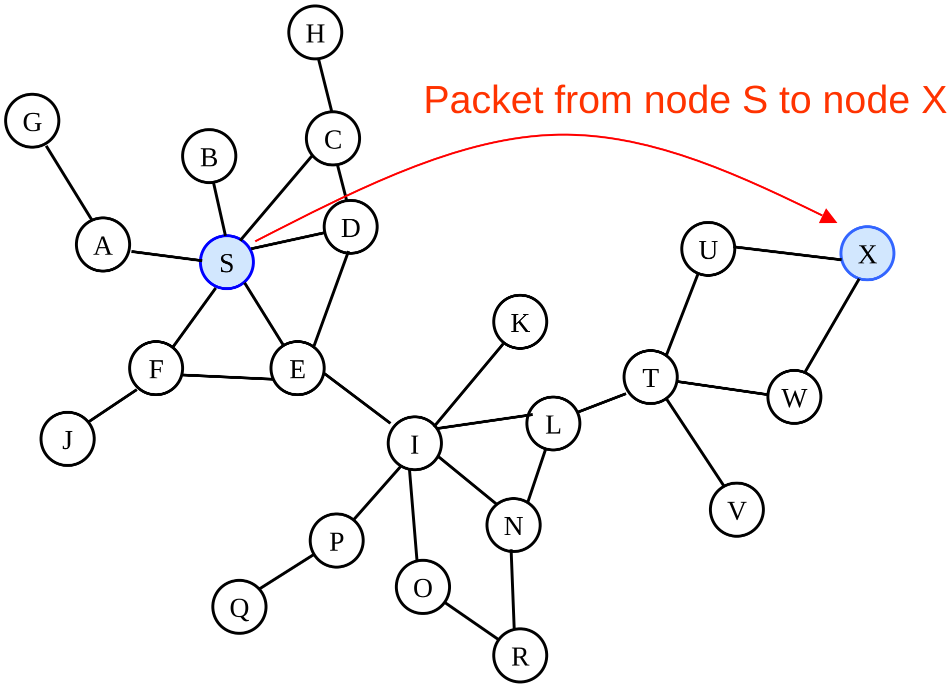
ZRP – Zone Routing Protocol

- Based on the concept of zones
  - Every node has a zone, with a specific zone radius
  - Zone radius given as hop count
  - The zones of neighboring nodes overlap
- Proactive routing used within the zone
  - Packets are most likely sent to nearby located destinations
  - Reduces the topology maintenance costs to a limited zone
- Reactive routing used outside the zone
  - Uses local topology information → not all nodes are queried
  - Bordercasting sends the route request to the border of the zone

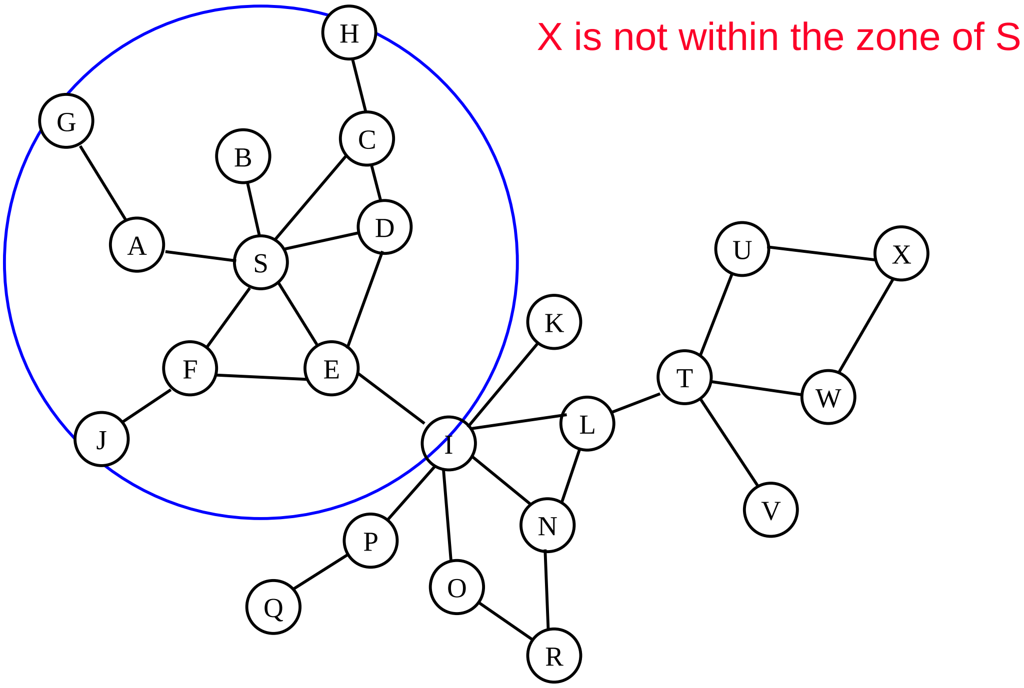
ZRP – Zone Routing Protocol



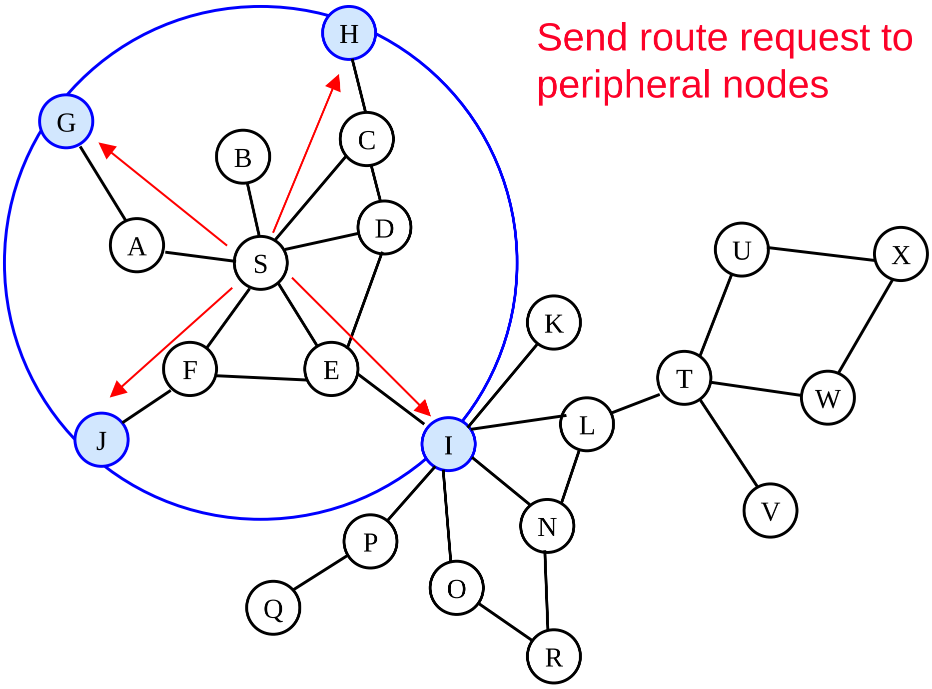
ZRP Example (1)



ZRP Example (2)

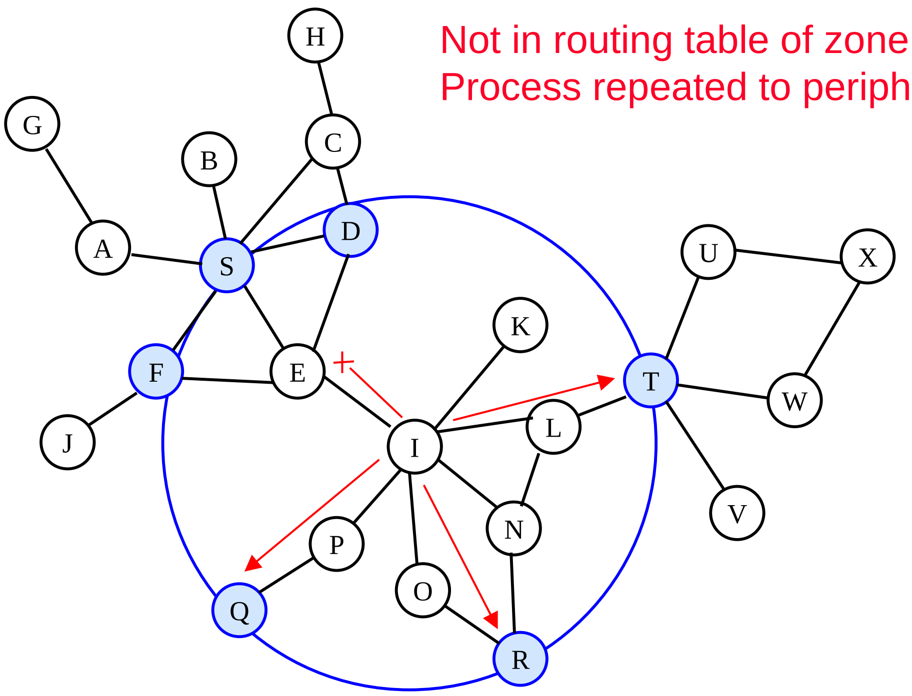


ZRP Example (3)



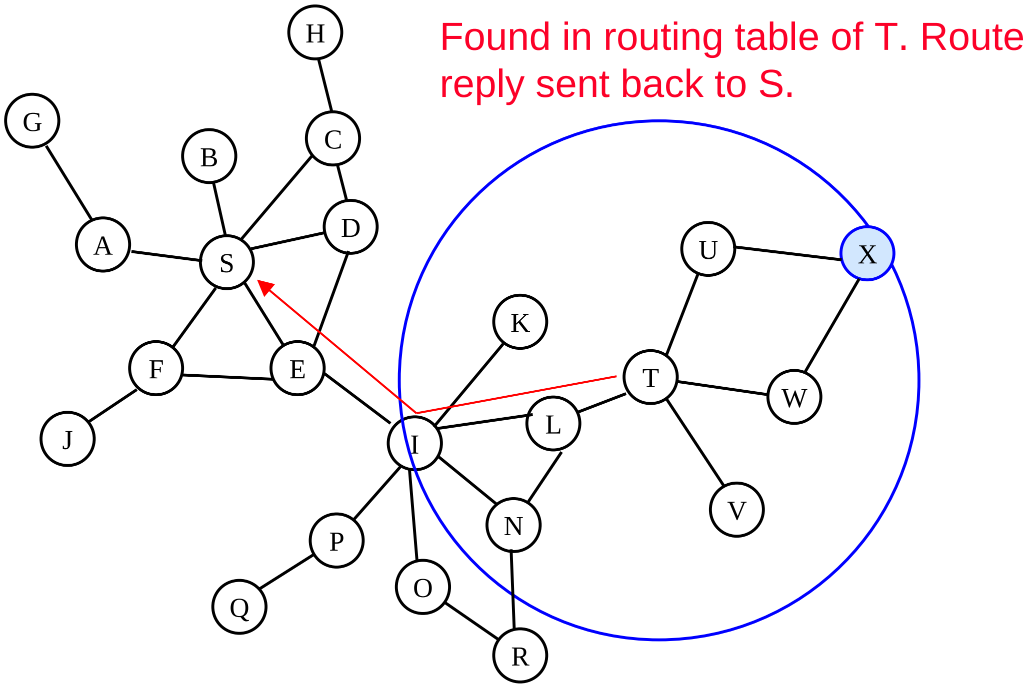
Send route request to peripheral nodes

ZRP Example (4)



Not in routing table of zone of I.
Process repeated to peripheral nodes.

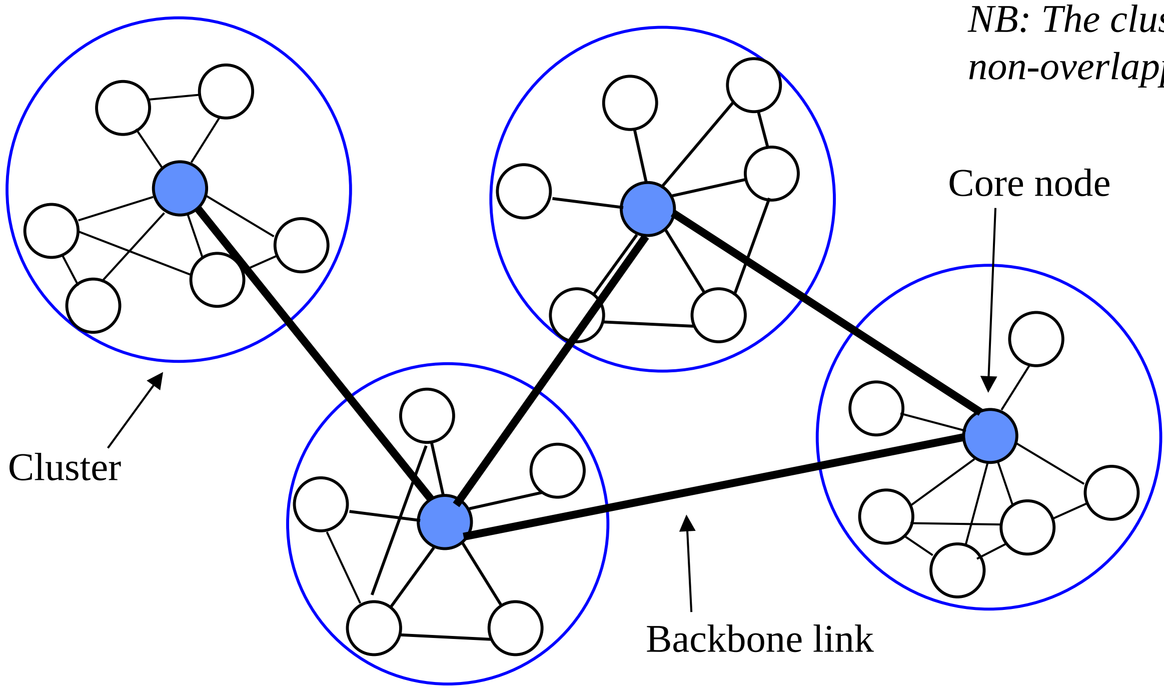
ZRP Example (5)



Clustering Routing Protocols

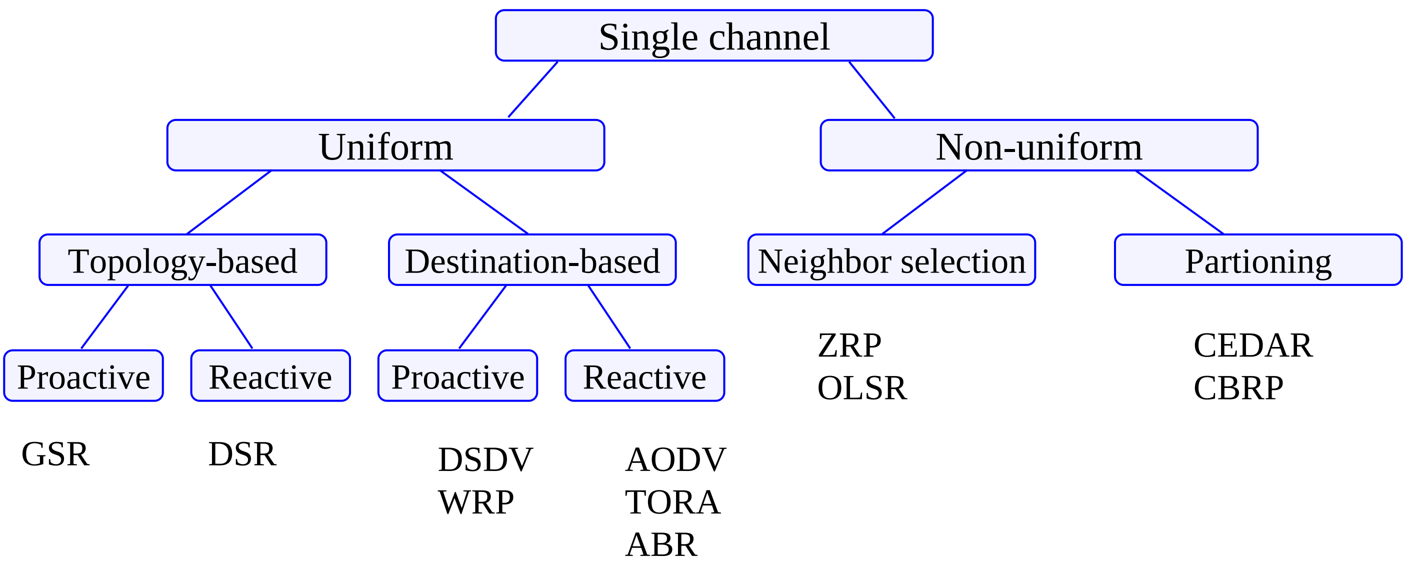
E.g. Core-Extraction Distributed Ad hoc Routing (CEDAR)

NB: The clusters are non-overlapping!



Summary, other approaches

Routing Protocol Classification



[L.M. Feeney, SICS]

Other routing approaches

- Geographical Routing
  - Utilize location information in routing
- Associativity-Based Routing (ABR)
  - Only links that have been stable for some time are used
- Multicasting in Ad hoc networks

Geographical routing in Ad hoc networks

- All nodes know their position (GPS, relative position)

1. Locating the destination (given the address, obtain the location)
   - ➢ Location service
     - Grid's Location Service (GLS)
   - ➢ Location updates
     - Predictive Location-based QoS Routing (PLQR)
     - Nodes send location updates periodically (interval depends on speed)
     - Extra updates are sent when velocity or direction changes
2. Routing to a destination (given the location, route the packet)
   - Geographical Routing Algorithm (GRA)
   - Each node routes the packet to the node that is closer to the destination than itself
   - Route discovery (flooding) if there is no node closer