Routing In Ad Hoc Networks

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2. Proactive routing protocols
   - OLSR
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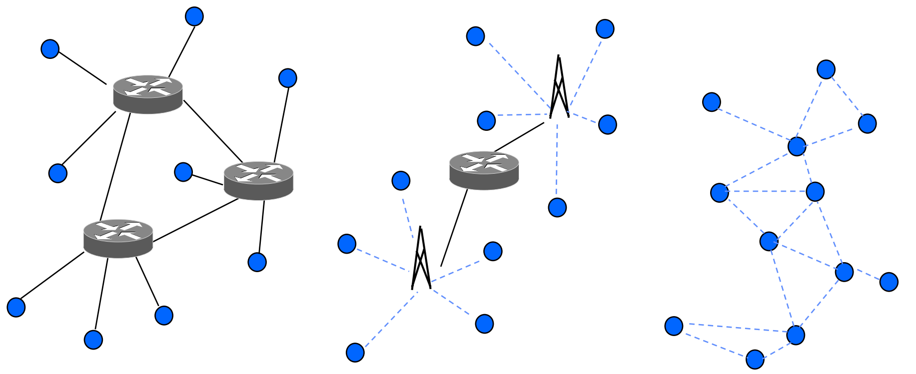
Material

- RFC 3561 - Ad hoc On-Demand Distance Vector (AODV) Routing
  – rfc3561.txt
- Dynamic Source Routing Protocol for Mobile Ad Hoc Networks
  – draft-ietf-manet-dsr-10.txt
- The Zone Routing Protocol (ZRP) for Ad Hoc Networks
  – draft-ietf-manet-zone-zrp-04.txt
- Charles E Perkins: Ad Hoc Networking

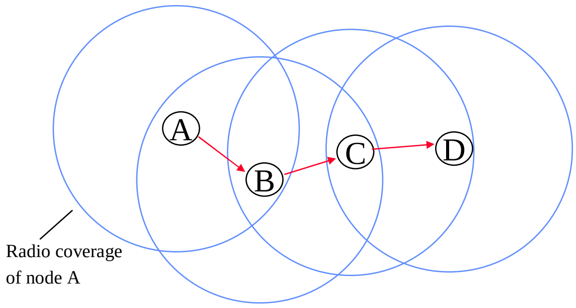
Introduction – fixed and wireless networks



Fixed network   Cellular network / WLAN   Mobile ad hoc network

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

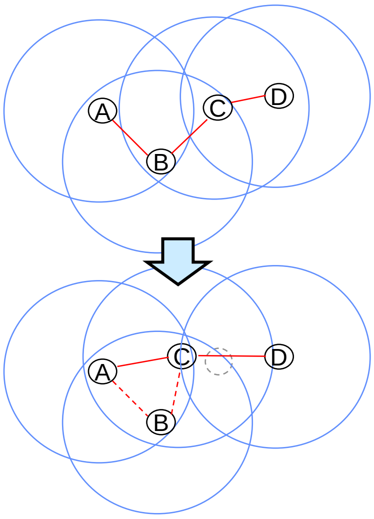
Ad Hoc Networks

- Characteristics
  - Dynamic topology (a “link” exists if two nodes have radio connectivity)
  - Links are low bandwidth, variable capacity, sometimes unidirectional
  - Limited battery power and other resources in the nodes
  - Many route alternatives (every node is a router)

- Typical applications
  - Military environments (soldiers, tanks, airplanes)
  - 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
    - ⇒Host-specific routes, no aggregation

Reactive routing works better in dynamic environments

- In *reactive routing* (on-demand routing) the routes are created when needed
  - Before a packet is sent, a *route discovery* is performed to find the destination
  - The route is stored in a cache as long as it is used
  - 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

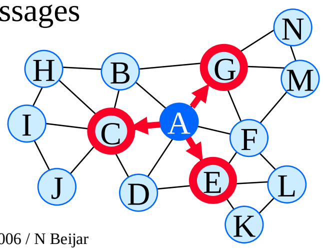
- Many routing protocols have been proposed
  - Both proactive and reactive
  - Some protocols adapted from wired networks, some invented for mobile ad hoc networks
- No single protocol works well in all environment
  - Depends on traffic patterns, density of nodes, degree of mobility, etc.
  - Attempts 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 in ad hoc networks

- Protocols
  - DSDV (Destination Sequenced Distance-Vector)
  - WRP (Wireless Routing Protocol)
  - GSR (Global State Routing)
  - FSR (Fisheye State Routing)
  - OLSR (Optimized Link State Routing)
    - RFC 3626, draft-ietf-manet-olsrv2-02.txt

Optimized Link State Routing (OLSR) is a proactive link state protocol

- Reduces the traffic by using *Multipoint Relays* (MPR)
  - A MPR is a neighbor which is chosen to forward packets
  - The MPRs are selected as the minimal set of one-hop neighbors that covers all two-hop neighbors of a node
  - Packets are only forwarded by the MPRs ⇒ reduces overhead
  - Information for selecting MPRs is gathered from Hello messages



Node A has chosen neighbors C, E and G as its MRP, because they cover all two-hop neighbors (H to N)

OLSR messages

- *Hello messages* are sent periodically to all neighbors
  - Contains information about neighbors, nodes chosen as MPR, list of neighbors without bidirectional connectivity
  - Bidirectional connectivity declared when own address is included in Hello message sent by the neighbor
- *Topology Information* messages are periodically flooded to the network
  - Contains the neighbors that selected this node as their MPR
  - Describes the topology
- *Multiple Interface Declaration* messages are flooded by nodes with OLSR running on several interfaces

OLSR

- Routing table is calculated from the learned information
  - Neighbors learned from Hello messages
  - Other nodes learned from Topology Information messages
- OLRS is suitable for large and dense networks that are not too dynamic

Reactive routing protocols in ad hoc networks

- Reactive routing protocols
  - DSR (Dynamic Source Routing)
    - draft-ietf-manet-dsr-10.txt
  - AODV (Ad-hoc On-demand Distance Vector)
    - RFC 3561
  - DYMO (Dynamic MANET On-demand)
    - draft-ietf-manet-dymo-02
  - TORA (Temporally Ordered Routing Algorithm)
  - ABR (Associativity Based Routing)

Route discovery in reactive routing protocols is based on flooding

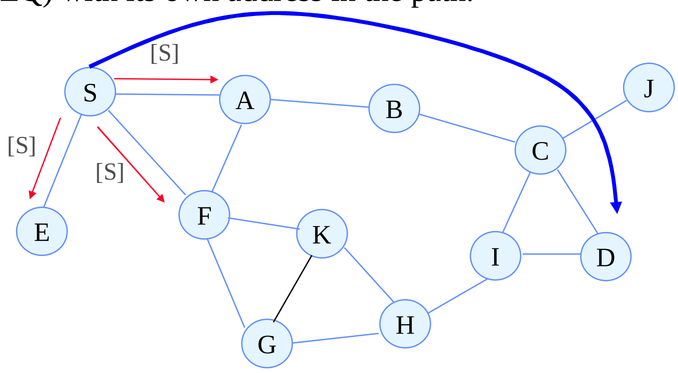
- The source must discover a route to the destination
  - The source broadcasts a *route request* message with an empty path field
  - Each node re-broadcasts the route request if it is has not been seen before, and adds its own address to the path field
  - When the destination receives the route request, it generates a *route reply*, which traverses the reverse path back to the source
  - The route is learned by the source or by the intermediate nodes
- 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 route is broken due to 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 locally 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

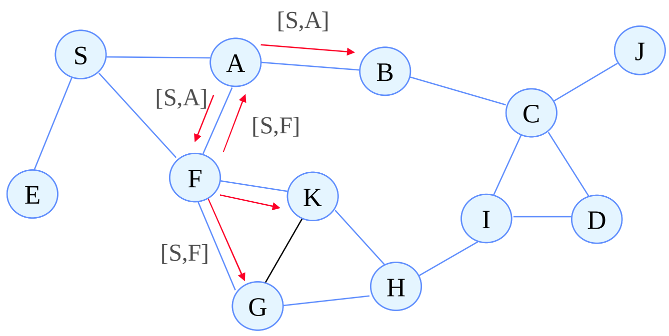
Example reactive protocol: Dynamic Source Routing (DSR)

Source node S has a packet to send to D. It floods a Route Request (RREQ) with its own address in the path.



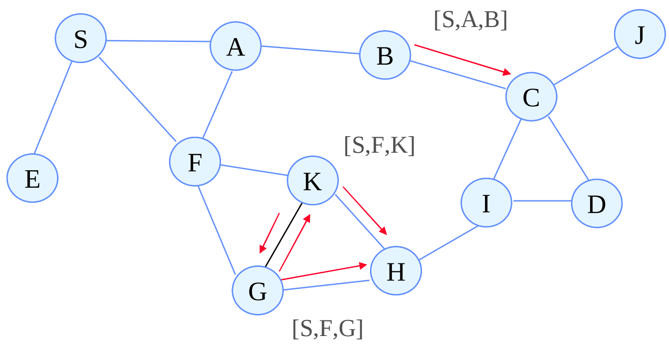
Example reactive protocol: Dynamic Source Routing (DSR)

Nodes receiving the Route Request inserts their address to the path and forward the request to their neighbors.



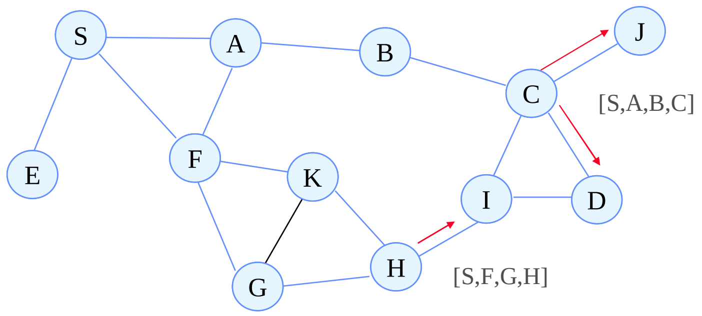
Example reactive protocol: Dynamic Source Routing (DSR)

The process is repeated…



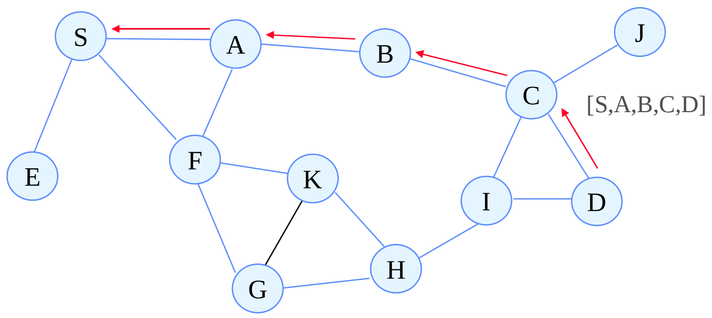
Example reactive protocol: Dynamic Source Routing (DSR)

Finally the destination node receives the Route Request



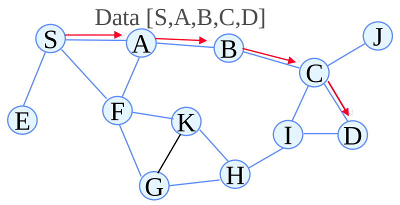
Example reactive protocol: Dynamic Source Routing (DSR)

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



Dynamic Source Routing (DSR) is based on 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

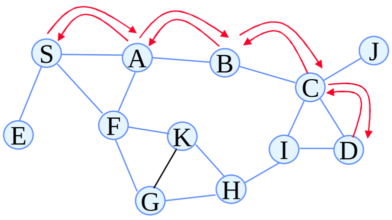


Properties of DSR

- 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)
  - Congestion if too many nodes reply
  - Stale caches

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

- 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 insert the route into their routing table
- The routing 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 (see next slide)
- Interface
- Hop count
- Next hop
- List of precursors (neighbors using it as their next hop)
- Lifetime (old entries time out)
- Flags
  - valid destination sequence number
  - valid, invalid, repairable, being repaired

The entries are identified with destination sequence numbers

- Sequence numbers 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 highest 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

AODV 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

AODV
Route replies

- If the destination replies
  - The current sequence number of the destination 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

AODV
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 with a *Route Error* (RERR) message
  - 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 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

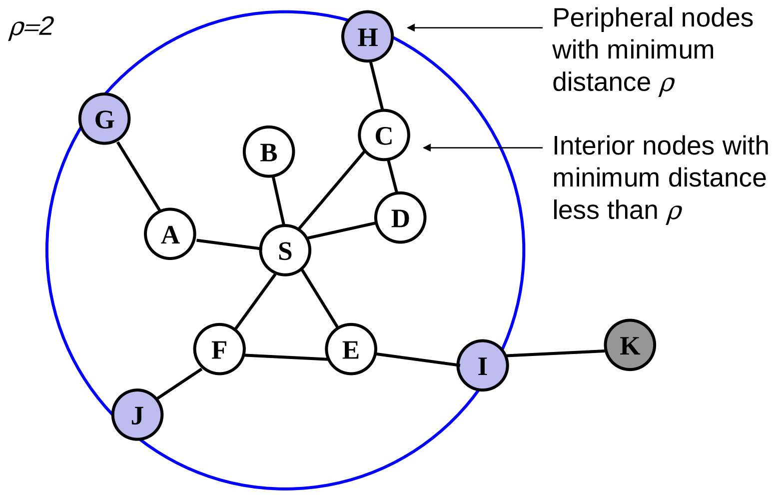
Non-uniform protocols

- 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)

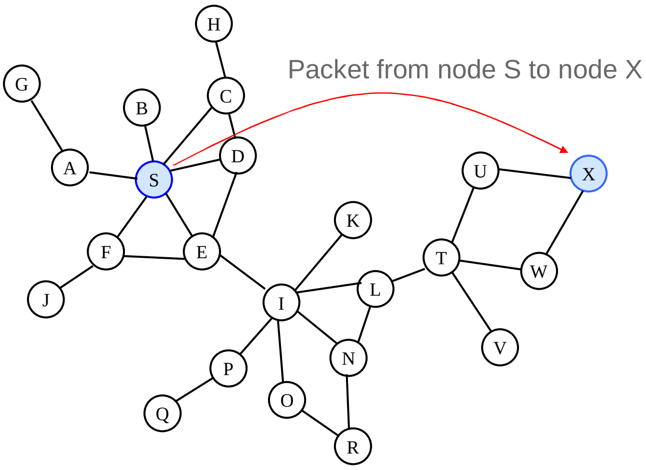
ZRP – Zone Routing Protocol

- Based on the concept of zones
  - Every node has a zone consisting of the surrounding nodes within ρ hops from it
  - The zone radius (ρ) is a network-wide parameter
  - 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

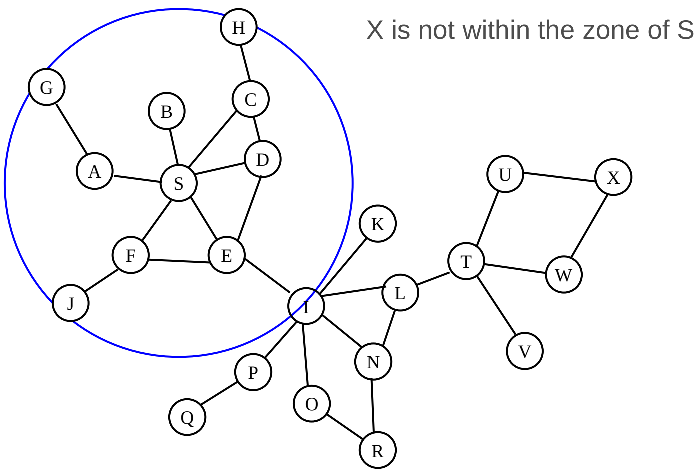
ZRP – Zone Routing Protocol



ZRP Example (1)

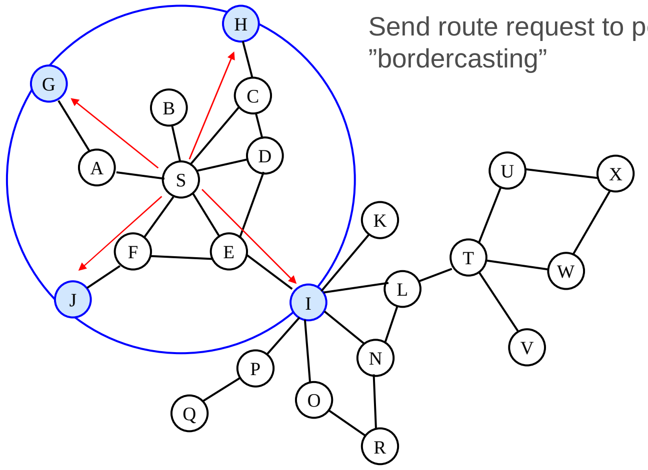


ZRP Example (2)



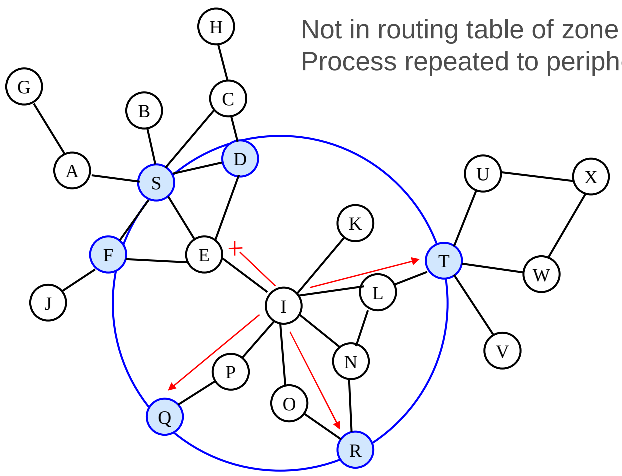
ZRP Example (3)

Send route request to peripheral nodes
”bordercasting”



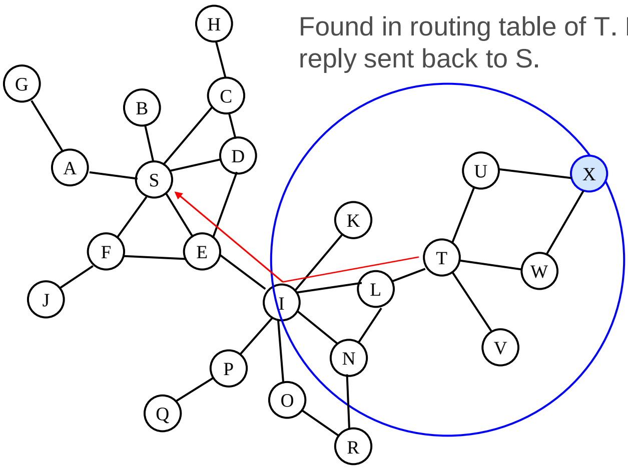
ZRP Example (4)

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



ZRP Example (5)

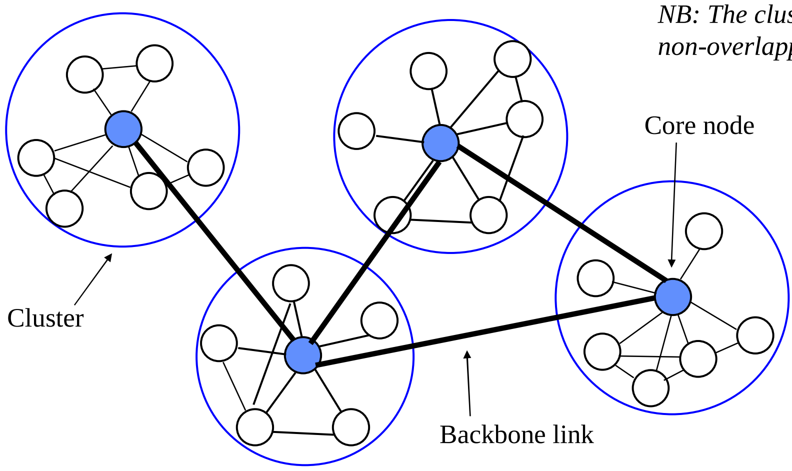
Found in routing table of T. Route reply sent back to S.



Clustering Routing Protocols

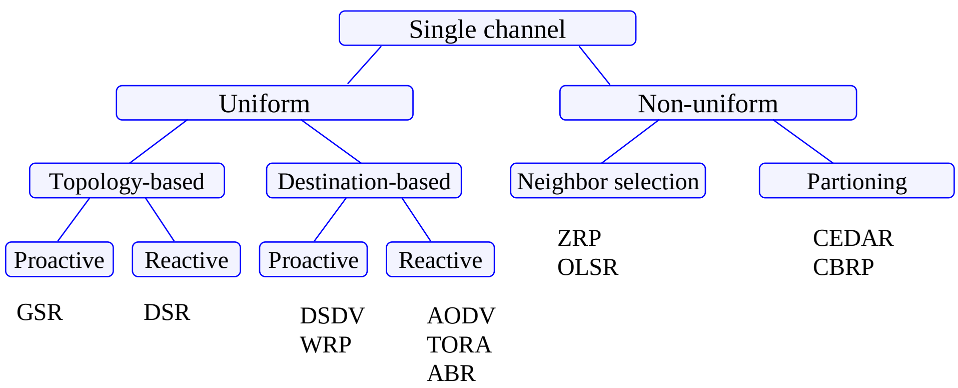
E.g. Core-Extraction Distributed Ad hoc Routing (CEDAR)

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

Good luck in the exam!