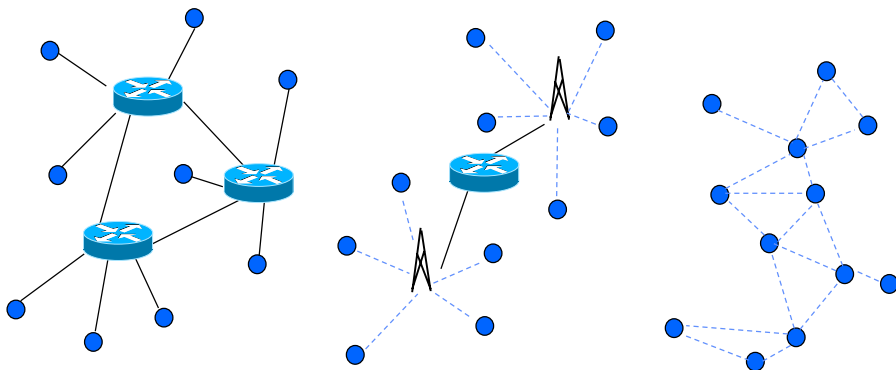


Routing In Ad Hoc Networks

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



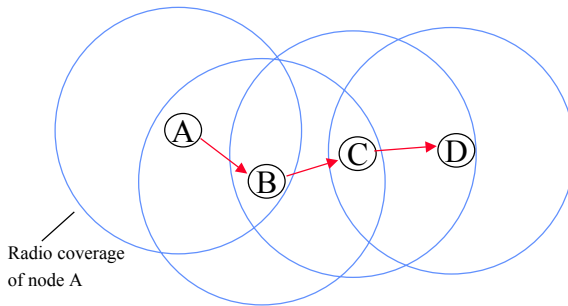
Fixed network

Cellular network / Wireless LAN

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

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AdHoc-3

Ad Hoc Networks

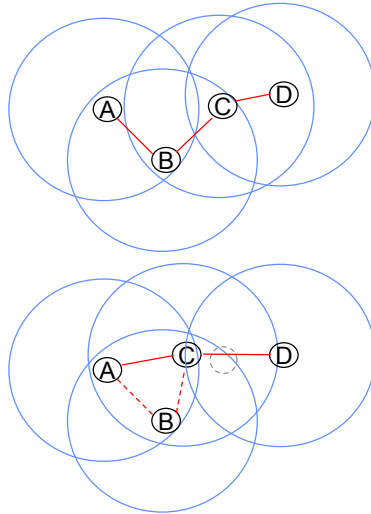
- Characteristics
 - Dynamic topology
 - Links are low bandwidth, variable capacity, sometimes unidirectional
 - Limited battery power and other resources in the nodes
 - More route alternatives (every node is a router)
- Typical applications
 - Military environments (soldiers, tanks, planes)
 - Emergency and rescue operations
 - Meeting rooms
 - Personal area networking, e.g. Bluetooth
 - Wireless home networking
 - Special applications (industrial control, taxis, boats)

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AdHoc-4

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



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AdHoc-5

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 \Rightarrow much of the routing information is never used
 - \Rightarrow Waste of capacity
 - Flat topology
 - \Rightarrow No aggregation

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AdHoc-6

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

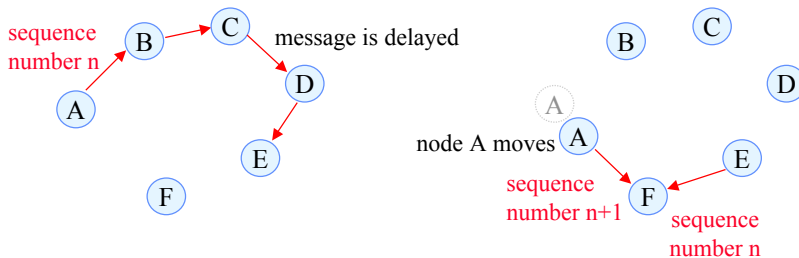
- Problems of distance vector protocols in ad-hoc networks
 - Topology changes are distributed too slowly
 - Moving nodes can create routing loops
 - The connectivity information is not valid at the new place
 - Bandwidth consuming
 - Count-to-infinity problem

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

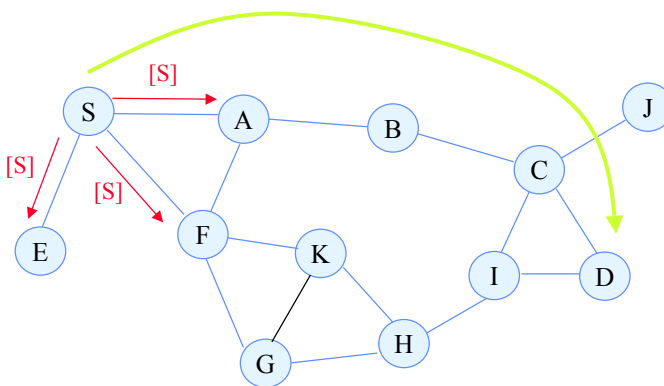
- The source and the intermediate nodes must maintain the route when it is used.
- If the topology changes, the route must be *repaired*
 - The source sends a new route request to the destination
 - Improvement: Intermediate nodes can discover broken links and automatically repair the connection
- Intermediate 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 few (DSR, AODV)

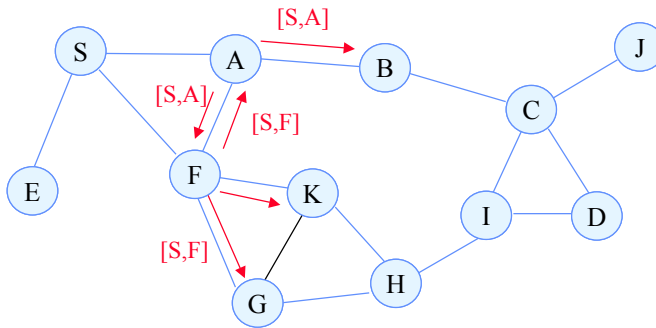
DSR – Dynamic Source Routing Example

Source node S floods a Route Request (RREQ)



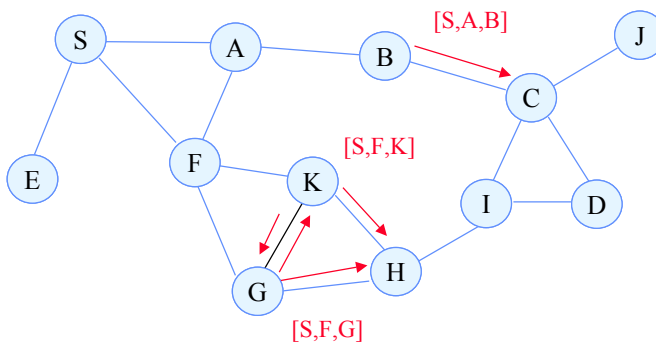
DSR – Dynamic Source Routing Example

Nodes receiving the Route Request forward it to their neighbors



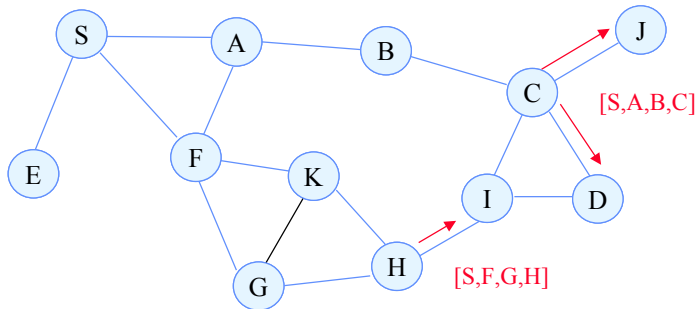
DSR – Dynamic Source Routing Example

The process is repeated



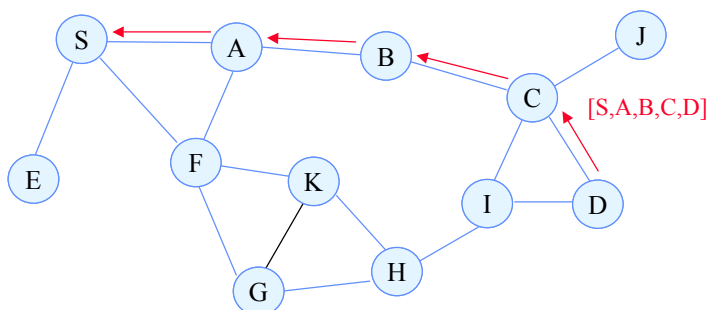
DSR – Dynamic Source Routing Example

The destination node receives the Route Request



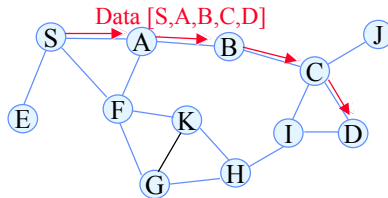
DSR – Dynamic Source Routing Example

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



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AdHoc-23

DSR Properties

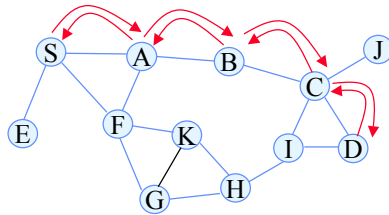
- Advantages
 - Only the communicating nodes need to maintain the route
 - Several alternative routes to the destination
 - Intermediate nodes can reply to requests using their cache
- Problems
 - Long routes ⇒ Long packets
(Large overhead in e.g. small voice packets)
 - Route request is flooded to the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

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AdHoc-24

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

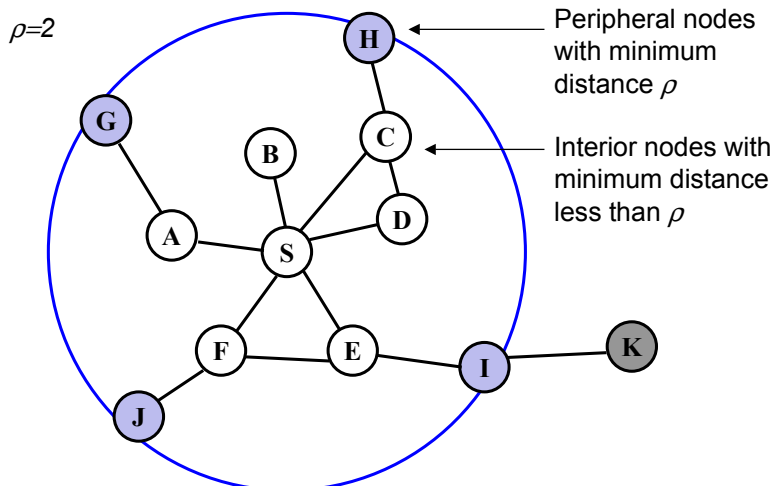
Non-uniform protocols

- 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)

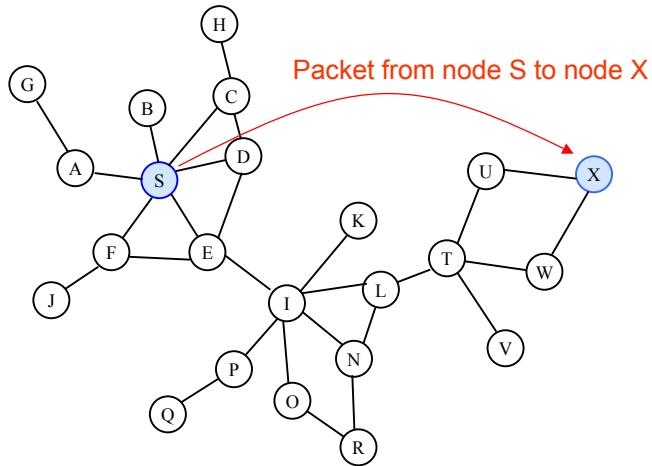
ZRP – Zone Routing Protocol

- 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

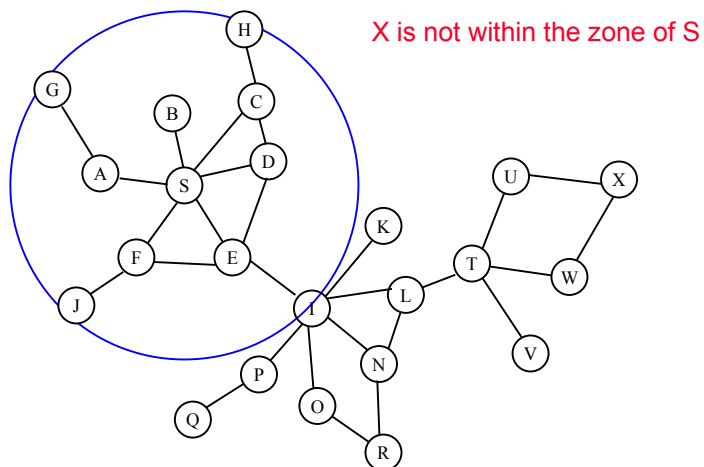
ZRP – Zone Routing Protocol



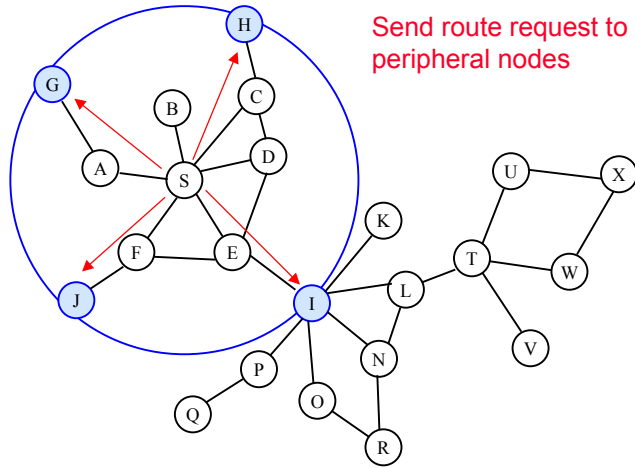
ZRP Example (1)



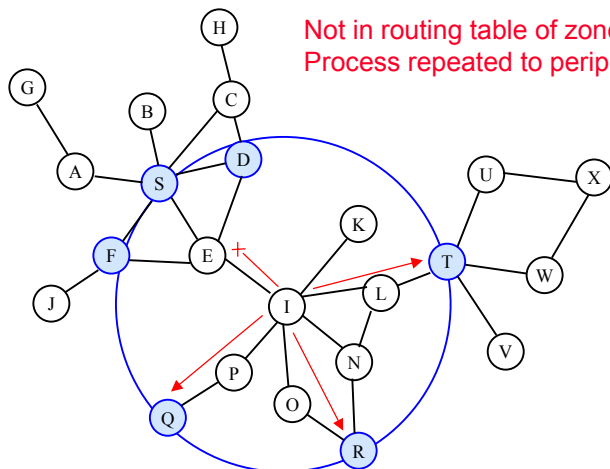
ZRP Example (2)



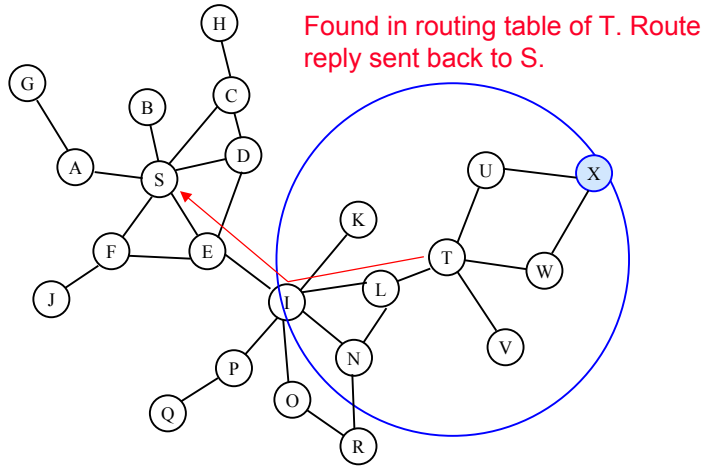
ZRP Example (3)



ZRP Example (4)

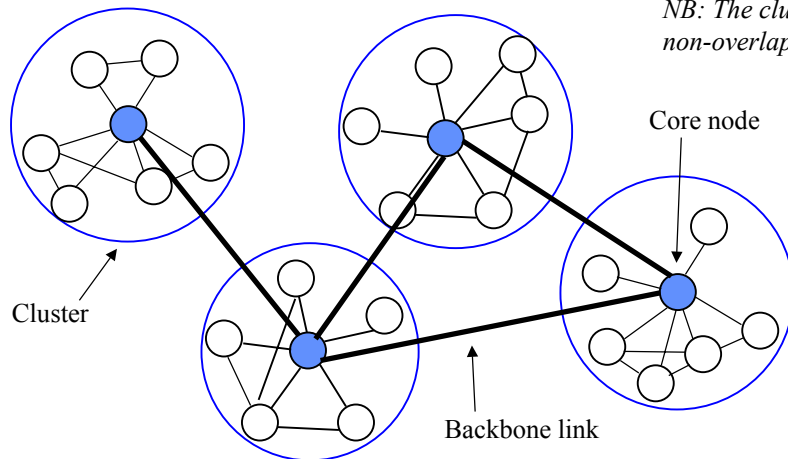


ZRP Example (5)



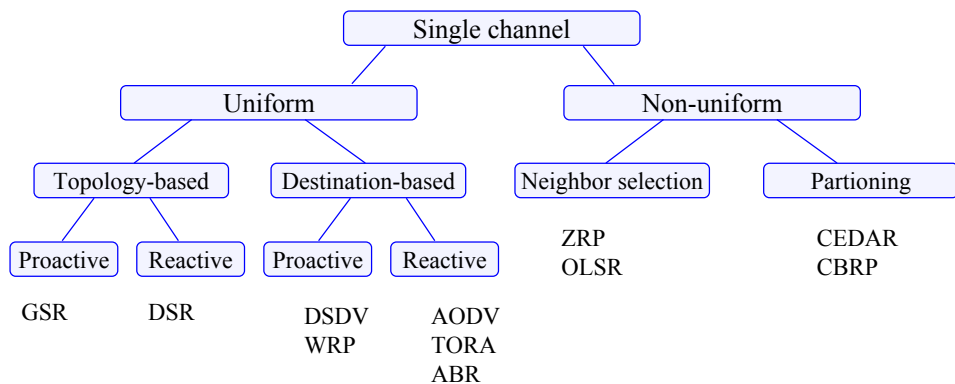
Clustering Routing Protocols

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



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