Scalable Routing Protocols for Mobile Ad Hoc Networks

Hafeth Hourani

hafeth.hourani@nokia.com

Contents

- Overview
- Routing in Flat Network Structure
- Hierarchical Routing Protocols
- GPS Assisted Routing
- Conclusions

Next . . .

- **Overview**
- Routing in Flat Network Structure
- Hierarchical Routing Protocols
- GPS Assisted Routing
- Conclusions

Overview

- MANET: Mobile Ad hoc Network
  - Self-organizing & self-configuring wireless network
- Routing challenges in MANETs
  - Node mobility
  - Very large number of nodes
  - Limited communication resources (bandwidth & power)

MANET Scalability

- When the MANET population increases
  - More and more routing messages
    - Excessive overhead
  - Routing tables gets larger
    - Large control packet size
    - Large link overhead

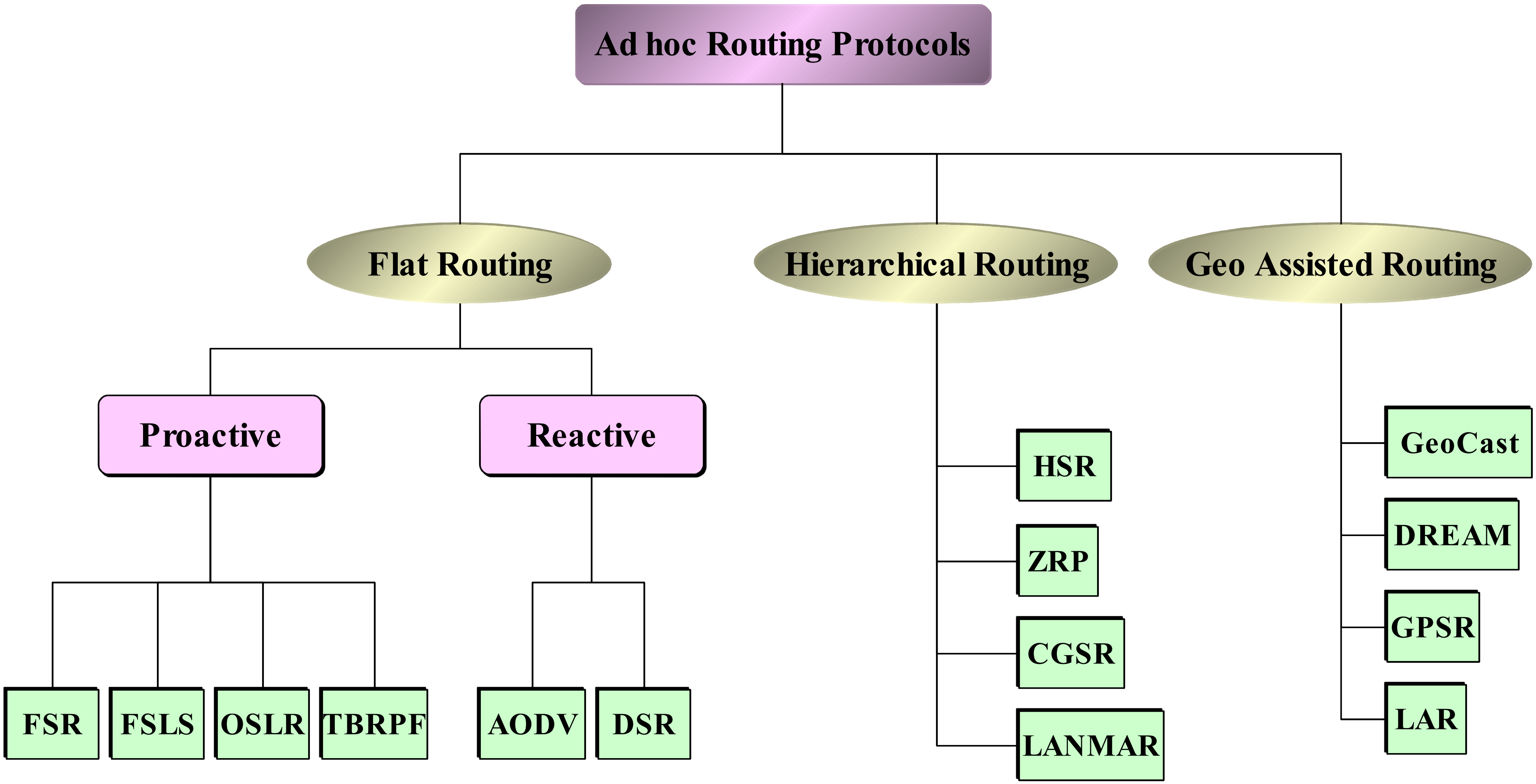
☞ **Routing Scalability is required . . .**

Routing Protocol Scalability

- Ad hoc routing protocols
  - Link State (LS) algorithm
    - Maintains the global network topology at each root
    - Periodical flooding of link information about neighbors
  - Distance Vector (DV) algorithm
    - A vector containing "hope distance" and "next hop" is kept and exchanged at each node
- Routing protocols introduces considerable overhead

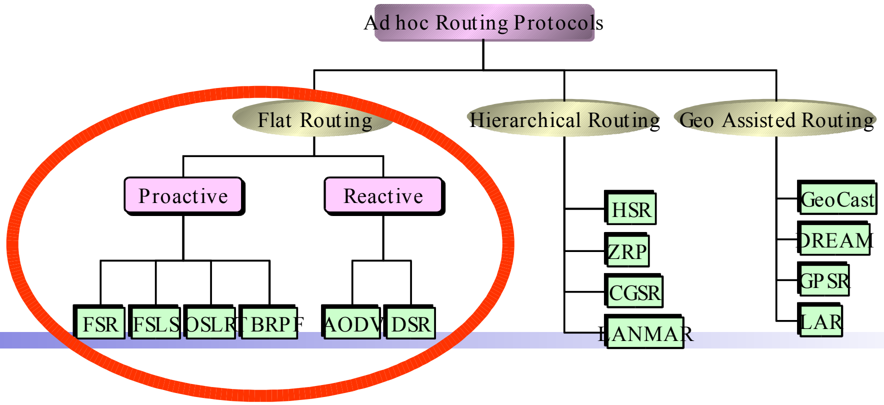
☞ **Protocol Scalability is required . . .**

Ad hoc Routing Protocols



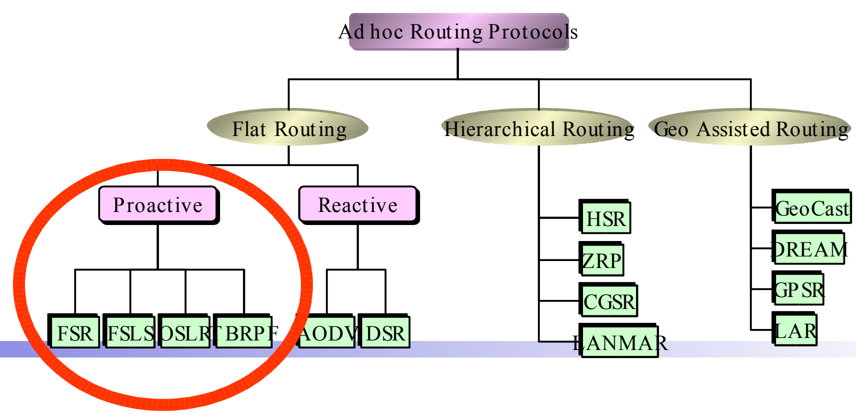
Next . . .

- Overview
- **Routing in Flat Network Structure**
- Hierarchical Routing Protocols
- GPS Assisted Routing
- Conclusions

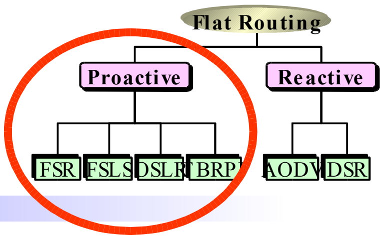


Next . . .

- Overview
- **Routing in Flat Network Structure**
  - **Proactive Routing Protocols** (Table-Driven)
  - Reactive Routing Protocols
- Hierarchical Routing Protocols
- GPS Assisted Routing
- Conclusions

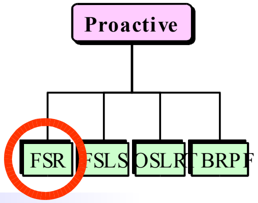


Proactive Routing Protocols



- Background routing info exchange regardless of communication requests
- Path information are stored in a routing table in each node
- <u>Basic Approach</u>
  - Periodically disseminate routing information among all nodes in the network
  - Every node has up-to-date information for all possible routes

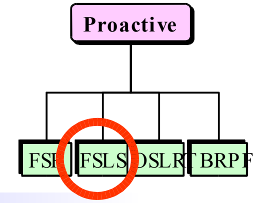
Fisheye State Routing (FSR)



- Fish do have 360° vision !
- Fisheye captures high details of the neighbors
- Fisheye view . . .

Fisheye State Routing (FSR)

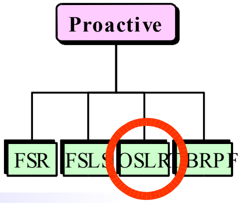
- FSR is similar to link state (LS) routing
  - Each node maintains a view of the network topology
- <u>Basic Approach</u>
  - Exchange the entire link state info only with neighbors
    - No flooding to the whole network
  - Re-exchange the link state info periodically
    - Exchanged with the neighbors, with progressively lower frequency as distance to destination increases
    - The further away the destination, the less accurate the route



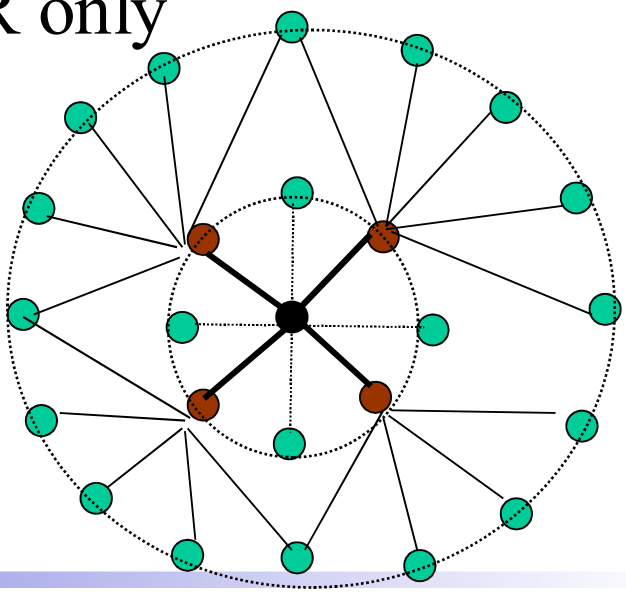
Fuzzy Sighted Link State (FSLS)

- Similar to the FSR
- FSLS includes an *optimal algorithm* called "Hazy Sighted Link State (HSLS)"
- HSLS
  - Send a link list update (LSU) every $2^k * T$ to a scope of 2^k
    - Where
      - k is hop distance
      - T minimum LSU transmit period

OLSR Protocol

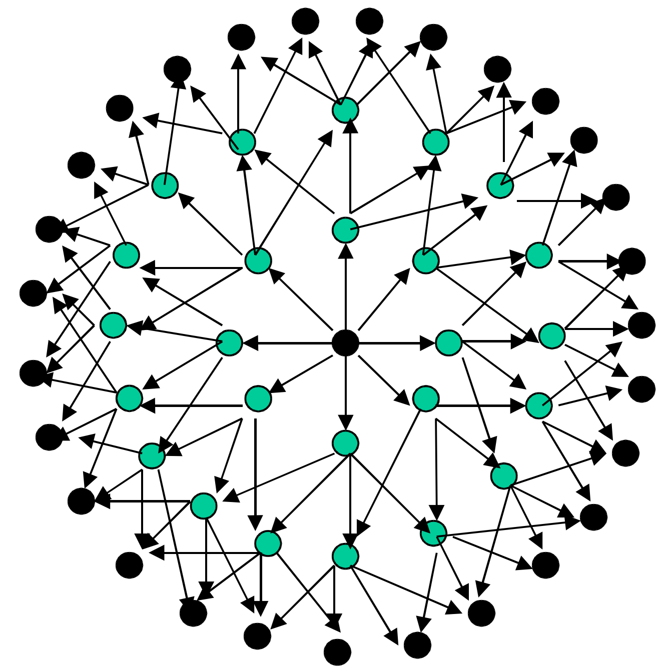


- Optimized Link State Routing is a *Link State* (LS) protocol
- Developed and maintained by IETF
- Selective flooding
- Periodic LS are generated by MPR only
- MPR are used for optimization



A Look @ Link State Routing (LSR)

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



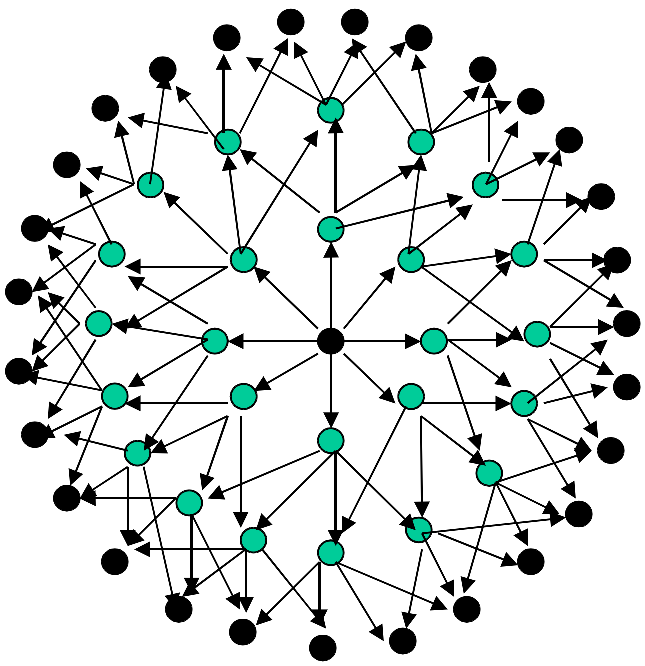
24 retransmissions to diffuse a message up to 3 hops

Retransmission node

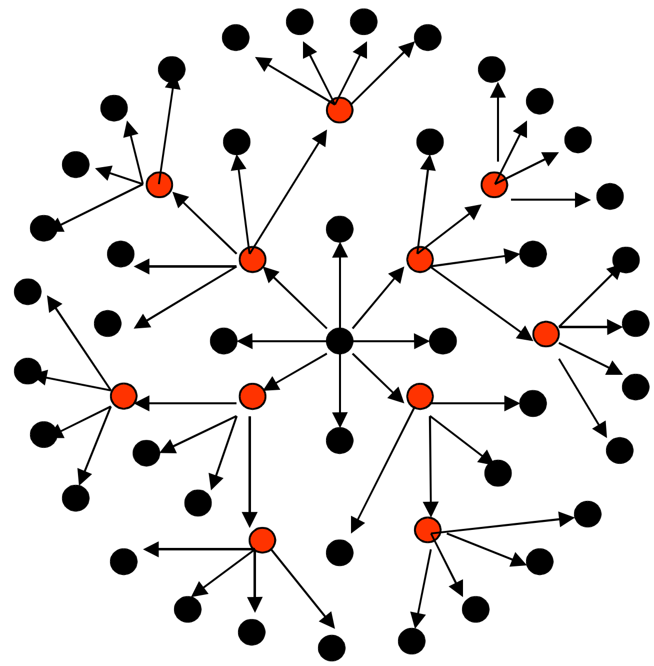
Optimizing the SLR ⇨ OSLR

- LSR
  - Unnecessary control message duplication
- OLSR
  - Only MPR retransmits the control messages
    - Reduce size of control message
    - Minimize flooding

LSR vs. OLSR



24 retransmissions to diffuse a message up to 3 hops



11 retransmission to diffuse a message up to 3 hops

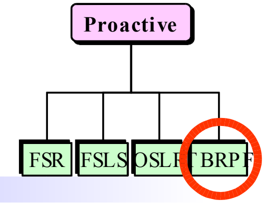

Retransmission node


Retransmission node

More about OLSR

- OLSR is particularly suited for dense networks
- In sparse networks, every neighbor becomes a multipoint relay (MPR)
  - Then, OLSR reduces to pure LSR

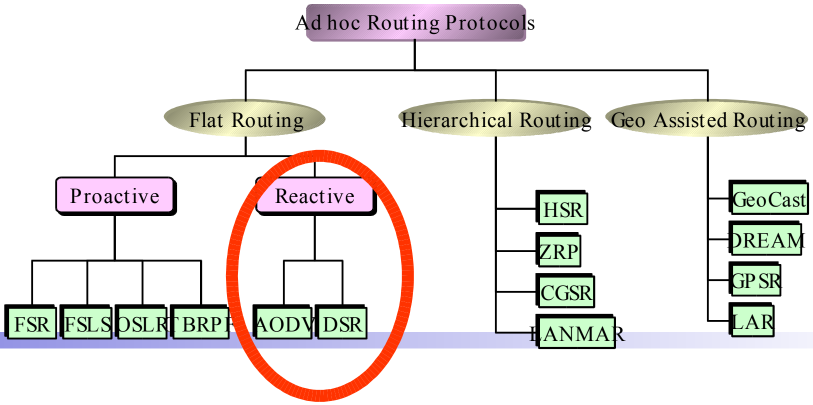
TBRPF Protocol



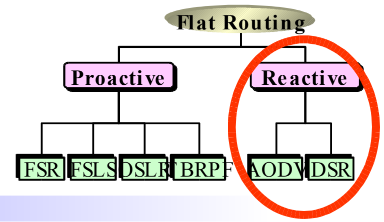
- *Topology Broadcast Based on Reverse Path Forwarding*
- Basic Approach
  - Send periodical *differential* HELLO messages that report only the changes (up or lost) of neighbors
  - The topology updates are broadcasted periodically and differentially
- Hence, TBRPF
  - Adapts to topology changes faster
  - Generates less routing overhead

Next . . .

- Overview
- **Routing in Flat Network Structure**
  - Proactive Routing Protocols
  - **Reactive Routing Protocols** (On-Demand Routing Protocols)
- Hierarchical Routing Protocols
- GPS Assisted Routing
- Conclusions

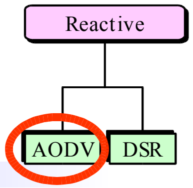


Reactive Routing Protocols



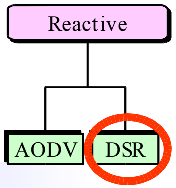
- Each node tries to reduce routing overhead by only sending routing packets when a communication is awaiting
- Maintain path information only for those destinations to be contacted
- Essential *route discovery phase* . . .
- Basic Approach
  - Send flood search message to obtain the needed path info

AODV Protocol



- *Ad hoc On-demand Distance Vector* Routing Protocol
- Basic Approach
  - Using backward learning
    - On receiving a query, the transit nodes "learn" that path to the source and enter the route in the forwarding table
    - The query packet is dropped if it encounters a node which already has a route to the destination
    - A link failure will trigger a *query response* procedure in order to find a new route

DSR Protocol



- ***D****ynamic* ***S****ource* ***R****outing* Protocol
- Source Routing:
  - A source indicates in a data packet's header the sequence of intermediate nodes on the routing path
- DSR takes advantage of existing route information at intermediate nodes to save route search overhead

Proactive vs. Reactive Protocols

- Proactive Routing Protocols
  - ☺ Routes to all reachable nodes in the network available
  - ☺ Minimal initial delay for application
  - ☹ Larger signaling traffic and power consumption

- Reactive Routing Protocols
  - ☺ Less signaling traffic and power consumption
  - ☹ Longer delay when no route is available

Summery

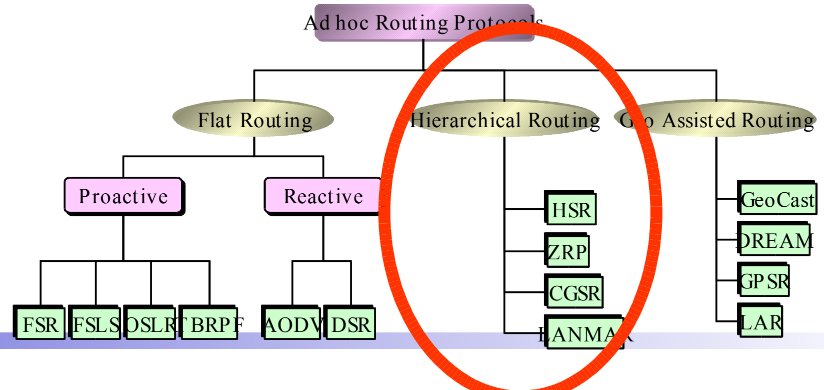
		[redacted]	[redacted]	[redacted]	[redacted]
Routing scheme	Proactive	Proactive	Proactive	On-demand	On-demand
Routing metric	Shortest path	Shortest path	Shortest path	Shortest path	Shortest path
Frequency of updates	Periodically	Periodically	Periodically, as needed	As needed (data traffic)	As needed (data traffic)
Use sequence number	Yes	Yes	Yes (HELLO)	Yes	No
Loop-free	Yes	Yes	Yes	Yes	Yes
Worst case exist	No	Yes (pure LSR)	No	Yes (full flooding)	Yes (full flooding)
Multiple paths	Yes	No	No	No	Yes
Storage complexity	O(N)	O(N)	O(N)	O(e)	O(e)
Communication complexity	O(N)	O(N)	O(N)	O(2N)	O(2N)

***N*: number of nodes**

***e* : number of communication pairs**

Next . . .

- Overview
- Routing in Flat Network Structure
- **Hierarchical Routing Protocols**
- GPS Assisted Routing
- Conclusions

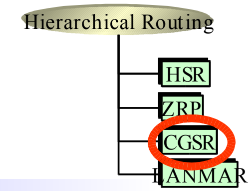


Hierarchical Routing Protocols

- For larger wireless networks, the *flat routing schemes* become infeasible
  - Higher link and processing overhead is introduced
- More scalable and efficient solution is the

☞ **Hierarchical Routing . . .**

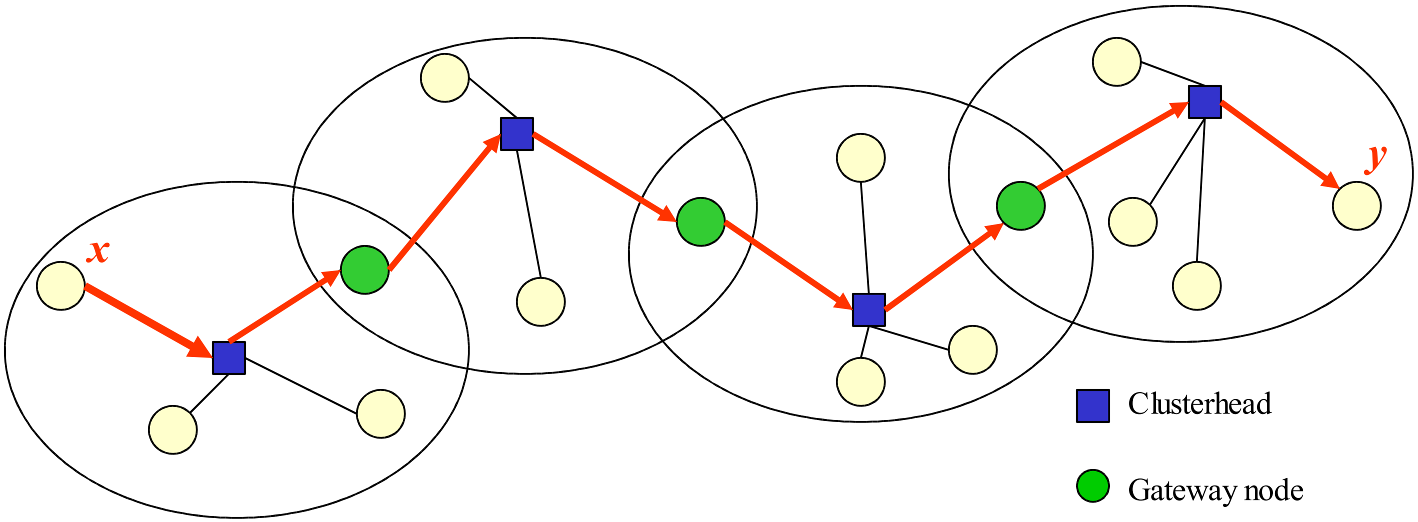
- Basic Approach:
  - Organize node in groups and then assign different functionalities for each node inside and outside the group



CGSR Protocol

- *Clusterhead-Gateway Switch Routing* Protocol
- Based on *Least Clusterhead Change* (LCC) algorithm
  - LCC is used to partition the whole network into clusters
  - A clusterhead is elected in each cluster
- Clusters are connected via gateways
- Basic Approach:
  - Each node maintain two tables
    - Cluster member table
      - Records the clusterhead for each node
    - DV routing table
      - One entry for each cluster recording the path to its clusterhead

CGSR in Action

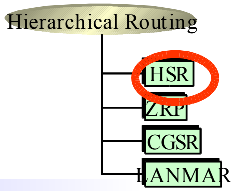


CGSR Pros. & Cons.

- Pros.
  - Less routing table size compared to DV protocols
    - One entry is needed for all nodes in the same cluster
  - Scales very well to large networks

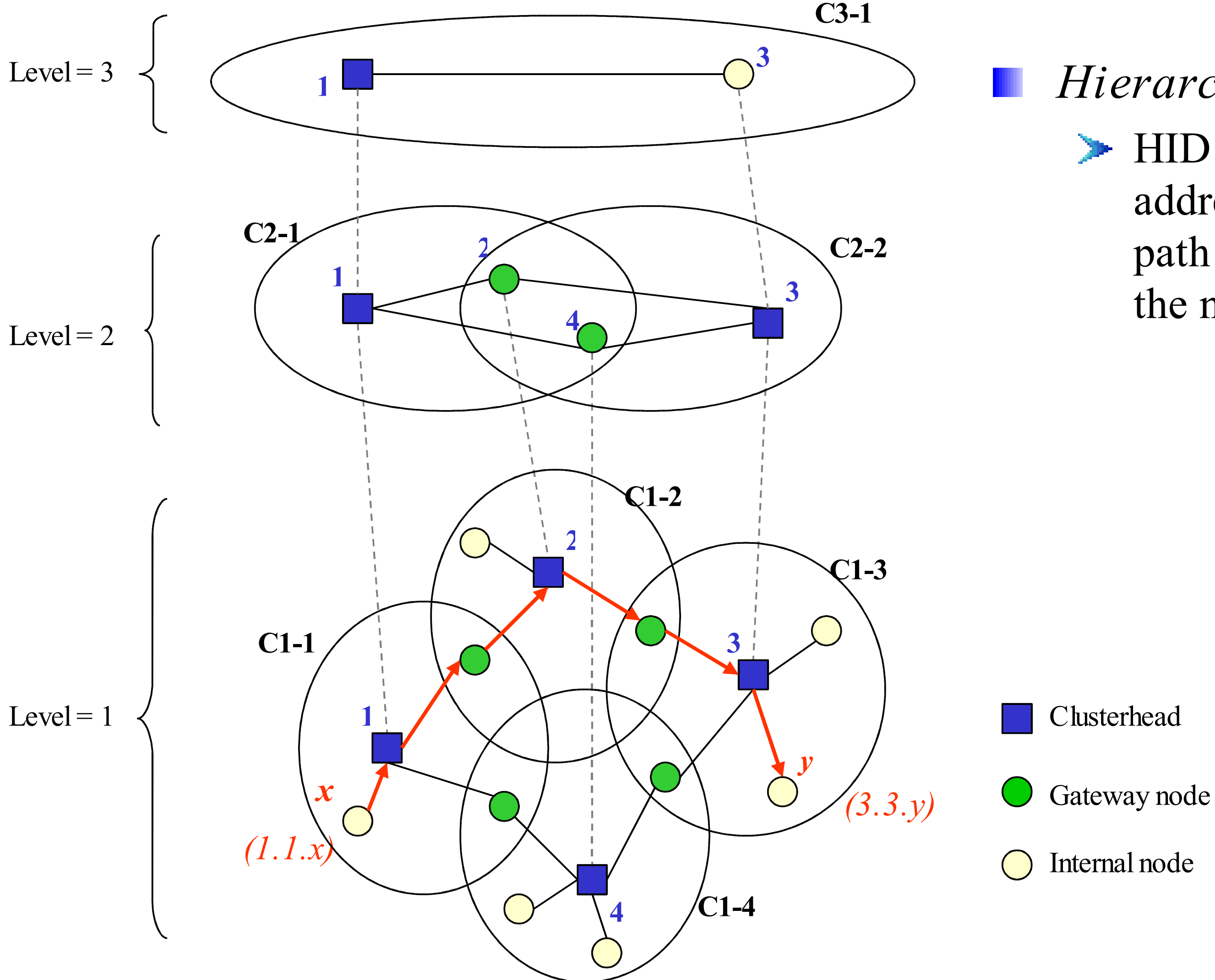
- Cons.
  - Difficulty to maintain the cluster structure in a mobile environment
  - LCC introduces additional overhead and complexity

HSR Protocol



- *Hierarchical State Routing* Protocol
- Based on LS
- Basic Approach:
  - Multilevel clustering
  - Maintains a logical hierarchical topology
    - By using clustering recursively
  - Nodes at same level are grouped into a cluster
  - The elected clusterhead at the lower level become a member of the next higher level
  - The clusterhead acts as a local coordinator within the cluster

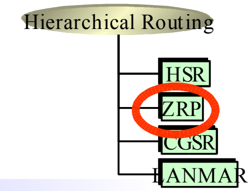
HSR in Action



- *Hierarchical ID* (HID)
  - HID is a sequence of MAC addresses of the nodes on the path from the top hierarchy to the node itself

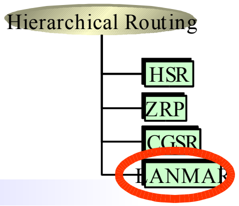
HSR Pros. & Cons.

- Pros.
  - Each node can dynamically and locally updates its own HID on receiving the routing updates from the nodes higher up in the hierarchy
  - The hierarchical address is sufficient to deliver a packet to its destination from anywhere in the network using HSR
- Cons.
  - Long hierarchical addresses
  - Frequent updates of the cluster hierarchy and the HIDs as nodes move
    - Difficult to track the hierarchical changes



Zone Routing Protocol

- ZRP is a *hybrid* routing protocol
  - It combines both *proactive* and *on-demand* routing
- Basic Approach
  - Each node has a predefined *zone* centered at itself in terms of number of hops
  - Inside zone: proactive routing
  - Outside zone: on-demand routing
- ZRP such hybrid schemes
  - Limits the proactive overhead to only the size of the zone
  - Limits the reactive search overhead to only selected border nodes



LANMAR Protocol

- *Landmark Routing* Protocol
- Designed for MANER that exhibits *group mobility*
- Basic Approach:
  - The whole network is partitioned into groups
  - Each group has a predetermined *landmark* which keeps track of the group

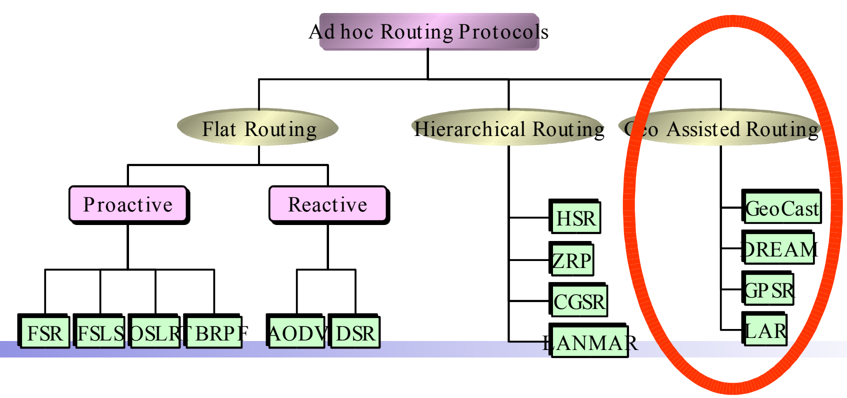
Summery

	[redacted]			
Hierarchy	Explicit two levels	Explicit multiple levels	Implicit two levels	Implicit two levels
Routing scheme	Proactive, DV	Proactive, LS	Hybrid, DV & LS	Proactive, DV & LS
Loop-free	Yes	Yes	Yes	Yes
Routing metric	Via critrical nodes	Via critrical nodes	Local short path	Local short path
Critical Nodes	Yes (clusterhead)	Yes (clusterhead)	No	Yes (landmark)
Storage complexity	*O(N/M)*	*O(M*H)*	*O(L) + O(e)*	*O(L) + O(G)*
Communication complexity	*O(N)*	*O(M*H)*	*O(N)*	*O(N)*

***N*: number of nodes**
***M*: average number of nodes in the cluster**
***L* : average number of nodes in the node's local scope**
H : number of hierarchical levels HSR
G : number of logical groups in LANMAR
***e* : number of communication pairs**

Next . . .

- Overview
- Routing in Flat Network Structure
- Hierarchal Routing Protocols
- **GPS Assisted Routing**
- Conclusions



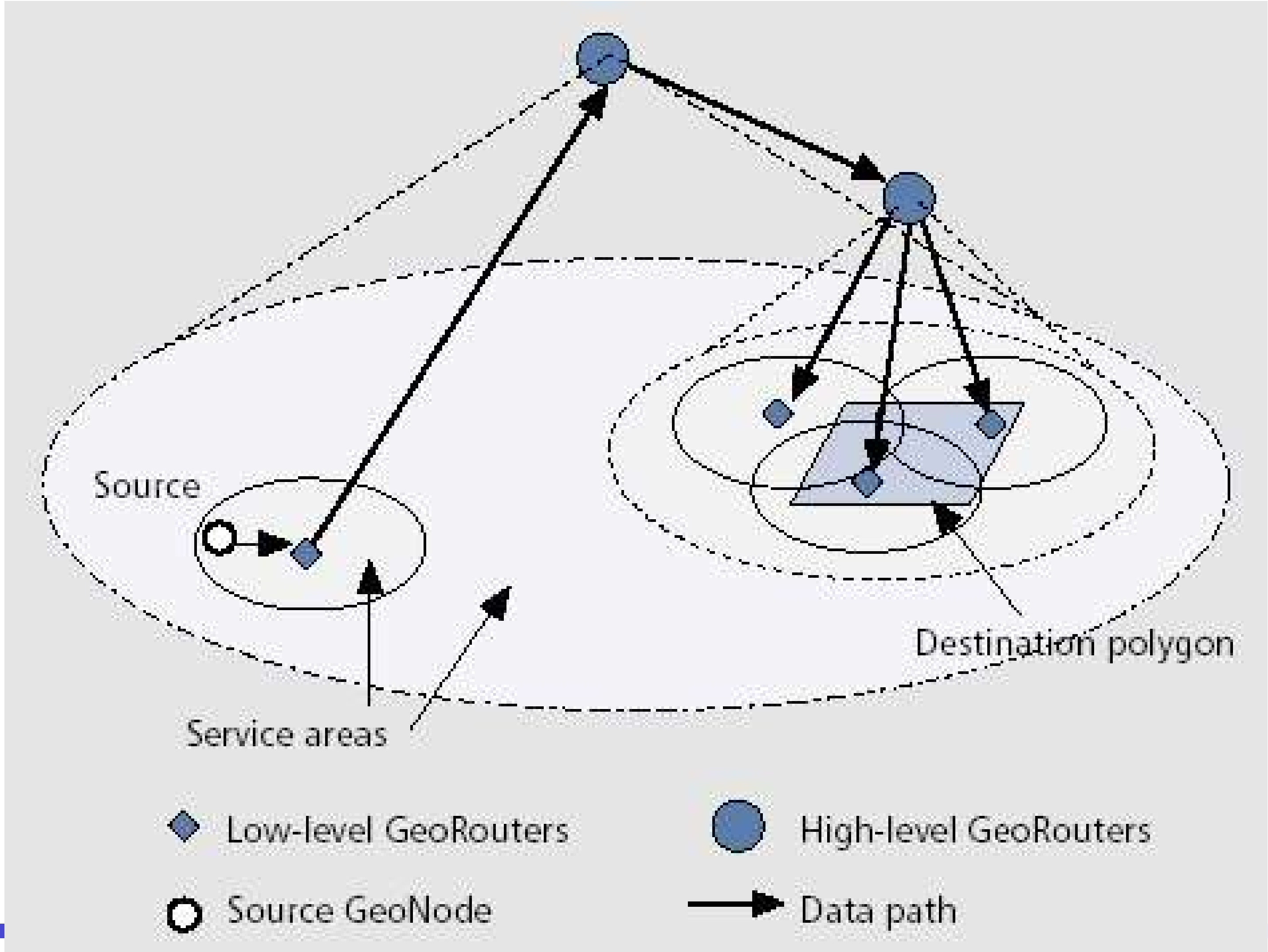
GPS Assisted Routing Protocols

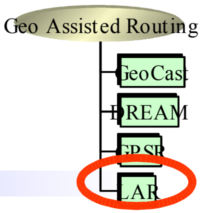
- The Global Positioning System (GPS) provides
  - Location information
    - With a precision within a few meters
  - Universal timing
    - Global synchronization among GPS equipped nodes

GeoCast Routing Protocl

- Geographic Addressing and Routing
- Basic Approach
  - Use specific geographic info to specify the destination, rather than logical node address
  - A special compute host is in charge of receiving and sending geographic messages (GeoHost)
  - The GeoHost is responsible for forwarding the packets to the local GeoRouter

GeoCast in Action





LAR

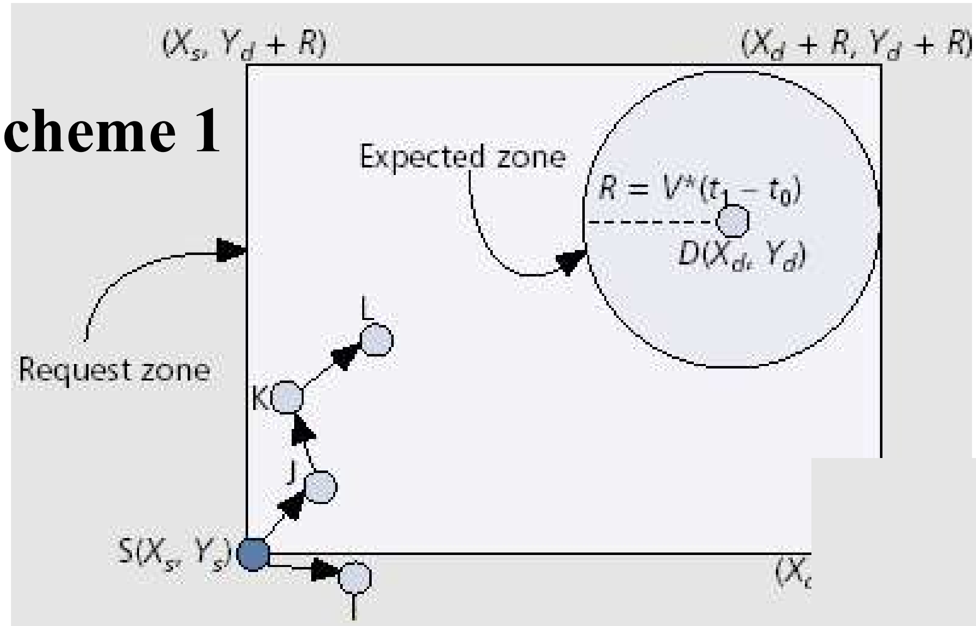
- *Location-Aided Routing* Protocol
- Basic Approach
  - LAR utilizes location information to limit the area for discovering a new route to a smaller *request zone*
  - Using location info, LAR performs the route discovery through *limited flooding* (to request zone)
- LAR provides two schemes to determine the request zone

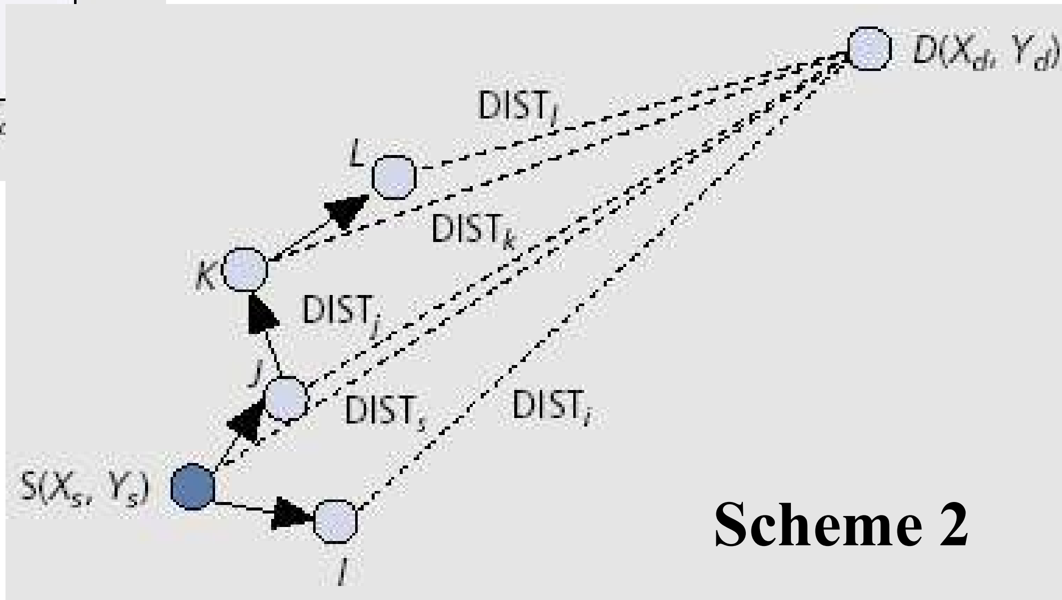
LAR Request Zone: How to Find

- Scheme 1
  - Estimate a circular area (expected zone) in which the destination is expected to be found
  - During the route request flood, only nodes inside the request zone forward the request message
- Scheme 2
  - The source calculates the distance to the destination (based on GPS info)
  - The distance is included in the route request message
  - A node relays a request message only if its distance to the destination is less than or equal to the distance included in the request message

Request Zone Schemes

Scheme 1

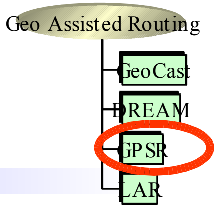




Scheme 2

DREAM Protocol

- *Distance Routing Effect Algorithm for Mobility* Protocol
- Basic Approach:
  - DREAM minimizes the routing overhead by using two principles
    - Distance Effect
      - The greater the distance spreading two nodes, the slower they appear to be moving w.r.t. each other
    - Mobility Rate
      - The faster a node moves, the more frequent it needs to advertise its new location
  - Each node maintains a location table (LT) for other nodes



GPSR Protocol

- *Greedy Perimeter Stateless Routing* Protocol
- Basic Approach
  - GPSR uses only neighbor location info in forwarding data packets
  - Each node broadcasts a beacon messages to its neighbors informing about its position
  - It uses two data forwarding schemes
    - *Greedy Forwarding*
    - *Perimeter Forwarding*

Summery

	[illegible]	[illegible]	[illegible]	[illegible]
Support location	Yes	Yes	Yes	No
Data forwarding by	Yes	No	Yes	Yes
Routing scheme	Proactive	On-demand	Proactive	Proactive (beacons only)
Sensitive to mobility	No	Yes	No	No
Routing metric	Shortest path	Shortest path	Shortest path	Shortest path
Loop-free	Yes	Yes	Yes	No
Worst case exists	No	Yes (full flooding)	No	Yes (loops and longer paths)
Multiple receivers	Yes	No	No	No
Storage complexity	*O(N)*	*O(N)*	*O(N)*	*O(M)*
Communication	*O(N)*	*O(e)*	*O(N)*	*O(M)*

***N*: number of nodes**
***M*: average number of nodes in the cluster**
***e* : number of communication pairs**

Next . . .

- Overview
- Routing in Flat Network Structure
- Hierarchal Routing Protocols
- GPS Assisted Routing
- **Conclusions**

Conclusions

- The underlying network structure has a great influence on the routing protocols
- Flat Routing Protocols
  - Proactive routing protocols
    - A great advantage of immediate route availability and strong QoS support
    - Routing overhead is efficiently limited
      - FSR & FSLS achieves routing traffic reduction by selectively adjusting routing update frequency
      - OLSR reduces both the size of routing packets and the number nodes forwarding such packets
      - TBRPF limits the propagation info by using differential update information

Conclusions (cont'd)

    - Both OLSR and TBRPF work more efficiently in dense networks, while FSR and FSLS are more suitable for large diameter networks
  - On-Demand routing protocols searches for available routes to destination only when needed
    - Less bandwidth usage
    - Both AODV and DSR scale well for large networks when the communication pattern is sparse and mobility is low
- Flat routing schemes only scale up to a certain degree
  - For larger networks
    - Proactive Protocols
      - Routing table sizes increase linearly with number of nodes
    - On-demand Protocols
      - Incurs a huge amount of flooding packets

Conclusions (cont'd)

- Hierarchical Routing Protocols
  - Major advantage is the drastic reduction of routing table storage and processing overhead
- With help of GPS, directional data forwarding can reduce routing info propagation

- **No winner protocol for all scenarios . . .**

Abbreviations

CGSR		Clusterhead-Gateway Switch Routing
DREAM		Distance Routing Effect Algorithm for Mobility
DSR		Dynamic Source Routing
DV		Distance Vector
FSLS		Fuzzy Sighted Link State
FSR		Fisheye State Routing
GeoCast		Geographic-based Broadcasting
GPS		Global Positioning System
GPSR		Greedy Perimeter Stateless Routing
HID		Hierarchical ID
HSLS		Hazy Sighted Link State
HSR		Heirarchical State Routing
IETF		Internet Engineering Task Force
LANMAR		Landmark Ad hoc Routing
LAR		Location-Aided Routing
LCC		Least Clusterhead Change
LS		Link State
LSU		Link State Update
LT		Location Table
MAC		Medium Access Control
MANET		Mobile Ad hoc NETwork
MPR		Multipoint Relay
OADV		On-demand Ad hoc Distance Vector
TBRPF		Topology Broadcast Based on Reverse Path Forwarding
ZRP		Zone Routing Protocol

References

- Pasi Maliniemi, "Fisheye State Routing (FSR)", URL: www.cwc.oulu.fi/~carlos/AdHoc_Presentations/Pasi_Maliniemi_fisheye%20v1.0.ppt
- Sung-Ju Lee, "The Scalability Study of AODV", URL: moment.cs.ucsb.edu/AODV/AODVng_Presentations/lee.pdf

Q & A

Thank You !