Source Initiated On-demand Routing Protocols

- **Ad hoc On-demand Distance Vector Routing (AODV)**
  C Perkins, E Belding-Royer, and S Das, "Ad hoc On-Demand Distance Vector (AODV) Routing, RFC 3581, Jul 2003.
- **Dynamic Source Routing Protocol (DSR)**
  DB Johnson and DA Maltz, "Dynamic Source Routing in Ad Hoc Wireless Networks", Mobile Computing, 1996, pp 153-181.
- **Temporally Ordered Routing Algorithm (TORA)**
  VD Park and MS Corson, "A highly adaptive distributed routing algorithm for mobile wireless networks", INFOCOM 1997, 7-11 Apr 1997.
- **Associativity Based Routing (ABR)**
  CK Toh, "Associativity-Based Routing for Ad Hoc Mobile Networks", Wireless Personal Communications, vol. 4, no. 2, Mar 1997, pp 103-139.
- **Signal Stability Routing (SSR)**
  R Dube, CD Rais, KY Wang and S Tripathi, "Signal stability-based adaptive routing (SSA) for ad hoc mobile networks", IEEE Personal Communications, vol. 4, no. 1, Feb 1997, pp 36-45.

What is "on-demand"

- The routes are created when required
- The source has to discover a route to the destination
- The source and intermediate nodes have to maintain a route as long as it is used
- Routes have to be repaired in case of topology changes.

II.1 Dynamic Source Routing Protocol (DSR)

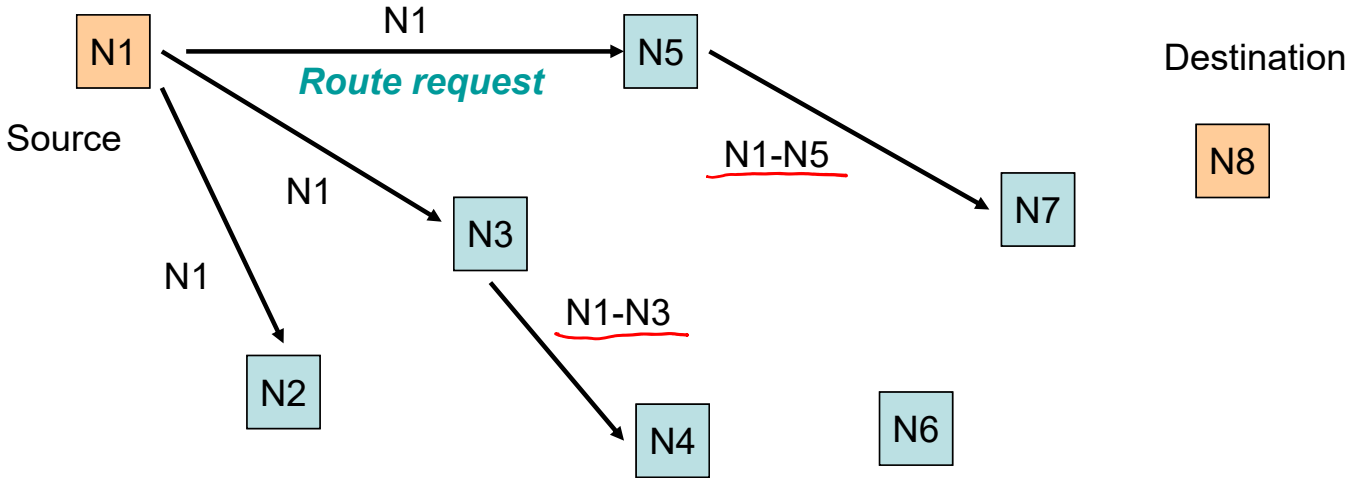
- *Note*: this method was proposed before AODV
- Mobile nodes maintain route caches that contain the source routes of which the mobile is aware
- Consists of two major phases :
  - Route discovery
  - Route maintenance

Route Discovery (DSR)

- Source broadcasts a packet containing address of source and destination
- If the packet has been received before by a mobile node, discard it
- Each node checks whether it knows of a route to the destination
- If it does not, it adds its own address to the packet and then forwards the packet

Route Discovery (DSR)

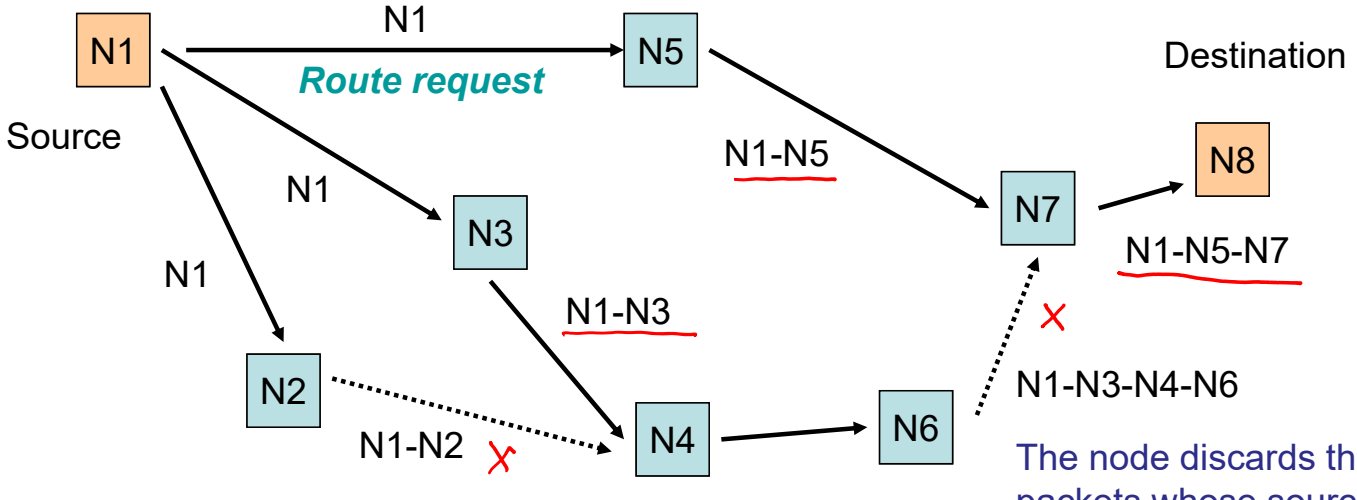
Source broadcasts a packet containing address of source and destination



Each node checks whether it knows of a route to the destination.
If not found, it adds its address into the packet, and forwards it.

Route Discovery (DSR)

Source broadcasts a packet containing address of source and destination



The node discards the packets whose source has been seen before

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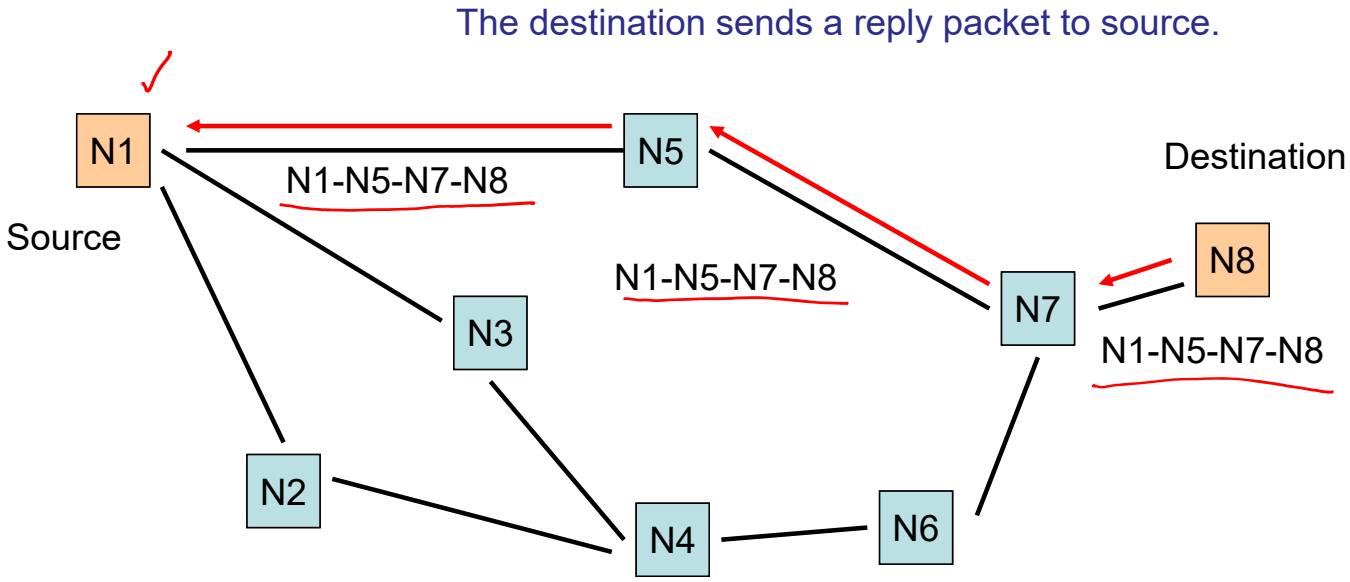
Route Reply (DSR)



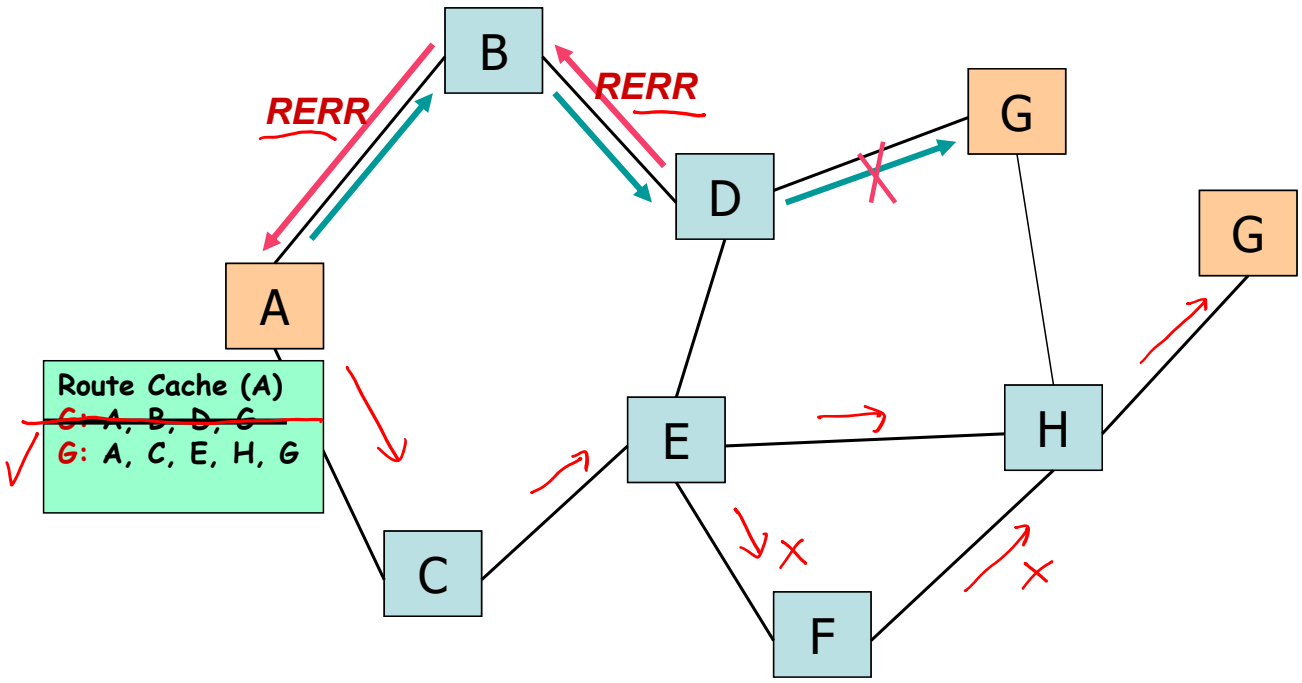
How to Return a Route Reply (DSR)

- If the destination has a route to the source in its route cache, use it
- Otherwise, if symmetric links are supported, reverse the route in the ***route record***
- If symmetric links are not supported, the destination initiates its own route discovery to source

Route Maintenance (DSR)

- Accomplished through the use of ***route error*** packets and acknowledgments
- ***Route error*** packets are generated at a node when the data link layer encounters a fatal transmission problem
- Acknowledgments are used to verify the correct operation of the route links

Route Maintenance (DSR)



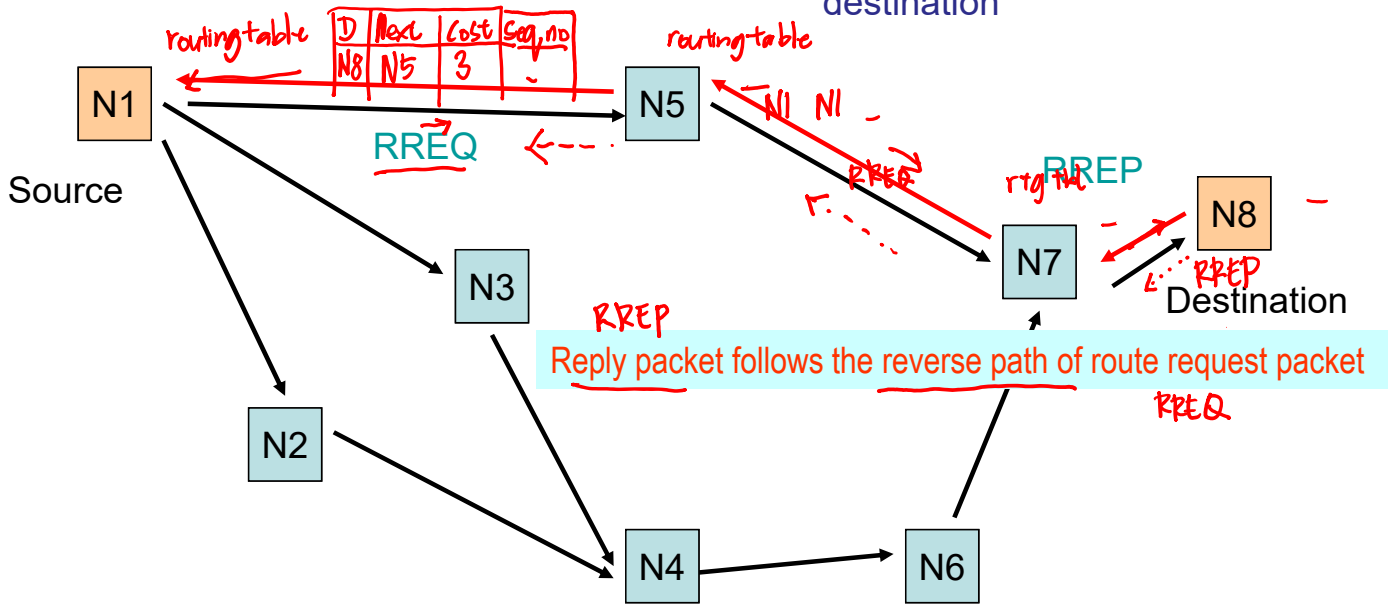
Ad Hoc On-demand Distance Vector Routing (AODV)

- AODV includes route discovery and route maintenance
- AODV minimizes the number of broadcasts by creating routes on-demand
- AODV only supports the use of symmetric links because a RREP (Route Reply) is forwarded along the path established by a RREQ (Route Request)
- AODV uses ***Hello*** messages to maintain the local connectivity of a node

Route Discovery (AODV)

The source broadcasts a RREQ

The neighbors in turn broadcast the packet till it reaches the destination



The node discards the packets having been seen

Refer to AODV paper(s)

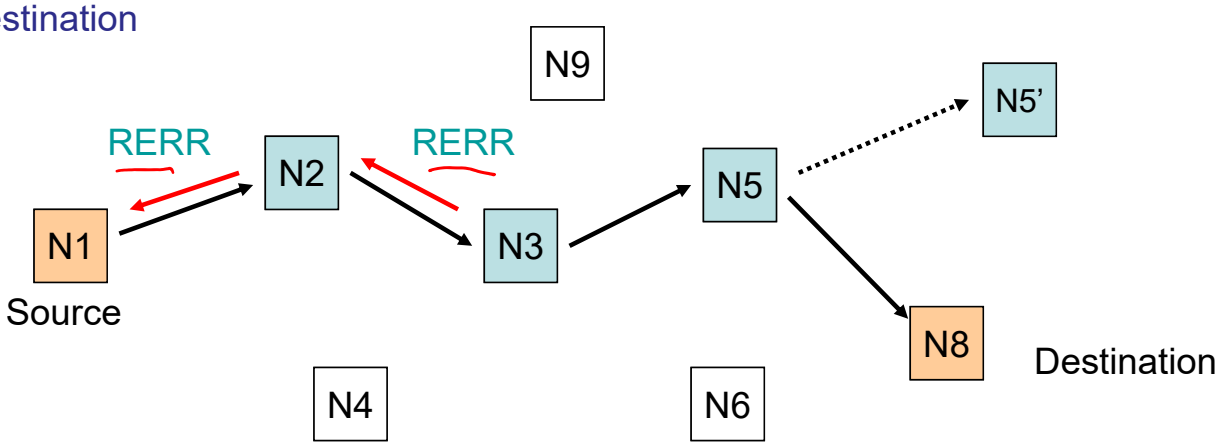
Route Maintenance (AODV)

- If the source node moves, it re-initiates route discovery to establish a new route to the destination.
- If intermediate node moves, its upstream node sends a Route Error (RERR) message to the source.
- When a source receives the RERR, it will reinitiate the route discovery if the route is still needed.

Route Maintenance (AODV)

The original path from the source to the destination

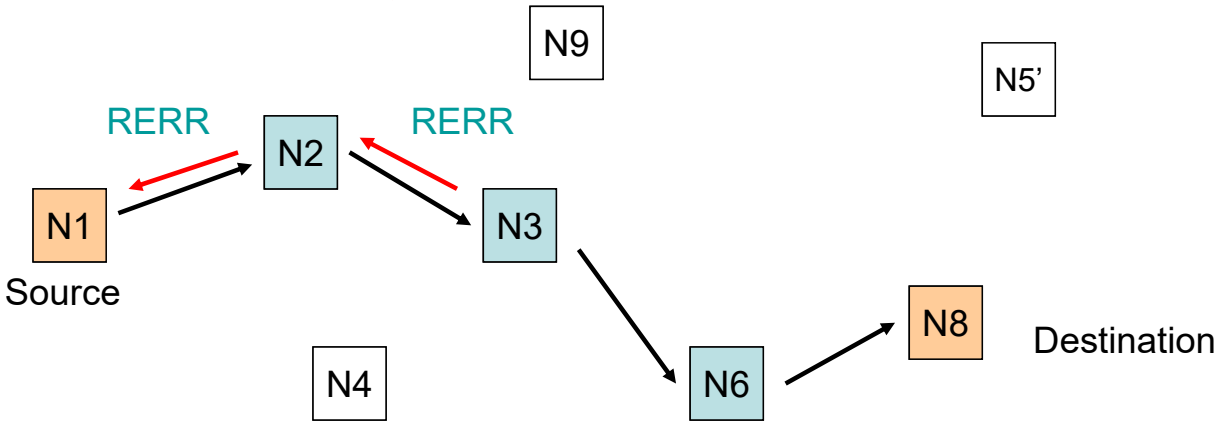
Node N5 then moves to location N5'



Node N3 notices this break and sends a RERR to the source

Route Maintenance (AODV)

On receiving the RERR, the source node re-initiates route discovery



The new route found through node N6

Comparison between DSR and AODV

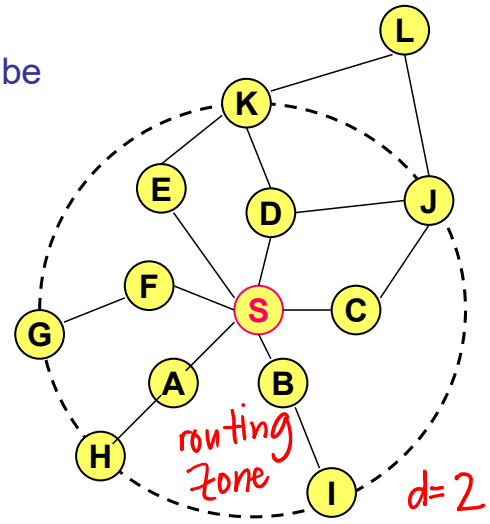
- DSR has less routing overhead than AODV.
- DSR is based on a source routing mechanism, whereas AODV uses a combination of DSR and DSDV mechanisms.
- AODV has better performance than DSR in higher-mobility scenarios.
- DSR has less frequent route discovery processes than AODV
  - after route expires, AODV needs to discover route again

Hybrid Routing Protocol

- **Zonal Routing Protocol (ZRP)**
  ZJ Haas, "A new routing protocol for the reconfigurable wireless networks", Universal Personal Communications, 12-16 Oct 1997.
- **Fisheye State Routing (FSR)**
  G Pei, M Gerla and TW Chen, "Fisheye state routing: a routing scheme for ad hoc networks", IEEE ICC 2000 18-22 Jun 2000.
- **Landmark Routing (LANMAR)**
  G Pei, M Gerla and X Hong, "LANMAR: Landmark routing for large scale wireless ad hoc networks with group mobility", 1st ACM International Symposium on Mobile ad hoc networking and computing, 2000, Boston, MA, USA, pp 11-18.
- **Location-Aided Routing (LAR)**
  YB Ko and NH Vaidya, "Location-aided routing (LAR) in mobile ad hoc networks", Journal on Wireless Networks, vol. 6, no. 4, Jul 2000, pp 307-321.

Zone Routing Protocol (ZRP)

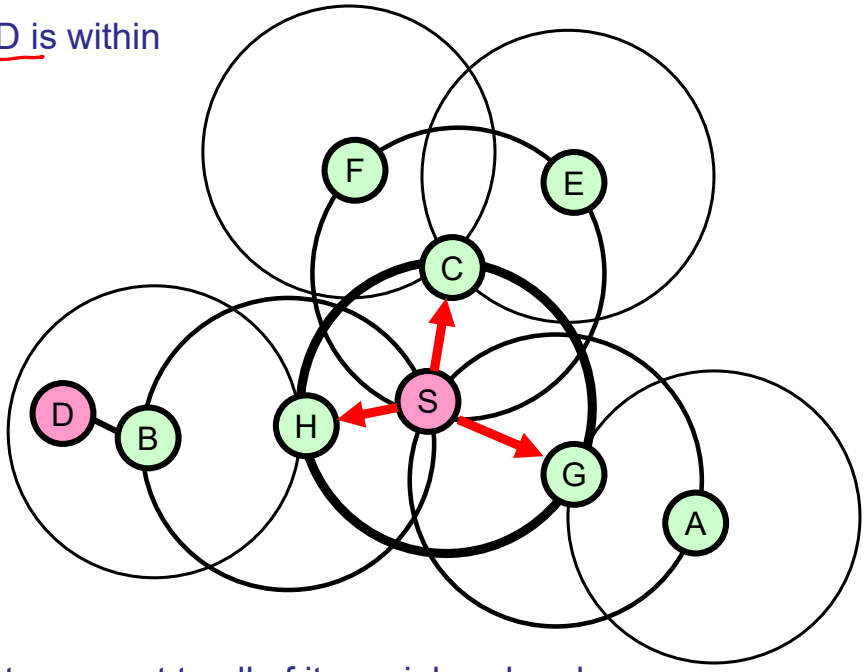
- ZRP combines
  - Proactive protocol: which pro-actively updates network state and maintains route regardless of whether any data traffic exists or not
  - Reactive protocol: which only determines route to a destination if there is some data to be sent to the destination
- All nodes within hop distance 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: pro-actively maintain state information for links within a short distance from any given node
  - Routes to nodes within short distance are thus maintained proactively.
- Inter-zone routing: use a route discovery protocol for determining routes to far away nodes. Route discovery is similar to DSR with the exception that route requests are propagated via peripheral nodes.



Routing zone of radius 2

Route Discovery (ZRP)

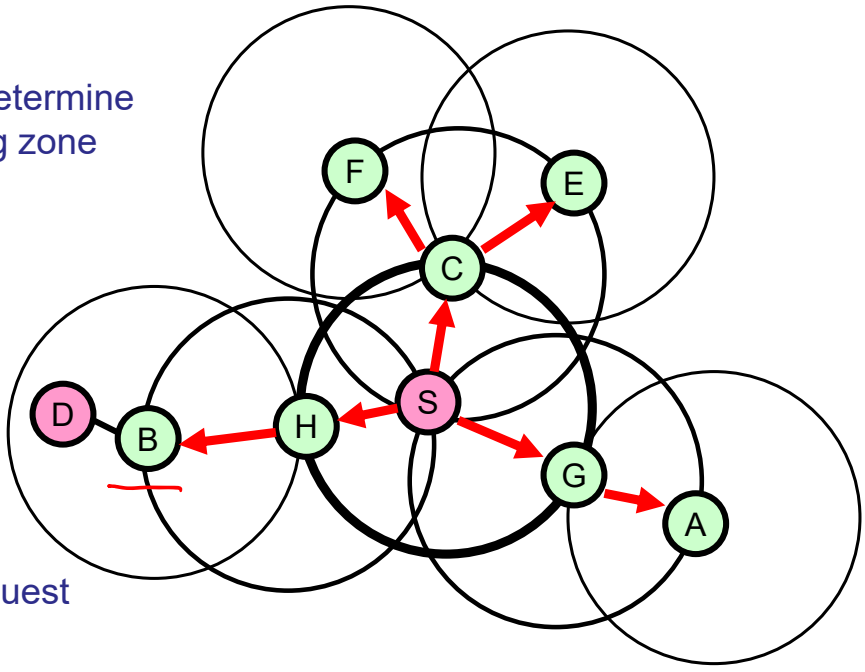
S first check whether D is within its routing zone



If not, S bordercasts a route request to all of its peripheral nodes

Route Discovery (ZRP)

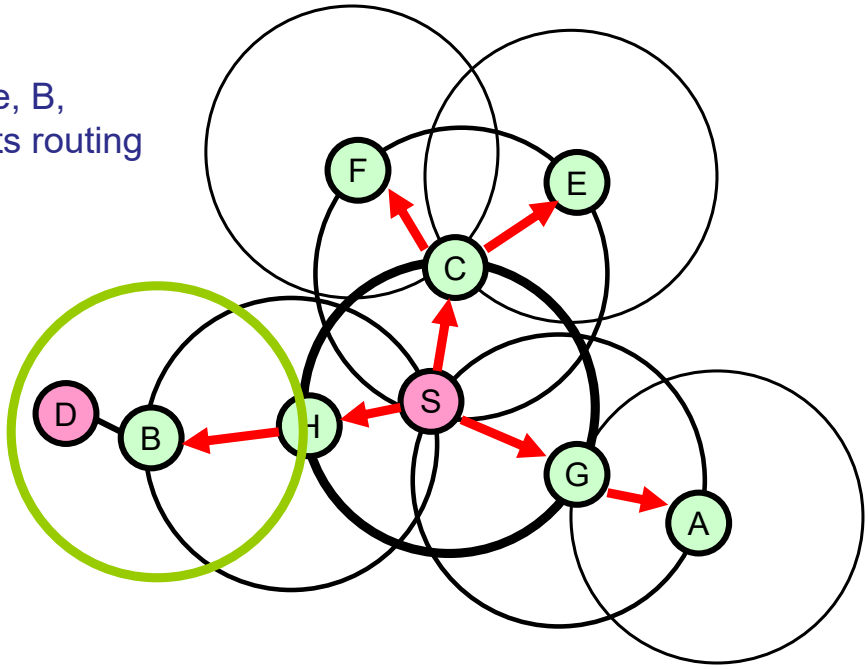
Nodes C, G, and H then determine that D is not in their routing zone



Therefore bordercast the request to ***their*** peripheral nodes

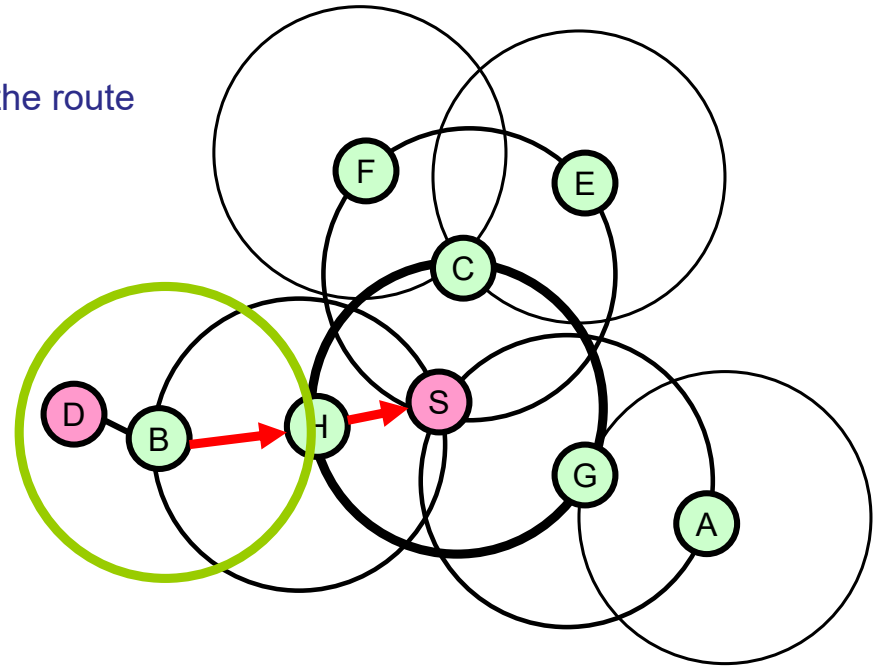
Route Discovery (ZRP)

One of H's peripheral node, B, recognizes D as being in its routing zone



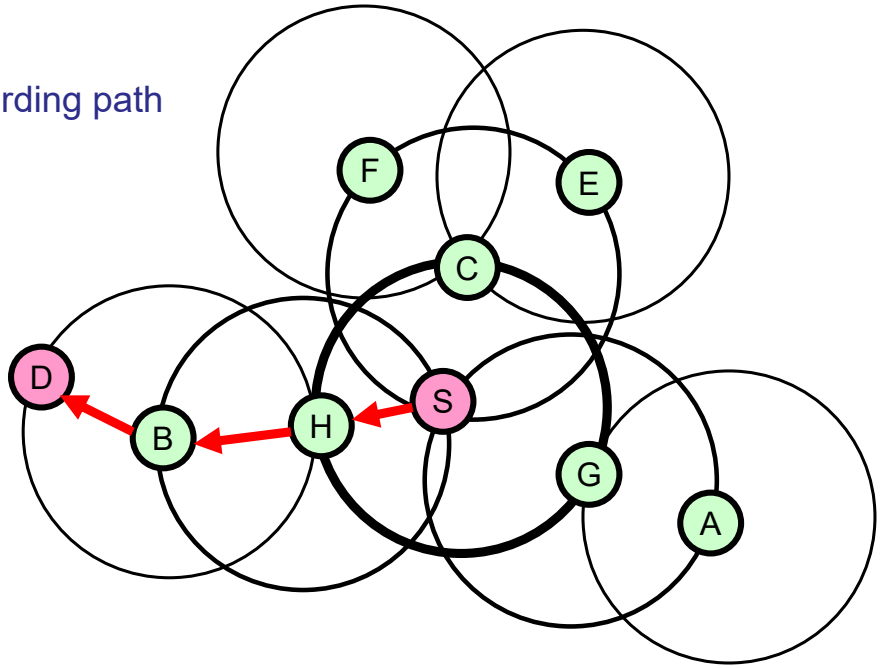
Route Discovery (ZRP)

Node B responds to the route request



Route Discovery (ZRP)

Indicating the forwarding path
S → H → B → D



Protocol Characteristics (1/2)

Routing Protocol	Route Acquisition	Flood for Route Discovery	Delay for Route Discovery	Multipath Capability	Effect of Route Failure
DSDV	Computed a priori	No	No	No	Updates the routing tables of all nodes
WRP	Computed a priori	No	No	No	Ultimately, updates the routing tables of all nodes by exchanging MRL between neighbors
DSR	On-demand, only when needed	Yes. Aggressive use of caching may reduce flood	Yes	Not explicitly. The technique of salvaging may quickly restore a route	Route error propagated up to the source to erase invalid path
AODV	On-demand, only when needed	Yes. Controlled use of cache to reduce flood	Yes	No, although recent research indicate viability	Route error propagated up to the source to erase invalid path

Protocol Characteristics (2/2)

Routing Protocol	Route Acquisition	Flood for Route Discovery	Delay for Route Discovery	Multipath Capability	Effect of Route Failure
AODV	On-demand, only when needed	Yes. Controlled use of cache to reduce flood	Yes	No, although recent research indicate viability	Route error propagated up to the source to erase invalid path
TORA	On-demand, only when needed	Basically one for initial route discovery	Yes. Once the DAG is constructed, multiple paths are found	Yes	Error is recovered locally
ZRP	Hybrid	Only outside a source's zone	Only if the destination is outside the source's zone	No	Hybrid of updating nodes' tables within a zone and propagating route error to the source
LAR	On-demand, only when needed	Reduced by using location information	Yes	No	Route error propagated up to the source

Scalability

- How large can an ad hoc network grow?
  - No one knows
  - It is safe to say that such a network cannot grow to the size of the Internet
  - Worse performance for route acquisition latency

Quality of Service

- Can delay-constrained applications operate well?
  - Vulnerable to dynamic link quality variations between neighboring nodes
  - A route between two endpoints that initially meets the application's QoS constraint may soon fail to meet them

Inter-operation with the Internet

- How can an ad hoc network take advantage of evanescent or dynamically changing points of connection to the Internet?
  - Through the Internet "gateway", a node has connectivity to the global Internet
  - Advertise itself as a default router
  - Other nodes can consider themselves connected to the default router by way of a multi-hop path