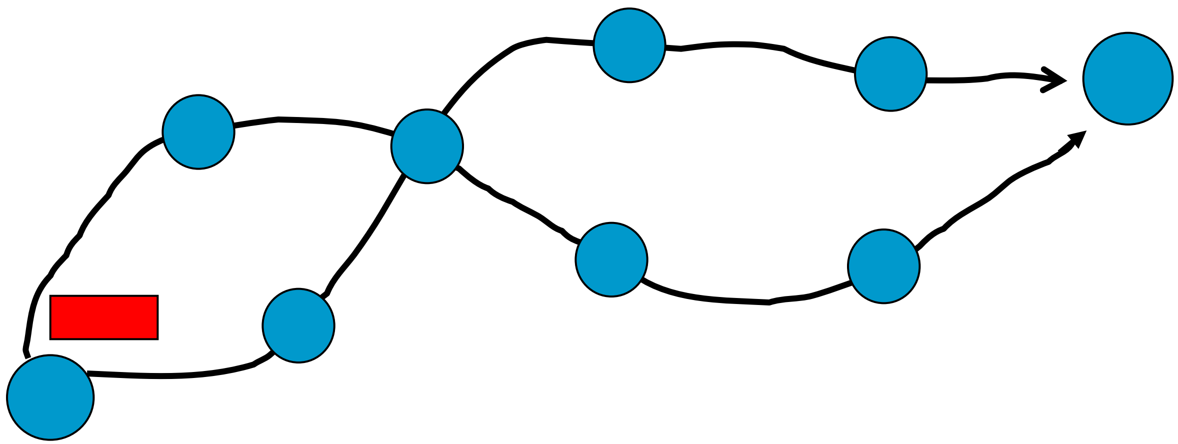
Routing Protocols In Ad Hoc Networks

Two Approaches

- Traditional routing algorithms adapted to ad hoc networks
- Geographical routing

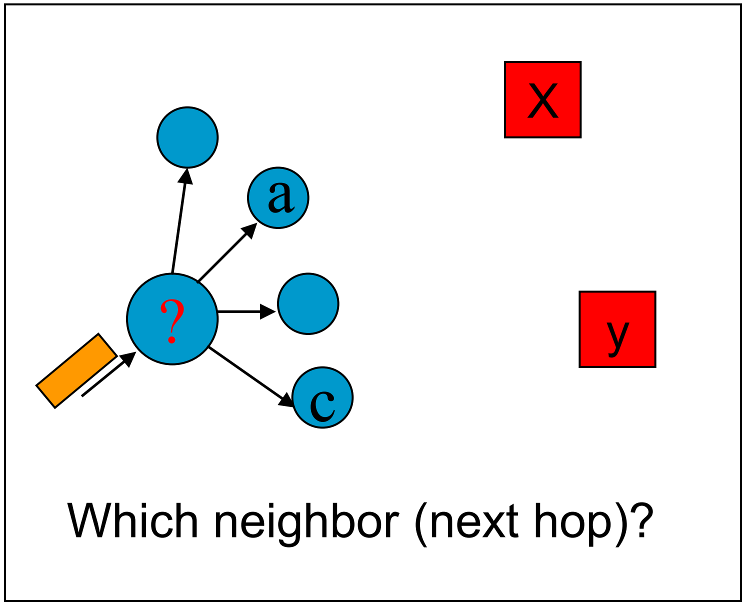
Review of Routing

- Next-hop routing
- Source routing
- Flooding



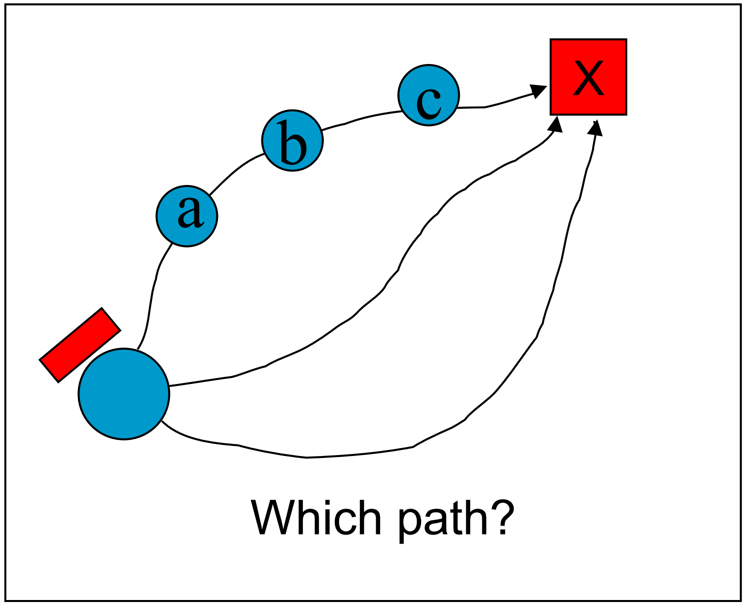
Next-Hop Routing

destination	next hop	cost
x	a	3
y	c	5
...		



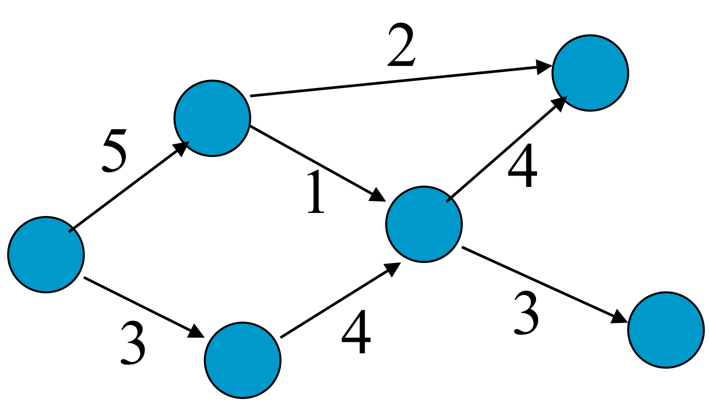
Source Routing

destination	path	cost
x	(a, b, c)	
y		
…		



Link-State Routing

- Each node periodically broadcasts the link states of its outgoing links to the entire network (by flooding).
- As a node receives this information, it updates its view of the network topology and routing table.



Distance-Vector Routing

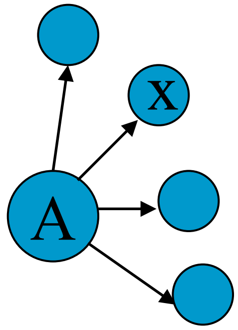
- least-cost(A,B) =

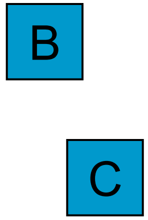
  min {cost(A,x) + least-cost(x,B):

  for all neighbors, x, of A}

- Neighbors exchange distance vectors

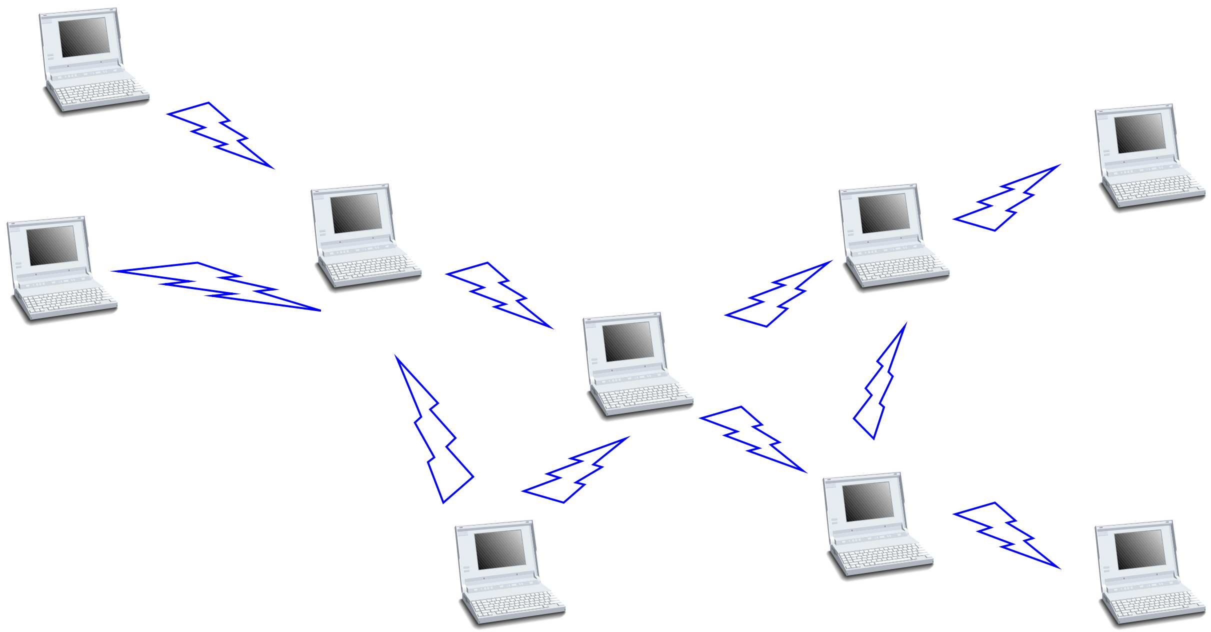
Destination	A	B	C	D	E	F	G
Distance	0	10	…				





Routing in MANETs

- Every node works as a router



Challenges

- Quick topology changes
- Scalability

Two Approaches

- Table-driven
  - Like existing Internet routing protocols
- On-demand

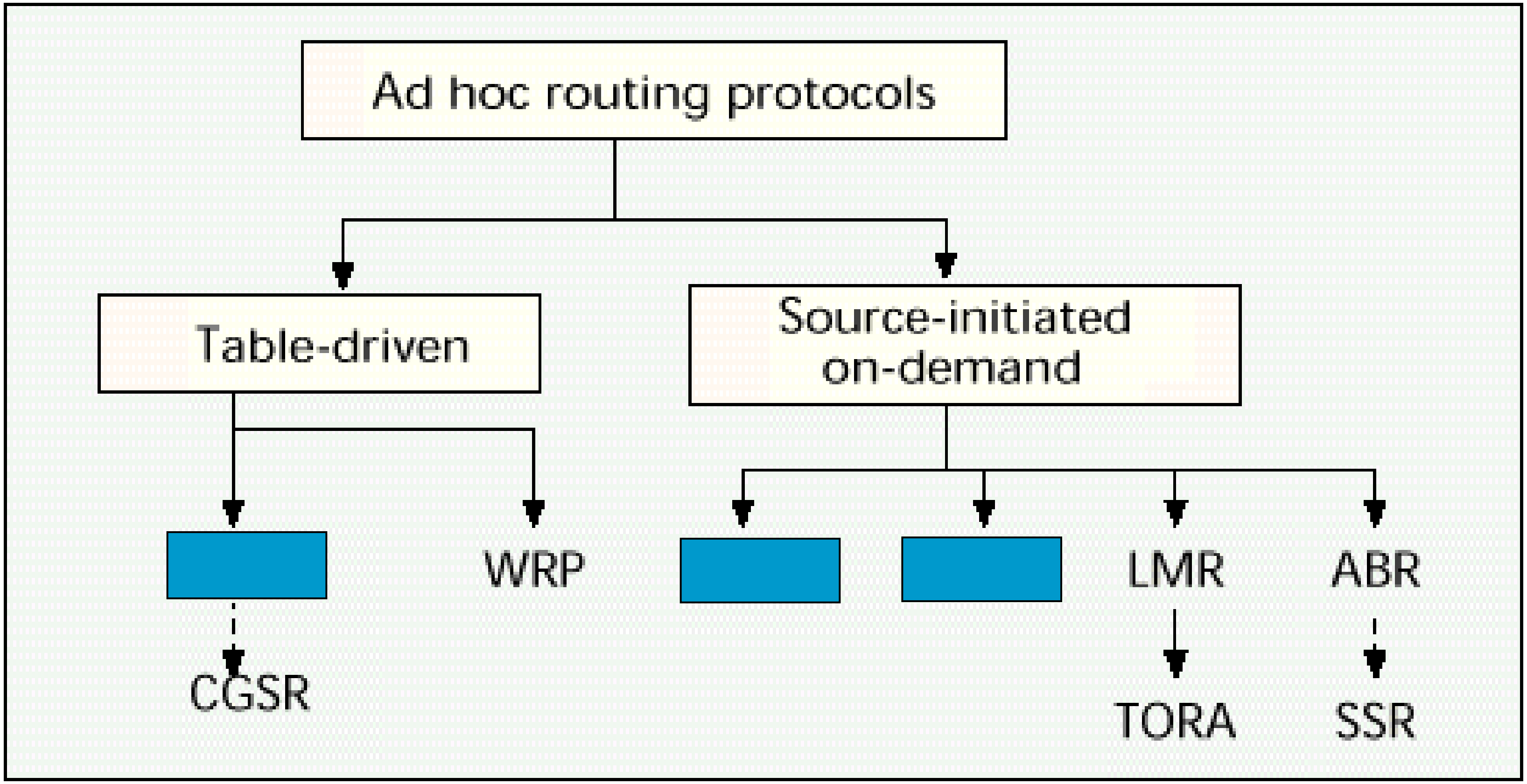
Table-Driven Routing Protocols

- Also called proactive routing protocols
- Continuously evaluate the routes
- Attempt to maintain consistent, up-to-date routing information
  - when a route is needed, it is ready immediately
- When the network topology changes
  - the protocol responds by propagating updates throughout the network to maintain a consistent view

On-Demand Routing Protocols

- Also called reactive routing protocols
- Discover routes when needed by the source node.
- Longer delay

Early Ad Hoc Routing Protocols



DSDV: Destination Sequence Distance Vector

- "Highly Dynamic Destination-Sequence Distance-Vector Routing (DSDV) for Mobile Computers"
- Charles E. Perkins & Pravin Bhagwat
- Computer Communications Review, 1994
- pp. 234-244

DSDV Overview

- DSDV = destination-sequenced distance-vector
- Distance-vector routing
- Each entry is tagged with a sequence number originated by the destination node.

Destination	A	B	C	D	E	F	G
Distance	0	10	…				
Sequence #							

DSDV Route Advertisement

- Each node periodically broadcasts its distance vector.
  - “broadcast” is limited to one hop.
  - sequence numbers
    - For the sender’s entry: Sender’s new sequence number (typically, +1)
    - For other entries: originally “stamped” by the destination nodes

Destination	A	B	C	D	E	F	G
Distance	0	10	…				
Sequence #							

DSDV Route Updating Rules

- Paths with more recent seq. nos. are always preferred.
- least-cost(A,B) =

  min {cost(A,x) + least-cost(x,B):

  for all neighbors, x, of A}

(Source-Initiated) On-Demand Routing Protocols

- DSR
- AODV
- ABR
- SSR
- ZRP

DSR: Dynamic Source Routing

- "Dynamic Source Routing in Ad-Hoc Wireless Networks"
- D. B. Johnson and D. A. Maltz
- Mobile Computing, 1996
- pp. 153-181

DSR : Outline

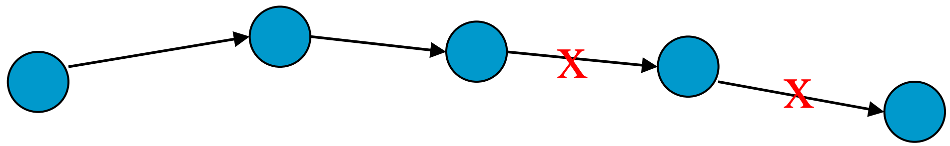
- Source Routing
- On-demand
- Each host maintains a route cache containing all routes it has learned.
- Two major parts:
  - route discovery
  - route maintenance

Route Discovery of DSR

- To send a packet, a source node first consults its route cache.
  - If there is an unexpired route, use it.
  - Otherwise, initiate a route discovery.
- Route Discovery:
  - Source node launches a ROUTE_REQUEST by flooding.
  - A ROUTE_REPLY is generated when
    - the route request reaches the destination
    - an intermediate node has an unexpired route to the destination

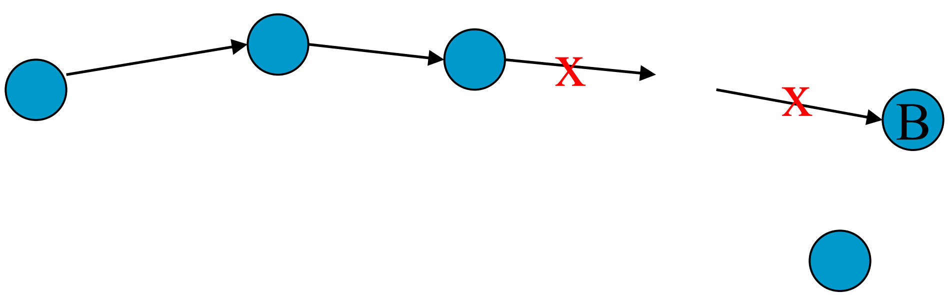
Stale Route Cache Problem

- Definition:
  - A cached route may become stale before it expires.



Route Maintenance of DSR

- When a node detects a link breakage, it generates a ROUTE_ERROR packet.
  - The packet traverses to the source in the backward direction.
  - The source removes all contaminated routes, and if necessary, initiates another ROUTE_REQUEST.



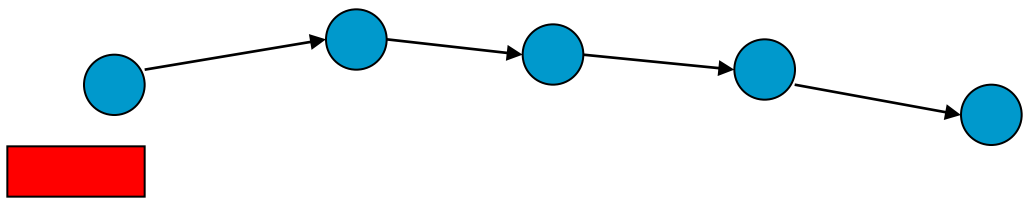
AODV: Ad-Hoc On-Demand Distance Vector Routing

- “Ad-hoc On-Demand Distance Vector Routing”
- Charles E Perkins, Elizabeth M Royer
- Proc. 2nd IEEE Wksp. Mobile Comp. Sys. and Apps., Feb. 1999.

AODV : Outline

- Next-hop Routing (cf. DSR: source routing)
- On-demand
- Each host maintains a routing table
- Two major parts:
  - route discovery (by flooding)
  - route maintenance

AODV vs. DSR



- DSR: Routes are discovered and cached
- AODV: Next-hop info is stored

- “Performance Comparison of Two On-Demand Routing Protocols for Ad Hoc Networks,” Personal Communications, February 2001

ABR: Associativity-Based Routing

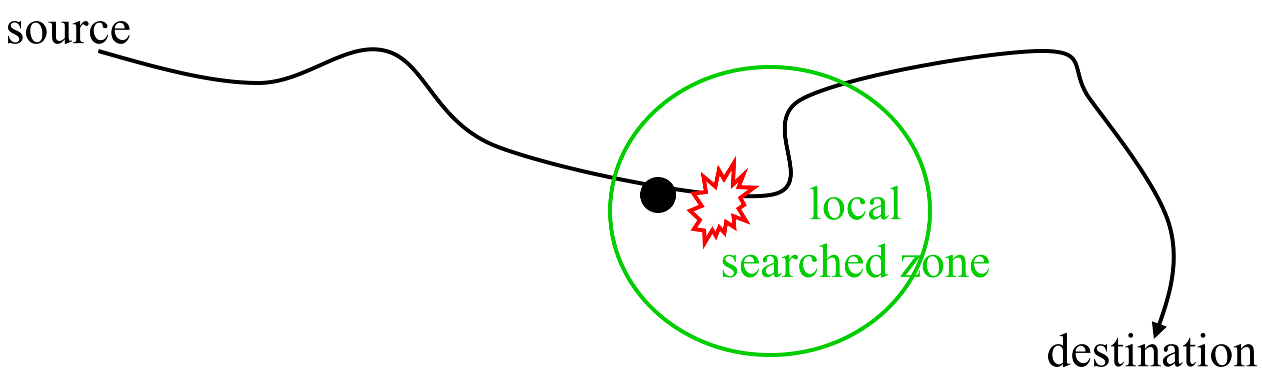
- "Associativity-Based Routing for Ad-Hoc Mobile Networks," C.K. Toh.

- ABR considers the stability of a link.
  - called the degree of association stability.
  - measured by the number of beacons received from the other end of the link.
  - The higher degree of a link's stability, the lower mobility of the node at the link's other end.

ABR Outline

- Route Discovery:
  - Same as DSR except the following.
  - Each ROUTE_REQUEST packet collects the association stability information along its path to the destination.
  - The destination node selects the best route in terms of association stability.

- Route Reconstruction:
  - On route error, a node performs a local search in hope of repairing the path.
  - If the local search fails, a ROUTE_ERROR is reported to the source.



SSA: Signal Stability-Based Adaptive Routing

- "Signal Stability-Based Adaptive Routing (SSA) for Ad Hoc Wireless Networks"
- University of Maryland
- R. Dube, C. D. Rais, K.-Y. Wang & S. K. Tripathi
- IEEE Personal Communications, '97

Basic Idea of SSA

- Observation:
  - The ABR only considers the connectivity stability.
- Two more metrics:
  - signal stability:
    - the strength of signal over a link
  - location stability
    - how fast a host moves

ZRP: Zone Routing Protocol

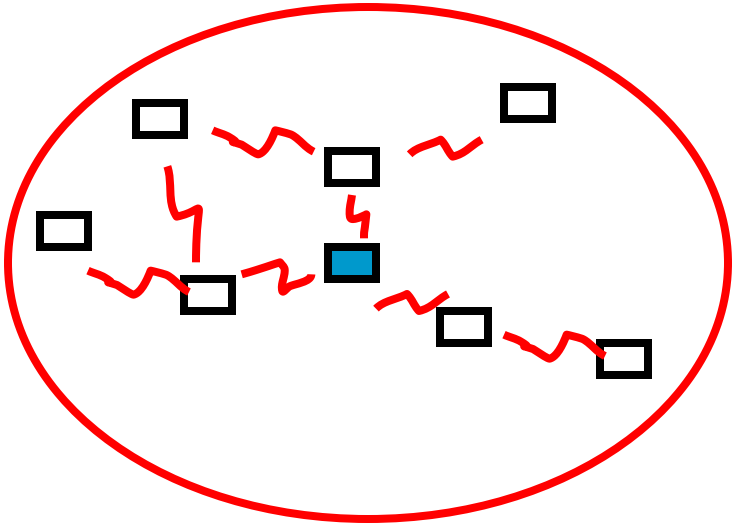
- The Zone Routing Protocol (ZRP) for Ad Hoc Networks
- Cornell University
- Z.J. Haas and M.R. Pearlman
- draft-ietf-manet-zone-zrp-01.txt, 1998

ZRP Outline

- Hybrid of table-driven and on-demand!!
- Each node is associated with a zone.
- Within a zone: table-driven (proactive) routing.
- Inter-zone: on-demand routing (similar to DSR).

Route Discovery

- By an operation called "boardercast":
  - sending the route-request to boarder nodes



ZRP Example

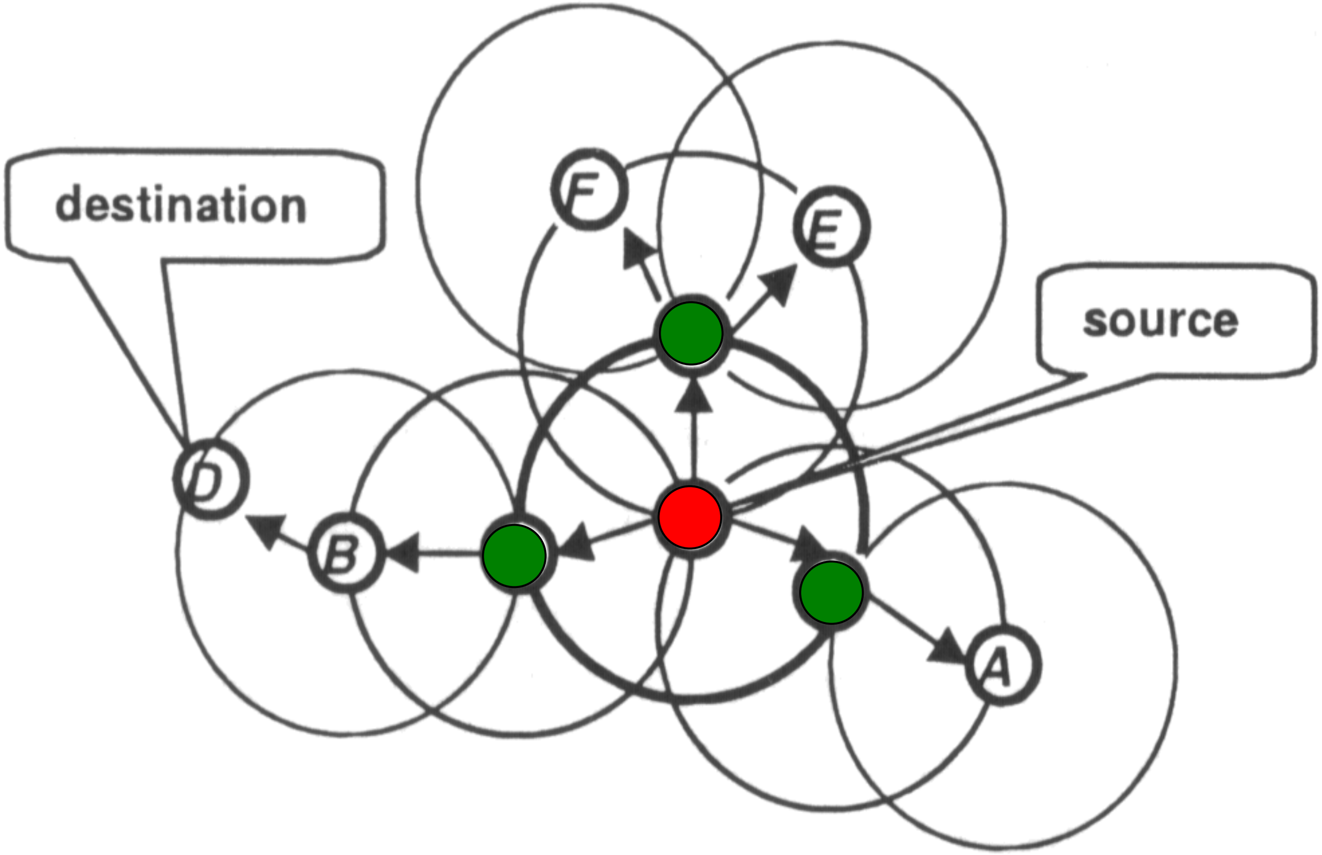
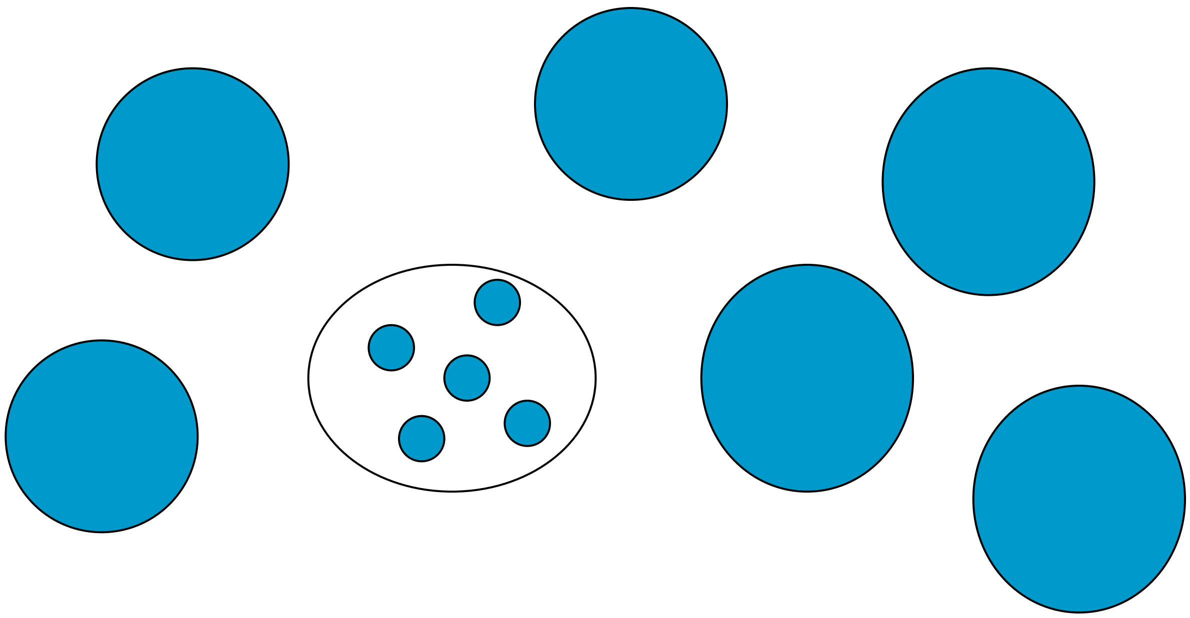


Figure 3: An example of the ZRP protocol

Scalability Problem in Large-Scale Network Routing

- Internet solution



Geographic Routing

- Make use of location information in routing

Assumptions

- Each node knows of its own location.
  - outdoor positioning device:
    - GPS: global positioning system
    - accuracy: in about 5 to 50 meters
  - indoor positioning device:
    - Infrared
    - short-distance radio
- The destination's location is also known.
  - How? (via a location service)

LAR: Location-Aided Routing

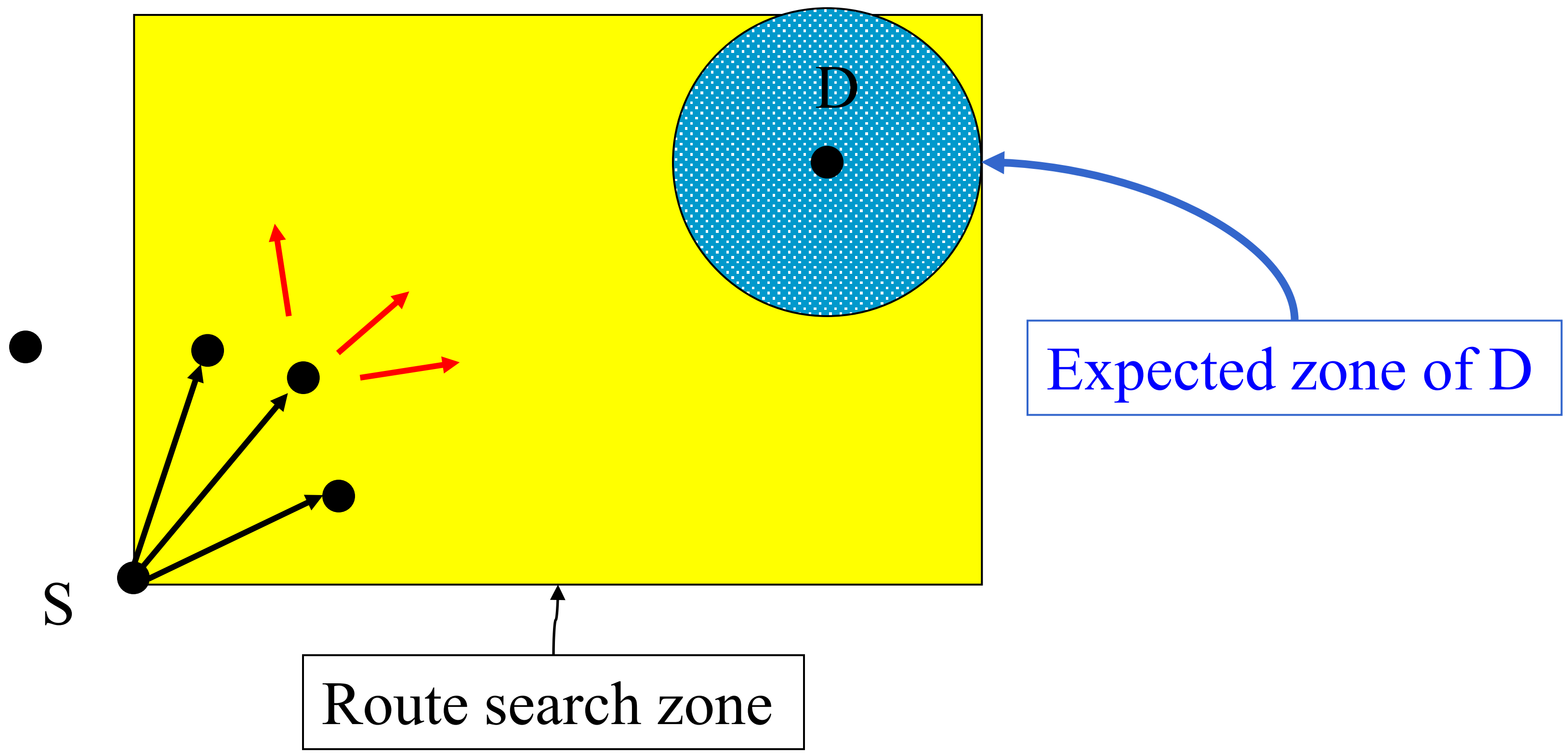
- Location-Aided Routing (LAR) in mobile ad hoc networks
- Young-Bae Ko and Nitin H. Vaidya
- Texas A&M University
- Wireless Networks 6 (2000) 307–321

Basic Idea of LAR

- All packets carry sender's current location.
- This info enables nodes to learn of each other's location.

Basic Idea of LAR (cont.)

- Same as DSR, except that if the destination's location is known, the ROUTE_REQ is only flooded over the "route search zone."



DREAM

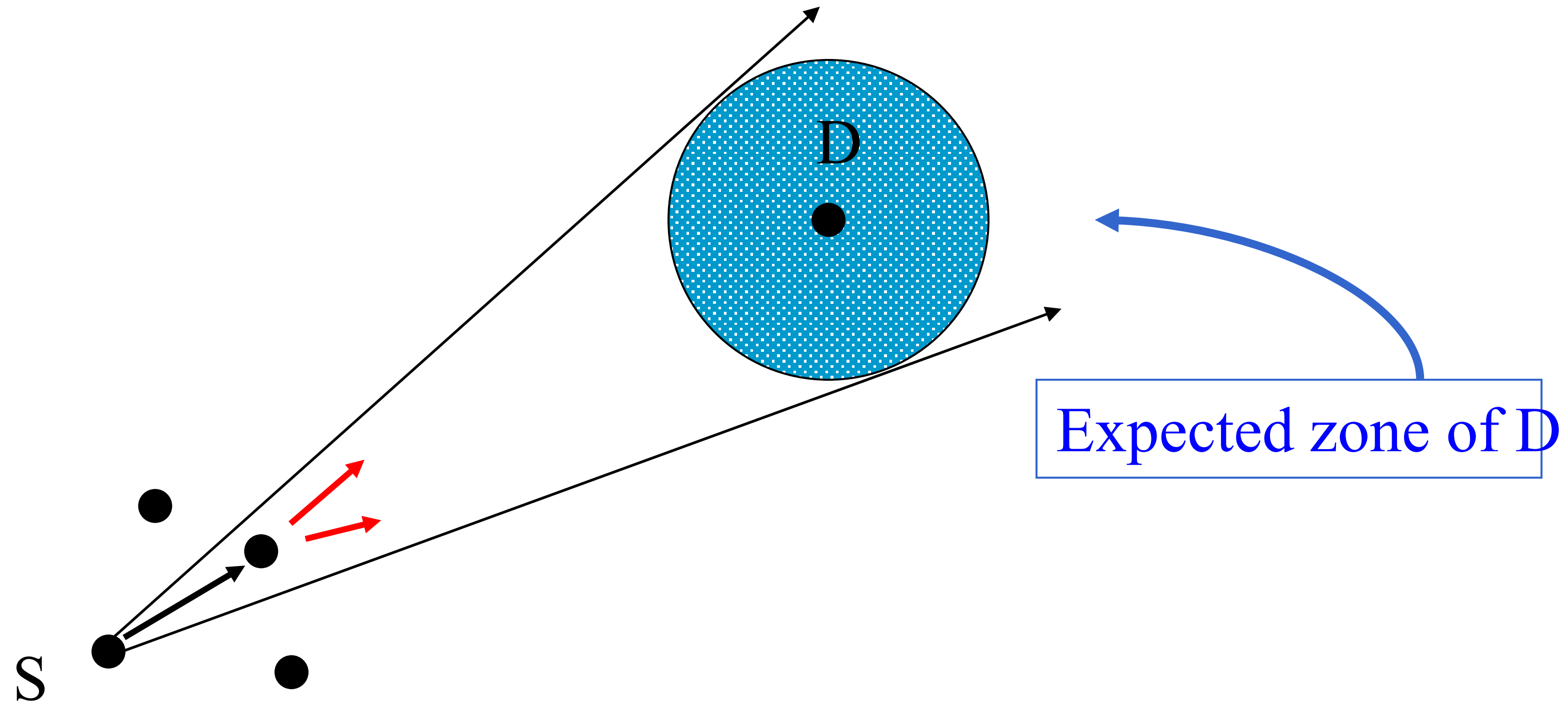
- A Distance Routing Effect Algorithm for Mobility (DREAM)
- S. Basagni, I. Chlamtac, V.R. Syrotiuk, B.A. Woodward
- The University of Texas at Dallas
- Mobicom'98

Basic Idea of DREAM

- Dissemination of location information:
  - Each node periodically advertises its location (and movement information) by flooding.
  - This way, nodes have knowledge of one another's location.

Basic Idea of DREAM

- Data Packet carries D's and S's locations.
- Forwarded toward only a certain direction.

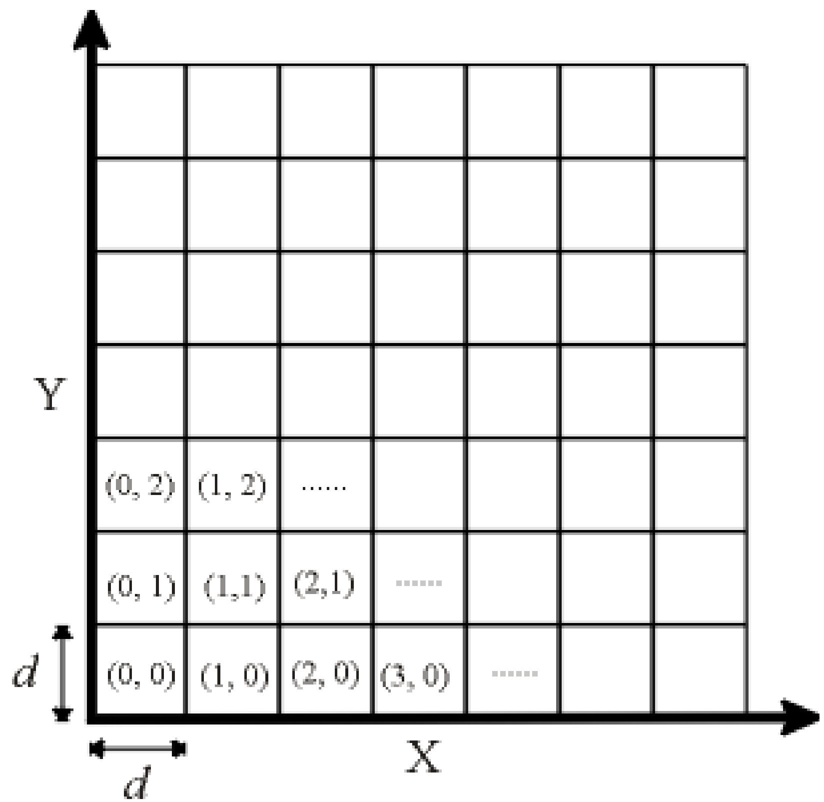


GRID Routing

- "GRID: A Fully Location-Aware Routing Protocol for Mobile Ad Hoc Networks"
- Wen-Hwa Liao, Yu-Chee Tseng, Jang-Ping Sheu
- NCTU
- Telecommunication Systems, 2001.

Basic Idea of GRID Routing

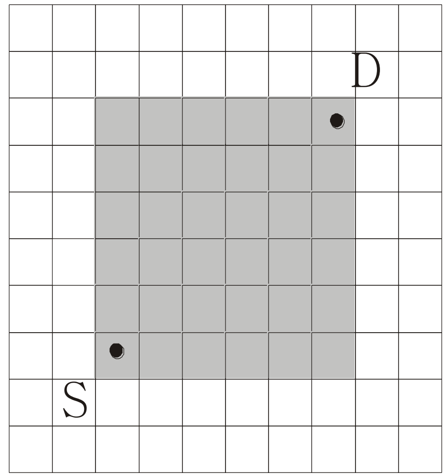
- Partition the physical area into *d* x *d* squares called *grids*.



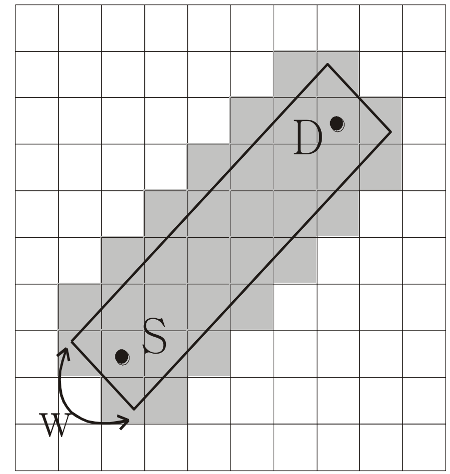
Protocol Overview

- In each grid, a leader is elected, called gateway.
- Responsibility of gateways:
  - forward route discovery packets
  - propagate data packets to neighbor grids
  - maintain routes which passes the grid
- Routing is performed in a grid-by-grid manner.

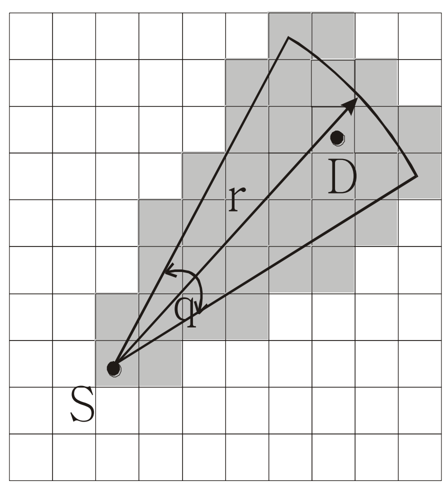
Route Search Range Options



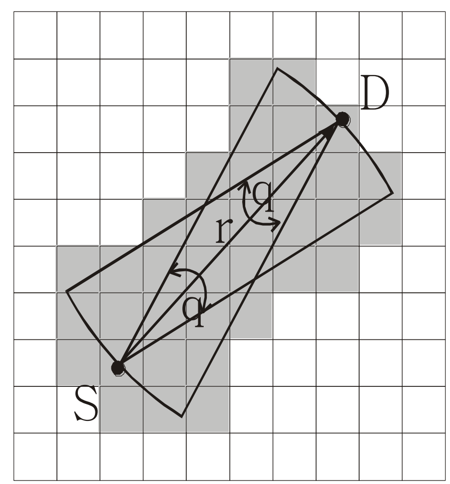
(a) Rectangle



(b) Bar(w)

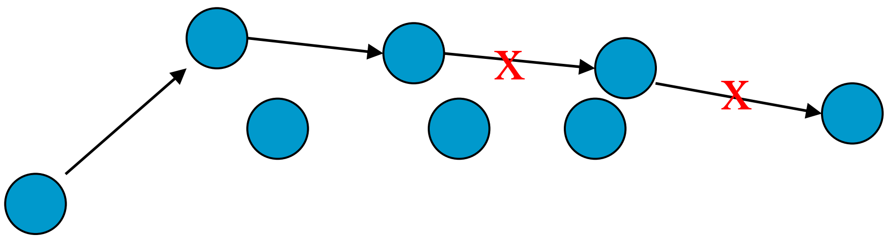


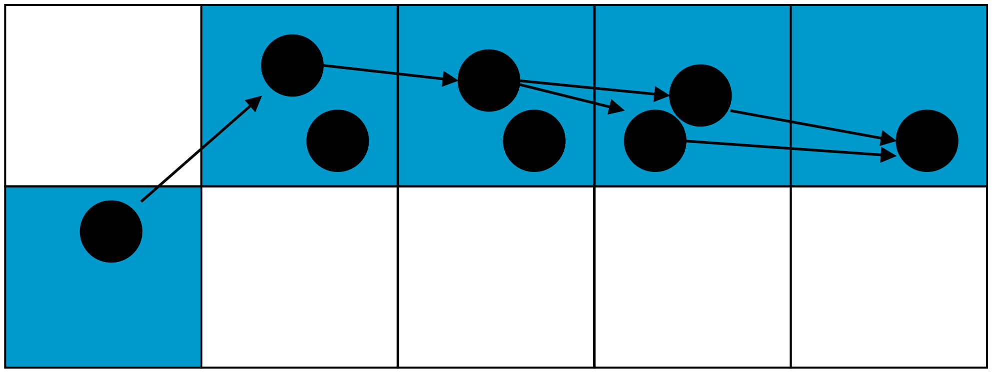
(c) Fan(q, r)



(d) Two_Fan(q, r)

Strength of Grid Routing





Gateway Election in a Grid

- Any "leader election" protocol in distributed computing can be used.
- Multiple leaders in a grid are acceptable.
- Preference in electing a gateway:
  - near the physical center of the grid
    - likely to remain in the grid for longer time
  - once elected, a gateway remains so until leaving the grid

Taxonomy of Geographic Routing Algorithms

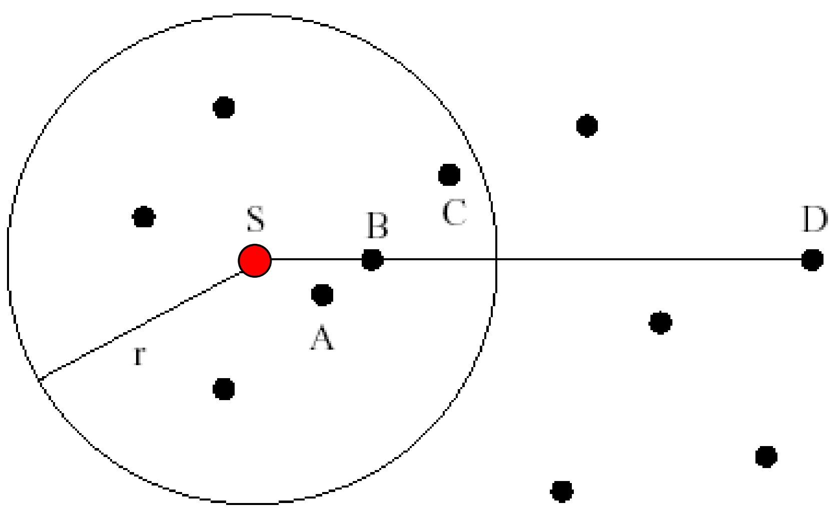
- Also called position-based routing
- Three major components of geographic routing:
  - Location services (dissemination of location information)
    - Next topic
  - Forwarding strategies
  - Recovery schemes

Forwarding Strategies

- Basic greedy methods
- Directional flooding
- Geographical source routing
- Power-aware routing

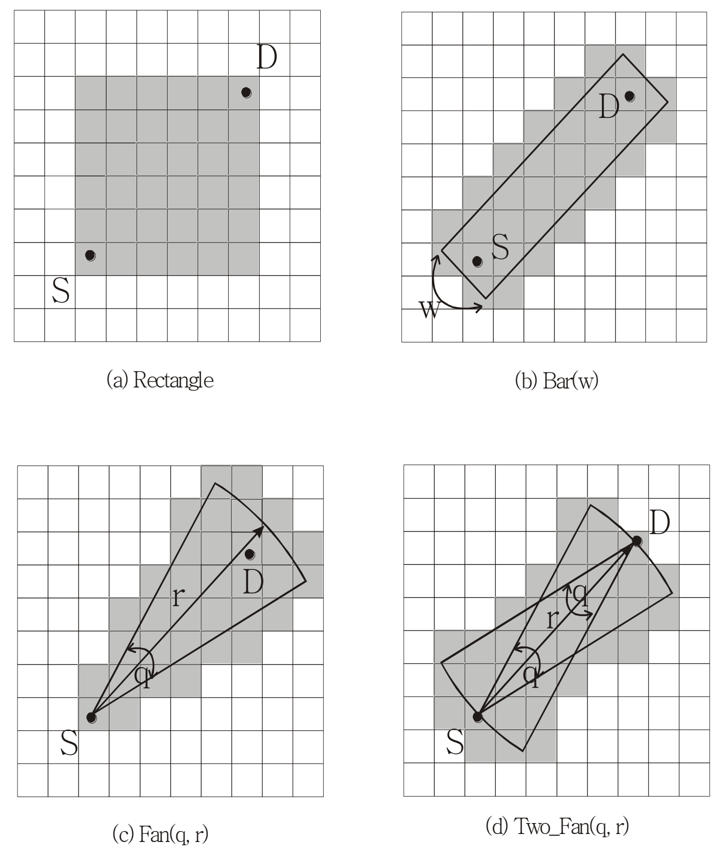
Basic greedy methods

- Most Forward within Radius (C), 1984
- Nearest Forward Progress (A), 1986
- Compass Routing (B) , 1999
- Random Progress (X), 1984
- The above schemes' 2-hop variants



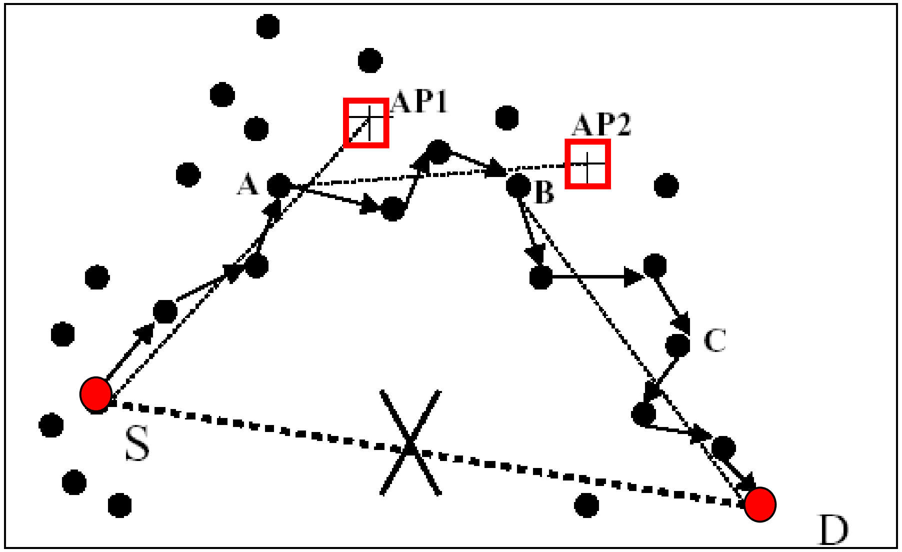
Directional Flooding

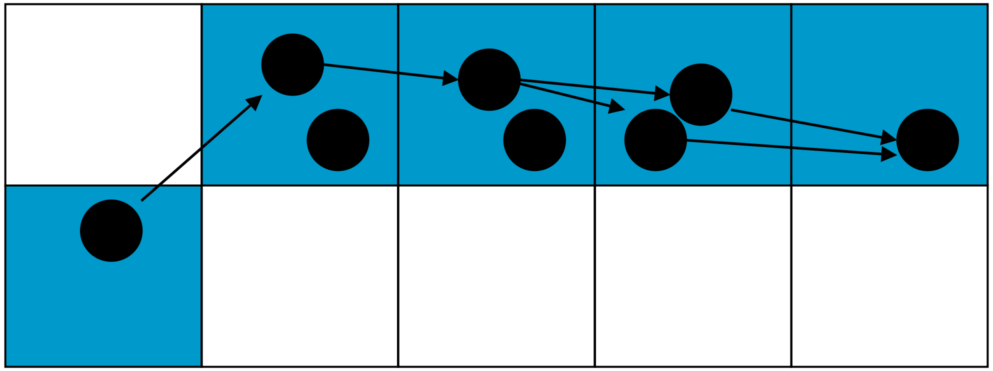
- DREAM (in data packet routing)
- LAR (in route discovery)
- GRID (in route discovery)



Geographical Source Routing

- Source specifies a geographical path
  - Needs an anchor path discovery protocol
- Terminode routing
- GRID



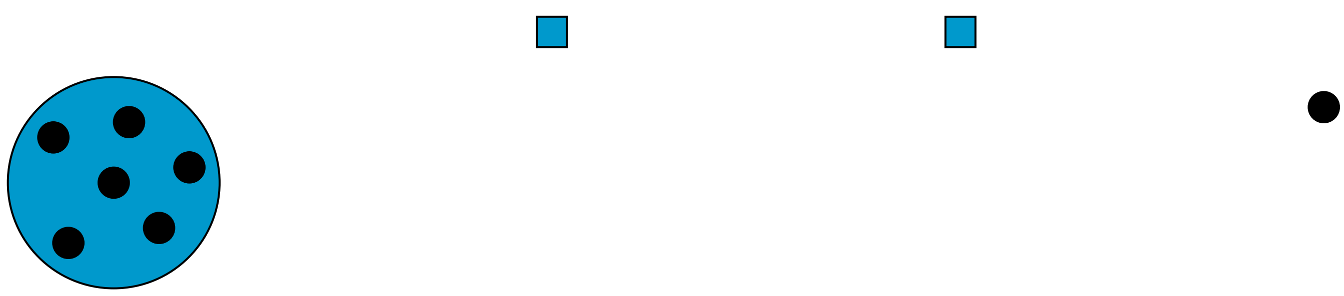


Terminode Routing

- "Self Organized Terminode Routing," Blazevic, Giordano, Le Boudec Cluster Computing Journal, Vol.5, No.2, April 2002
- Remote destinations:
  - Use geographical routing
- Local destinations:
  - Use non-geographical, proactive routing
- Similar to Zone Routing in this sense

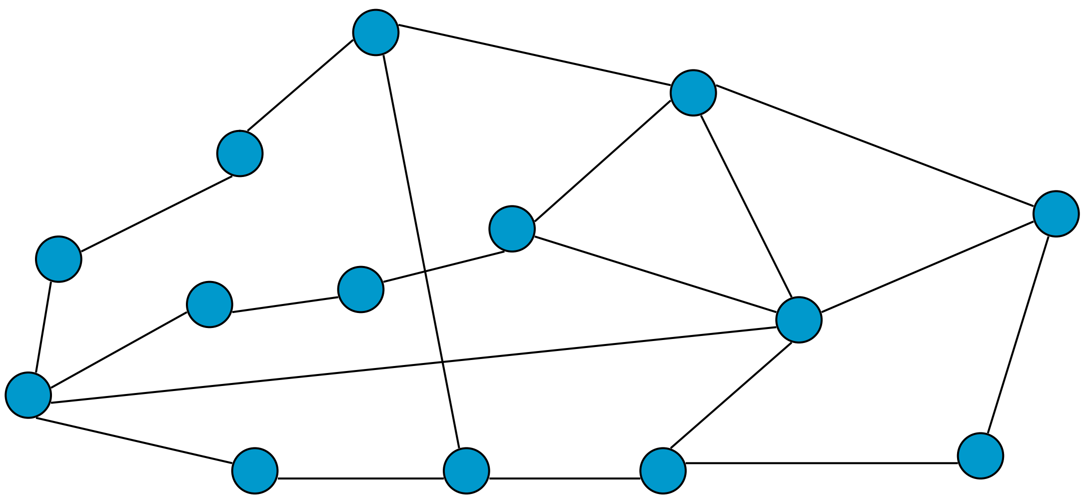
Terminode Routing

- Remote Routing
  - Anchored Geodesic Packet Forwarding
  - Geodesic Packet Forwarding (if no anchored path known)
  - Friend Assisted Path Discovery
    - Based on Small World Graphs

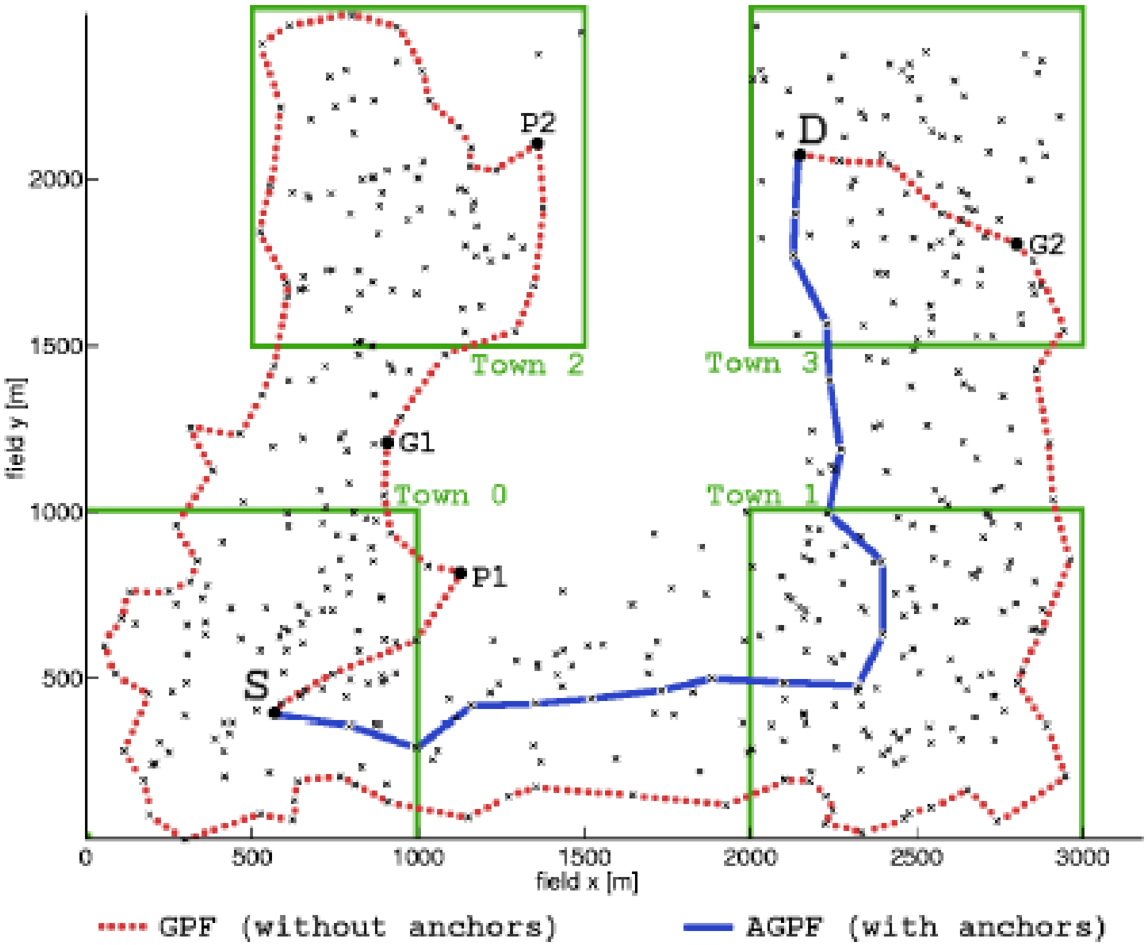


Small World Graphs

- Two nodes are connected if they are acquainted
- Sparse, small diameter



Terminode routing

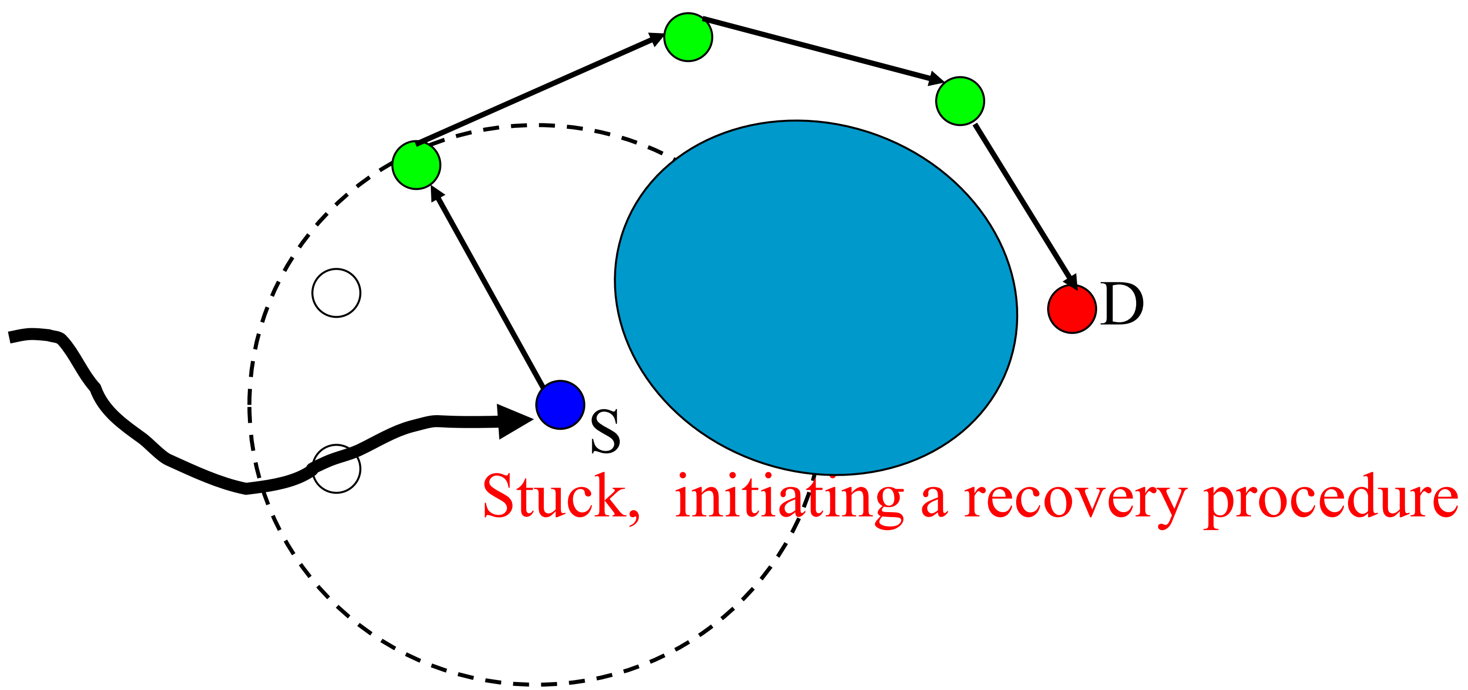


Power-Aware Routing

- "Geographical and Energy Aware Routing: a recursive data dissemination protocol for wireless sensor networks"
- Y. Yu, R. Govindan, D. Estrin
- UCLA

Recovery Schemes

- With any of the above forwarding strategies, packets may get stuck (hitting a hole).
- A recovery scheme is invoked to get around the hole.
  - Initiate a route discovery
  - GPSR (enter the perimeter mode)

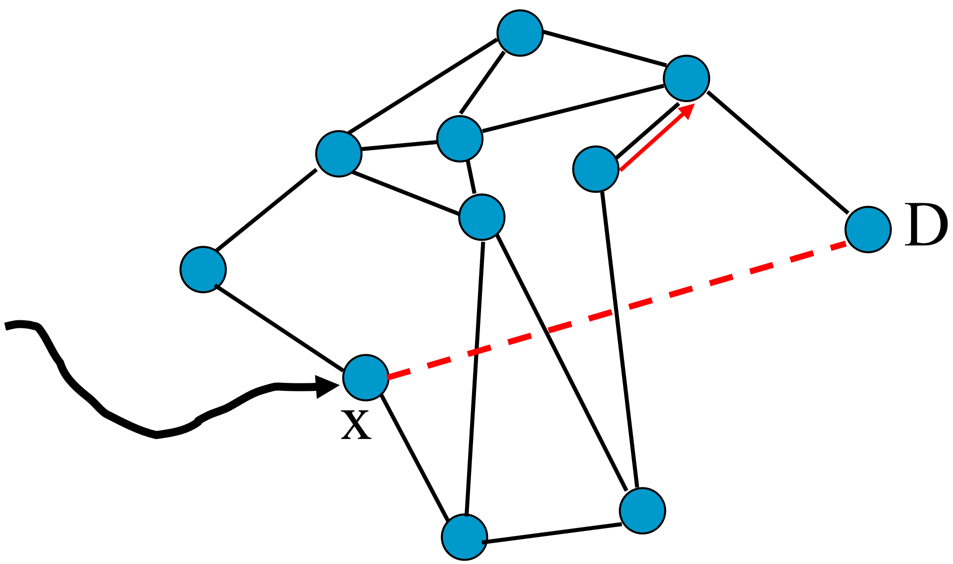


GPSR

- "GPSR: Greedy Perimeter Stateless Routing for Wireless Networks"
- Brad Karp, H.T. Kung
- Harvard University
- MobiCom 2000
- Two modes:
  - Greedy (for regular forwarding)
  - Perimeter (for recovery)

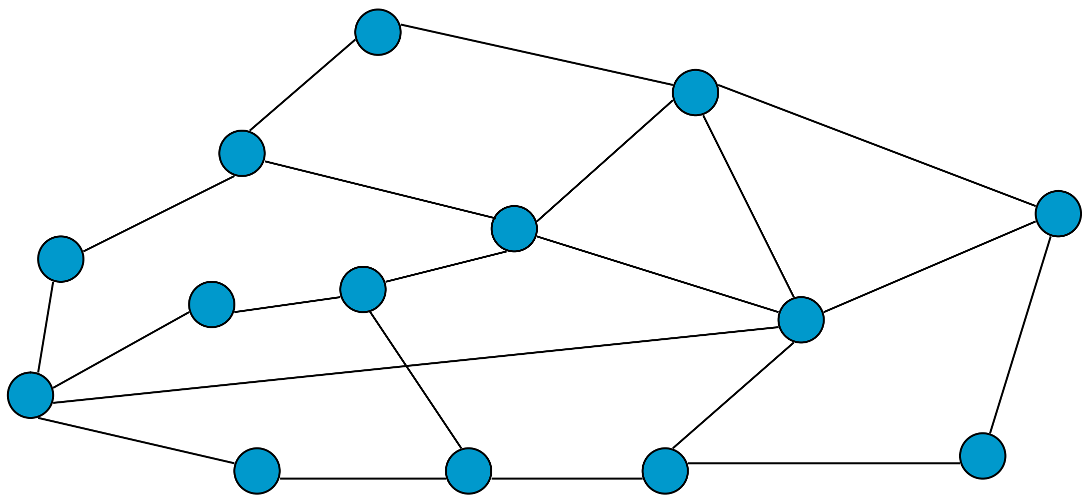
Perimeter Mode of GPSR

- Suppose nodes x and D are connected by a planar graph.
- The graph divides the plane into faces.
- Line xD crosses one or more faces.



Planar Graphs

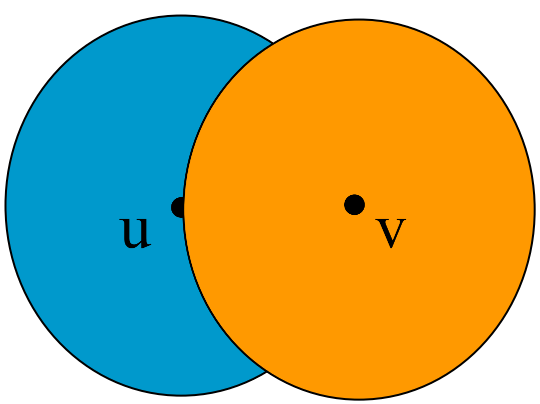
- Graphs without crossing edges.



Not Planar

Planar Subgraph

- G: communication graph
- Relative neighborhood graph (RNG):
  - Subgraph of G
  - Keep edge (u, v) iff there are no nodes in the overlapped area.
- RNG is planar



Evolution

- Distance Vector, Link State
- Proactive
- On demand
- Hybrid (zone routing)
- Geographical routing
  - Location Service
  - Location-based Forwarding
  - Recovery

Next?

- Location service
- Geographical routing without location services
- Geocasting:
  - sending a message to every node within a region.