15-496 : A Hand-on Introduction to Wireless Networks

Lecture 11: Multi-hop Wireless

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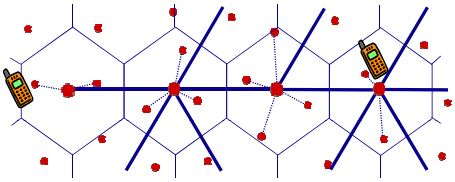
http://www.cs.cmu.edu/~prs/wireless08/

Outline

- What is an ad hoc network
- Why do we need them
- Routing challenges
- DSR
- AODV
- Recent developments

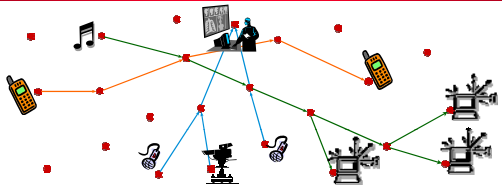
- Based on slides by Prof JP Hubaux, EPFL

Traditional Solution for Mobile Networks



- 2nd generation (GSM, IS-41,…) and 3rd generation (UMTS,…) deployed soon
- Huge, expensive fixed infrastructure
- License for a share of the spectrum
- Operational responsibility: network operators (telcos, ISPs)

A New Paradigm: Ad Hoc networks



- Terminal and node merge
- Initial applications: communication in the battlefield
  - Packet Radio Networks, in the 70's
- The network is *self-organized*: wireless devices collaborate
- Similar trend at the application layer: peer-to-peer (e.g., Napster → Gnutella)

Application Examples of Ad Hoc Networks

- Sensor networks
- Mesh networks: ad hoc access networks
  - Extend reach of infrastructure wireless networks
- Cars
  - Assisted driving (adaptive cruise control,…)
  - Collision avoidance
  - Optimization of traffic flows
  - …
- Crisis networks (e.g., rescue operations after major disaster)
- Military networks

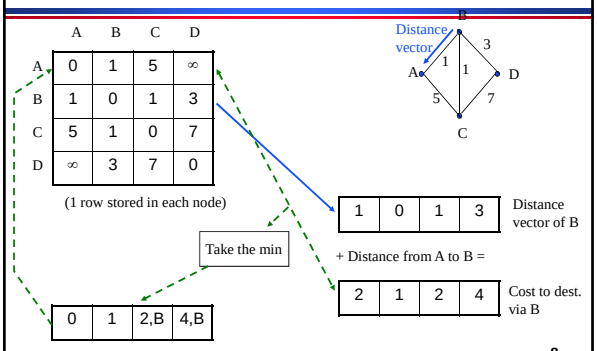
Routing in Ad Hoc Networks

- Challenges: node mobility and high rate of link failure
  - → Traditional routing approaches are not well suited
- Some common assumptions
  - Multihop communication
  - Symmetric links and omnidirectional antennas
  - All nodes have equal capabilities and responsibilities
- Figures of merit
  - Latency of route discovery
  - Overhead (bandwidth, energy, processing power)
  - Security
- Current status of research: many, many proposals
  - Optimal solution depends on deployment scenario: mobility patterns, radio model, traffic characteristics,…
  - Problem can be made arbitrarily hard: intruders, battery power, high mobility, low node density, ...

Brief Reminder : Link-state Protocols

- Example: OSPF
- May consume a lot of resources to update the routes (broadcast!)
- Does not seem to be well suited to cope with mobility: all nodes maintain the global network state
- Techniques to alleviate the problem: limit the propagation of information

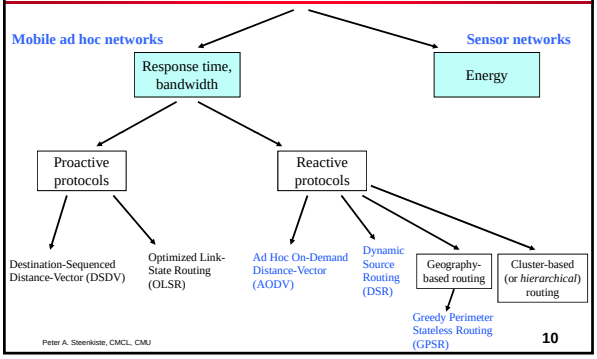
Distance Vector Routing Review



Distance Vector Routing Discussion

- Even if the updates are asynchronous, the routing tables converge
  - » Although it may take a while
- Limited view (neighbors) is both a strength and a weakness
- Limits the amount of information that must be exchanged, but ...
- Undesirable behaviour when links go up and down
  - » E.g., count to infinity problem

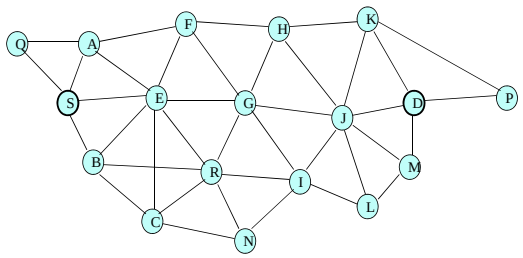
Routing Protocols for Ad Hoc Networks



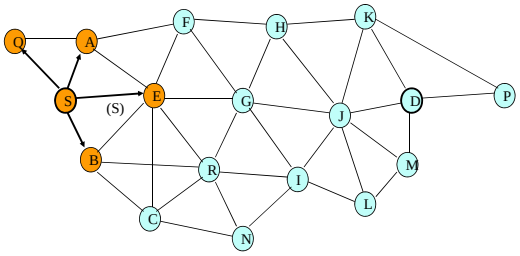
Dynamic Source Routing (DSR)

- Reactive routing protocol: only finds a route when it is needed
- 2 phases, operating both on demand:
  - » Route discovery
    - – Used only when source S needs to send a packet to destination D
    - – Based on flooding of Route Requests (RREQ)
  - » Route maintenance
    - – When S can no longer use its route (because a link along that route no longer works), it will detect the problem and fix the route

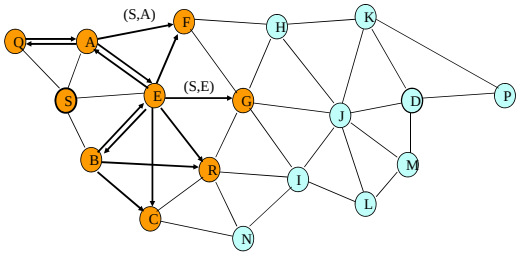
DSR: Route Discovery (1)



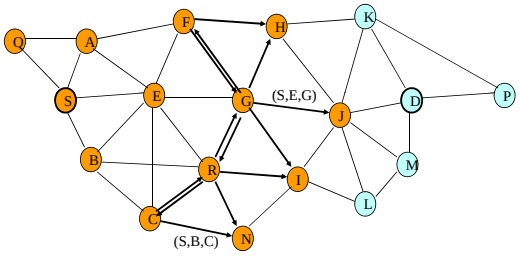
DSR: Route Discovery (2)



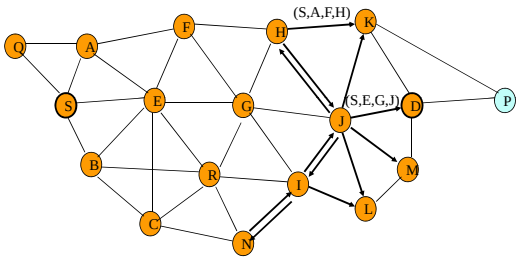
DSR: Route Discovery (3)



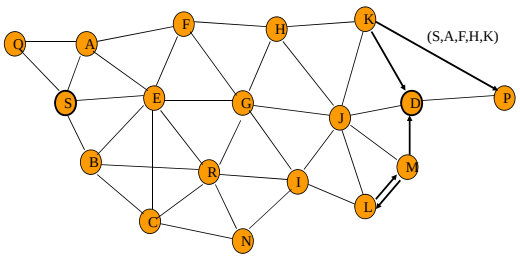
DSR: Route Discovery (4)



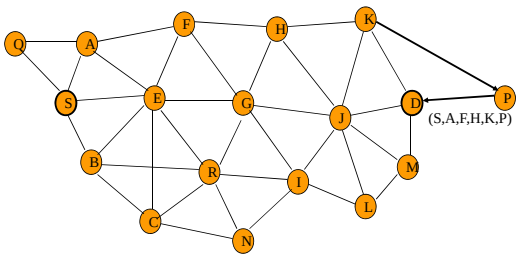
DSR: Route Discovery (5)



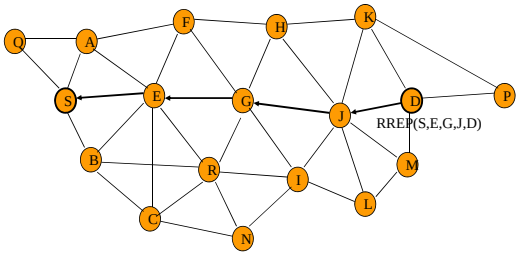
DSR: Route Discovery (6)



DSR: Route Discovery (7)



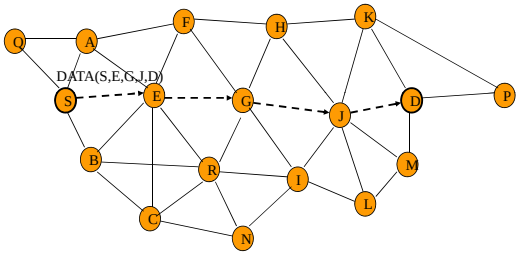
DSR: Route Discovery (8)



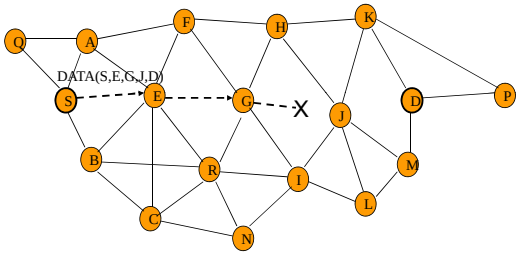
DSR: Route Discovery Discussion

- Route reply by reversing the route (as illustrated) works only if all the links along the route are bidirectional
- If unidirectional links are allowed, then RREP may need a route discovery from D to S
- Note: IEEE 802.11 assumes that links are bidirectional

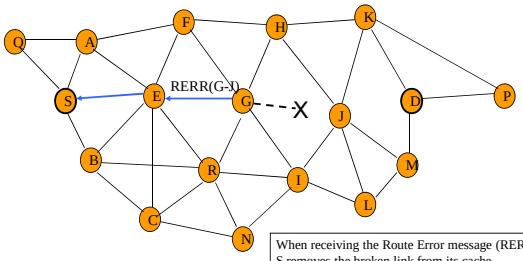
DSR: Data delivery



DSR: Route Maintenance (1)



DSR: Route Maintenance (2)



When receiving the Route Error message (RERR), S removes the broken link from its cache. It then tries another route stored in its cache; if none, it initializes a new route discovery

DSR: Optimization of Route Discovery: Route Caching

- Principle: each node caches a new route it learns by any means
- Examples
  - When node S finds route (S, E, G, J, D) to D, it also learns route (S, E, G) to node G
  - In the same way, node E learns the route to D
  - Same phenomenon when transmitting route replies
- Moreover, routes can be overheard by nodes in the neighbourhood
- However, route caching has its downside: stale caches can severely hamper the performance of the network

DSR: Strengths

- Routes are set up and maintained only between nodes that need to communicate
- Route caching *can* further reduce the effort of route discovery
- A single route discovery may provide several routes to the destination

DSR: Weaknesses

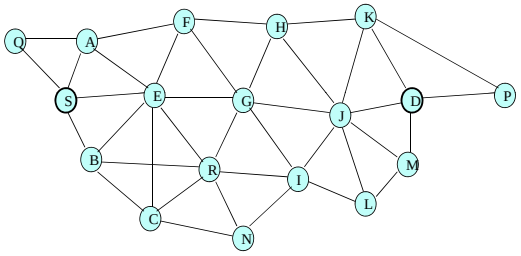
- Route requests tend to flood the network and generally reach all the nodes of the network
- Because of source routing, the packet header size grows with the route lengh
- Risk of many collisions between route requests by neighboring nodes ➔ need for random delays before forwarding RREQ
- Similar problem for the RREP (*Route Reply storm* problem), in case links are not bidirectional

Note: *Location-aided routing* may help reducing the number of useless control messages

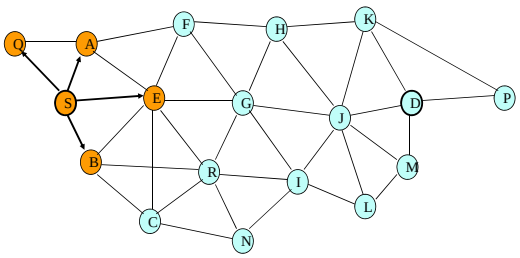
Ad Hoc On-Demand Distance Vector Routing (AODV)

- As it is based on source routing, DSR includes source routes in data packet headers
- Large packet headers in DSR ➔ risk of poor performance if the number of hops is high
- AODV uses a route discovery mechanism similar to DSR, but it maintains routing tables at the nodes
- AODV *ages* the routes and maintains a hop count
- AODV assumes that all links are bi-directional

AODV : Route Discovery (1)



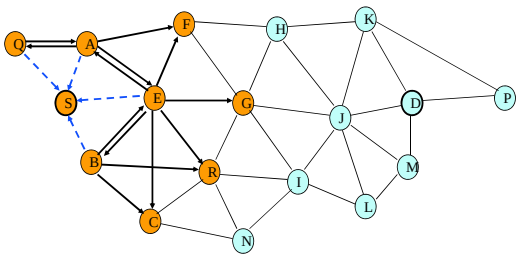
AODV : Route Discovery (2)



: Route Request (RREQ)

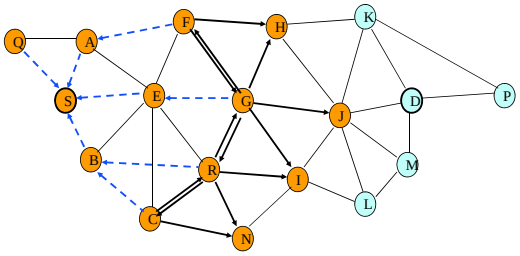
Note: if one of the intermediate nodes (e.g., A) knows a route to D, it responds immediately to S

AODV : Route Discovery (3)

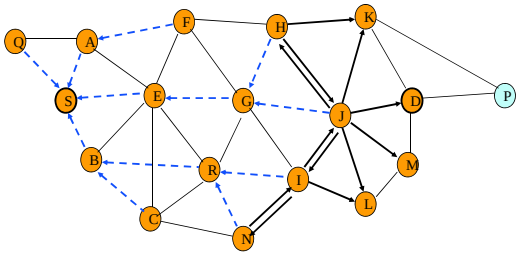


: represents a **link** on the **reverse path**

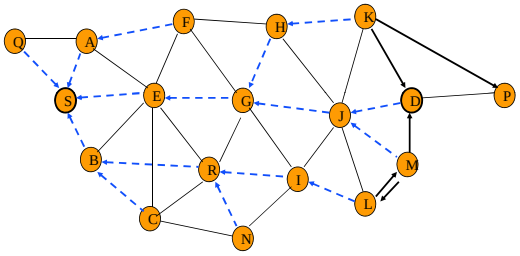
AODV : Route Discovery (4)



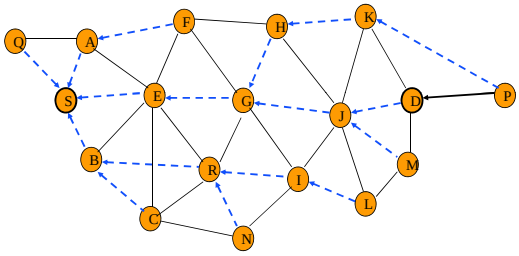
AODV : Route Discovery (5)



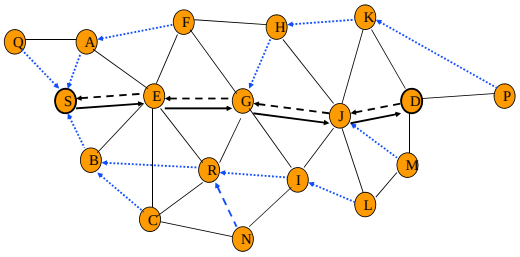
AODV : Route Discovery (6)



AODV : Route Discovery (7)



AODV : *Route Reply* and Setup of the *Forward Path*



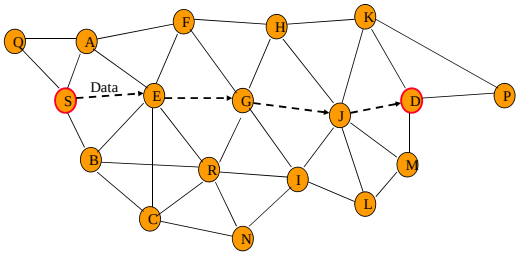
: Link over which the RREP is transmitted

: Forward path

Route Reply in AODV

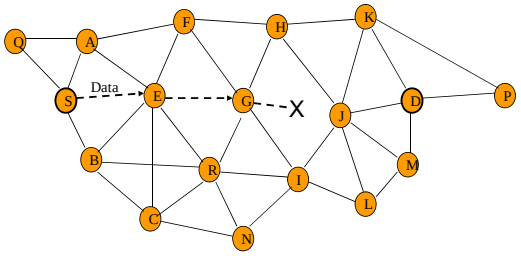
- **In case it knows a path more recent than the one previously known to sender S, an *intermediate node* may also send a route reply (RREP)**
- **The freshness of a path is assessed by means of destination sequence numbers**
- **Both reverse and forward paths are purged at the expiration of appropriately chosen timeout intervals**

AODV : Data Delivery

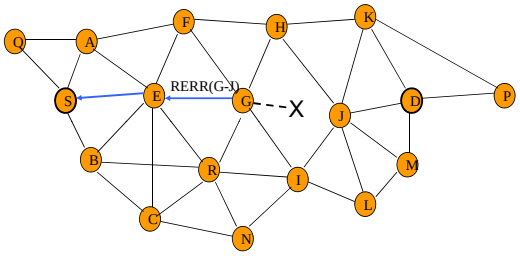


The route is not included in the packet header

AODV : Route Maintenance (1)



AODV : Route Maintenance (2)

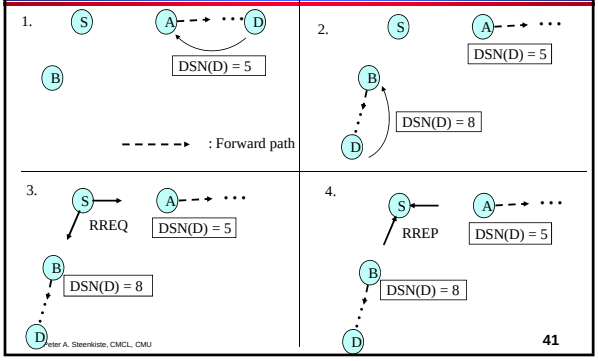


When receiving the Route Error message (RERR), S removes the broken link from its cache. It then initializes a new route discovery.

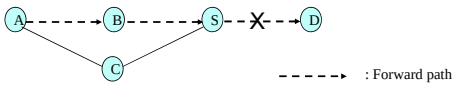
AODV: Destination Sequence Numbers

- **If the destination responds to RREP, it places its current sequence number in the packet**
- **If an *intermediate* node responds, it places its record of the destination's sequence number in the packet**
- **Purpose of sequence numbers:**
  - **Avoid using stale information about routes**
  - **Avoid loops (no source routing!)**

AODV : Avoiding the Use of Stale Routing Tables



AODV : Avoiding Loops



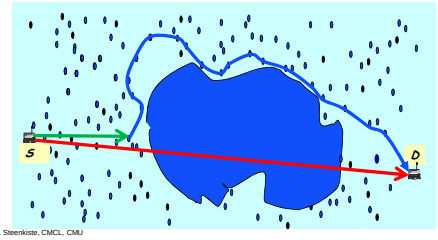
- Assume there is a route between A and D; link S-D breaks; assume A is not aware of this, e.g. because RERR sent by S is lost
- Assume now S wants to send to D. It performs a RREQ, which can be received by A via path S-C-A
- Node A will reply since it knows a route to D via node B ➔ loop!
- The presence of sequence numbers will let S discover that the routing information from A is outdated
- Principle: when S discovers that link S-D is broken, it increments its value of DSN(D), so it is greater than any value stored by other nodes.

AODV Conclusion

- Nodes maintain routing information only for routes that are in active use
- Unused routes expire even when the topology does not change
- Each node maintains at most one next-hop per destination
- Many comparisons with DSR (via simulation) have been performed ➔ no clear conclusion so far

Geographic Routing

- Example: Greedy Perimeter Stateless Routing
  - » Move in direction towards to destination (e.g. based on GPS)
  - » Travel around obstacles in the middle
- Many variants exist



Improving Routing Metrics

- Traditional shorts path metric has many problems
  - » Tends to route through the center
  - » Insensitive to load, interference, link quality, etc.
- Assess the link quality: expected transmission time for the packet over the link
  - » Using sequence of probes or real traffic
- Assess interference or level of contention
  - » Listen to traffic in the neighborhood
- Assess the traffic load
  - » E.g. queue length, listen in on transmissions, etc.

Conclusion on Ad Hoc Routing

- DSR and AODV are the mainstream proposals
- Both have been extensively studied (by simulation)
- No clear superiority of one relative to the other
- Scalability is still an open issue
- Other very promising proposals