LCA

Mobile Ad Hoc Networking

Silvia Giordano

LCA-EPFL

University of Pisa - 2002

Overview

- IP routing
- characteristics and principles of mobile ad hoc routing
- main actors
  - DSR
  - AODV
- the self-organisation view at routing layer

Section goals:

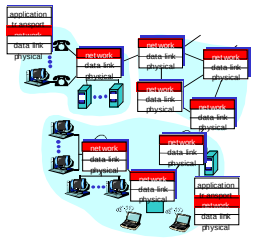
- understand ad hoc routing
- are ad hoc routing mechanism "ad hoc" for mobile ad hoc networks?

Network layer functions

- transport packet from sending to receiving hosts
- network layer protocols in *every* host, router

three important functions:

- *path determination:* route taken by packets from source to dest. *Routing algorithms*
- *switching:* move packets from router's input to appropriate router output
- *call setup:* some network architectures require router call setup along path before data flows

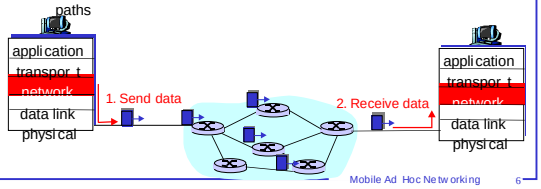


Network service model

- The *network service model* defines edge-to-edge channel
- The most important abstraction provided by network layer:
  - **network-layer connection-oriented service:** virtual circuit
  - **network-layer connectionless service:** datagram

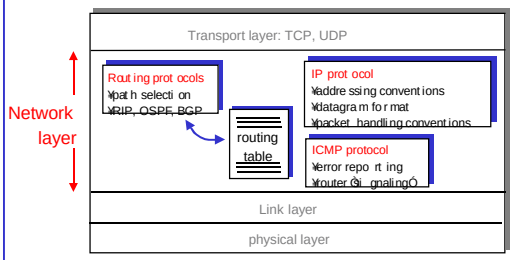
Datagram networks: the Internet model

- no call setup at network layer
- routers: no state about end-to-end connections
  - no network-level concept of "connection"
- packets typically routed using destination host ID
  - packets between same source-dest pair may take different paths



The Internet Netw ork layer

Host, rou ter netw ork layer functions:

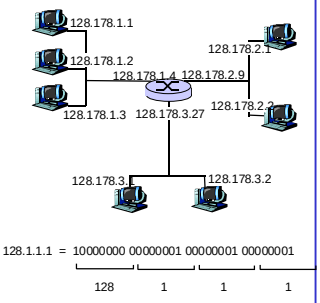


Intern et and intr anet

- an intranet
  - *a* collection of end and intermediate systems interconn ected using the TCP/IP architecture
  - normall y inside one org anizatio n
- the Internet
  - the global co llection of all hosts and routers i nterconnected using the TCP/IP architecture
  - coordinated allocati on of addresses and impl ementation requirements by the Internet Soci ety
- intranets are ofte n connected to the Internet by firewalls
  - hosts that act as ap plicati on level relays

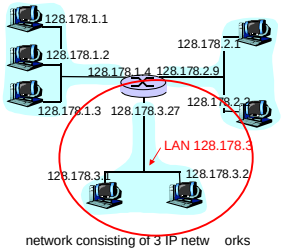
IP Addressing: introduc tion

- IP addr ess: 32-bit identifier f or host, router *interface*
- *interface:* connection between host, router and physical link
  - routerÕs typi cally have multipl e interfaces
  - host may hav e multiple interfaces
  - IP addresses associated with interface, no t host, router



IP Addre ssing

- IP addr ess:
  - network (o r prefix) part (hi gh order bits)
  - host part (low order bits)
- *WhatÕs a network ?* (from IP address perspecti ve)
  - device interfaces with same network part o f IP address
  - can physi cally reach each other withou t intervening router



network consisting of 3 IP netw orks (for IP addresses starting with 128, first 24 bits are netwo rk ad dress)

Routing and Packet forwar ding

- Routing
  - computation of routing tables o r da ta structures for unicast and multicast
  - normally only between routers
  - non-real time: latency up to 2 minutes
  - uses protocols s uch as RIP, OSPF, EIGRP (Cisco) for unicast and DVMRP, M-OSPF, PIM for multicast
- Packet Forwarding
  - for every pac ket
  - real time

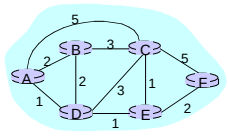
Routing

Routing protocol

Goal: determine ÒgoodÓ p ath (sequence of routers) thru network from so urce to dest .

Graph abstrac tion for routing algorithms:

- graph nodes are routers
- graph ed ges are physical links
  - link cost: delay, $ cost, or congestio n level



- ÒgoodÓ path:
  - typicall y means minimum cost path
  - other defÕs possible

Routing Algorithm c lassification

Global or decentra lized information?

Global:

- all routers h ave complete topolog y, link cost info
- Ølink stateÓalgori thms

Decentralized:

- router knows physical ly-connected neighbors , link costs to neig hbors
- iterative pr ocess of computation , exchange of info with neig hbors
- Ødistance vectorÓalg orithms

Static or dynamic?

Static:

- routes change s lowly over time

Dynamic:

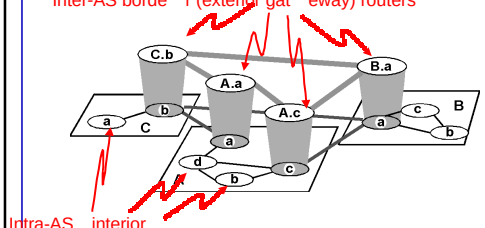
- routes change mor e quickly
  - periodi c update
  - in resp onse to link cost changes

Routing in the Int ernet

- The Global Internet c onsists of Autonomou s Systems (AS) interconnected with each othe r:
  - **Stub AS**: small cor poration
  - **Multih omed AS**: large corpo ration (no transit)
  - **Transit AS** : provider
- Two-level routing :
  - **Intra-AS:** adminis trator is resp onsible for ch oice
  - **Inter-AS:** unique s tandard

Intern et AS Hiera rchy

Inter-AS borde r (exterior gat eway) routers



Intra-AS interior (gateway) routers

Intra-AS and inter-AS Routi ng

Intra-AS r outing:

- Also kn own as Interior Gateway Protocol s (IGP)
- Most common IGPs:
  - RIP: Routi ng Information Pr otocol
  - OSPF: Open Shortest Path Fi rst
  - EIGRP: Extended Interior Gateway Routi ng Protocol (Cisco propr .)

Inter-AS r outing:

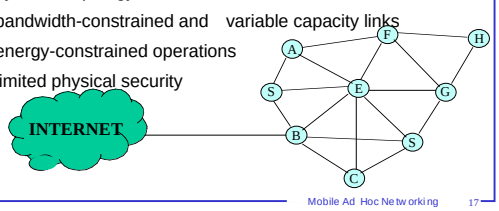
- Also kn own as Exterior Gateway Protocol s (EGP)
- BGP (Border Gateway Protocol): *the* de facto standard

Why are there Different Inter-AS and Intra-AS Routing Protocols?

- Policy
- Scale
- Performance

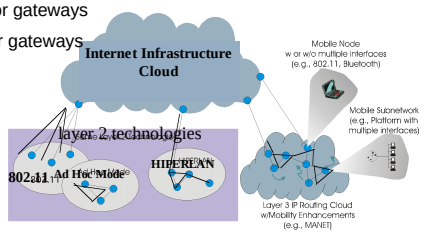
IP Mobile Ad H oc Network R outing

- A MANET tha t explicitl y support s the Inter net present s the following characteristics :
  - dynamic topology
  - bandwidth-constrained and variable capacity links
  - energy-constrained operations
  - limited physical security



IP Mobile Ad H oc Network R outing

- based on the tra ditional two level hierarc hy routing archite cture:
  - exterior gateways
  - interior gateways



IP Mobile Ad H oc Network R outing

many emerging interior gatewa ys protocols for MANETs

- MANET as auto nomous syste ms
- inter wor king by EG of Int erne t
- a step towar d S- O

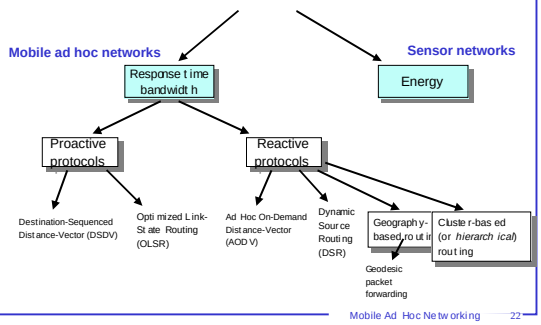
Main Assumptions

- Multihop point-to-point communica tion
- Symmetric l inks (in most ca ses)
- Omnidirecti onal antennas (in most cases)
- All nodes have equa l capabilities and responsibilities
- every node is a switch (Internet)

Current sta tus of rese arch

- Many, ma ny proposals
- not wid ely available commercially
- some prototypes
- Optimal solution depends on deployment scenario: mobilit y patterns, radio model, tra ffic characteristic s,É
- MERIT

Protocols Classification



Protocols Classification

- Proactive Solutions: (t able-driven):
  - attempt to maintain routes continuous ly
  - routes are excha nged among neighbours at any cha nge
- Reactive Solutions (t raffic-driven):
  - send a control message for discovering a r oute when needed
  - destination sends back the route to th e source

Protocols Classification

- Proacti ve Soluti ons:
  - traditional IP routing design (bet ter f or transp ort)
  - net tr affic p atter ns with larg e % of c ouples S-D
  - low scalability (updat es overhead & large table s)
- Reactive Solut ions :
  - more scalable
  - net tr affic p atter ns with small % of coup les S-D
  - long delay in disc overy phase
  - large header

Dynamic source routing (DSR)

- Reactive routing protocol (Johnson et al, 1996) based on route caches
- 2 phases, operating both **on demand**
  - Route discovery
    - Used only when S attempts to send a packet to D
    - Based on flooding of Route Requests (RREQ)
  - Route maintenance
    - makes S able to detect, while using a source route to D, if it can no longer use its route (because a link along that route no longer works)

DSR: Route Discovery

- RD is via broadcasting a RREQ packet that accumulates the route as it travels to D
- route reply by either D or N that has a cached route to D (works only if all links along the route are bidirectional - as assumed in 802.11)
- if unidirectional links are allowed, then RREP may need a route discovery from D/N to S
- Routing Record stores the hops in the route and it is then piggibacked to data pkt by S

DSR: Strengths

- Routes are set up and maintained only between nodes who 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 of unidirectional links

Ad Hoc On-Demand Distance Vector Routing (AODV)

- Reactive routing protocol (Perkins et al, 1999) based on routing tables
- AODV uses a route discovery mechanism similar to DSR, but it maintains routing tables
- for local topology maintenance nodes use hello msg or listening for retransmissions
- AODV *ages* the routes (fresh routes) and maintains a hop count
- AODV assumes that all links are bi-directional

AODV Route request and reply

- RREQ needs to reach N in the way to D that has a fresh route to it
- if N knows a path more recent than the one previously known to S, an *intermediate node* sends 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 appr. chosen timeout intervals
- link failure notification toward S

AODV Weaknesses and Strengths

- 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 (waiting for MERIT!)

More on DSR and AODV

Courtesy of:

Jean-Pierre Hubaux - EPFL

Dynamic source routing (DSR)

- Reactive routing protocol
- 2 phases, operating both **on demand**:
  - **Route discovery**
    - Used only when source S attempts to to send a packet to destination D
    - Based on flooding of Route Requests (RREQ)
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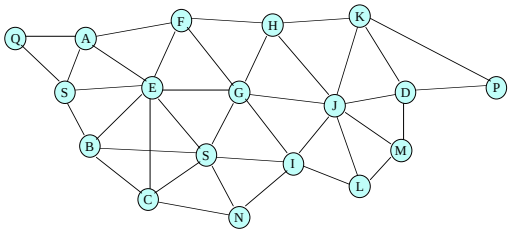
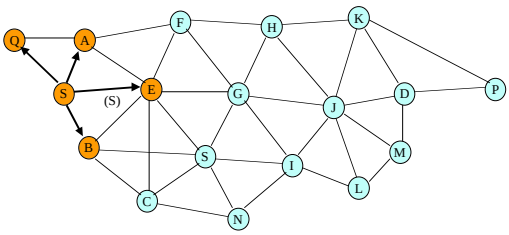
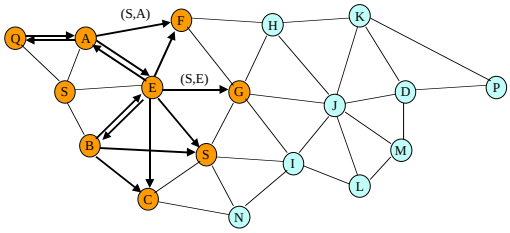
DSR: Route discovery (1)



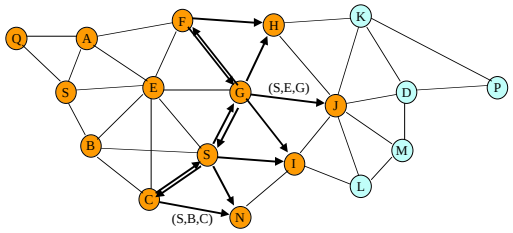
DSR: Route discovery (2)



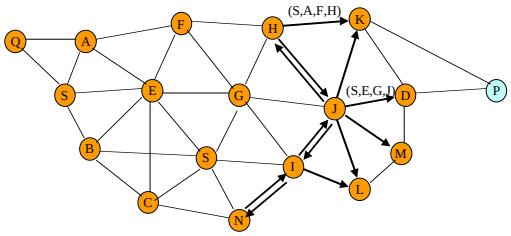
DSR: Route discovery (3)



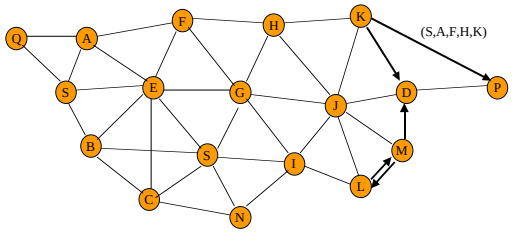
DSR: Route discovery (4)



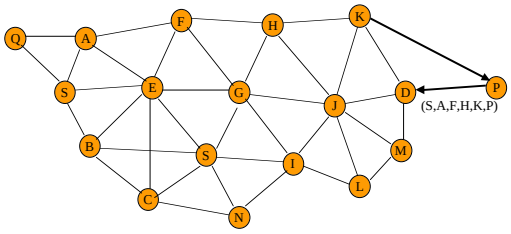
DSR: Route discovery (5)



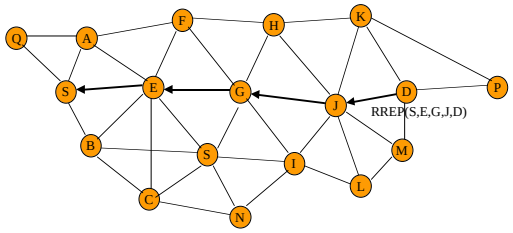
DSR: Route discovery (6)



DSR: Route discovery (7)



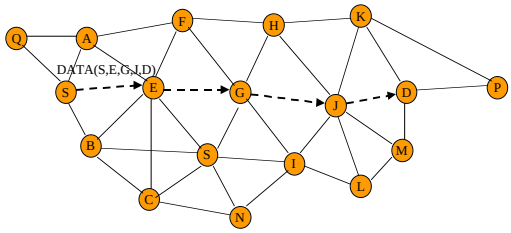
DSR: Route discovery (8)



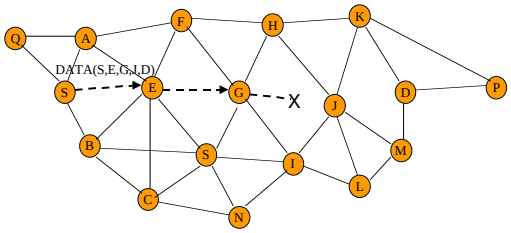
DSR: Route Discovery (9)

- 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

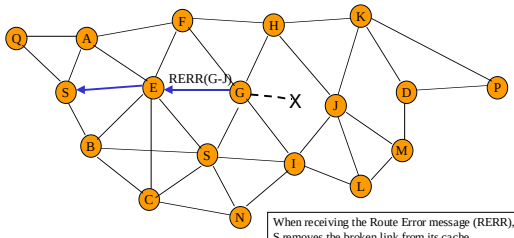
DSR: Data delivery



DSR: Route maintenance (1)



DSR: Route maintenance (2)

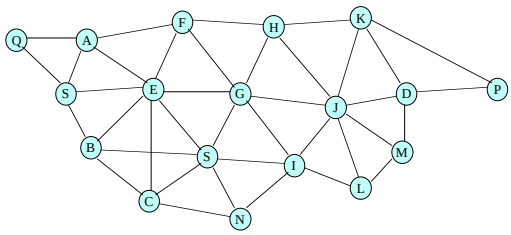


When receiving the Route Error message (RERR), S removes the broken link from its cache. It then tries another route stored in its cache; if none, it initializes a new route discovery

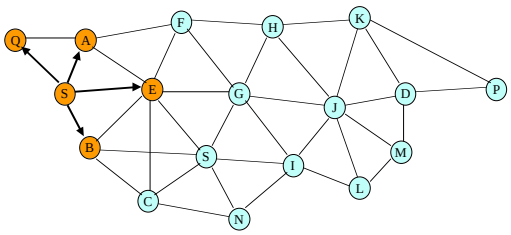
Ad Hoc On-Demand Distance Vector Routing (AODV)

- 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)



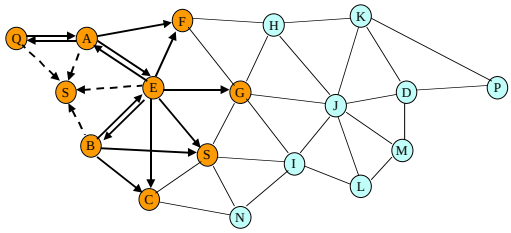
AODV : Route discovery (2)



: Route Request (RREQ)

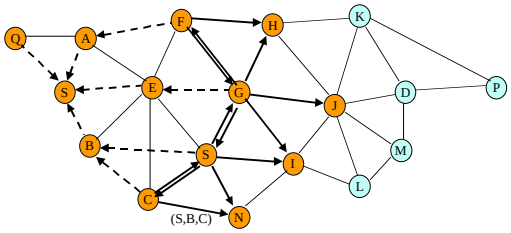
Note: if one of the intermediate nodes (e.g., A) knows a route to D, it responds immediately to S

AODV : Route discovery (3)

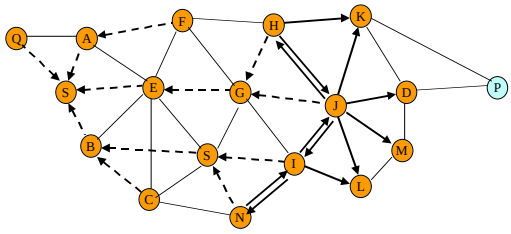


: represents a **link** on the **reverse path**

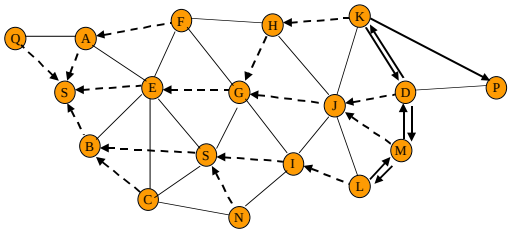
AODV : Route discovery (4)



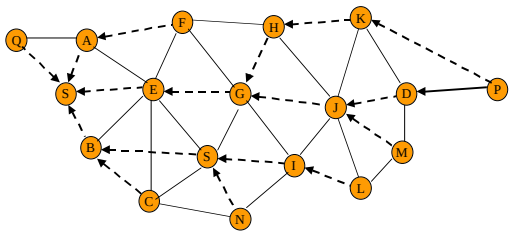
AODV : Route discovery (5)



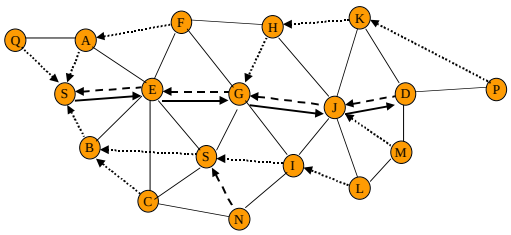
AODV : Route discovery (6)



AODV : Route discovery (7)



AODV : *Route reply* and setup of the *forward path*



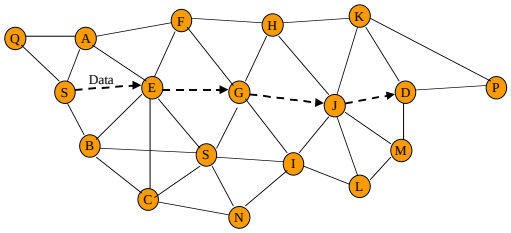
: Link over which the RREP is transmitted

: Forward path

Route reply in AODV

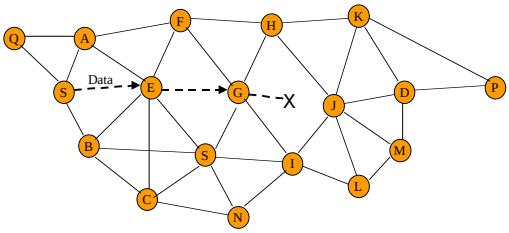
- In case it knows a path more recent than the one previously known to sender S, an *intermediate node* may also send a route reply (RREP)
- The freshness of a path is assessed by means of **destination sequence numbers**
- Both reverse and forward paths are purged at the expiration of appropriately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

AODV : Data delivery

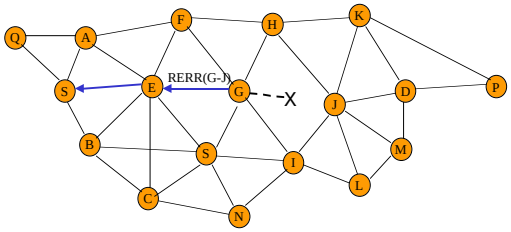


The route is not included in the packet header

AODV : Route maintenance (1)



AODV : Route maintenance (2)

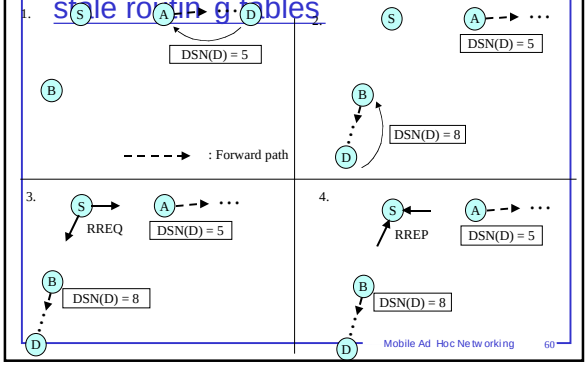


When receiving the Route Error message (RERR), S removes the broken link from its cache. It then initializes a new route discovery.

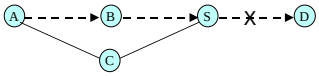
AODV: Destination sequence numbers

- 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 usage 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
- This would result in a loop (S-C-A-B-S)
- 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 local value of DSN(D). In this way, the new local value will be greater than the one stored by A.

AODV (unicast) : 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

Conclusion on routing

- DSR and AODV
  - DSR and AODV are the mainstream proposals
  - Both have been extensively studied (by simulation)
  - No clear superiority of one wrt the other
  - Scalability is still an open issue
  - not really self-organised
- Other solutions

Summary

- what's & why ad hoc networking
- what is ad hoc routing
- principles of (IP) MANETs

Questions

- Questions?????

References

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