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Ad-hoc networking

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Goals and topics

- Ad-hoc networking terminology & outline
- Ad-hoc networking hot topics - routing

- Discuss how ad-hoc networks differ from other wireless networks.
- Discuss protocol engineering for ad-hoc networks – ad-hoc protocols.
  – Some remarks on Bluetooth.

Literature

- Charles Perkins, Ed., ”Ad Hoc Networking”, Addison-Wesley.
- C-K Toh, ”Ad Hoc Mobile Wireless Networks, Protocols and Systems”, Prentice Hall.
- IETF Mobile Ad-hoc networks - MANET Working Group (www.ietf.org).
- Bluetooth (www.bluetooth.org).
- Wireless Ethernet Compatibility Alliance (www.wirelessethernet.org).

Ad-hoc networking - Intro

- Mobile wireless communication
- Ad-hoc networking - terminology
- Problem setting in ad-hoc networking
- Ad-hoc networking model of operation
- Ad-hoc networking applications
- Technical/market issues
- General remarks on routing

Mobile wireless communication

- Enable anywhere/anytime connectivity.
- Enable mobility (reachability).
- Bring computer communication to areas without pre-existing wired infrastructure.
- Enable new applications.
- 1 B wireless communication devices 2002.
- 400 million new wireless phones annually.
- Embedded network devices.

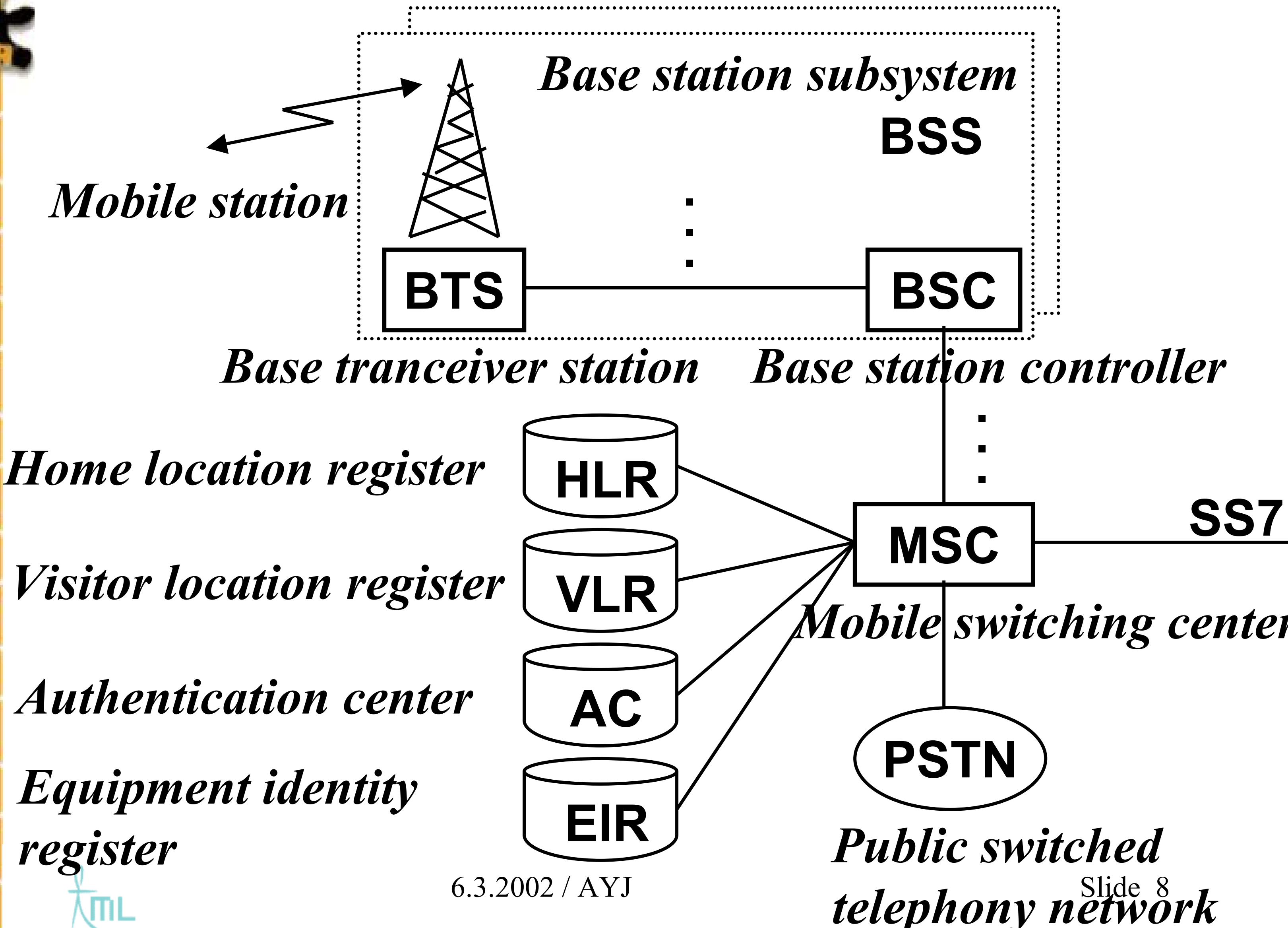
Mobile wireless networks

- Infrastructure networks
- Infrastructureless networks

Wireless networks with Infrastructure

- Fixed backbone (can be wired or wireless).
- Infrastructure supports services.
  - Centralized elements.
- Mobile devices communicate with access points.
- Suitable for locations where access points can be placed.

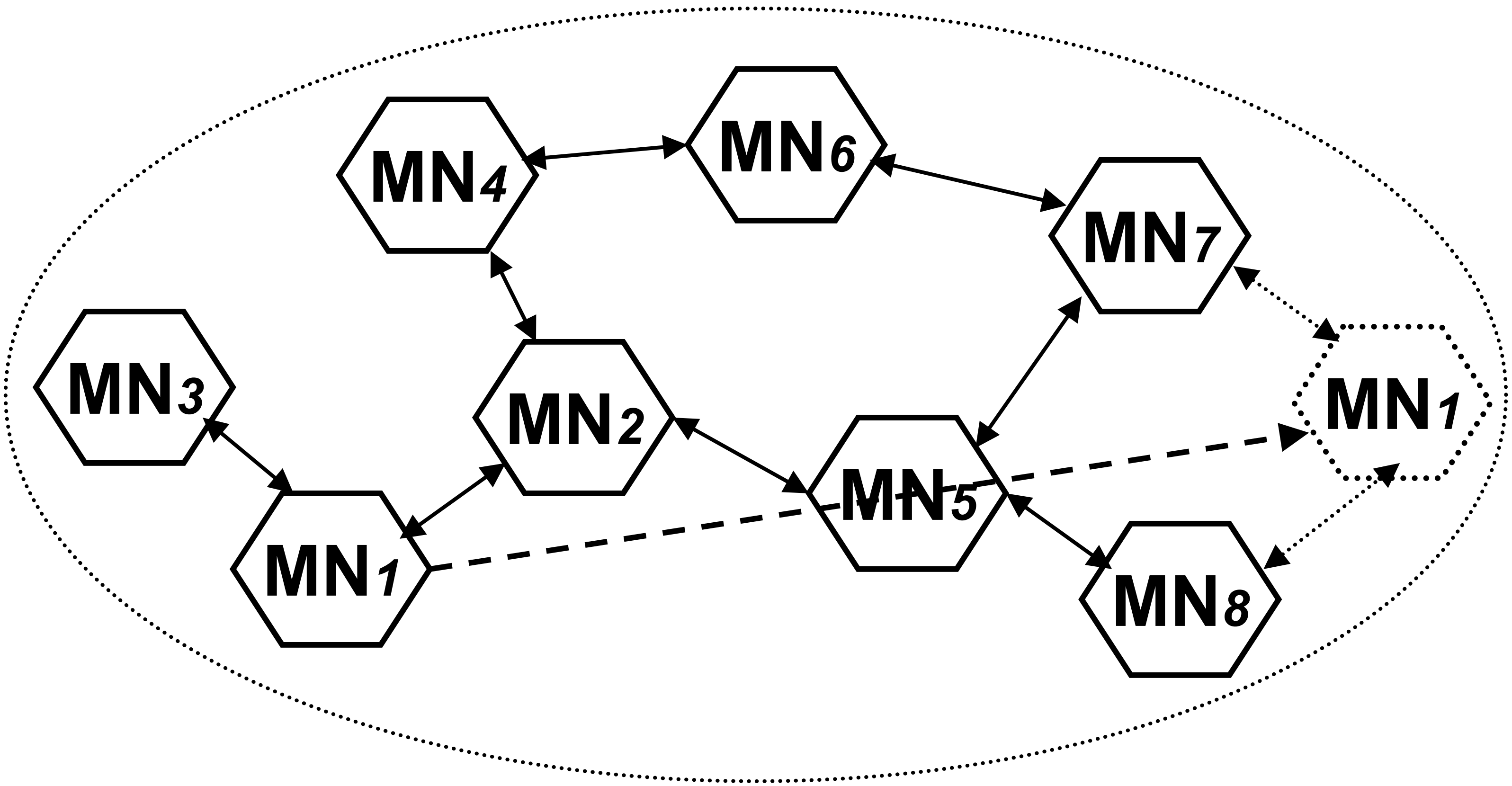
Cellular networks -GSM



Mobile wireless networks without Infrastructure

- No fixed (wired/wireless) backbone.
- No centralized servers needed.
- No centralized administration.
- All nodes are capable for movement.
- All nodes serve as routers.
  – Multi-hop routes.
- Ease of deployment.

Wireless networks without Infrastructure



Ad-hoc networking - terminology

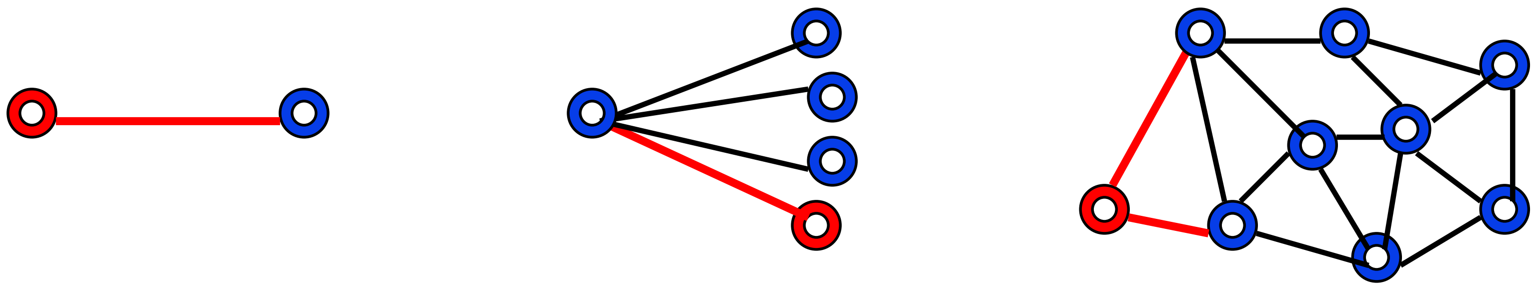
- Terminal = a device with connection end-point(s), but the device does not re-forward or route the received information to any other node or terminal.
- Node = device where in addition of connection point(s) also a new connection to another node or terminal can be established and further communication of information is possible (hop-by-hop/multihop routing).

Ad-hoc - terminology

- Terminal or node creates a connection with its adjacent terminal or node, only using its own and adjacent point resources, i.e., not using any servers or other auxiliary components to create a connection between terminals or nodes.
- Regardless of the network topology ad-hoc connectivity can happen in point-to-point, point-to-multipoint or mesh networks.

Ad-hoc - terminology

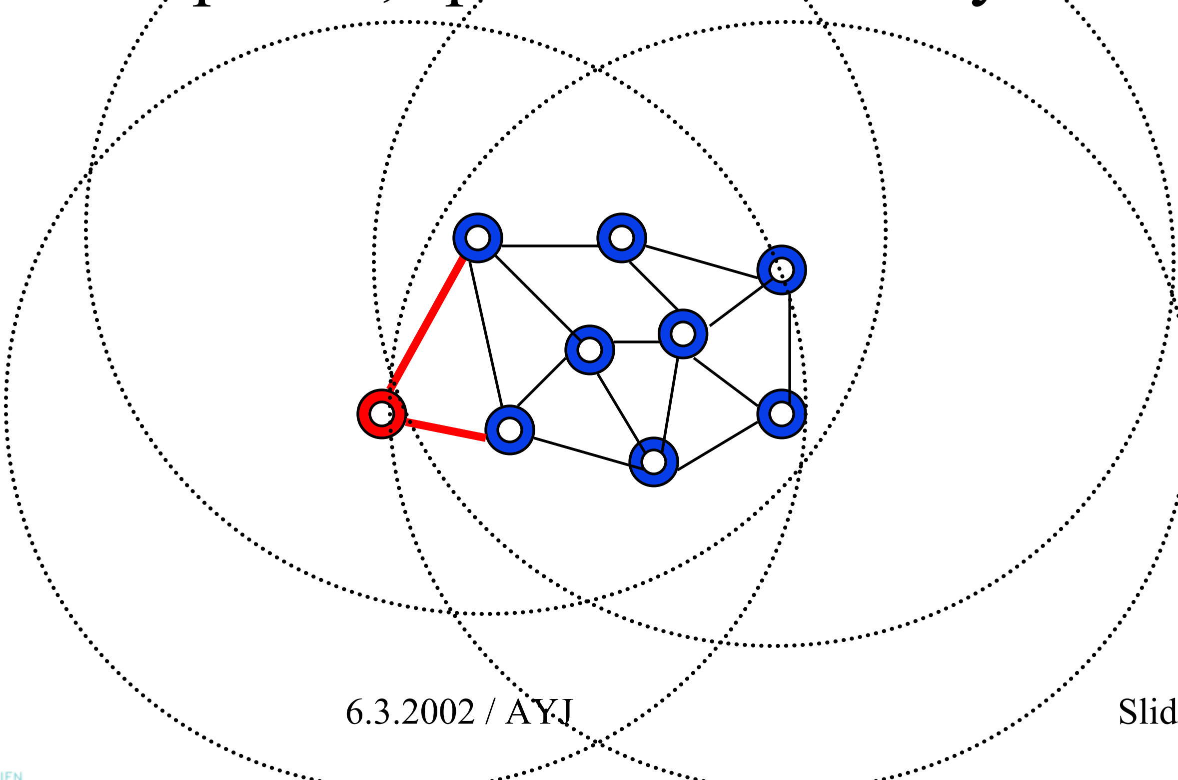
Point-to-point **Point-to-multipoint** **Mesh**



- Node or terminal capable for ad-hoc connectivity
- Ad-hoc connectivity negotiation and establishement

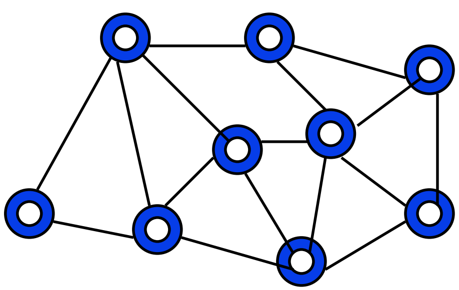
Ad-hoc - terminology

- If all of the wireless nodes are within range of each other, no routing is needed, and the network is fully connected.
  – radio power, spectrum efficiency.

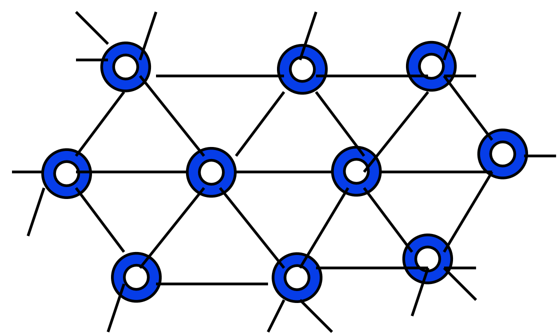


Ad-hoc - terminology

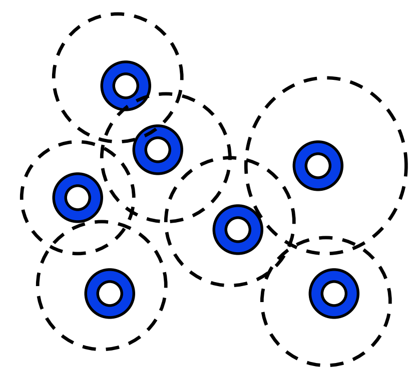
- Mesh - Nodes and terminals create a compound net having a connection to usually more than only one other node or terminal.



Fixed Mesh topology not defined in advance

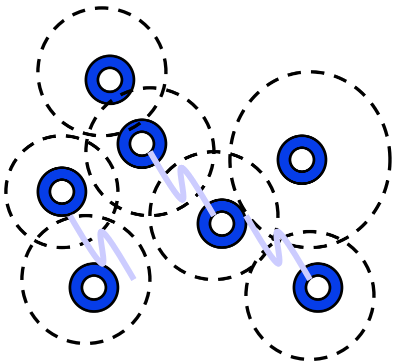


Fixed Mesh topology defined in advance

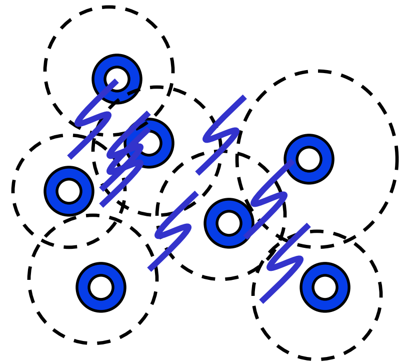


Wireless Mesh topology not defined (changing)

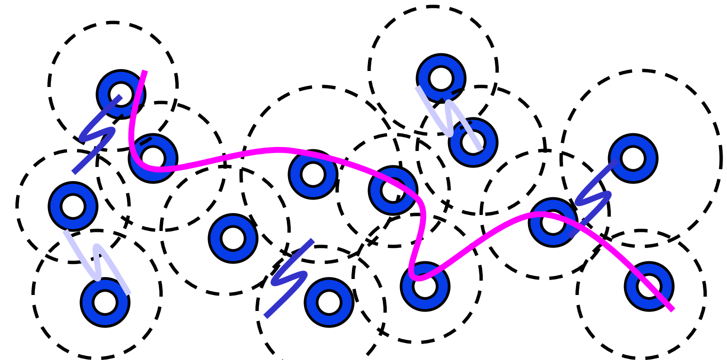
Ad-hoc - terminology



Connection establishme nt



Ad-hoc routing



Communication between partners, some links dropping and appearing

Problem setting in ad-hoc networking

- The nodes are using IP and they have IP addresses assigned.
- The nodes are far apart so that not all of them are within radio reach of each other.
- The nodes may be mobile - two nodes within range at one point.
- The nodes are able to assist each other in the process of delivering packets.

Ad-hoc - model of operation

- Symmetric links.
  - Unidirectional routing is difficult.
- Link-layer (layer-2) ad-hoc solutions.
  - Layer-3 protocols -> Layer-2 operations.
- Proactive versus reactive protocols.
  - All destinations vs. immediate links (delay).
  - Control traffic, ad-hoc nature of links.
- Multicast.
  - Reduce bandwidth utilization.

Ad-hoc networking applications

- Spontaneous networking (conferencing, business, in-field research).
- Home networking.
- Personal area networks (PAN).
- Sharing of personal content.
- Emergence search-and-rescue.
- Embedded computing.
- Battlefield.

Ad-hoc networking - issues

- Limited power (mobile devices).
- Low data rate (wireless channels).
- High bit-error-rate (BER).
- High quality variability.
- Security issues (broadcast by nature).
- Dynamic topology (complexity).
- Addressing.
- Scalability (non-ubiquitous coverage).

Ad-hoc routing

- Each node in an ad-hoc network participates in forming the network topology.
- Similar to the Internet routing infrastructure.
- Routing protocols provide information to forward packets to the next hop (s to d).
- Can we adapt existing Internet routing protocols for use in ad-hoc networks ?

General issues on routing

- Routing protocols in the Internet:
  - Adapt to changing network conditions.
  - Offer multihop paths across the networks.
- Distance vector routing vs. link state routing.
- We might like to wish to manage topology changes in an ad-hoc network requiring nodes to run routing protocols.

General issues on routing

- The Internet uses routing protocols based on network broadcast (OSPF).
- OSPF is link-state protocol:
  - Each node gathers information about the state of the links between nodes.
  - SPF algorithm applicable for this case.
- Traditional link state protocols are not applicable for dynamic networks:
  - Bandwidth needed to maintain network state.

General issues on routing

- Routing in multihop packet radio networks was in the past based on shortest-path-first (SPF) algorithms.
- Distributed Bellman-Ford (DBF).
- Store little information of non-connected links.
- For each destination a table entry, i.e., next hop (node i, destination x, neighbor j: D*ij(x)*).
- Also known as distance-vector algorithms.

General issues on routing

- Distance vector algorithms
  - Easy to program.
  - UC Berkeley– Routing Information Protocol.
  - Slow convergence.
  - ”Counting to infinity” problem.
  - Use less memory than link-state algorithms.
  - Do not scale well.

Ad-hoc networking protocols

- Medium access control (IEEE 802.11).
  - Proactive MAC layer optimized WINGs.
- Unicast
  - Proactive (DSDV).
  - Reactive (AODV, DSR).
  - Geographical (LAR).
- Multicast
  - Tree-based (MAODV).
  - Mesh-based (ODMRP).
  - Geographical (LBM, GeoTORA)
- Bluetooth

Ad-hoc networking protocols

- DSDV – Destination-Sequenced Distance Vector protocol.
- AODV – Ad-hoc On-Demand Distance Vector protocol.
- DSR – Dynamic Source Routing protocol
- LAR – Location Aided Routing.
- ZRP – Hybrid framework for rerouting.
- TORA – Temporally Ordered Routing Algorithm.
- And many more, …

Unicast routing

- Minimal control overhead.
- Minimal processing overhead.
- Multi-hop path routing capability.
- Dynamic topology maintenance.
- No loops.
- Self-starting.

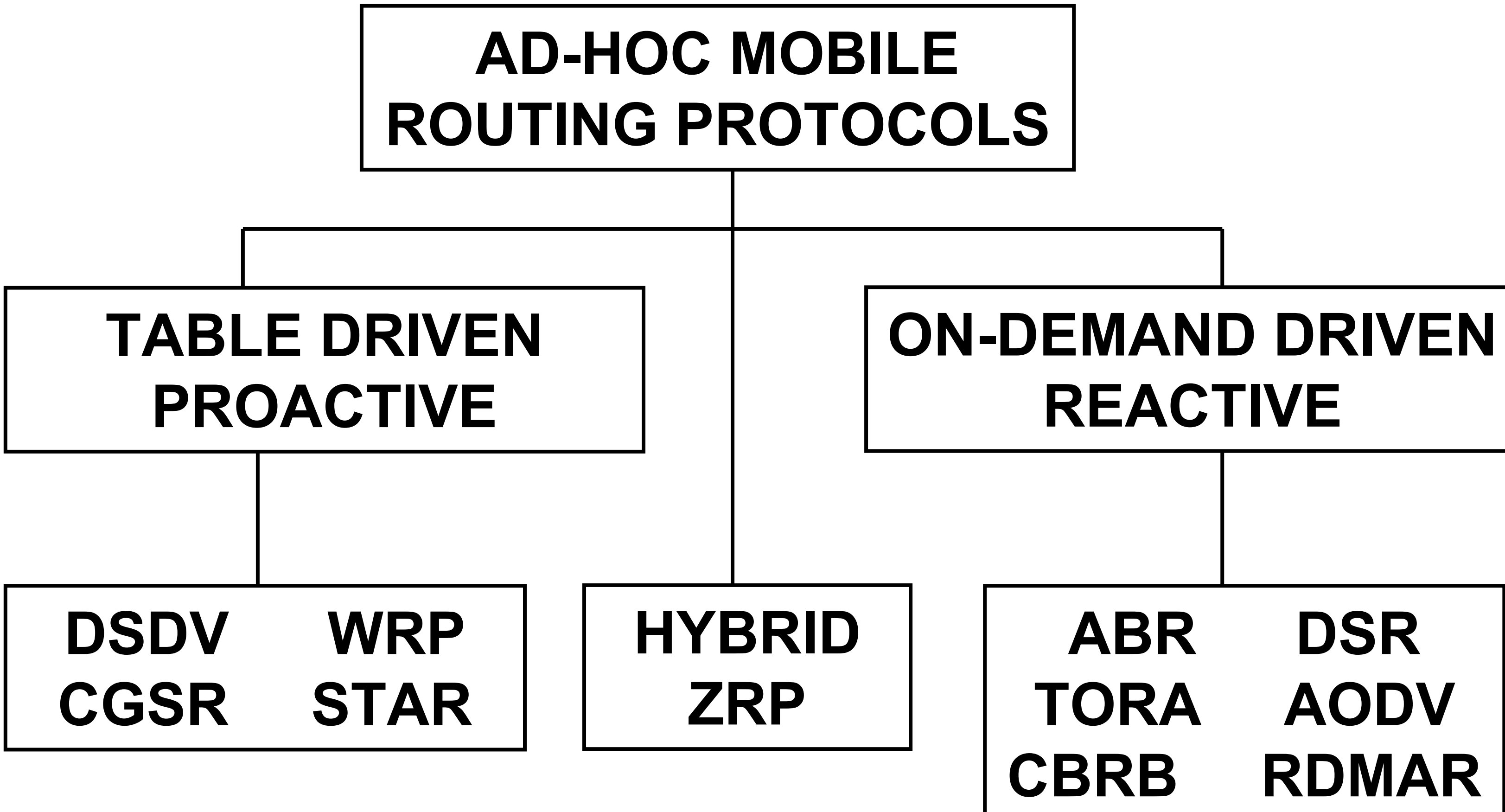
Unicast routing - proactive

- Based on traditional distance-vector and link-state protocols.
- Each node maintains route to each other network node.
- Periodic and/or event triggered routing update exchange.
- Higher overhead in most scenarios.
- Longer route convergence time.
- Examples: DSDV.

Unicast routing - reactive

- Source build routes on-demand by flooding.
- Maintain only active routes.
- Route discovery cycle.
- Typically, less control overhead, better scaling properties.
- Drawback: route acquisition latency.
- Example: AODV, DSR.

Ad-hoc mobile routing protocols



Ad-hoc routing protocols

- Internet routing protocols
  – Typically not applicable for ad-hoc as such.

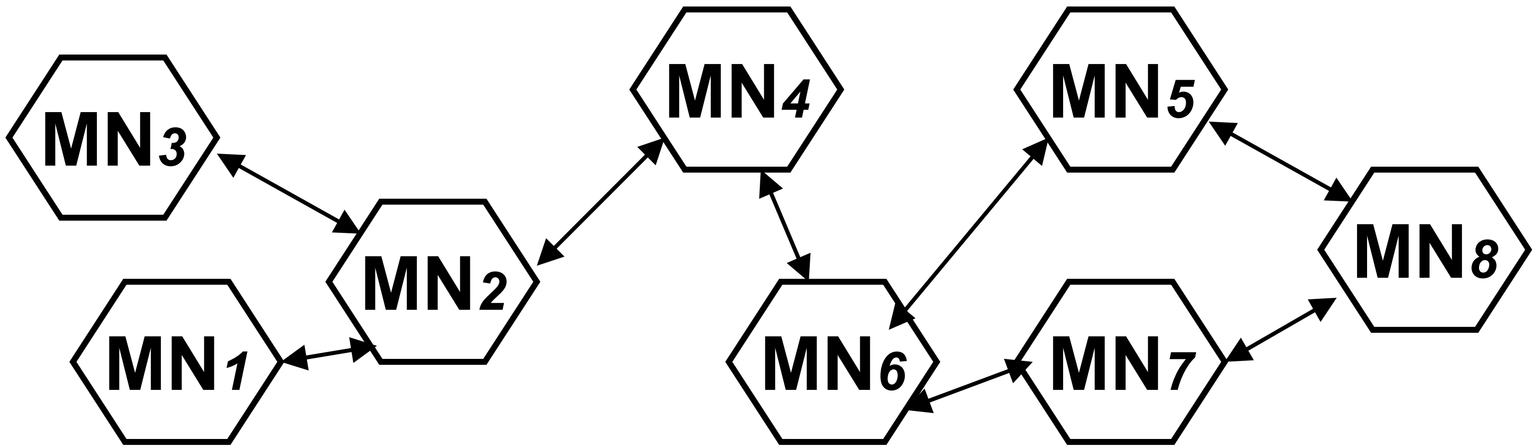
- Link-state–send routing tables to everyone.
- Distance vector–send routing table to neighbors.

- Proactive - keep route tables at all times.
  – Overhead due to routing updates.
- Reactive – find route on demand.
  – Route acquisition latency.

DSDV

- DSDV – Destination-Sequenced Distance Vector routing protocol.
- Proactive.
- Each node maintains its own sequence number.
  - Updates (increments) at each change in neighbourhood information.
  - Used for loop freedom.
- Each node maintains routing table with entry for each node in the network.

DSDV – route table for MN4



Destination	Next Hop	Metric	DestSequence#	InstallTime
MN1	MN2	2	406	
MN2	MN2	1	128	
MN3	MN2	2	564	
MN4	MN4	0	710	
MN5	MN6	2	392	
MN6	MN6	1	076	
MN7	MN6	2	128	
MN8	MN6	3	050	

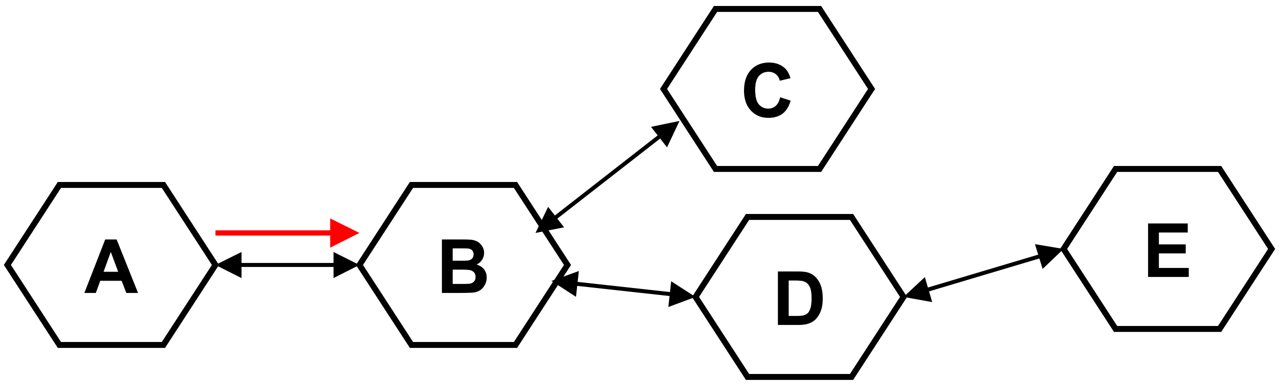
DSDV routing updates

- Each node periodically transmits updates.
  - Includes its own sequence#, route table updates
- Nodes also send routing table updates for important link changes.
- When two routes to a destination received from two different neighbors:
  - Choose the one with greatest destination sequence number.
  - If equal, choose the smaller metric (hopcount).

DSDV – full dump

- Full dumps
  - Carry all routing table information
  - Transmitted relatively infrequently
- Incremental updates
  - Carry only information changed since last full dump
  - Fits within one network protocol data unit (NPDU).
  - When updates can no longer fit in one NPDU, send full dump.

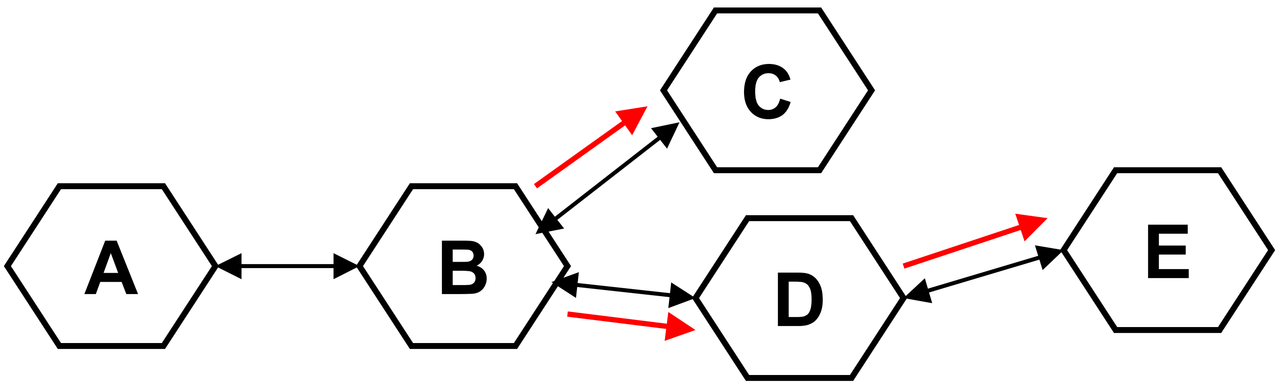
DSDV – link additions



A joins network, route table for B

Destination	SequenceNumber	NextHop	Metric
B	132	B	0
C	144	C	1
D	202	D	1
E	155	D	2

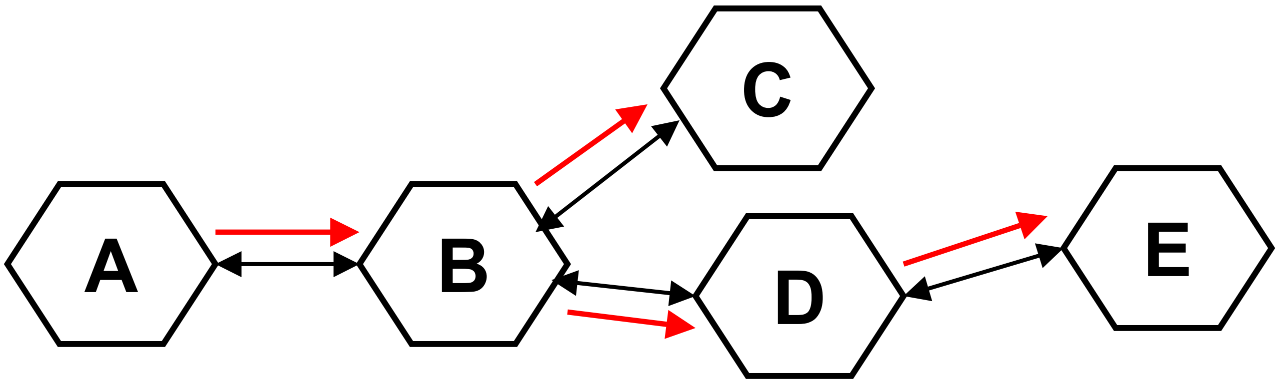
DSDV – link additions



A joins network, route table for B

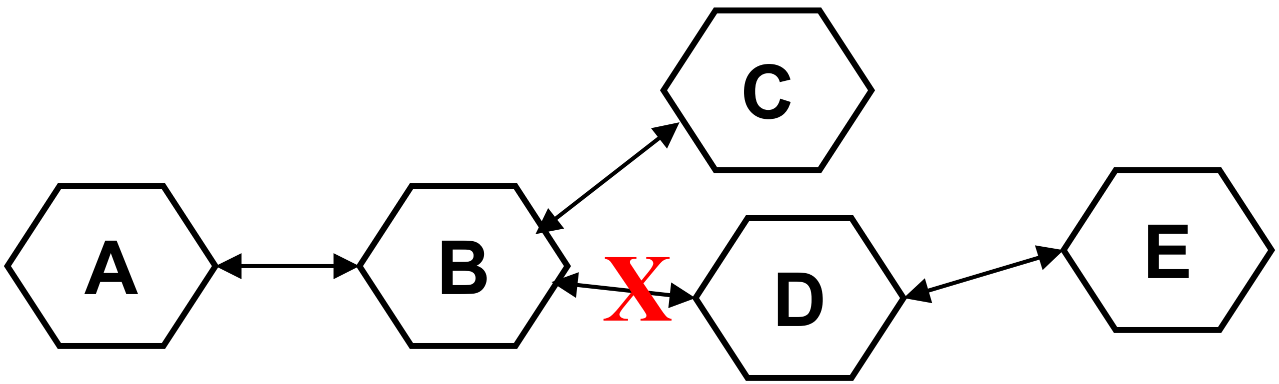
Destination	SequenceNumber	NextHop	Metric
B	132	B	0
C	144	C	1
D	202	D	1
E	155	D	2
A	101	A	1

DSDV – link additions



1. **Node *A* joins network.**
2. **Node *A* transmits routing table: <*A*, 101, 0>.**
3. **Node *B* receives transmission, inserts: <*A*, 101, 1>.**
4. **Node *B* propagates new route to neighbors <*A*, 101, 1>.**
5. **Neighbors update their routing tables: <*A*, 101, *B*, 2>, and continue propagation of information.**

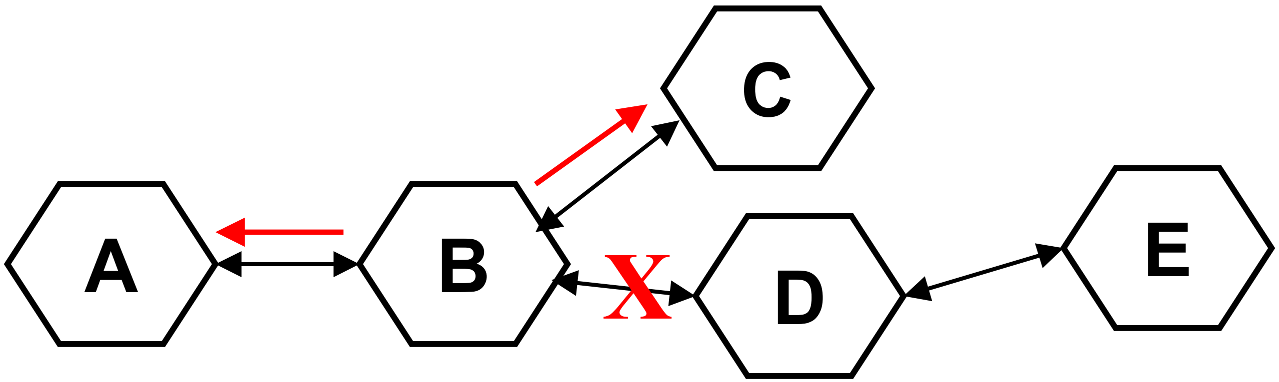
DSDV – link breaks



Link between B and D breaks, route table for B

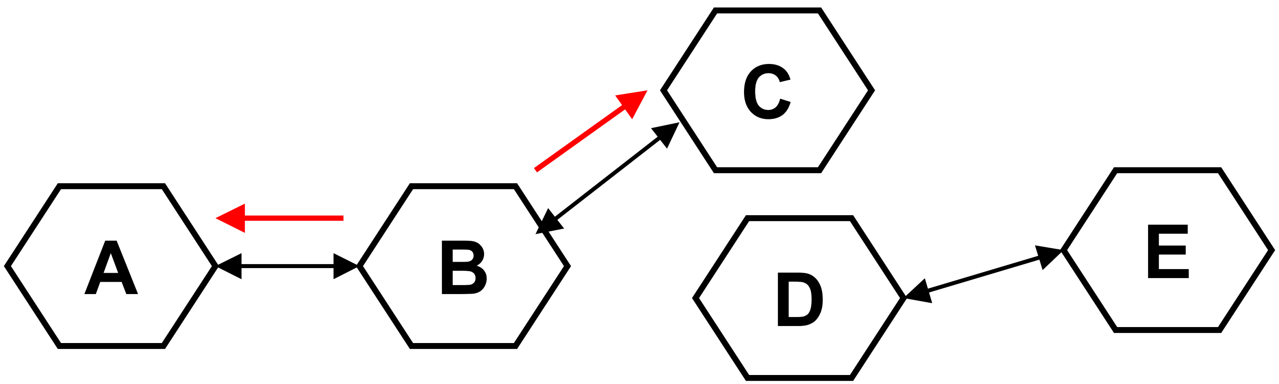
Destination	SequenceNumber	NextHop	Metric
B	132	B	0
C	144	C	1
D	202	D	1
E	155	D	2
A	101	A	1

DSDV – link breaks



1. **Link between B and D breaks.**
2. **Node B notices break**
   1. **Updates hopcount for D and E to be infinity**
   2. **Inrements sequence number for D and E.**
3. **Node *B* sends update with new route information.**
   1. **<D, 203, infinite>**
   2. **<E, 156, infinite>**

DSDV – link breaks



Link between B and D breaks, route table for B

Destination	SequenceNumber	NextHop	Metric
B	132	B	0
C	144	C	1
D	203	D	infinite
E	156	D	infinite
A	101	A	1

DSDV Summary

- Proactive algorithm.
- Routes maintained through periodic and event triggered routing table exchanges.
- Incremental dumps and settling time used to reduce control overhead.
- *Proactive protocols tend to perform best in networks with low to moderate mobility, few nodes, and many data sessions.*

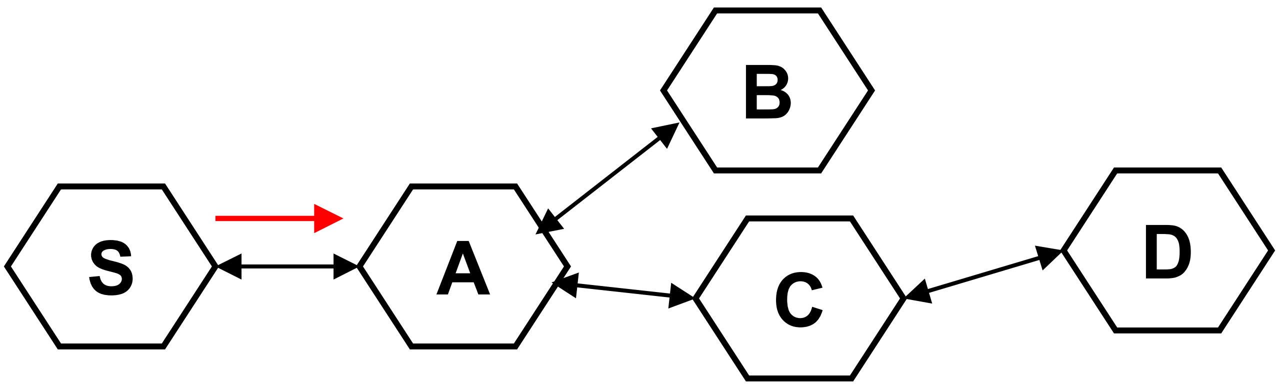
AODV

- Ad-hoc On-Demand Distance Vector routing.
- Reactive.
- Route discovery cycle used for route finding.
- Maintenance of active routes.
- Sequence numbers used for loop prevention and route freshness criteria.
- Descendant of DSDV.
- Provides unicast and multicast communication.

AODV – unicast route discovery

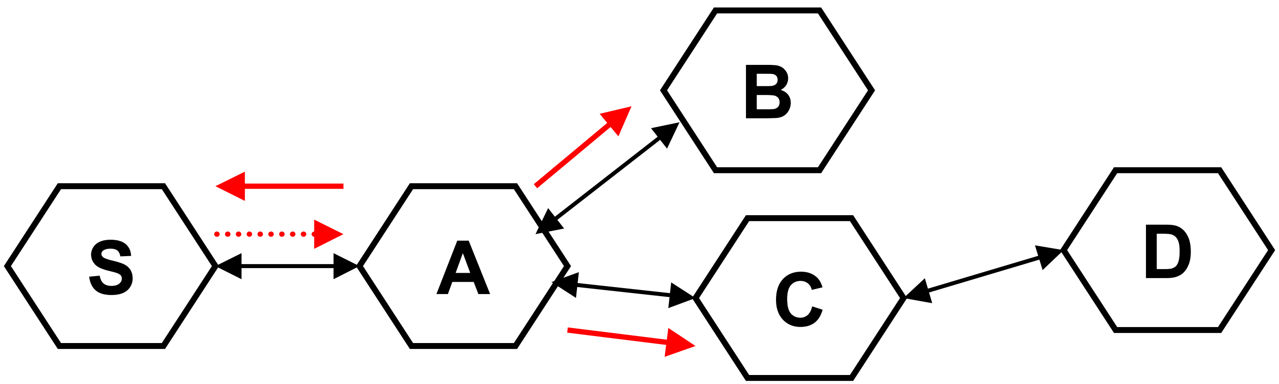
- RREQ (route request) is broadcast
  - Reverse is set up along the way.
  - RREQ message contains <bcast_id, dest_IP, dest_seqno, src_seqno, hp_count>.
- RREP (route reply) is unicast back
  - From destination if necessary.
  - From intermediate node if that node has a recent route.

AODV – route discovery



1. Node S needs a route to D
2. Creates a Route Request (RREQ)
   - Enters D's IP address, sequence number
   - S's IP address, sequence number
   - Hopcount (=0)
3. Node S broadcasts RREG to neighbors

AODV – route discovery



4. **Node A receives RREQ**

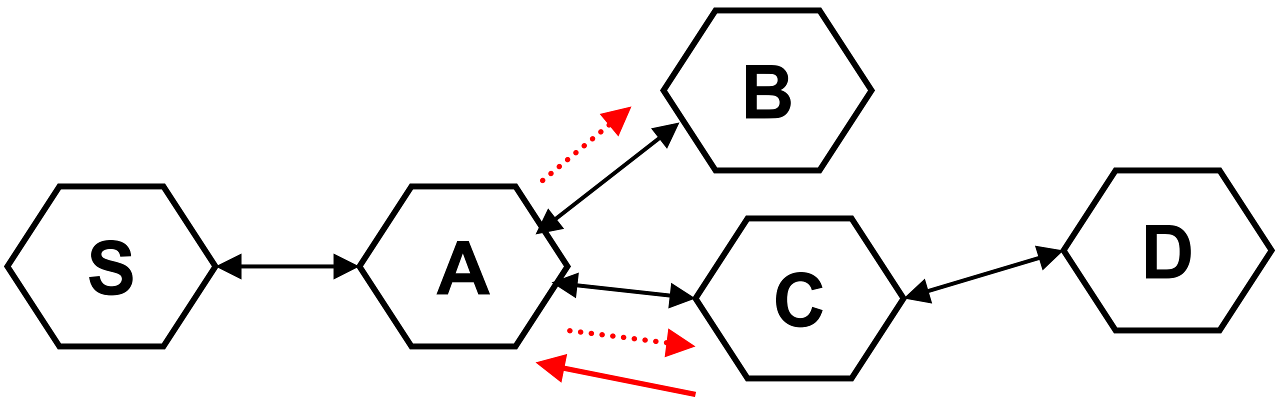
   Makes reverse route entry for S

   dest=S, nexthop=S, hopcount=1

   It has no route to D, so it broadcasts RREG

5. **Node C receives RREQ**

AODV – route discovery



5. **Node C receives RREQ**

   Makes reverse route entry for S (dest=S, nexthop=A, 2).

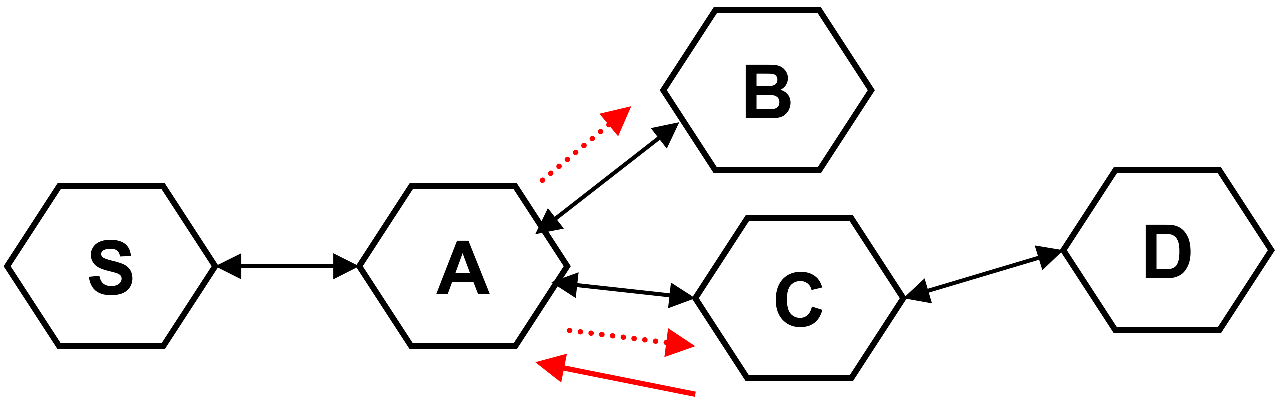
   It has route to D & the seq# for route D > seq# in RREQ.

   Creates a Route Reply (RREP)

   - **Enters D's IP address, sequence number**
   - **S's IP address, hopcount to D (=1)**

   Unicasts RREP to A

AODV – route discovery



5. **Node C receives RREQ**

   Unicasts RREP to A

6. **Node A receives RREP**

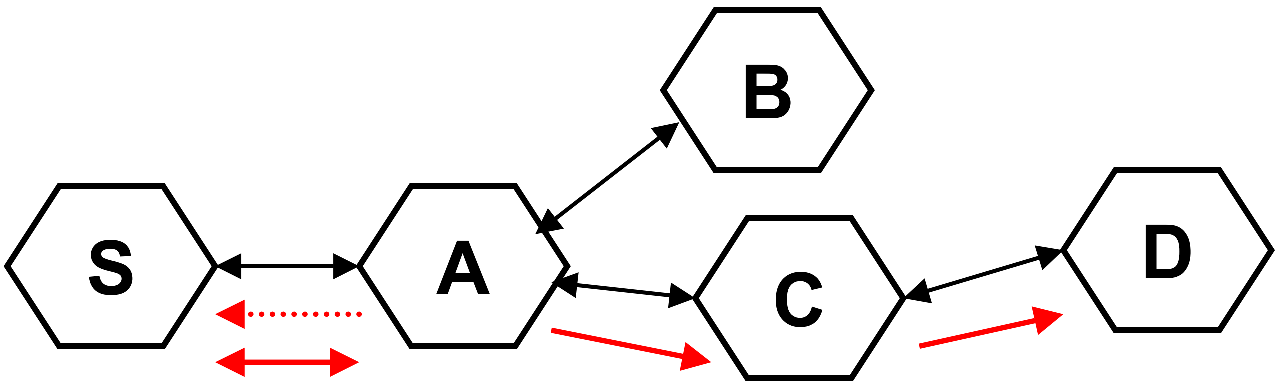
   Makes forward route entry to D

   dest=D, nexthop=C, hopcount=2

   Unicasts RREP to S

7. **Node S receives RREP**

AODV – route discovery



6. Node A receives RREP

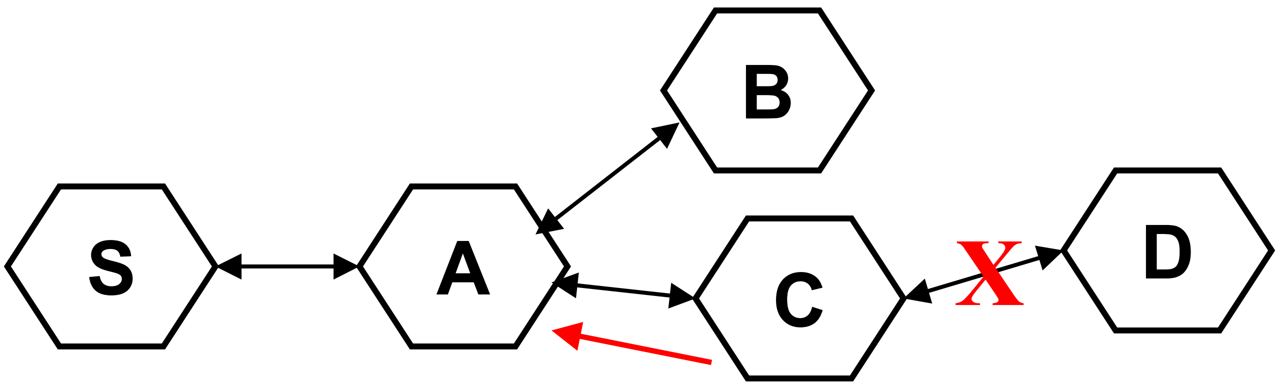
7. Node S receives RREP

Makes forward route entry to D

dest=D, nexthop=A, hpcount=3

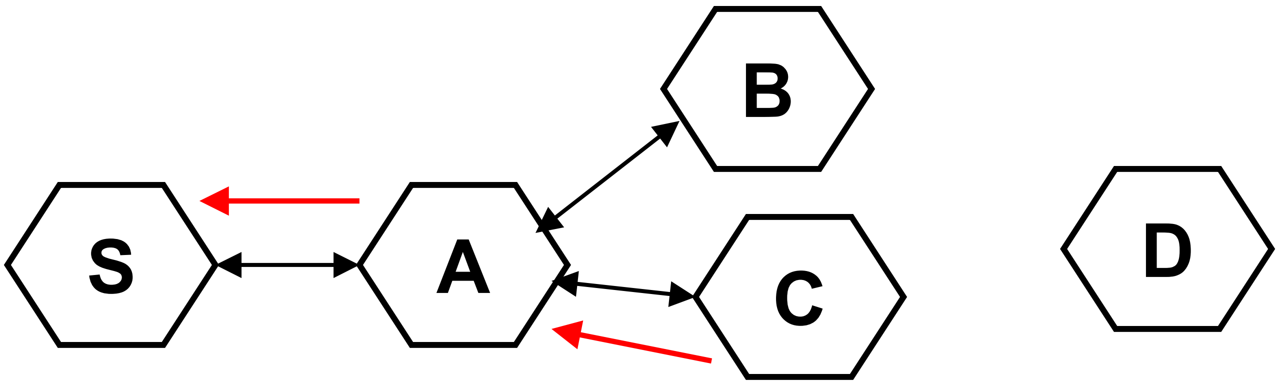
Sends data packets on route to D

AODV – route maintenance



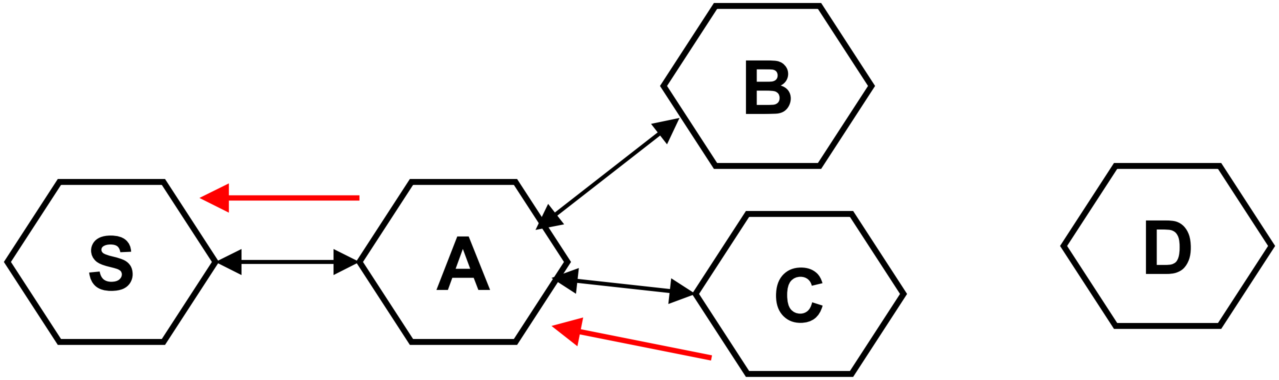
1. Link between C and D breaks
2. Node C invalidates route to D in route table
3. Node C creates Route Error (RERR) message
   - Lists all destinations which are now unreachable
   - Sends to upstream neighbors
4. Node A receives RERR

AODV – route maintenance



1. Link between C and D breaks
2. Node C invalidates route to D in route table
3. Node C creates Route Error (RERR) message
4. Node A receives RERR
   - Checks whether C is its next hop on route to D
   - Deletes route to D
   - Forwards RERR to S

AODV – route maintenance



3. Node C creates Route Error (RERR) message
4. Node A receives RERR
5. Node S receives RERR
   - Checks whether A is its next hop on route to D
   - Deletes route to D
   - Rediscovers route if still needed

AODV Optimizations

- Local repair
  - Repair breaks in active routes locally instead of notifying source.
  - Use small TTL because destination probably hasn't moved far
  - If first repair attempt is unsuccessful, send RERR to source.
  - Advantage: repair links with less overhead, delay and packet loss
  - Disadvantage: longer delay and greater packet loss when unsuccessful

Properties of AODV protocol

- Each mobile node is a router.
- Loop-free at all instances.
- Dynamic, multi-hop, self-starting.
- Low memory requirements.
- Quick convergence via triggered updates.
- Routes available on demand.
- Reasonable network load.
- Designed for 500+ mobile nodes (depends on mobility factor)

AODV Summary

- Reactive / on-demand.
- Sequence numbers used for route freshness and loop prevention.
- Route discovery cycle.
- Maintains only active routes.
- Optimizations can be used to reduce overhead and increase scalability.

Bluetooth

- Personal Area Network (PAN).
- Example applications:
  - Connecting cell phone and headset.
  - Connecting digital camera to PDA.
  - WEB surfing through cell phone from PDA.
  - Automatic sync of laptop and PDA.

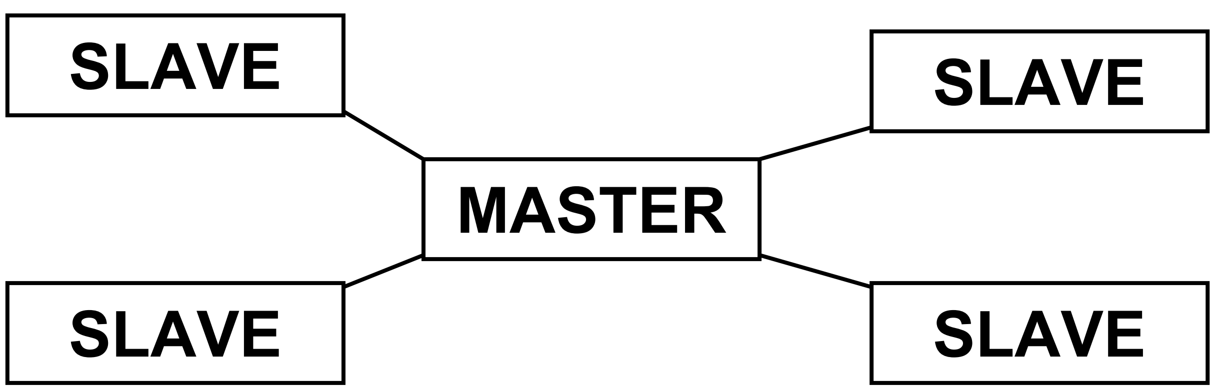
  → Cable replacement
- Goal: cheap and low power.
- Not originally designed for multihop routing.

Bluetooth

- Defines its own protocol stack (not OSI).
- 2.4 GHz IMS band.
- Frequency-hopping spread spectrum (FHSS): 1,600 hops/second.
- Less than 1 Mbps link speed.
- Less than 10 m range.

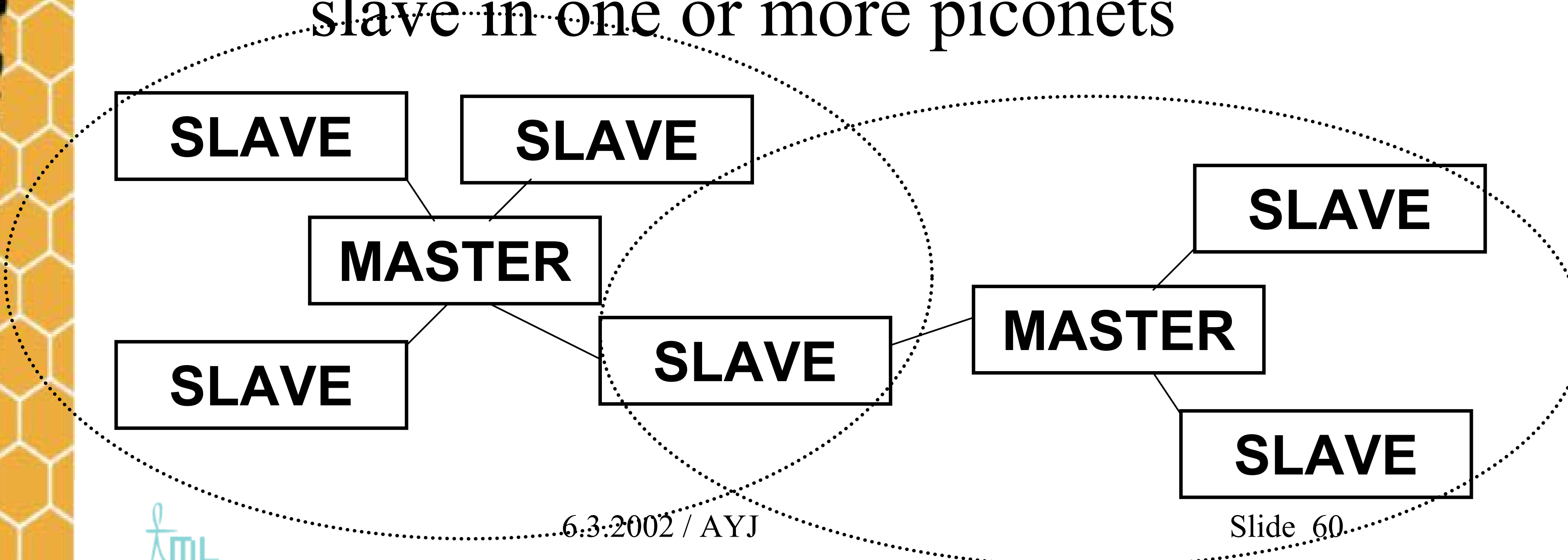
Bluetooth - connectivity

- Piconet: set of Bluetooth devices sharing a common channel
  - One master, and up to seven active slaves
  - Any device be either a master or a slave



Bluetooth - connectivity

- Scatternet: set of two or more interconnected piconets
  - A node can be a slave in multiple piconets, or can be a master in one and a slave in one or more piconets



Ad-hoc networking

- Ad-hoc networking is an inexperienced networking phenomenon for the public.
- There is a potential marketplace for ad-hoc solutions.
- There are many issues to be solved in technical perspective.
- Ad-hoc networking is an attractive research area as well as a commercial opportunity -> many protocols proposed.

Summary

- Explained fundamentals of ad-hoc networking.
  - Motivation for ad-hoc networking.
  - Ad-hoc networking terminology.
  - Some basics on routing and ad-hoc routing.

- Discussed ad-hoc network protocols.
  - Exemplified ad-hoc network protocols.
  - DSDV and AODV ad-hoc routing protocols.