Advanced Networks

(EENGM4211)

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Slides courtesy: Prof. Reza Nejabati and Slides from Ross's Book

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Part 5:
Routing in Wireless Networks

Outline & Topics

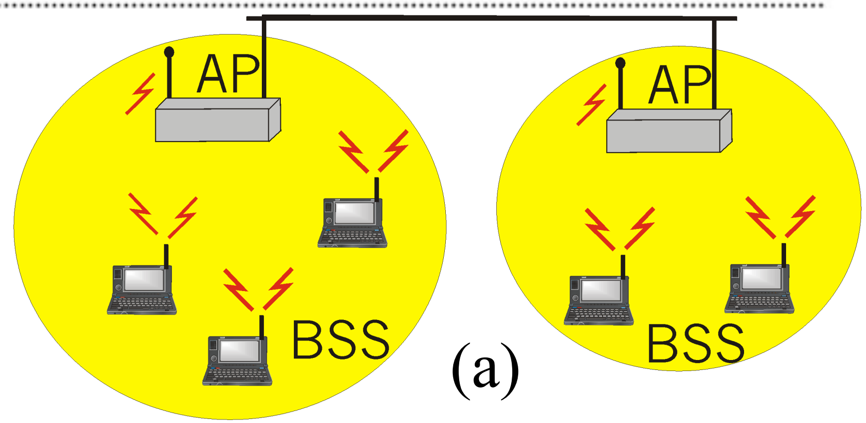
- Wireless Networks Classification
  - Infrastructure based
  - ad-hoc based
- Ad-hoc routing algorithms and protocols
- Typical link technologies

ILOs

Wireless networks: Classification

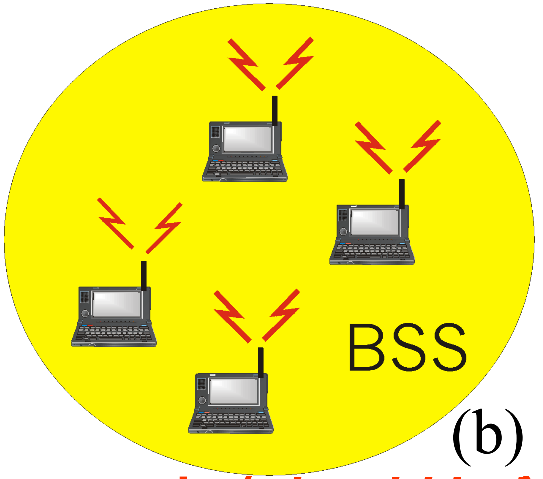
Infrastructure (a)

- Nodes communicate through base-station (AP)
- Network management support via fixed infrastructure



Ad-hoc (b)

- No base-station; end-nodes communicate with each-other
- Nodes need to be both routers and end-nodes



Main difference is (*<u>should be!</u>*) in the functions supported by the mobile nodes.

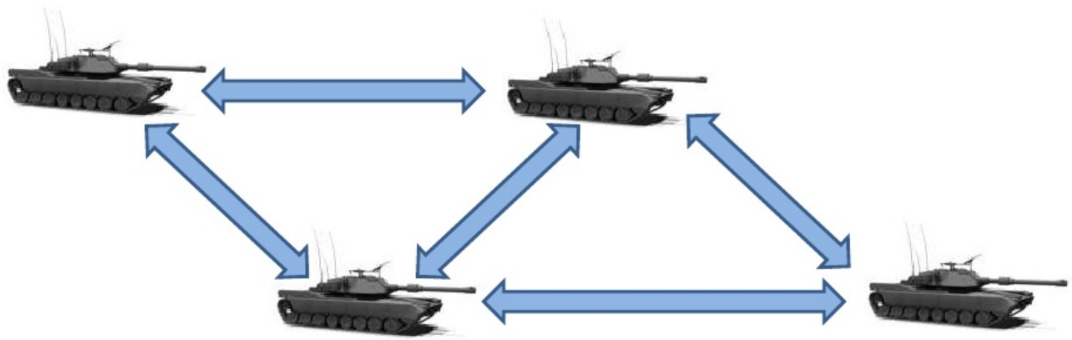
Characteristics

- Infrastructure
  - Use of wireless links
  - Usually carefully planned and deployed
  - Usually connected to other network systems
- Ad-hoc
  - Formed by wireless hosts (possibly mobile)
  - (often) Does not require existing infrastructure, i.e. requires very little or no planning at all
  - Potentially multi-hop (always assumed in practice)

Cellular	Ad-Hoc Networks
Infrastructure networks. Fixed, pre-located cell sites and base station. Static backbone network topology. Relatively caring environment and stable connectivity. Detailed planning before base station can be installed. High setup costs. Large setup time.	Infrastructureless networks. No base station, and rapid deployment. Highly dynamic network topologies. Hostile environment and irregular connectivity. Ad-Hoc network automatically forms and adapts to changes. Cost-effective. Less setup time.

Application Examples

- Military, civil emergency situation, personal area networks, meeting/conference scenarios, …

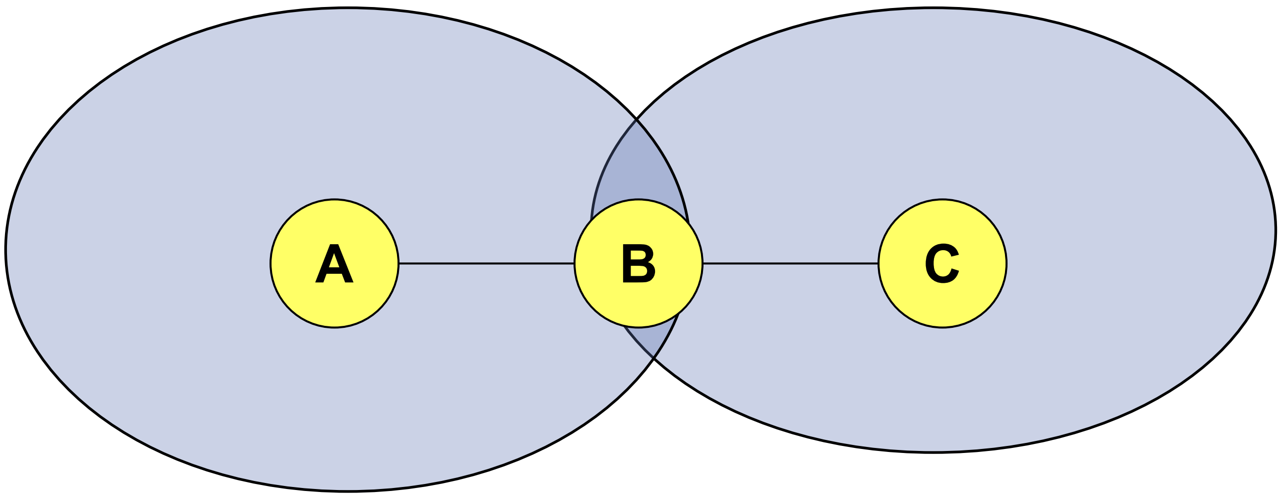


- **Mobile ad hoc networks (MANETs)**
- **Vehicular ad hoc networks (VANETs)**
- **Smart phone ad hoc networks (SPANs)**
- **Wireless Sensor Networks (WSN)**

Wireless networking challenges

- Dynamic link characteristics
  - Propagation path, interference, ….
- Hidden-terminal problem
- Exposed node Problem
- Resource constraints (processing, memory, power)
- Mobility
  - Environment, speed of movement, directionality, density of population, uniformity…
- Highly dynamic topology
  - Because of mobility and wireless link characteristics

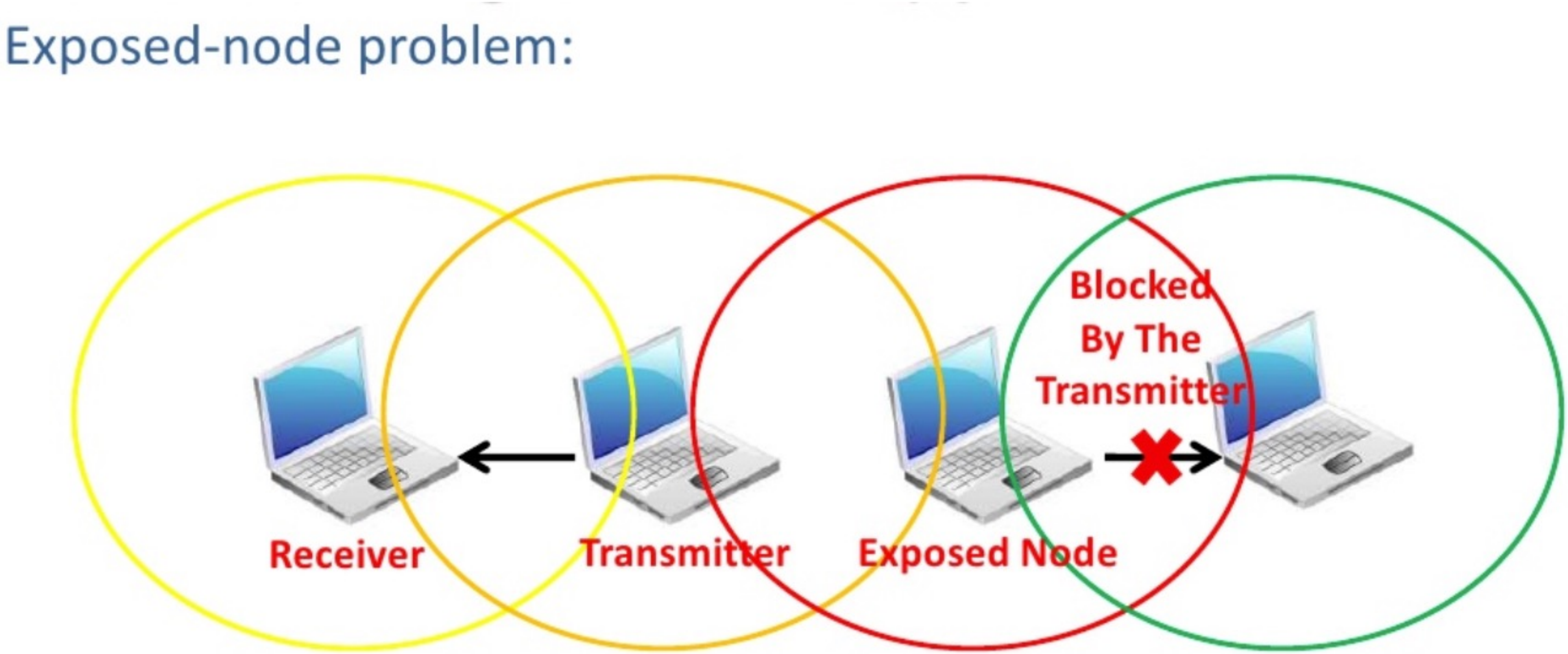
Hidden Terminal Problem



- Nodes A and C cannot **"hear"** each-other, i.e., A and C are hidden from each other; while A←→B and B ←→C is OK.

- A and C cannot communicate with each other as they are out of range of each other, and thus start to transmit simultaneously preventing B from receiving messages intended for it.

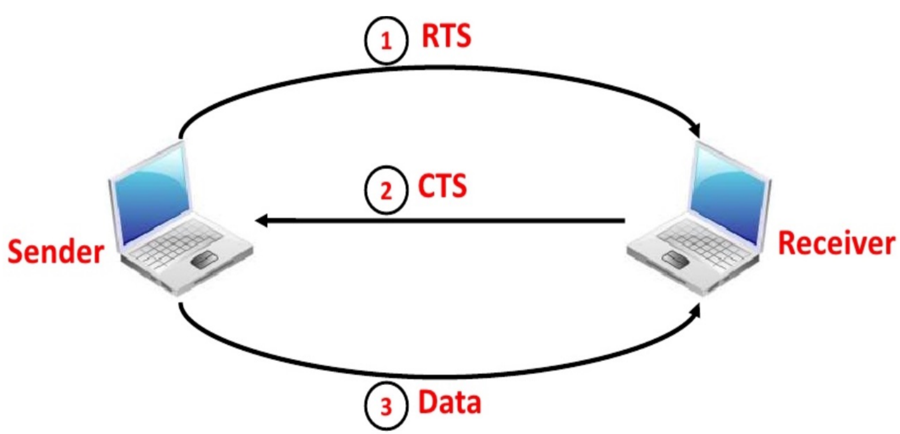
Exposed Node problem



The exposed node problem occurs when a node is prevented from sending packets to other nodes because of co-channel interference with a neighboring transmitter

Ad-hoc Media Access Protocols

- The medium is shared by all the nodes
- Transmit any time -> contention
- Medium Access Control (MAC) protocols



1- RTS: request for transmit
2- CTS informs which node can transmit.
CTS gives duration of transmission
3-Data is sent

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- Routing in Ad-hoc Networks

Why routing in ad-hoc is different from wired networks?

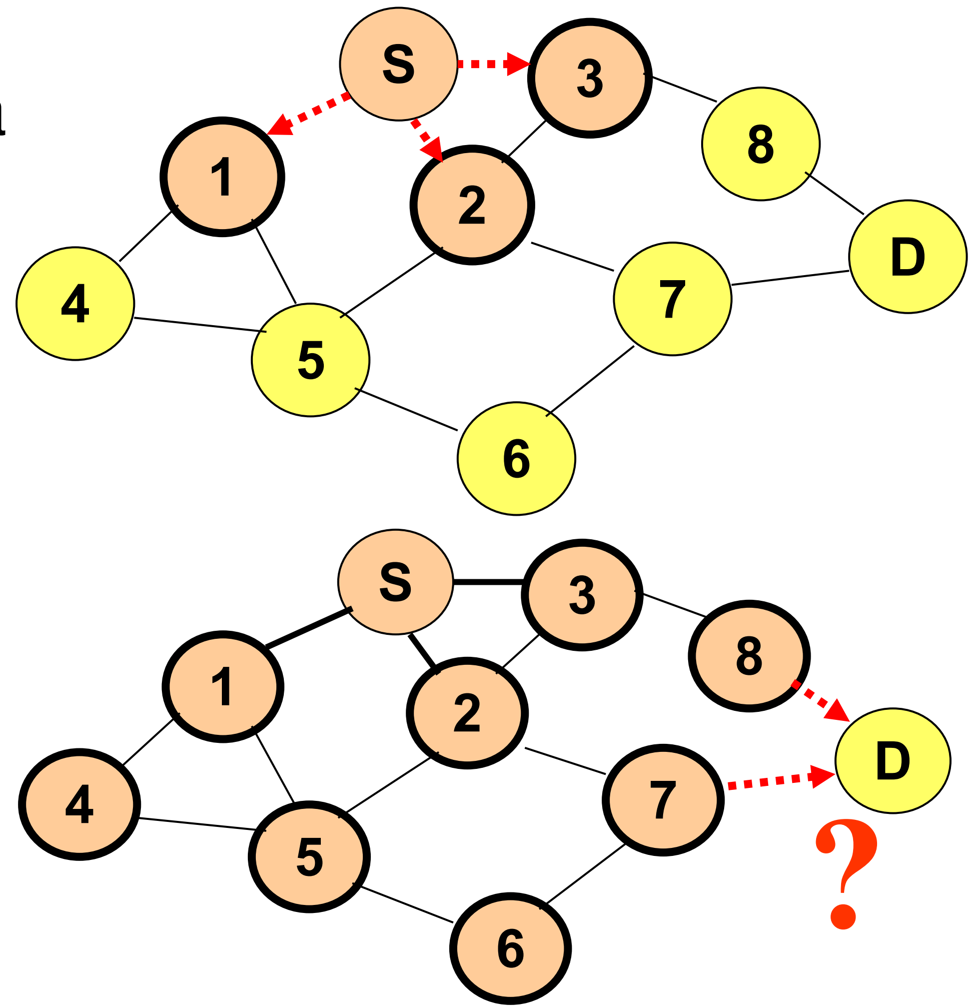
- All nodes can act as both host and router
  - Symmetric and asymmetric algorithms
  - Link failure may (and usually does) have different characteristics and causes from wired networks
- Rate of topology change (caused by link failures) can vary dramatically (e.g. when nodes move fast relative to each-other)
- Link characteristics are not always binary (on/off); link can be up but with lower bandwidth
  - This means more variables to consider for optimisation!
- Resource constraints – mainly power

Routing Algorithms

- Distance Vector
  - Similar to IP equivalent
- Link state
  - Similar to IP equivalent
- Source routing
  - sender of a packet to specify the route the packet takes through the network. In contrast, in non-source routing protocols (like distance-vector), routers in the network determine the path based on the packet's destination.
- Link reversal
- Flooding

Ad-hoc routing protocols : Flooding (1/2)

- Sender broadcasts data packet to all its neighbours
- Each receiver forwards the packet to all its neighbours (sequence numbers used to detect duplicates)
- When packet reaches the destination, it is not forwarded any more



Ad-hoc routing algorithm,: Flooding (2/2)

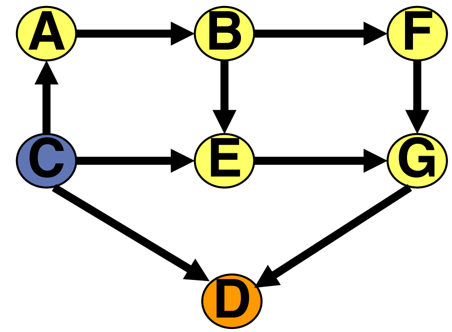
Advantages

- Simple: matches the broadcasting nature of the wireless medium
- Possibly higher reliability of data delivery
  - Data is delivered over multiple paths

Against

- Possible very high overhead
  - Depends on the traffic characteristics and the mobility scenario
- No reliability guarantees
  - Cannot tell if the packet was delivered at all

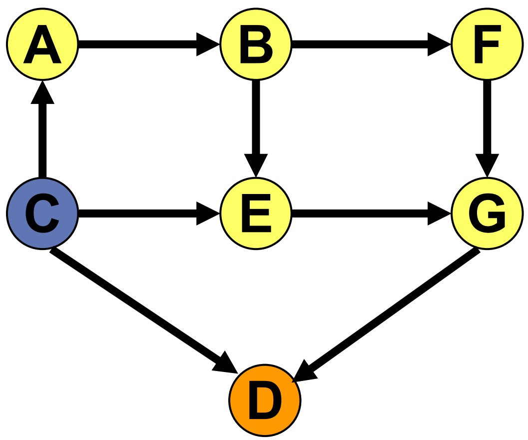
Ad-hoc routing algorithm: Link Reversal



- Algorithm imposes directionality on links (even if they are bi-directional)
- The algorithm aims to maintain a directed acyclic graph, with the destination as the only sink
  - Describes the network of nodes with Directed Acyclic Graph (DAG), which is a graph with directed arcs. Acyclic means that the graph has no loops.
- The graphs have exactly one node, which has only incoming links i.e. the node has only upstream neighbors
- Other nodes have either incoming and outgoing links or just outgoing links.
- The node with only incoming links is the destination node.
- Every route of the DAG finally leads to the destination.

Ad-hoc routing Algorithm: Link Reversal

Aim: To maintain a DAG (directed acyclic graph), with the destination as the only sink (no outgoing links)



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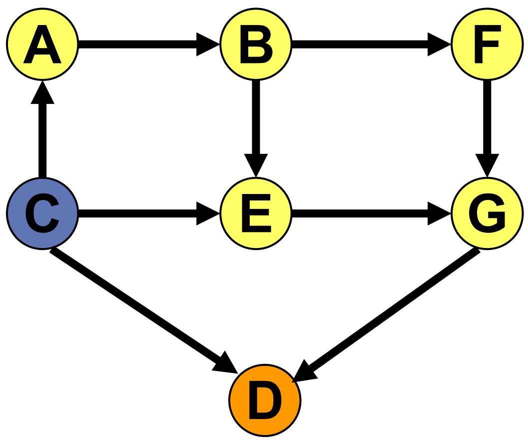

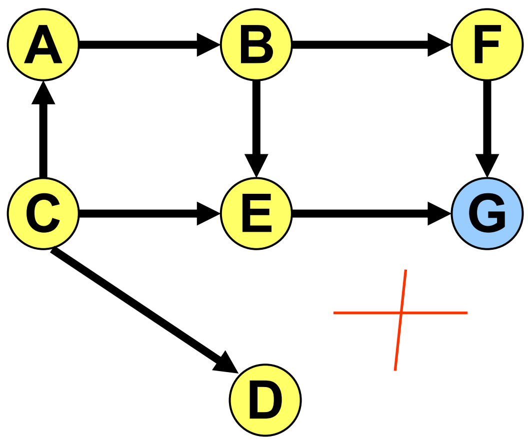

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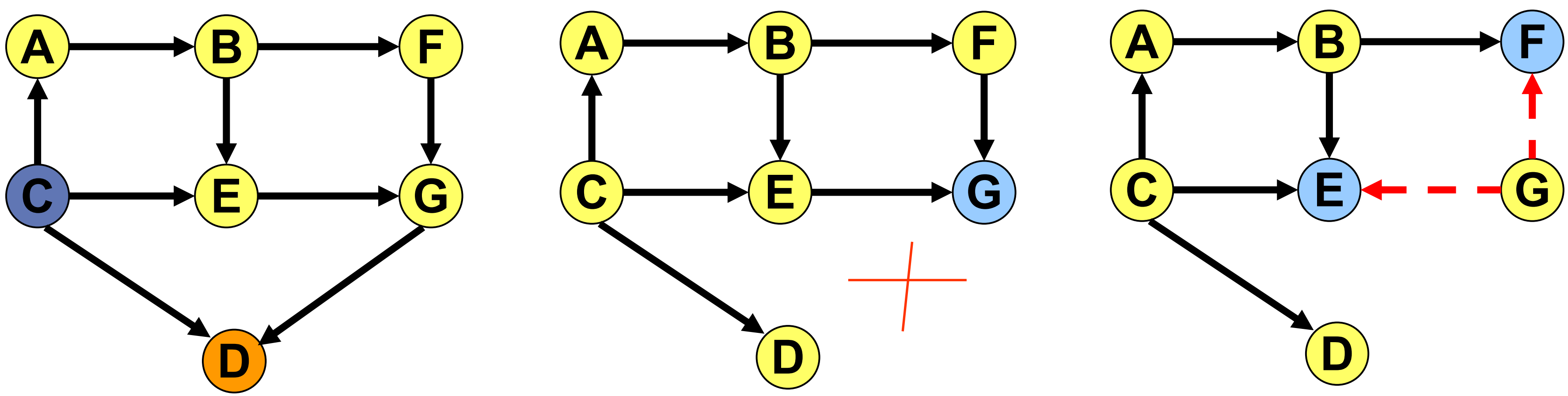

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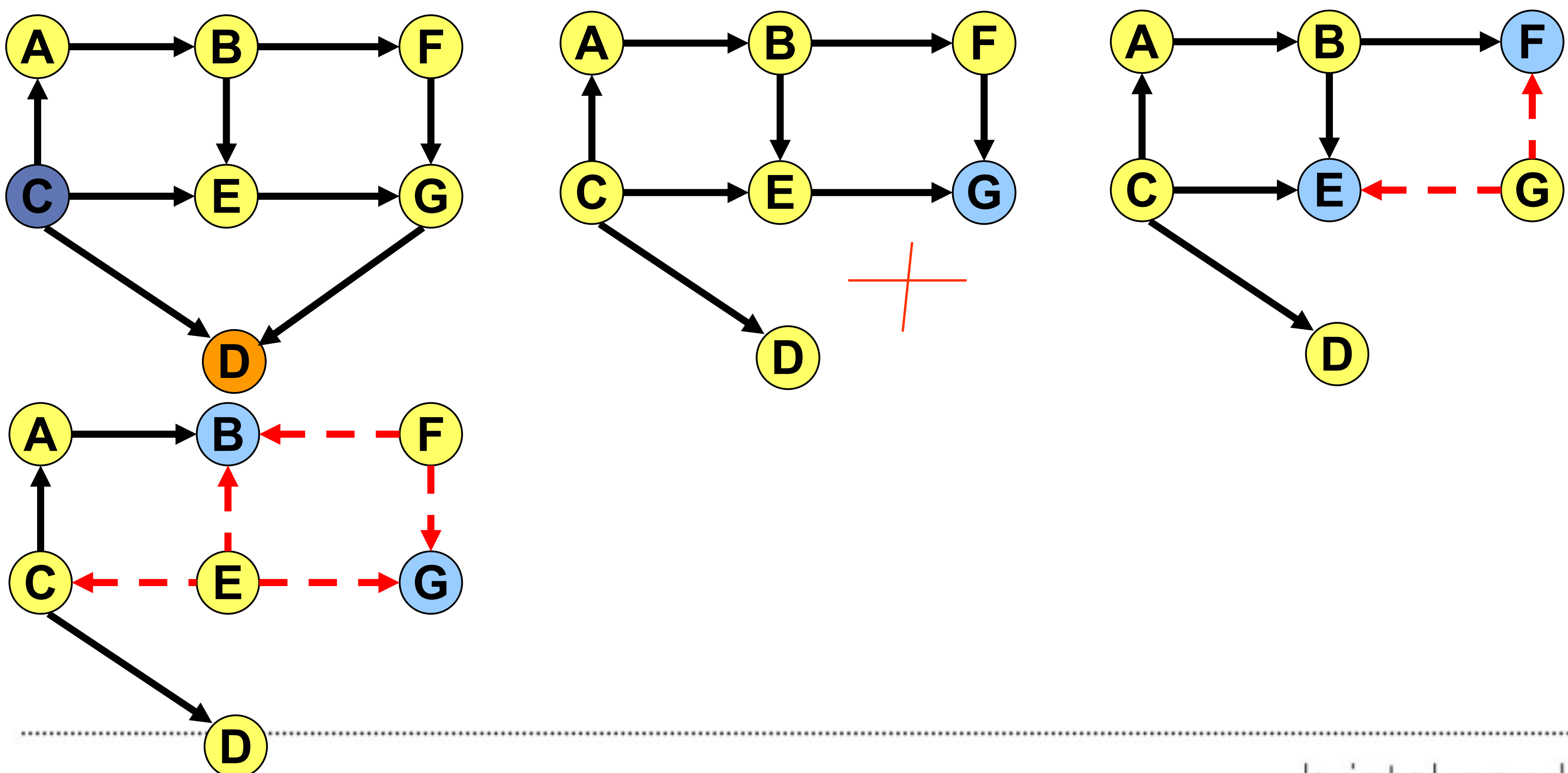

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Ad-hoc routing Algorithm: Link Reversal

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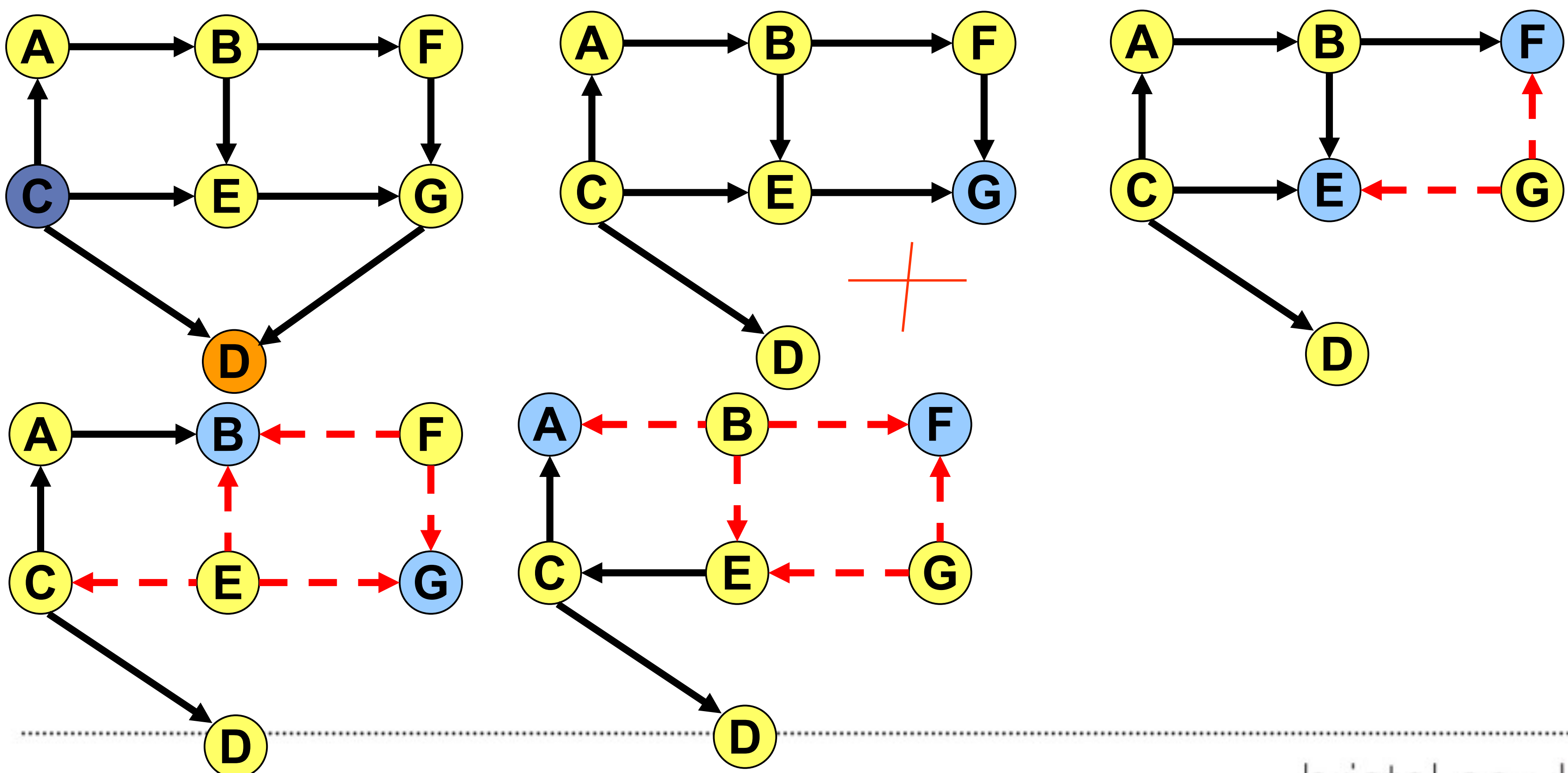

Ad-hoc routing Algorithm: Link Reversal

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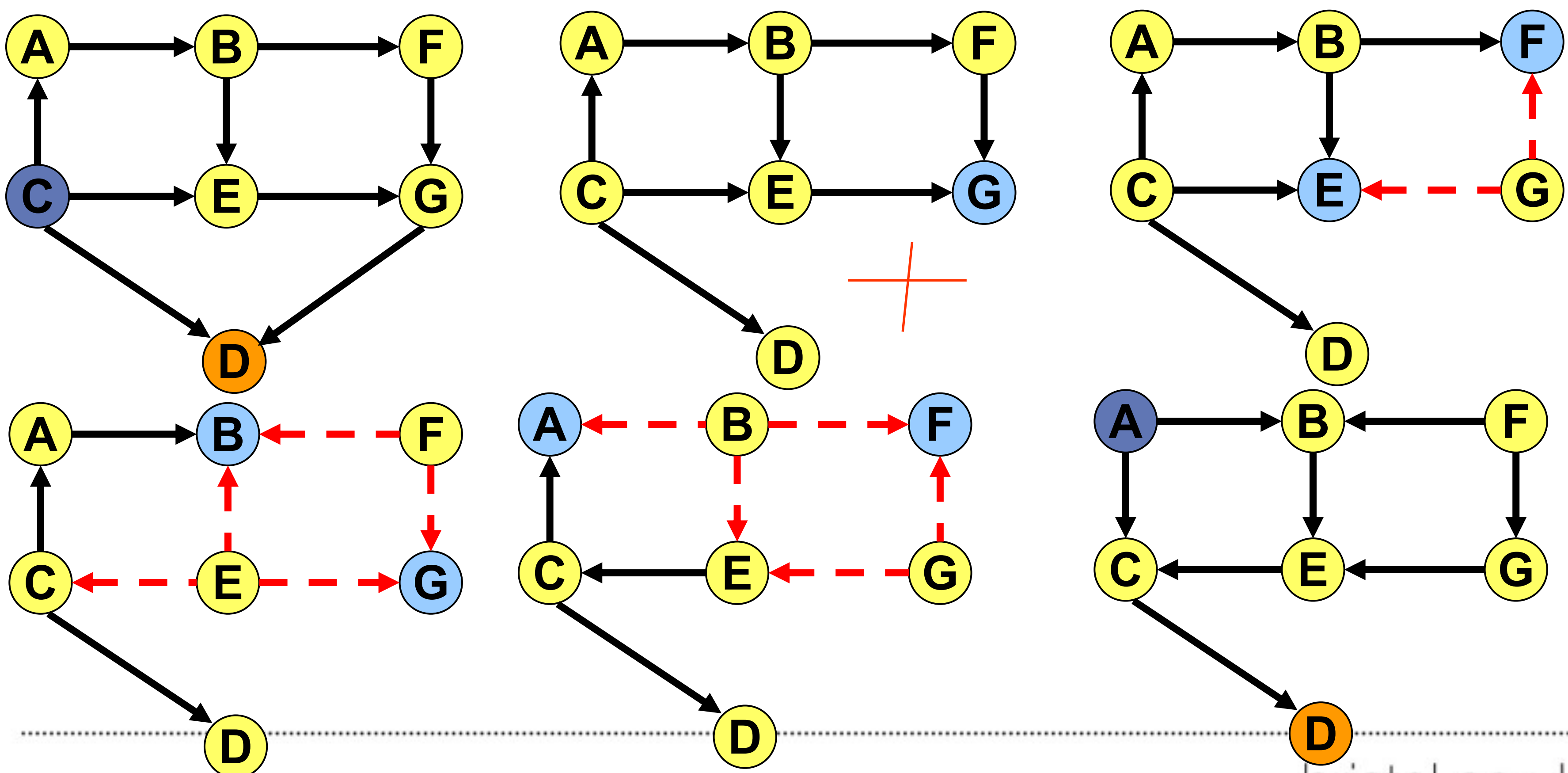


Ad-hoc routing algorithm: Link Reversal

- Advantages
  - Local updates related to the link failure; minimises control traffic
  - Some level of redundancy
    - Each node may have multiple routes to destination

- Against:
  - Needs a mechanism to detect link failure – difficult in wireless networks!
  - Link reversals may not converge!

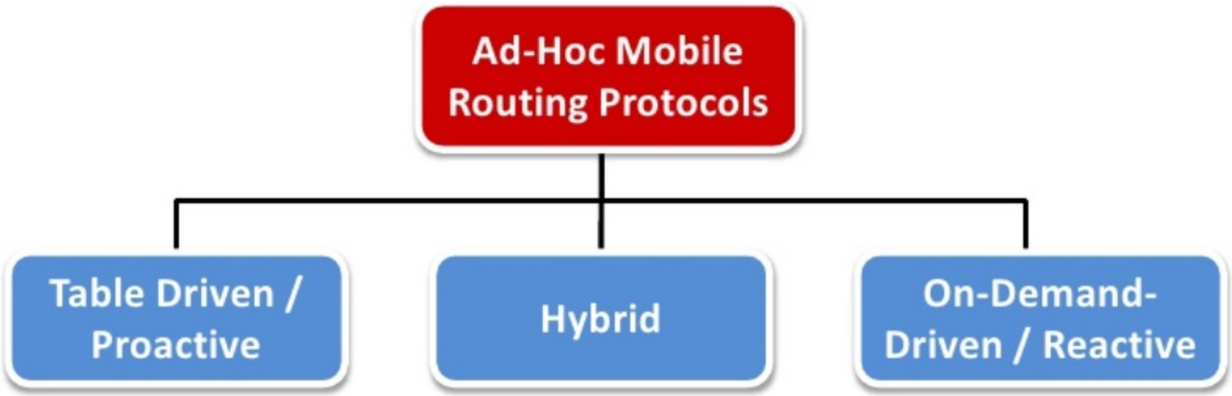
Ad-hoc Routing Protocols : Classification

- Proactive protocols
  - Determine routes independent of traffic demand
    - Similar to wired networks
  - Examples include variants based on traditional link-state and distance-vector routing protocols
  - Maintain routing tables to all destinations, updated periodically
  - Large overhead, low latency

- Reactive protocols
  - Establish and maintain routes only if needed, i.e. on-demand routing
  - Rely on route discovery and route maintenance
  - Low overhead, high latency

- Hybrid protocols
  - Why? Because neither of the above provides the solution

Ad-hoc Routing Protocols

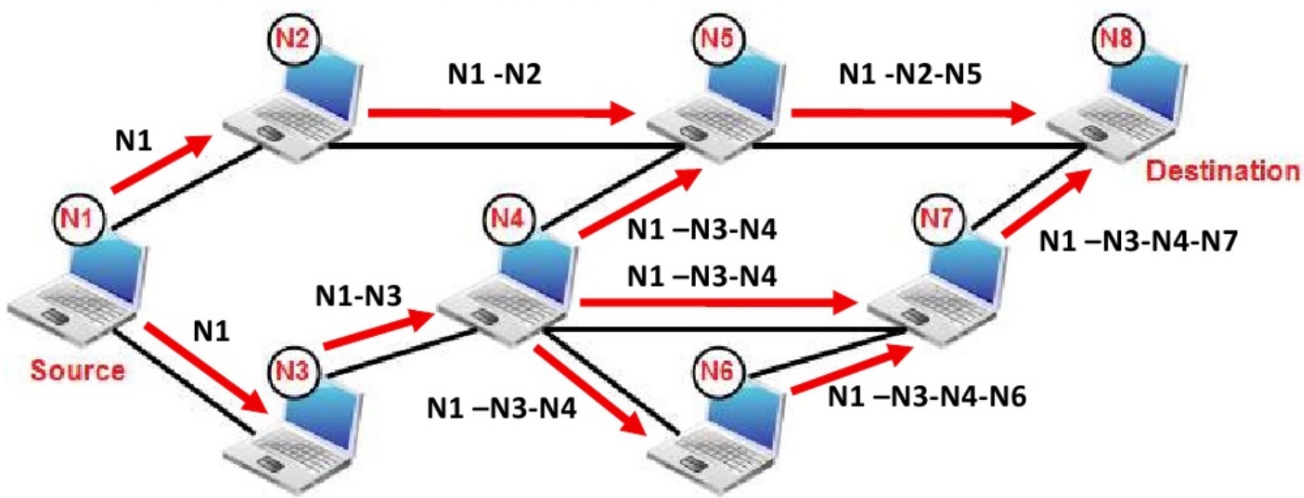


- Dynamic Source Routing (Reactive)
- Ad-hoc On-Demand Distance Vector Routing (AODV) (Reactive)
- Optimized Link State Routing (Proactive)
- Destination-Sequenced Distance Vector (Proactive)
- ZRP = Zone Routing Protocol (Hybrid)

Ad-hoc routing protocols: DSR (1/4)

- DSR (Dynamic Source Routing)
- Reactive protocol with source routing algorithm
  - Source *S* has packet to send to destination *D*, but does not know the path
  - S initiates a route discovery
    - Flood Route Requests (RREQ)
    - Forwarding nodes append their own address onto the forwarded request packet

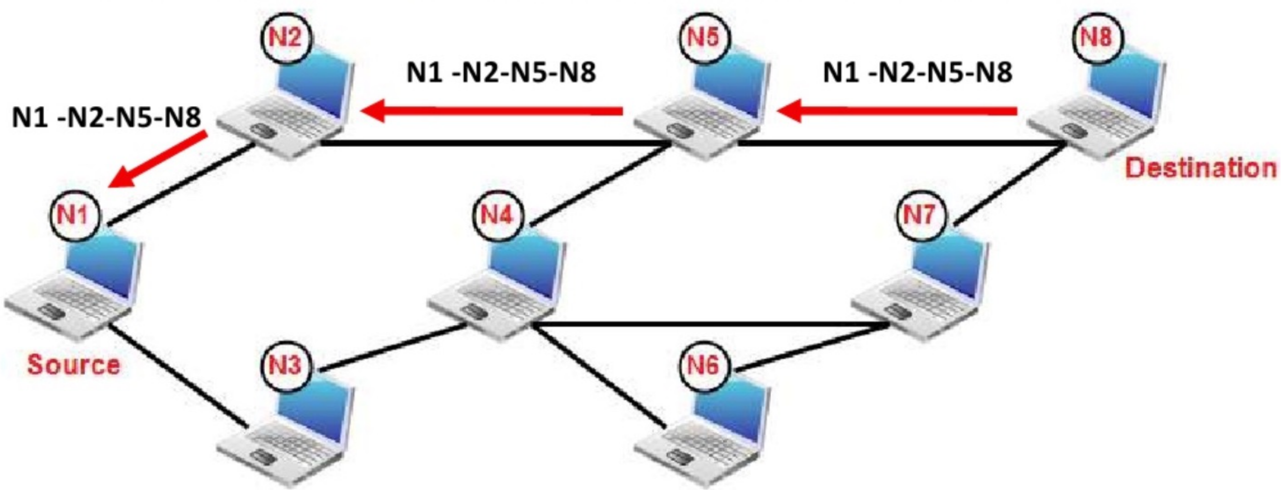
Propagation of the route request messages:



Ad-hoc routing protocols: DSR (2/4)

- *D*, upon receiving RREQ, sends a Route Reply (RREP)
  - D reverses the route recorded in the RREQ packet
  - RREP contains the path from S to D that RREQ has travelled.
- Upon receiving RREP, S records the route
- When S sends a data packet to D the whole route is included in the packet header (i.e. source routing)

Propagation of the route replay with the route record :



Ad-hoc routing protocols: DSR (3/4)

- Constraints
  - Request-reply protocol requires symmetric path (links are bi-directional)
  - If this is not the case, how can this be solved?
    - either D may know path to S;
    - or D may initiate a route discovery, attaching the RREP to it.
- Optimisations
  - Node caches routes in any way it can
    - Overhearing data packets;
    - Forwarding RREQ / RREP
    - Forwarding data packets

Ad-hoc routing protocols: DSR (4/4)

- Advantages
  - Routes maintained only when needed ➔ lower maintenance overhead
  - Route caching can be used to optimise overhead further
  - Some redundancy
    - One route discovery may return more than one route to destination

- Against
  - Source routing overhead (larger route = larger header)
  - Possibility of many (probably old) route replies originating from node caches rather than request-reply flooding
    - RREP storm problem
  - Collision between neighbour nodes propagating different/same RREQ
  - Latency! (time required to learn route before sending packet)

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Ad-hoc routing protocols: AODV (1/4)

- Ad-hoc On-Demand Distance Vector Routing (AODV)
- AODV is used in ZigBee (**IEEE 802.15.4)**

- Non-source-routing

- Reactive protocol
  - Routes are discovered/maintained only between nodes that need to communicate

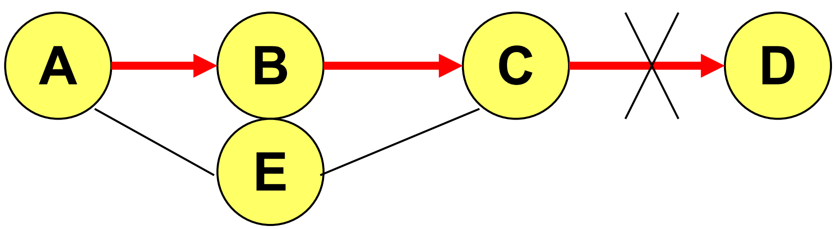
- Protocol:
  - RREQ forwarded same as DSR.
    - However each node only record next hop
  - AODV assumes symmetric links; when a node forwards a RREQ, it sets a reverse path in the local routing table pointing towards S
  - RREP travels from D according to the reverse path stored in tables in each node along the route
  - RREP-ACK used to handle problems caused by uni-directional links

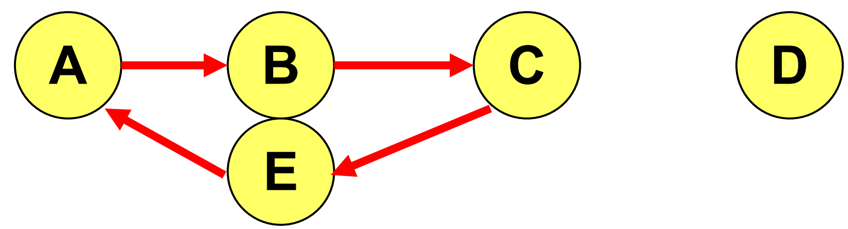
Ad-hoc routing protocols: AODV (2/4)

- To improve responsiveness, intermediate nodes may send RREP (from their knowledge cache), provided it knows a more recent path
  - Destination Sequence Numbers (DSEQ) are used to establish this; each new RREQ for a destination D is assigned a higher DSEQ; an intermediate node replies only if it has a higher DSEQ for that destination
- Soft state maintenance
  - Routing table entries are purged periodically unless updated
  - Reverse path timeout should be greater than time needed for RREP to come back
  - Forward path timeout is a dynamic value, based on traffic persistence
- Route Error messages used for link failure reporting

Ad-hoc routing protocols: AODV (3/4)

- Sequence numbers in AODV
  - To determine which route is newer (i.e. most likely to be still good)
  - To avoid loops





- Assuming A does not know about failure in C-D link
- C performs a route discovery for D; A, upon receiving RREQ (C-E-A) will reply, since it knows the route to D via B
- Loop!

Ad-hoc routing protocols: AODV (4/4)

- Advantages
  - No source routing
  - Only active nodes/routes are maintained in the routing tables
  - Only one route is maintained
    - DSR may maintain several
  - More responsive than DSR
- Against
  - Unused routes expire even if topology does not change
  - Only one route is maintained

Reading and References

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