The Basics of Wireless Communication

Octav Chipara

Agenda

- **Channel model: the protocol model**
- **High-level media access**
  - TDMA, CSMA
  - hidden/exposed terminal problems
- **WLAN**
- **Fundamentals of routing**
  - proactive
  - on-demand

Channel models

- **Channel models - document assumptions of wireless properties**
  - the basis upon which we build and analyze network protocols

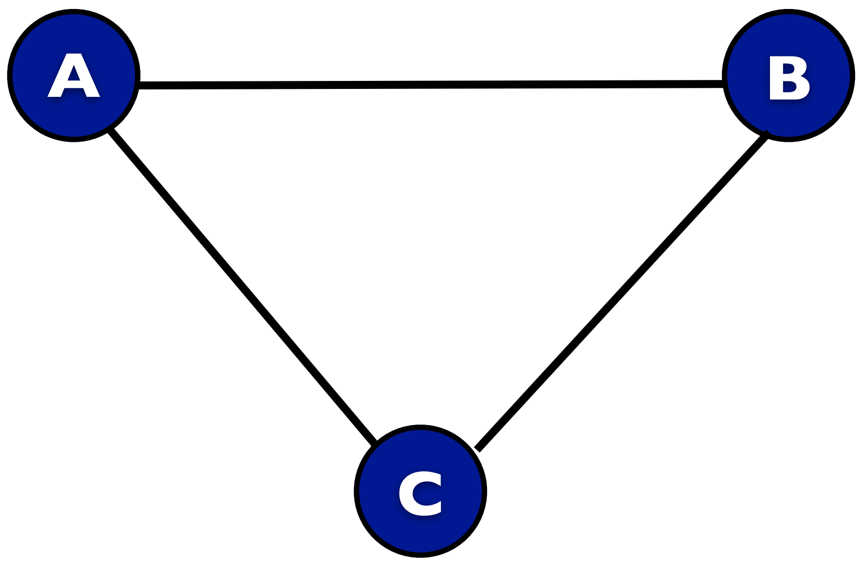
- **A good model is one that is**
  - simple - reason effectively about the properties of protocols
  - accurate - capture prevalent properties of wireless channels
  - these requirements are often conflicting

- **Must provide insight into fundamental problems**
  - media access
  - routing
  - congestion

- **Today, simple channel model..., next lecture more realistic models**

Protocol model

- **Network is modeled as a graph**
  - vertices - all nodes in a graph
  - edges - connect nodes that may communicate
- **Properties:**
  - captures connectivity information
  - packet collisions (**collisions happen only at the receiver**)
  - radios are half-duplex



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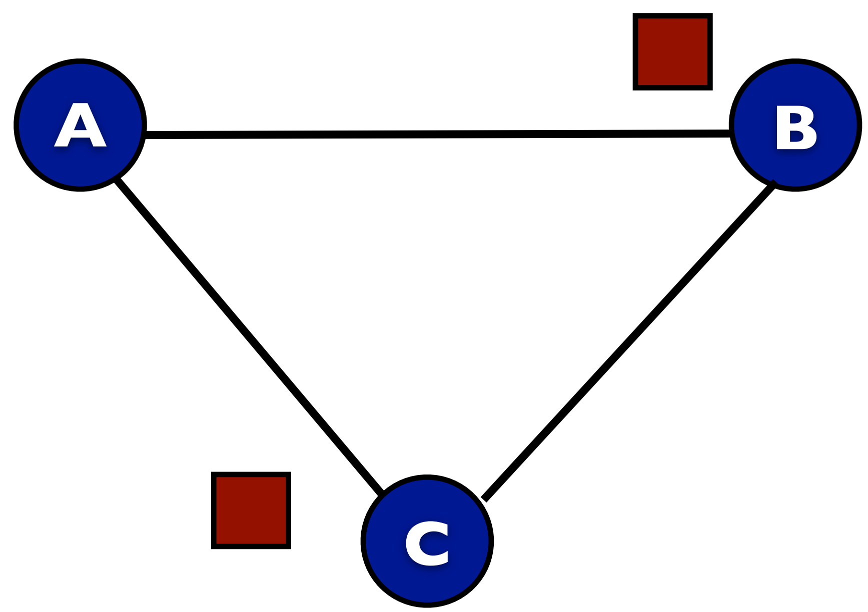

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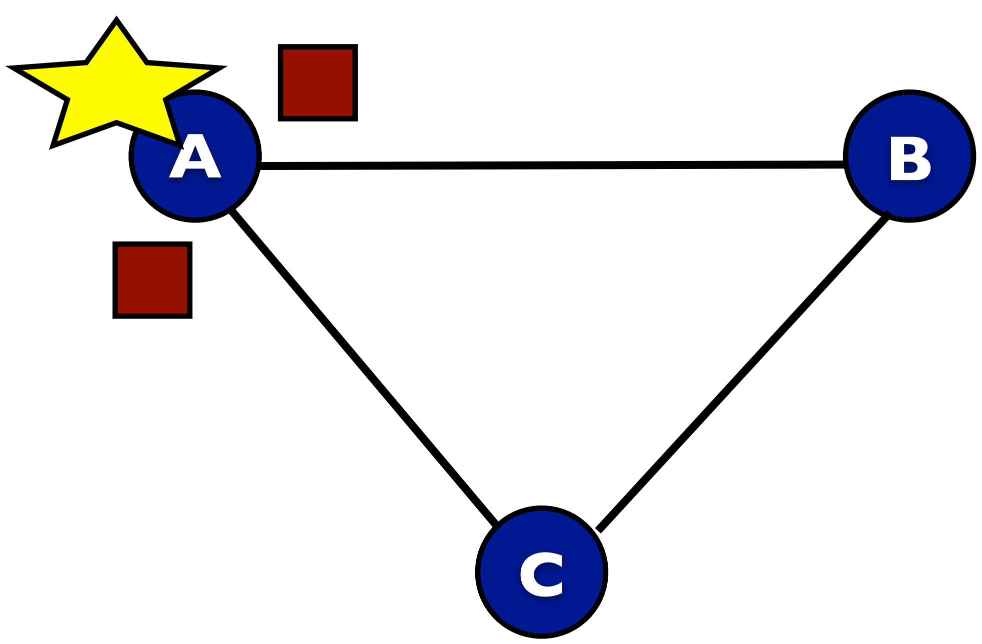

Media Access and Control (MAC)

- **Problem: multiple nodes want to transmit concurrently**
  - nodes transmitting concurrently ➔ packet collisions

- **Metrics for characterizing MAC performance**
  - throughput - number of packets delivered per second
  - latency - time to deliver a packet
  - energy efficiency - energy consumed for tx and rx
  - fairness - each node gets its “fair” share of the channel
  - flexibility - how does the MAC handle changes in workload

- **Approaches**
  - CSMA - Carrier Sense Multiple Access
  - TDMA - Time Division Multiple Access

CSMA

- **CSMA - Carrier Sense Multiple Access**
- **Approach:**
  - **1:** node will attempt to transmit after a random delay t ∈ CW
  - **2:** check if channel is available
    - free ➔ perform packet transmission
    - busy ➔ CW = CW * 2, go to step 1

- **Notes:**
  - nodes operate independently!
  - the underlying performance is highly dependent on selecting CW
    - CW - reflects the expected number of contenders for the channel
    - CW increases exponentially [the rate depends on protocol]
  - assumption: the sender can accurately check if channel is free/busy
    - usually holds because:
      receiver sensibility << channel quality required for communication

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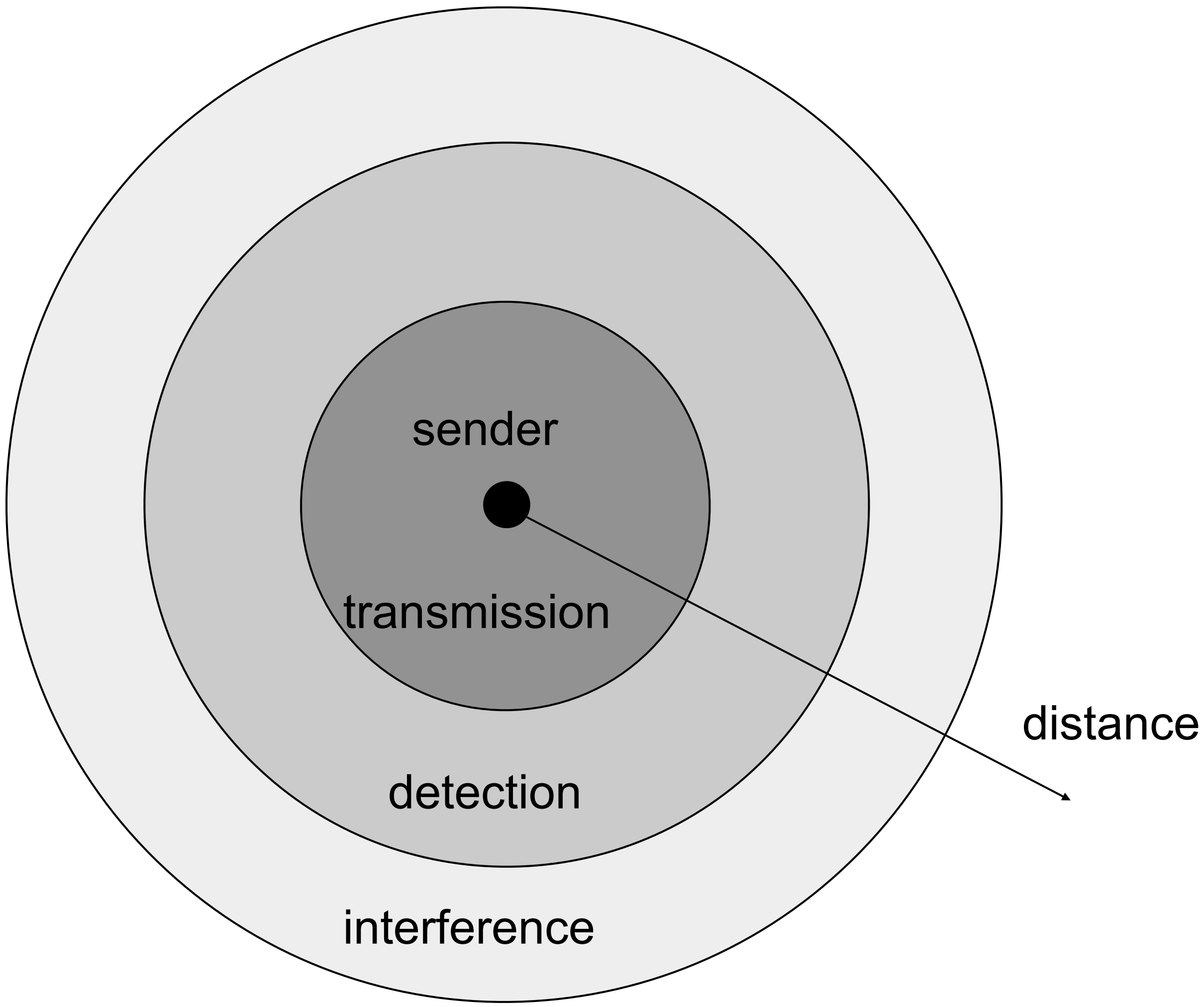
Signal propagation ranges

- **Transmission range**
  - communication possible
  - low error rate
- **Detection range**
  - detection of the signal possible
  - no communication possible
- **Interference range**
  - signal may not be detected
  - signal adds to the background noise



TDMA

- **TDMA - Time Division Multiple Access**
- **Approach:**
  - **1:** construct a frame in which each node gets a slot to transmit
    - **F** - frame size, **fn** - slot in which node n is assigned to transmit
  - **2:** a node n will transmit at time (**t** mod **F**) = **fn**
- Notes:
  - time synchronization is required
  - frame construction requires a global agreement among nodes
  - underlying performance depends on matching a node's workload demand with its slot allocations
    - hard to do due to dynamic workloads and channel properties
  - assumption: only one successful transmission per slot

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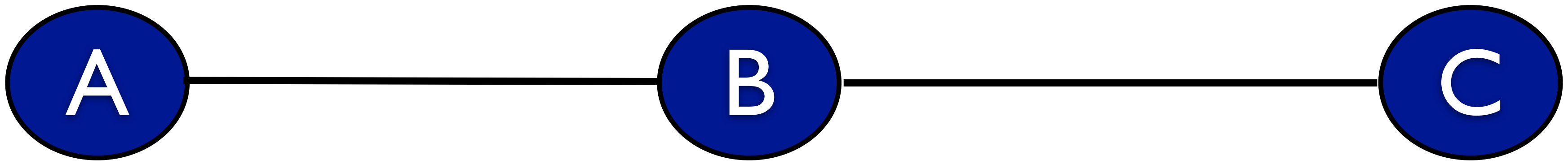
Single-hop vs. multiple hops

- **Single-hop networks**
  - both CSMA and TDMA protocols are easy to implement
- **Multi-hop networks**
  - important challenges arise due to asymmetrical views of the networks
  - hidden-terminal problem
  - exposed-terminal problem

Hidden terminal problem



- **Node A and C are hidden (edge (AC) is not in the graph)**
  - they cannot sense their packet transmissions
- **Consequences for MAC protocols**
  - CSMA protocols will never increase CW
  - TDMA protocols will have to agree on a frame over multiple hops

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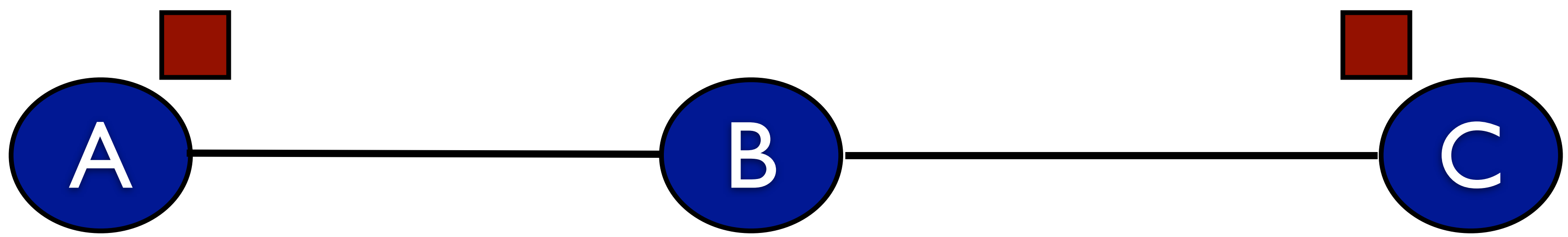

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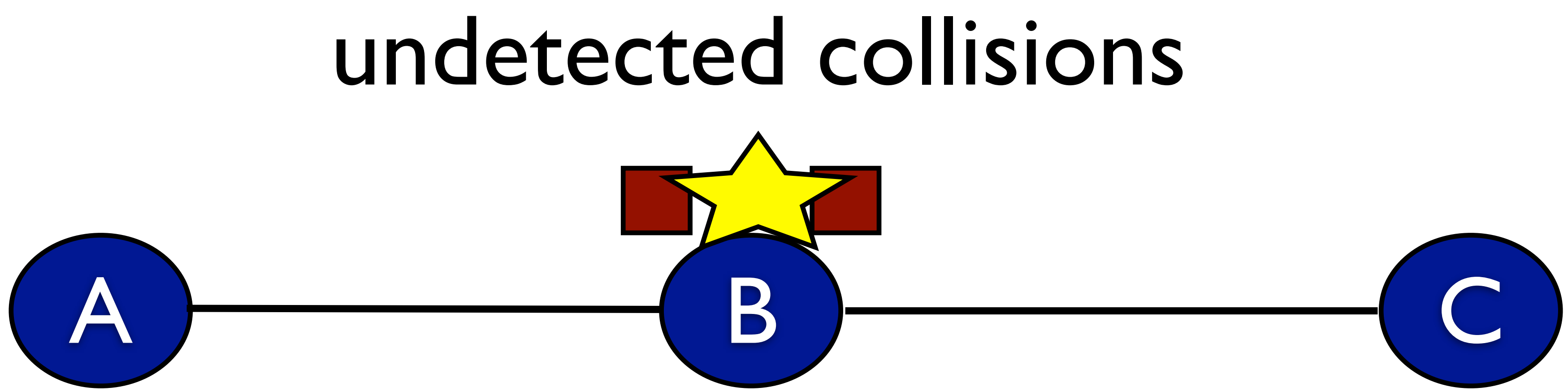

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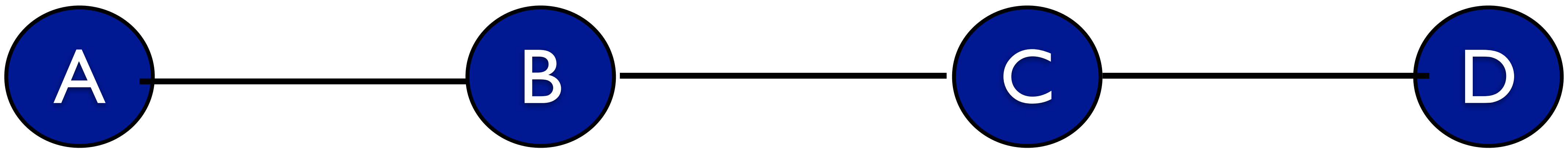

- **Node B and C can communicate**
  - (BA) and (CD) can occur currently (collisions at receivers)
- **Consequences for MAC protocols**
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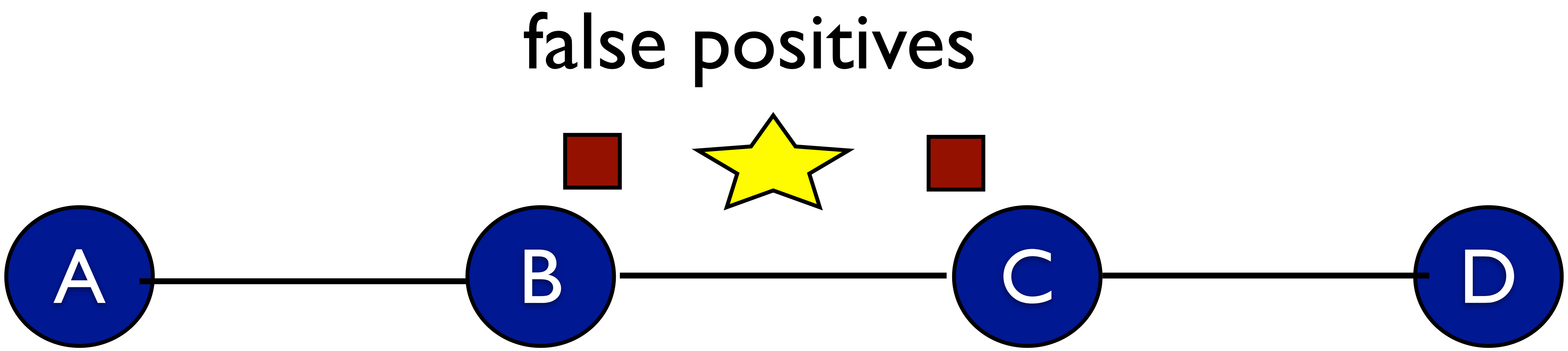

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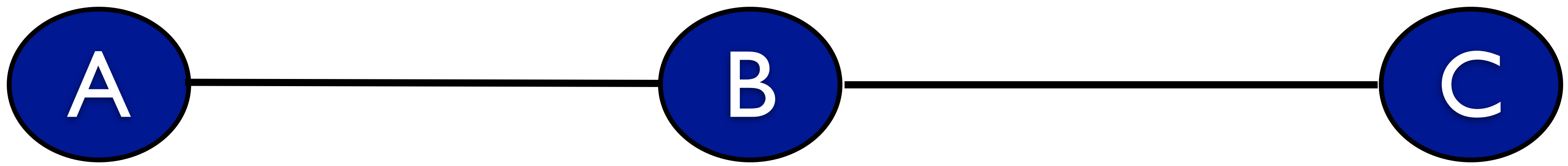
RTS/CTS a solution for CSMA protocols

- **Add two additional messages to the TDMA protocol**
  - RTS - request to send
  - CTS - clear to send
- **Algorithm**
  - node **n** wants to send packet to **m**
    - transmit **RTS**(n, m)
  - node a_1, a_2, ..., a_n, **m** receive **RTS**(n, m)
    - node **m** replies with **CTS**(n, m) if its channel is free
  - node b_1, b_2, ..., b_n, **n** receives **CTS**(n, m)
    - node **n** transmits the data packet
- **The algorithm signals access requests over 2-hops**

Hidden terminal problem



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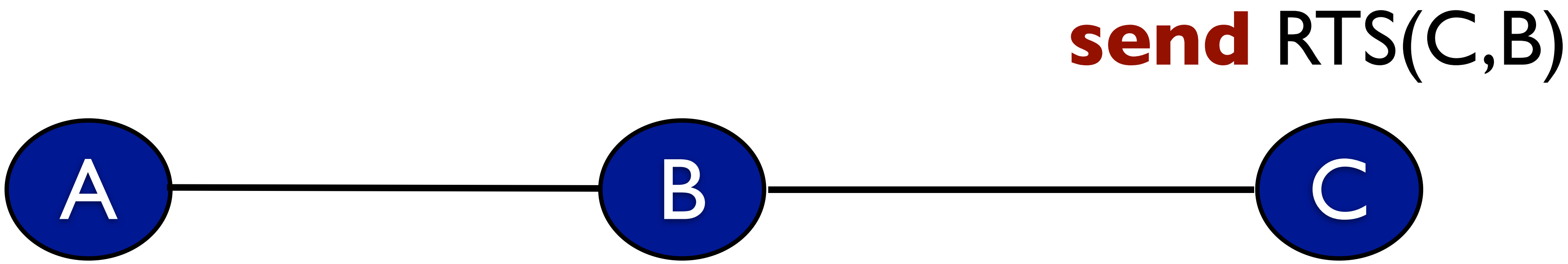

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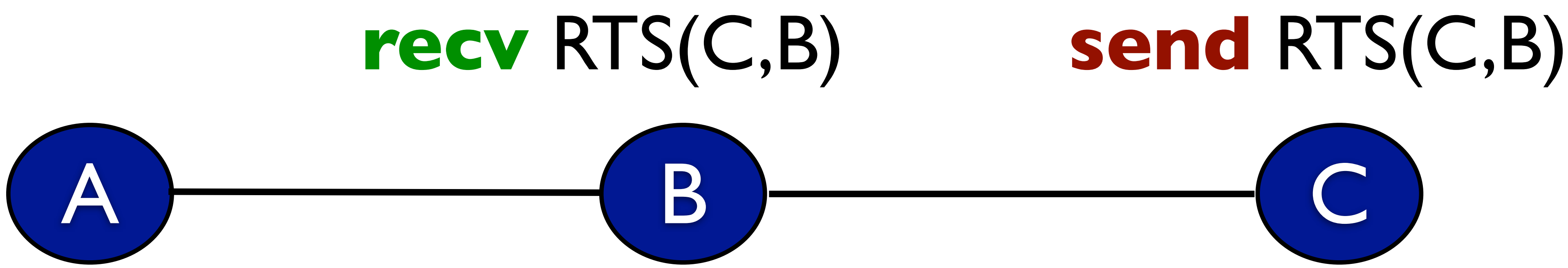

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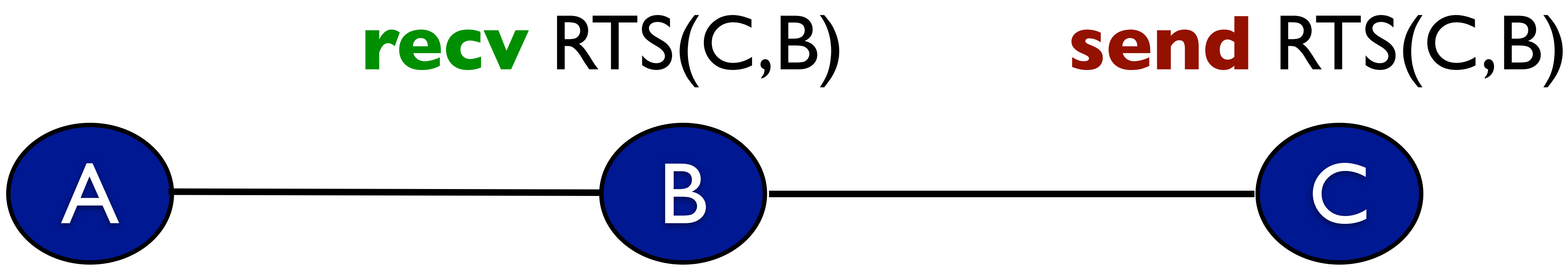

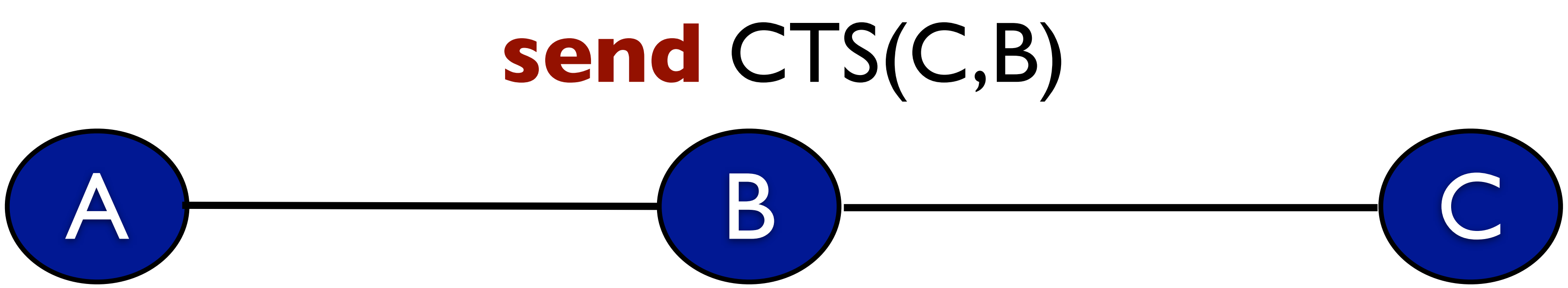

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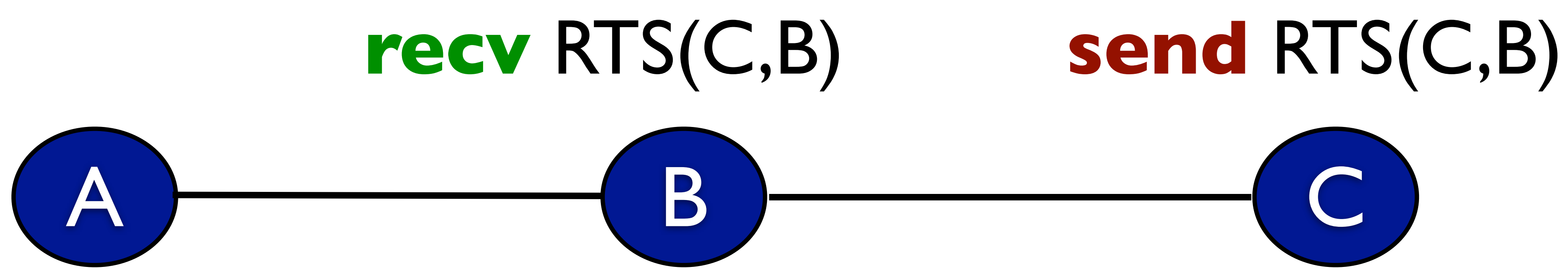

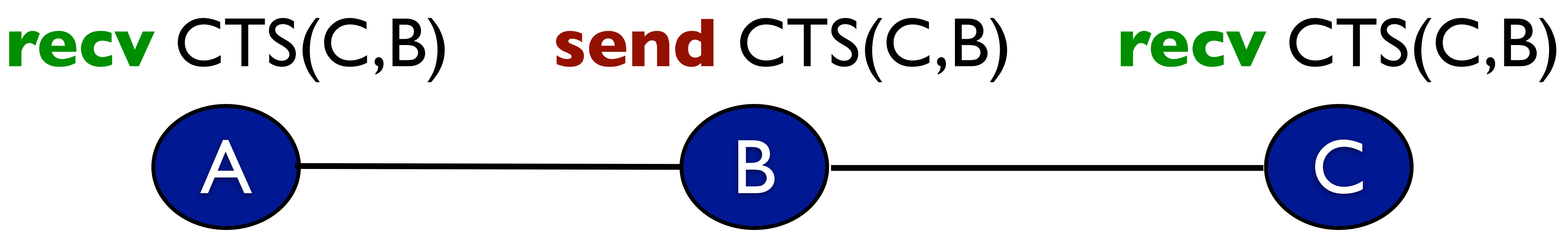

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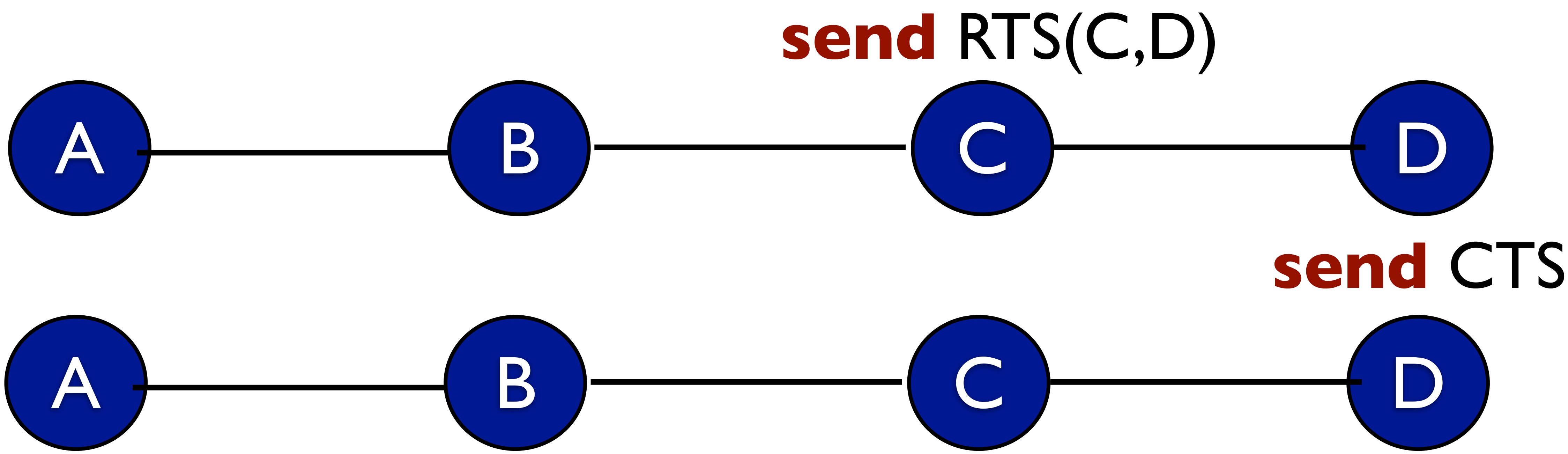

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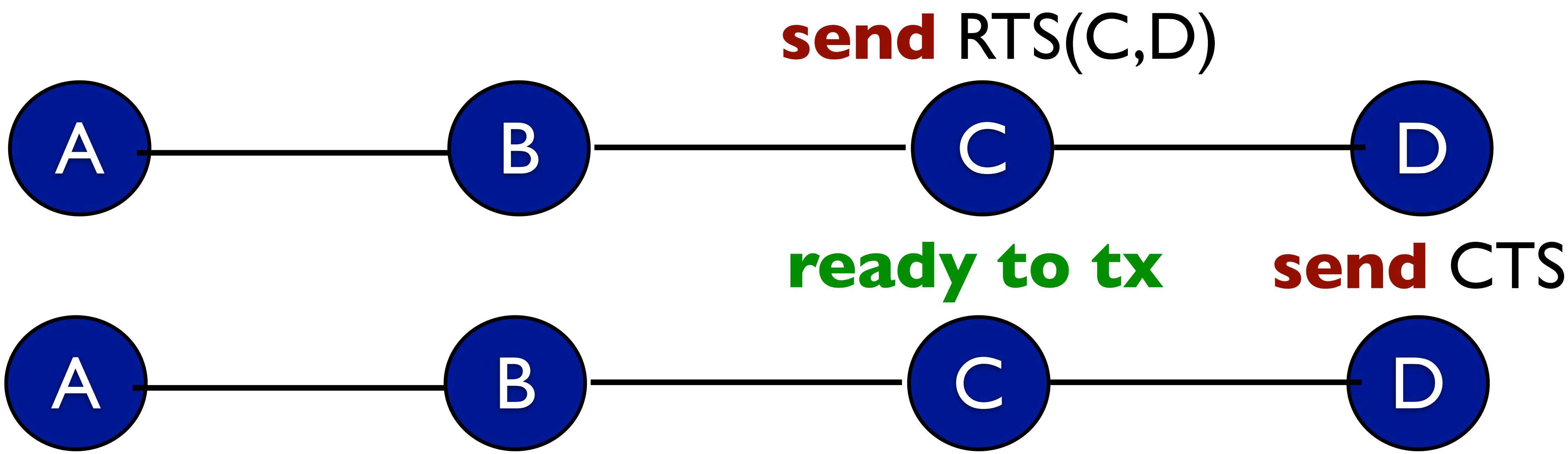

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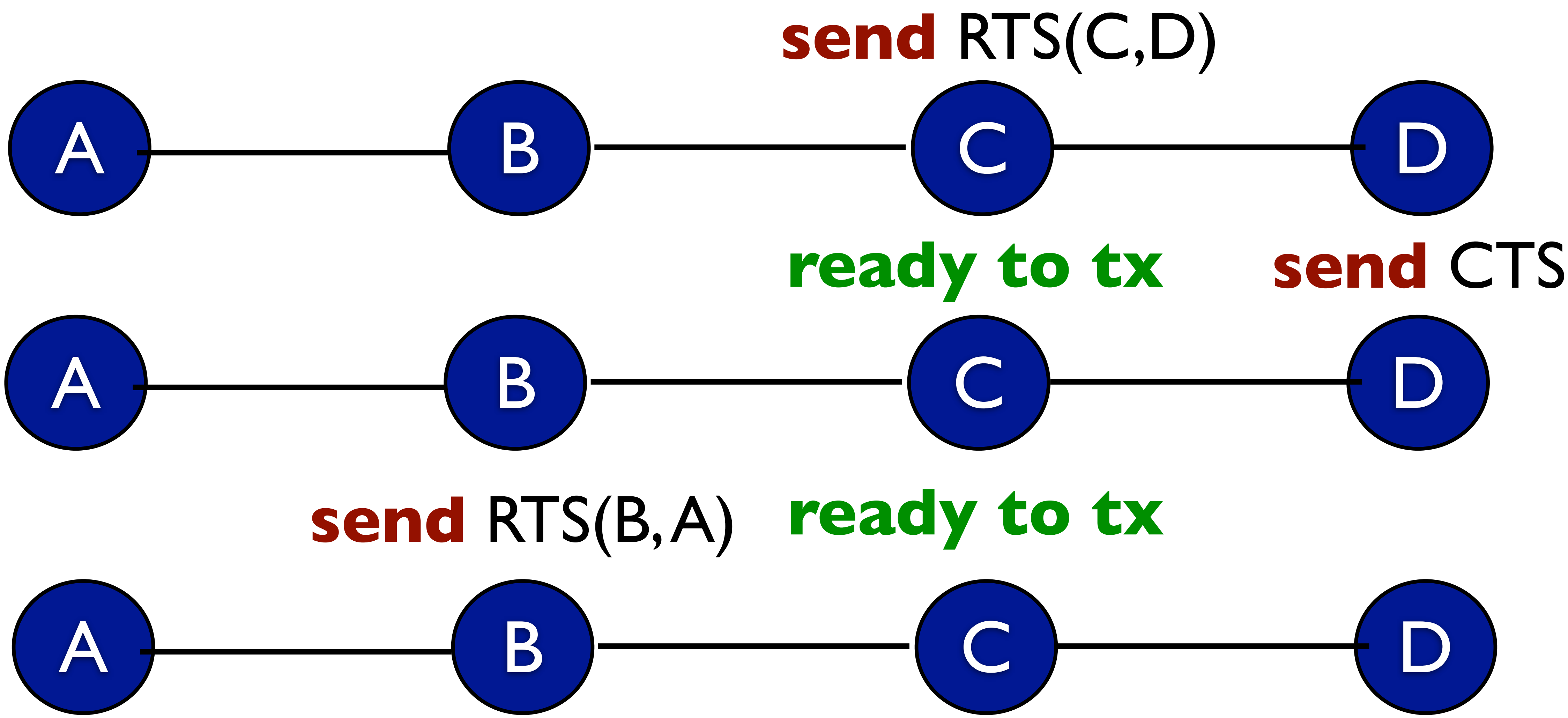

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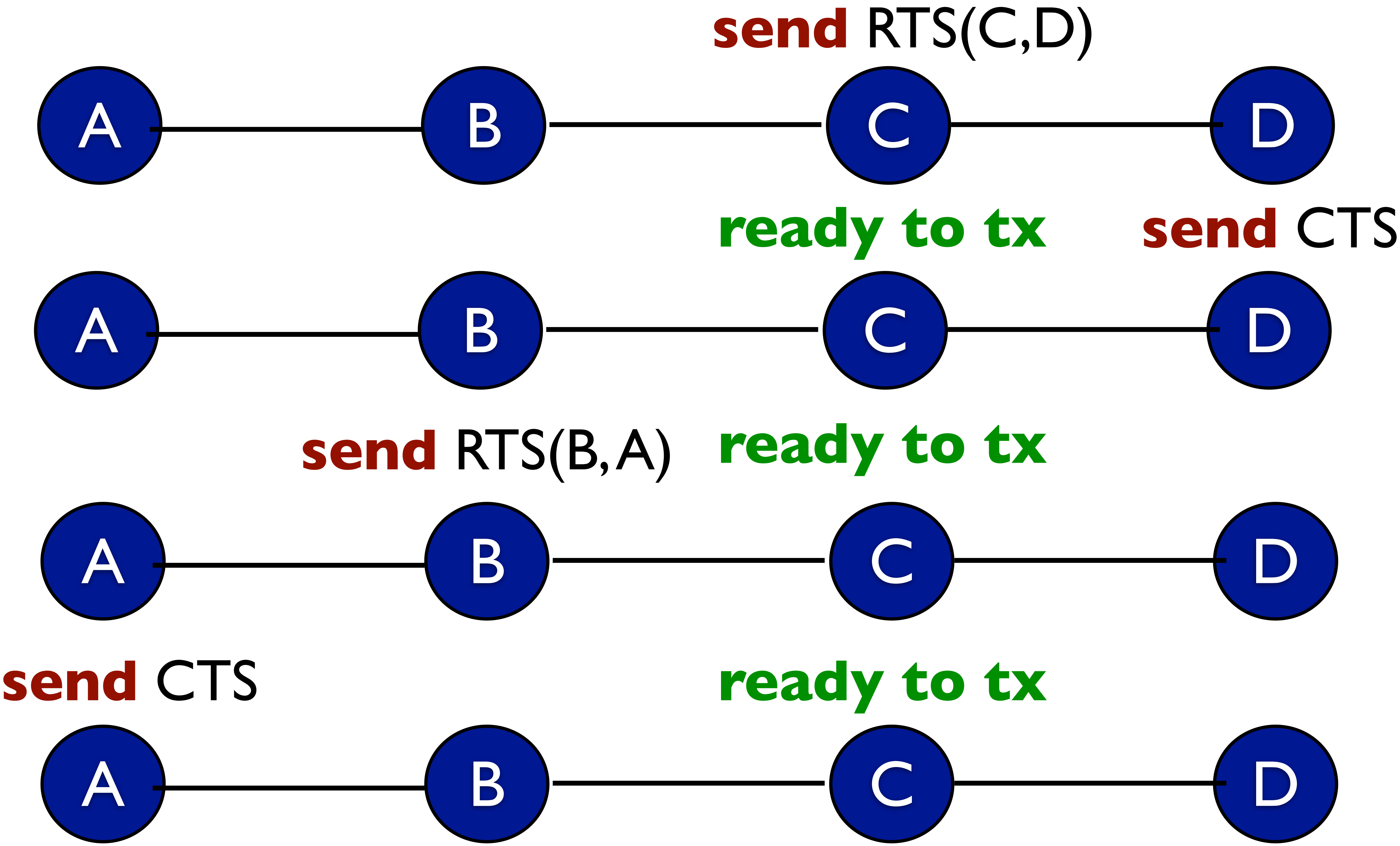

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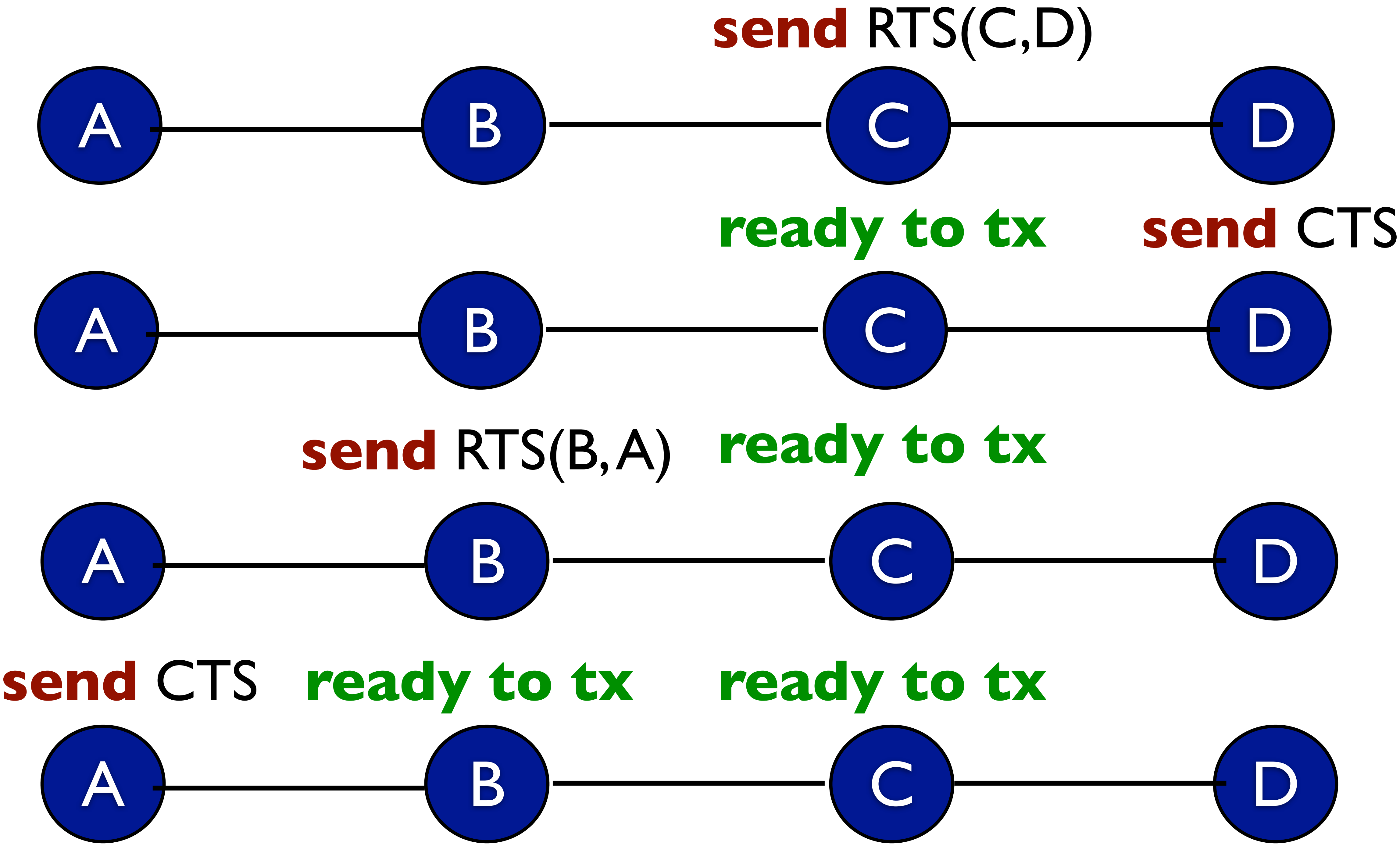
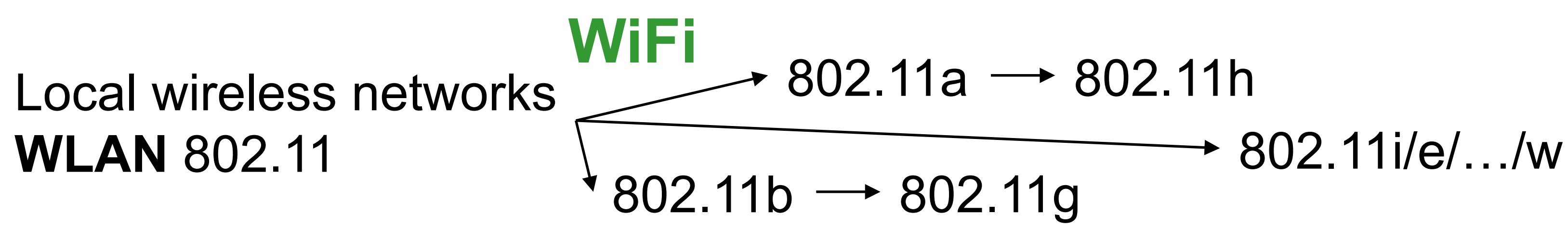


WLAN technology

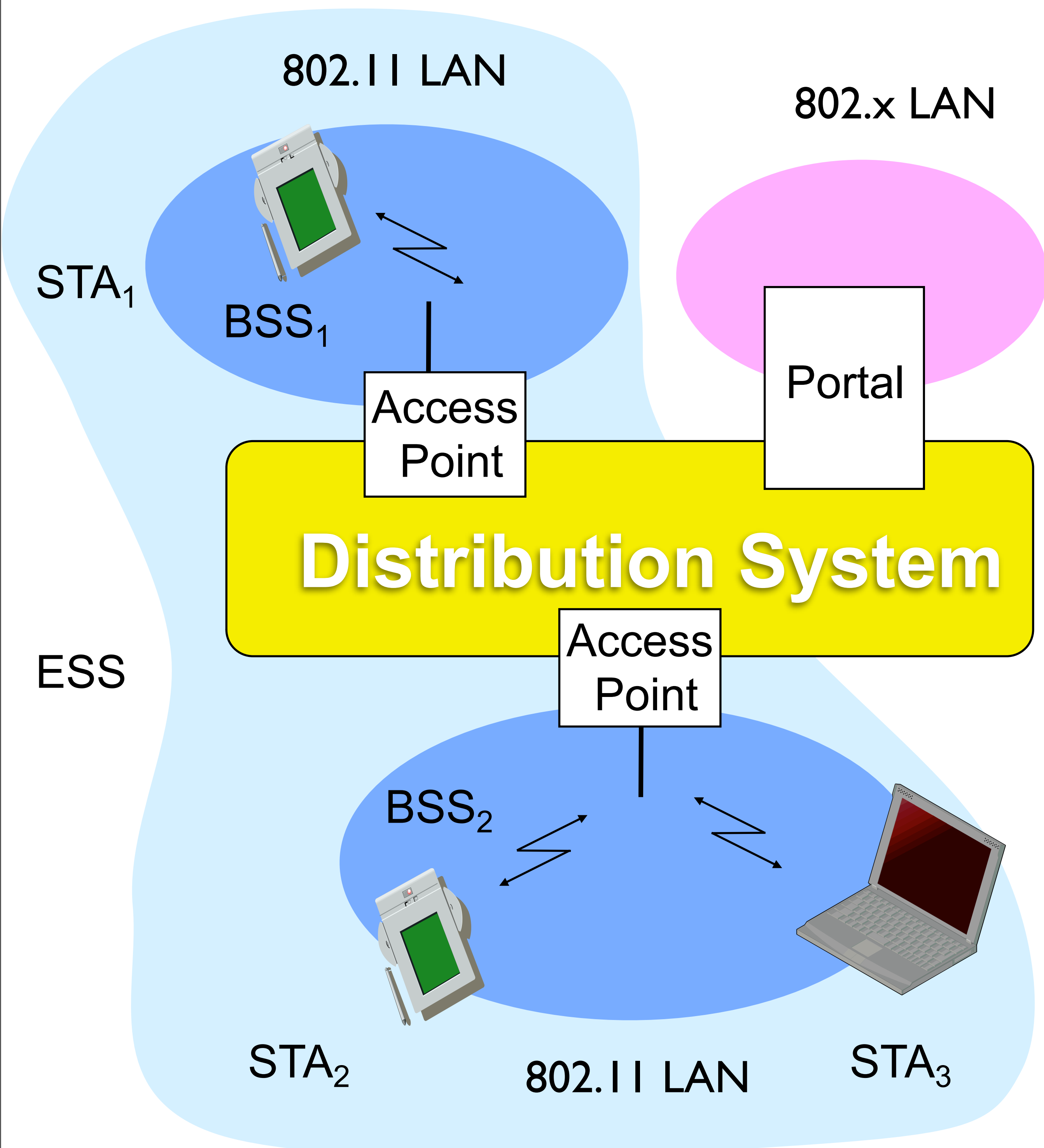
- **Protocol soup:**



- **Goals:**
  - seamless operation
  - leverage on existing wired infrastructure
  - low-power operation on stations

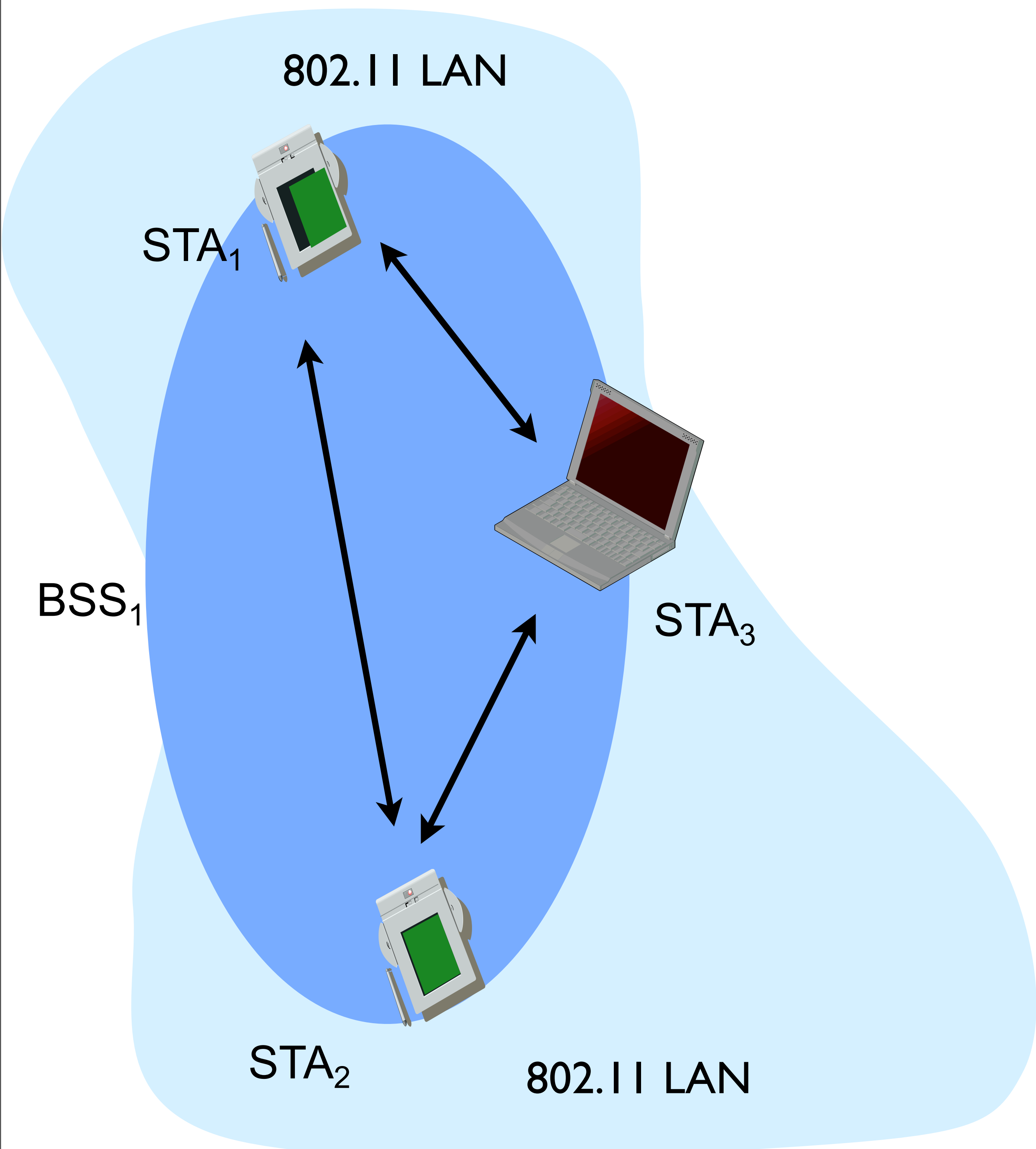
- **Two architectures: infrastructure + ad-hoc**

802.11: Architecture of an infrastructure network



- **Station (STA)**
  - terminal with wireless access mechanisms to contact the access point
- **Basic Service Set (BSS)**
  - group of stations using the same radio frequency
- **Access Point**
  - station integrated into the wireless LAN and the distribution system
- **Portal**
  - bridge to other (wired) networks
- **Distribution System**
  - interconnection network to/form one logical network

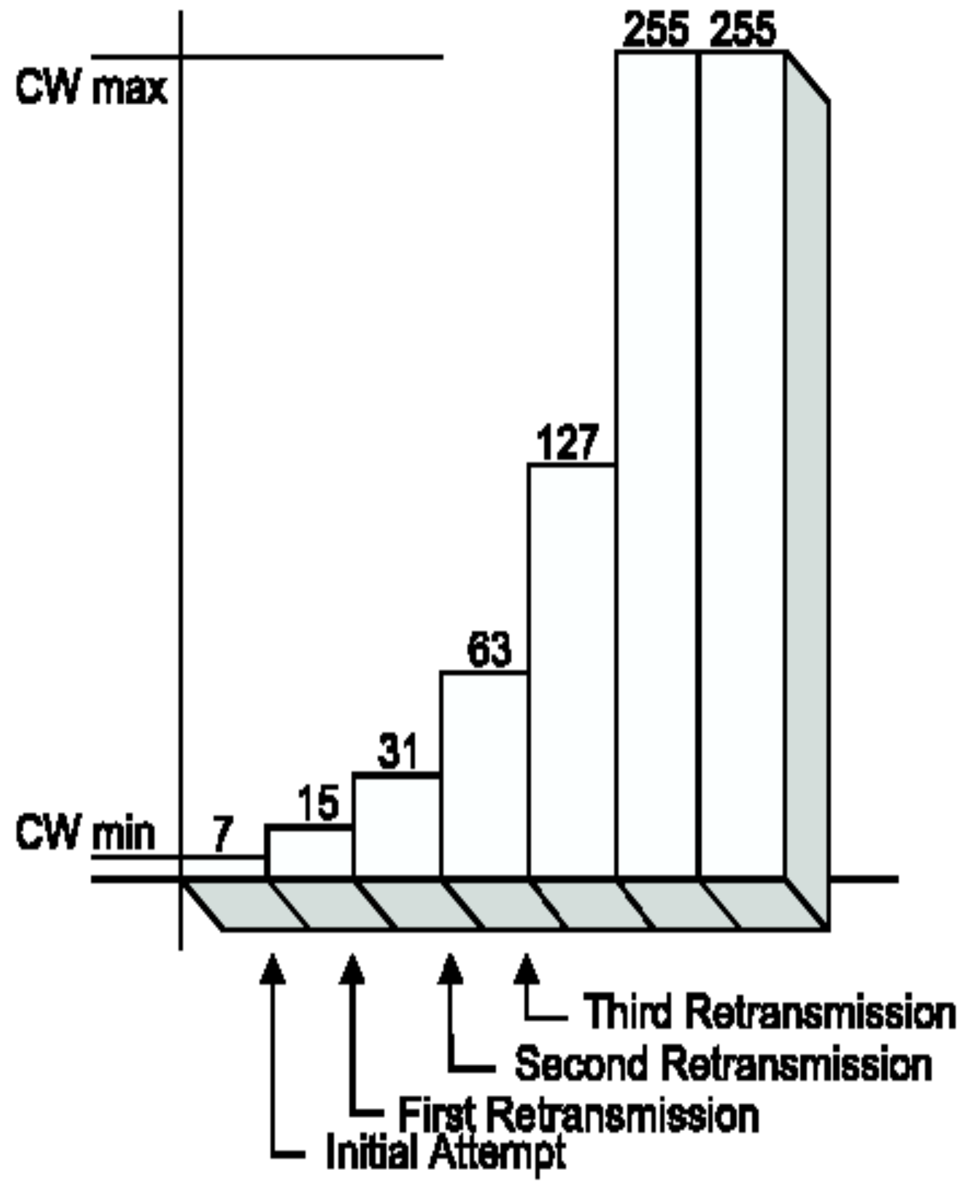
802.11: Architecture of an ad-hoc network



- **Direct communication within a limited range**
  - Station (STA): terminal with access mechanisms to the wireless medium
  - Independent Basic Service Set (IBSS): group of stations using the same radio frequency
- **When no direct link is feasible between two station, a third station may act as a relay (multi-hop communications)**

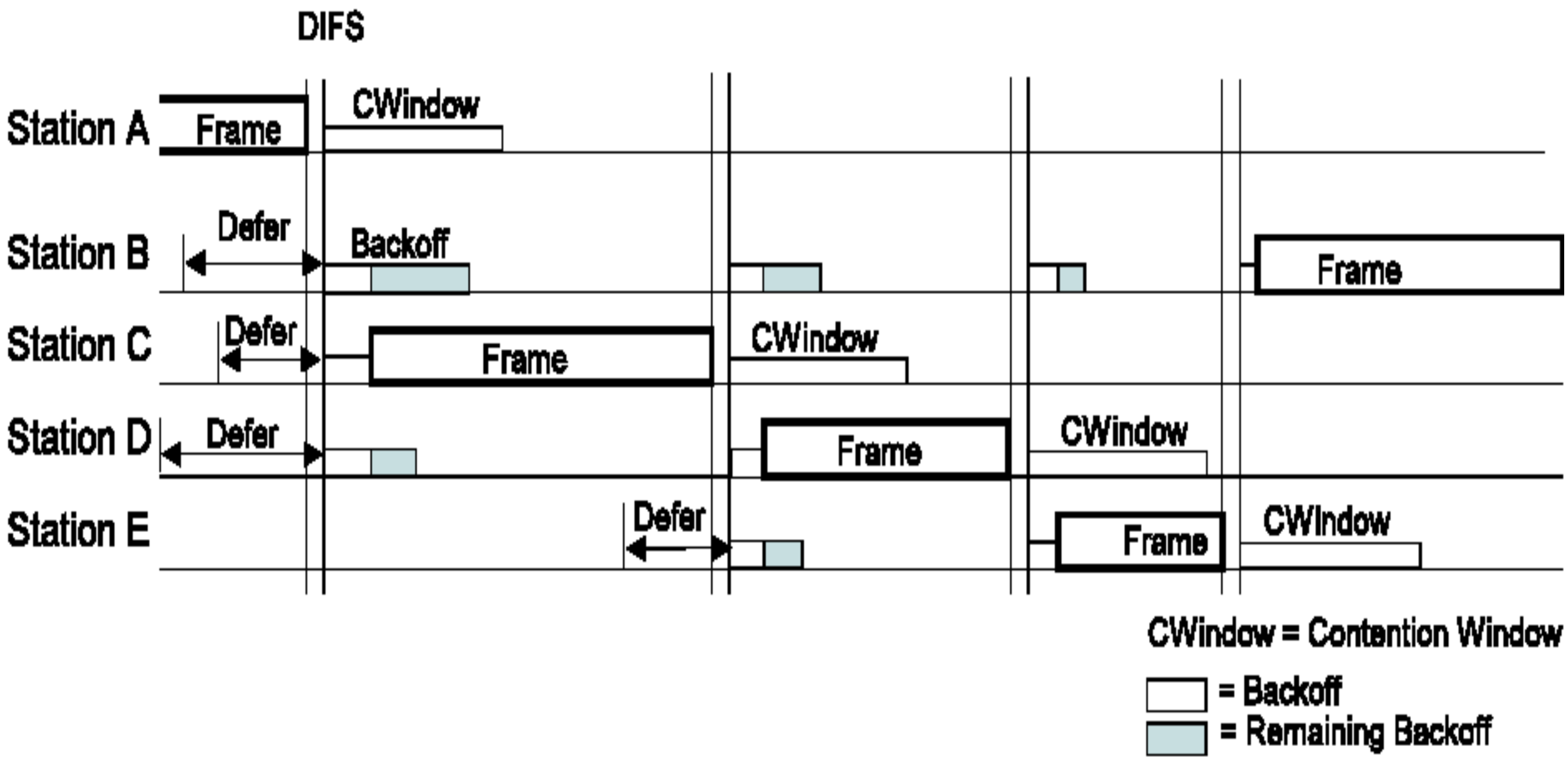
802.11b - Distributed Coordination Function

- **Exponential back-off**
  - Chosen for uniformly from (0, CW-1),
  - CW increase exponentially with the number of failed attempts
  - CW_{min} – minimum contention window
  - $CW_{max} = 2^m CW_{min}$ – maximum contention window



802.11b - Distributed Coordination Function

- Message resent when the backoff counter reaches zero
- Backoff counter decremented only when the channel is idle
- Backoff counter is reset to zero after a successful transmission



Routing

- **Routing consists of two fundamental steps**
  - Forwarding packets to the next hop (from an input interface to an output interface in a traditional wired network)
  - Determining how to forward packets (building a routing table or specifying a route)
- **Forwarding packets is easy, but knowing where to forward packets (especially efficiently) is hard**
  - Reach the destination
  - Minimize the number of hops (path length)
  - Minimize delay
  - Minimize packet loss
  - Minimize cost

Routing Decision Point

- **Source routing**
  - Sender determines a route and specifies it in the packet header
- **Hop-by-hop (datagram) routing**
  - A routing decision is made at each forwarding point (at each router)
  - Standard routing scheme for IP
- **Virtual circuit routing**
  - Determine and configure a path prior to sending first packet
  - Used in ATM (and analogous to voice telephone system)

Routing Table

- **A routing table contains information to determine how to forward packets**
  - Source routing: Routing table is used to determine route to the destination to be specified in the packet
  - Hop-by-hop routing: Routing table is used to determine the next hop for a given destination
  - Virtual circuit routing: Routing table used to determine path to configure through the network

Routing Approaches

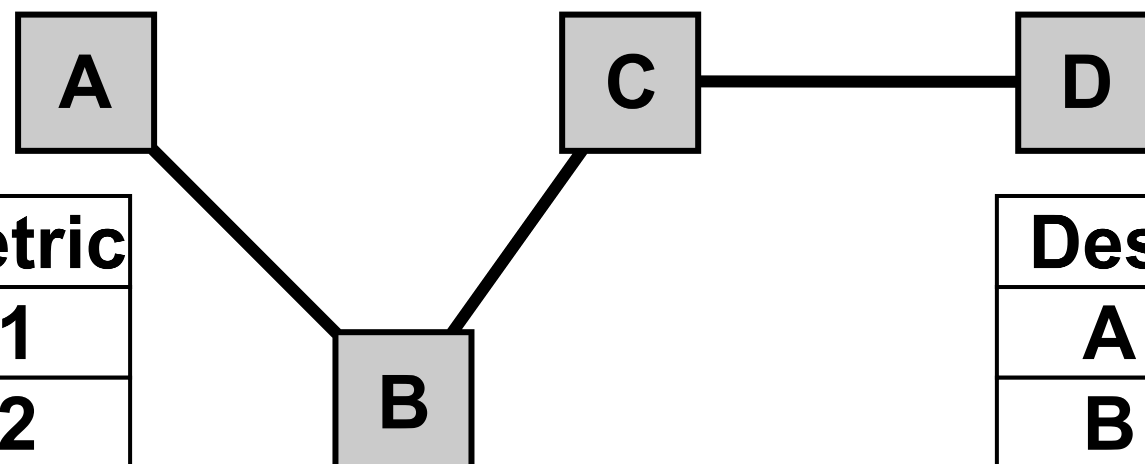
- **Reactive (On-demand) protocols**
  - discover routes when needed
  - source-initiated route discovery
- **Proactive protocols**
  - traditional distributed shortest-path protocols
  - based on periodic updates. High routing overhead
- **Tradeoff**
  - state maintenance traffic vs. route discovery traffic
  - route via maintained route vs. delay for route discovery

Distance Vector Algorithms (1)

- **"Distance" of each link in the network is a metric that is to be minimized**
  - each link may have "distance" 1 to minimize hop count
  - algorithm attempts to minimize distance
- **The routing table at each node…**
  - specifies the next hop for each destination
  - specifies the distance to that destination
- **Neighbors can exchange routing table information to find a route (or a better route) to a destination**

Distance Vector Algorithms (2)

Dest	Next	Metric
A	B	2
B	B	1
D	D	1



Dest	Next	Metric
B	B	1
C	B	2
D	B	3

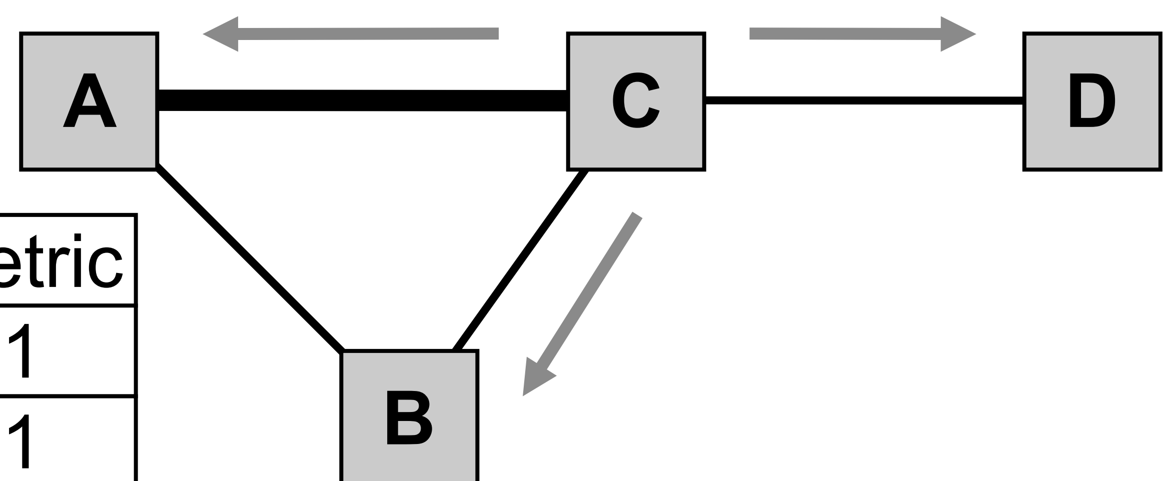
Dest	Next	Metric
A	A	1
C	C	1
D	C	2

Dest	Next	Metric
A	C	3
B	C	2
C	C	1

Distance Vector Algorithms (3)

- **Node A will learn of Node C's shorter path to Node D and update its routing table**

Dest	Next	Metric
A	A	1
B	B	1
D	D	1

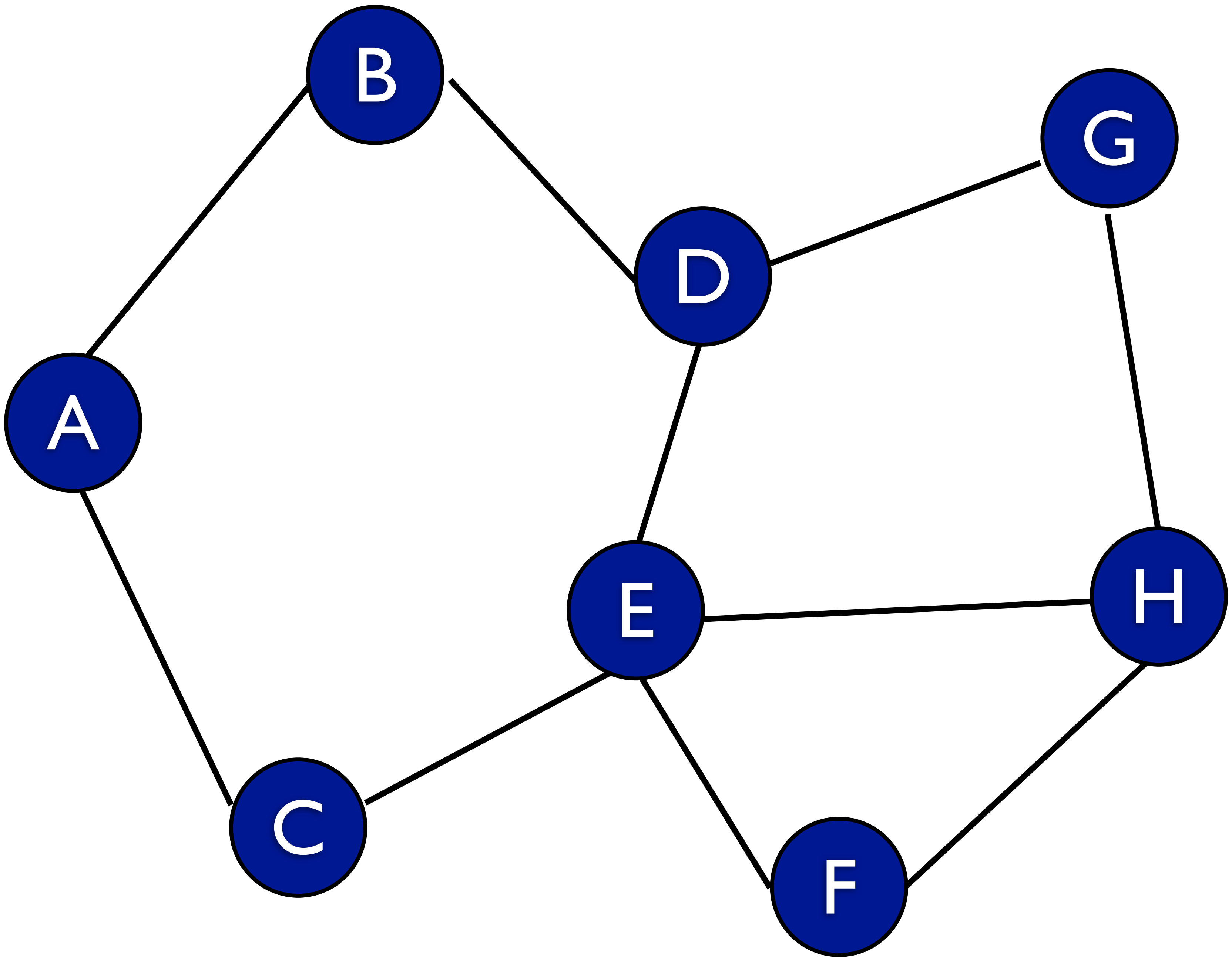


Dest	Next	Metric
B	B	1
C	C	1
D	C	2

Reactive Routing – Source initiated

- **Source floods the network with a route request packet when a route is required to a destination**
  - flood is propagated outwards from the source
  - pure flooding = every node transmits the request only once
- **Destination replies to request**
  - reply uses reversed path of route request
  - sets up the forward path

Route Discovery



RREQ FORMAT

Initiator
Initiator seq #
Destination
Partial Route

A-B-C

Route Request (RREQ)

A-B-C

Route Reply (RREP)

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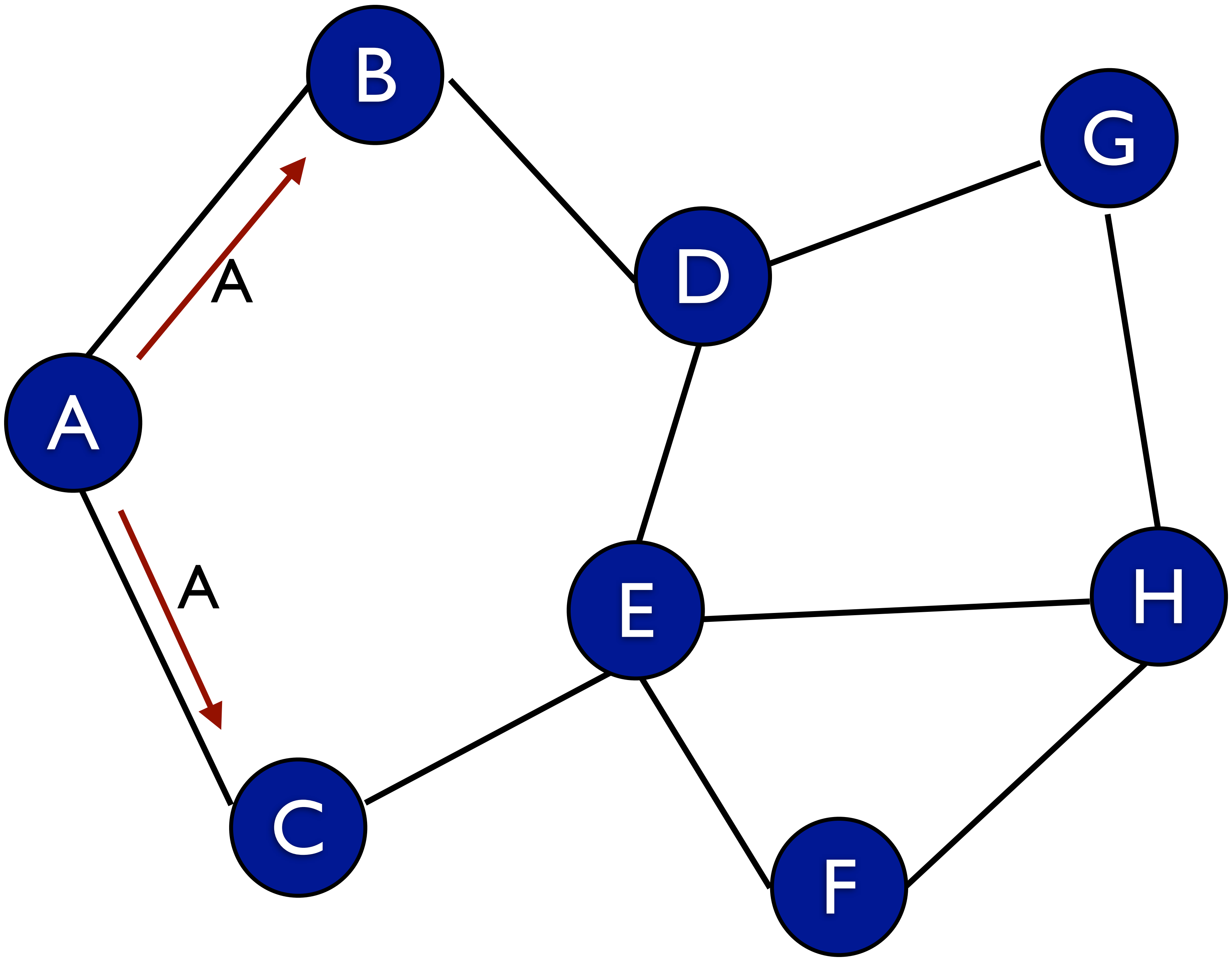

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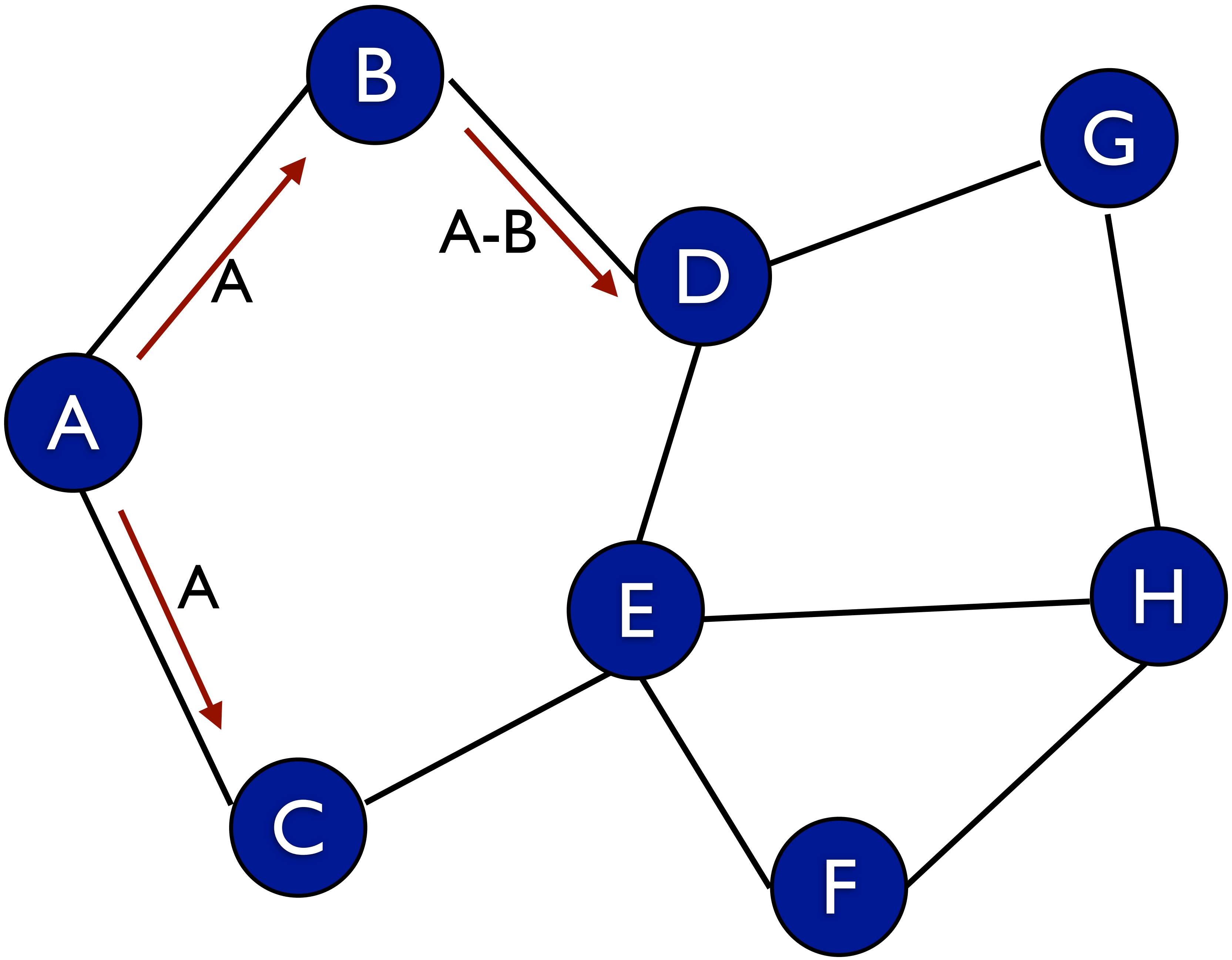

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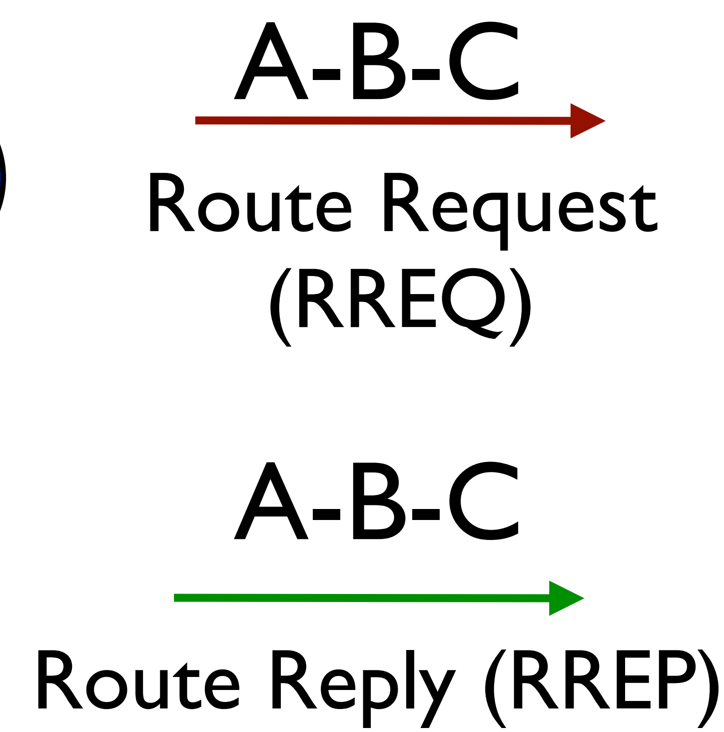

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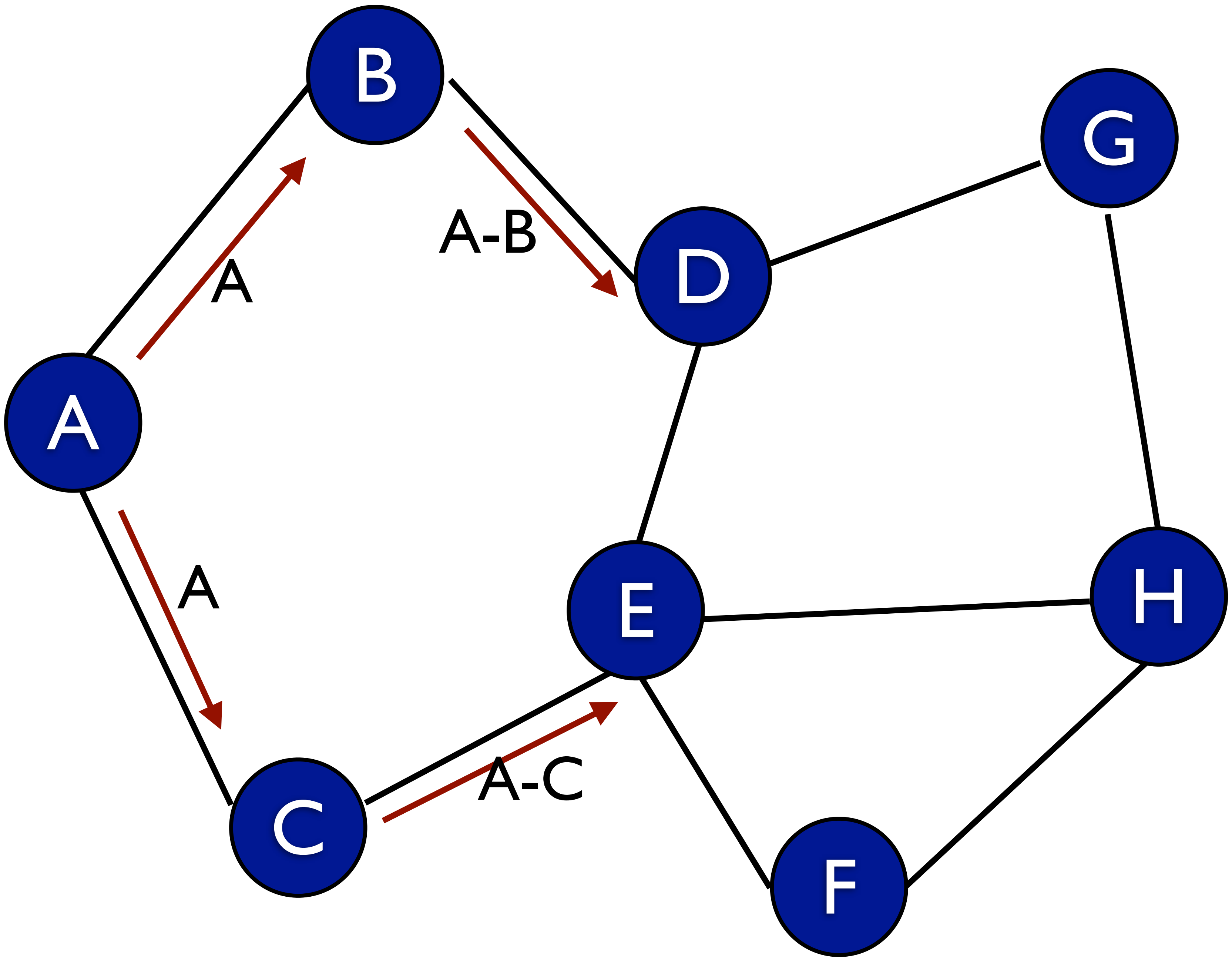

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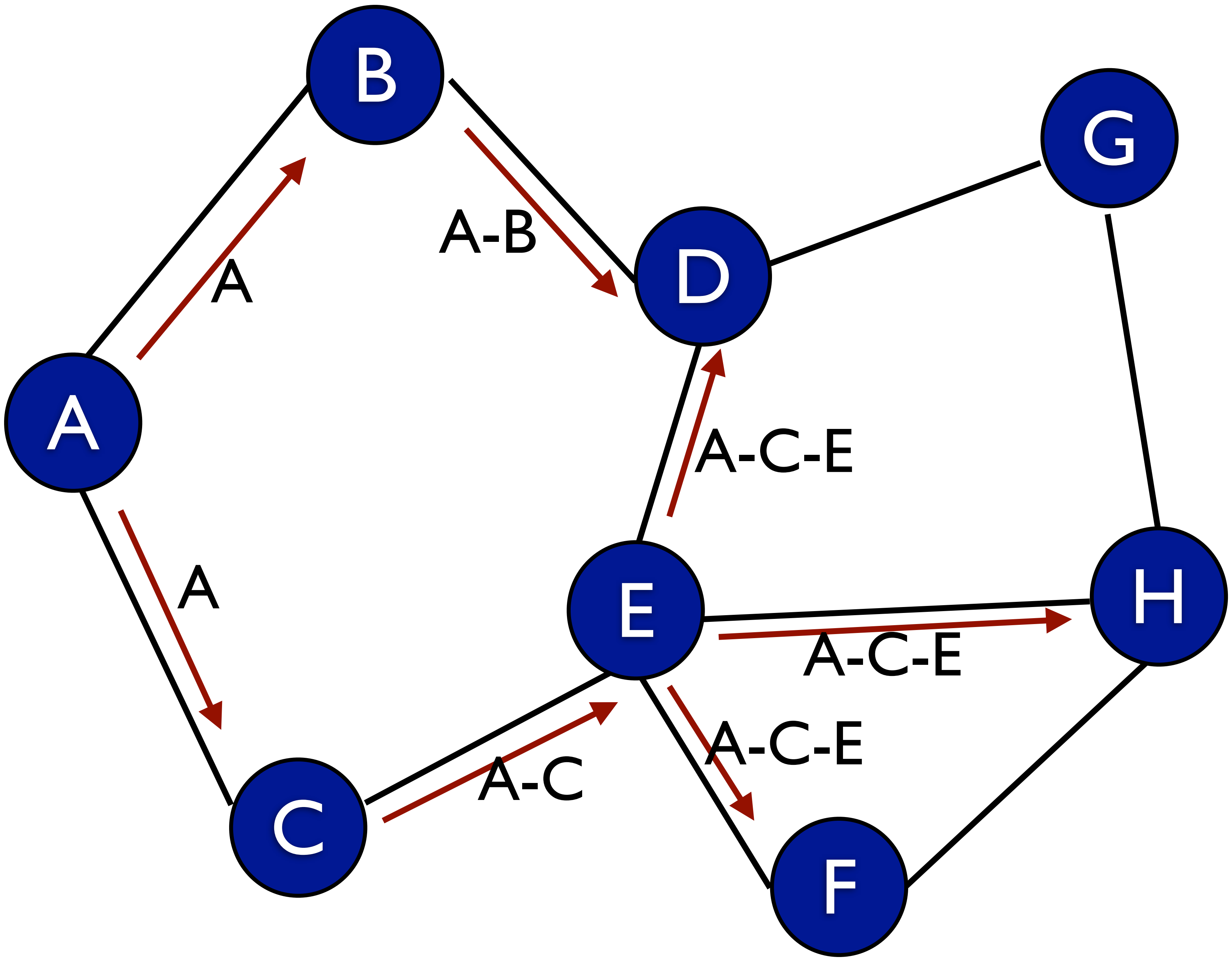

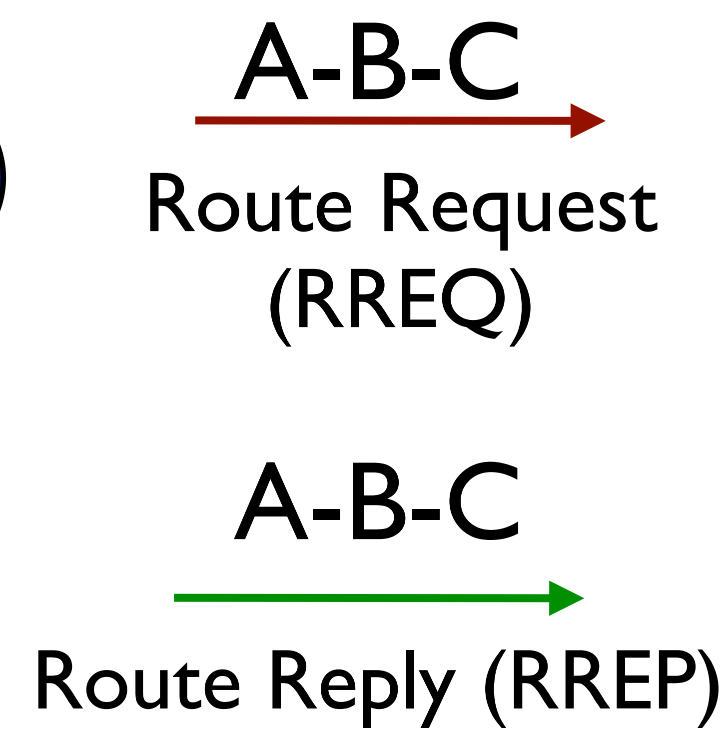

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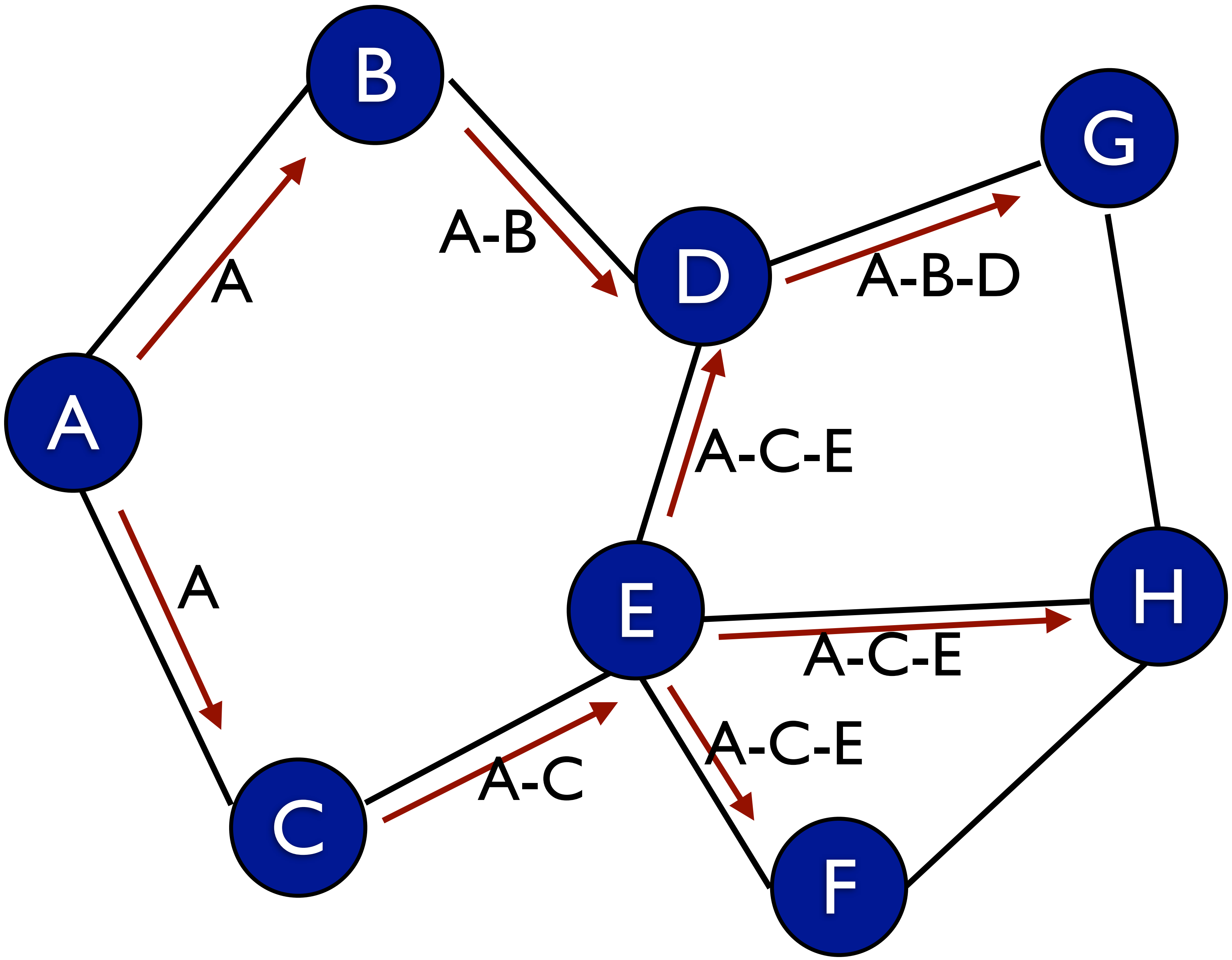

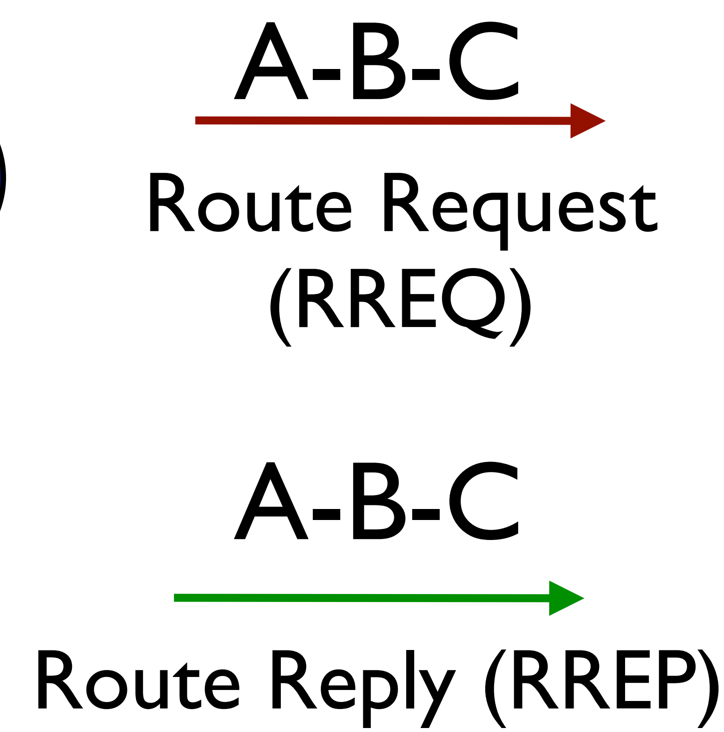

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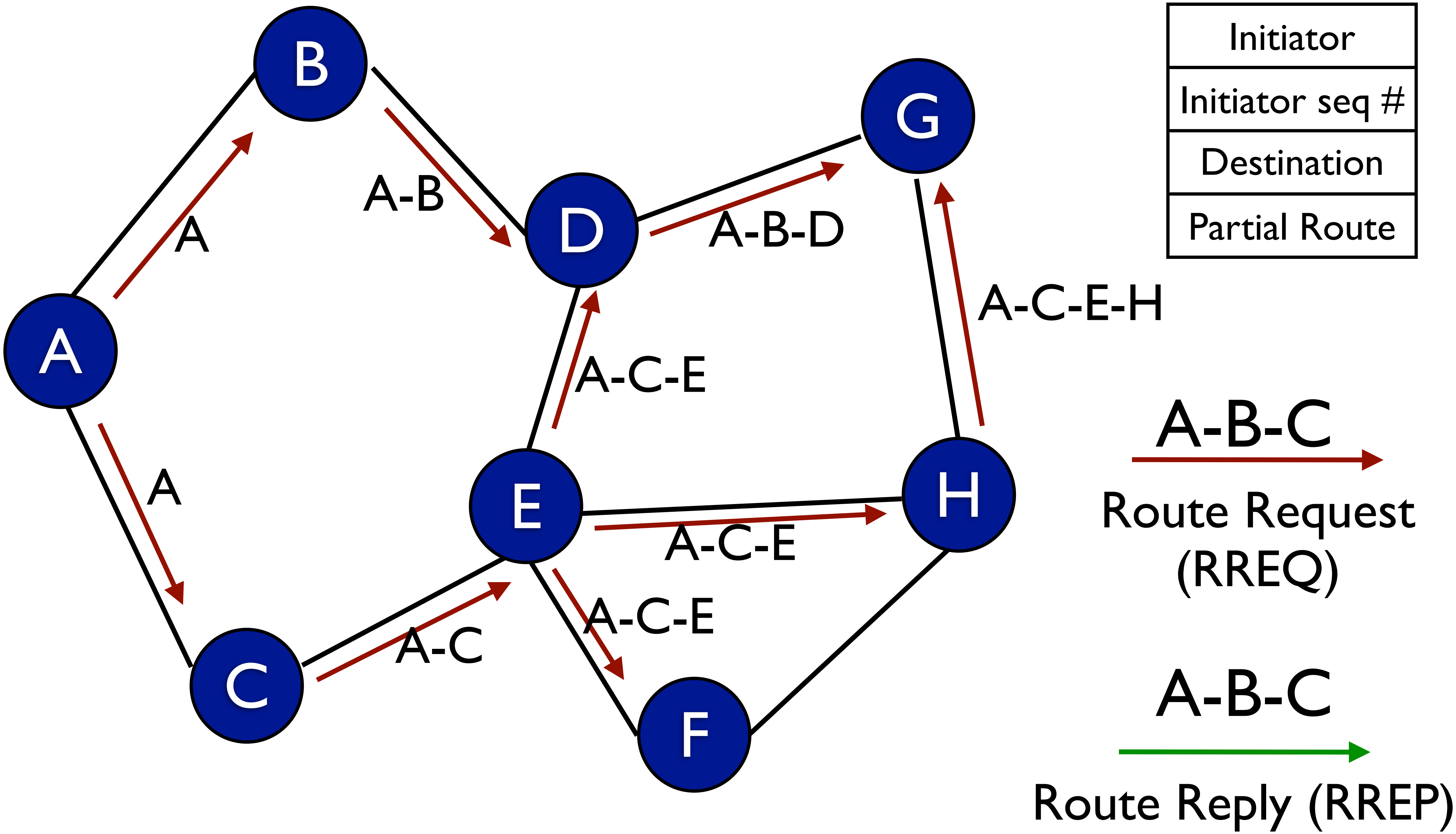

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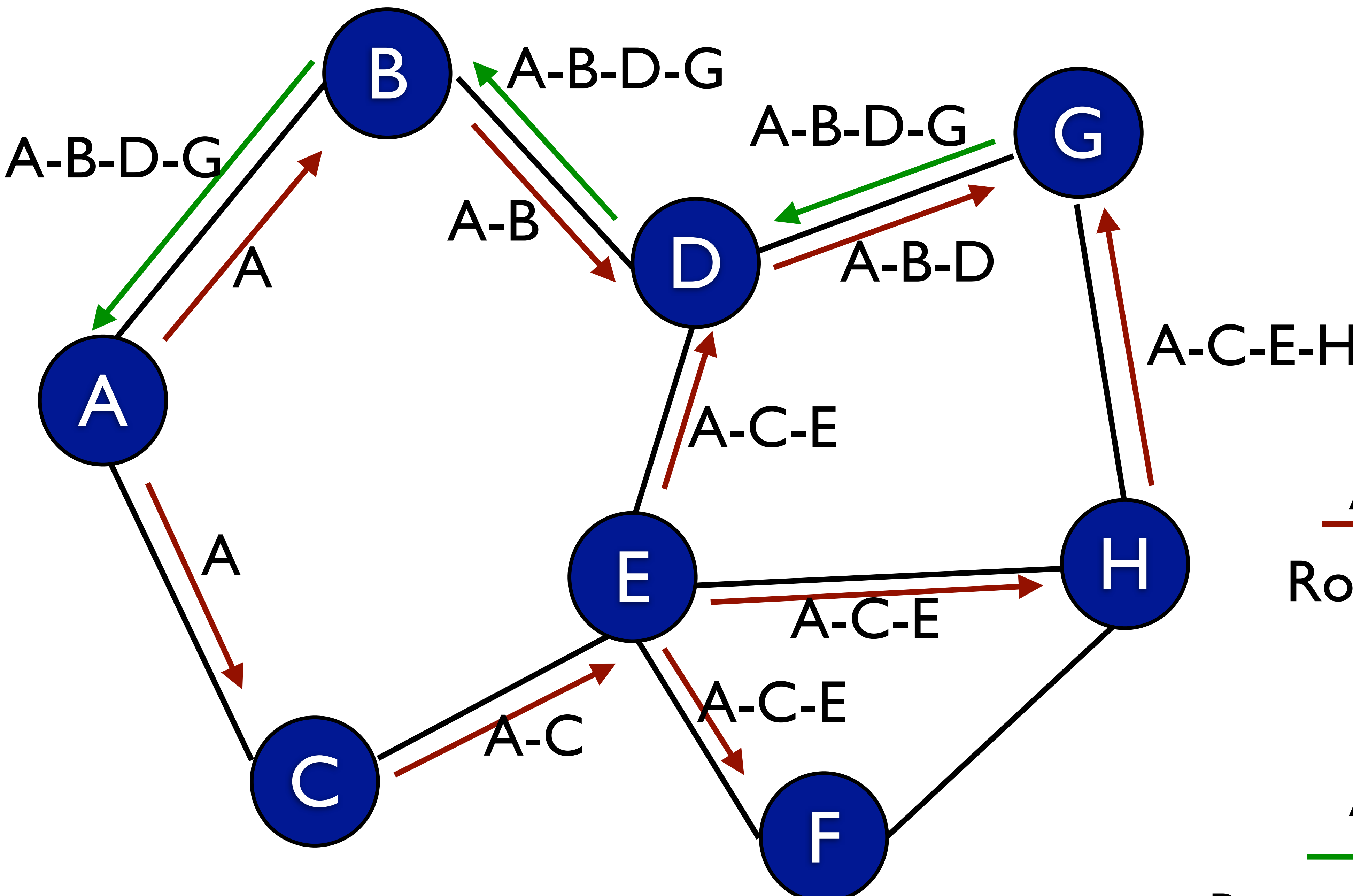

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Partial Route

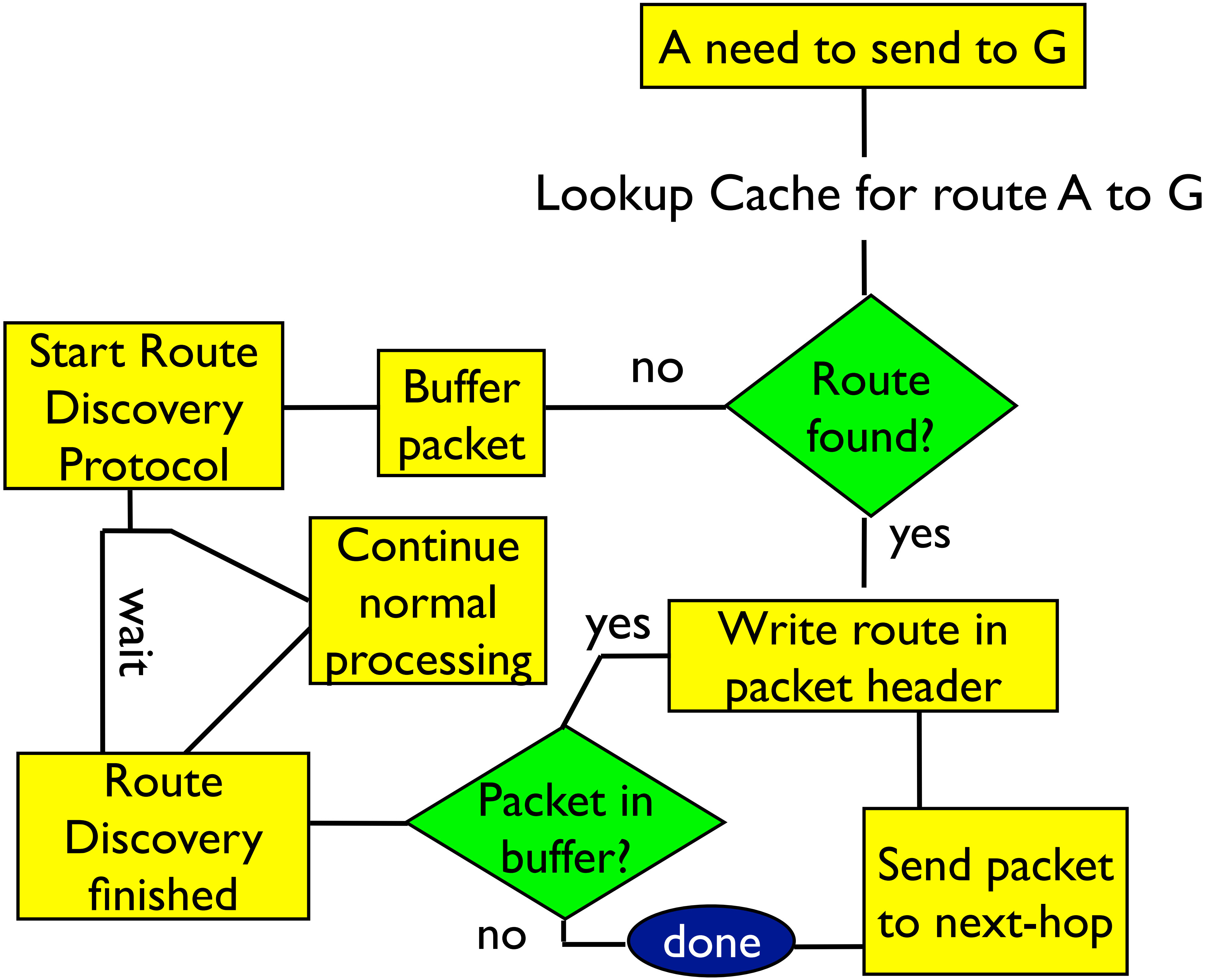
A-B-C

Route Request (RREQ)

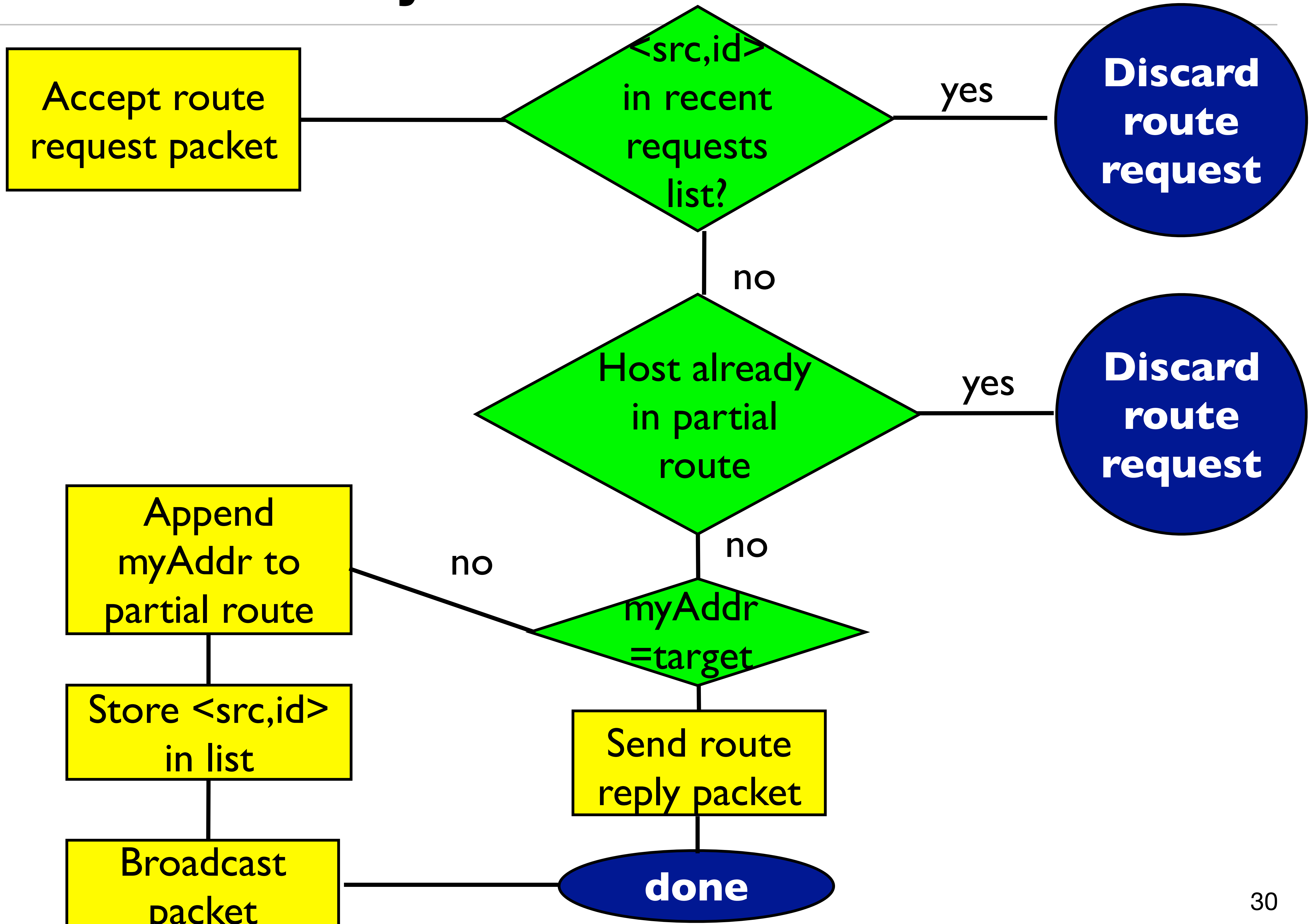
A-B-C

Route Reply (RREP)

Route Discovery: at source A



Route Discovery: At an intermediate node



Route Discovery

- **Route Reply message containing path information is sent back to the source either by**
  - the destination, or
  - intermediate nodes that have a route to the destination
  - reverse the order of the route record, and include it in Route Reply.
  - unicast, source routing
- **Each node maintains a Route Cache which records routes it has learned and overheard over time**

Route Maintenance

- **Route maintenance performed only while route is in use**
- **Error detection:**
  - monitors the validity of existing routes by passively listening to data packets transmitted at neighboring nodes
- **When problem detected, send Route Error packet to original sender to perform new route discovery**
  - Host detects the error and the host it was attempting;
  - Route Error is sent back to the sender the packet – original src