
University of Colorado Boulder

Fundamentals of Data Communications

IP Routing

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Review

Static Routing

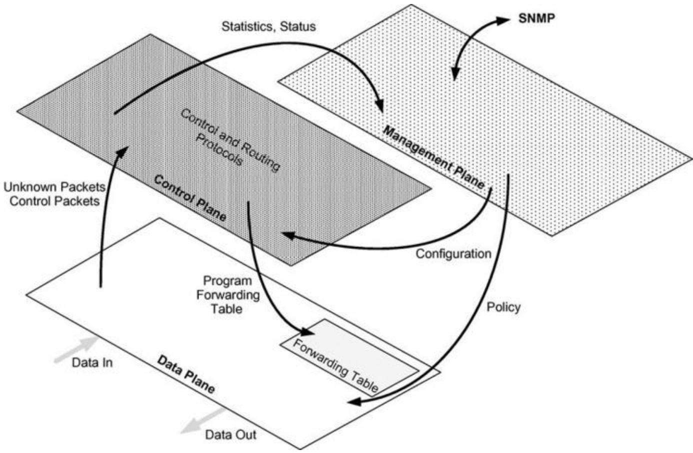
- **What is the purpose of routing?**

- **What is a static route?**

- **Static Routing vs Routing Protocols**
  - Manual
    - ***Administrative Overhead***
    - ***Scalability***
  - Static not dynamic
    - ***(failover)***

- **Routing Table**

Router

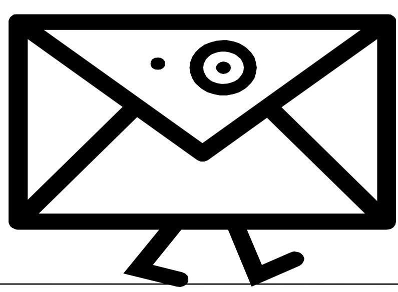


- **Inside a router**
  - Control plane: routing protocols
  - Data plane: packet forwarding
- **Path selection**
  - Minimum-hop/cost and shortest-path routing
  - Algorithms: Link-state vs. Distance vector routing
- **Topology change**
  - Using beacons to detect topology changes
  - Propagating topology information

What is Routing?

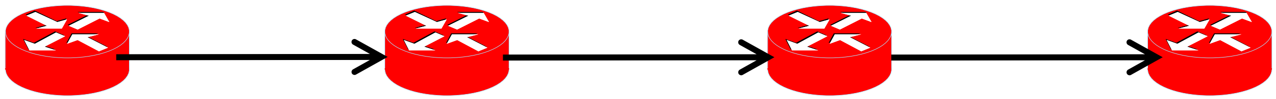
- **A famous quotation from RFC 791**

  "A *name* indicates what we seek.
  An *address* indicates where it is.
  A *route* indicates how we get there."
  -- Jon Postel

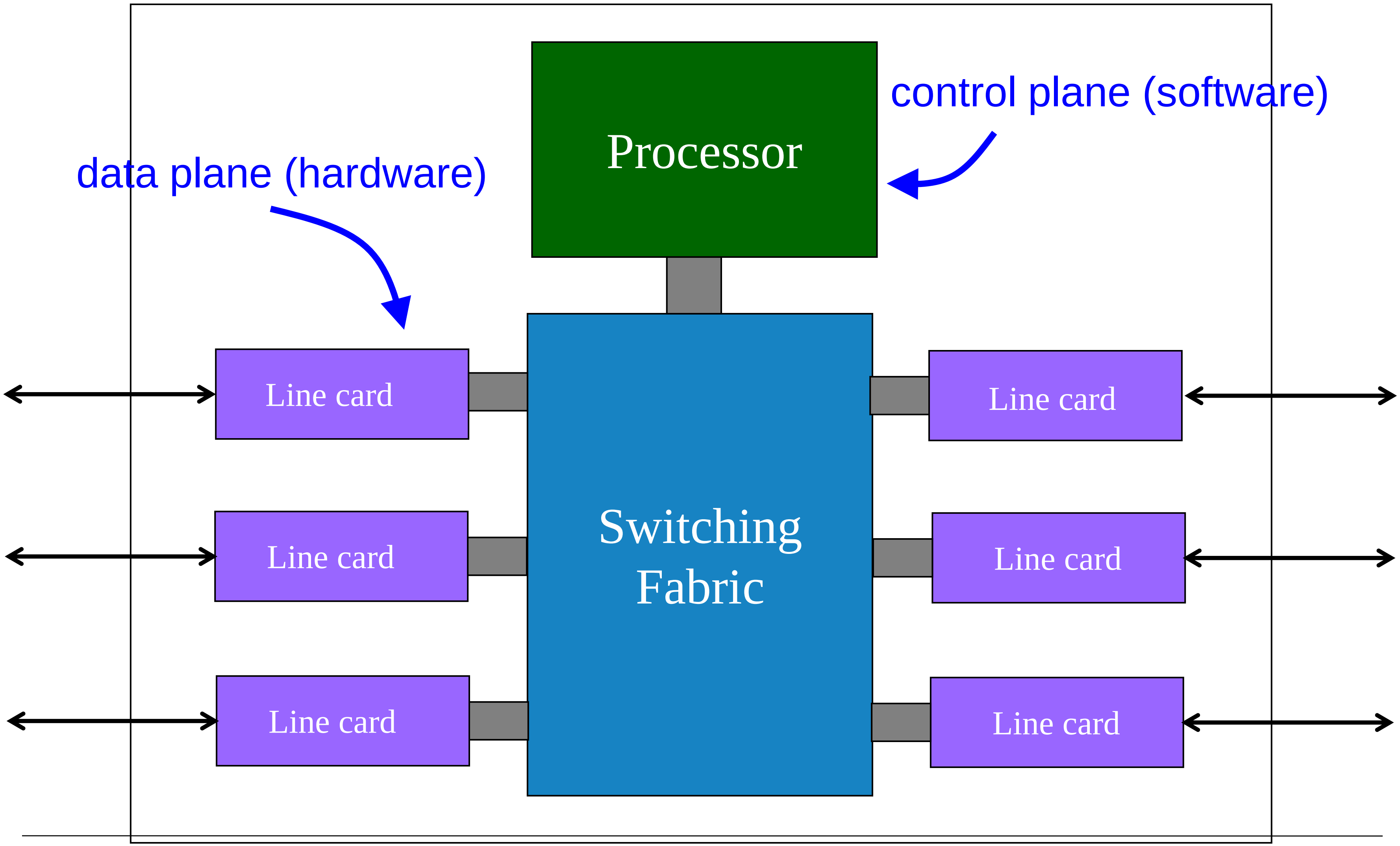


Routing vs. Forwarding

- **Routing: control plane**
  - Computing paths the packets will follow
  - Routers talking amongst themselves
  - Individual router *creating* a forwarding table
- **Forwarding: data plane**
  - Directing a data packet to an outgoing link
  - Individual router *using* a forwarding table



Data and Control Planes



Where do Forwarding Tables Come From?

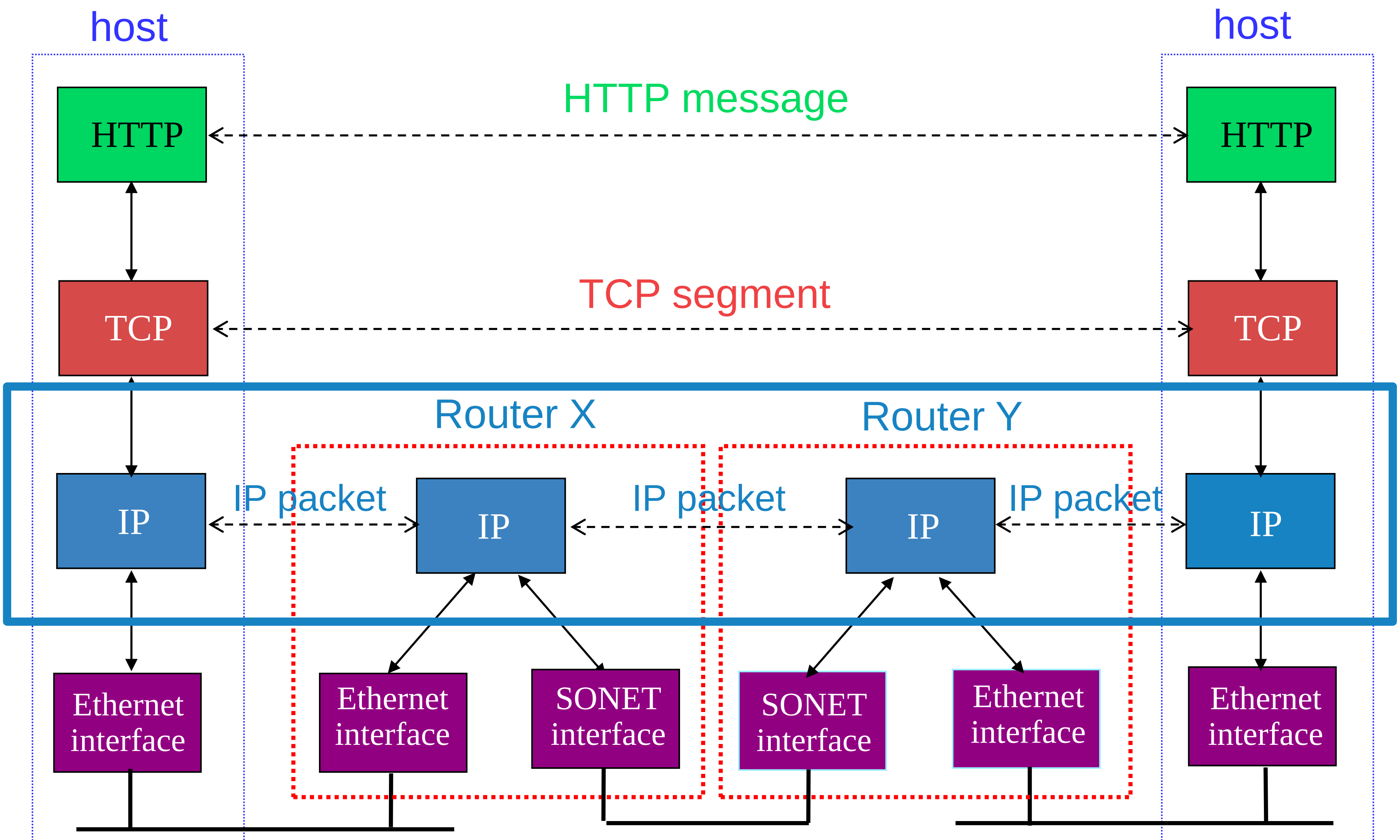
- **Routers have forwarding tables**
  - Map IP prefix (subnet) to outgoing link(s)

- **Entries can be statically configured**
  - E.g., “map 12.34.158.0/24 to fastethernet 0/0.1”

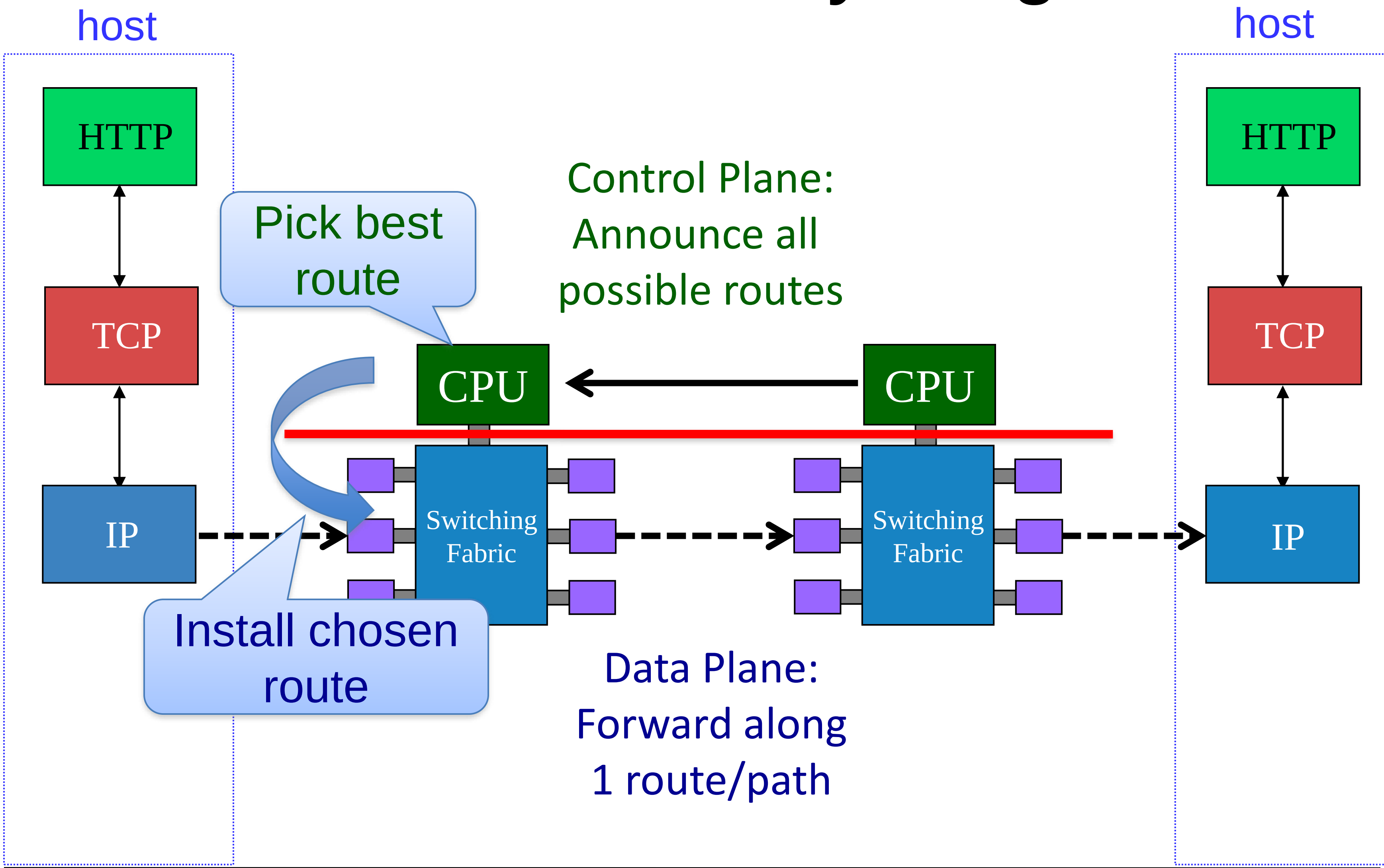
  - But, this doesn’t adapt
    - ***To failures***
    - ***To new equipment***
    - ***To the need to balance load***

  - That is where routing protocols come in!

Recall the Internet Layering Model

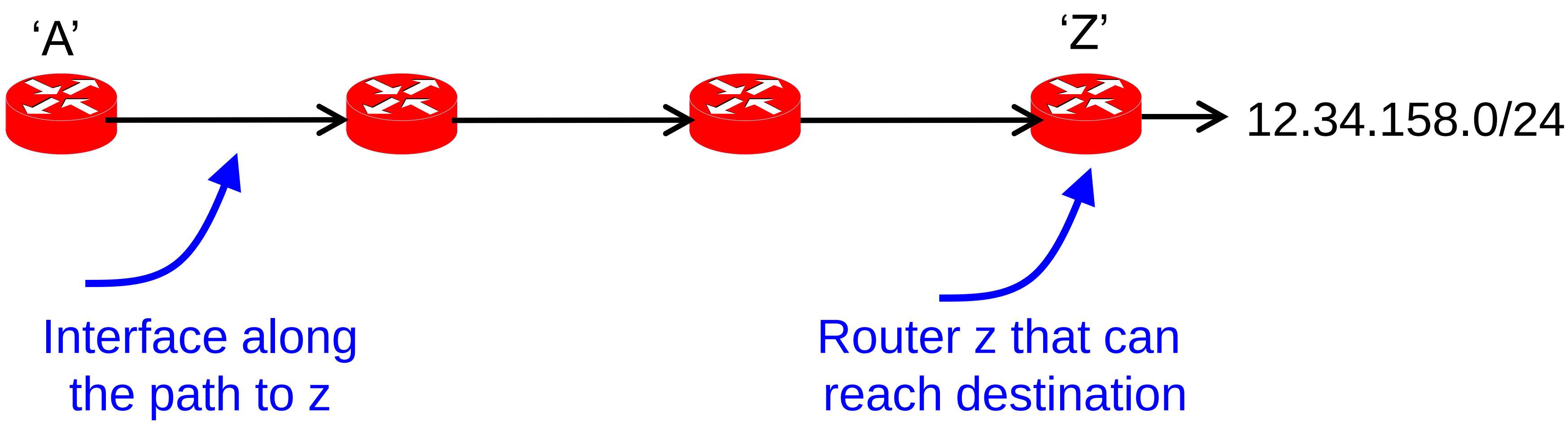


Recall the Internet Layering Model



Computing Paths Between Routers

- **Routers need to know two things:**
  1. Which router to use to reach a destination prefix
  2. Which outgoing interface to use to reach that router



Routers and Routing

- **Routing**
  - The process by which data/traffic gets from one location to another

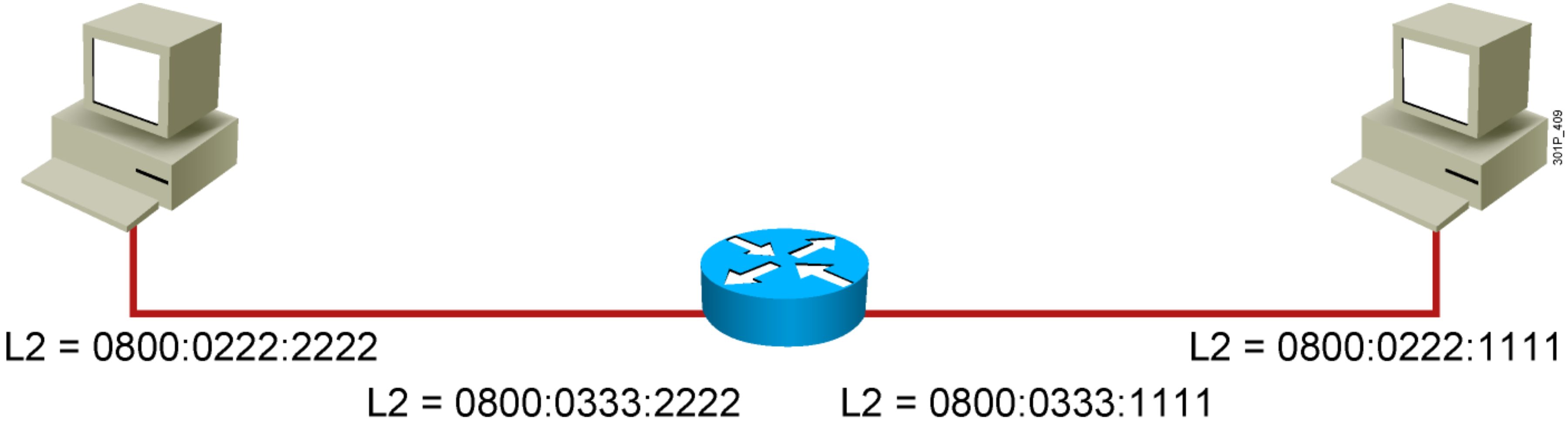
- **A router is the device used to route traffic**

- **Routers can forward packets over static routes or dynamic routes**
  - Based on the router configuration and network design

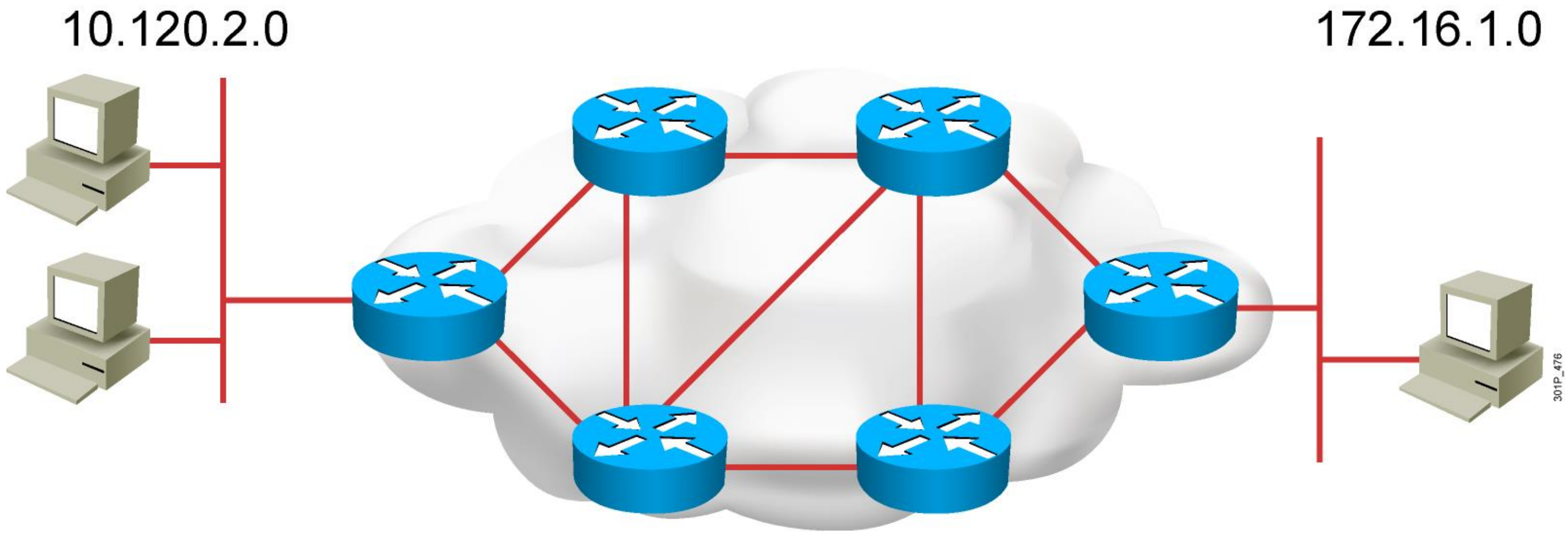
- **Static routes**
  - A route that a network administrator enters into the router manually
  - Unidirectional static routes must be configured **to** and **from** networks to allow bidirectional communications to occur

- **Dynamic routes**
  - A route that a network routing protocol adjusts automatically for topology or traffic changes

Layer 2 Addressing

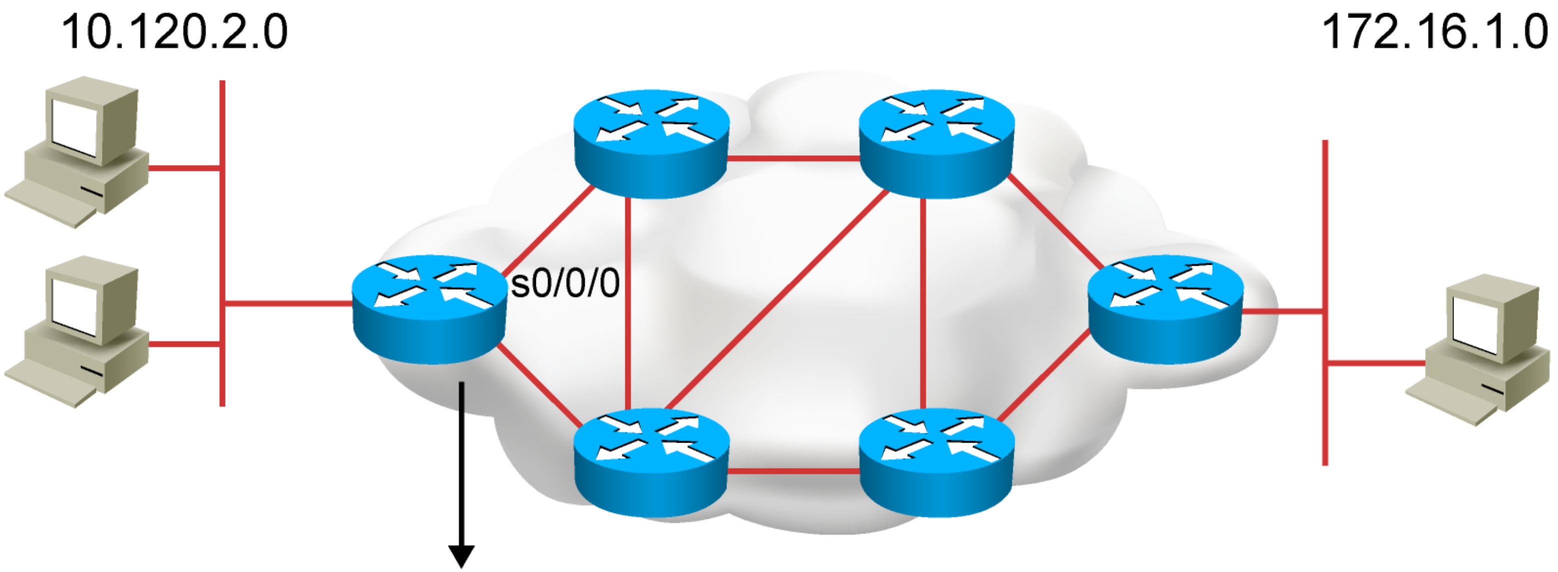


Router Operations



- **A router needs to do the following:**
  - Know the destination address
  - Identify the sources from which the router can learn
  - Discover possible routes to the intended destination
  - Select the best route
  - Maintain and verify routing information

Router Operations (Cont.)



Network Protocol	Destination Network	Exit Interface
Connected	10.120.2.0	fa0/0
Learned	172.16.1.0	s0/0/0

Routed Protocol: IP?

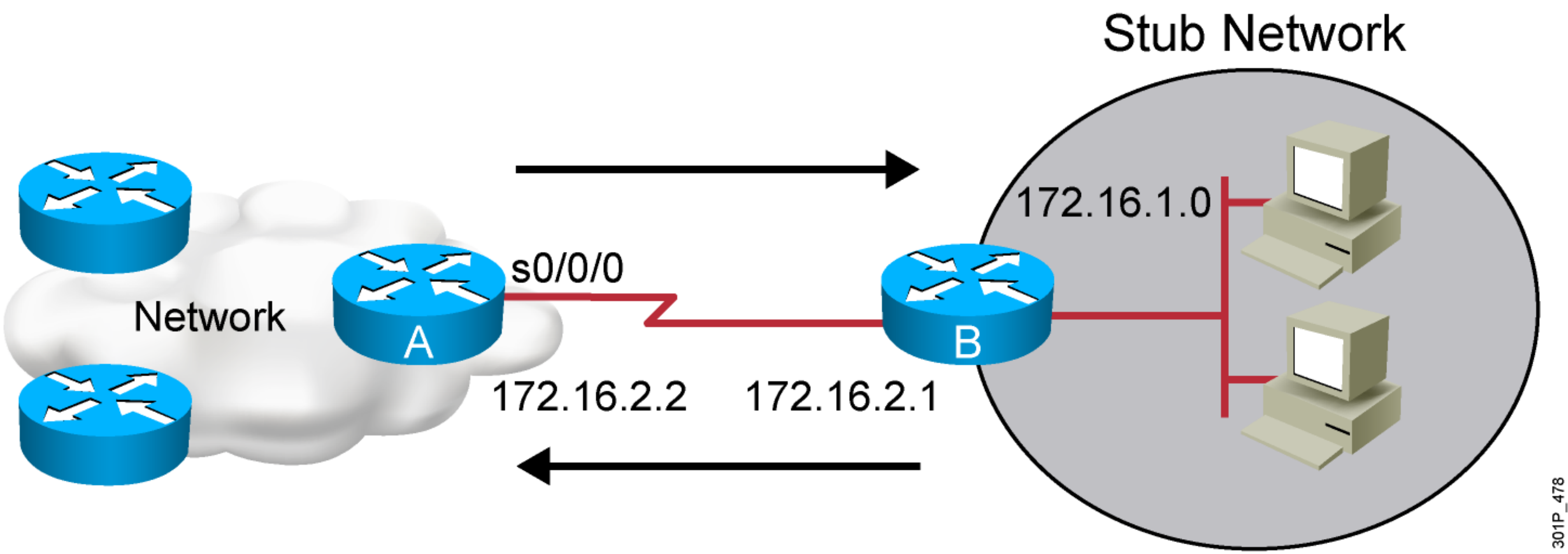
- Routers must learn destinations that are not directly connected
    - Routers automatically learn connected routes (if the interface is up!)

Identifying Static and Dynamic Routes

- **Static route**
  - Uses a route that a network administrator enters into the router manually

- **Dynamic route**
  - Uses a route that a network routing protocol adjusts automatically for topology or traffic changes

Static Routes



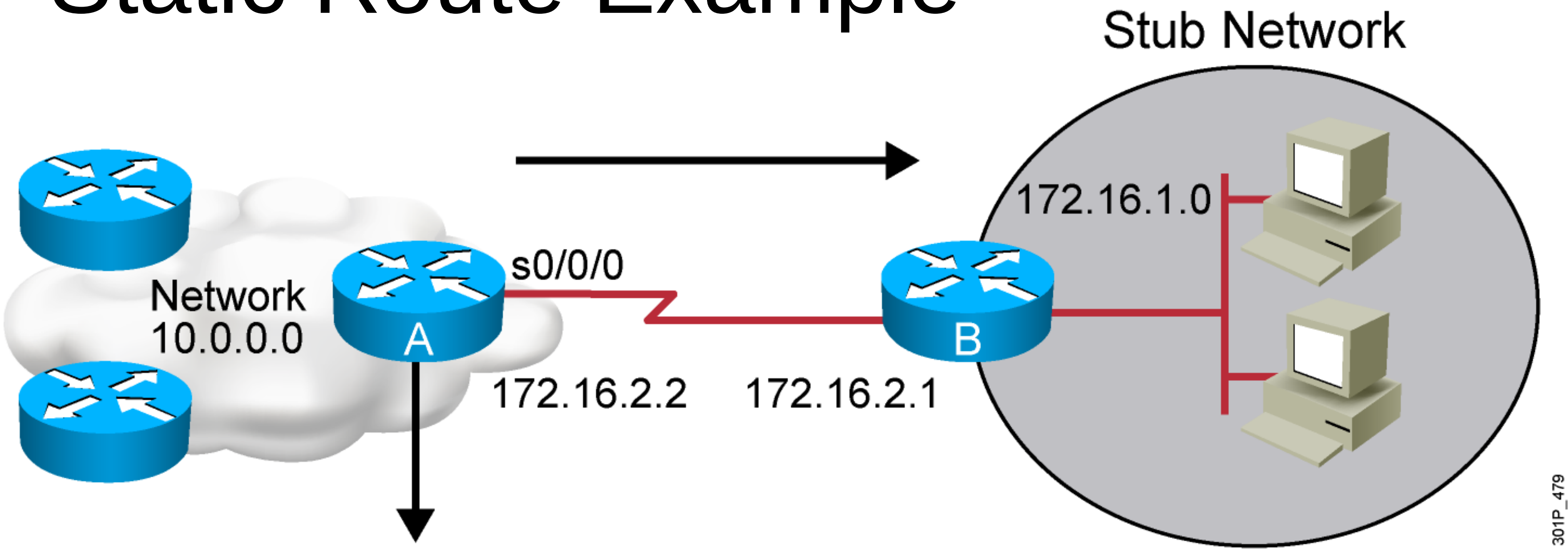
Configure unidirectional static routes **to** and **from** a network to allow communications to occur.

Static Route Configuration

```
(config)# ip route network  [mask]
{address | interface}[distance] [permanent]
```

- Defines a path to an IP destination network or subnet or host
- Address = IP address of the next hop router
- Interface = outbound interface of the local router
- Example:
  - ***ip route 192.168.1.0   255.255.255.0 192.168.222.254***

Static Route Example



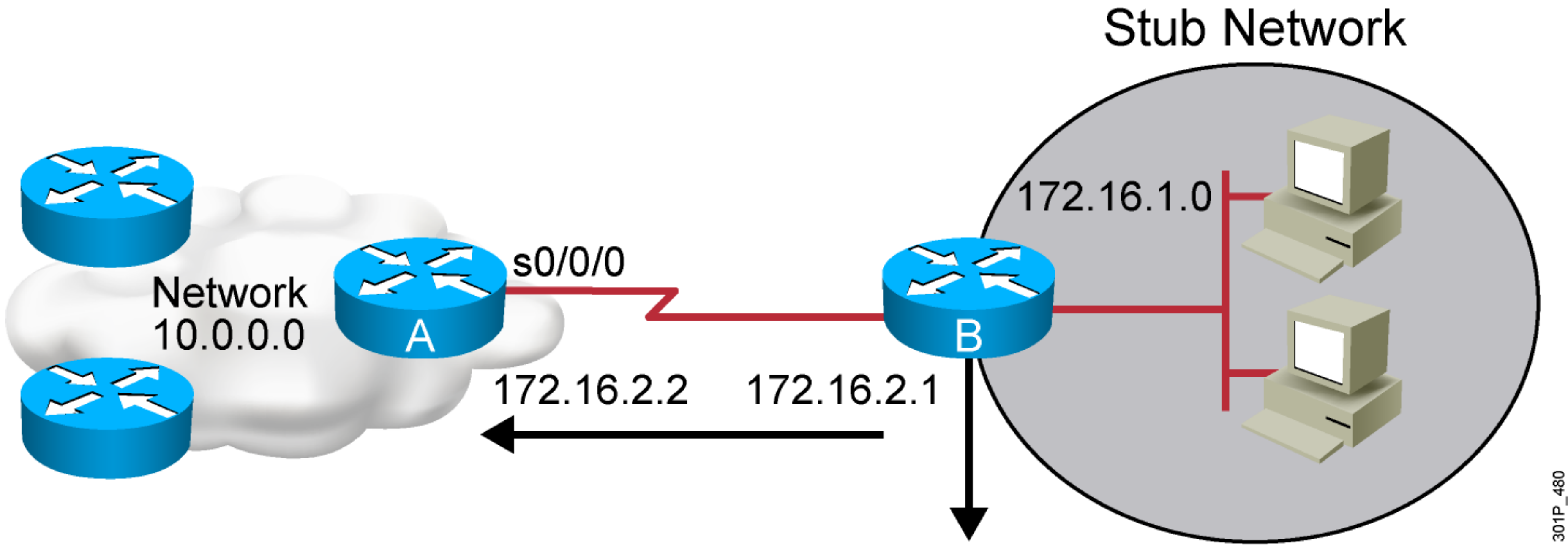

```
(config)# ip route 172.16.1.0 255.255.255.0 172.16.2.1
```

or

```
(config)#ip route 172.16.1.0 255.255.255.0 s0/0/0
```

- This is a unidirectional route.
- You must have a route configured in the opposite direction for traffic to return.

Default Routes




```
RouterX(config)# ip route 0.0.0.0 0.0.0.0 172.16.2.2
```

- This route allows the “stub network” (behind RouterB) to reach all networks beyond Router A.

Verifying the Static Route Configuration

- **Route Table**

```
RouterX# show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route

Gateway of last resort is 0.0.0.0 to network 0.0.0.0

     10.0.0.0/8 is subnetted, 1 subnets
C       10.1.1.0 is directly connected, Serial0/0/0
S*   0.0.0.0/0 is directly connected, Serial0
```

P2P with Internet

Floating Static Routes

Dynamic Routing

Overview and Terminology

– Think beyond directly connected devices

– “Network Map” and Routing tables

– Static Routes (type the Internet)
  - ***Nearly 1 million routes!***

– ***Routing* protocols**: Propagate information about available networks

– ***Routed* protocols**: L3 protocols that can be routed (IP)

Overview and Terminology

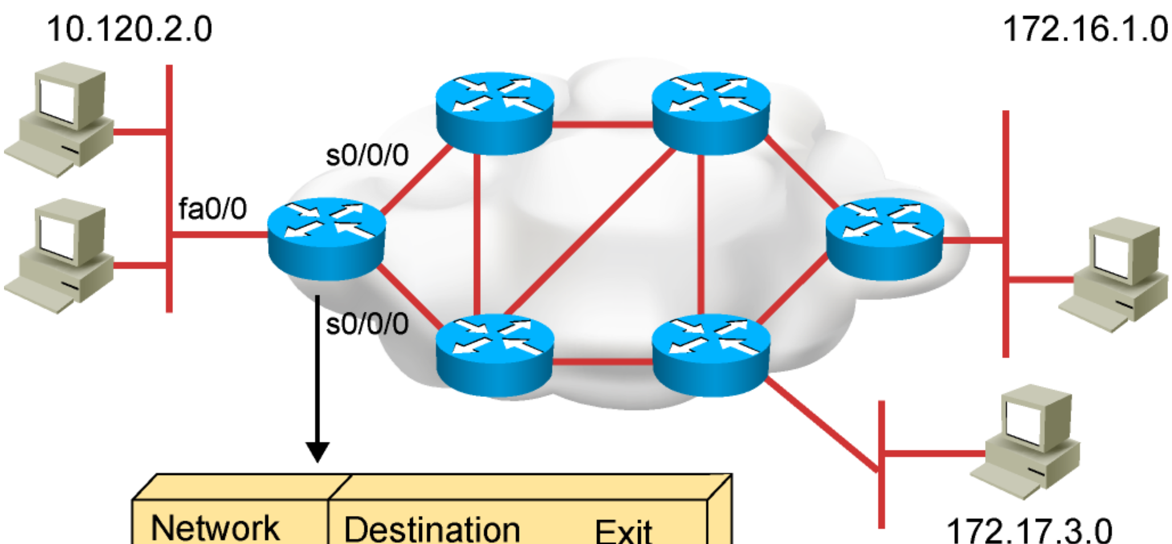
- ***Routing type***: Link State vs. Distance Vector vs. Path Vector
- ***Exterior Routing Protocols (EGP)***: Inter-corporate route distribution
- ***Interior Routing Protocols (IGP)***: Intra-corporate route exchange
- ***Autonomous System (AS)***: Network under single management control (ISP)

Routing Objectives

- Build a routing table (learn & propagate)
- Pick best routes (if more than one available)
- Remove invalid routes
- Replace routes if better advertisement received
- Restore routes fast (convergence time)
- Prevent loops

What is a Routing Protocol?

- **Routing** protocols are used between routers to determine paths and maintain routing tables.
- After the path is determined, a router can route a **routed** protocol.

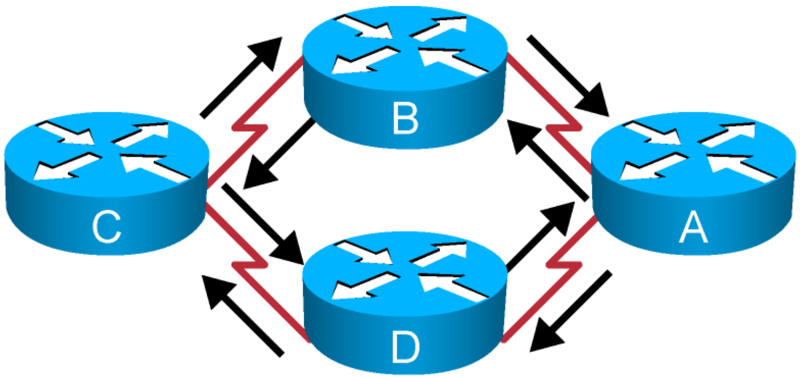


Network Protocol	Destination Network	Exit Interface
Connected	10.120.2.0	fa0/0
RIP	172.16.1.0	s0/0/0
EIGRP	172.17.3.0	s0/0/0

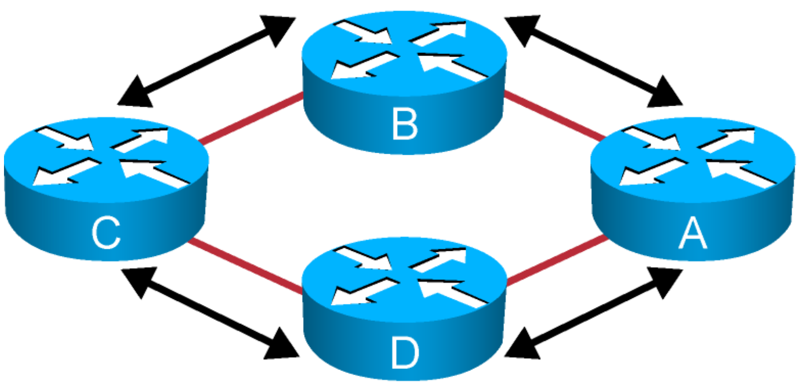
Routed Protocol: IP
Routing Protocol: RIP, EIGRP

Classes of Routing Protocols

Distance Vector



Hybrid Routing



Link-State

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Interior Gateway Routing Protocols (IGP)

- Several available in the market. Protocols have evolved over time to respond to changing network conditions

- Considerations while choosing a protocol:
  - **Type of routing protocol**
    - ***Distance vector***
    - ***Link-state***
    - ***Hybrid***
  - **Update process**
    - ***Full updates***
    - ***Partial updates***
  - **Convergence time**
  - **Metric**
    - ***Measure of link quality / preference***
  - **VLSM support**
    - ***Subnet size variations***
    - ***Permit better address allocation***
  - **Classless vs. Classful**
    - ***TX or Not TX mask info***
    - ***If TX then VLSM supported***

Distance Vector Protocols

- **Distance Vector Logic**
  - Add directly connected
  - Send updates out include directly connected and learned routes
    - ***"Routing by Rumor"***
  - Listen for routing updates
  - Routing info: subnet & metric
  - Use broadcast or multicast for updates
  - Chose best of multiple routes
  - Send/expect periodic full updates
  - If updates no longer received, remove routes learned from such neighbor
  - Assume that the advertising router is the next hop for a route

Distance Vector Protocols

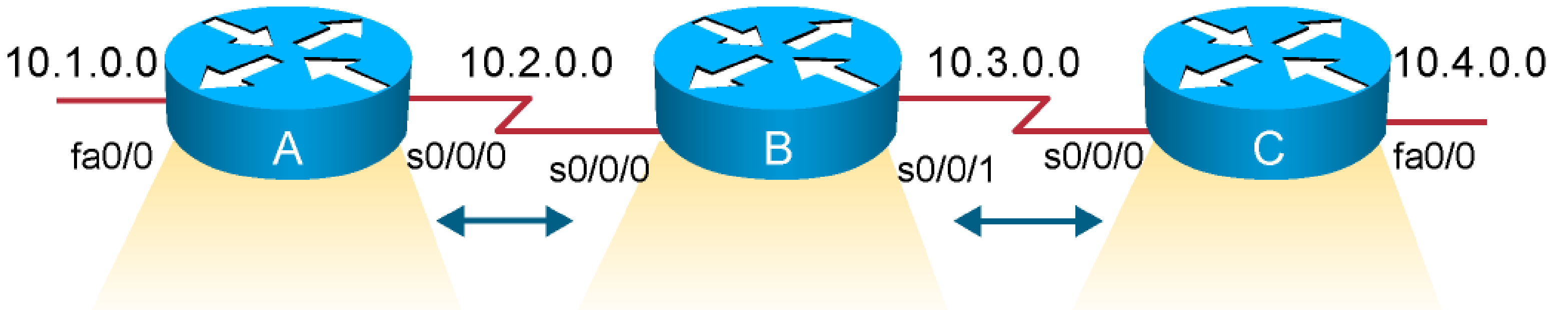
- **RIPv1**
  - Metric: hop count (smaller better) Infinite metric = 16
  - Full updates every 30s (subnet # & metric)
  - Convergence 3-5 minutes (depending on size of routing table)
  - Classful (no VLSM)
  - Broadcasts updates (255.255.255.255)
  - “Route-poisoning” and split horizon
    - ***Infinite metric of 16***
    - ***Prevent advertising back to the interface it was received***

- **RIPv2**
  - Same features as RIPv1
  - Adds: VLSM support (updates include subnet #, mask & metric)
  - MD5 and plain text authentication
  - Includes next hop router IP on updates
  - Uses external route tags (redistribution)
  - Multicast routing updates (224.0.0.9)

Distance Vector Protocols

- **IGRP**
  - Proprietary
  - Metric: bandwidth + delay (default), reliability, load, MTU
  - Metric value (1 - 4 billion), smaller better.
  - Metrics are cumulative: multi-hop path adds links delays
  - Metrics are configurable
  - Full updates every 90s
  - No VLSM supported
  - Infinite metric = 4,294,967,295 (smaller better)

Sources of Information and Discovering Routes



Routing Table (A)

10.1.0.0	fa0/0	0
10.2.0.0	s0/0/0	0
10.3.0.0	s0/0/0	1
10.4.0.0	s0/0/0	2

Routing Table (B)

10.2.0.0	s0/0/0	0
10.3.0.0	s0/0/1	0
10.4.0.0	s0/0/1	1
10.1.0.0	s0/0/0	1

Routing Table (C)

10.3.0.0	s0/0/0	0
10.4.0.0	fa0/0	0
10.2.0.0	s0/0/0	1
10.1.0.0	s0/0/0	2

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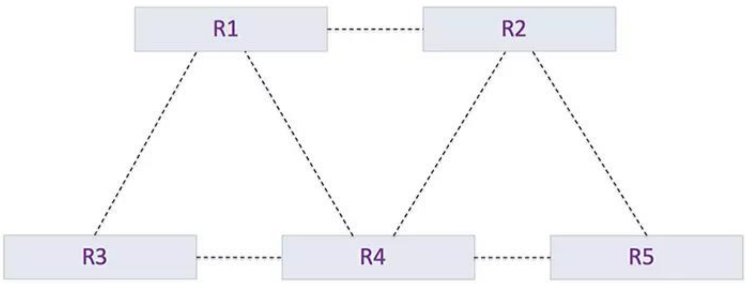
– Routers discover the best path to destinations from each neighbor.

Link State Protocols

- **Link State logic**
  - Add directly connected
  - Don’t transmit routing info until neighbors are discovered
  - Routing info: topological information about the network, at the end every router has a complete map of the network.
  - Use reliable protocol for route updates
  - Calculate shortest path first (SPF) algorithm (Dijkstra) to determine best routes and next hop (also prevents loops)
  - Full updates at start and after long periods of time (~30 min.)
  - Partial updates when a link fails
  - Fast convergence

Link State Protocols



- **OSPF**
  - Most popular
  - Discover neighbors, then exchange routes
  - Reliable Transport Protocol
  - Run SPF and store best routes
  - More memory required, more processing
  - Metric: “cost” based on bandwidth (smaller-better)
  - Averages 10s convergence time
  - VLSM supported
  - Hello messages to confirm neighbor reachability
  - Full updates every 30 min
  - Partial updates when link fails

Interface type	bandwidth	Cost
Fast Ethernet and faster	100 Mb/s and higher	1
Ethernet	10 Mb/s	10
E1	2 Mb/s	48
T1	1.544 Mb/s	64
128bps	128bps	781
64kbps	64kbps	1562
56kbps	56kbps	1785

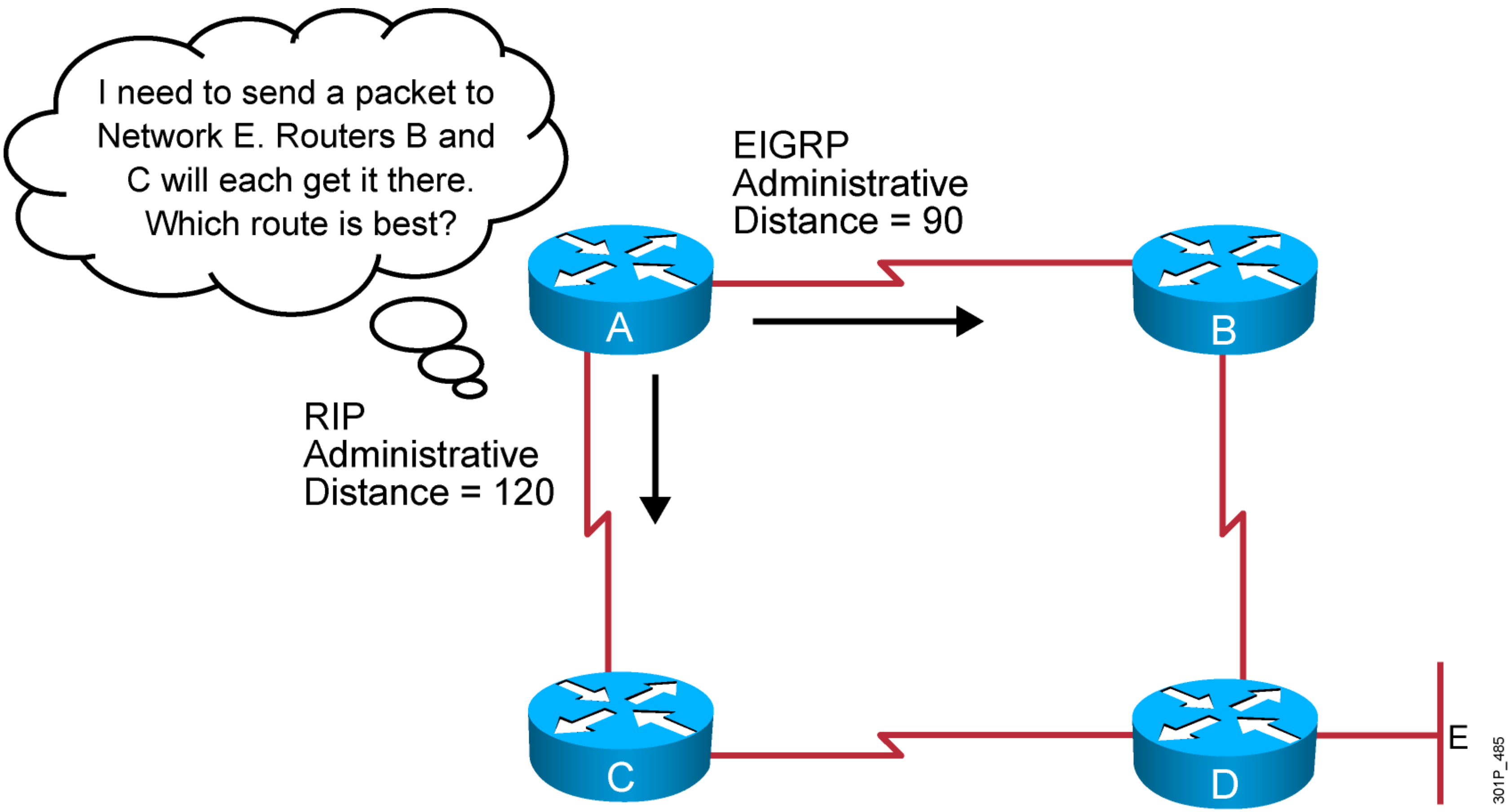
Hybrid Protocols

- **EIGRP**
  - Cisco Proprietary*
  - Uses features from both link-state and distance vector protocols (balanced hybrid protocol: topology + routing tables)
  - Diffused Update Algorithm (DUAL): exchange more info than distance vector but less than link-state
  - Demands less computation
  - Calculated best and “feasible successor routes” (alternatives), permits **immediate convergence**.
  - Discovers neighbors like OSPF
  - Metric based on bandwidth and delay (Idem IGRP * 256)
  - Does not send periodic full updates

Loop Prevention in Distance Vector Protocols

- **Problems:**
  - Multiple routes to same network
  - Miscommunications on a single link
  - Information loops through alternative paths
  - Counting to infinity

Administrative Distance: Ranking Routes



Administrative Distance

- Applies to similar routes received from different protocols
- Prioritizes different routing protocols (which protocol do I believe first?)
- **The <u>lower</u> the AD number, the better**

- Examples:
    - ***Directly connected 0***
    - ***Static Routes 1***
    - ***eBGP 20***
    - ***EIGRP (internal) 90***
    - ***IGRP 100***
    - ***OSPF 110***
    - ***IS-IS 115***
    - ***RIP 120***
    - ***EIGRP (external) 170***
    - ***iBGP 200***

Classful Routing Protocol

- Classful routing protocols do not include the subnet mask with the route advertisement.
- Within the same network, consistency of the subnet masks is assumed.
- Summary routes are exchanged between foreign networks.
- These are examples of classful routing protocols:
  - ***RIPv1***
  - ***IGRP***

Classless Routing Protocol

- Classless routing protocols include the subnet mask with the route advertisement.
- Classless routing protocols support a variable-length subnet mask (VLSM). (aka subnetting)
- Summary routes can be manually controlled within the network.
- These are examples of classless routing protocols:
  - ***RIPv2***
  - ***EIGRP***
  - ***OSPF***
  - ***IS-IS***

Link-State Routing can be Problematic

- **Topology information is flooded**
  - High bandwidth and storage overhead
  - Forces nodes to divulge sensitive information
- **Entire path computed locally per node**
  - High processing overhead in a large network
- **Minimizes some notion of total distance**
  - Works only if policy is shared and uniform
- **Typically used only inside an AS**
  - E.g., OSPF and IS-IS

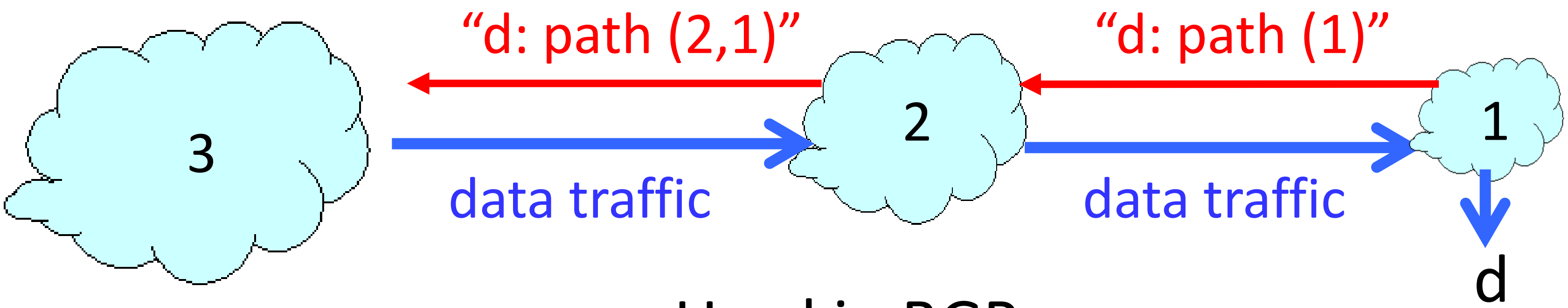
Distance Vector is on the Right Track

- **Advantages**
  - Hides details of the network topology
  - Nodes determine only “next hop” toward the destination
- **Disadvantages**
  - Minimizes some notion of total distance, which is difficult in an interdomain setting
  - Slow convergence due to the counting-to-infinity problem (“bad news travels slowly”)
- **Idea: extend the notion of a distance vector**
  - To make it easier to detect loops

Path-Vector Routing

- **Extension of distance-vector routing**
  - Support flexible routing policies

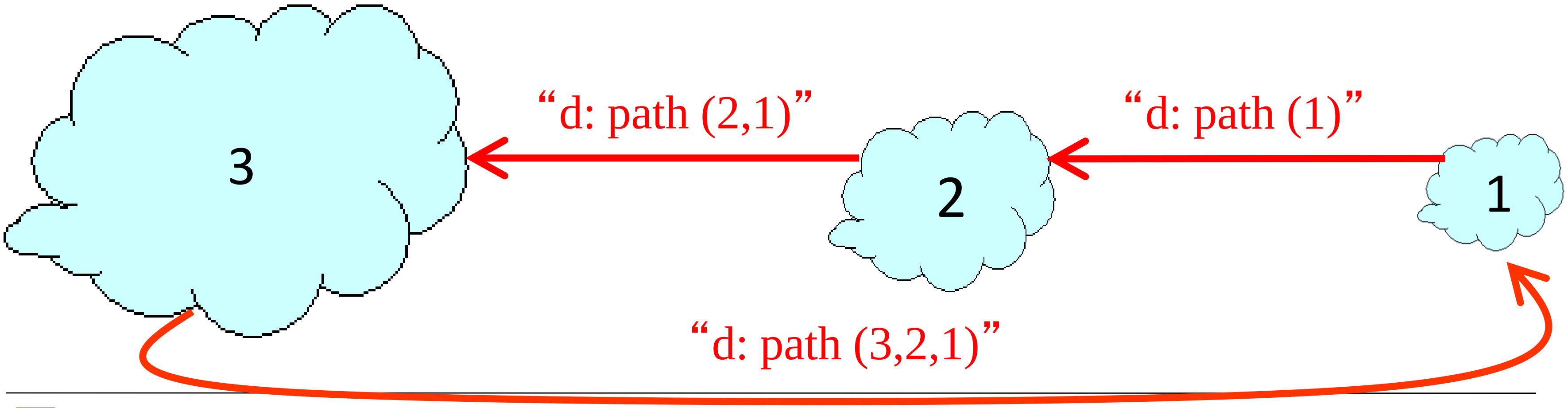
- **Key idea: advertise the entire path**
  - Distance vector: send *distance metric* per dest d
  - Path vector: send the *entire path* for each dest d



Used in BGP

Faster Loop Detection

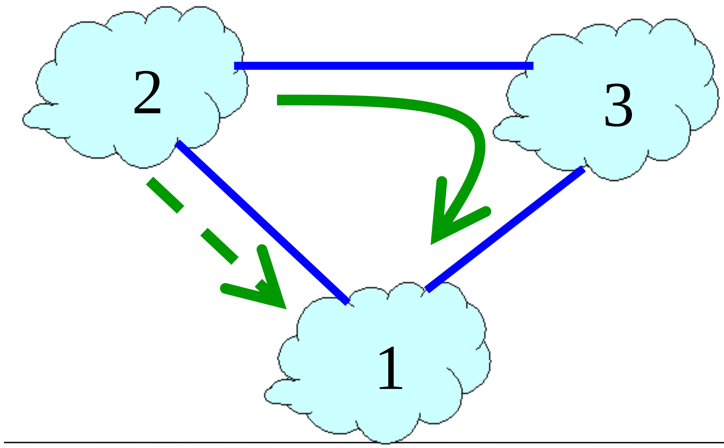
- **Node can easily detect a loop**
  - Look for its own node identifier in the path
  - E.g., node 1 sees itself in the path “3, 2, 1”
- **Node can simply discard paths with loops**
  - E.g., node 1 simply discards the advertisement



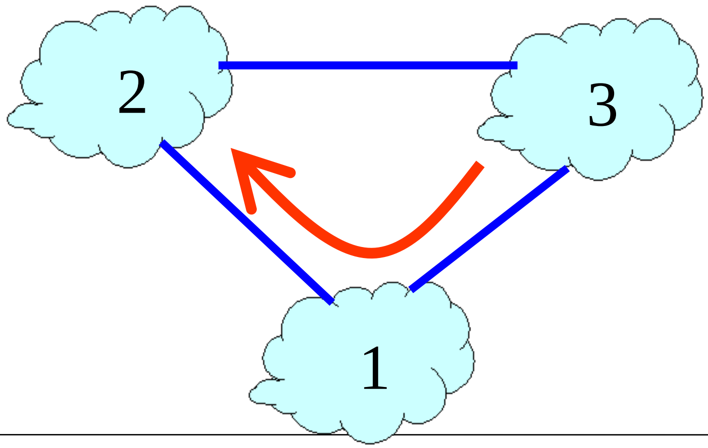
Path-Vector: Flexible Policies

- **Each node can apply local policies**
  - Path selection: Which path to use?
  - Path export: Which paths to advertise?

Node 2 prefers
“2, 3, 1” over “2, 1”

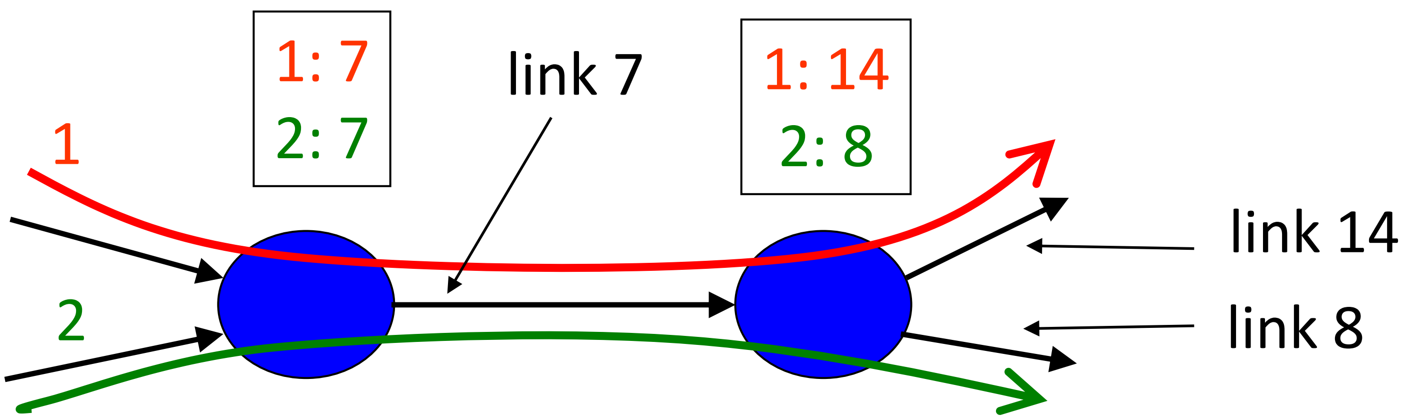


Node 1 doesn’t let 3
hear the path “1, 2”



End-to-End Signaling

- **Establish end-to-end path in advance**
  - Learn the topology (as in link-state routing)
  - End host or router computes and signals a path
    - ***Signaling: install entry for each circuit at each hop***
    - ***Forwarding: look up the circuit id in the table***



Used in MPLS with RSVP

Distance Vector vs. Path Vector

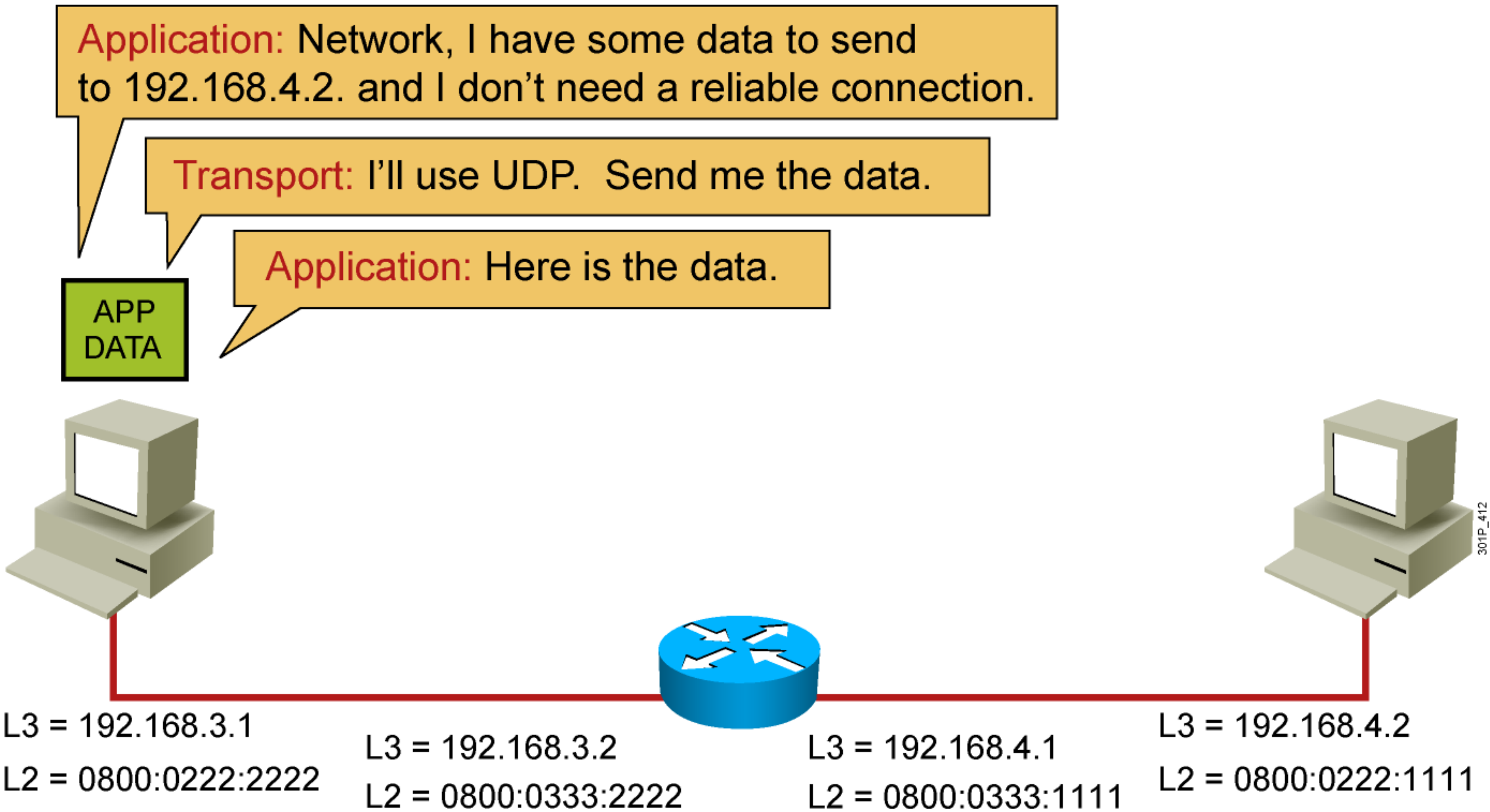
- **Distance-vector routing**
  - Pro: Less information and computation than link state
  - Con: Slower convergence (e.g., count to infinity)
- **Path-vector routing**
  - Share entire path, not distance: faster convergence
  - More flexibility in selecting paths
- **Different goals / metrics if inter- or intra-domain**

Questions?

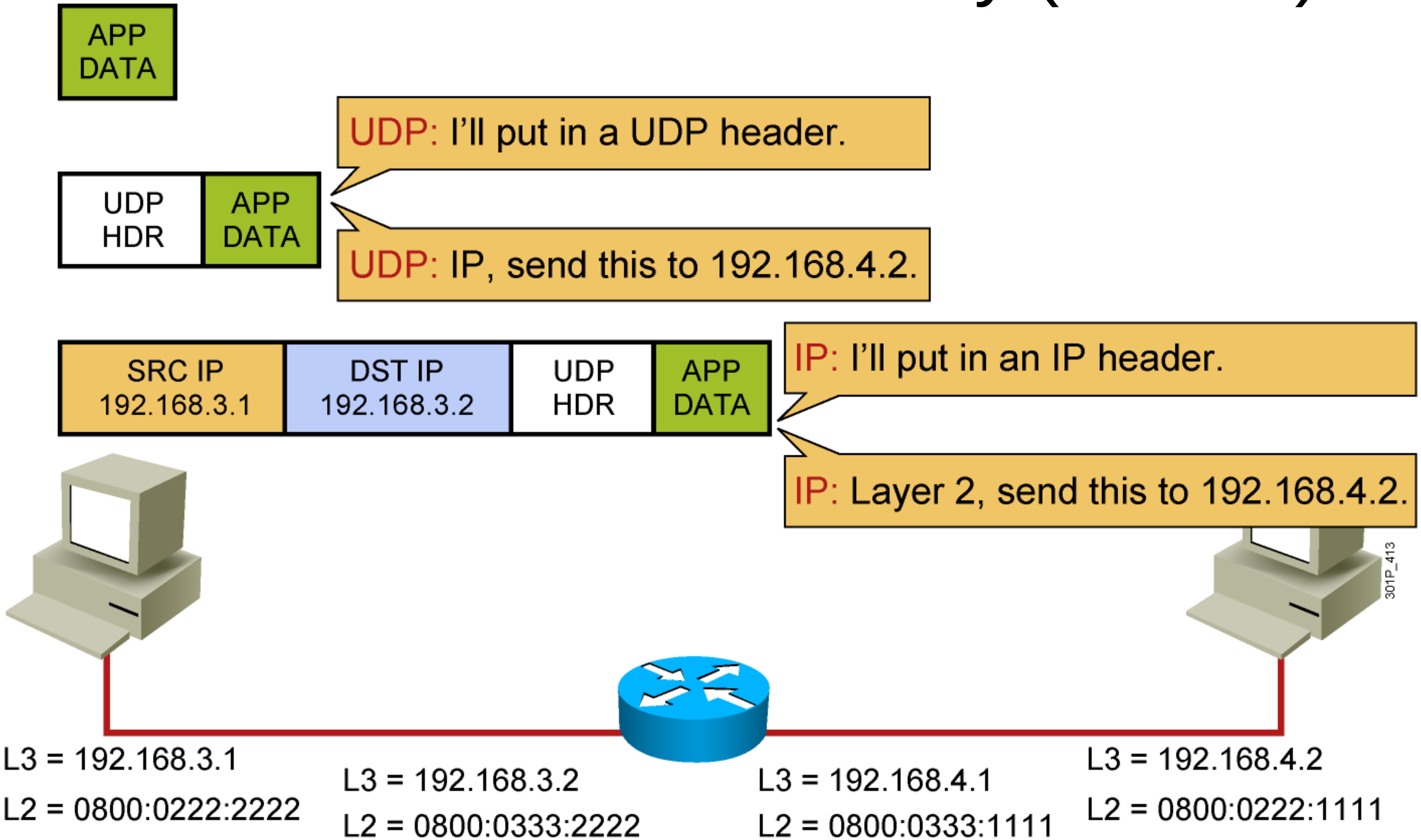
Lab

Appendix A

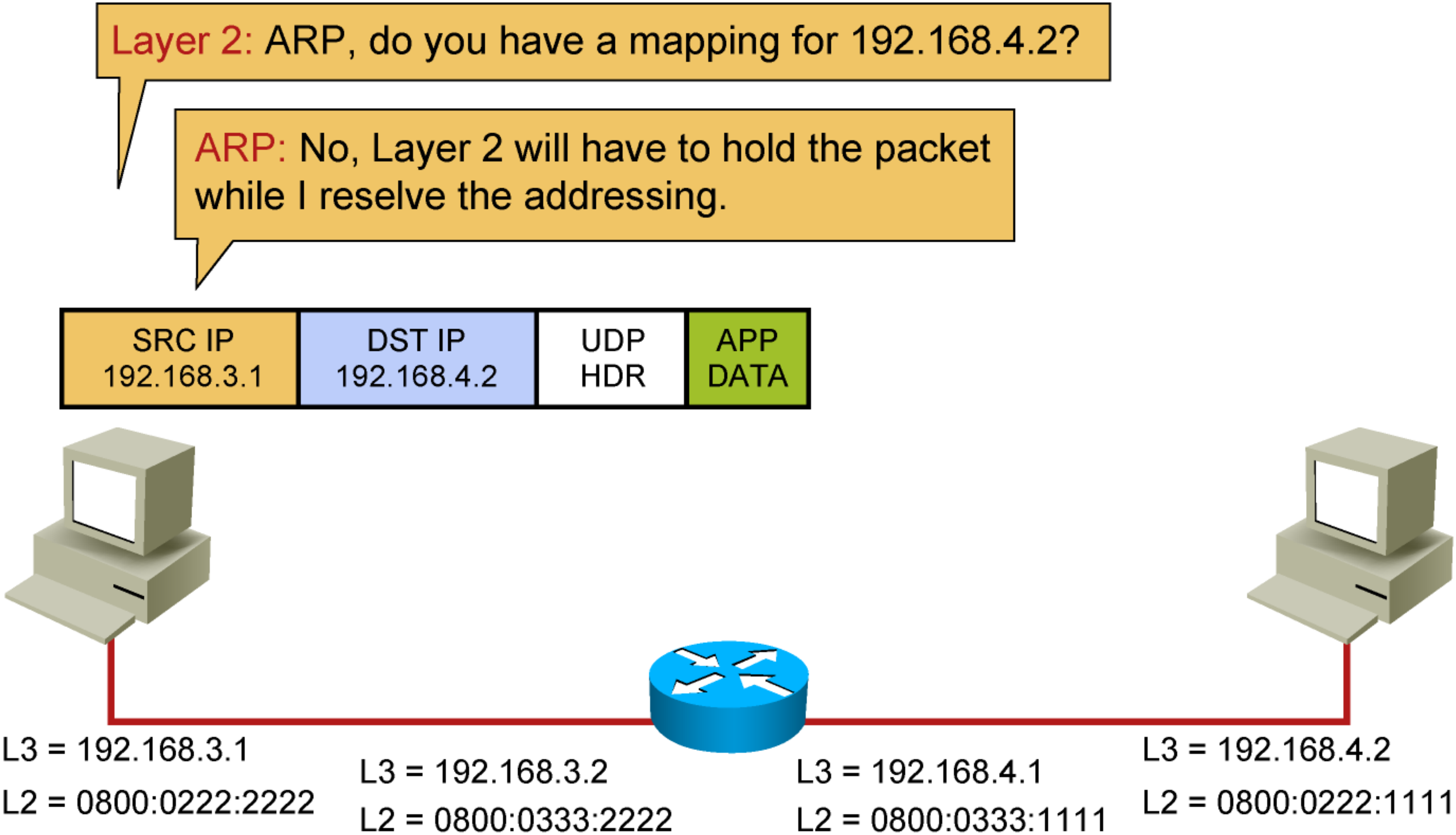
Host-to-Host Packet Delivery (1 of 17)



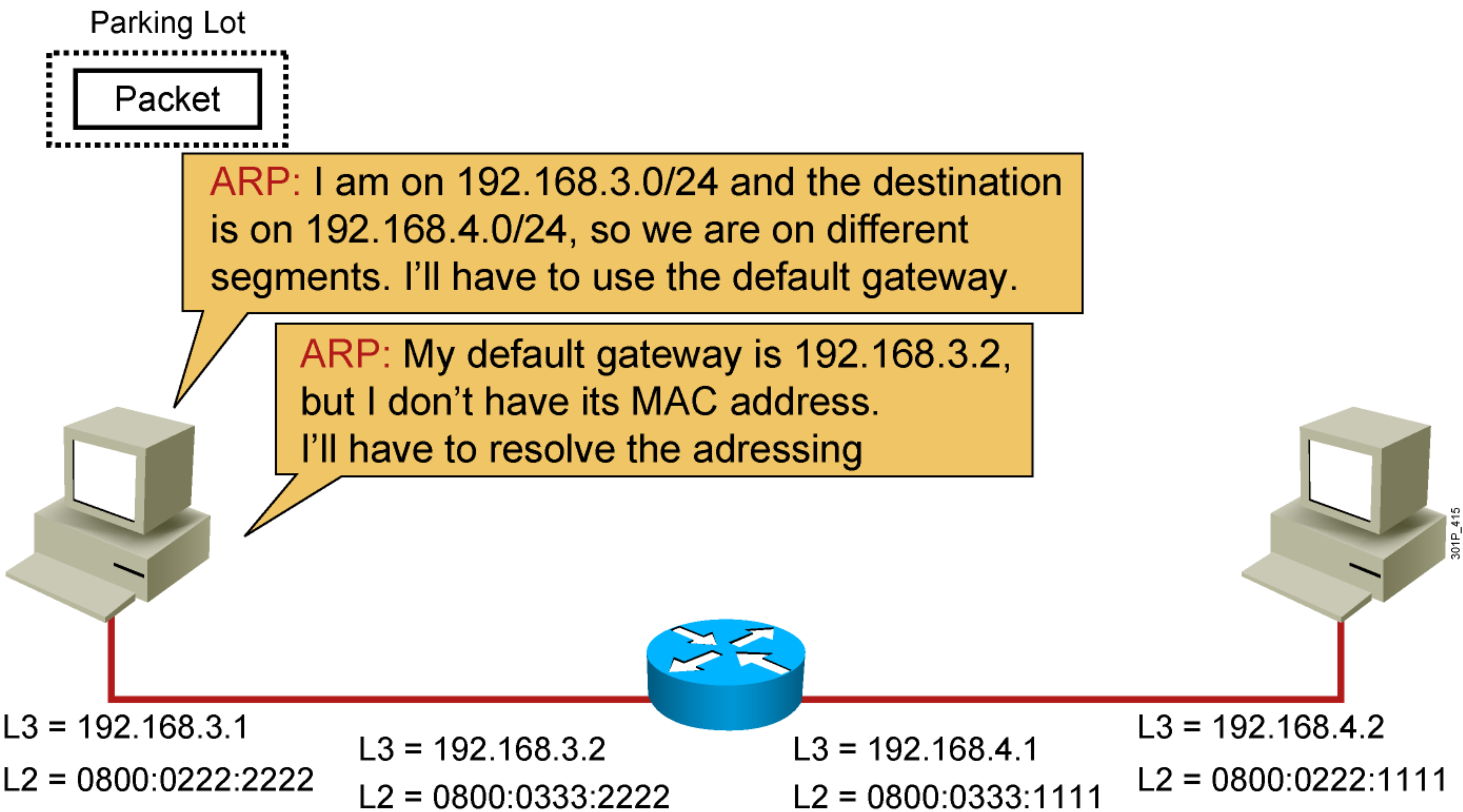
Host-to-Host Packet Delivery (2 of 17)



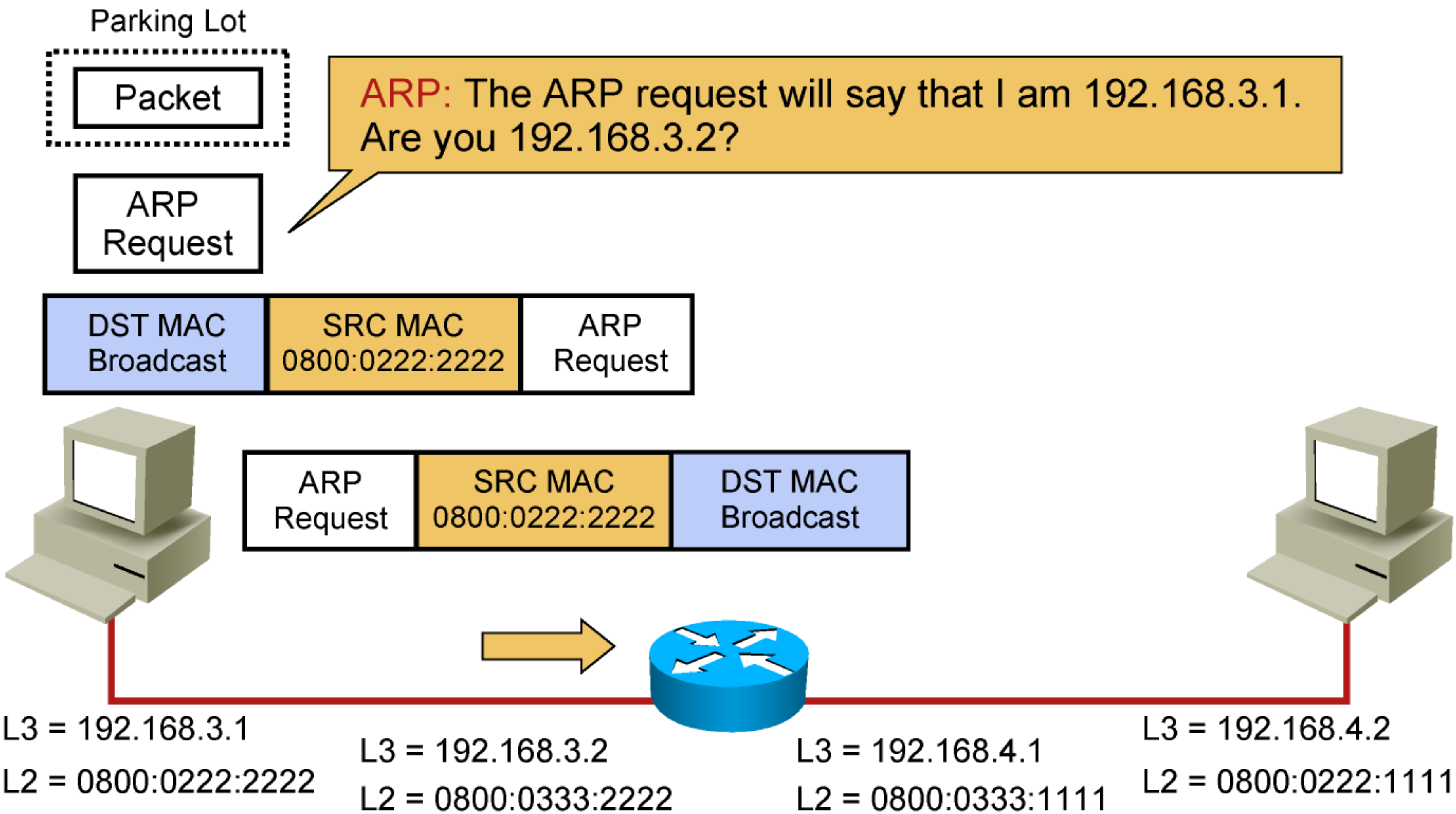
Host-to-Host Packet Delivery (3 of 17)



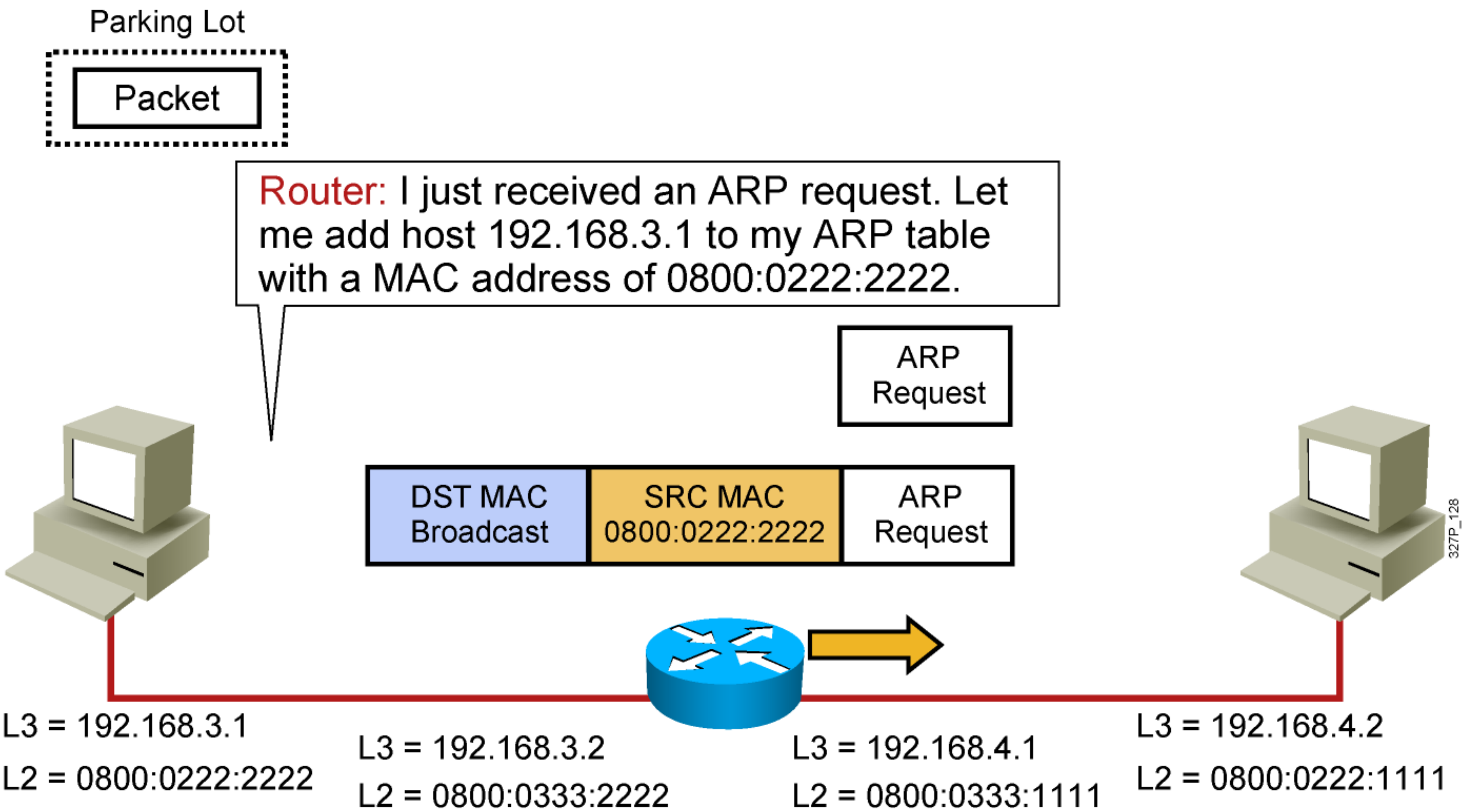
Host-to-Host Packet Delivery (4 of 17)



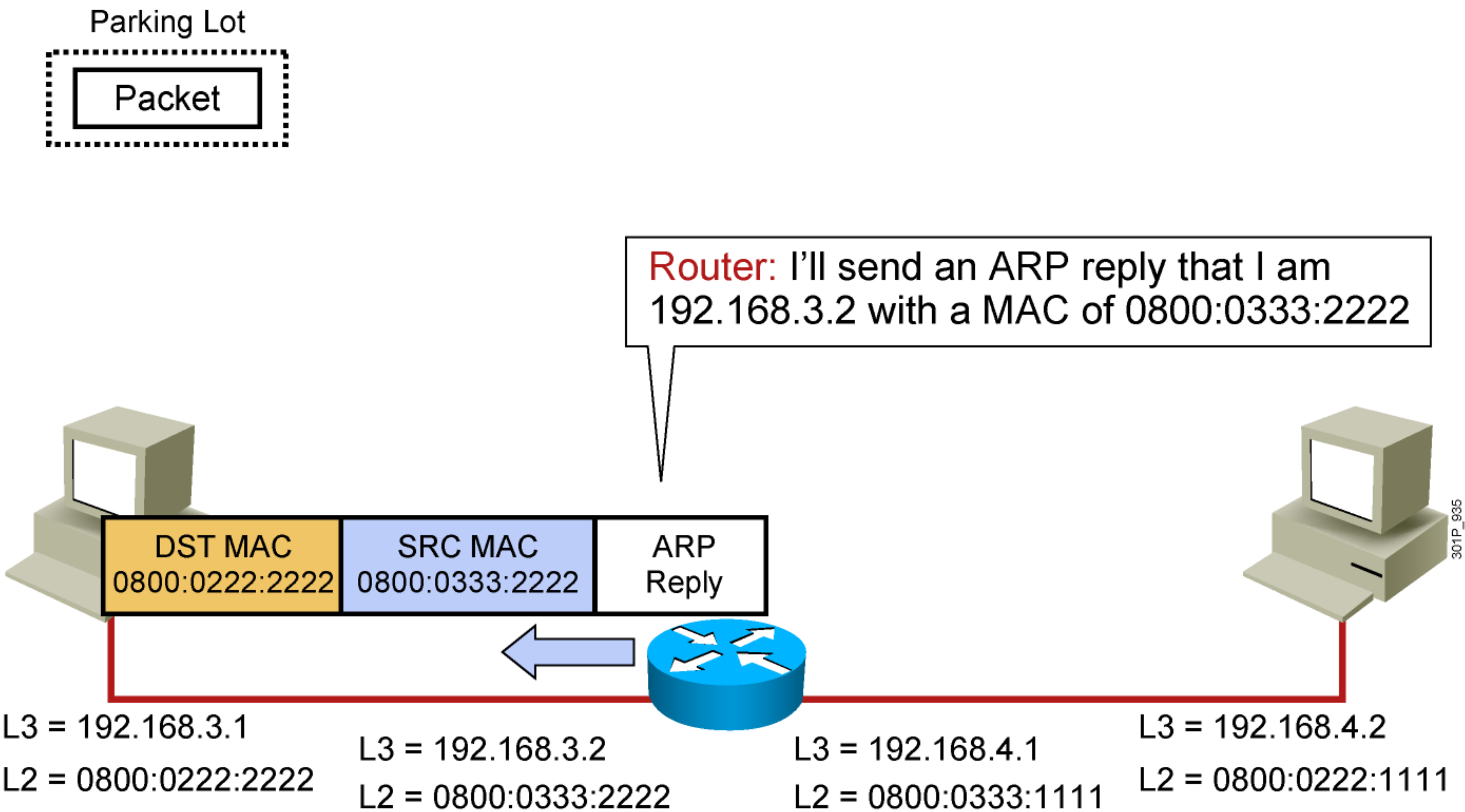
Host-to-Host Packet Delivery (5 of 17)



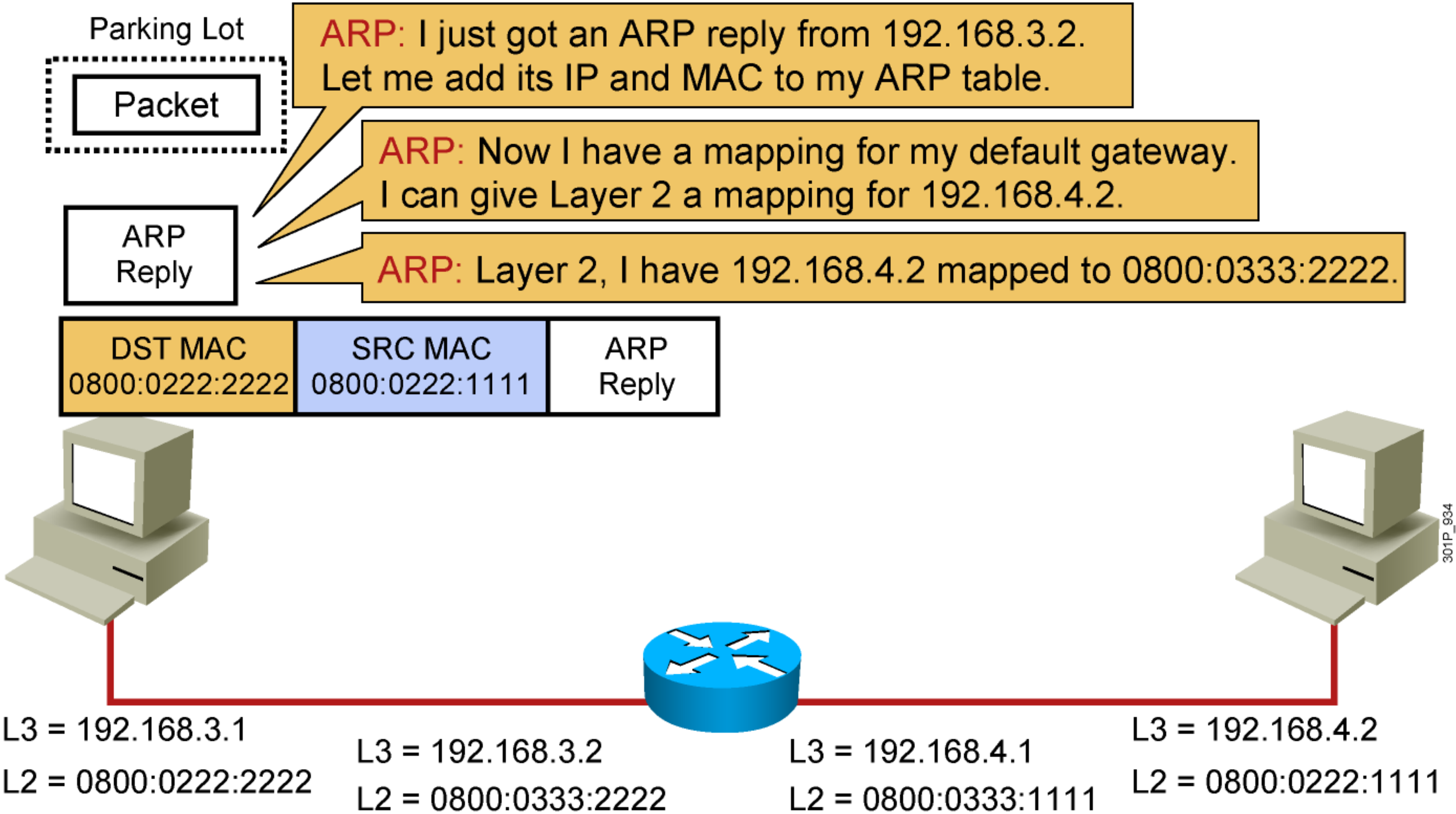
Host-to-Host Packet Delivery (6 of 17)



Host-to-Host Packet Delivery (7 of 17)



Host-to-Host Packet Delivery (8 of 17)



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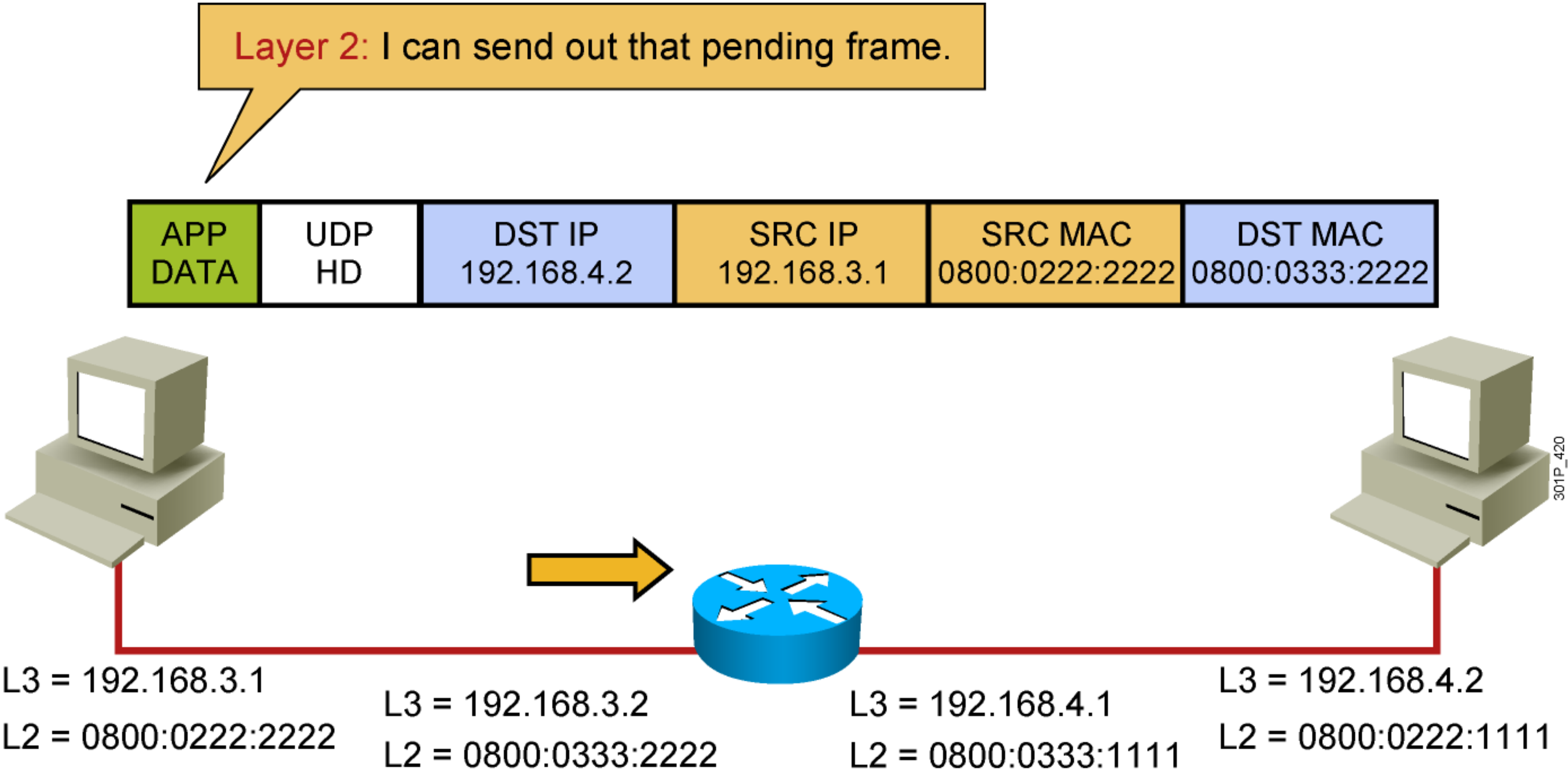
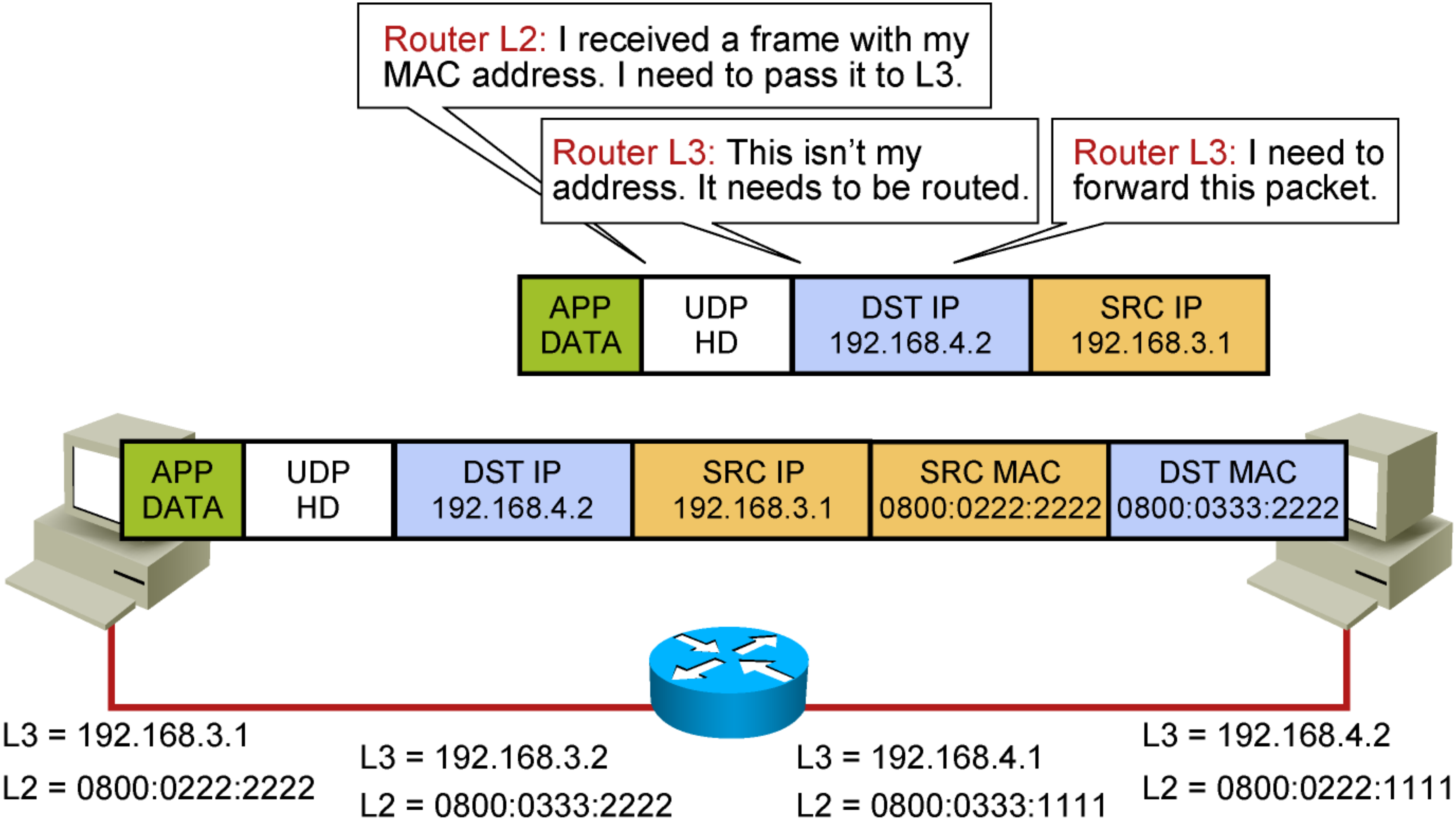
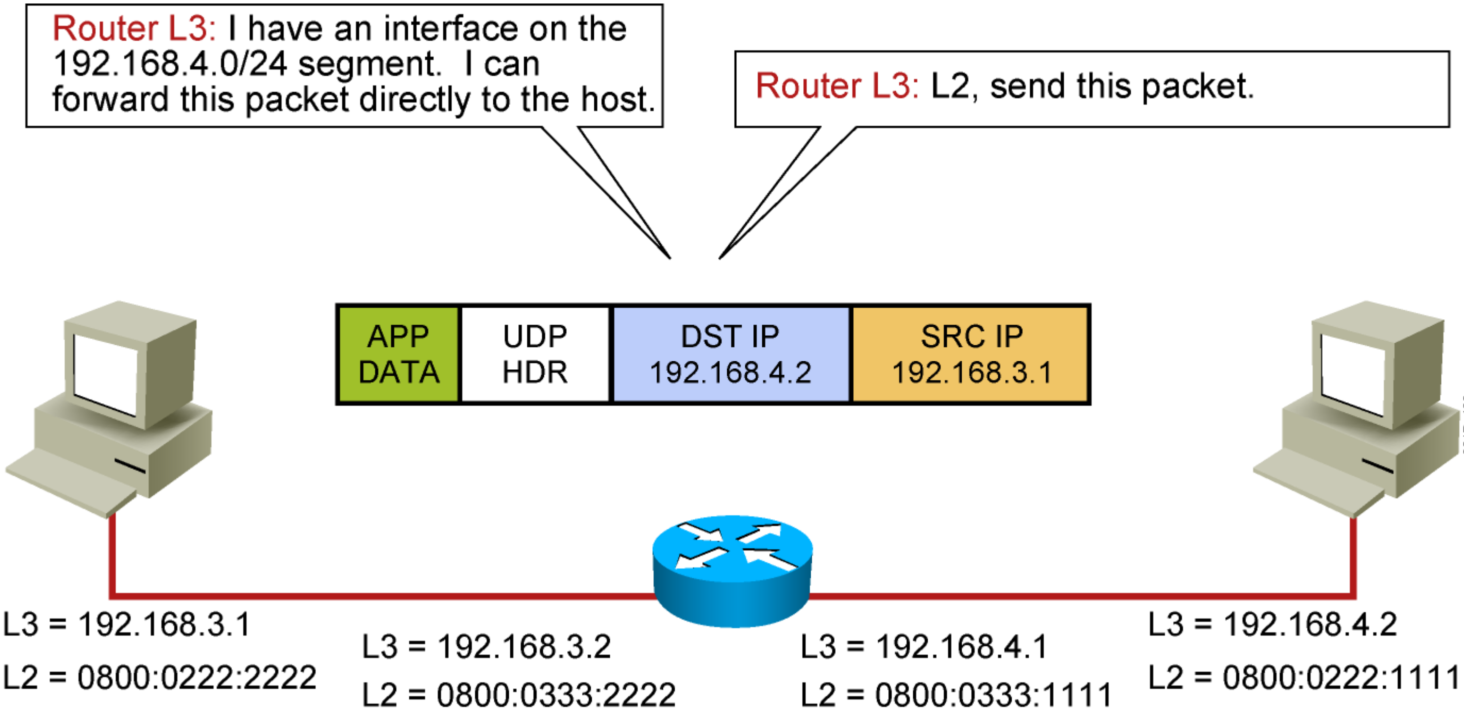


Host-to-Host Packet Delivery (10 of 17)

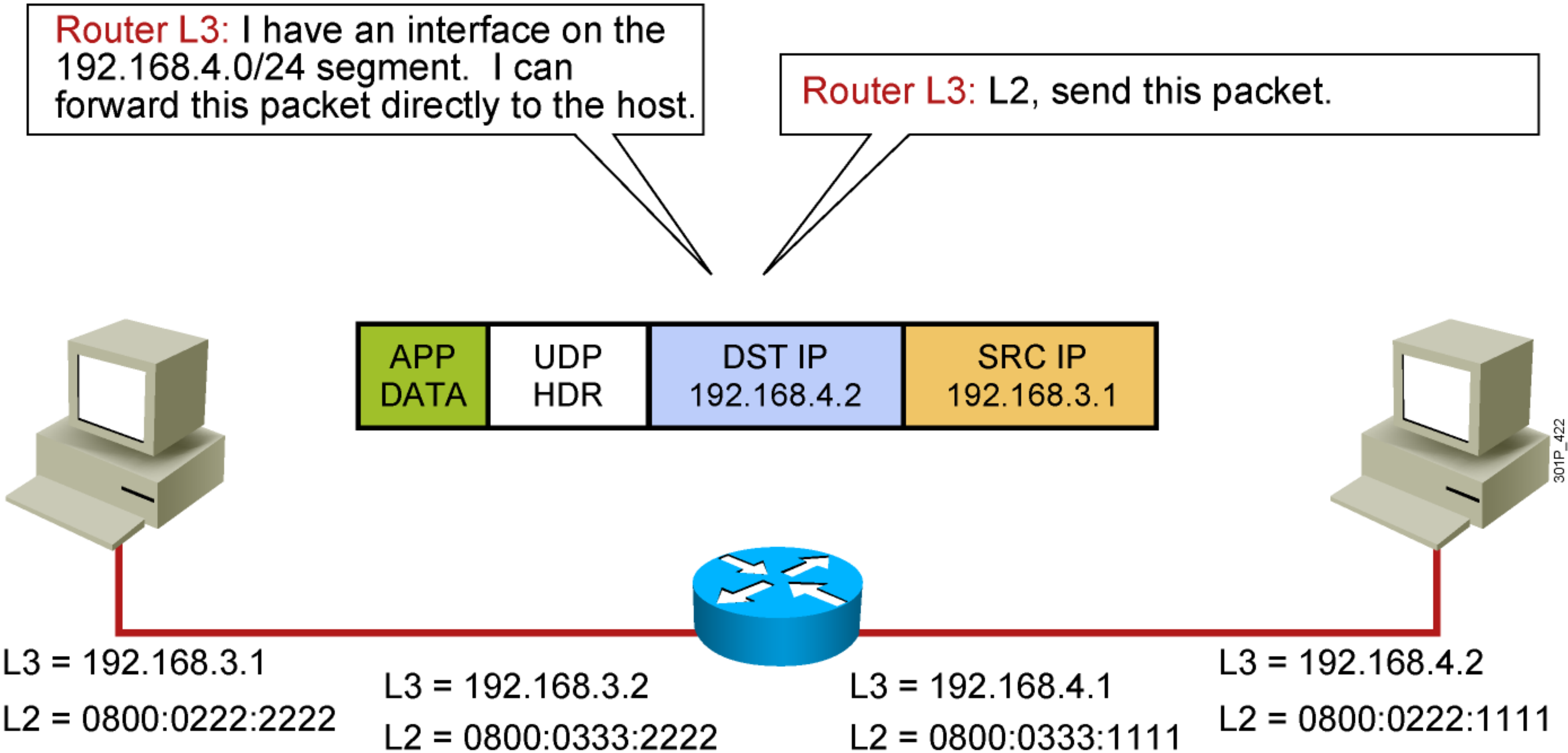


Host-to-Host Packet Delivery (11 of 17)

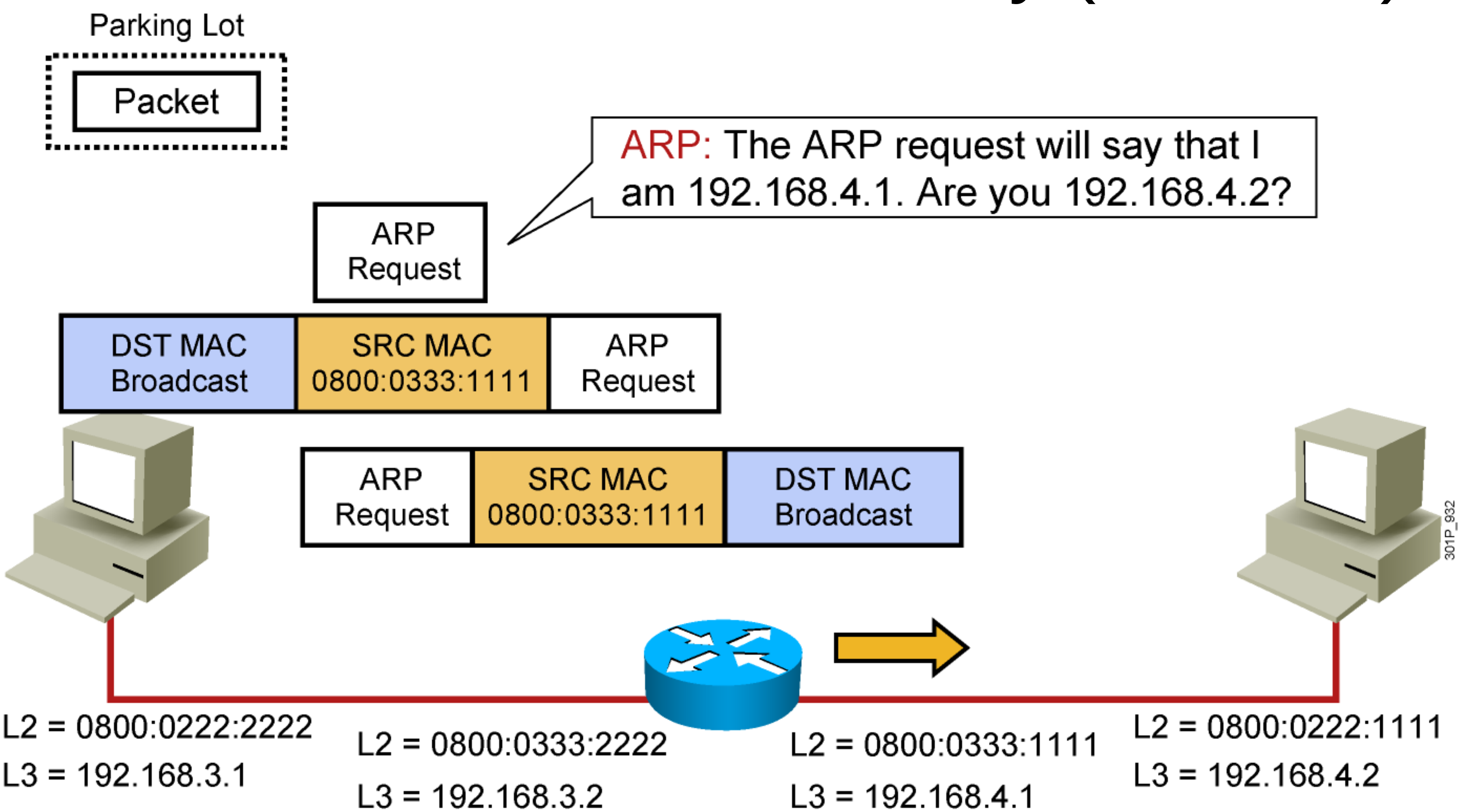
Destination	Next Hop	Interface
192.168.3.0/24	Connected	fa 0/0
192.168.4.0/24	Connected	fa 0/1



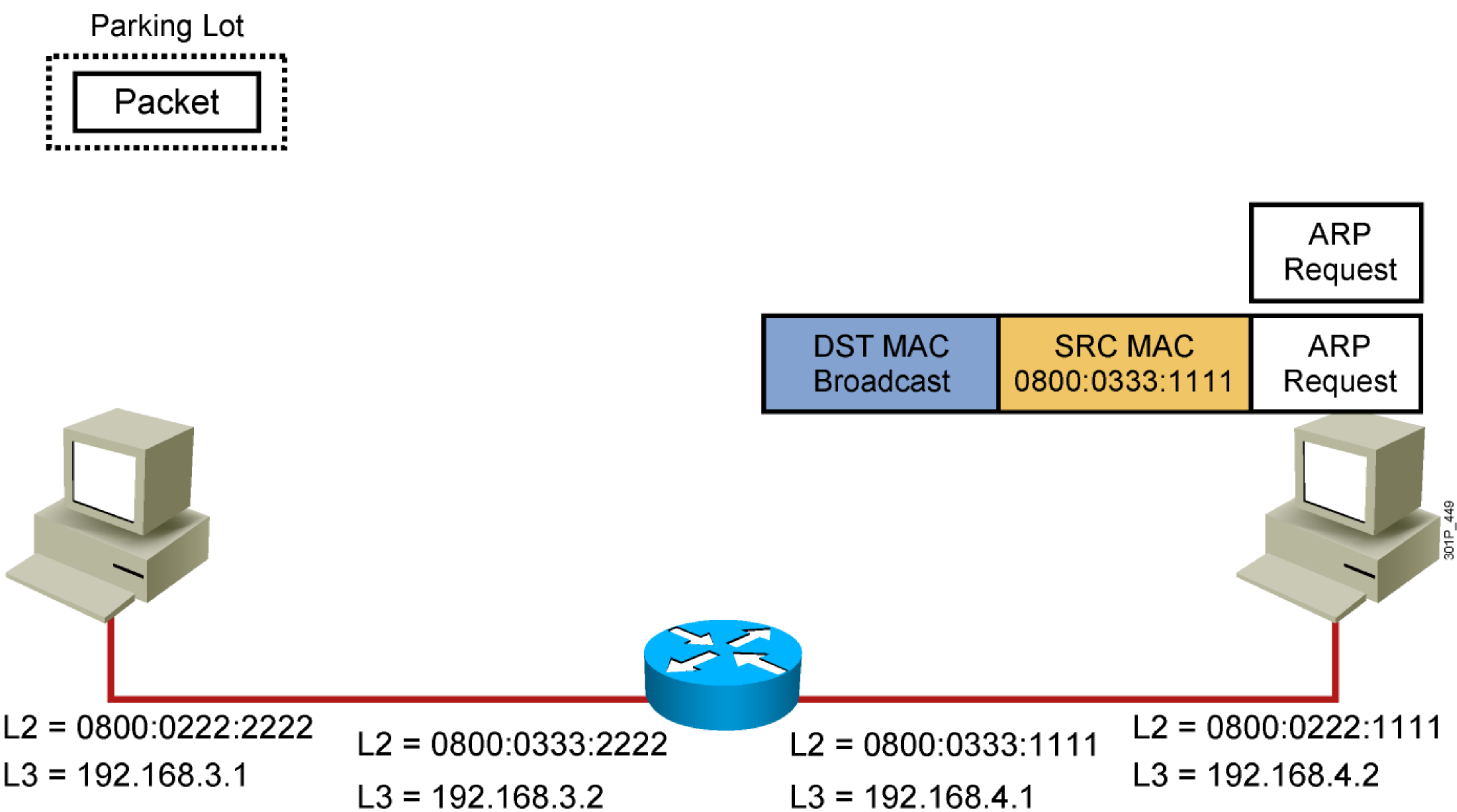
Host-to-Host Packet Delivery (12 of 17)



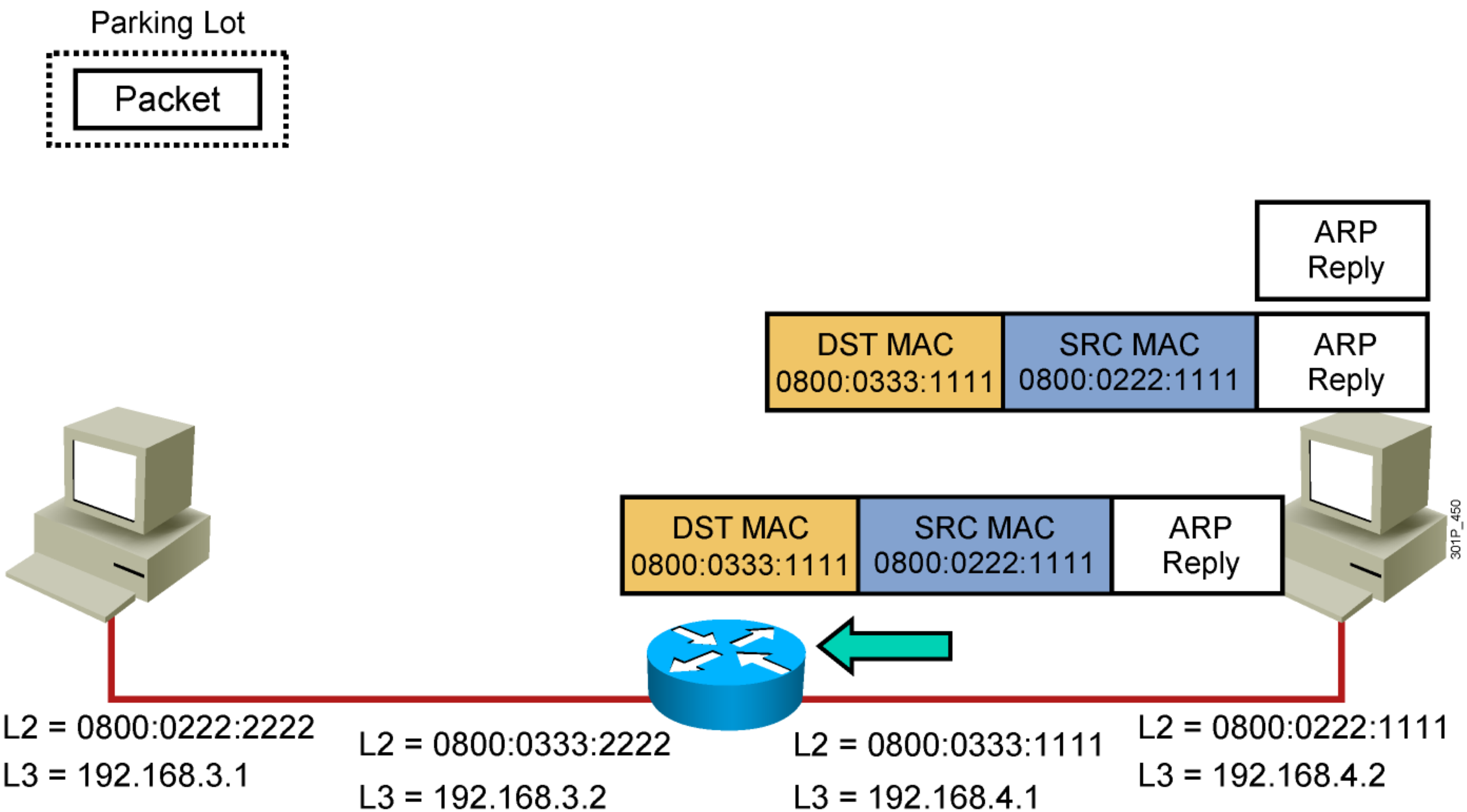
Host-to-Host Packet Delivery (13 of 17)



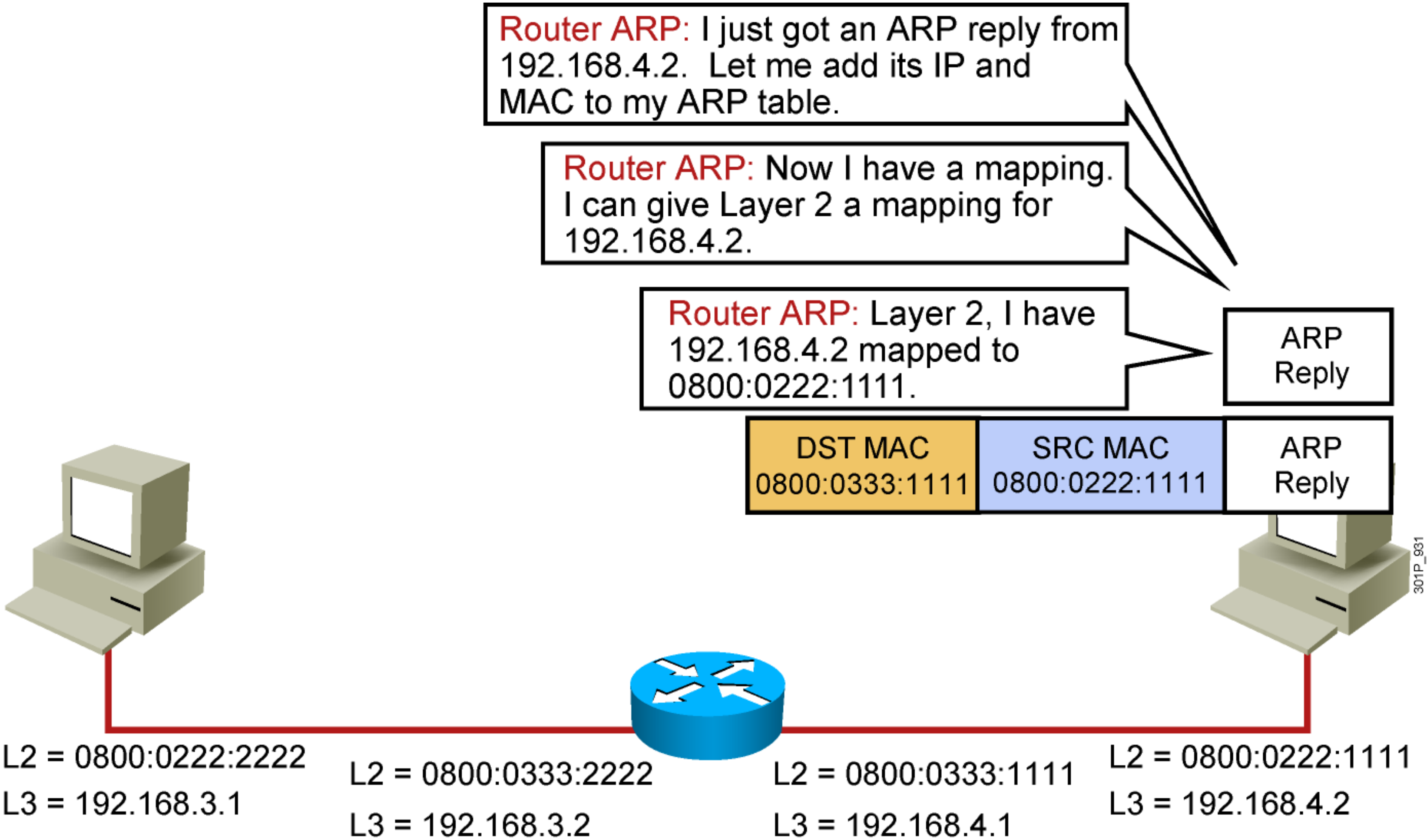
Host-to-Host Packet Delivery (14 of 17)



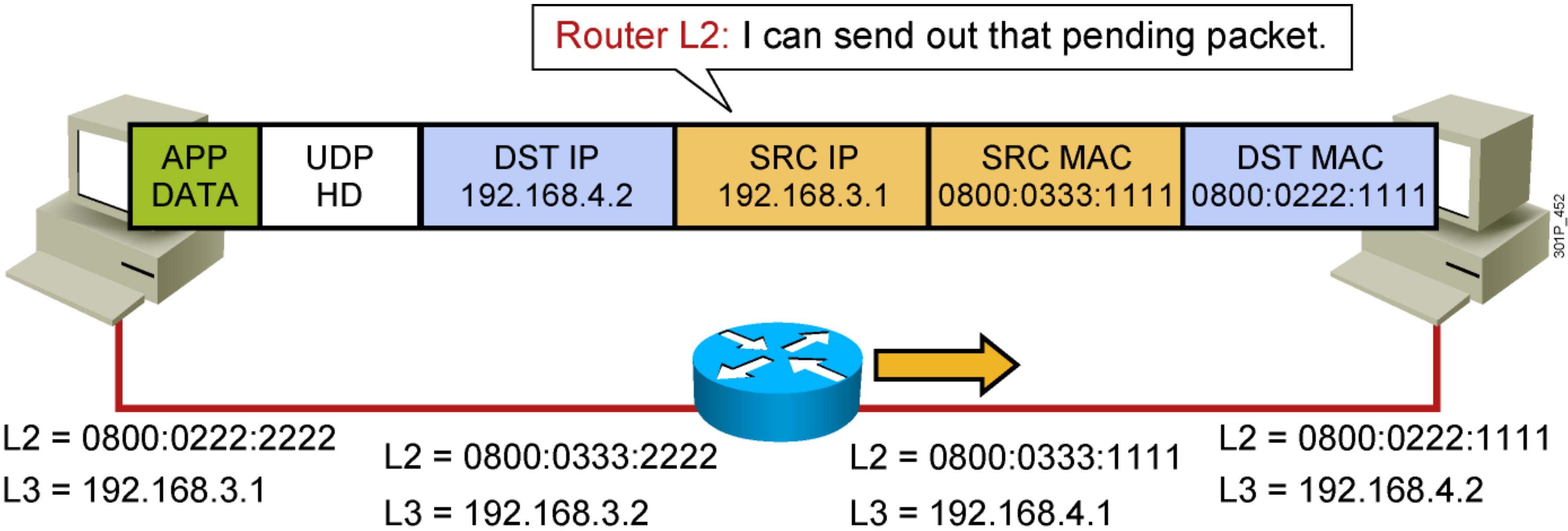
Host-to-Host Packet Delivery (15 of 17)



Host-to-Host Packet Delivery (16 of 17)

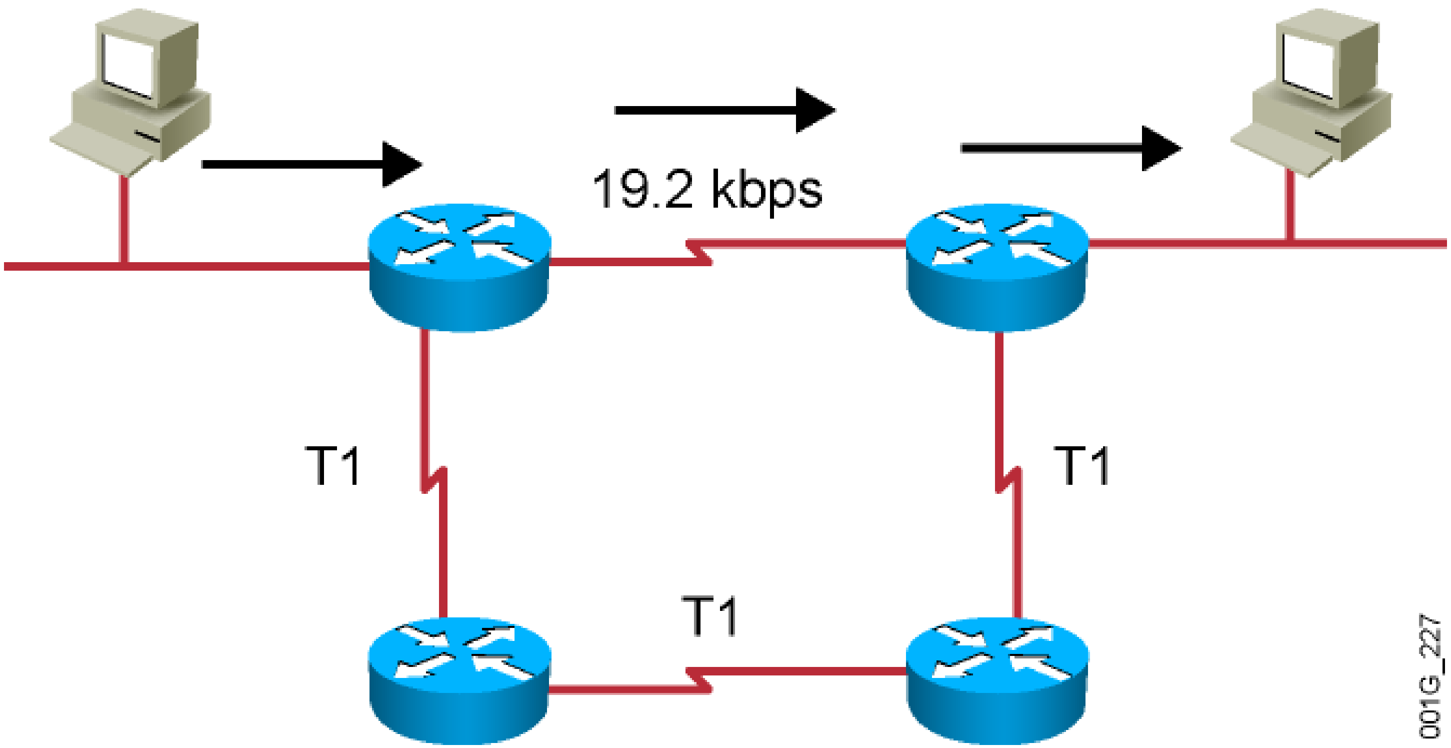


Host-to-Host Packet Delivery (17 of 17)



Appendix B

RIP Overview



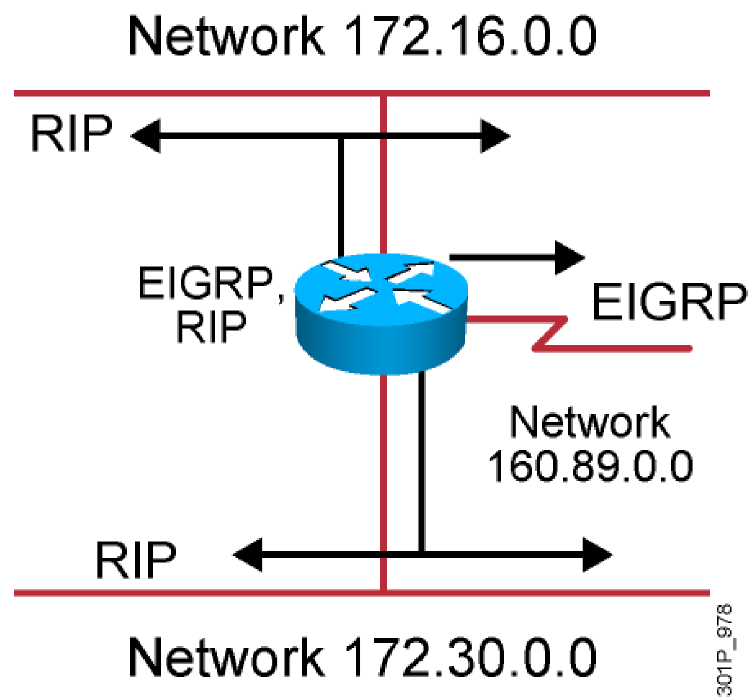
– Maximum is 16 equal-cost paths (default = 4)
– Hop-count metric selects the path
– Routes update every 30 seconds

RIPv1 and RIPv2 Comparison

	RIPv1	RIPv2
Routing protocol	Classful	Classless
Supports variable-length subnet mask?	No	Yes
Sends the subnet mask along with the routing update?	No	Yes
Addressing type	Broadcast	Multicast
Defined in …	RFC 1058	RFCs 1721, 1722, and 2453
Supports manual route summarization?	No	Yes
Authentication support?	No	Yes

IP Routing Configuration Tasks

- Router configuration
  - ***Select routing protocols***
  - ***Specify networks or interfaces***



RIP Configuration

```
RouterX(config)# router rip
```

– Starts the RIP routing process

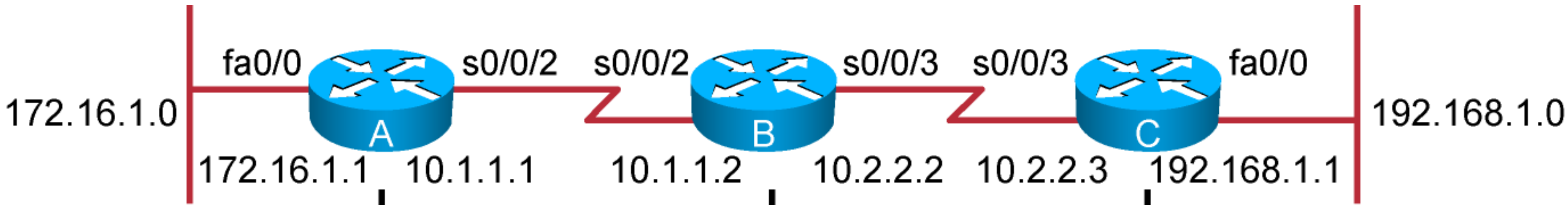
```
RouterX(config-router)# version 2
```

- Enables RIP version 2

```
RouterX(config-router)# network network-number
```

- Selects participating attached networks
- Requires a major classful network number

RIP Configuration Example




```
router rip
version 2
network 172.16.0.0
network 10.0.0.0
```

```
router rip
version 2
network 192.168.1.0
network 10.0.0.0
```

```
router rip
version 2
network 10.0.0.0
```