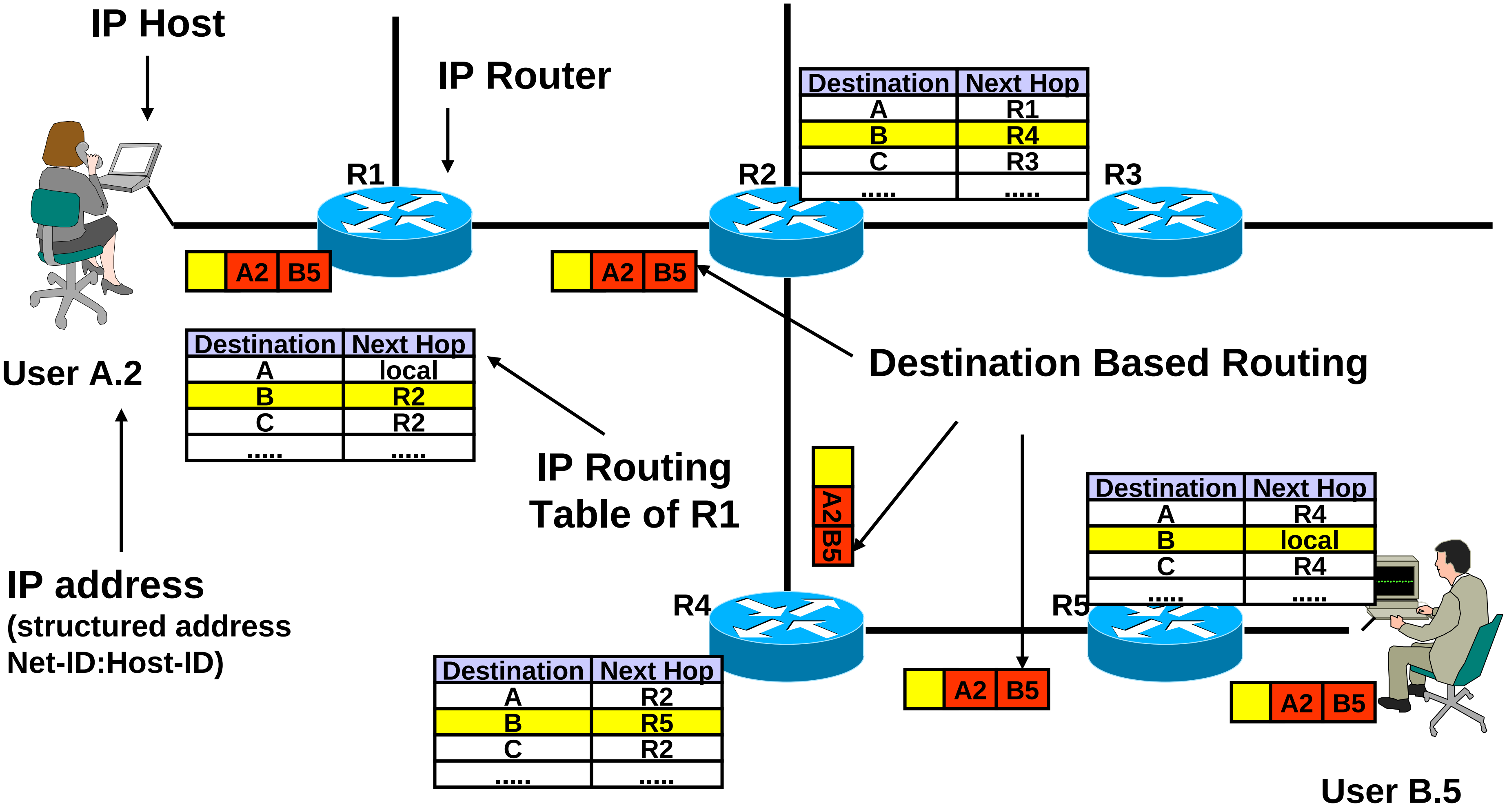
Routing Introduction

Direct vs. Indirect Delivery

Static vs. Dynamic Routing

Distance Vector vs. Link State

IP Datagram Service



Destination	Next Hop
A	local
B	R2
C	R2
.....	.....

Destination	Next Hop
A	R1
B	R4
C	R3
.....	.....

Destination	Next Hop
A	R2
B	R5
C	R2
.....	.....

Destination	Next Hop
A	R4
B	local
C	R4
.....	.....

Routing Paradigm

- **Destination Based Routing**
  - Source address is not taken into account for the forward decision
- **Hop by Hop Routing**
  - IP datagram's follow the signposts given by routing table entries
  - Network's routing state must be loop-free and consistent
- **Least Cost Routing**
  - Typically only the best path is entered into routing table

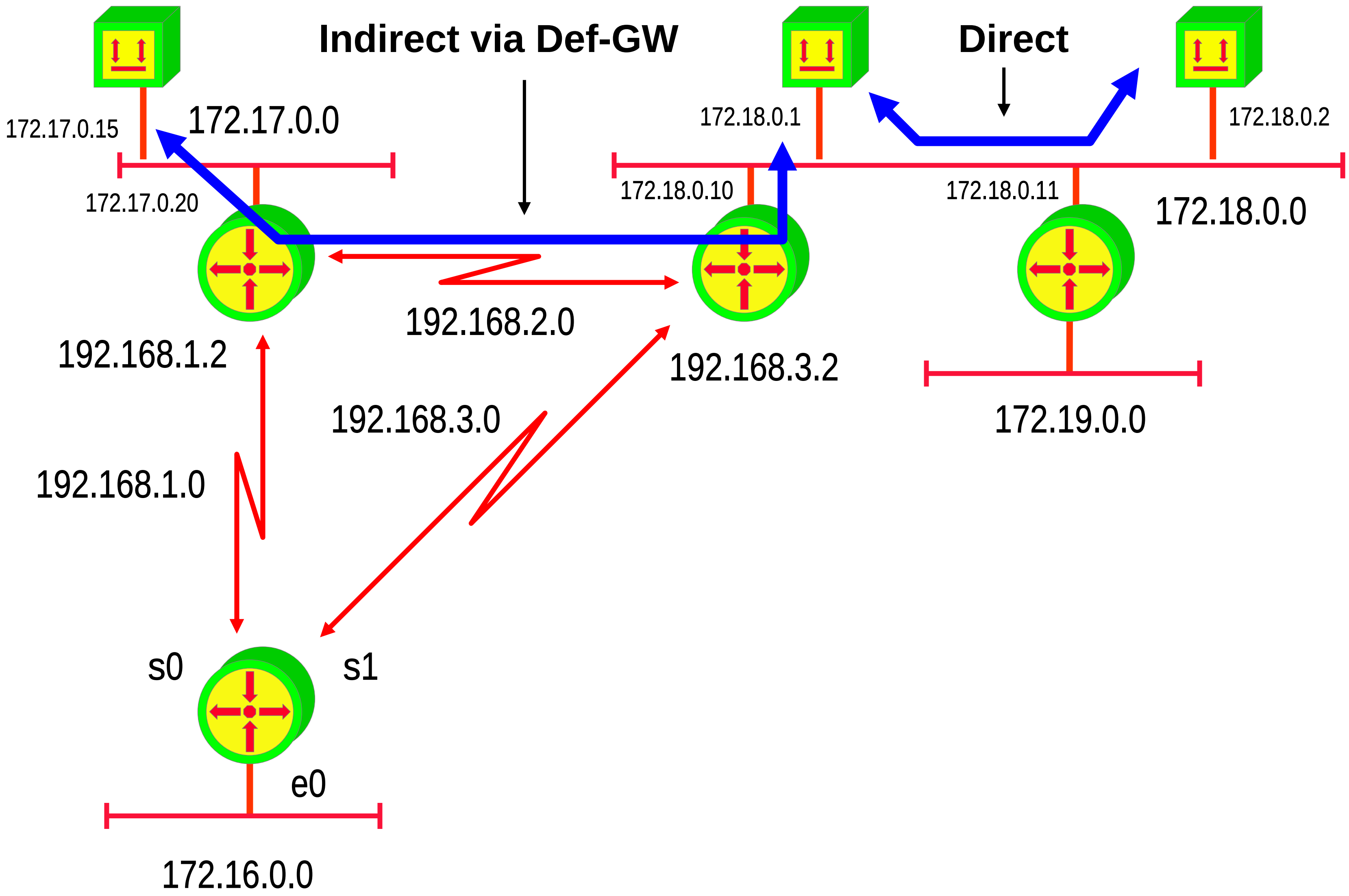
Routing Basics

- **Routing Introduction**
  - **Direct Delivery**
  - **Indirect Delivery**
  - **Static Routing**
  - **Default Routing**
- **Dynamic Routing**
  - **Distance Vector Routing**
  - **Link State Routing**

What is routing?

- ***Finding a path to a destination address***
- **Direct delivery performed by host**
  - **Destination network = local network**
- **Indirect delivery performed by router**
  - **Destination network ≠ local network**
  - **Packet is forwarded to default gateway**

Direct versus Indirect Delivery



Direct Delivery

- IP host checks if packet's destination network is identical with local network
  - By applying the configured subnet mask of the host's interface
- If destination network = local network then the L2 address of the destination is discovered using ARP
  - Not necessary on point-to-point connections

IP Host Facts

- **Also IP hosts have routing tables !**
  - **But typically only a static route to the default gateway is entered**
- **ARP cache aging timer: 20 minutes**

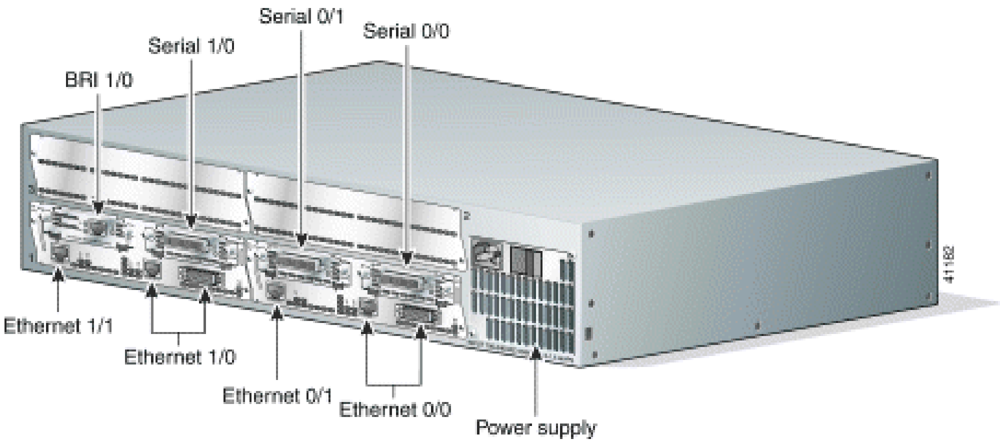
Indirect Delivery

- **Default gateway delivers packet in behalf of its host using a routing table**
- **Routing table components**
  - **Destination network (+ subnet mask)**
  - **Next hop (+ outgoing interface)**
  - **Metric (+ Administrative Distance)**

Router

- **Initially Unix workstations with several network interface cards**
- **Today specialized hardware**

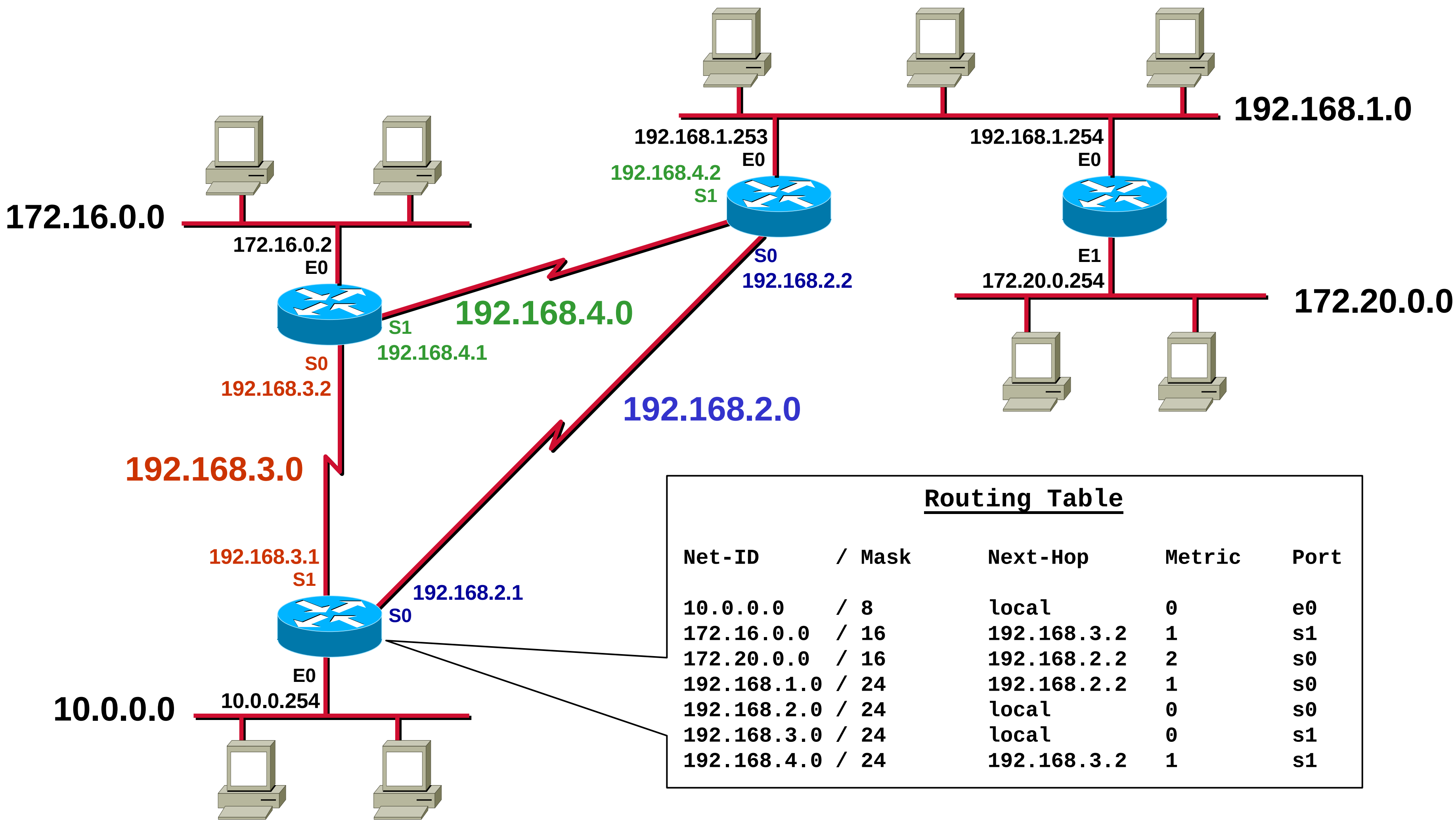
Cisco 3600 Router



“The most simple way to accelerate a Router is at 9.8 m/sec/sec.”

Seen on Usenet

IP Routing Basics



Routing Table

Net-ID	/ Mask	Next-Hop	Metric	Port
10.0.0.0	/ 8	local	0	e0
172.16.0.0	/ 16	192.168.3.2	1	s1
172.20.0.0	/ 16	192.168.2.2	2	s0
192.168.1.0	/ 24	192.168.2.2	1	s0
192.168.2.0	/ 24	local	0	s0
192.168.3.0	/ 24	local	0	s1
192.168.4.0	/ 24	192.168.3.2	1	s1

Routing Table Example

```
Gateway of last resort is 175.18.1.2 to network 0.0.0.0

     10.0.0.0 255.255.0.0 is subnetted, 4 subnets
C       10.1.0.0 is directly connected, Ethernet1
R       10.2.0.0  [120/1] via 10.4.0.1, 00:00:05, Ethernet0
R       10.3.0.0  [120/5] via 10.4.0.1, 00:00:05, Ethernet0
C       10.4.0.0 is directly connected, Ethernet0
R    192.168.12.0  [120/3] via 10.1.0.5, 00:00:08, Ethernet1
S    194.30.222.0 [1/0] via 10.4.0.1
S    194.30.223.0 [1/0] via 10.1.0.5
C    175.18.1.0 255.255.255.0 is directly connected, Serial0
S*   0.0.0.0 0.0.0.0 [1/0] via 175.18.1.2
```

Static or Dynamic

- **Static routing entries are configured manually**
  - **Override routes learned via dynamic routing**
  - ***Can* be set as permanent (will not be removed if interface goes down)**
  - **Only way for certain technologies (DDR)**
- **Dynamic routing entries are learned by routing protocols**
  - **Adapts to topology changes**
  - **But additional routing-traffic overhead**

Reasons for Static Routing

- Very low bandwidth links (e. g. dialup links)
- Administrator needs control over the link
- Backup links
- Link is the only path to a stub network
- Router has very limited resources and cannot run a routing protocol

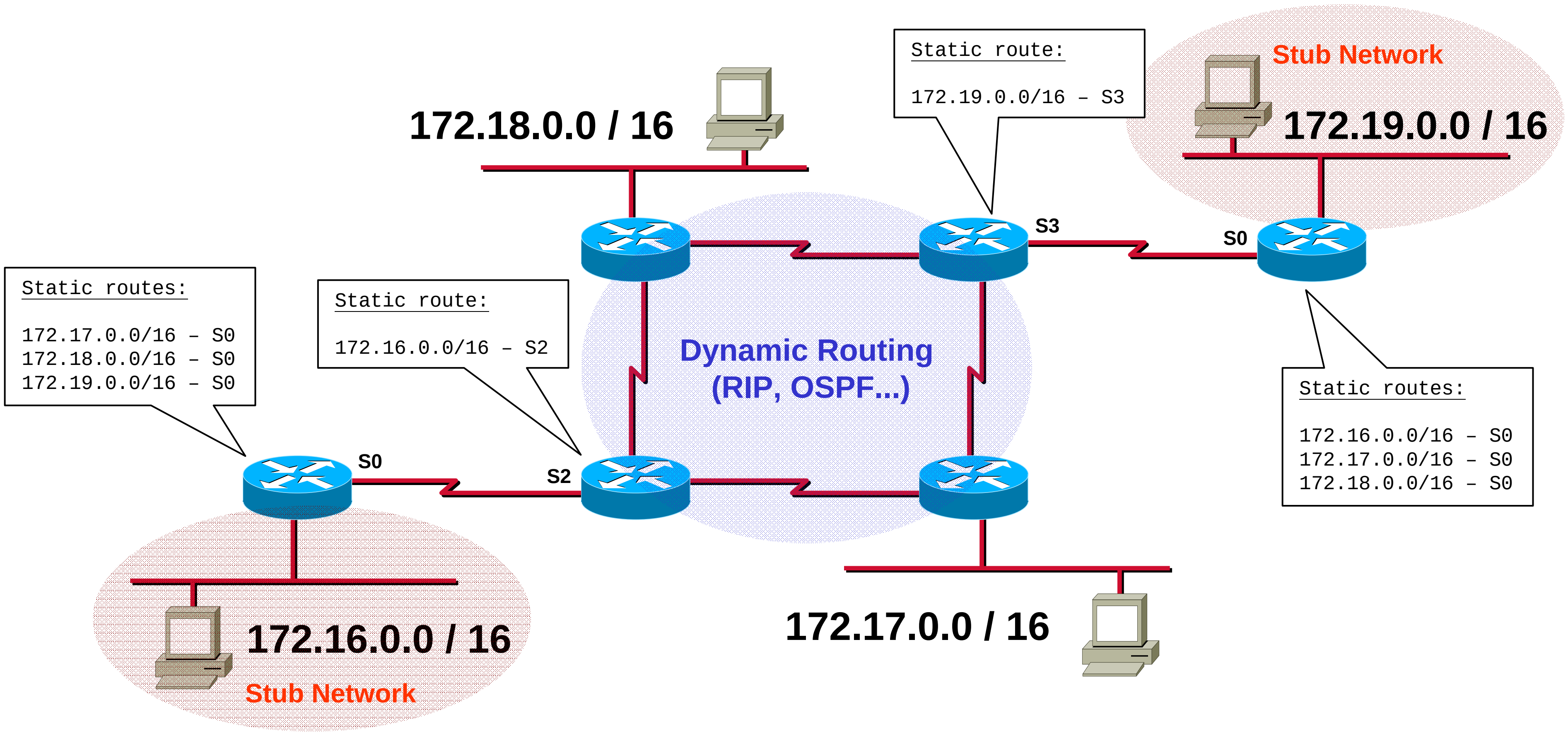
ip route *prefix mask* **{***ip-address* **|** *interface-type interface-number***}** **[***distance***]** **[tag** *tag***]** **[permanent]**

Tag value that can be used as a "match" value for controlling redistribution via route maps

Specifies that the route will not be removed, even if the interface shuts down

Static Routing (1)

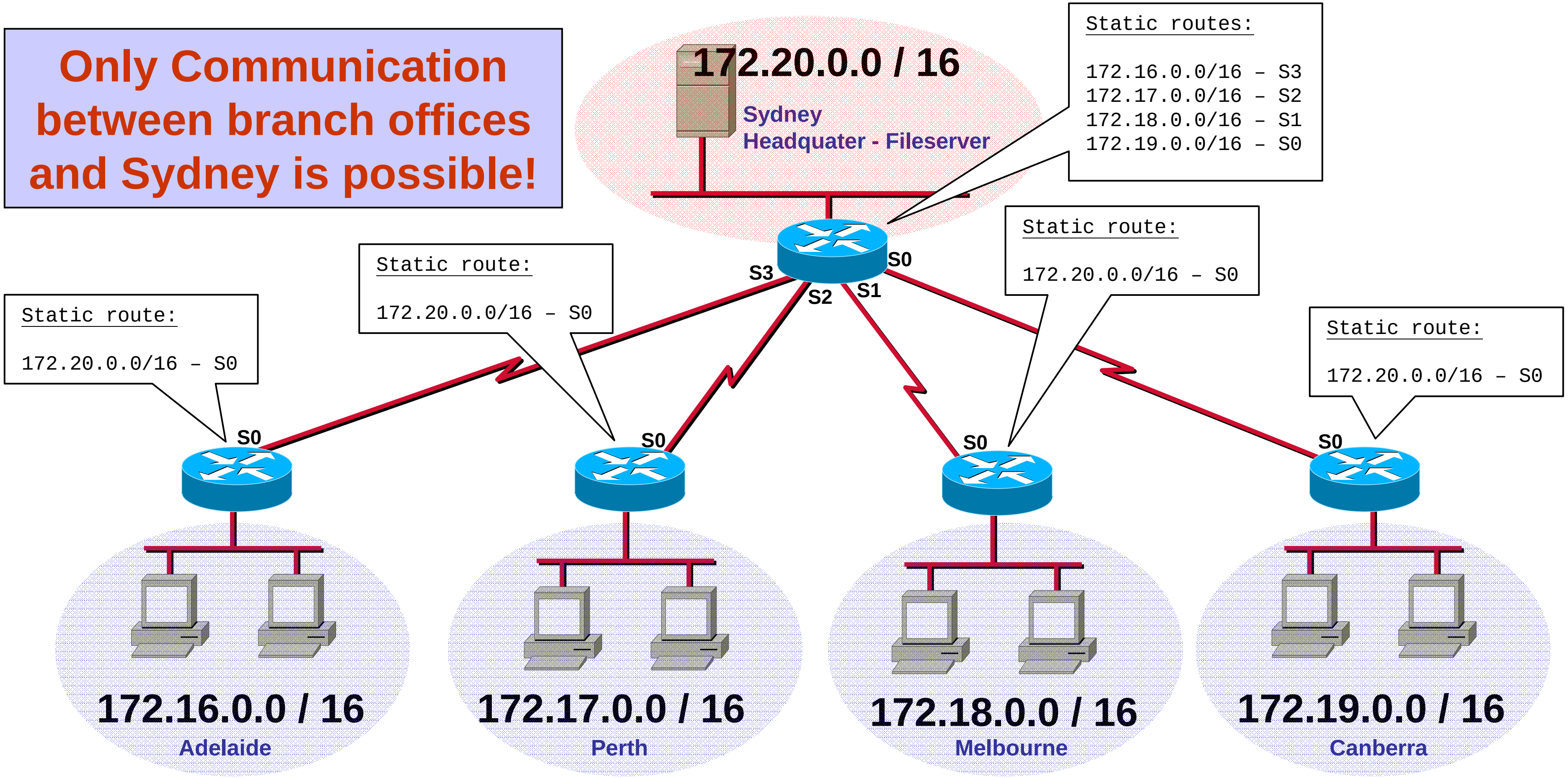
- Static routes to and from stub networks



Static Routing (2)

- Static routes in "Hub and Spoke" topologies

Only Communication between branch offices and Sydney is possible!

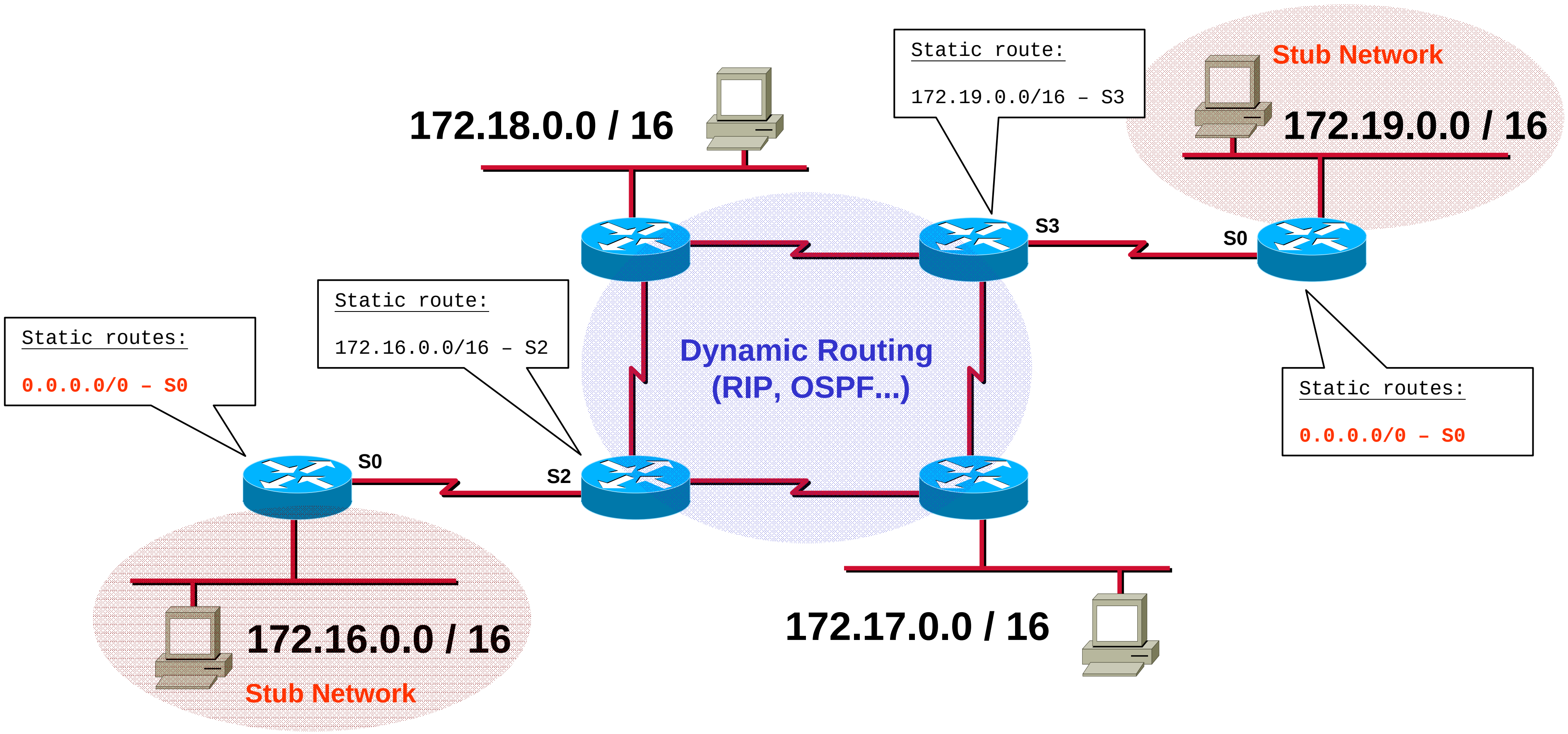


Default Routing

- **Special static route**
  - **Traffic to unknown destinations are forwarded to default router ("Gateway of Last Resort")**
- **Routing table entry "0.0.0.0 0.0.0.0"**
- **Hopefully, default gateway knows more destination networks**
- **Advantage: Smaller routing tables!**

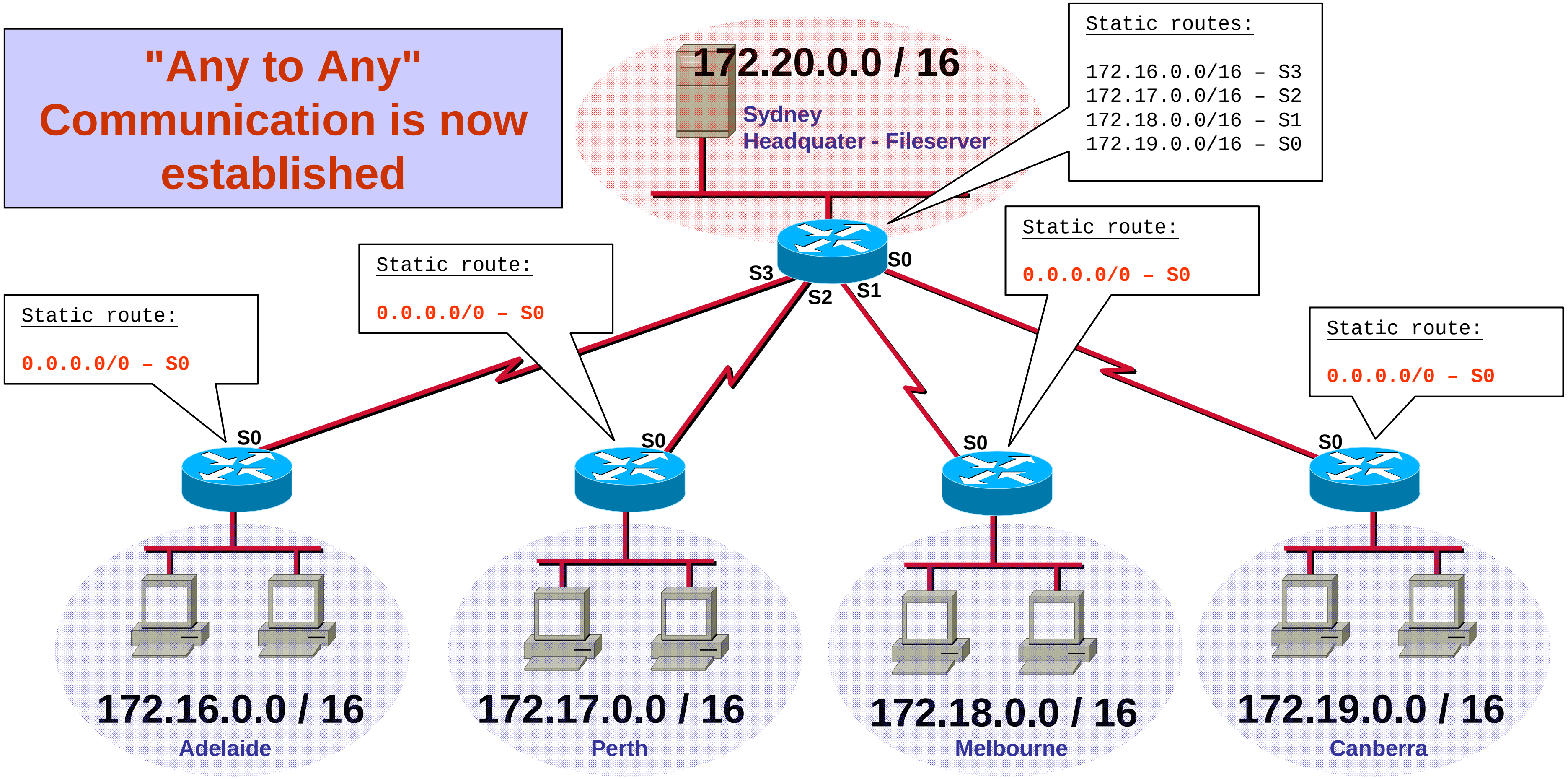
Default Routing (1)

- **Default Routes from stub networks**



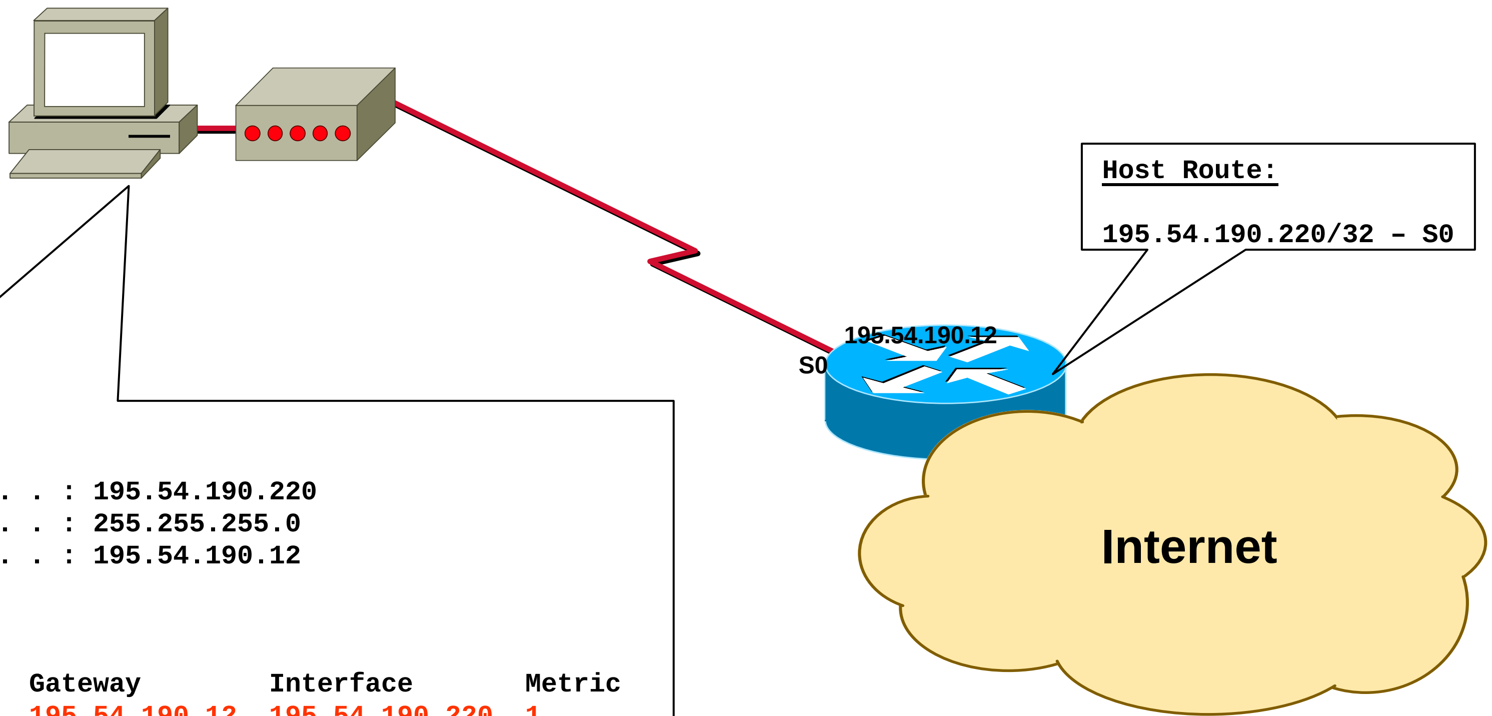
Default Routing (2)

- **Default routes in "Hub and Spoke" topologies**



Default Routing (3)

- **Default Routes to the Internet**



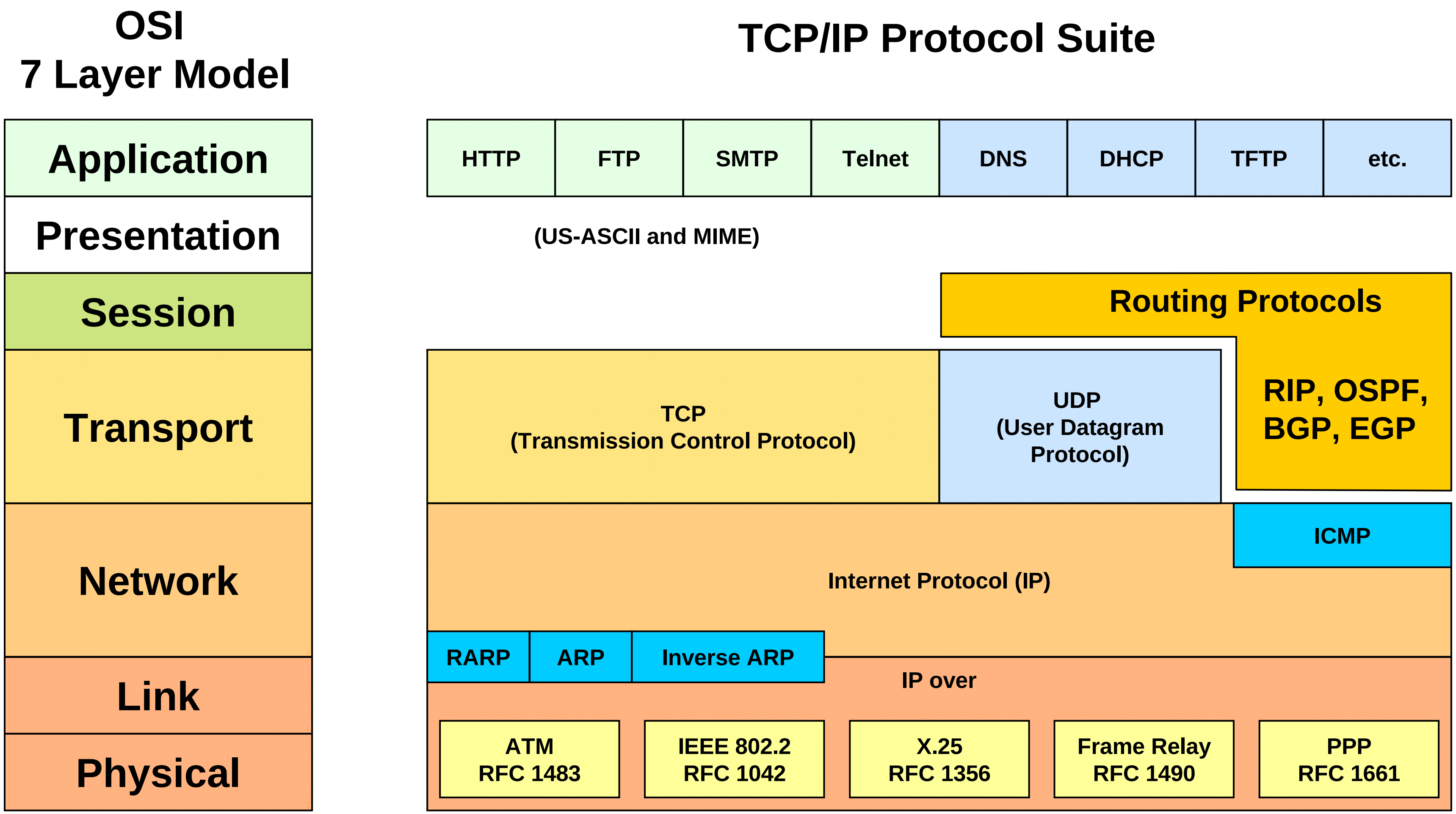

```
C:> ipconfig

IP Address. . . . . . : 195.54.190.220
Subnet Mask . . . . . : 255.255.255.0
Default Gateway . . : 195.54.190.12

C:> route print

Network  Netmask  Gateway       Interface      Metric
0.0.0.0  0.0.0.0  195.54.190.12 195.54.190.220 1
```

On Demand Routing (ODR)

- **Efficient for hub-and-spoke topologies**
  - **Same configuration at each router**
- **Uses CDP to send the prefixes of attached networks from the spokes, or stub networks, to the hub or core router**
  - **CDP does this automatically (!)**
- **The hub router sends its interface address of the shared link as the default route for the stub router**
- **Note:**
  - **Don't enable routing protocols on spoke routers**
  - **CDP must be enabled (don't forget e. g. ATM interfaces)**
  - **Every 60 sec a CDP message is sent per default (change with "cdp timer" command)**

(config)# **router odr**	**! Only on hub router**

Dymanic IP Routing Protocols



Dynamic Routing

- **dynamic routing**
  - routing tables are dynamically updated with information from other routers done by routing protocols
  - routing protocol
    - discovers current network topology
    - determines the best path to every reachable network
    - stores information about best paths in the routing table
  - metric information is necessary for best path decision
    - in most cases summarization along the a given path of static preconfigured values
      - hops, interface cost, interface bandwidth, interface delay, etc.
  - two basic technologies
    - distance vector, link state

Metric

- Routing protocols typically find out more than one route to the destination
- Metrics help to decide which path to use
  - Static values
    - Hop count, Distance
    - Cost (reciprocal value of bandwidth)
    - Bandwidth (EIGRP), Delay (EIGRP), MTU
  - Variable values
    - Load (EIGRP)
    - Reliability (EIGRP)

Dynamic Routing

- Each router can run one or more routing protocols
- Routing protocols are information sources to create routing table
- Routing protocols differ in convergence time, loop avoidance, network size, complexity

Routing Protocol Comparison

Routing Protocol	Complexity	Max. Size	Convergence Time	Reliability	Protocol Traffic
RIP	very simple	16 Hops	Up to 480 secs	Not absolutely loop-safe	High
RIPv2	very simple	16 Hops	Up to 480 secs	Not absolutely loop-safe	High
IGRP	simple	x	x	medium	medium
EIGRP	complex	x	x	x	x
OSPF	very complex	Thousands of Routers	Fast	High	low/ depends
IS-IS	complex	Thousands of Routers	Fast	High	x
BGP-4	complex	more than 100,000 networks	Fast	Very High	x

Administrative Distance

- Several routing protocols independently find out different routes to same destination
  - Which one to choose?
- "Administrative Distance" is a trustiness-value associated to each routing protocol
  - The lower the better
  - Can be changed

Administrative Distances Chart

Unknown	255
I-BGP	200
E-EIGRP	170
EGP	140
RIP	120
IS-IS	115
OSPF	110
IGRP	100
I-EIGRP	90
E-BGP	20
EIGRP Summary Route	5
Static route to next hop	1
Static route through interface	0
Directly Connected	0

Remember

1) Using the METRIC *one* routing protocol determines the best path to a destination.

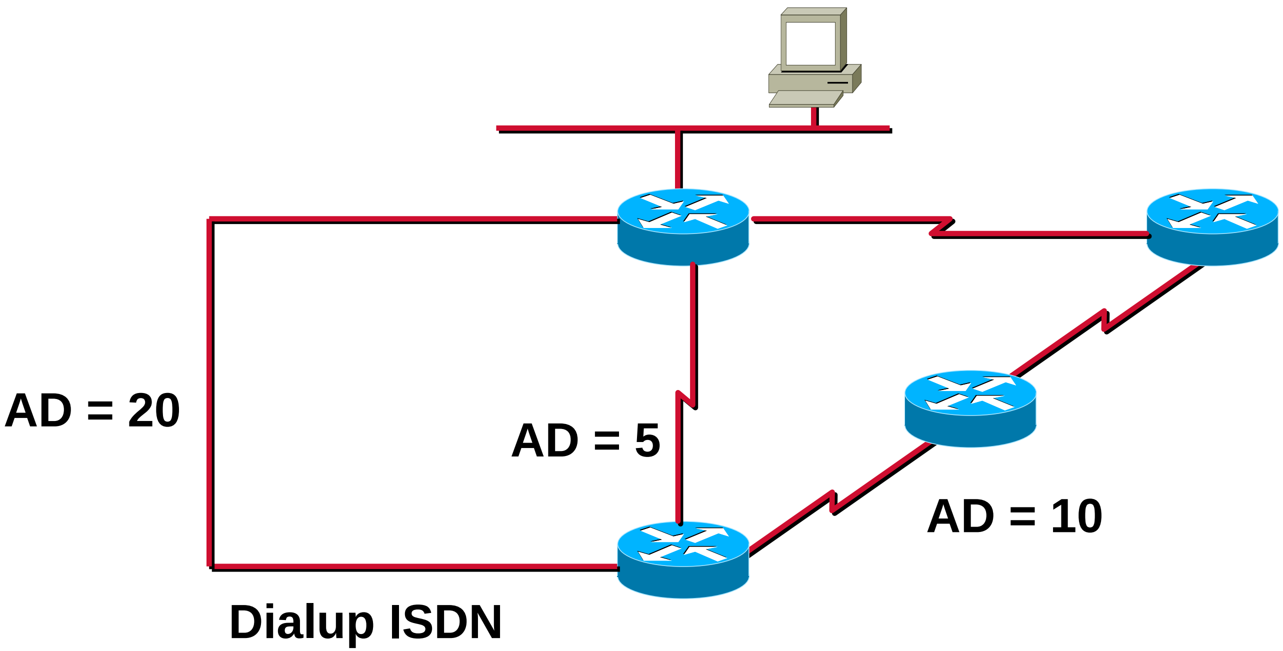
2) A router running multiple routing protocols might be told about multiple possible paths to one destination.

3) Here the METRIC cannot help for decisions because *different type of METRICS* cannot be compared with each other.

4) A router chooses the route which is proposed by the routing protocol with the *lowest* ADMINISTRATIVE DISTANCE

AD with Static Routes

- **Each static route can be given a different administrative distance**
- **This way fall-back routes can be configured**



Classification

- Depending on age:
  - Classful (no subnet masks)
  - Classless (VLSM/CIDR supported)
- Depending on scope:
  - IGP (Inside an Autonomous System)
  - EGP (Between Autonomous Systems)
- Depending on algorithm:
  - Distance Vector (Signpost principle)
  - Link State (Roadmap principle)

Distance Vector (1)

- After powering-up each router only knows about directly attached networks
- Routing table is sent periodically to all neighbor-routers
- Received updates are examined, changes are adopted in own routing table
- Metric information (originally) is number of hops
- "Bellman-Ford" algorithm

Distance Vector (2)

- Next hop is always originating router
  - Topology behind next hop unknown
  - Signpost principle
- Loops can occur!
  Additional mechanisms needed:
  - Maximum hop count
  - Split horizon (with poison reverse)
  - Triggered update
  - Hold down
- Examples: RIP, RIPv2, IGRP (Cisco)

Link State (1)

- **Each two neighbored routers establish adjacency**
- **Routers learn real topology information**
  - **Through "Link State Advertisements"**
  - **Stored in database (Roadmap principle)**
- **Updates only upon topology changes**
  - **Propagated by *flooding* (very fast convergence)**

Link State (2)

- Routing table entries are calculated by applying the Shortest Path First (SPF) algorithm on the database
  - Loop-safe
  - Alternative paths immediately known
  - CPU and memory greedy
- Large networks can be split into areas
- Examples: OSPF, Integrated IS-IS

Summary

- Routing is the "art" of finding the best way to a given destination
- Can be static or dynamic
  - Static means: YOU are defining the way packets are going
  - Dynamic means: A routing protocol is "trying" to find the best way to a given destination
- In today's routers the route with the longest match is used
- Routing protocols either implement the principle *Distance Vector* or *Link State*