IP Routing

Objectives

- How are source and destination IP addresses used to route traffic through a network?
- What are sources for routing information used to populate a router’s routing table?
- How do routed protocols differ from routing protocols?
- When multiple routing protocols know how to reach a destination network, which route is chosen?
- When a single routing protocols knows of multiple routes to reach a destination network, how is the preferred path (or paths) chosen?
- What is the distinction between IGP and EGP?
- What are the primary differences between distance-vector and link-state routing protocols?
- What are the characteristics of the following routing protocols: RIP, OSPF, IS-IS, EIGRP, and BGP?
- How does NAT perform IP address translation, and how do the PAT, SNAT and DNAT approaches to NAT differ?

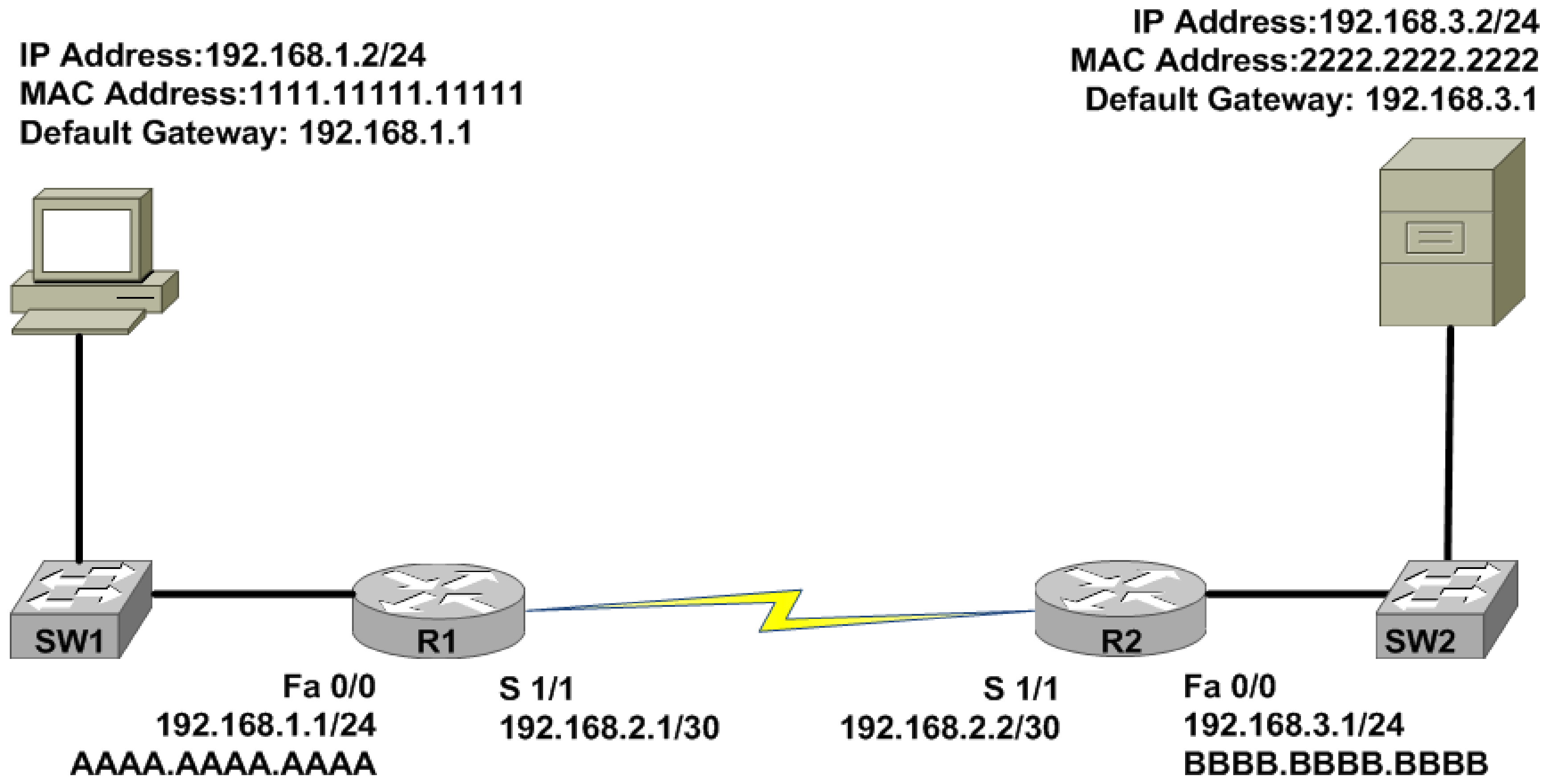
Routing Basics

- In IT, routing essentially refers to the process of taking a packet from one device and sending it through the network to another device on a different network.
- Routers don’t really care about hosts—they only care about networks and the best path to each network.
- The logical network address of the destination host is used to get packets to a network through a routed network, and then the hardware address of the host is used to deliver the packet from a router to the correct destination host.

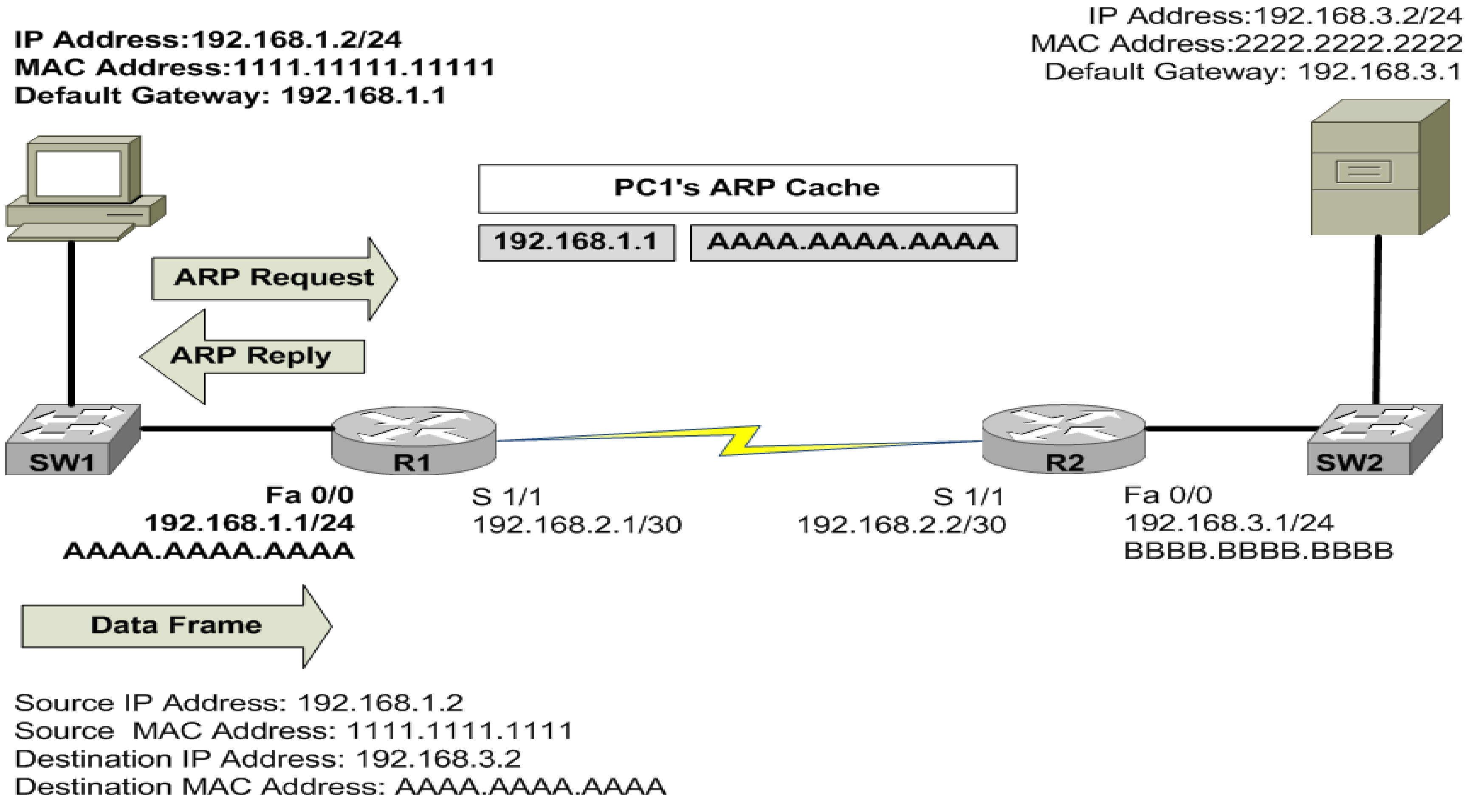
Essential device?

- No. If your network has no routers, then, you are not routing

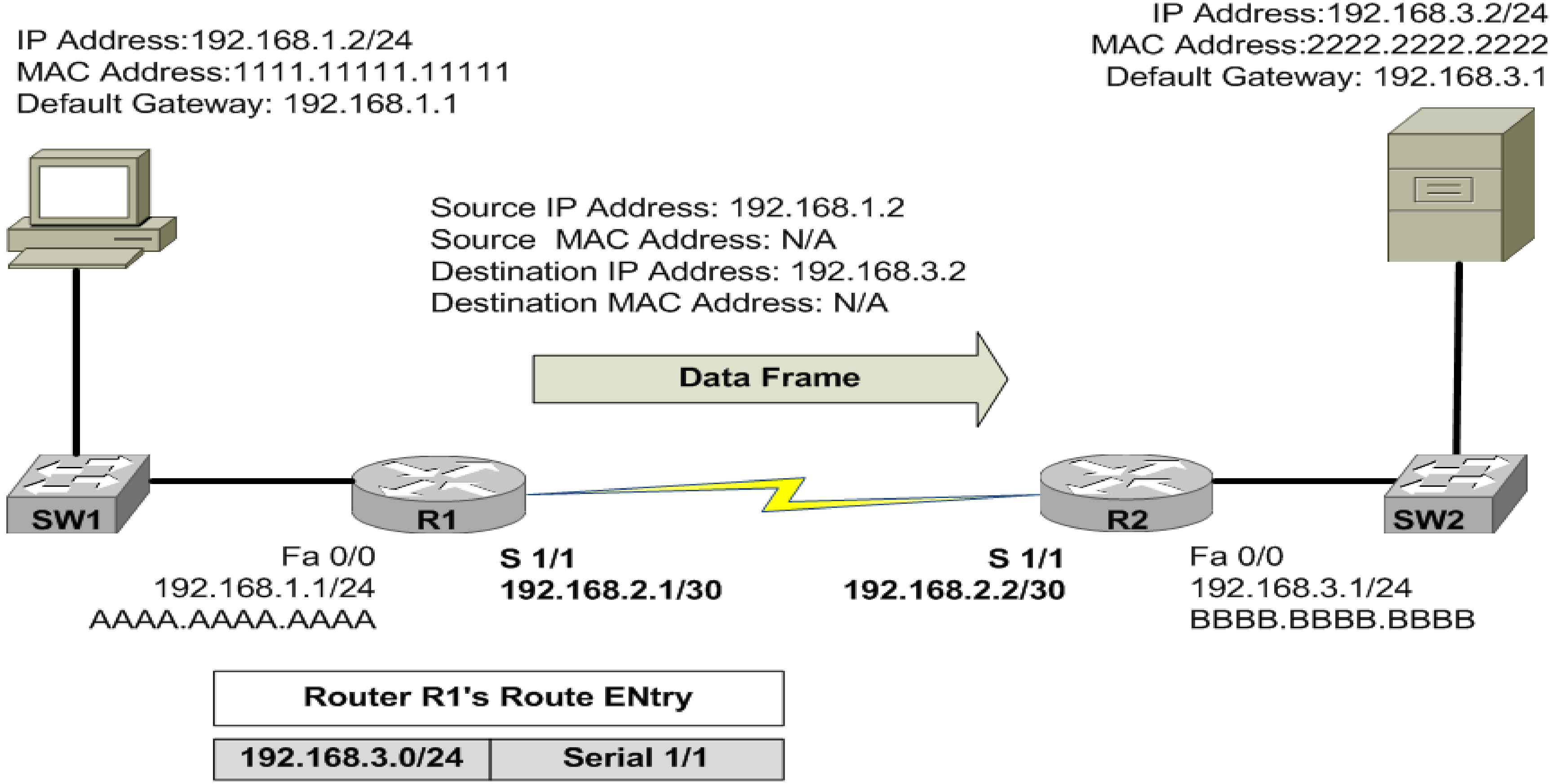
Basic Routing



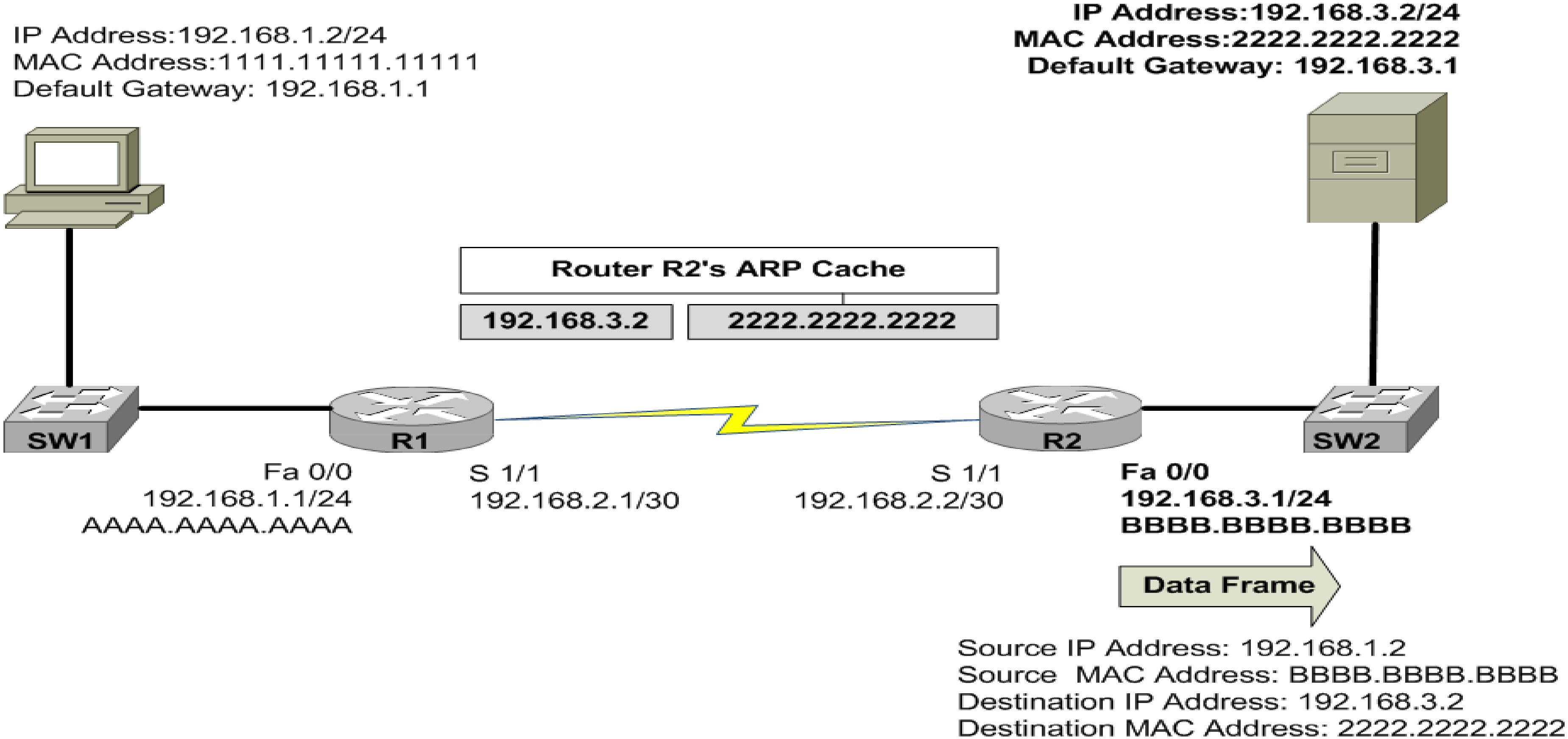
Basic Routing



Basic Routing



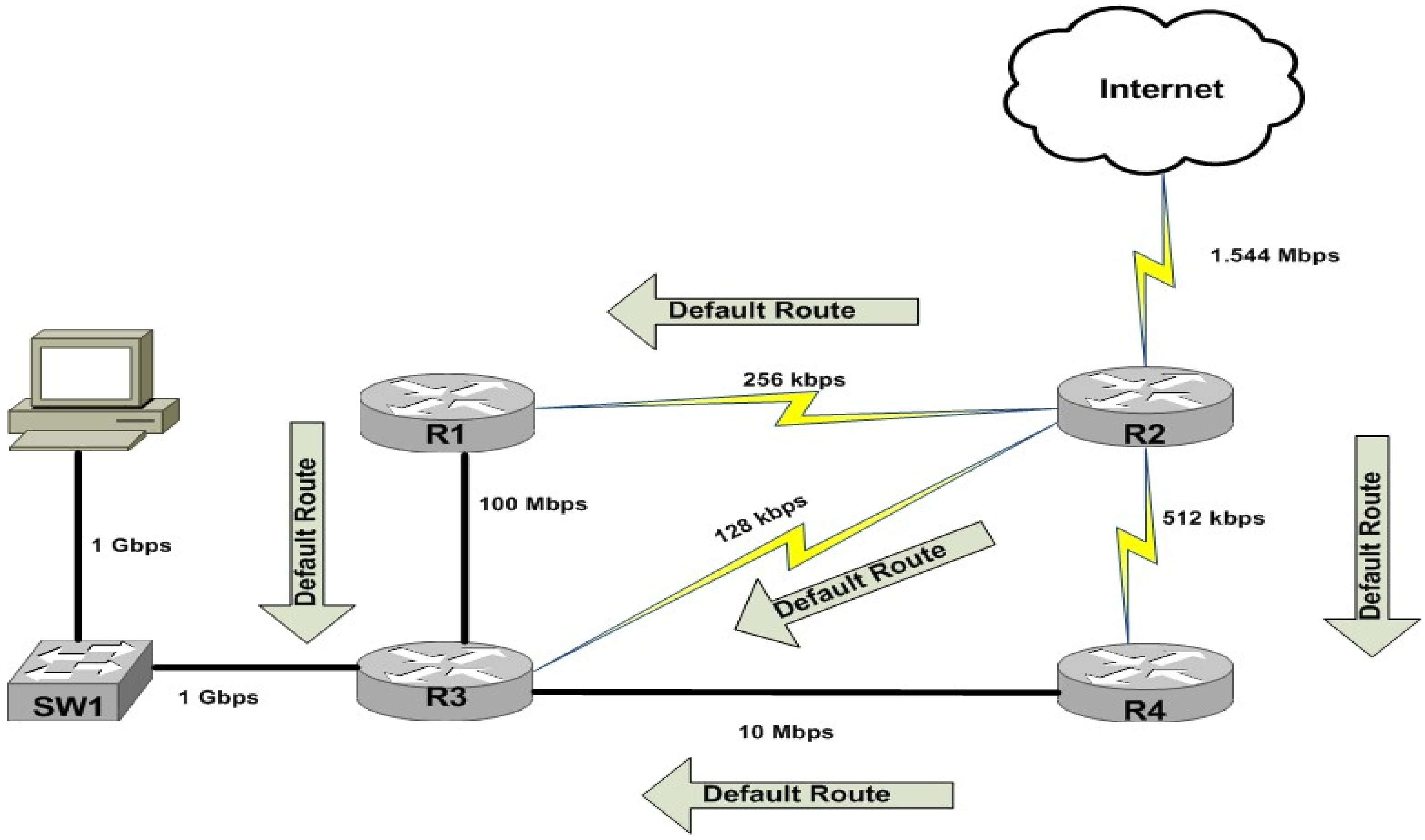
Basic Routing



Source of Routing Information

- Before a router can route an IP packet, it needs to populate its routing table. A Router's routing table can be populated from the following sources.
  - From directly connected networks (configured interfaces)
    - Called a ***directly connected route***
  - An administrator could statically configure a route table.
    - Called a ***static route,*** an/or ***default static route***
  - A router could learn routes dynamically via routing protocols.
    - Called a ***dynamic route*** or ***learned route***

Sources of Routing Information



Routing & Routed Protocols

- A routing protocol is a tool used by routers to dynamically find all the networks in the internetwork, as well as to ensure that all routers have the same routing table.
- Basically, a routing protocol determines the path of a packet through an internetwork.
- Examples of routing protocols are Routing Information Protocol (RIP), RIPv2, Enhanced Interior Gateway Routing Protocol (EIGRP), and Open Shortest Path First (OSPF).
- Once all routers know about all networks, a routed protocol can be used to send user data (packets) through the established internetwork.
- Routed protocols are assigned to an interface and determine the method of packet delivery.
- Examples of routed protocols are Internet Protocol (IP) and IPv6.

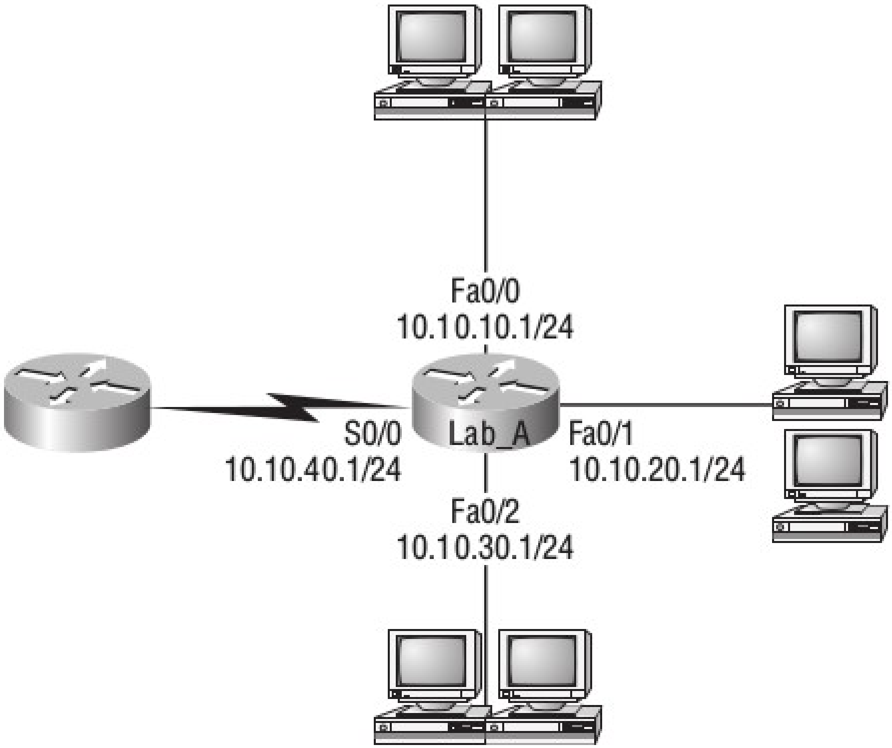
Router – basic information

- To be capable of routing packets, a router must know at least the following information:
  - Destination address
  - Neighbor routers from which it can learn about remote networks
  - Possible routes to all remote networks
  - The best route to each remote network
  - How to maintain and verify routing information

Static vs Dynamic Routing

- Static routing :
  - Which can be a ton of work because it requires someone to hand-type all network locations into the routing table.
- Dynamic routing :
  - A protocol on one router communicates with the same protocol running on neighbor routers.
  - The routers then update each other about all the networks they know about and place this information into the routing table.
  - If a change occurs in the network, the dynamic routing protocols automatically inform all routers about the event.

A simple routing example




```
Router_A#show ip route
[output cut]
Gateway of last resort is not set
C      10.10.10.0/24 is directly connected, FastEthernet0/0
C      10.10.20.0/24 is directly connected, FastEthernet0/1
C      10.10.30.0/24 is directly connected, FastEthernet0/2
C      10.10.40.0/24 is directly connected, Serial 0/0
```

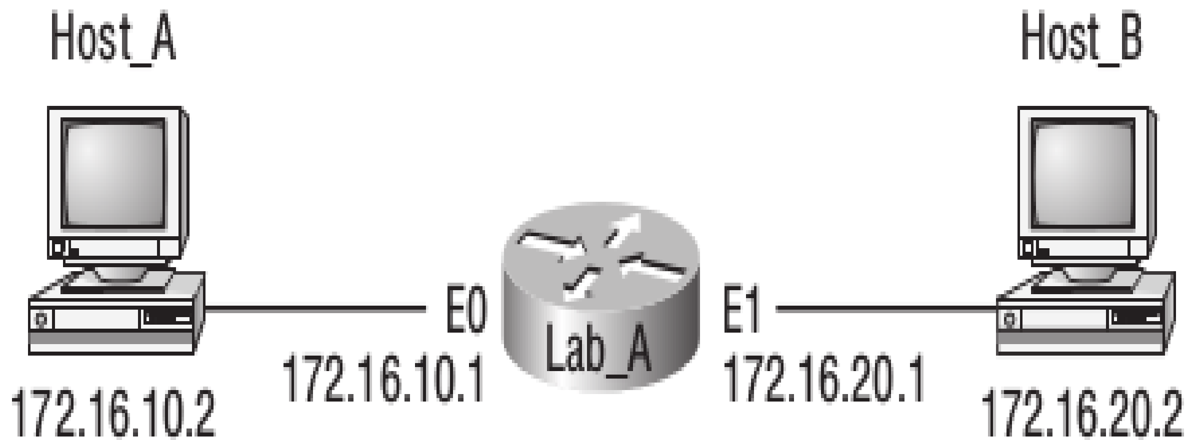
Question

- Based on the output of the next routing table, which interface will a packet with a destination address of 10.10.10.14 be forwarded from?

```
Router_A#sh ip route
[output cut]
Gateway of last resort is not set
C      10.10.10.16/28 is directly connected, FastEthernet0/0
C      10.10.10.8/29 is directly connected, FastEthernet0/1
C      10.10.10.4/30 is directly connected, FastEthernet0/2
C      10.10.10.0/30 is directly connected, Serial 0/0
```

The IP Routing Process

IP routing example using two hosts and one router



Packet delivery - steps

- A packet is created on the host
- The packet is forwarded
- The router receives the packet
- The router routes the packet
- Finally, the remote host receives the packet
- The destination host becomes a source host
- Time for the router to route another packet
- The original source host, now the destination host, receives the reply packet

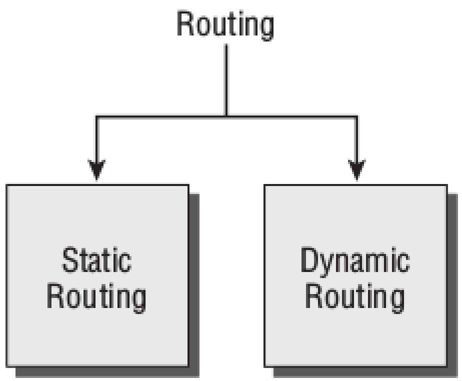
Static and Dynamic Routing

- What happens when a router receives a packet for a network that isn’t listed in the routing table?
  - It doesn’t send a broadcast looking for the remote network—the router just discards the packet.
- There are several ways to configure the routing tables to include all the networks so that packets will be forwarded.

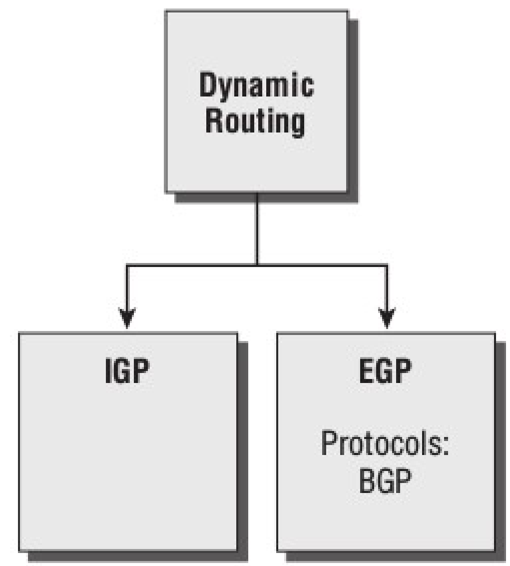
Static and Dynamic Routing...

- We can configure a router either with static or dynamic routing.
- If we choose static routing, then we have to go to each router and type in each network and the path that IP will use to send packets.
- However, static routing does not scale well in large networks, but dynamic routing does because network routes are automatically added to the routing table via the routing protocol

Routing options



Dynamic routing options



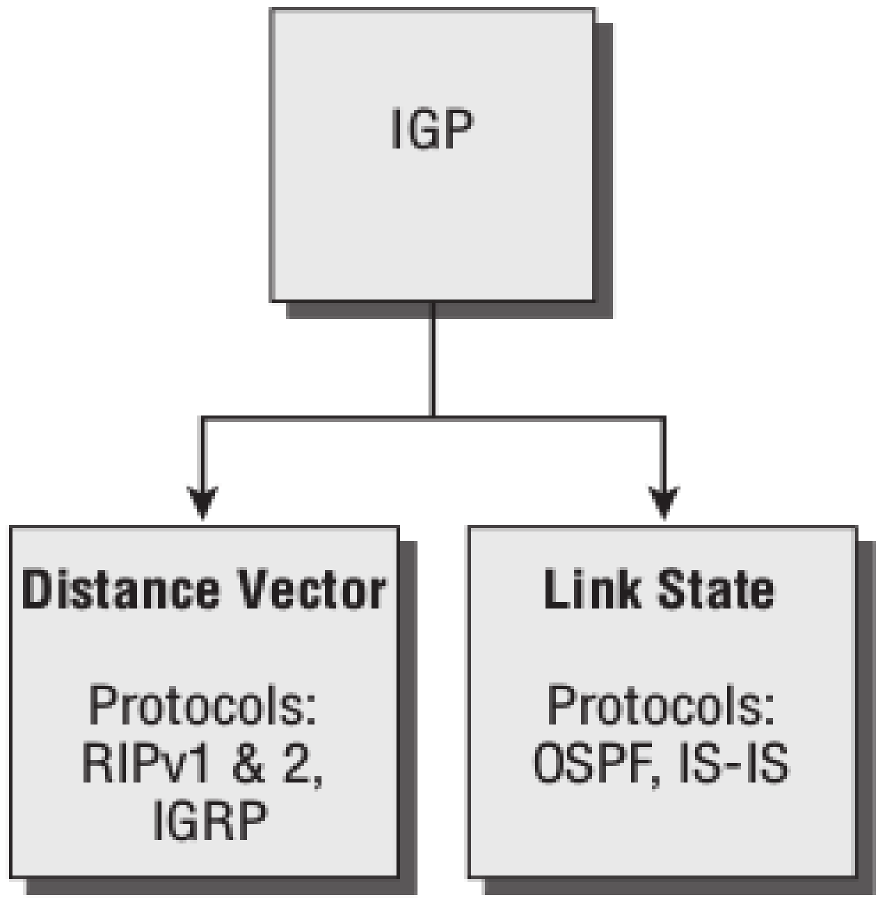
Autonomous system

- A collection of networks or subnets that are in the same administrative domain.
- This is another way of saying an administrative domain is within your company’s network, and you control or administer all the subnets that are within it.
- You control and set the policy for what happens in the network or autonomous system.
- You can now see that an IGP operates and routes within an AS and an EGP works outside or between more than one AS.

EGP

- The most popular protocol for an EGP is Border Gateway Protocol (BGP), which is typically used by ISPs or really large corporations.
- As an administrator of a small-to-medium-size network, you’ll probably never use BGP.

IGP – Distant vector and Link State



Distance Vector routing protocols

- Base their decisions on the best path to a given destination based on the distance.
- Distance is usually measured in hops, though the distance metric could be delay, packets lost, or something similar.
- If the distance metric is hop, then each time a packet goes through a router, a hop is considered to have traversed.
- The route with the least number of hops to a given network is concluded to be the best route towards that network.

Distance vector protocols...

- The vector shows the direction to that specific network.
- Distance vector protocols send their entire routing table to directly connected neighbors.
- Examples of distance vector protocols include RIP - Routing Information Protocol and IGRP - Interior Gateway Routing Protocol

Link State Routing Protocols

- Also called shortest-path-first protocols.
- Link state routing protocols have a complete picture of the network topology.
- Hence they know more about the whole network than any distance vector protocol.

Link State Routing Protocols...

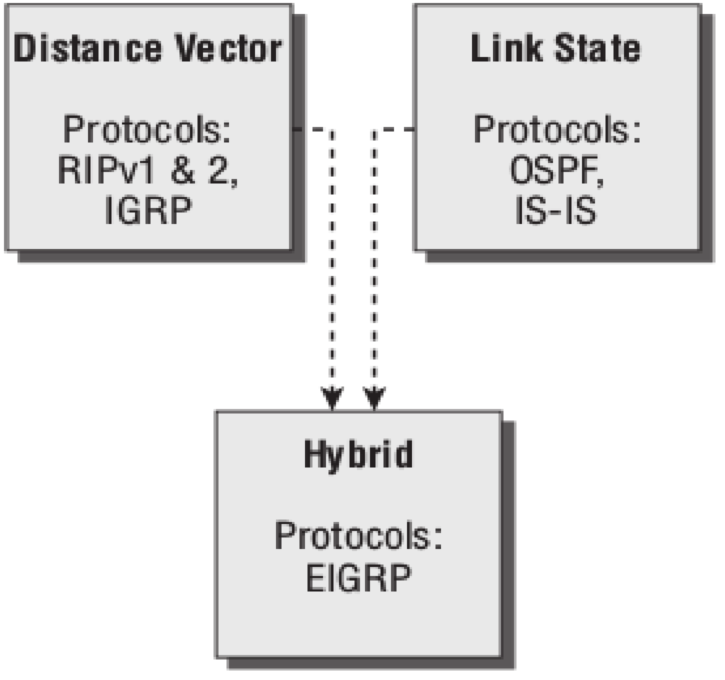
- Three separate tables are created on each link state routing enabled router.
  - One table is used to hold details about directly connected neighbors,
  - One is used to hold the topology of the entire internetwork
  - One is used to hold the actual routing table.

Link State Routing Protocols...

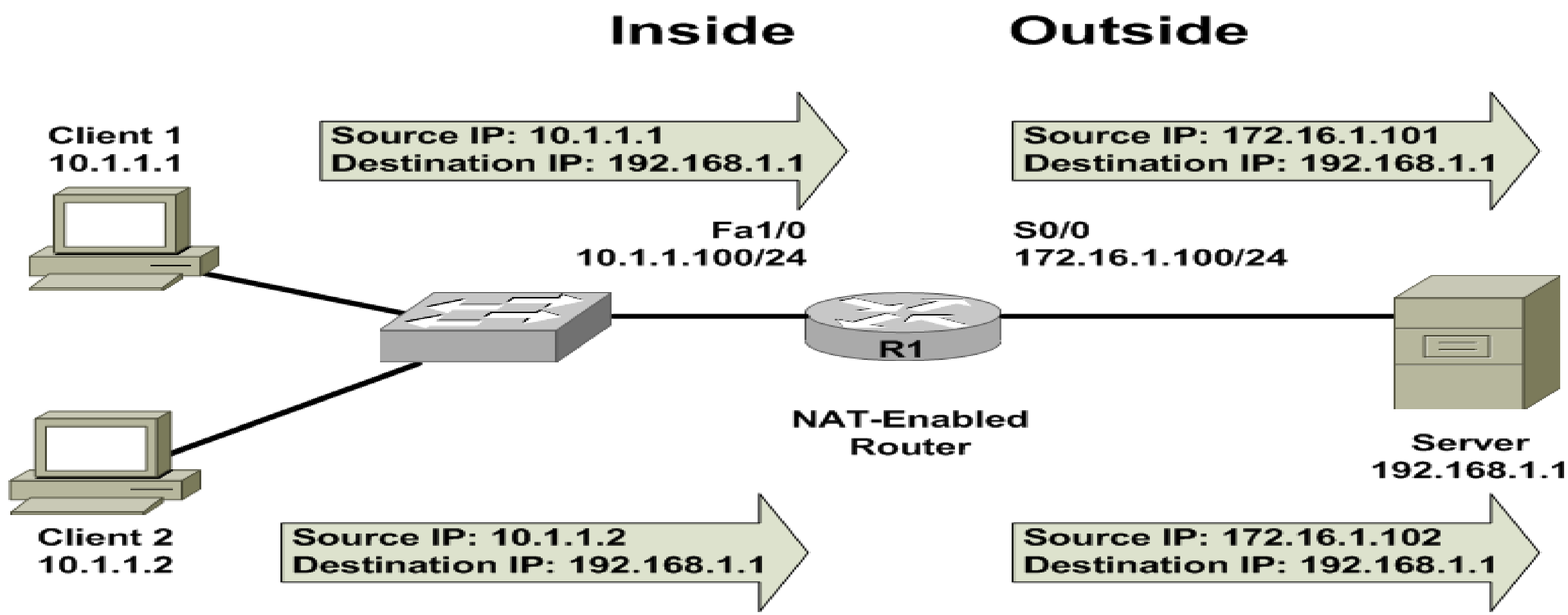
- Link state protocols send information about directly connected links to all the routers in the network.
- Examples of Link state routing protocols include OSPF - Open Shortest Path First and IS-IS - Intermediate System to Intermediate System.

Hybrid Routing

- The only protocol under this category is EIGRP. It is Cisco proprietary and uses the features of both DV and LS.



Address Translation



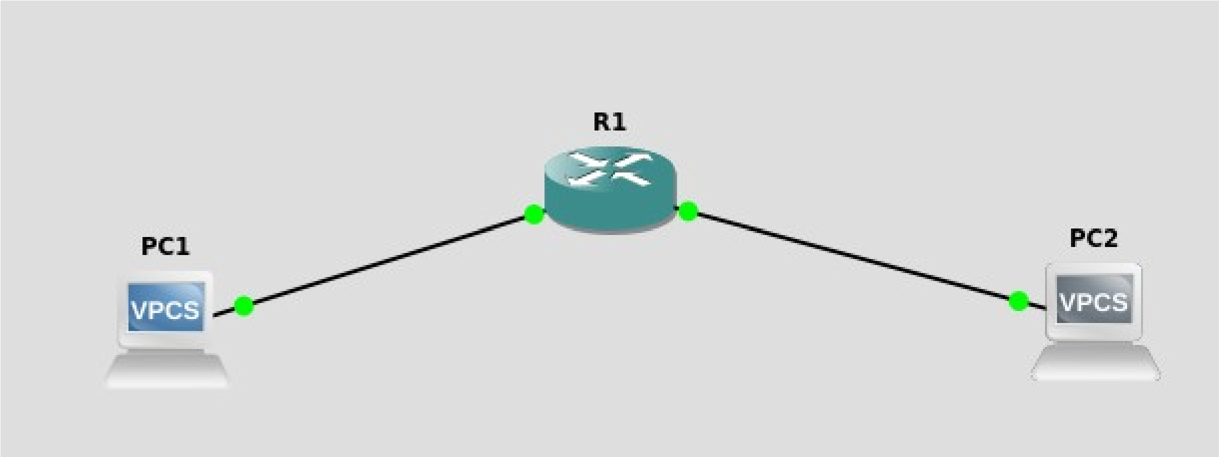
Router R1's NAT Translation Table

Inside Local Address	Inside Global Address
10.1.1.1	172.16.1.101
10.1.1.2	172.16.1.102

Address Translation

- Network Address Translation (NAT)
  - Dynamic NAT (DNAT) – assigns IP address from a pool of addresses, <u>one to one</u> translations.
  - Static NAT (SNAT) – assigns IP address manually, <u>one to one </u>translations
  - Port Address Translation (PAT) – assigns IP address using a <u>many to one </u>translation.

Lab – GNS3



PC1> ip 192.168.1.1 /24 192.168.1.100
PC1> save

PC2> ip 192.168.2.1 /24 192.168.2.100
PC2> save

R1#configure terminal
R1(config)#interface ethernet 0/0
R1(config-if)#ip address 192.168.1.100 255.255.255.0
R1(config-if)#no shutdown
R1(config)#interface ethernet 1/0
R1(config-if)#ip address 192.168.2.100 255.255.255.0
R1(config-if)#no shutdown
exit
do wr

PC1> ping 192.168.1.100
PC1> ping 192.168.2.100
PC1> ping 192.168.2.1

Lab – With Linux

- Ifconfig eth0 192.168.1.100
- Ifconfig eth1 192.168.2.100
- echo 1 >/proc/sys/net/ipv4/ip_forward

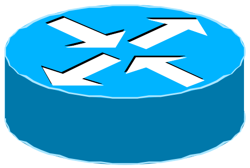
- Connect PC1 to eth0 – set ip 192.168.1.1
- Connect PC2 to eth1 – set ip 192.168.2.1
- From PC1, ping 192.168.2.1

Questions?

Introduction to Internet

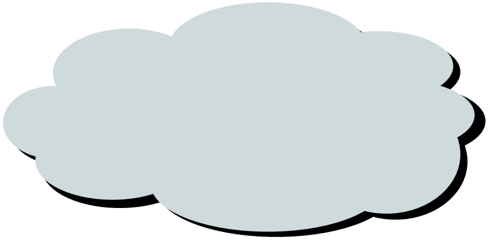
Slides courtesy: APNIC

Some Icons…



Router
(layer 3, IP datagram forwarding)

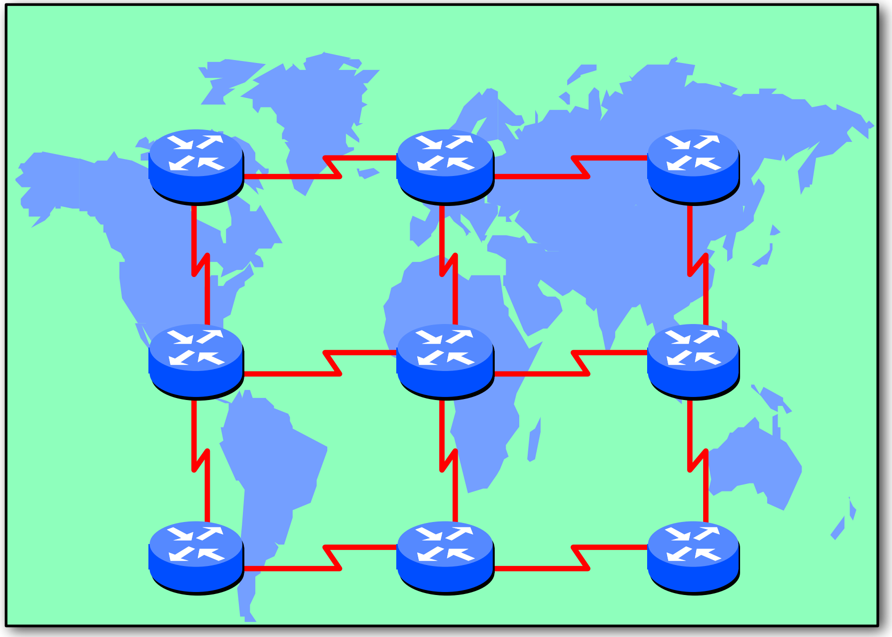
Ethernet switch
(layer 2, packet forwarding)



Network Cloud

Routed Backbone

- ISPs build networks covering regions
  - Regions can cover a country, sub-continent, or even global
  - Each region has points of presence built by the ISP
- Routers are the infrastructure
- Physical circuits run between routers
- Easy routing configuration, operation and troubleshooting
- The dominant topology used in the Internet today



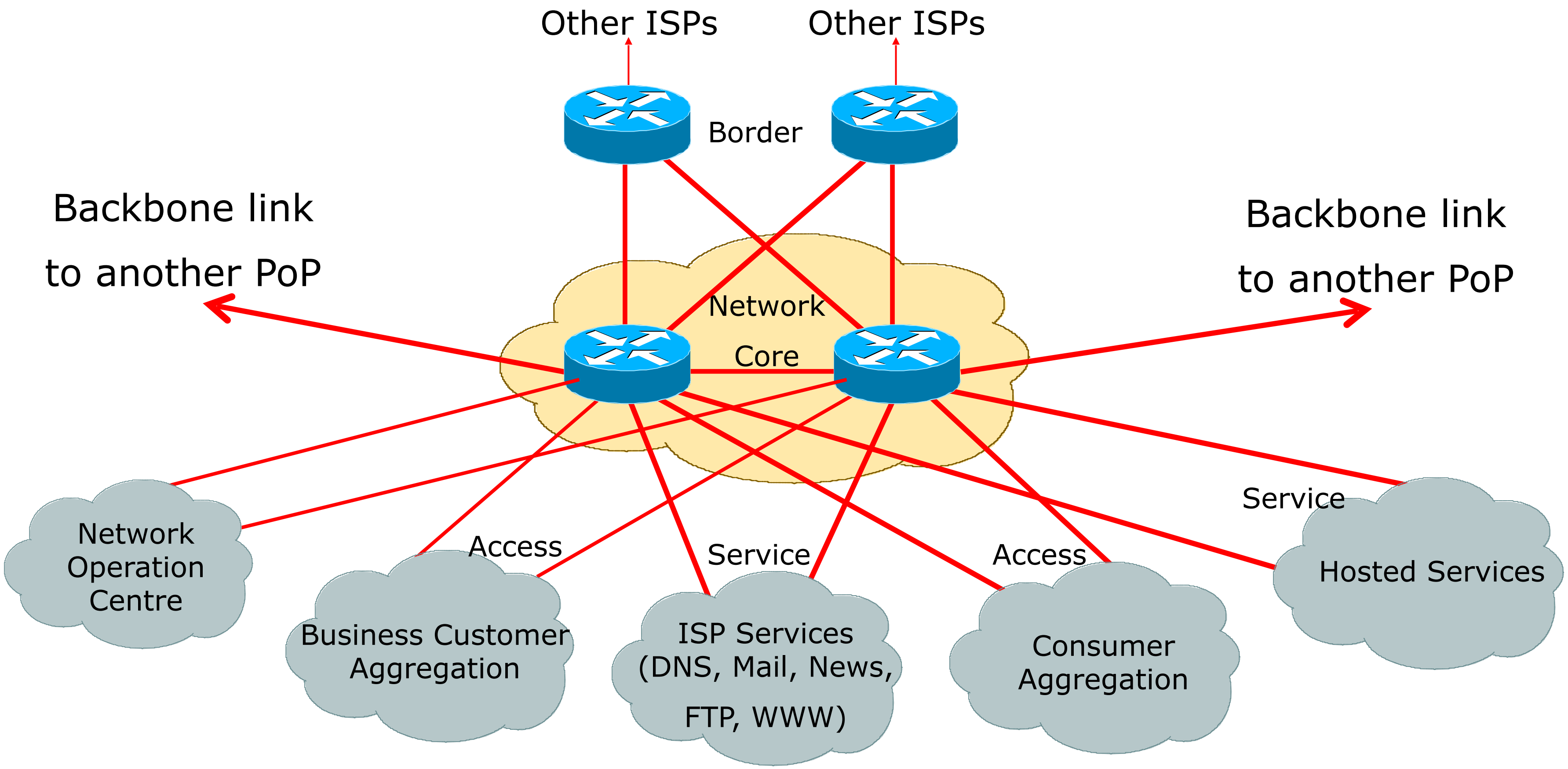
Points of Presence

- PoP – Point of Presence
  - Physical location of ISP’s equipment
  - Sometimes called a “node”
- vPoP – virtual PoP
  - To the end user, it looks like an ISP location
  - In reality a back hauled access point
  - Used mainly for consumer access networks
- Hub/SuperPoP – large central PoP
  - Links to many PoPs

PoP Topologies

- Core routers
  - high speed trunk connections
- Distribution routers
  - higher port density, aggregating network edge to the network core
- Access routers
  - high port density, connecting the end users to the network
- Border routers
  - connections to other providers
- Service routers
  - hosting and servers
- Some functions might be handled by a single router

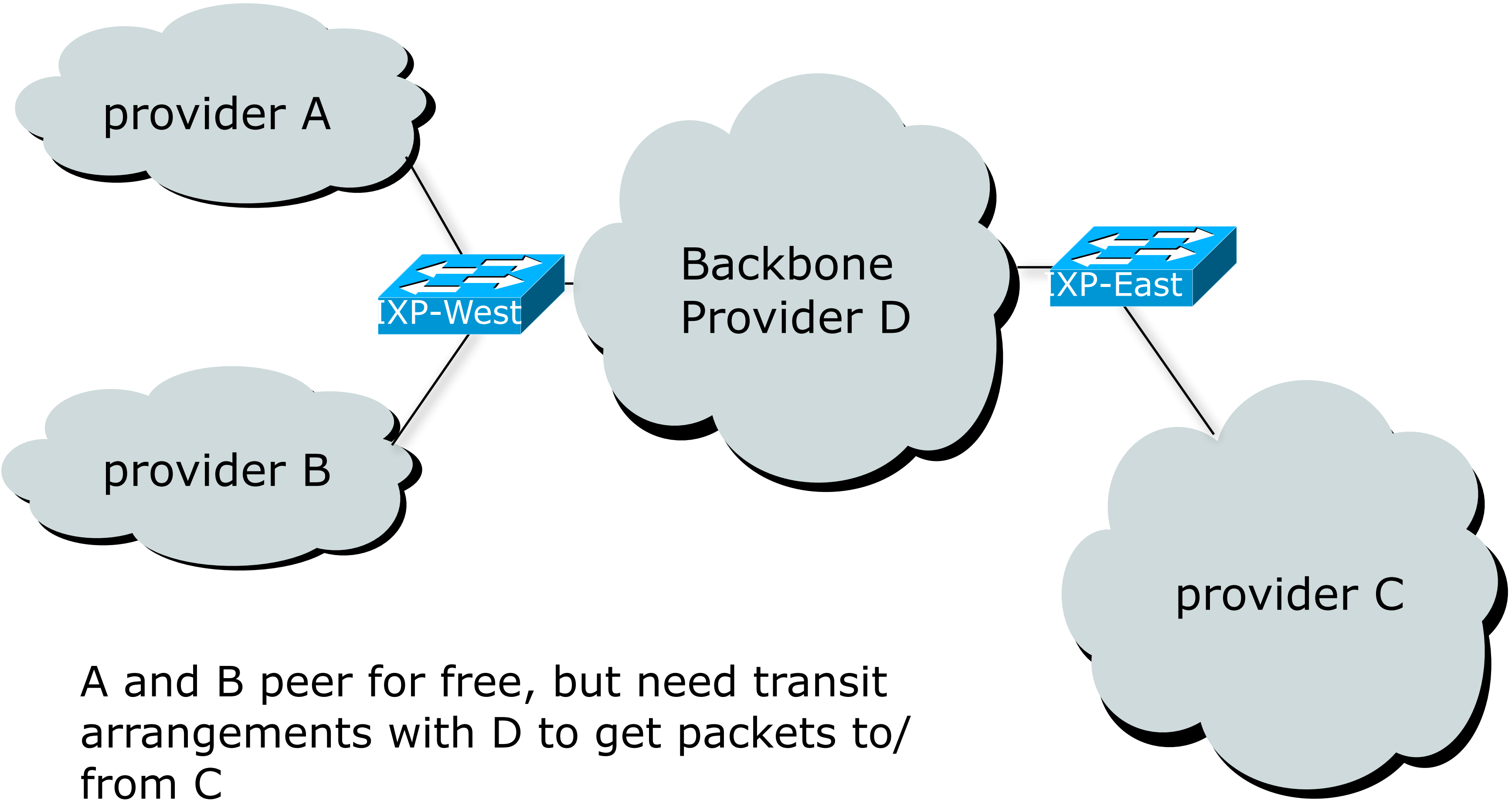
Typical PoP Design



More Definitions

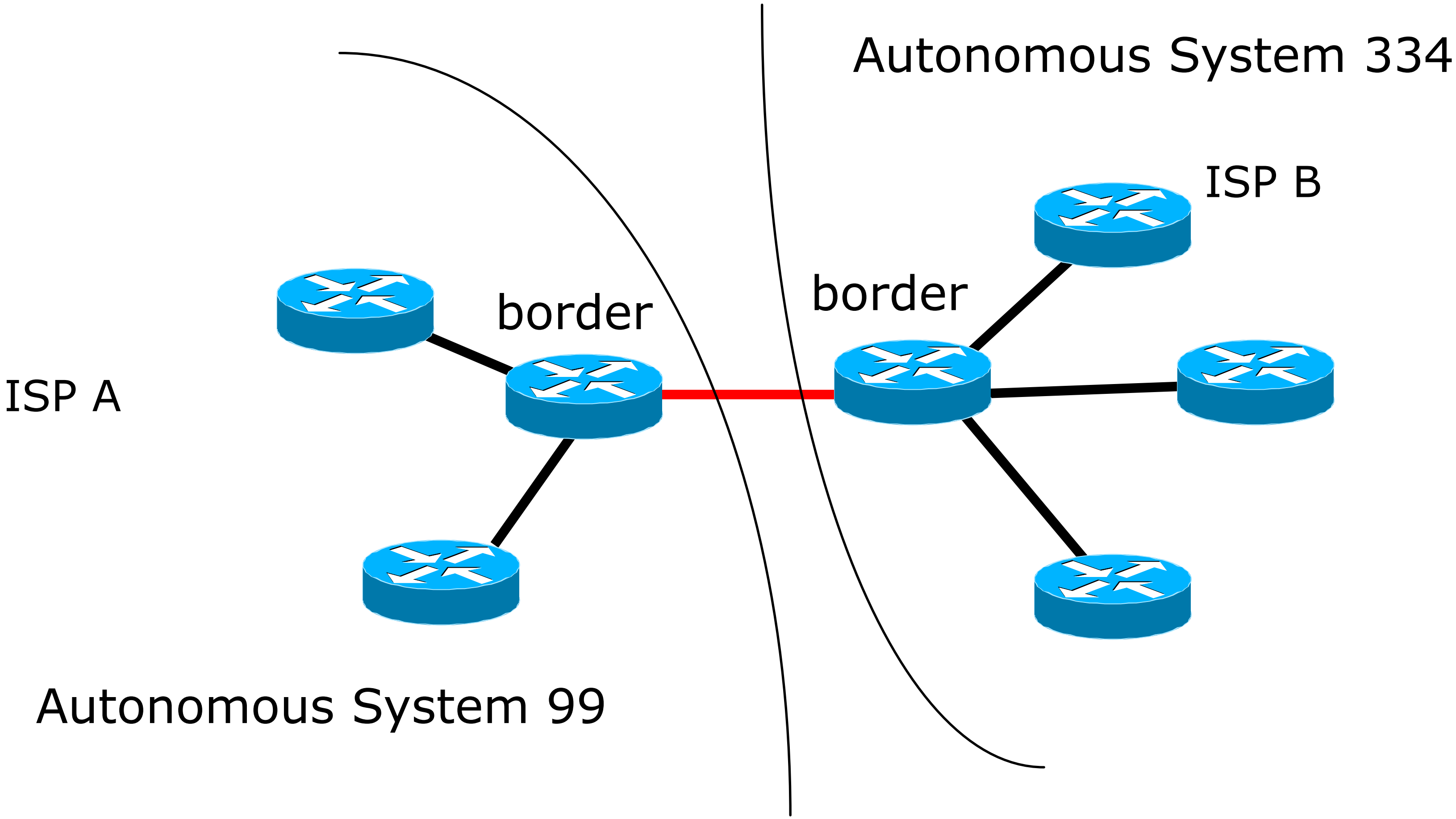
- Transit
  - Carrying traffic across a network
  - Usually **for a fee**
- Peering
  - Exchanging routing information and traffic
  - Usually **for no fee**
  - Sometimes called **settlement free peering**
- Default
  - Where to send traffic when there is no explicit match in the routing table

Peering and Transit example



A and B peer for free, but need transit arrangements with D to get packets to/from C

Private Interconnect



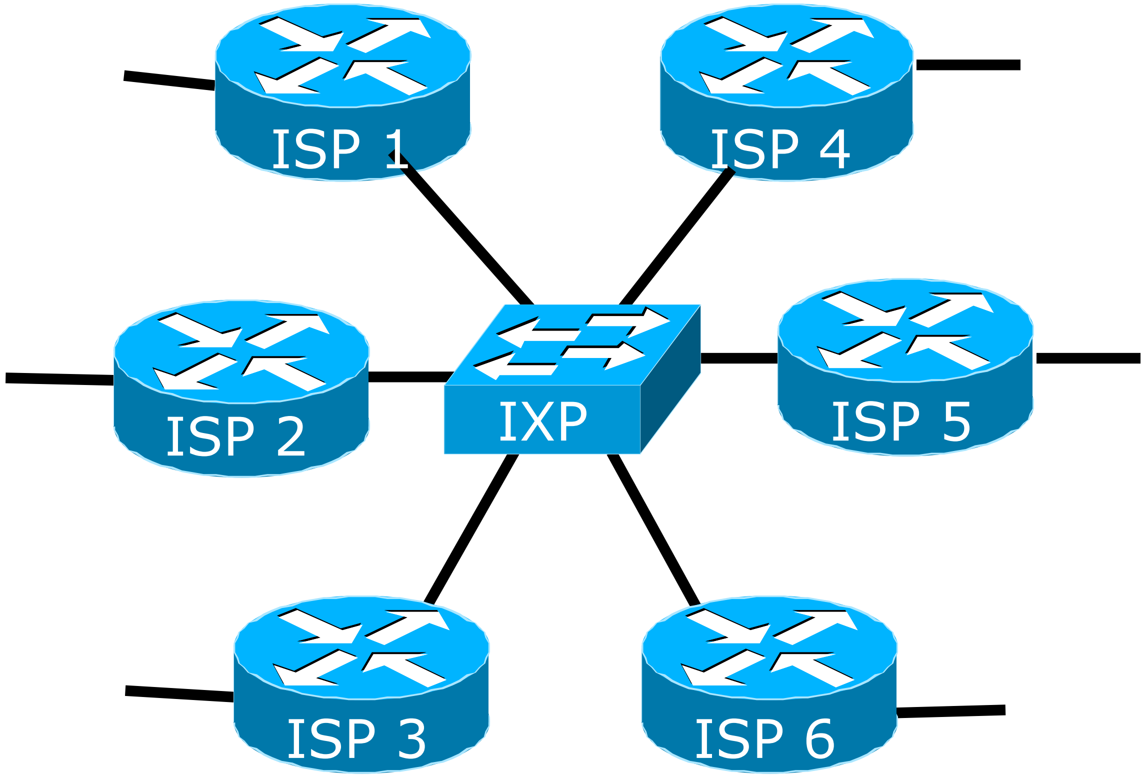
Public Interconnect

- A location or facility where several ISPs are present and connect to each other over a common shared media
- Why?
  - To save money, reduce latency, improve performance
- IXP – Internet eXchange Point
- NAP – Network Access Point

Public Interconnect

- Centralised (in one facility)
- Distributed (connected via WAN links)
- Switched interconnect
  - Ethernet (Layer 2)
  - Technologies such as SRP, FDDI, ATM, Frame Relay, SMDS and even routers have been used in the past
- Each provider establishes **peering** relationship with other providers at IXP
  - ISP border router peers with all other provider border routers

Public Interconnect

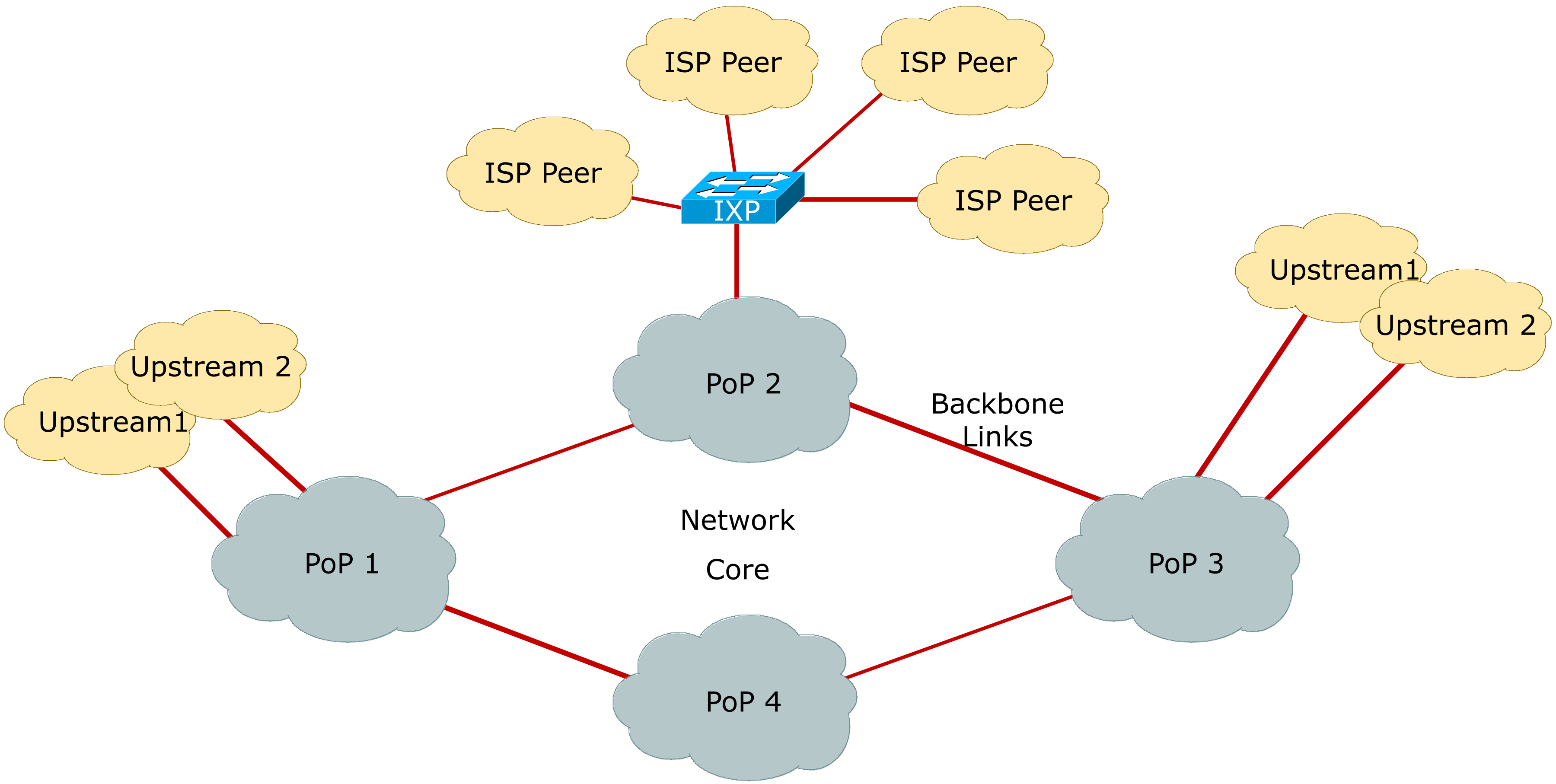


Each of these represents a border router in a different autonomous system

ISPs participating in Internet

- Bringing all pieces together, ISPs:
  - Build multiple PoPs in a distributed network
  - Build redundant backbones
  - Have redundant external connectivity
  - Obtain transit from upstream providers
  - Get free peering from local providers at IXPs

Example ISP Backbone Design



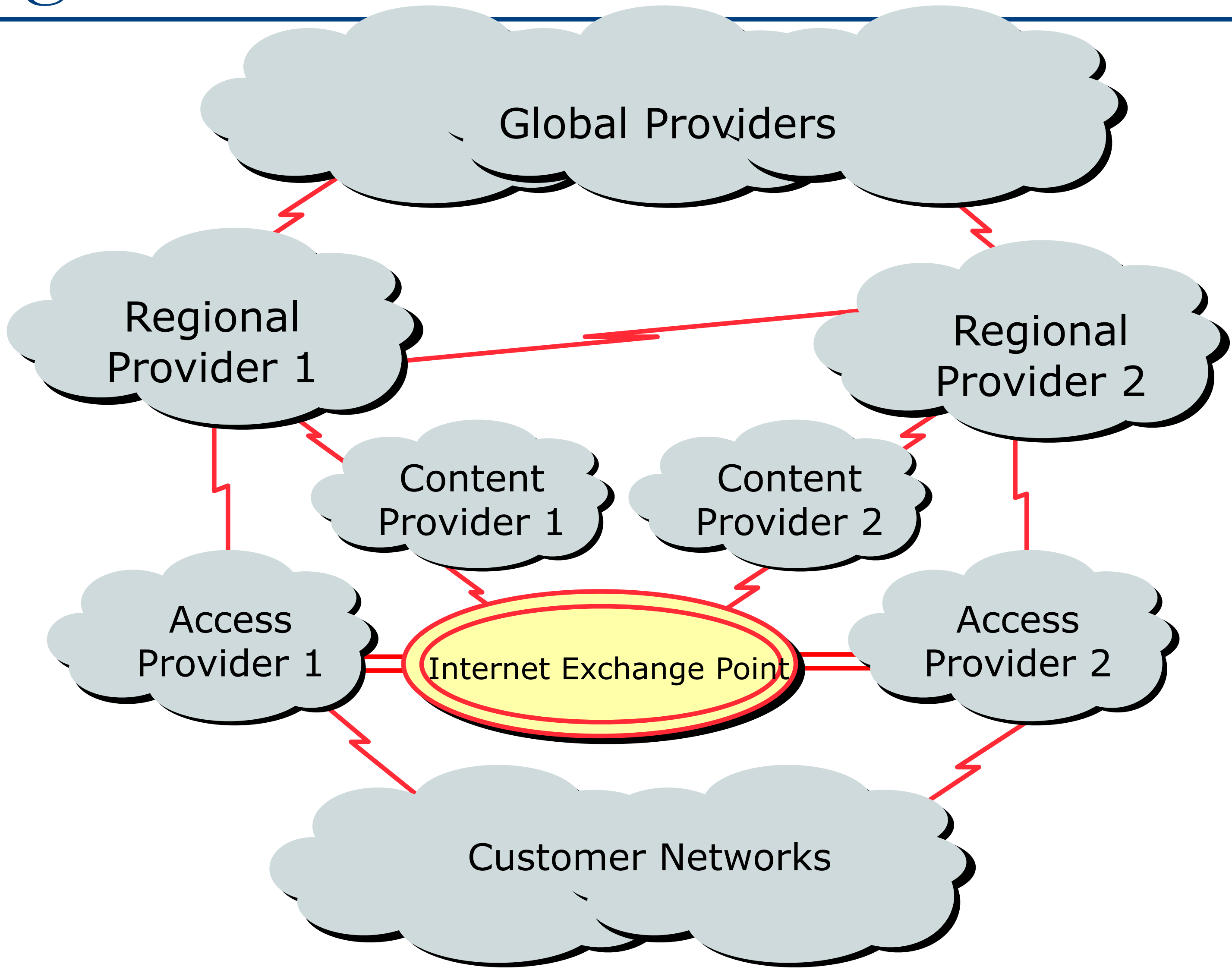
IP Addressing

- Internet uses classless routing
- Concept of IPv4 class A, class B or class C is no more
  - Engineers talk in terms of prefix length, for example the class B 158.43 is now called 158.43/16.
- All routers must be CIDR capable
  - Classless InterDomain Routing
  - RFC1812 – Router Requirements

IP Addressing

- IP Address space is a resource shared amongst all Internet users
  - Regional Internet Registries delegated allocation responsibility by the IANA
  - AfriNIC, APNIC, ARIN, LACNIC & RIPE NCC are the five RIRs
  - RIRs allocate address space to ISPs and Local Internet Registries
  - ISPs/LIRs assign address space to end customers or other ISPs
- All usable IPv4 address space has been allocated to the RIRs by the IANA (February 2011)
  - The time for IPv6 is now

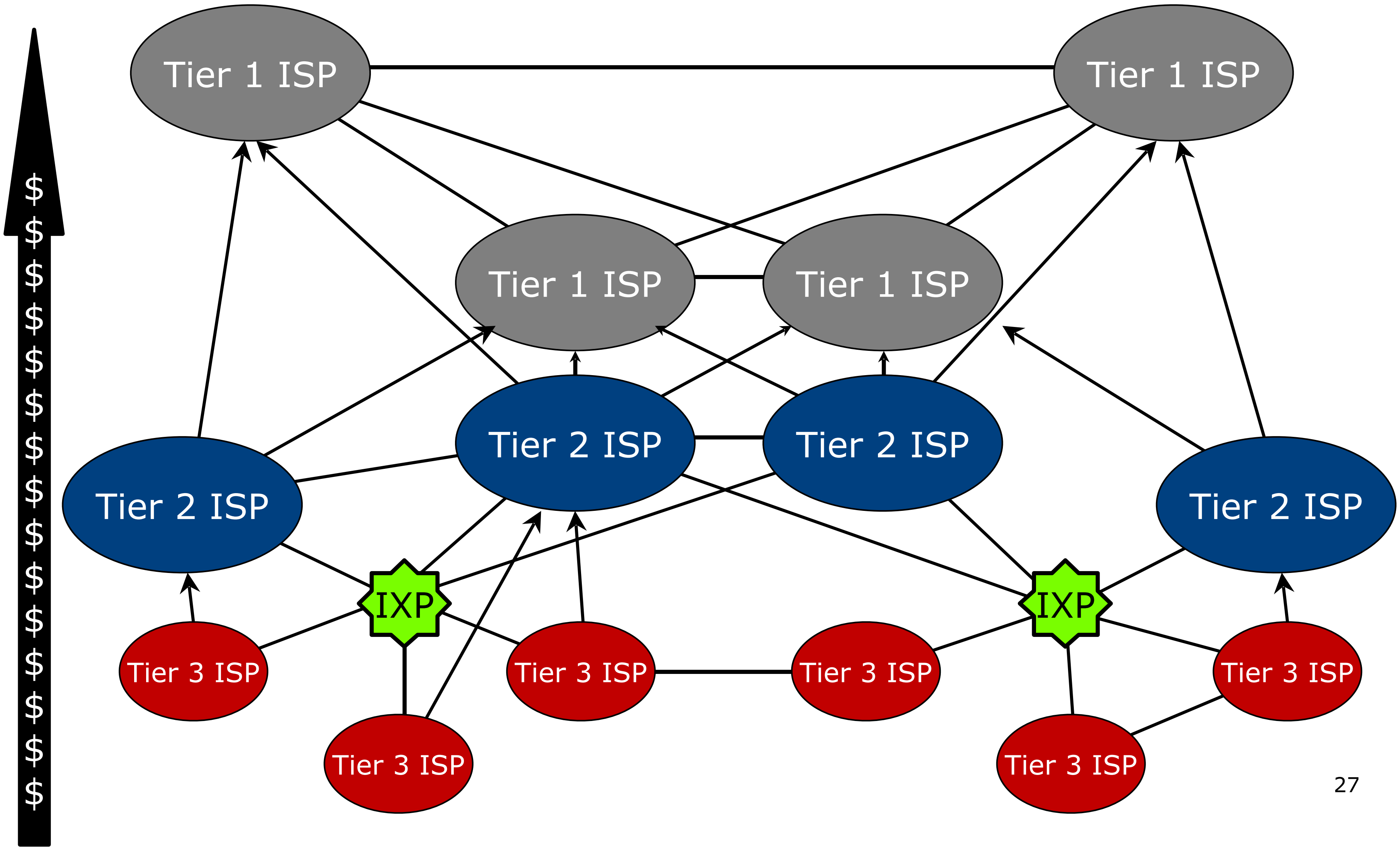
High Level View of the Global Internet



Detailed View of the Global Internet

- Global Transit Providers
  - Connect to each other
  - Provide connectivity to Regional Transit Providers
- Regional Transit Providers
  - Connect to each other
  - Provide connectivity to Content Providers
  - Provide connectivity to Access Providers
- Access Providers
  - Connect to each other across IXPs (free peering)
  - Provide access to the end user

Categorising ISPs



Inter-provider relationships

- Peering between equivalent sizes of service providers (e.g. Tier 2 to Tier 2)
  - Shared cost private interconnection, equal traffic flows
  - No cost peering
- Peering across exchange points
  - If convenient, of mutual benefit, technically feasible
- Fee based peering
  - Unequal traffic flows, “market position”

Default Free Zone

The default free zone is made up of Internet routers which have explicit routing information about the rest of the Internet, and therefore do not need to use a default route

NB: is not related to where an ISP is in the hierarchy

Gluing it together

- Who runs the Internet?
  - No one
  - (Definitely not ICANN, nor the RIRs, nor the US,…)
- How does it keep working?
  - Inter-provider business relationships and the need for customer reachability ensures that the Internet by and large functions for the common good
- Any facilities to help keep it working?
  - Not really. But…
  - Engineers keep working together!

Engineers keep talking to each other...

- North America
  - NANOG (North American Network Operators Group)
  - NANOG meetings and mailing list
  - www.nanog.org
- Latin America
  - Foro de Redes
  - NAPLA
  - LACNOG – supported by LACNIC
- Middle East
  - MENOG (Middle East Network Operators Group)
  - www.menog.net

Engineers keep talking to each other...

- Asia & Pacific
  - APRICOT annual conference
    - www.apricot.net
  - APOPS & APNIC-TALK mailing lists
    - mailman.apnic.net/mailman/listinfo/apops
    - mailman.apnic.net/mailman/listinfo/apnic-talk
  - PacNOG (Pacific NOG)
    - mailman.apnic.net/mailman/listinfo/pacnog
  - SANOG (South Asia NOG)
    - E-mail to sanog-request@sanog.org

Engineers keep talking to each other...

- Europe
  - RIPE meetings, working groups and mailing lists
  - e.g. Routing WG: www.ripe.net/mailman/listinfo/routing-wg
- Africa
  - AfNOG meetings and mailing list
- And many in-country ISP associations and NOGs
- IETF meetings and mailing lists
  - www.ietf.org