Routing

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Outline

- Classless Interdomain Routing
- Autonomous System
- Routing Introduction

IP Addresses Revisited

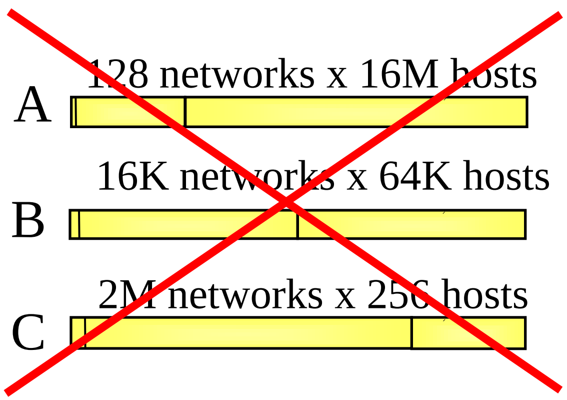
- Potential exhaustion of IPv4 address space (due to inefficiency)
  - Class B is too big
  - Class C is too small (many are available)
- Growth of back bone routing tables
  - Lots of small networks causes large routing tables
  - Route calculation and management requires high computational overhead

Classless InterDomain Routing (CIDR)

- Try to balance two competing effects
  - Address utilization
  - Router complexity
- CIDR allows routers to break the rigid interpretation of IP address structures
- Also called “Supernet”
  - Opposite of “Subnet”

Classful & Classless addressing

Classful



Obsolete

- *inefficient*
- *depletion of B space*
- *too many routes from C space*

Classless

Hosts	Prefix	Classful
2	/31	
4	/30	
8	/29	
16	/28	
32	/27	
64	/26	
128	/25	
256	/24	1 C
...	...	...
4096	/20	16 C
8192	/19	32 C
16384	/18	64 C
32768	/17	128 C
65536	/16	1 B
...	...	...

Best Current Practice

Prefix Length

/n	Mask	/n	Mask	/n	Mask	/n	Mask
/1	128.0.0.0	/9	255.128.0.0	/17	255.255.128.0	/25	255.255.255.128
/2	192.0.0.0	/10	255.192.0.0	/18	255.255.192.0	/26	255.255.255.192
/3	224.0.0.0	/11	255.224.0.0	/19	255.255.224.0	/27	255.255.255.224
/4	240.0.0.0	/12	255.240.0.0	/20	255.255.240.0	/28	255.255.255.240
/5	248.0.0.0	/13	255.248.0.0	/21	255.255.248.0	/29	255.255.255.248
/6	252.0.0.0	/14	255.252.0.0	/22	255.255.252.0	/30	255.255.255.252
/7	254.0.0.0	/15	255.254.0.0	/23	255.255.254.0	/31	255.255.255.254
/8	255.0.0.0	/16	255.255.0.0	/24	255.255.255.0	/32	255.255.255.255

CIDR Example

What is the first address in the block if one of the addresses is 167.199.170.82/27?

Solution

Address in binary:	**10100111 11000111 10101010 01010010**
Keep the left 27 bits:	**10100111 11000111 10101010 01000000**

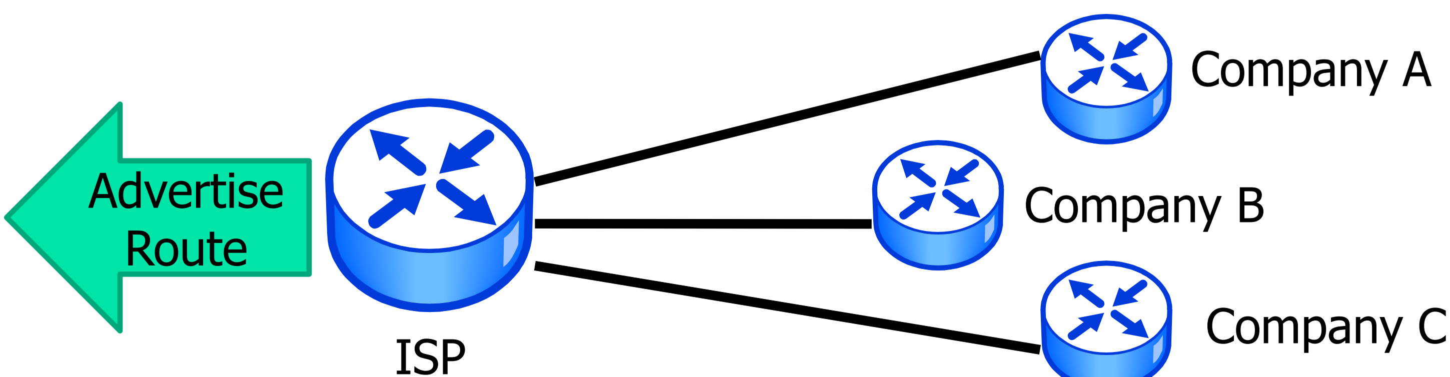
Result in CIDR notation: 167.199.170.64/27

Supernetting: CIDR

- Enable network number to be any length (No Class)
- Collapse multiple addresses assigned to a single AS to one address
- All routers must understand CIDR addressing
  - Need both Address and Mask (prefix and suffix)
  - Slash notation (123.10.16.0 /20)
- Some prefixes are reserved for private add.
  - 10/8, 172.16/12, 192.168/16, 169.254/16
  - These are not routable in the Internet

Example of CIDR

- Consider an ISP providing IP connection to a number of private companies
- If the IP addresses for the companies are carefully selected
  - a border router need only advertise one "aggregated" route for all the companies



Example of CIDR (Supernetting)

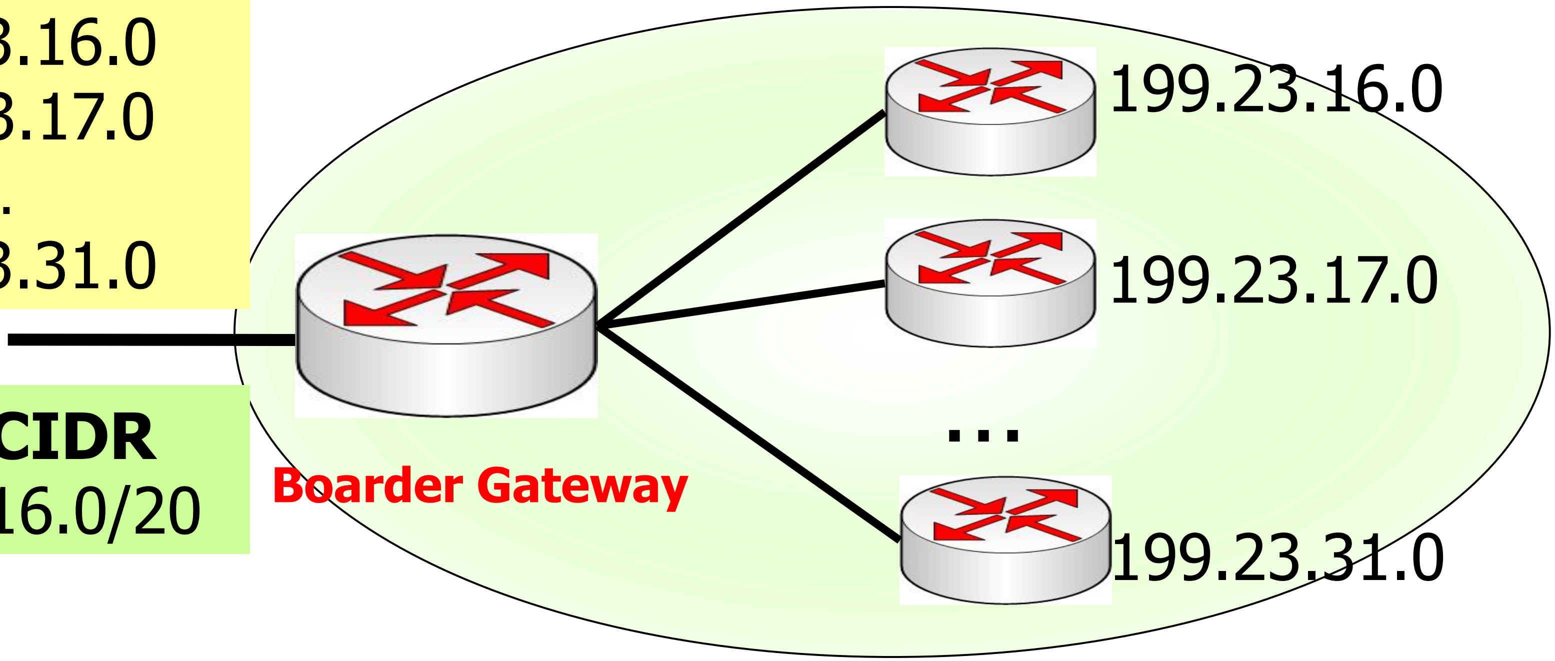
- If ISP needs 16 class C addresses
  - make them contiguous
- Eg. 199.23.16.0 to 199.23.31.0
  - enables a 20-bit network number

```
199.23.0001 0000.0 → 199.23.16.0
199.23.0001 0001.0 → 199.23.17.0
199.23.0001 0010.0 → 199.23.18.0
199.23.0001 0011.0 → 199.23.19.0
…
199.23.0001 1111.0 → 199.23.31.0
```

Example of CIDR

Without CIDR
199.23.16.0
199.23.17.0
...
199.23.31.0

With CIDR
199.23.16.0/20



Aggregation

- Some pairs of consecutive prefixes
- Example: routes within the same AS:

  AS has 2 address blocks:

1.2.2.0/24 = 0000001.00000010.**00000010**.00000000/24
1.2.3.0/24 = 0000001.00000010.**00000011**.00000000/24

Can announce 1.2.2.0/23

CIDR: Longest prefix match

- Because prefixes of arbitrary length allowed, overlapping prefixes can exist.
- Example:
  router hears 124.39.0.0/16 from one neighbor
  and 124.39.11.0/24 from another neighbor
- Router forwards packet according to most specific forwarding information, called longest prefix match
  - Packet with destination 124.39.11.32 will be forwarded using /24 entry.
  - Packet with destination 124.39.22.45 will be forwarded using /16 entry

CIDR: Longest prefix match

- Implicit ordering in the routing table
  - longer prefixes higher up the table
  - So, the first match is the right one
- Explicit route to directly attached host
  - a netmask of 0.0.0.0

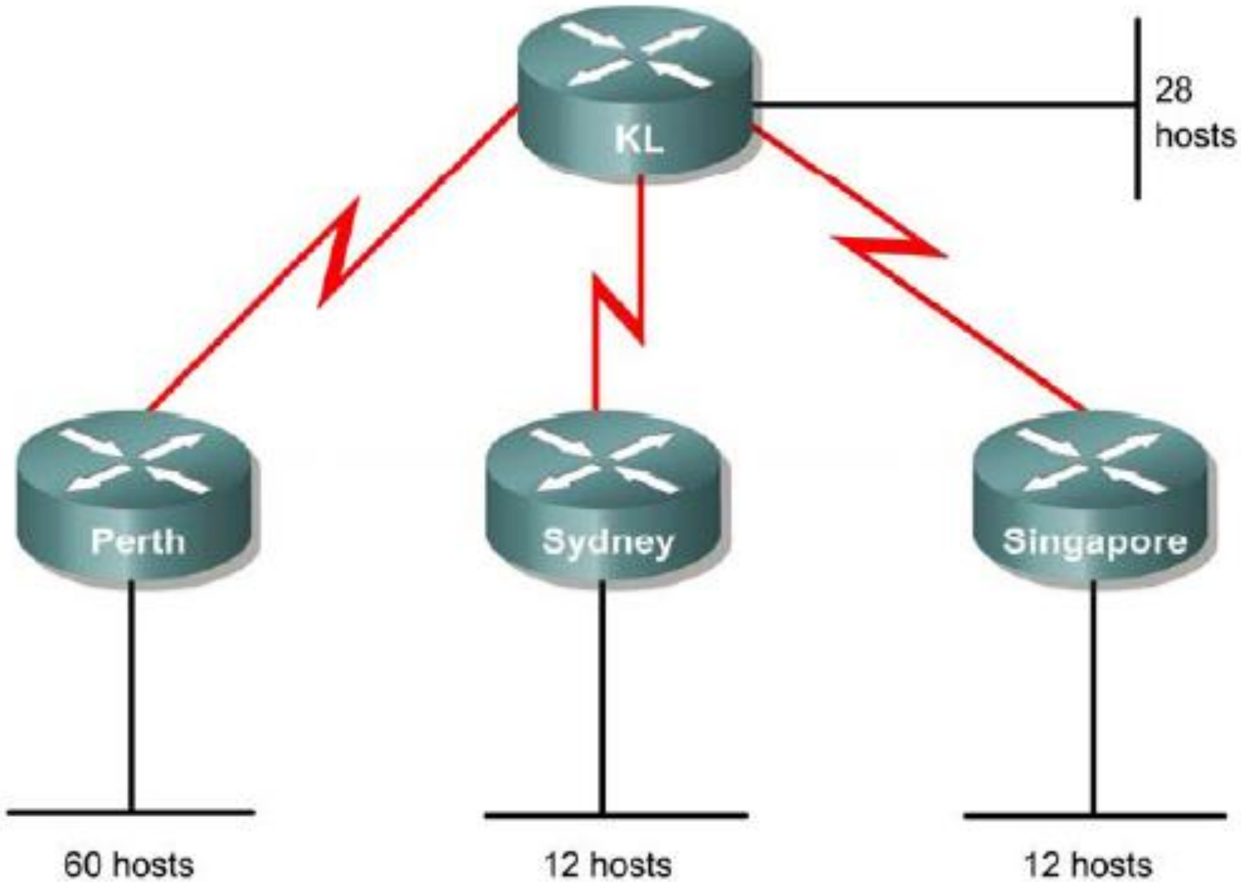
VLSM

VLSM

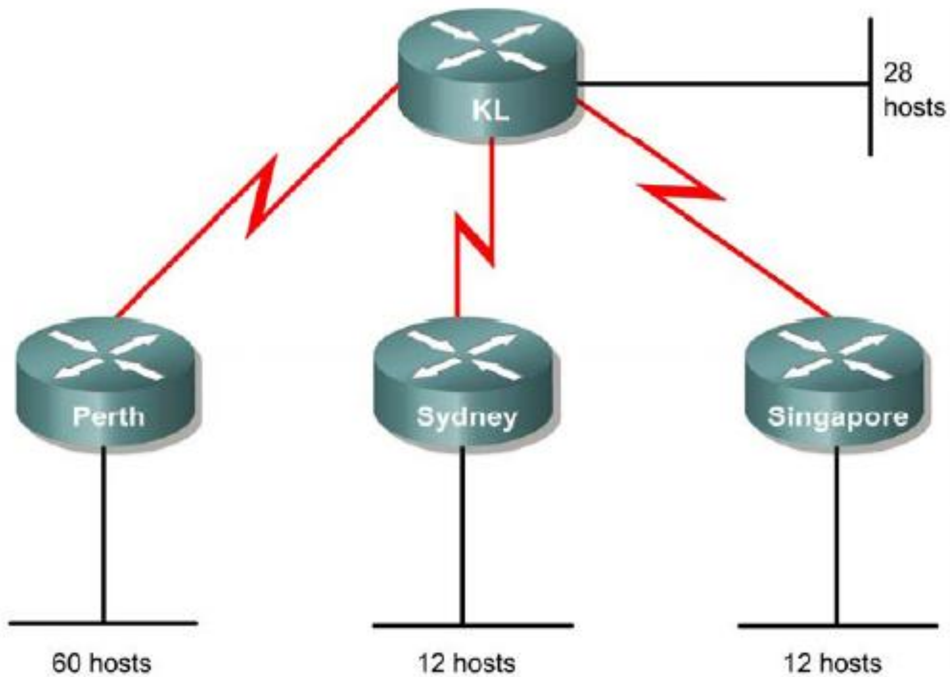
- Variable-length subnet mask
- Classful allows only one subnet in a network
  - > one subnet in an autonomous system
- Maximizing the use of address (Subnet Zero)
- “Subnetting a Subnet”
- Routing that support VLSM
  - OSPF, Integrated IS-IS, EIGRP, RIPv2, and static routing

Subnet with VLSM

192.168.10.0/24



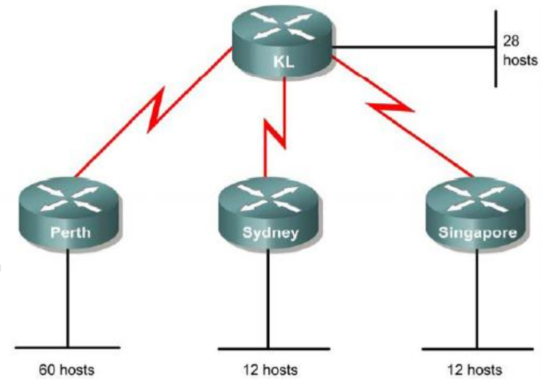
Regular Subnet



192.168.10.0/24

7 subnets; The largest subnet needs **60** hosts
If 3 bits for subnet (8 subnets) ➔ 5 bits for host (32 hosts)
If 6 bits for host (64 hosts) ➔ 2 bits for subnet (4 subnets)

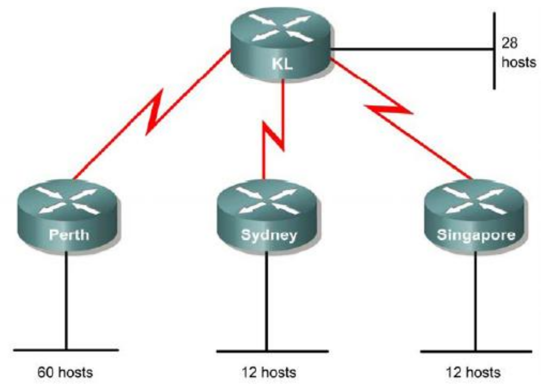
Subnet with VLSM



- Select the biggest first
- 192.168.10.0/24
  - 192.168.10.0/26 ← **Perth**
  - 192.168.10.64/26
  - 192.168.10.128/26
  - 192.168.10.192/26

192.168.10.64/26
  - 192.168.10.64/27 ← **KL**
  - 192.168.10.96/27

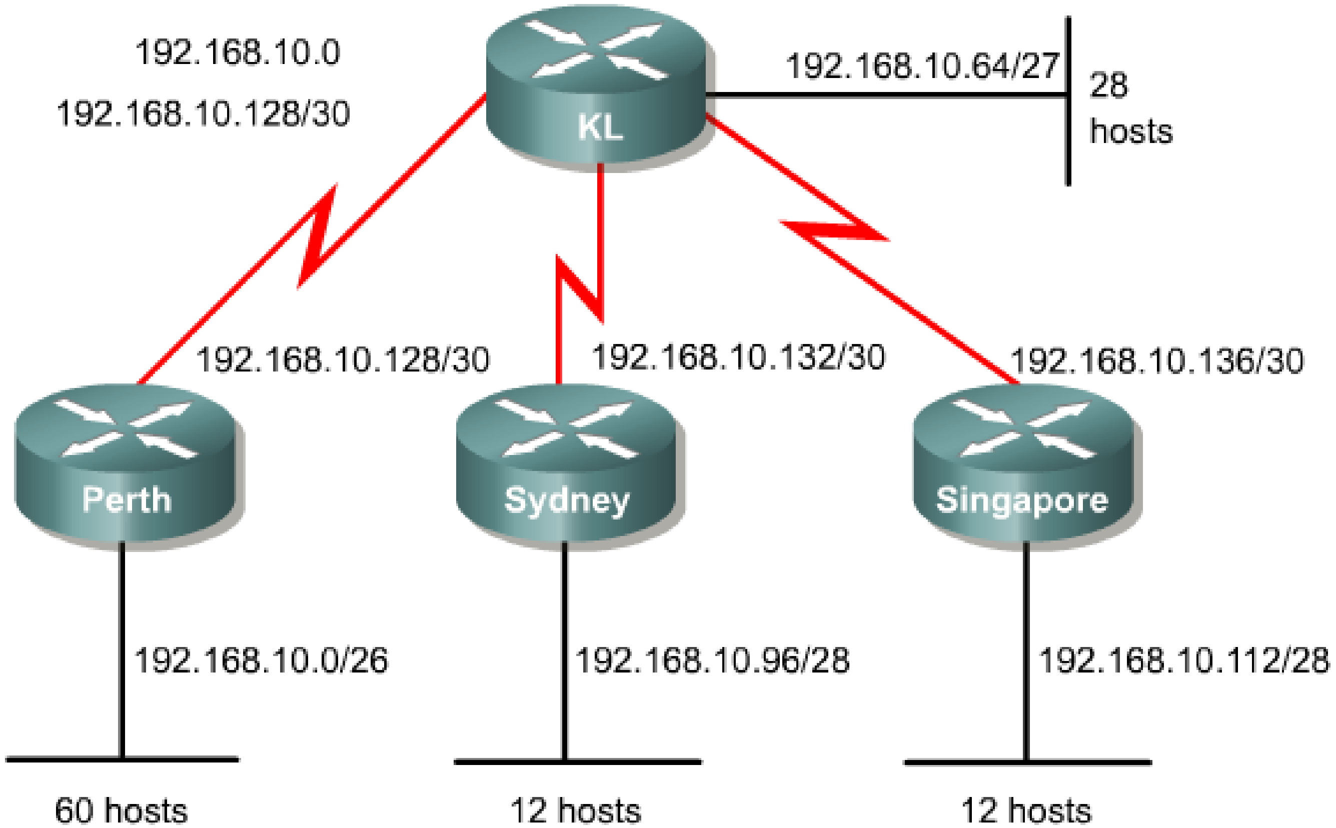
Subnet with VLSM



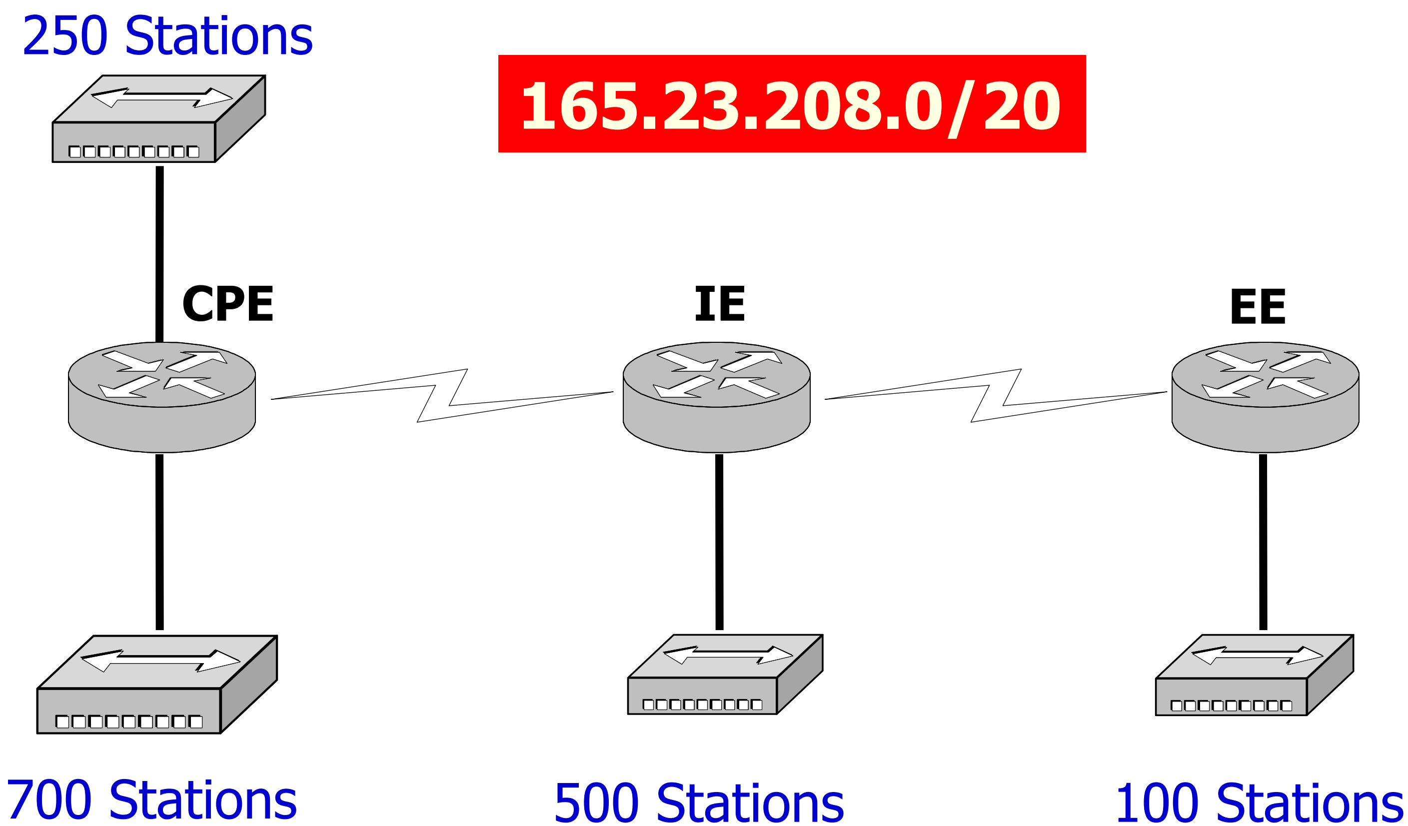
- 192.168.10.96/27
  - 192.168.10.96/28 ← **Sydney**
  - 192.168.10.112/28 ← **Singapore**

- 192.168.10.128/**26**
  - 192.168.10.128/30 ← **Perth – KL**
  - 192.168.10.132/30 ← **Sydney – KL**
  - 192.168.10.136/30 ← **Singapore – KL**
  - 192.168.10.140/30
  - …

Final: Subnet with VLSM

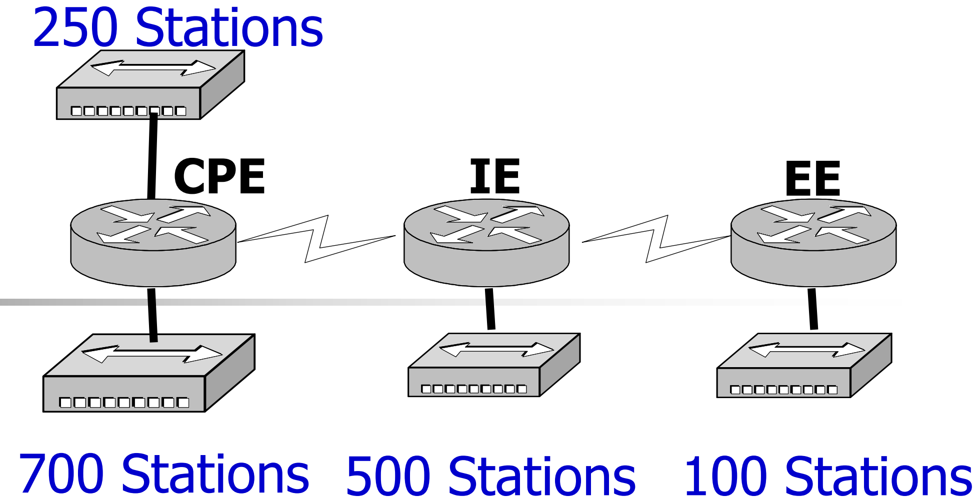


Assignment



250 Stations
165.23.208.0/20
CPE
IE
EE
700 Stations
500 Stations
100 Stations

Solution



- 165.23.208.0/20
  - **165.23.208.0/22** 1022 Hosts
  - 165.23.212.0/22
  - 165.23.216.0/22
  - 165.23.220.0/22

The largest subnet needs **700** hosts
→10 bits for host (1024 hosts)

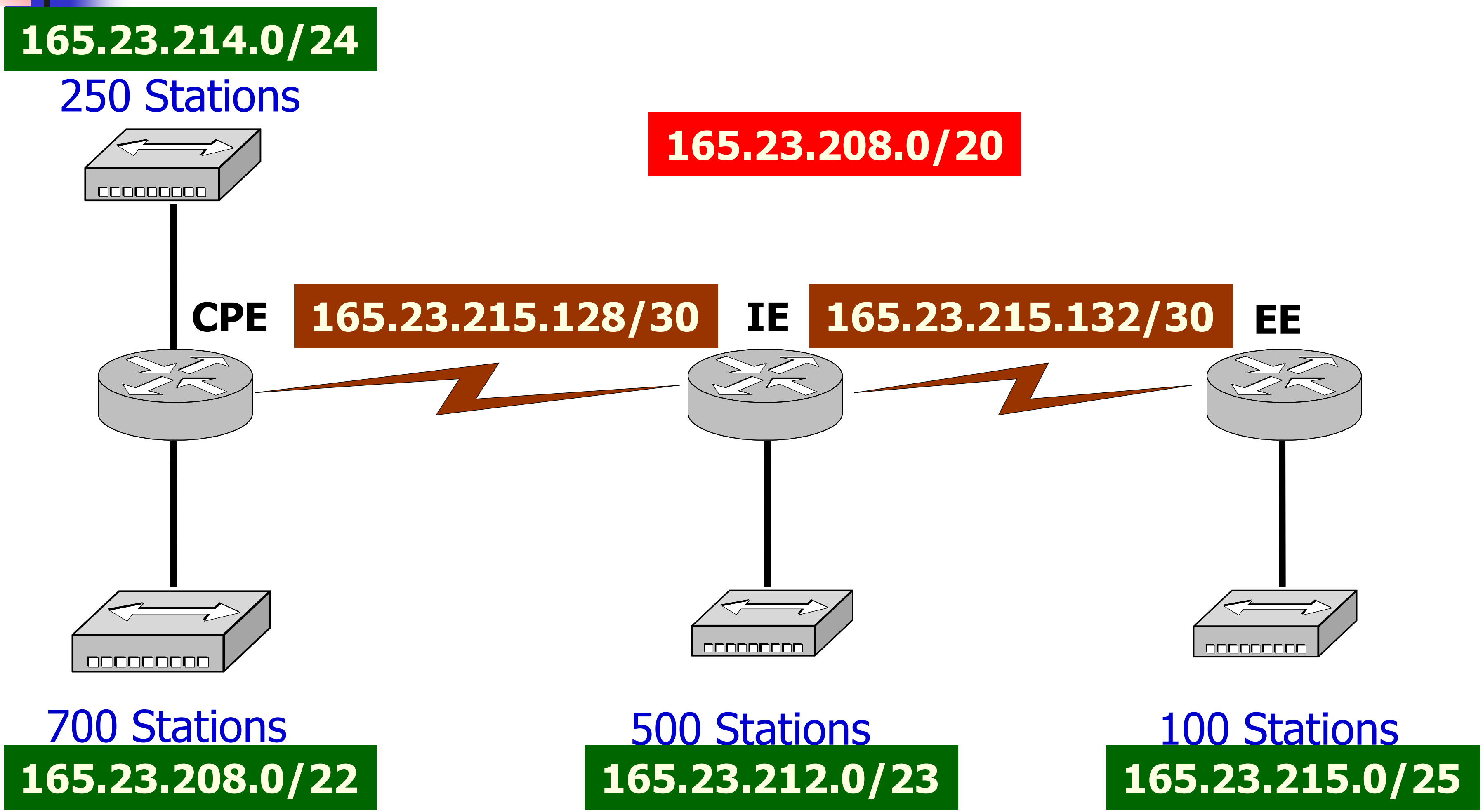
- 165.23.212.0/22
  - **165.23.212.0/23** 510 Hosts
  - 165.23.214.0/23

- 165.23.214.0/23
  - **165.23.214.0/24** 254 Hosts
  - 165.23.215.0/24

- 165.23.215.0/24
  - **165.23.215.0/25** 126 Hosts
  - 165.23.215.128/25

- 165.23.215.128/25 2 Hosts
  - **165.23.215.128/30**
  - **165.23.215.132/30**
  - 165.23.215.136/30
  - …

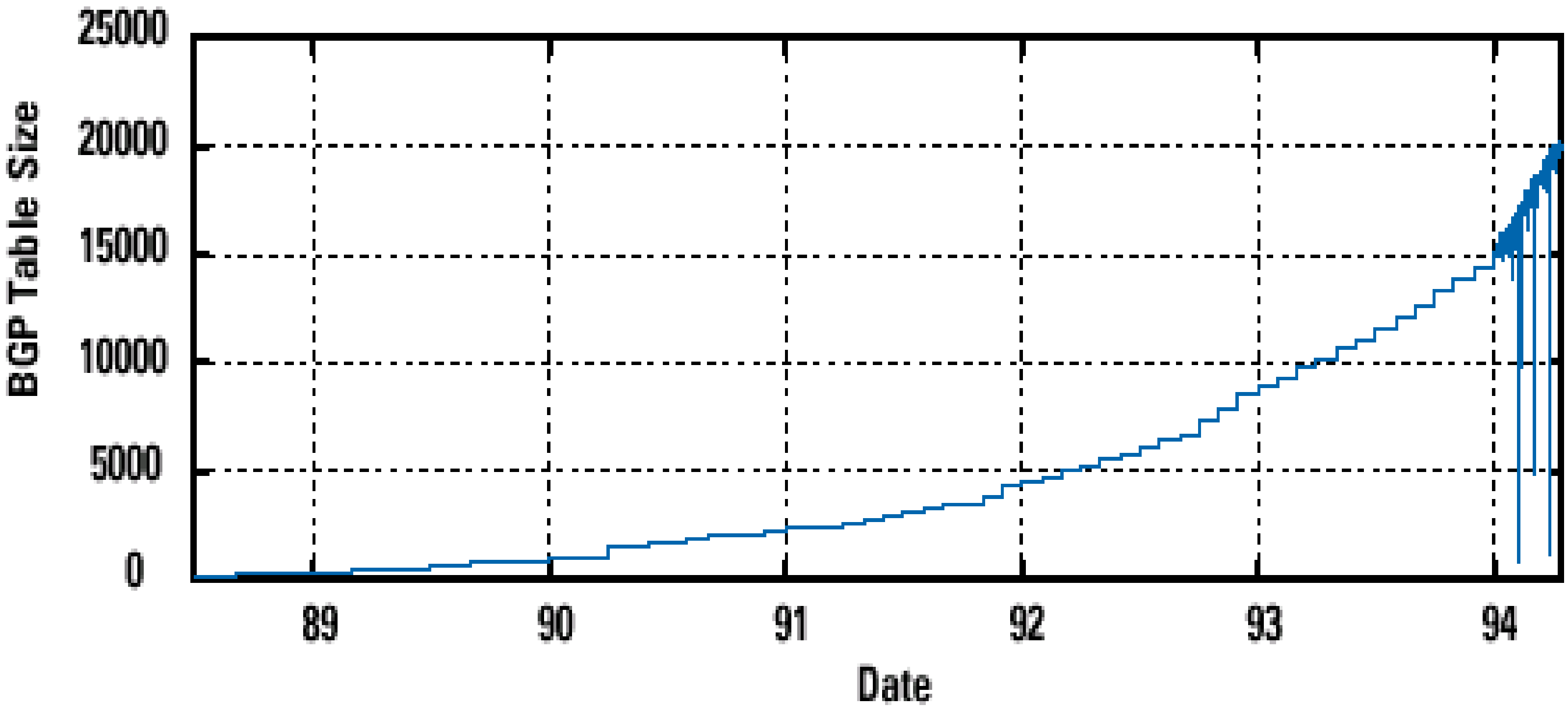
Final Solution



Notes for CIDR

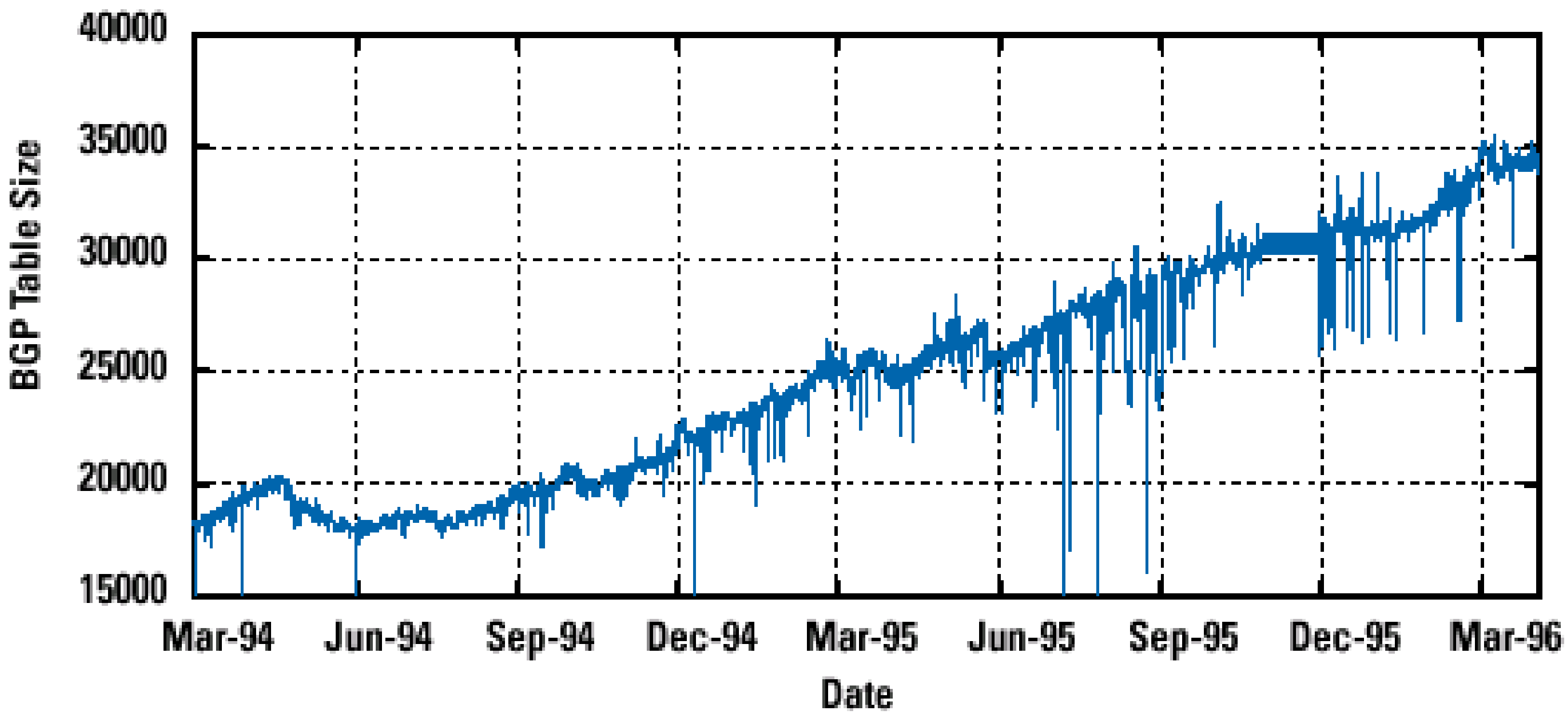
- CIDR was actually intended as a quick fix
  - Solve addressing crisis until IPv6 was deployed
- Unfortunately, CIDR has been widely adopted
  - IPv6 deployment has proven to be very, very slow
- CIDR is currently deployed
  - However, IPv6 is not compatible with IPv4
  - Generates a big migration problem

Growth in Routing Table Size



Pre-CIDR (1988-1994): Steep Growth Rate

Growth in Routing Table Size



CIDR Deployment (1994-1996): Much Flatter

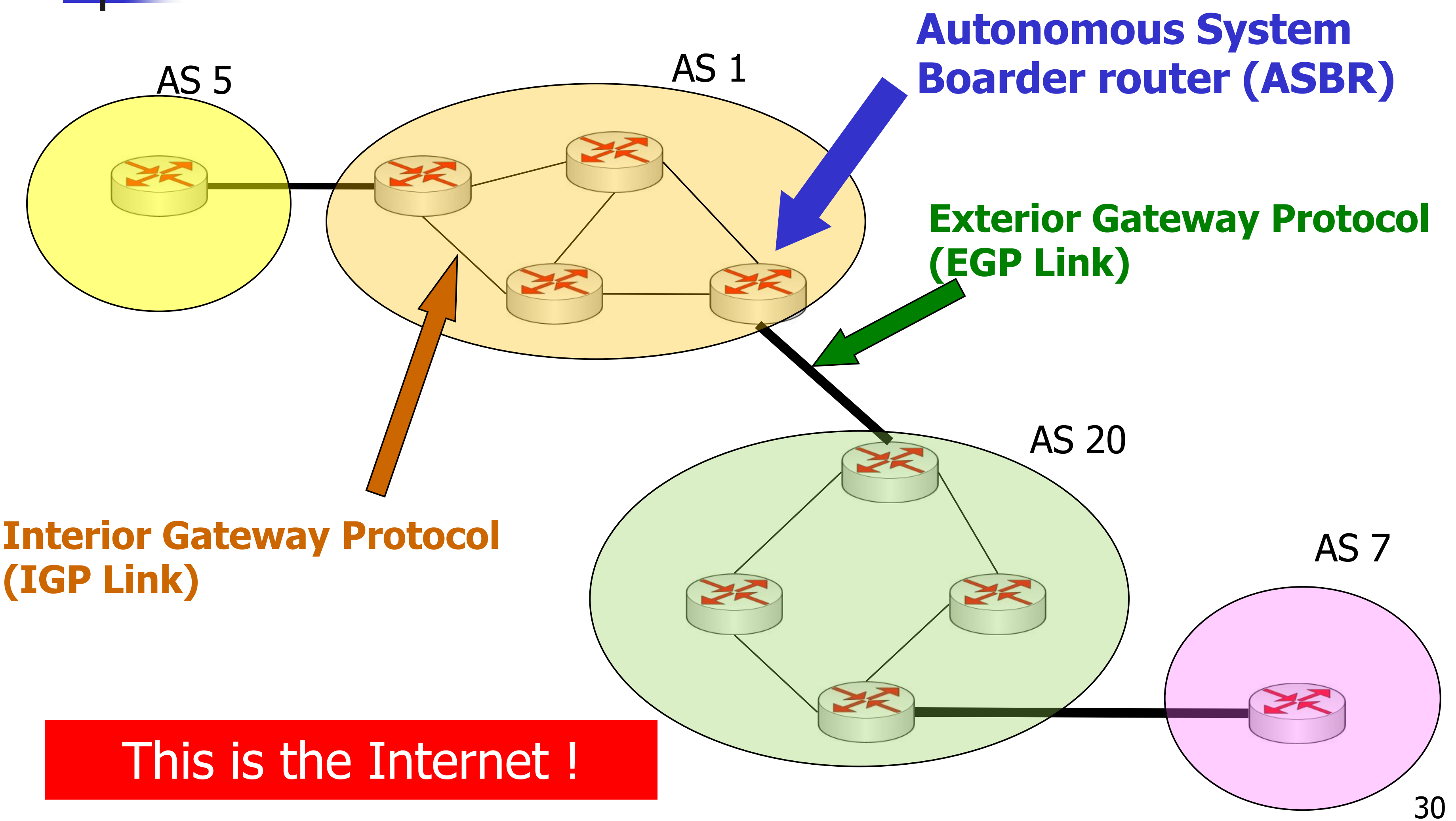
Autonomous System (AS)

- A single network domain
- Grouping of computers/routers
- Operate in isolation from other groups
- A single network administrative entity

Autonomous System (AS)

- Need protocols for distribute routing information in the AS
  - Interior Gateway Protocols (IGPs)
  - Intradomain routing algorithms
- Between AS
  - Need interdomain routing algorithms
  - Exterior Gateway Protocols (EGPs)
  - More complex task

Autonomous System (AS)



This is the Internet !

Types of AS

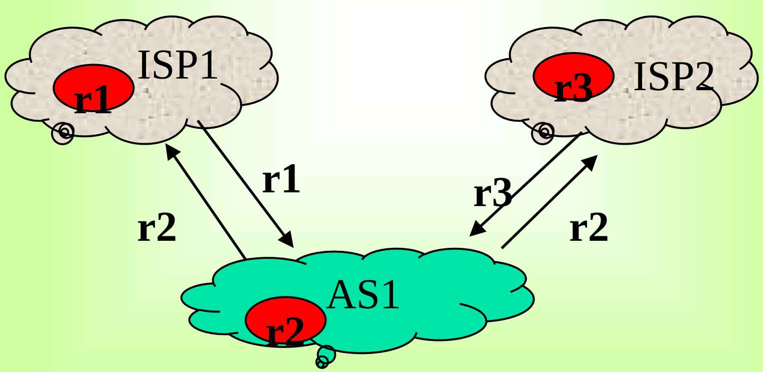
- **Stub AS**
  - Only has a single connection to one other AS
  - only carries *local traffic*
- **Multihomed AS**
  - Connect to more than one other AS
  - But will not carry *transit traffic*
- **Transit AS**
  - Connect to more than one other AS
  - Can carry both *local* and *transit* traffic

Transit vs. Nontransit AS

Transit traffic = traffic whose source and destination are outside the AS

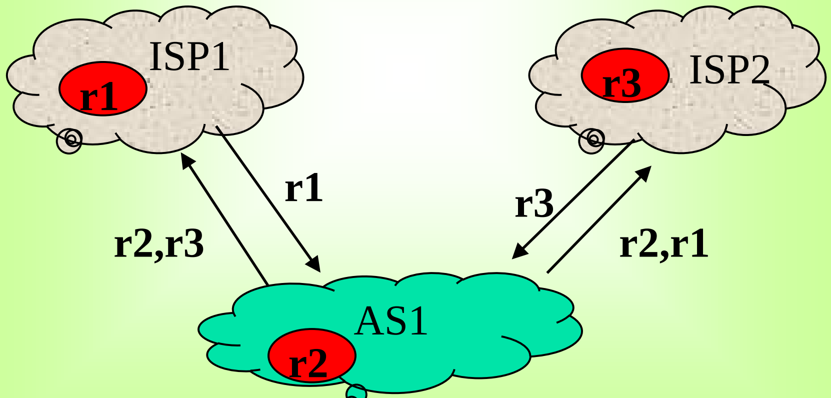
Nontransit AS: does not carry transit traffic

- Advertise own routes only
- Do not propagate routes learned from other AS's



Transit AS: does carry transit traffic

- Advertises its own routes PLUS routes learned from other AS's



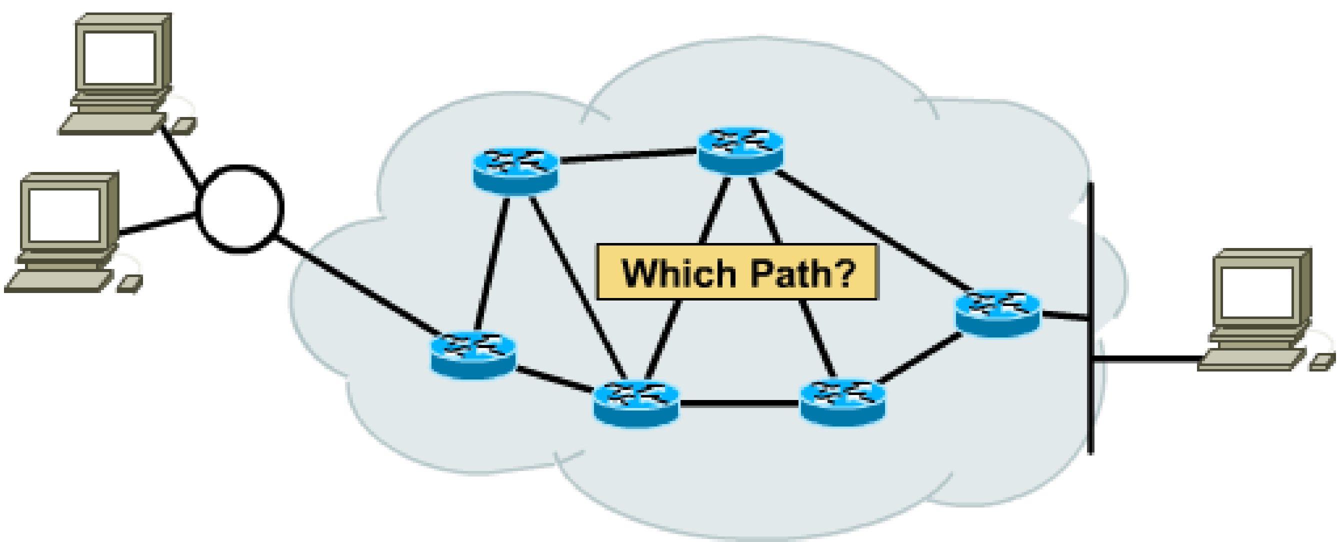
Routing

Routing ?

- Spelling/pronounce
  - British: routeing
  - American: routing
- Definition (Goal)
  - "Learning how to get from here to there."
  - "Process of discovering, selecting, and employing paths from one place to another (or to many others) in a network" [from David M. Piscitello, Bellcore and A. Lyman Chapin, BBN]

Routing Process

- Finding how to get there
- Actually getting to there



Routing Methods

- Source Routing
  - Source keep all information (how to get there)
  - Insert the information in the packet
  - Intermediate node just read and act
- Hop-by-Hop Routing
  - Source only knows how to get to the next hop
  - Assume that Intermediate node knows how to get to the next hop
  - ... until destination reach

<u>Example:</u> Driving a car

Routing Principle

- **Goal**: Arriving at the destination
- Considerations:
  - Direct route (shortest)
  - Reliable route
  - Scenic route (of course, not for network!)
  - Cheap route
  - Safe route

Routing Objectives

- Maximizing the network performances
  - Delay
  - Throughput
- Minimizing the cost
  - Equipment
  - Computation power / complexity

Routing Constraints

- Network (Switching) Technology
- Dynamics of the networks
  - Traffic
  - Network service available

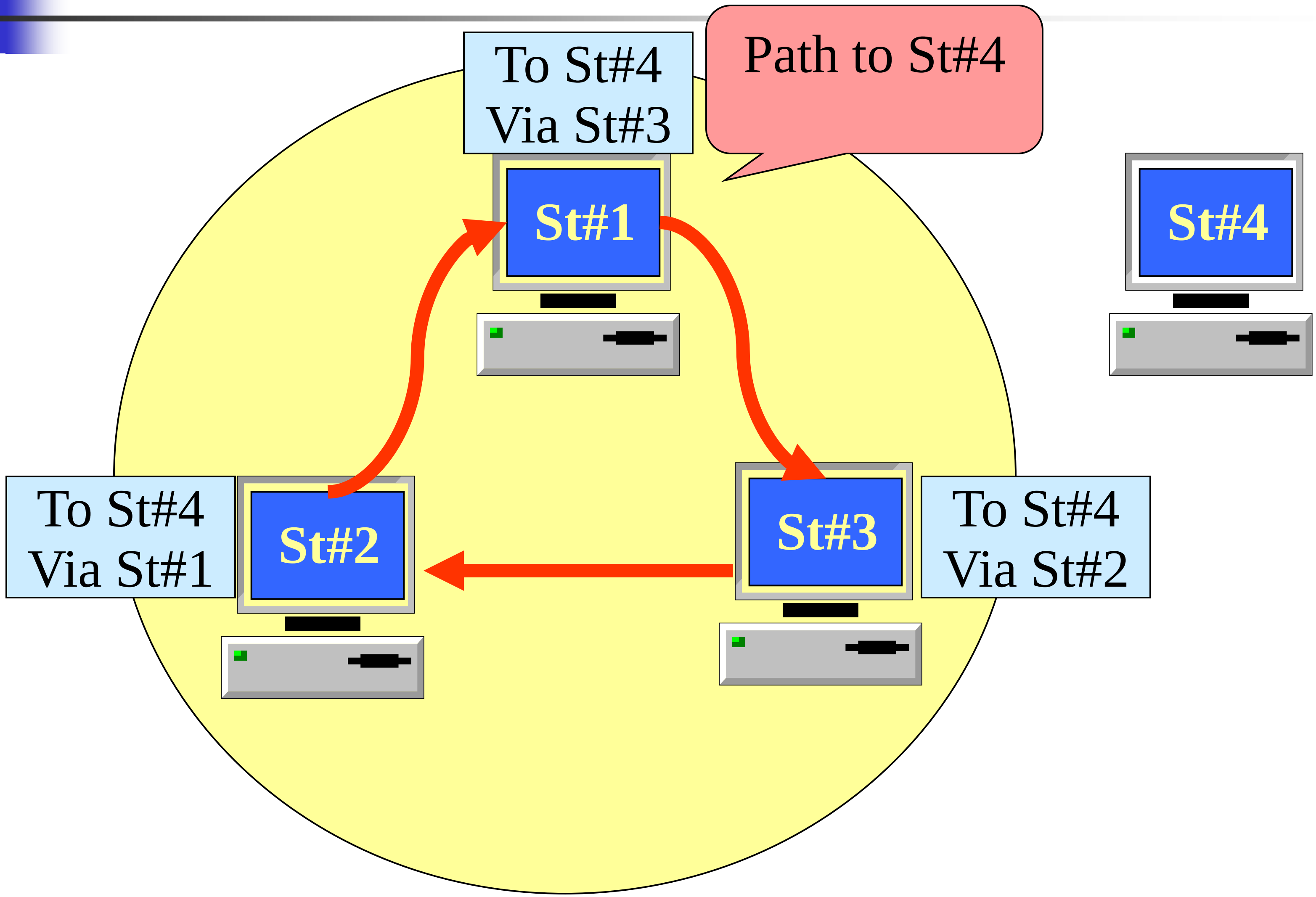
Routing Requirements

- Scalability
- Multi technology support
- Topology-change adaptability (fast & minimum cost)
- QoS support
- Secure/Private connection

Ideal Routing Algorithm

- Correct
- Robust
- Stable (Convergence)
- Efficient
- Flexible (Topology change)
- Scalable
- Loop-Free (no deadlock)
- Easy (Maintainable)
- Secure

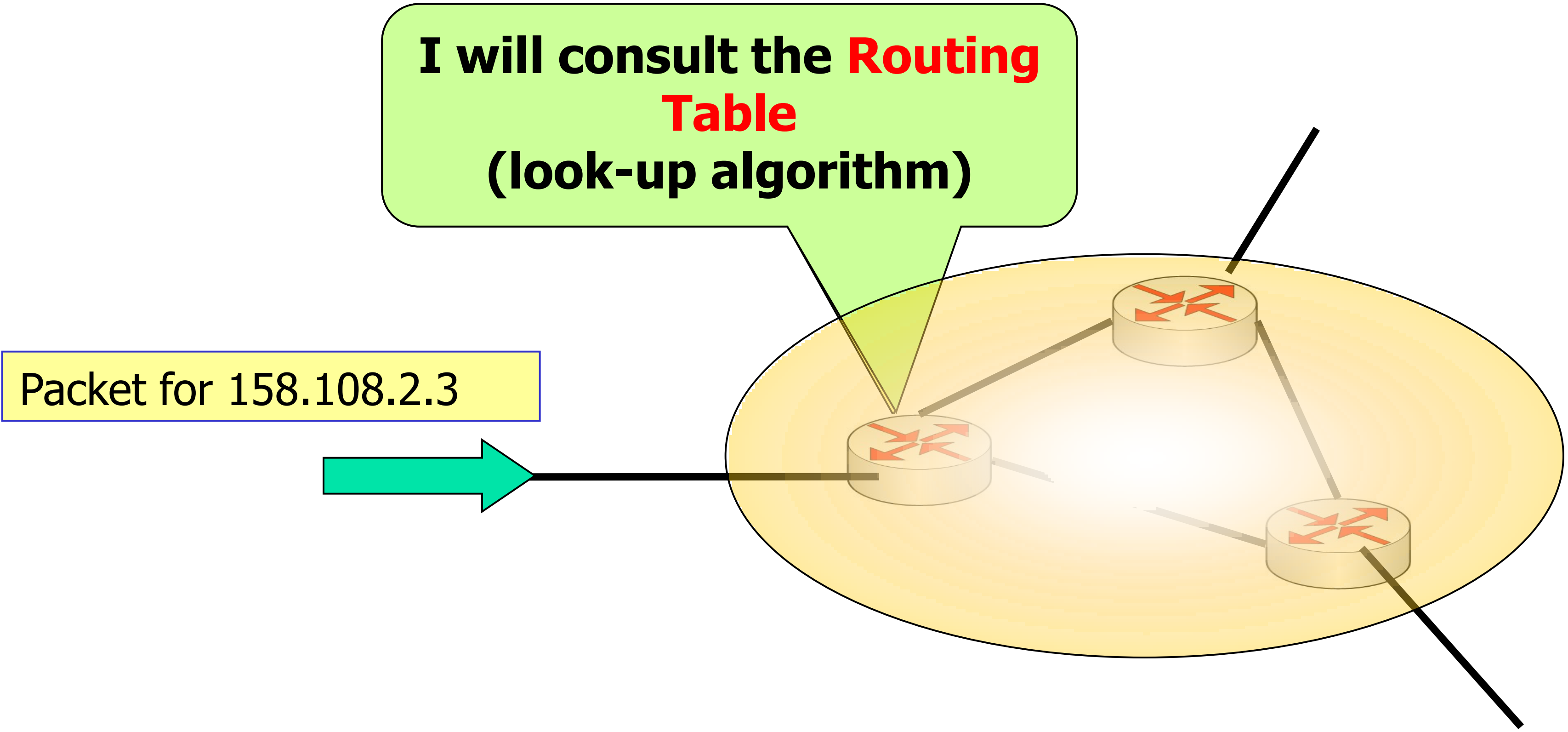
Classic Routing Problem



Routing Elements

- Routing protocol
  - Allow End/Intermediate nodes to collect and distribute the information necessary to determine routes
- Routing database (table)
  - Like a directory information base
- Routing algorithm
  - Uses the information contained in the routing database to derive routes

Routing Information



Routing table

- The ordered list
- Add. matches several entries in the list
  - >1 possible path
  - and may be different qualities
- Router looks up network number of destination address and sends it
- Next router will do the same, until it arrives at the right network

Where does the Routing Table come from?

- By talking with other routers
- Routing table is built by exchanging info with other routers
- The goal of this exchange is
  - to “map out” the network
- Each router wants to know
  - who it can talk to directly
  - and who those routers can talk to
- Finally
  - Send packet to the directly connect host
  - Or asking other routers to act as “middle men” and deliver packets for it

Routing table

- Associated with each route
  - A cost of the link
- Cost could be
  - level of congestion
  - inverse of the bandwidth
  - monetary cost
- In practice, this is often just a hop count or infinity.

Routers

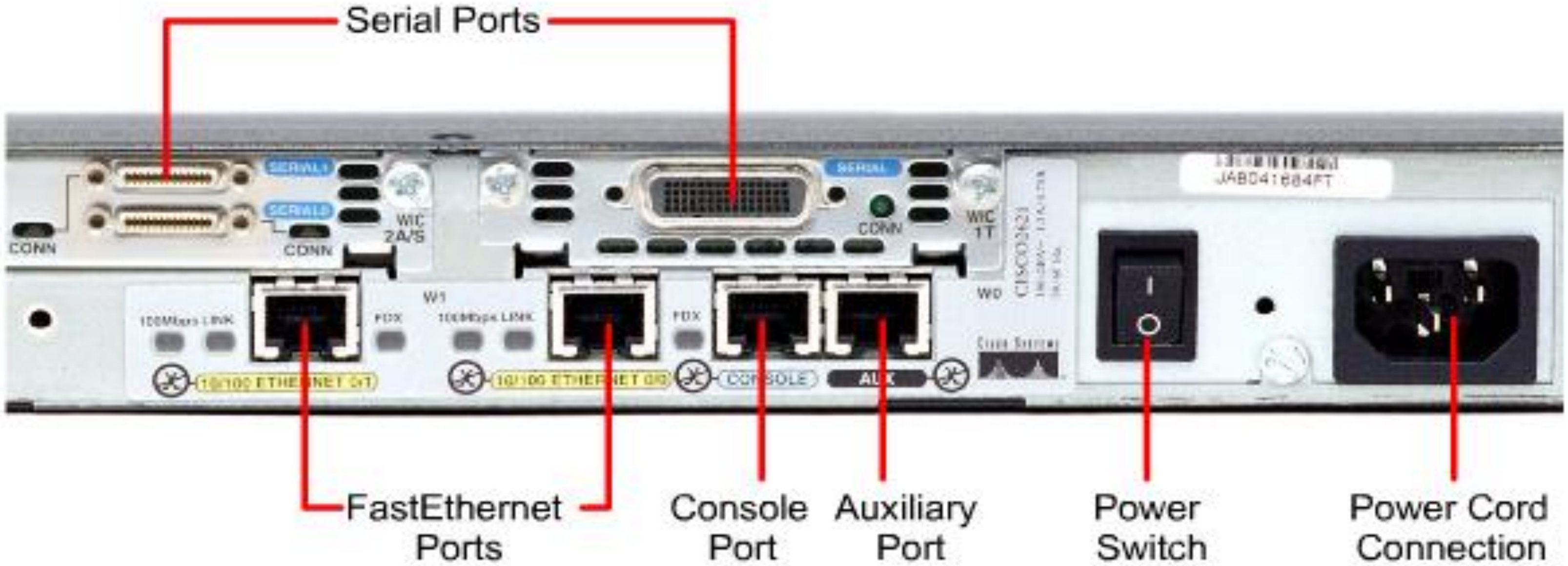
19 inches (48 cm) wide

Small Routers
Stacked
For Branch Offices

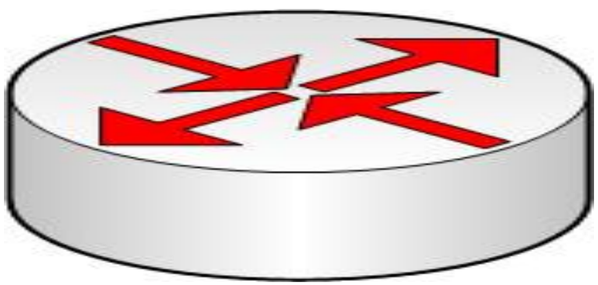
19 inches (48 cm) wide

Large Routers
for Large Sites and ISPs

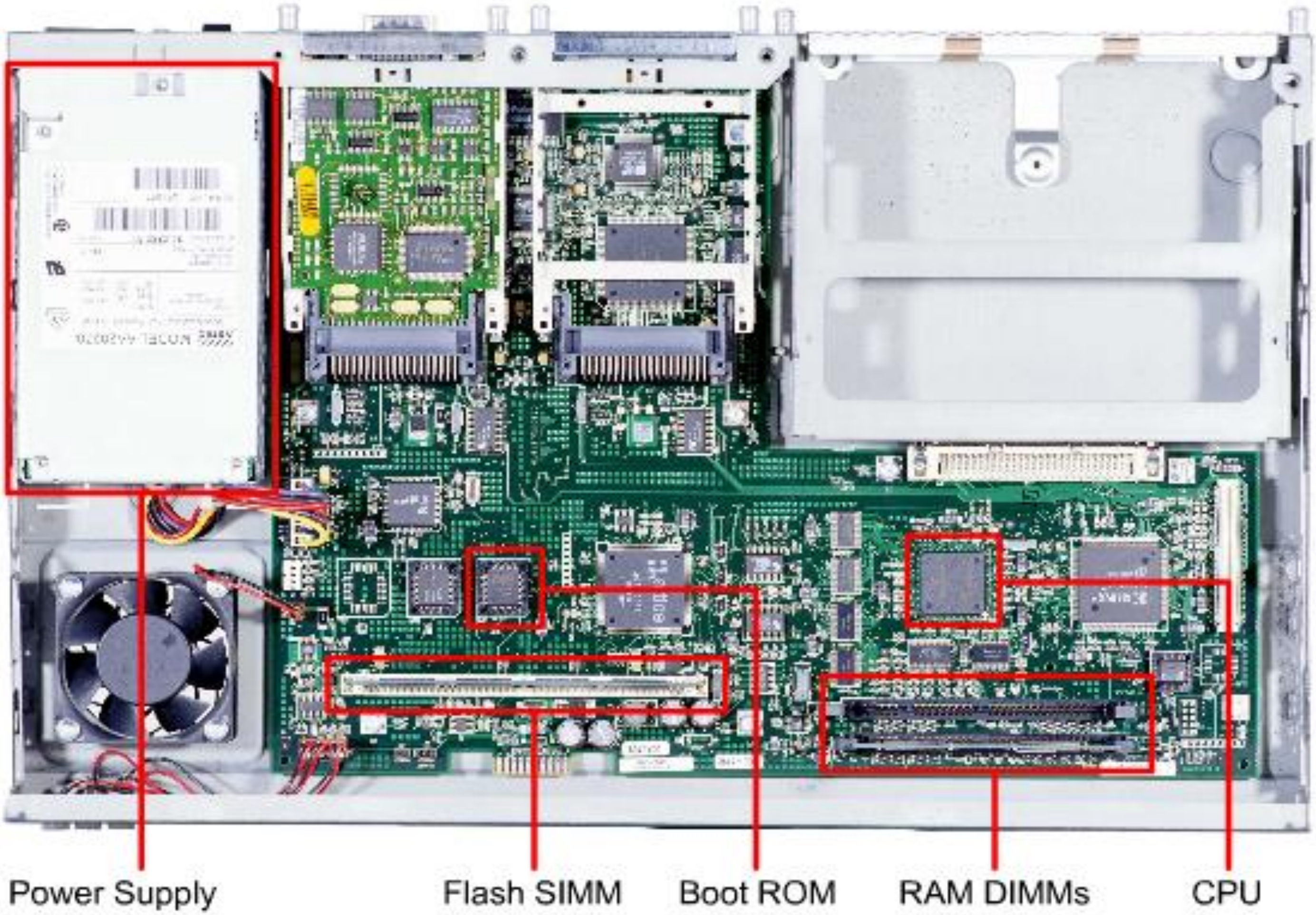
Router



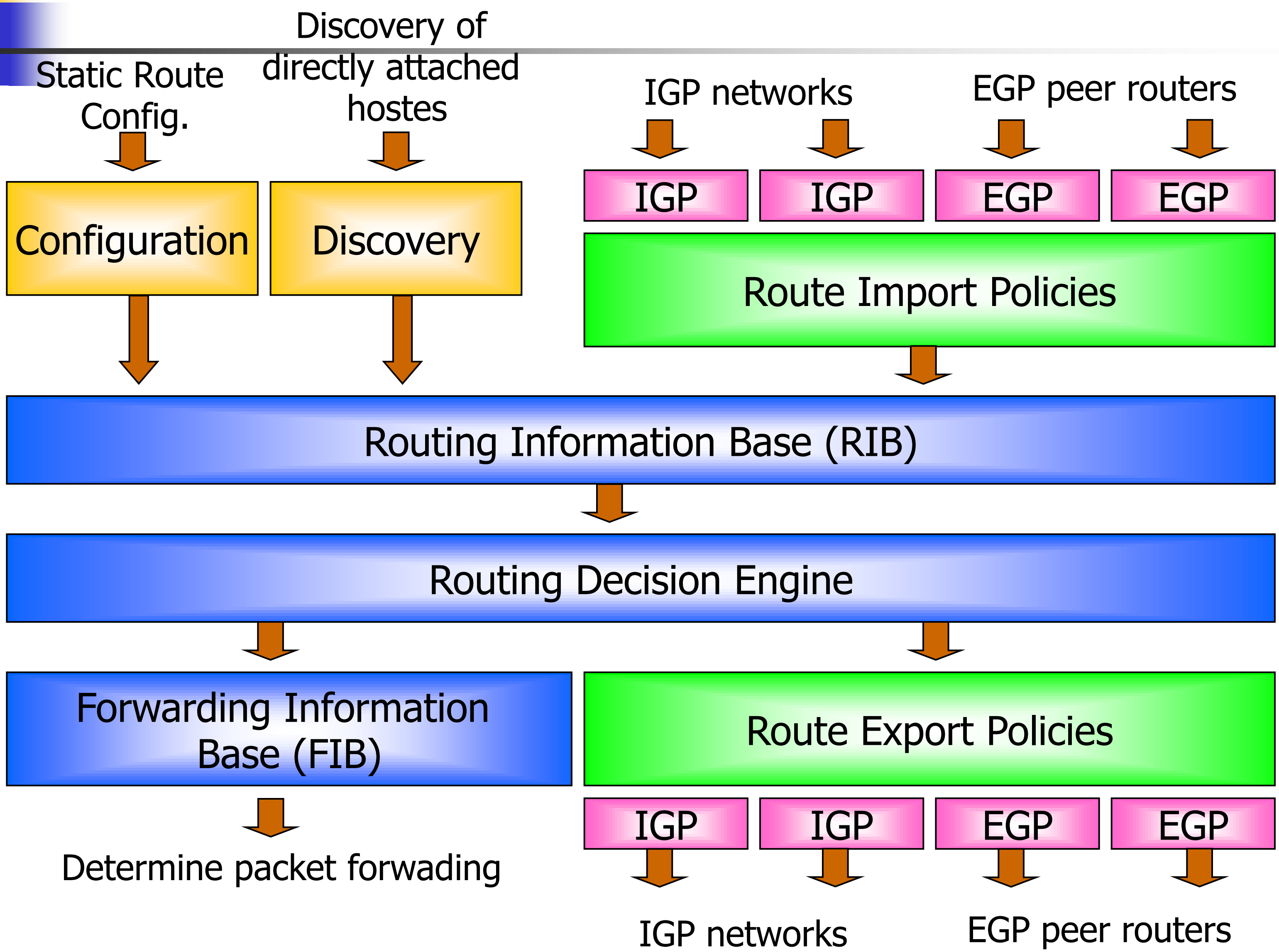
Serial Ports
FastEthernet Ports
Console Port
Auxiliary Port
Power Switch
Power Cord Connection



Router



The Internals of a Router



References

- “Gregory Kesden” lecture of 20-770 Communications and Networking
- “Nina Taft”, The Basics of BGP Routing and its Performance in Today’s Internet, Sprint.
- “Anonymous”
  - lecture of Addressing and Domain Name System, CS640
  - Telecom App2b
- Cisco CCNA Material
- “Jennifer Rexford”, Internet Routing (COS 598A)