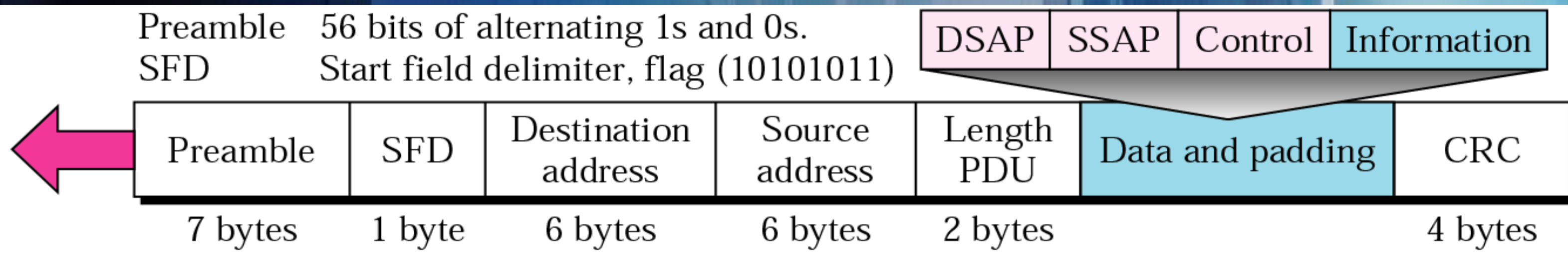
Overview

- Switches / Ethernet Switches
- Network Layer
- Addressing, IPv4 Addresses & Routers
- CIDR
- NAT
- ARP

802.3 MAC Format



- 64-bit frame preamble (10101010) used to synchronize reception
  - 7 bit preamble (10101010) + 1 start flag (10101011)

- Maximum frame length: 1536 bytes
  - ⇨ max 1500 bytes payload
- Minimum frame length: 64 bytes
  - ⇨ min 46 bytes payload

* Figure is courtesy of B. Forouzan

Ethernet Standards

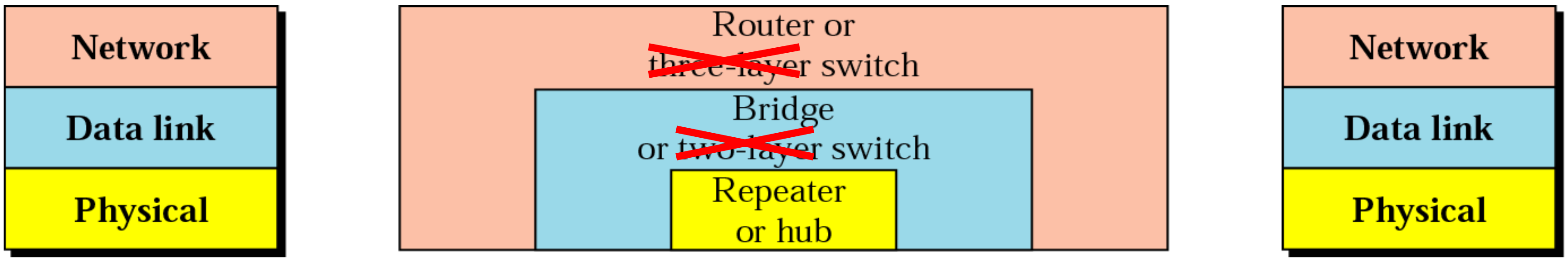
Name	Cable	Max. seg.	Nodes/seg.	Advantages
10Base5	Thick coax	500 m	100	Original cable; now obsolete
10Base2	Thin coax	185 m	30	No hub needed
10Base-T	Twisted pair	100 m	1024	Cheapest system
10Base-F	Fiber optics	2000 m	1024	Best between buildings

Name	Cable	Max. segment	Advantages
100Base-T4	Twisted pair	100 m	Uses category 3 UTP
100Base-TX	Twisted pair	100 m	Full duplex at 100 Mbps
100Base-FX	Fiber optics	2000 m	Full duplex at 100 Mbps; long runs

Name	Cable	Max. segment	Advantages
1000Base-SX	Fiber optics	550 m	Multimode fiber (50, 62.5 microns)
1000Base-LX	Fiber optics	5000 m	Single (10 µ) or multimode (50, 62.5 µ)
1000Base-CX	2 Pairs of STP	25 m	Shielded twisted pair
1000Base-T	4 Pairs of UTP	100 m	Standard category 5 UTP

* Figure is courtesy of A. Tanenbaum

Connecting Devices



- Physical Layer: Repeater or Hub

- Data Link Layer: Bridge or Layer-2 Switch

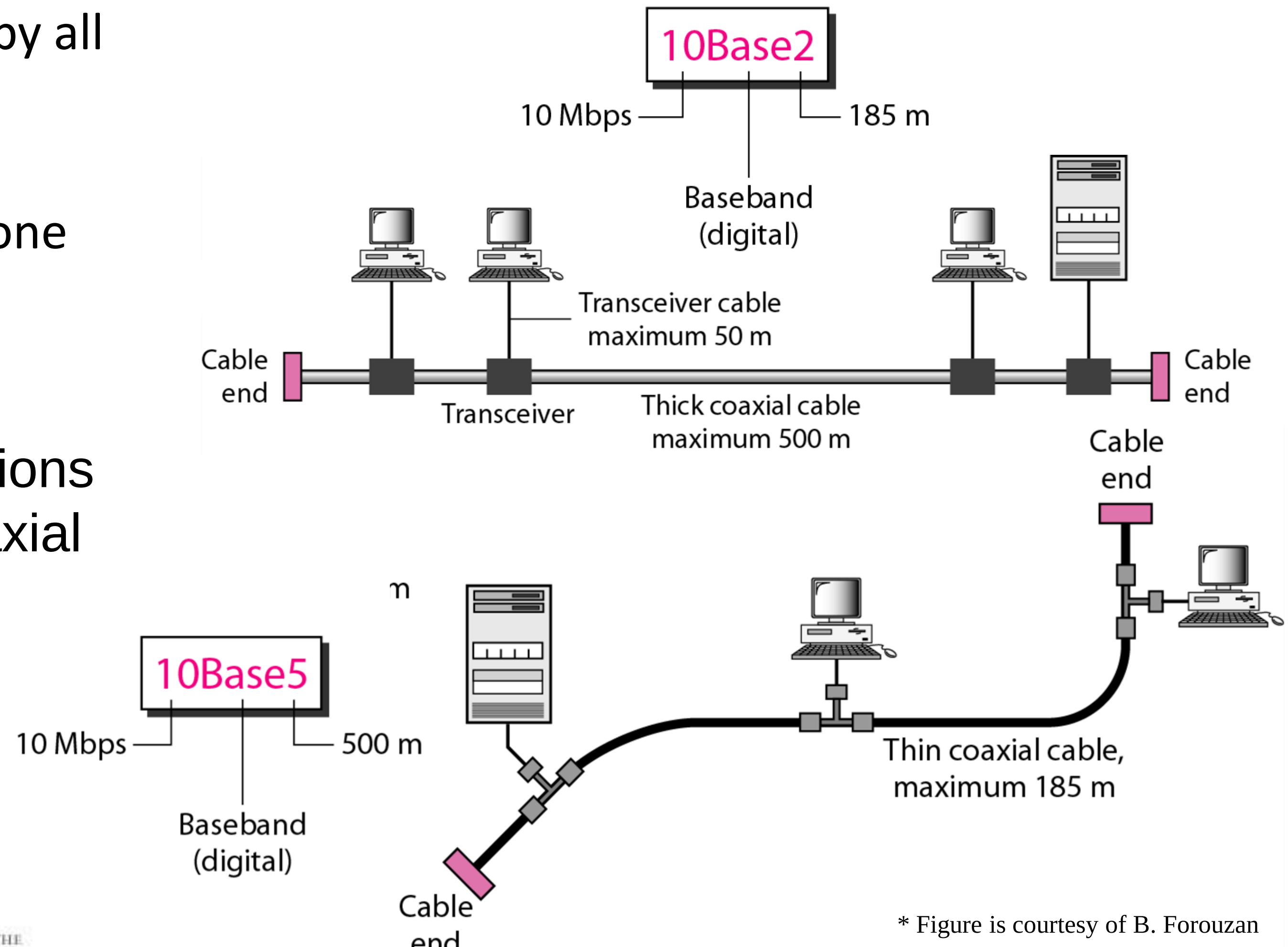
- Network Layer: Router or Layer-3 Switch

* Figure is courtesy of B. Forouzan

10Base5 & 10Base2

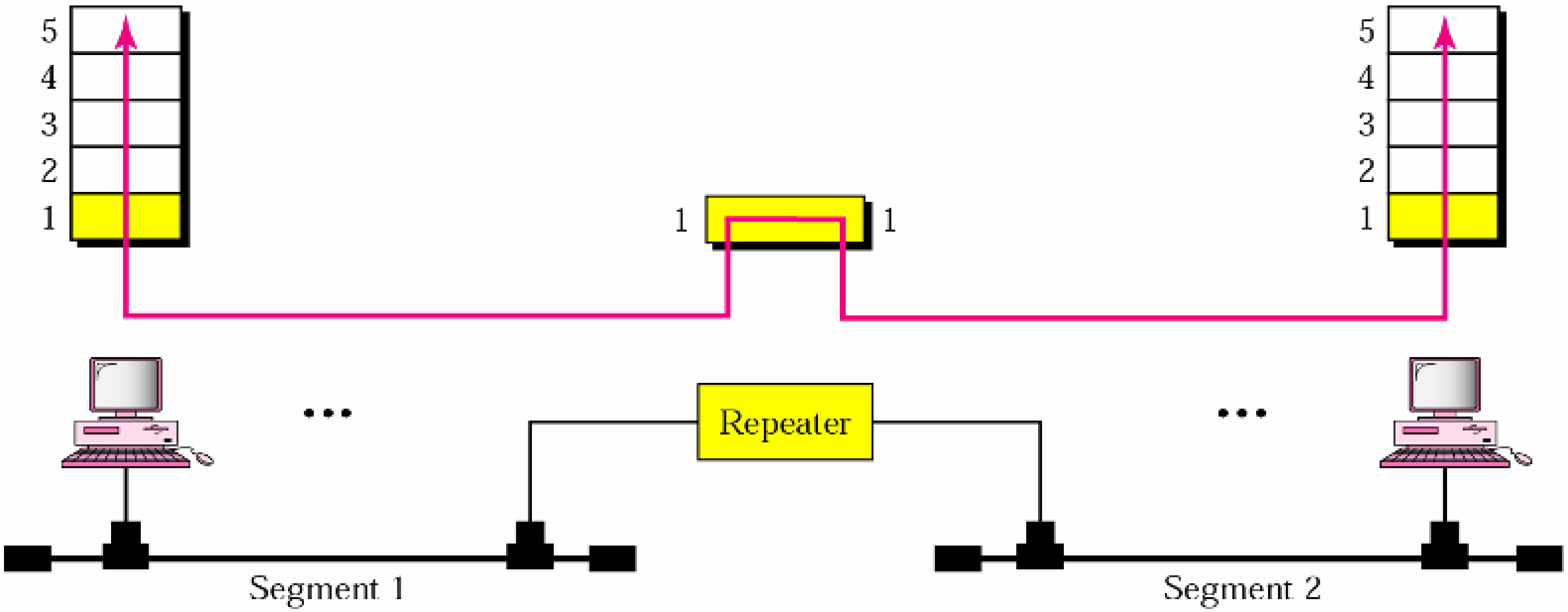
- Signal travels over cable & is picked up by all stations
- Used as backbone technology

- 10Base5: Stations linked into coaxial cable



* Figure is courtesy of B. Forouzan

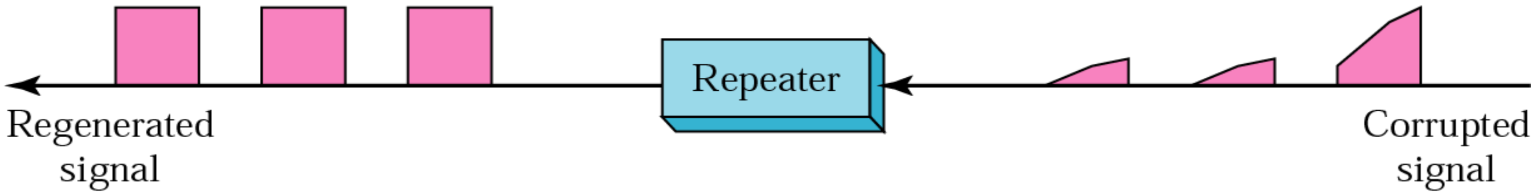
Repeater



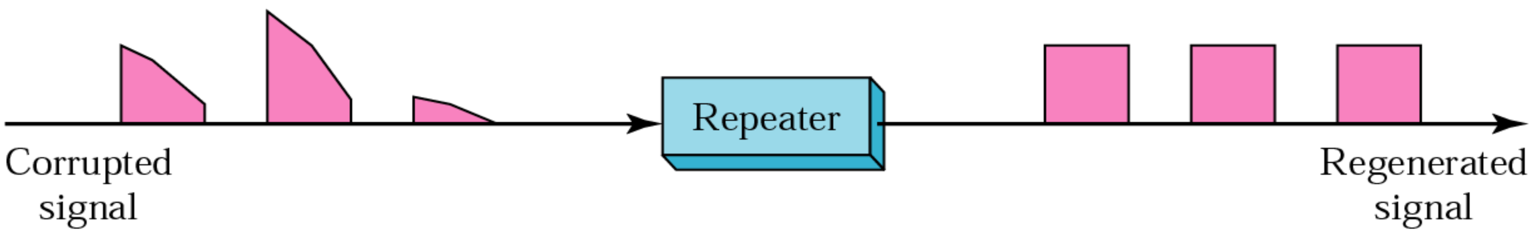
- A repeater connects segments of a LAN
- A repeater forwards every frame; it has no filtering capability

* Figure is courtesy of B. Forouzan

Function of a Repeater



a. Right-to-left transmission.



b. Left-to-right transmission.

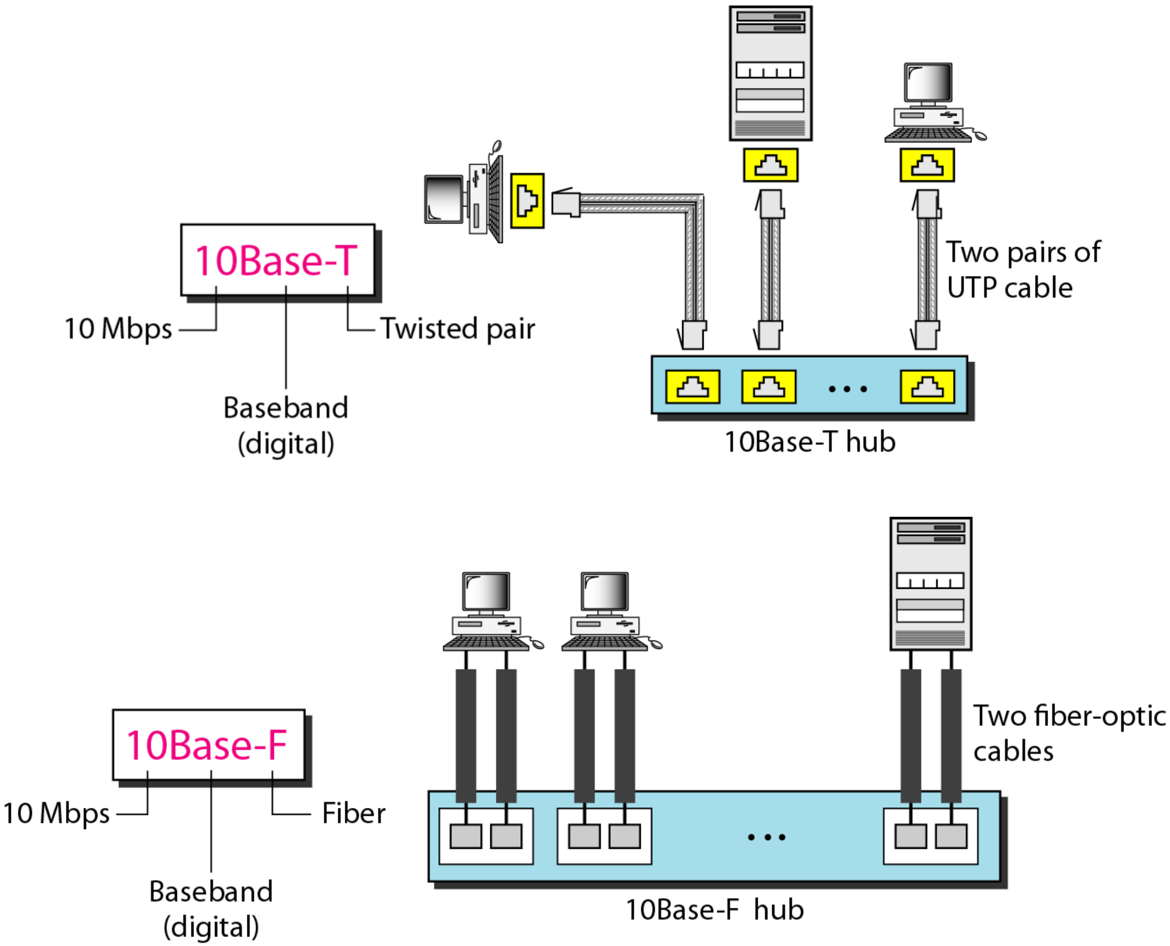
- A repeater is a regenerator,

  not an amplifier!

* Figure is courtesy of B. Forouzan

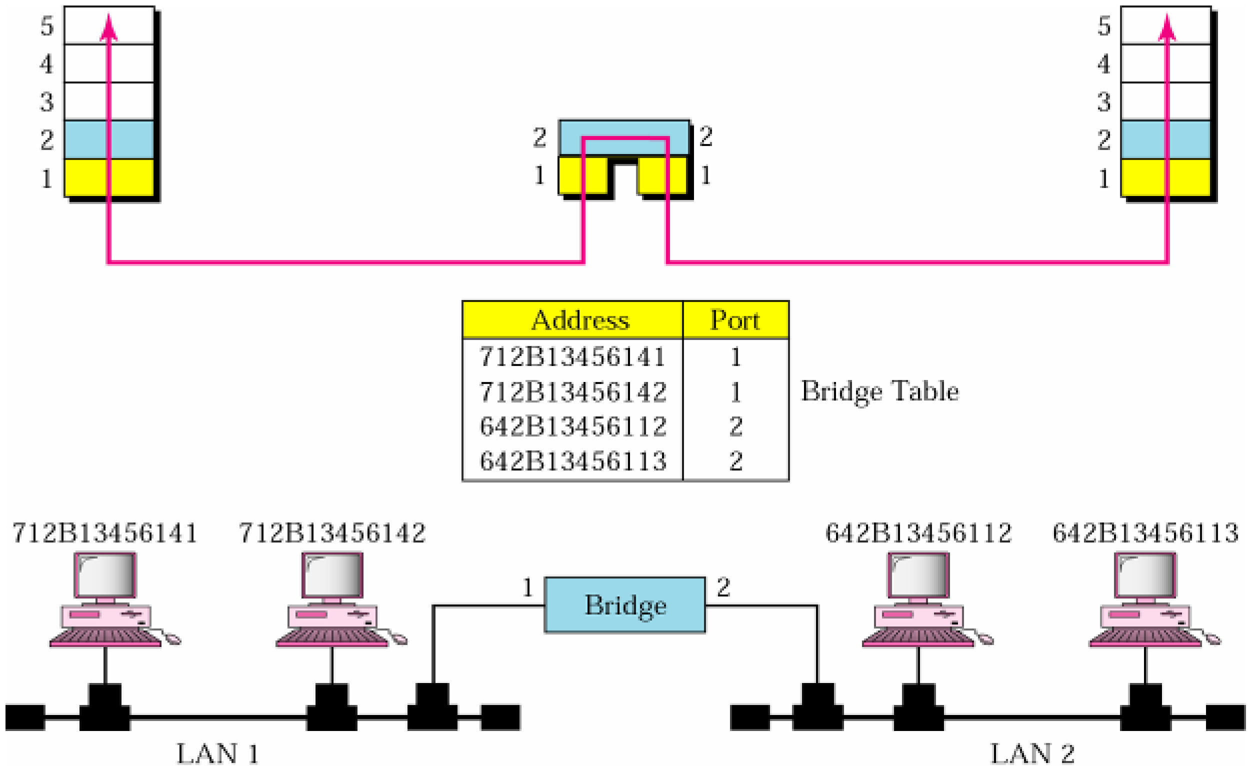
10Base-T & 10Base-F

- Hub replicates traffic to connected stations
- Each station has its own connection to hub
- Every station hears all traffic!



* Figure is courtesy of B. Forouzan

Functions of a Bridge

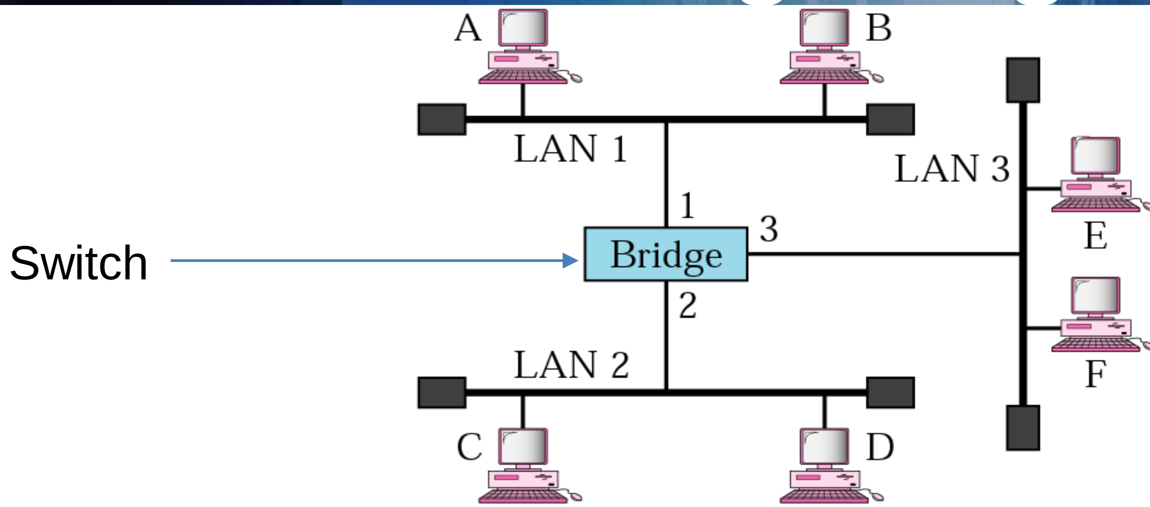


Address	Port
712B13456141	1
712B13456142	1
642B13456112	2
642B13456113	2

- Read all frames transmitted on one LAN and accept those address to any station on the other LAN
- Using MAC protocol for second LAN, retransmit each frame
- Do the same the other way round

* Figure is courtesy of B. Forouzan

Learning Bridges



Address	Port

a. Original

Address	Port
A	1

b. After A sends a frame to D

Address	Port
A	1
E	3

c. After E sends a frame to A

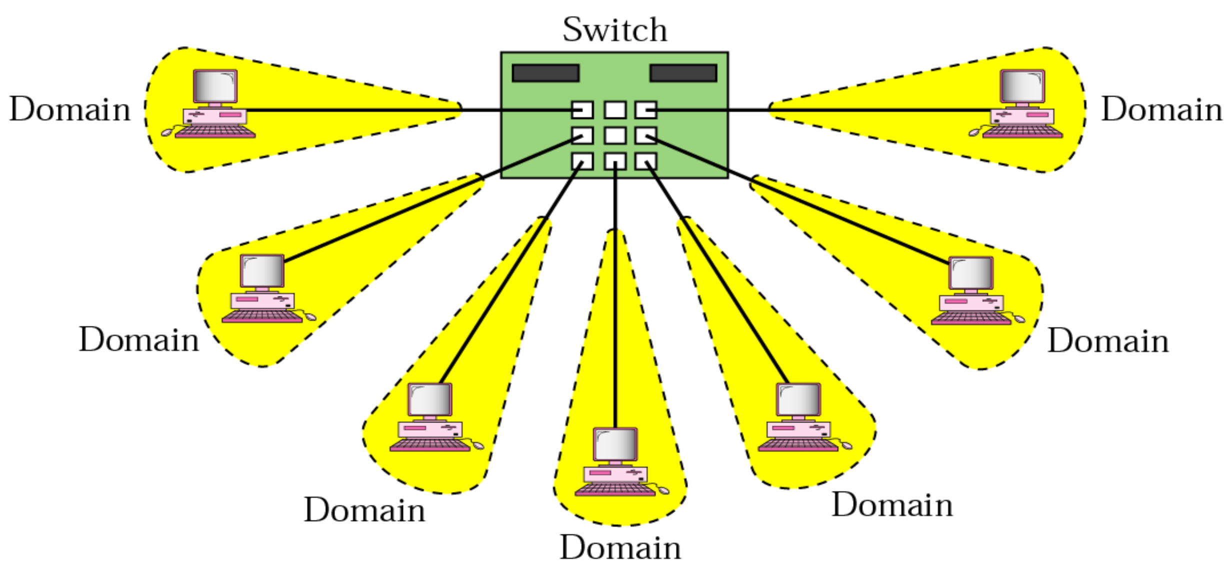
Address	Port
A	1
E	3
B	1

d. After B sends a frame to C

- Initially bridge forwards frames on all segments except incoming port
- Learns addresses from frames that pass through

* Figure is courtesy of B. Forouzan

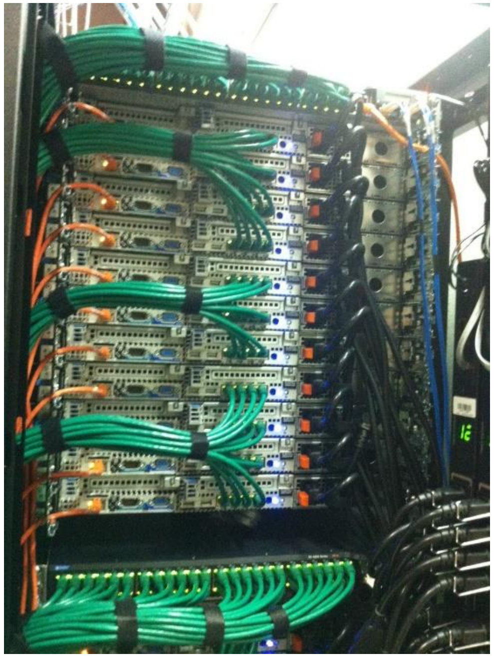
Switched Ethernet



- Switch delivers packets to individual machines
  - Without affecting communication with other machines
- Collisions only occur on individual links

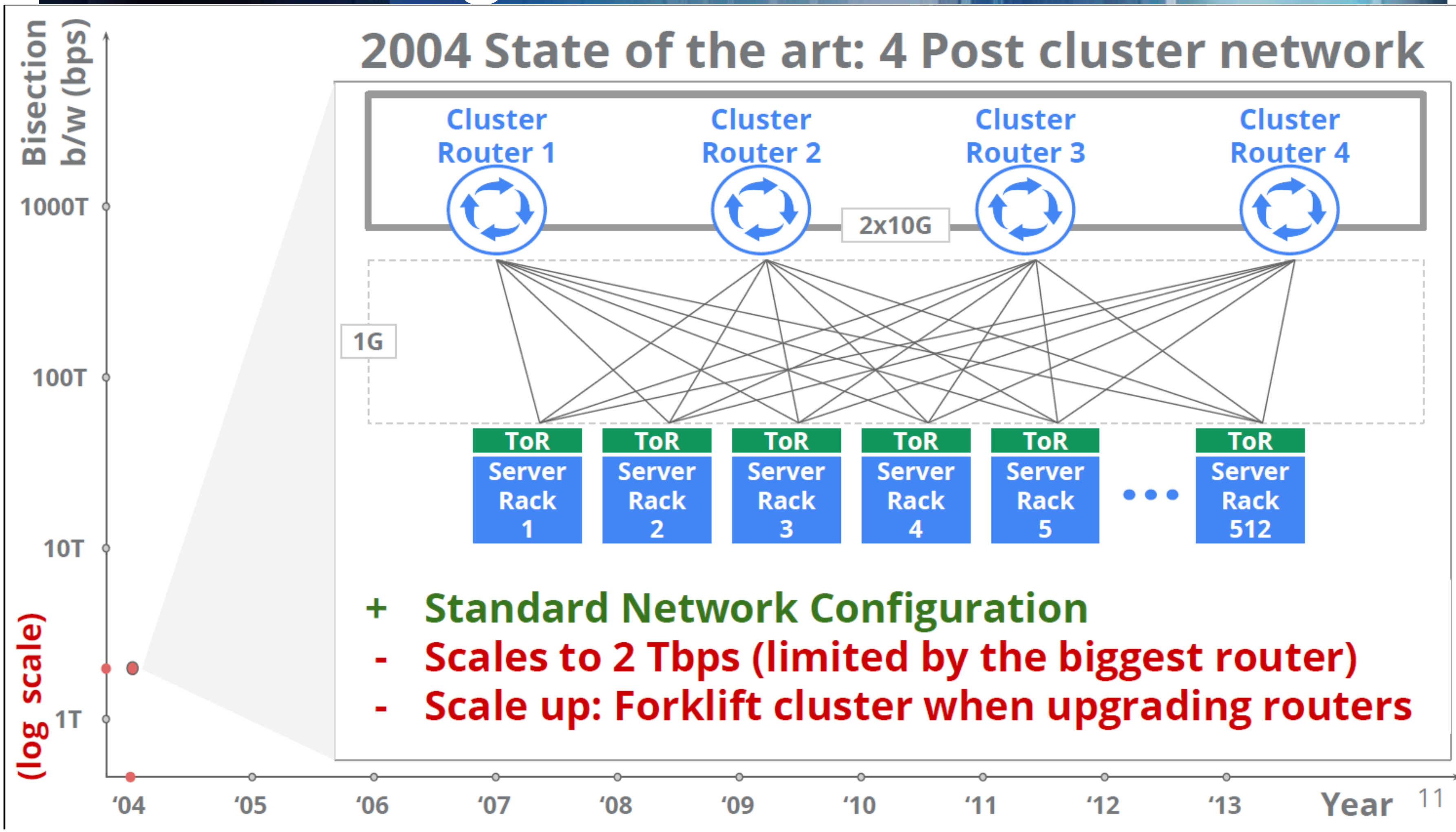
* Figure is courtesy of B. Forouzan

Switch



* Figure is courtesy of Cisco & Reddit

Google's Infrastructure



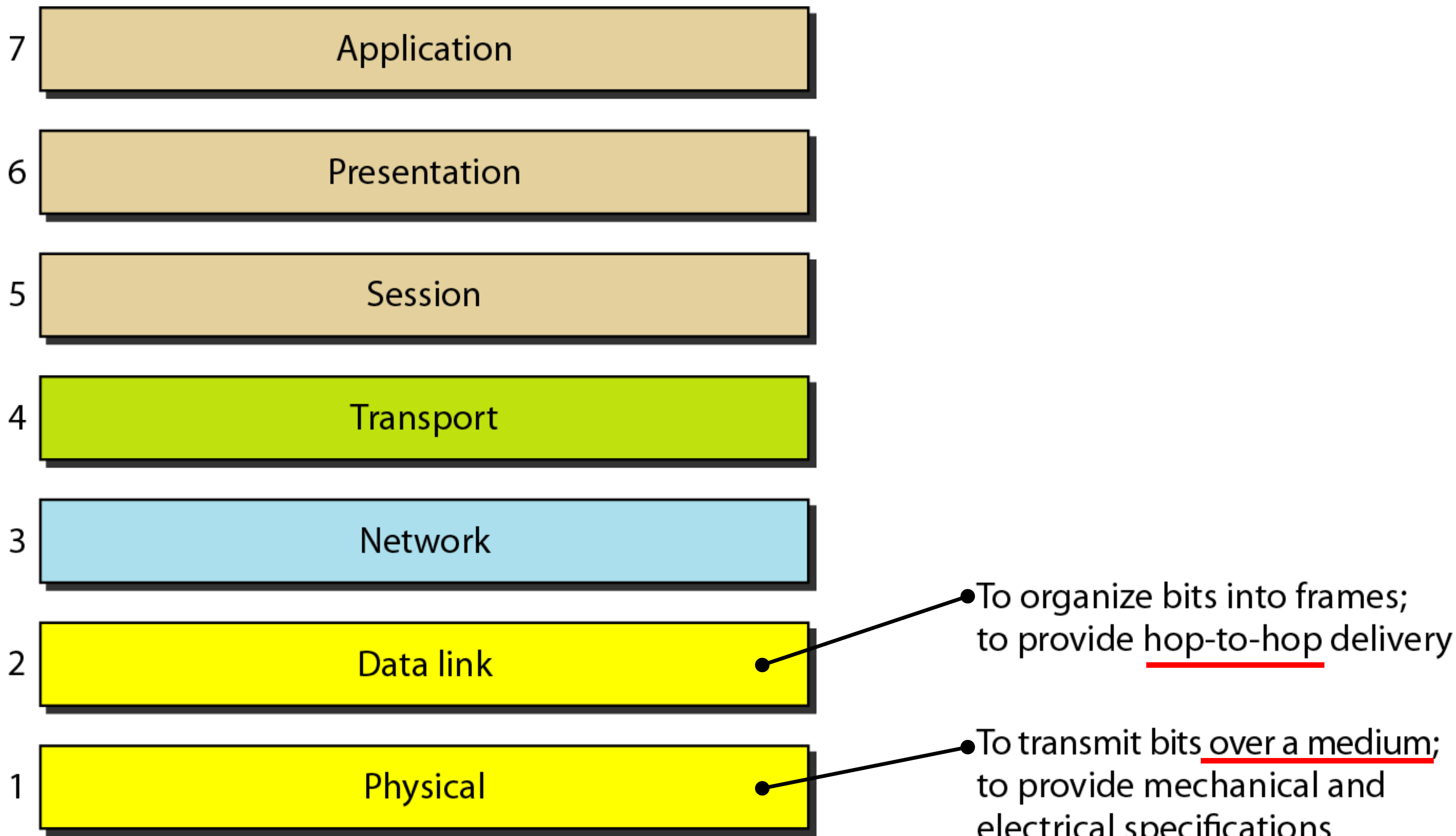
Types of Layer 2 Switches

- Store-and-Forward switch
  - Accepts frame on input line
  - Buffers it briefly,
  - Then routes it to appropriate output line
  - Delay between sender and receiver
  - Boosts integrity of network
- Cut-Through switch
  - Takes advantage of destination address appearing at beginning of frame
  - Switch begins repeating frame onto output line as soon as it recognizes destination address
  - Highest possible throughput
  - Risk of propagating bad frames
    - Switch unable to check CRC prior to retransmission

CS2031
Telecommunications II

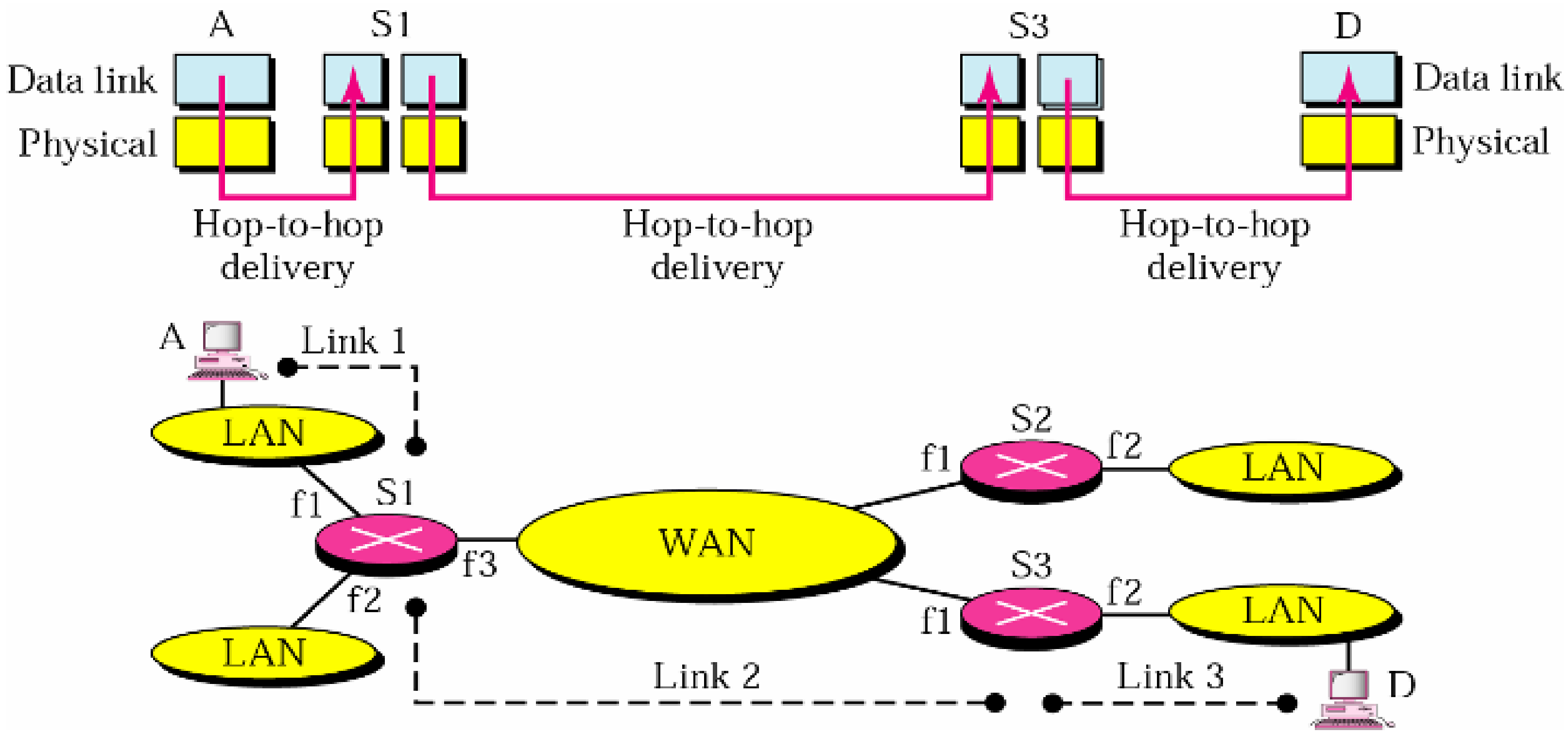
Network Layer

OSI Model



* Figure is courtesy of B. Forouzan

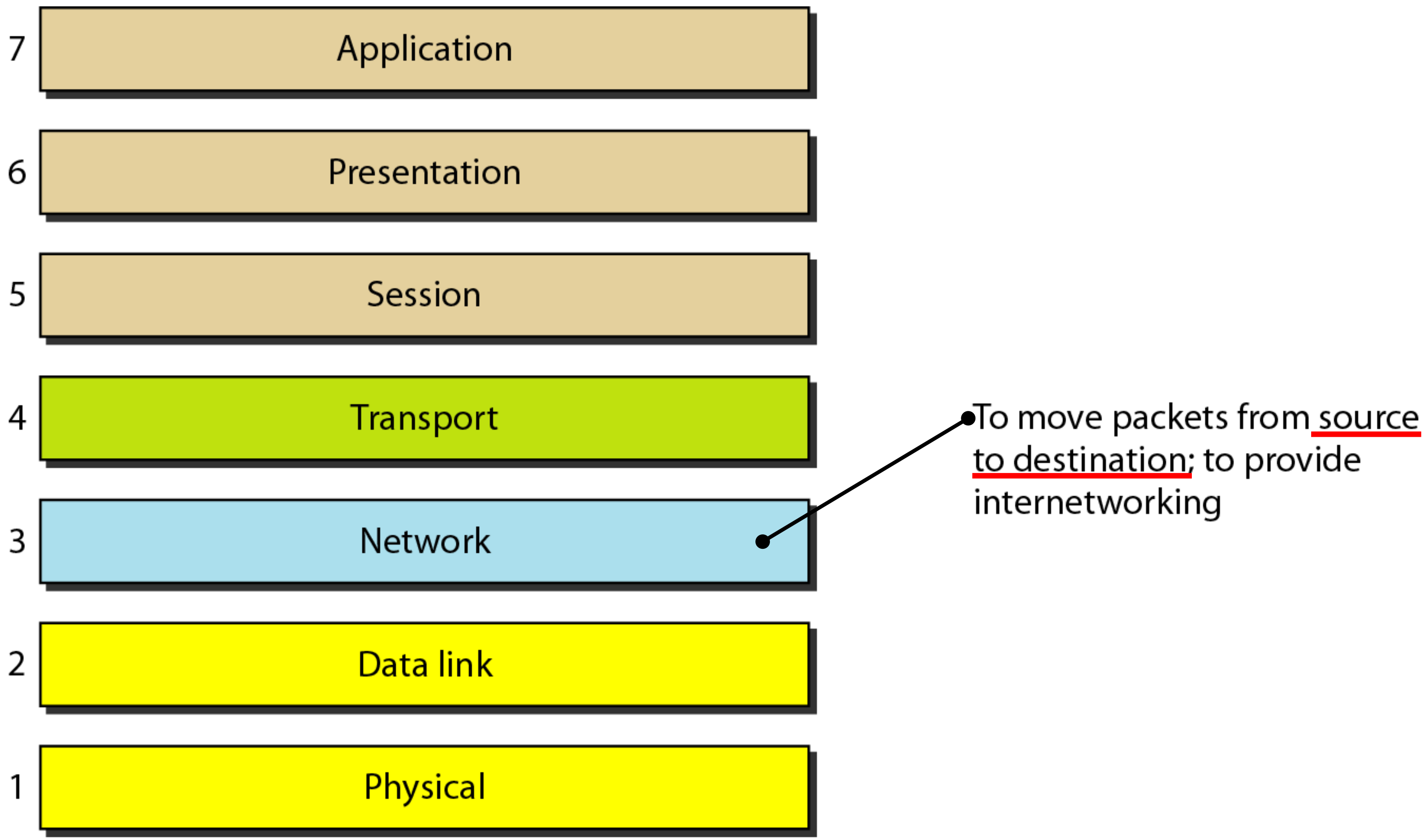
Data Link Layer



- Hop-to-hop communication

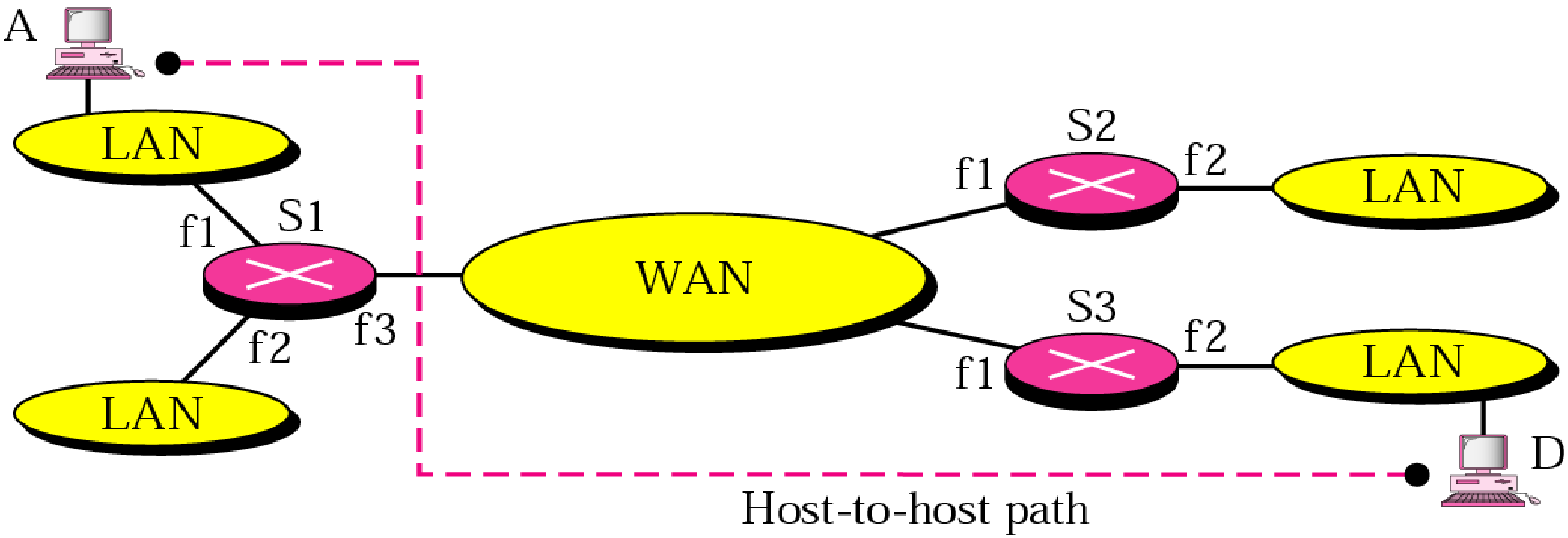
* Figure is courtesy of B. Forouzan

OSI Model



* Figure is courtesy of B. Forouzan

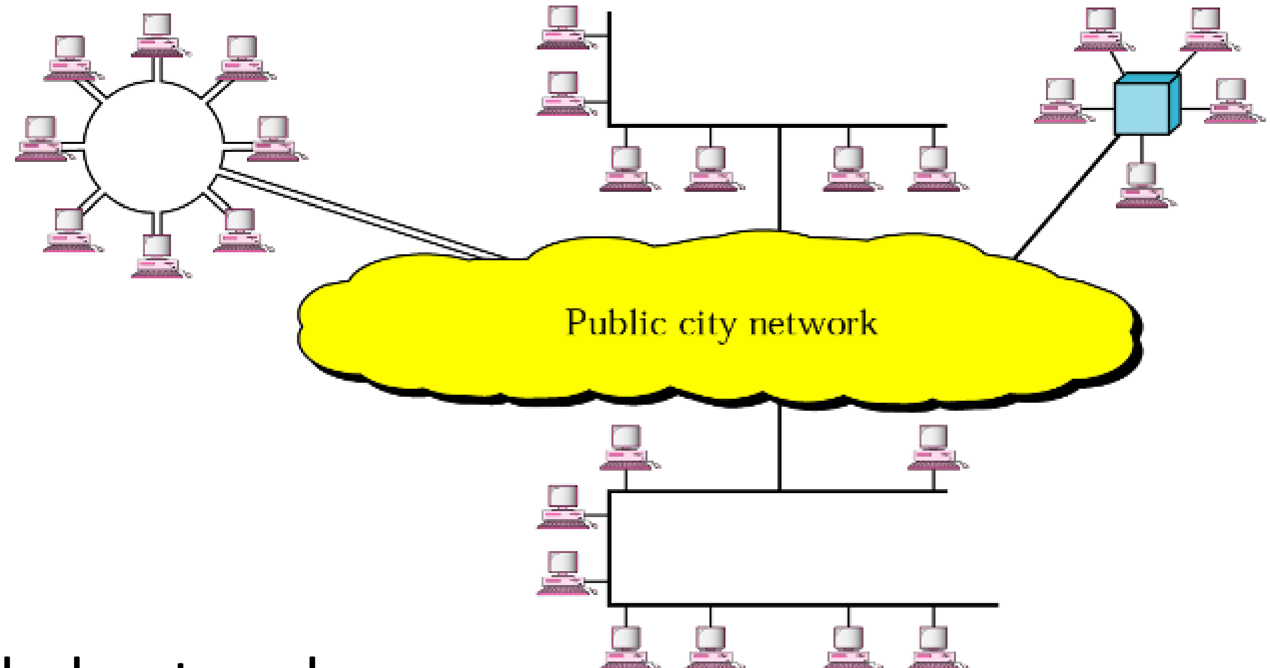
Network Layer



- Responsible for source-to-destination delivery of a packet across multiple network links.

* Figure is courtesy of B. Forouzan

Problems faced by Network Layers



- Global networks
  - Various different architectures
  - Various formats for hardware addresses
  - Various maximum transmission units (MTUs)

* Figure is courtesy of B. Forouzan

Paul Baran, 1964

- Paul Barran, On Distributed Communication Networks, IEEE Transactions on Communication Systems, Volume 12, No. 1, March 1964

- Introduced Concepts of
  - Distributed Networks
  - Routing (hot-potato-routing)
  - Packet-Switching (message-block)

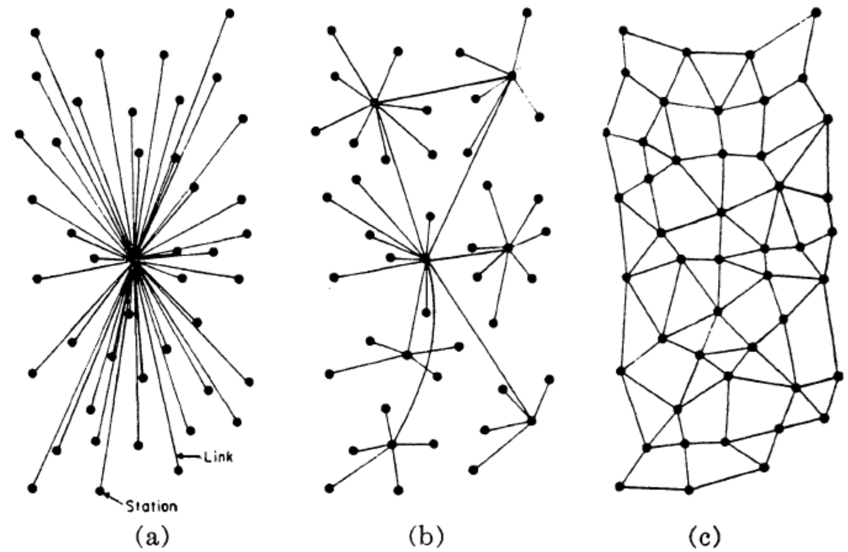
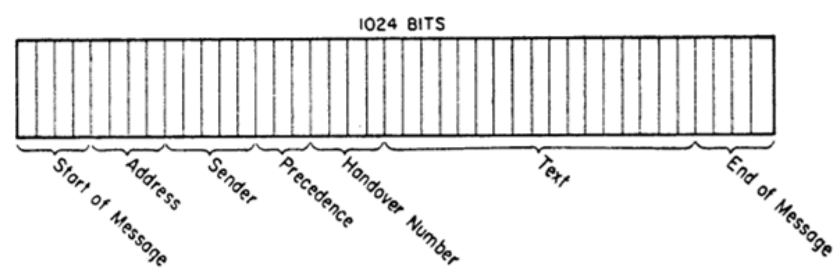


Fig. 1—(a) Centralized. (b) Decentralized. (c) Distributed networks.



AT&T's comment back then was that packet-switching will never be useful.

HOST-HOST Communication, 1970

- Paul Barran, On Distributed Communication Networks, IEEE Transactions on Communication Systems, Volume 12, No. 1, March 1964

- Introduced Concepts of
  - Distributed Networks
  - Routing (hot-potato-routing)
  - Packet-Switching (message-block)

- Name worth mentioning: Bob Kahn

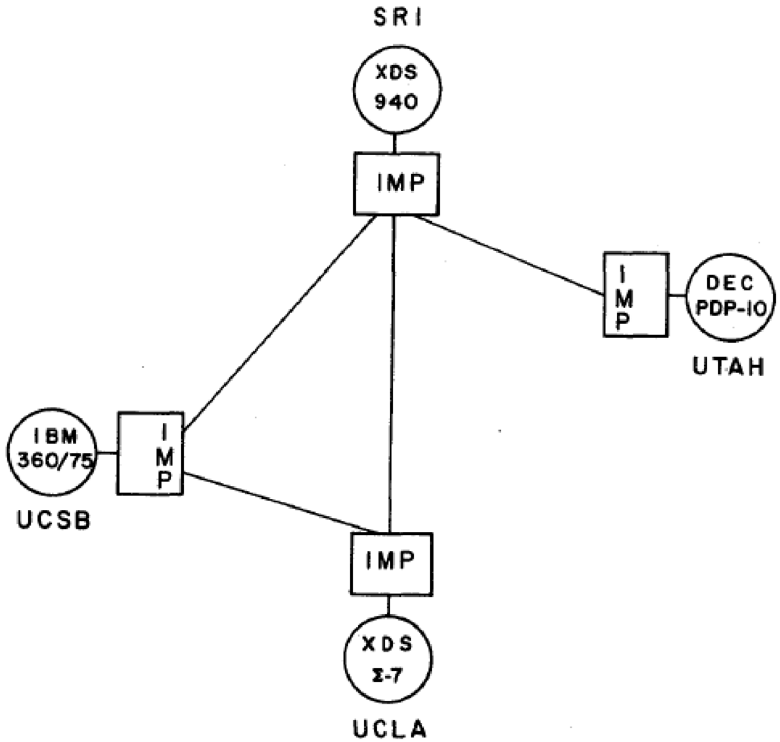
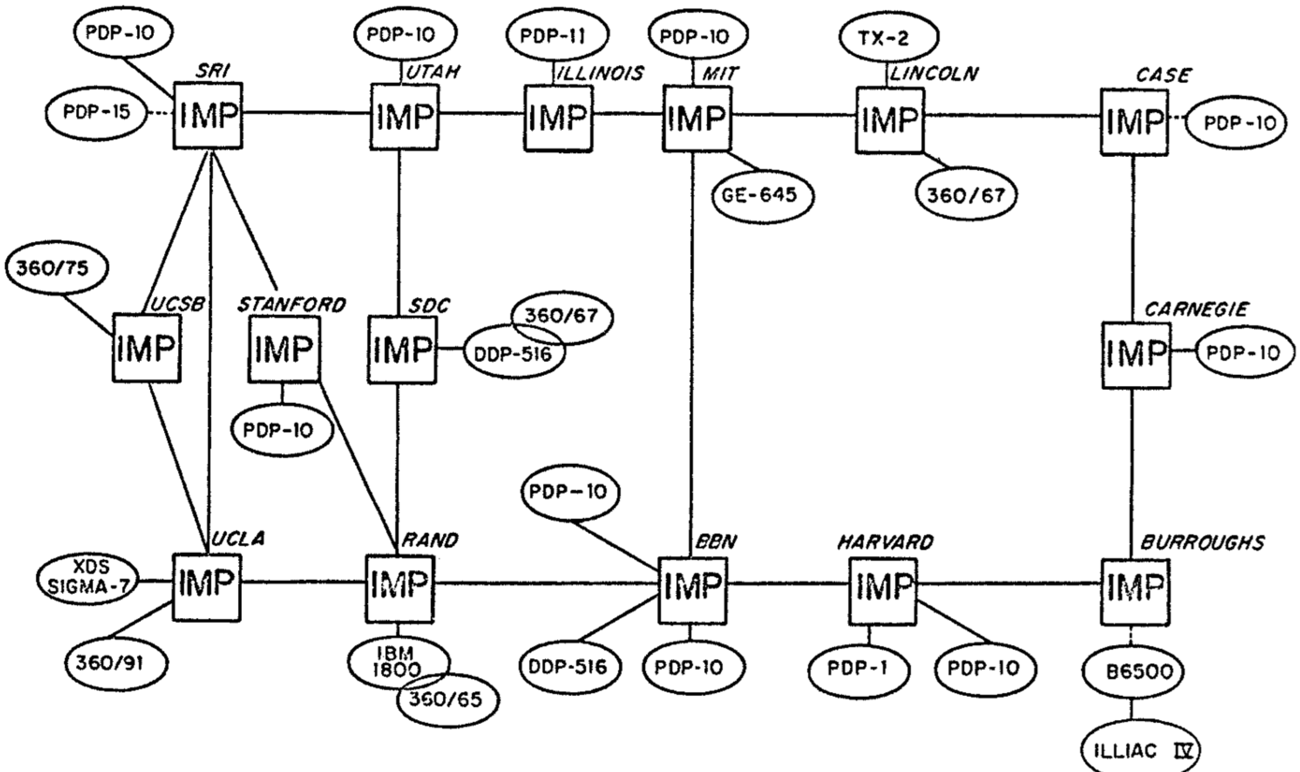


Figure 1—Initial network configuration

* C. Stephen Carr, Stephen D. Crocker, and Vinton G. Cerf, HOST-HOST Communication Protocol in the ARPA Network, Spring Joint Computer Conference, pages 589-597, Atlantic City, NJ, USA, May 1970

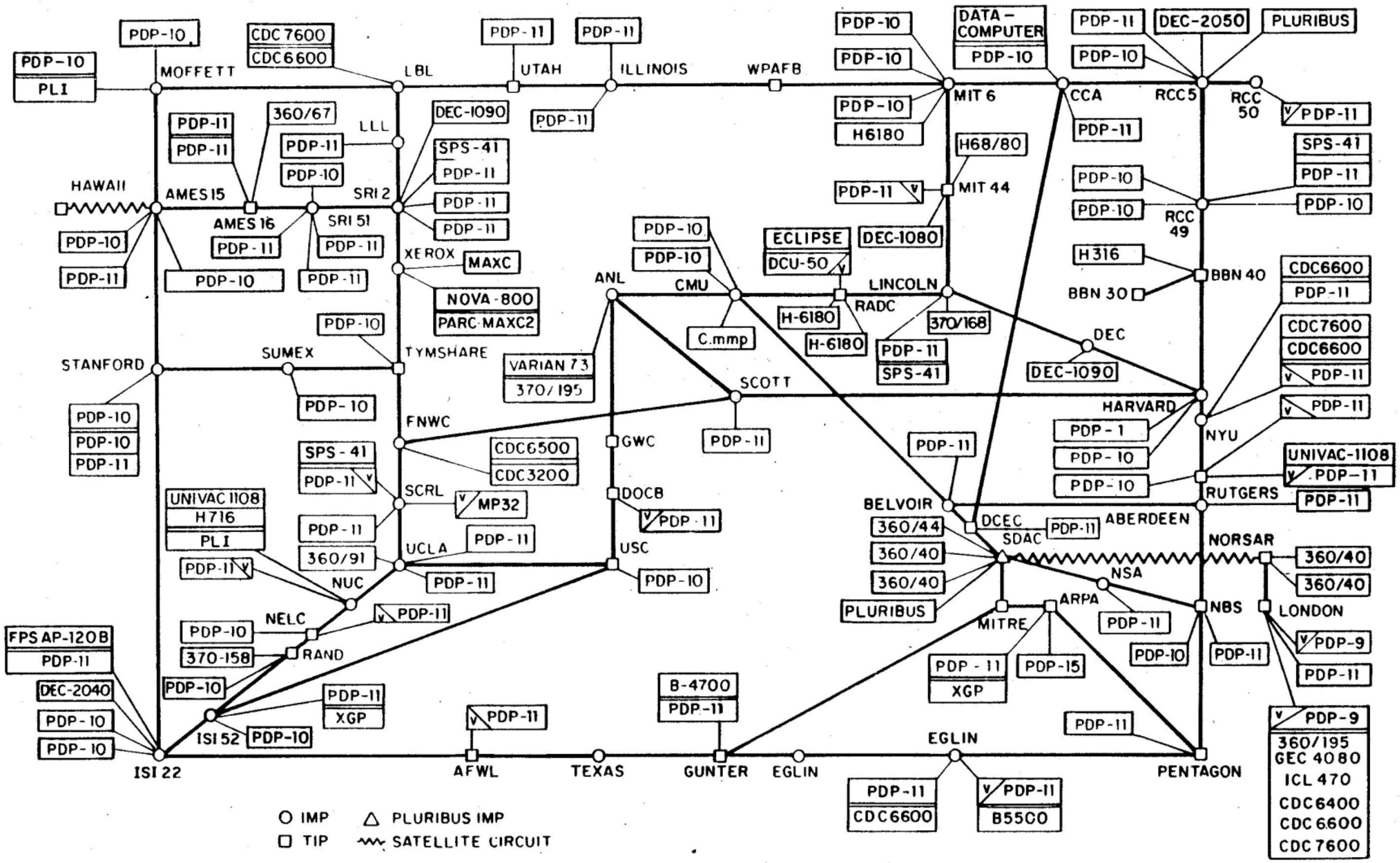
AT&T's comment was that packet-switching will never be useful.

ARPANET 1971



ARPA NET, APRIL 1971

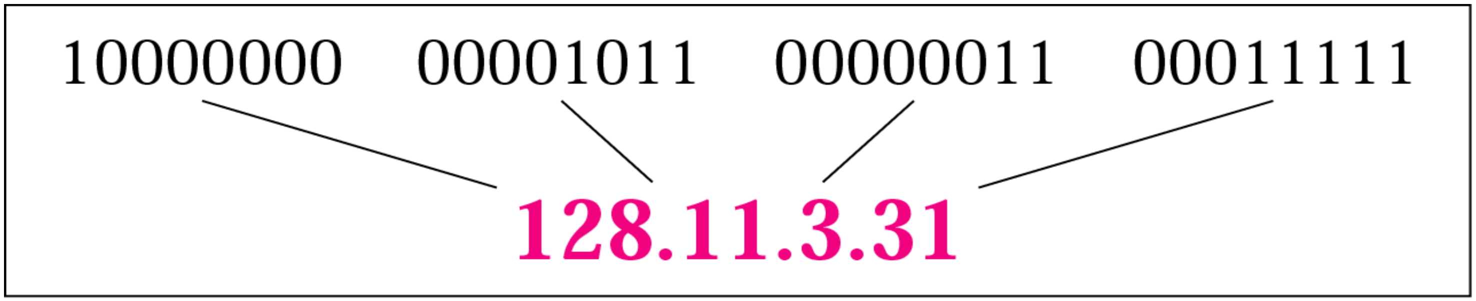
ARPANET 1977



(PLEASE NOTE THAT WHILE THIS MAP SHOWS THE HOST POPULATION OF THE NETWORK ACCORDING TO THE BEST INFORMATION OBTAINABLE, NO CLAIM CAN BE MADE FOR ITS ACCURACY)

NAMES SHOWN ARE IMP NAMES, NOT (NECESSARILY) HOST NAMES

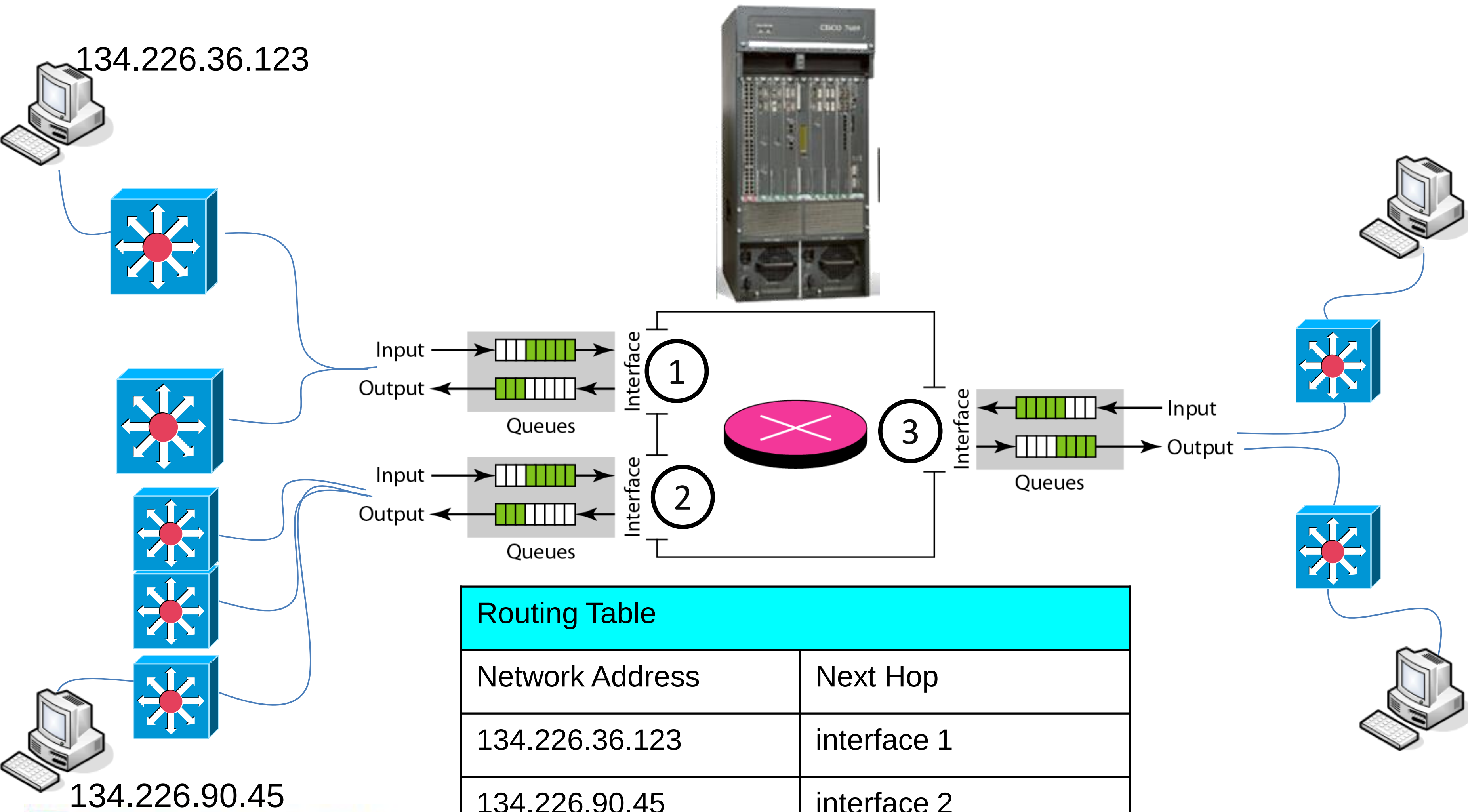
IP Addresses



- 32-bit number
  - 4.294.967.296 addresses
- IP addresses are unique and universal
  - with some exceptions
- Dotted decimal notation:
  - Bytes of binary notation represented as decimal separated by dot

* Figure is courtesy of B. Forouzan

Task of Routers



Routing Table	
Network Address	Next Hop
134.226.36.123	interface 1
134.226.90.45	interface 2

Routers

- One Main Interest
  Forwarding Packets

- Important Aspects
  Queue Length
  Routing Table

Destination	Gateway	Interface
IP $Range_1$ IP $Range_2$	G_1 G_2	IF_1 IF_2

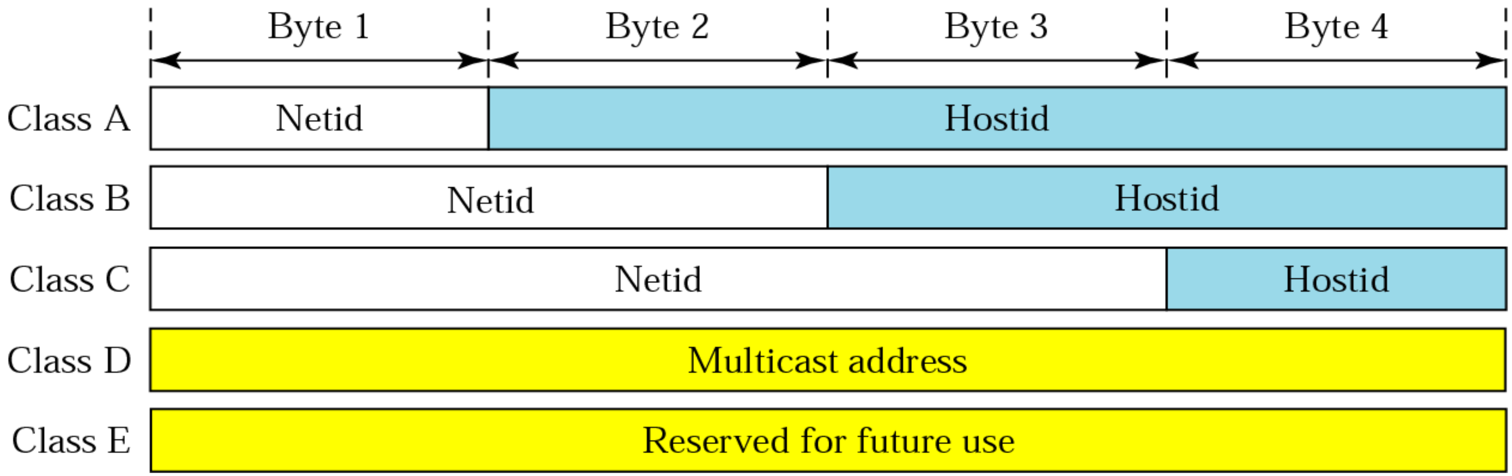
* Figure is courtesy of Cisco

Everything's a Router

```
Active Routes:
Network Destination        Netmask          Gateway       Interface  Metric
          0.0.0.0          0.0.0.0    192.168.192.1  192.168.192.37     25
        127.0.0.0        255.0.0.0         On-link        127.0.0.1    306
        127.0.0.1  255.255.255.255         On-link        127.0.0.1    306
  127.255.255.255  255.255.255.255         On-link        127.0.0.1    306
     192.168.21.0    255.255.255.0         On-link     192.168.21.1    276
     192.168.21.1  255.255.255.255         On-link     192.168.21.1    276
   192.168.21.255  255.255.255.255         On-link     192.168.21.1    276
    192.168.111.0    255.255.255.0         On-link    192.168.111.1    276
    192.168.111.1  255.255.255.255         On-link    192.168.111.1    276
  192.168.111.255  255.255.255.255         On-link    192.168.111.1    276
    192.168.150.0    255.255.255.0         On-link    192.168.150.1    276
    192.168.150.1  255.255.255.255         On-link    192.168.150.1    276
  192.168.150.255  255.255.255.255         On-link    192.168.150.1    276
    192.168.192.0    255.255.255.0         On-link   192.168.192.37    281
   192.168.192.37  255.255.255.255         On-link   192.168.192.37    281
  192.168.192.255  255.255.255.255         On-link   192.168.192.37    281
```

4.294.967.296 Possible Nodes???

Network ID and Host ID



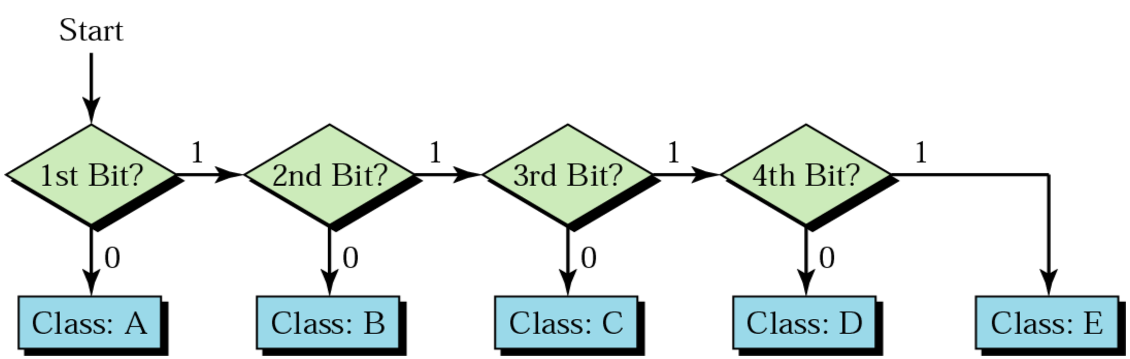
- Network ID: Used to find a particular network
- Host ID: Identifies indentify individual nodes

* Figure is courtesy of B. Forouzan

Classes in Binary Notation

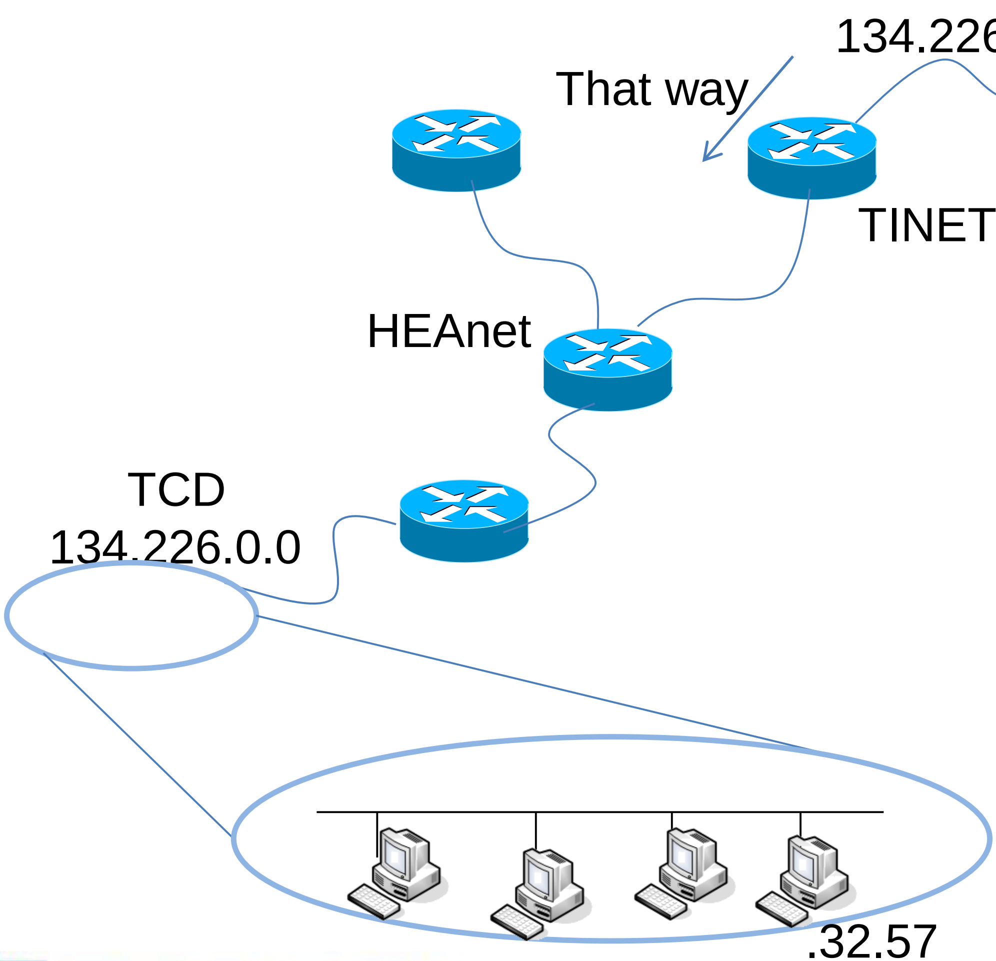
	First byte	Second byte	Third byte	Fourth byte
Class A	**0**			
Class B	**10**			
Class C	**110**			
Class D	**1110**			
Class E	**1111**			

- Decision Process:



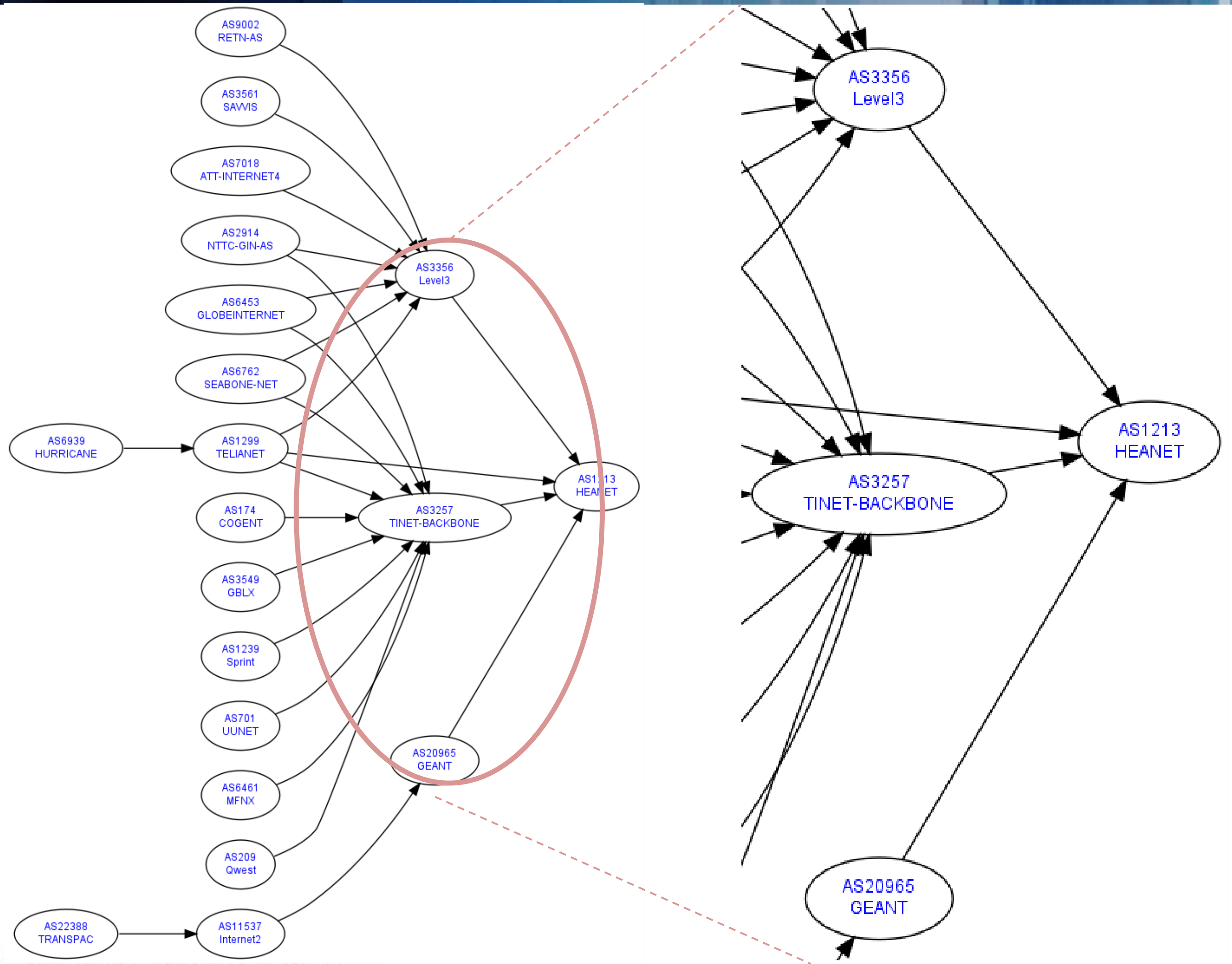
* Figure is courtesy of B. Forouzan

Network IDs and Host IDs

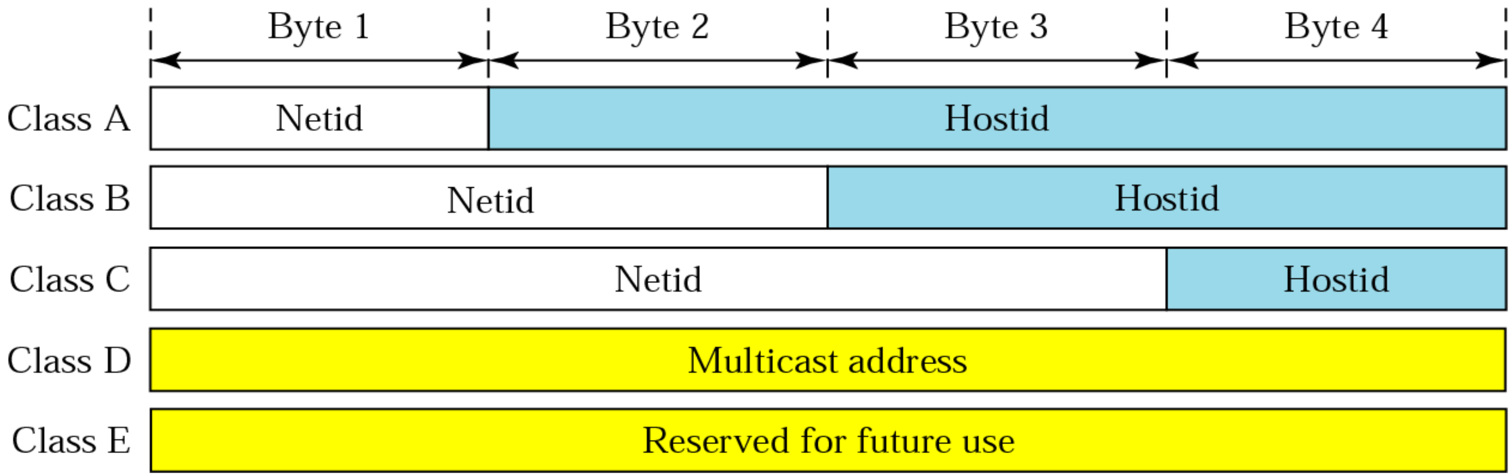


- Routing split into:
  - Routing to the destination network
  - Routing within the destination network

AS1213 - HEANET



Classful Addresses



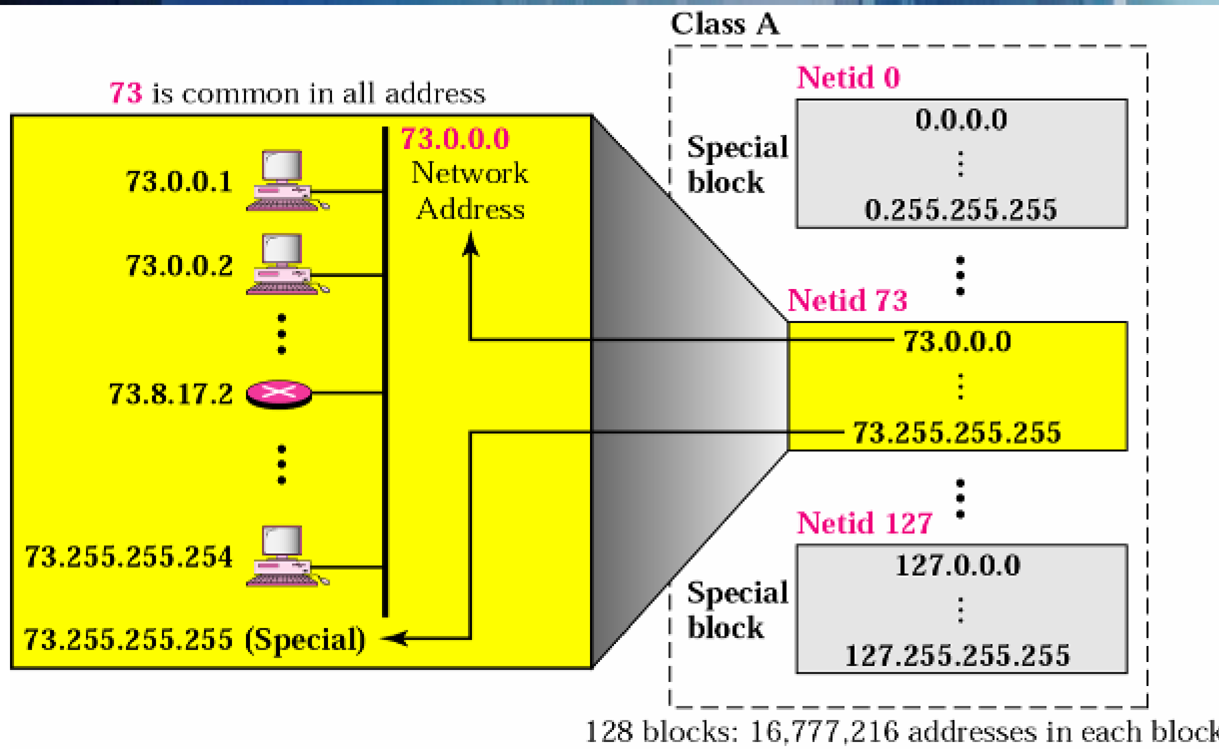
- Class A (international organisations)
  - 126 networks with 16,277,214 hosts each

- Class B (large companies)
  - 16,384 networks with 65,354 hosts each

- Class C (smaller companies)
  - 2,097,152 networks with 254 hosts each

* Figure is courtesy of B. Forouzan

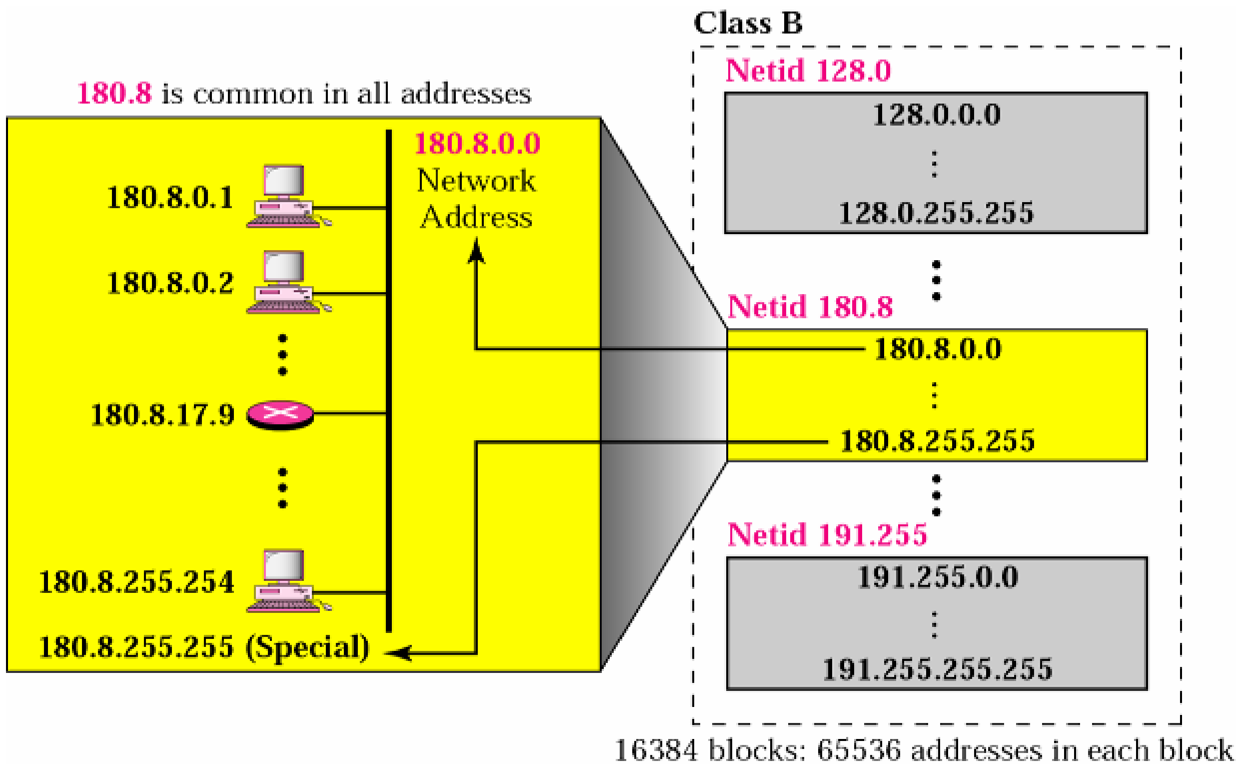
Class A



- Limited number of very large networks
- 126 networks with 16,277,214 hosts each

* Figure is courtesy of B. Forouzan

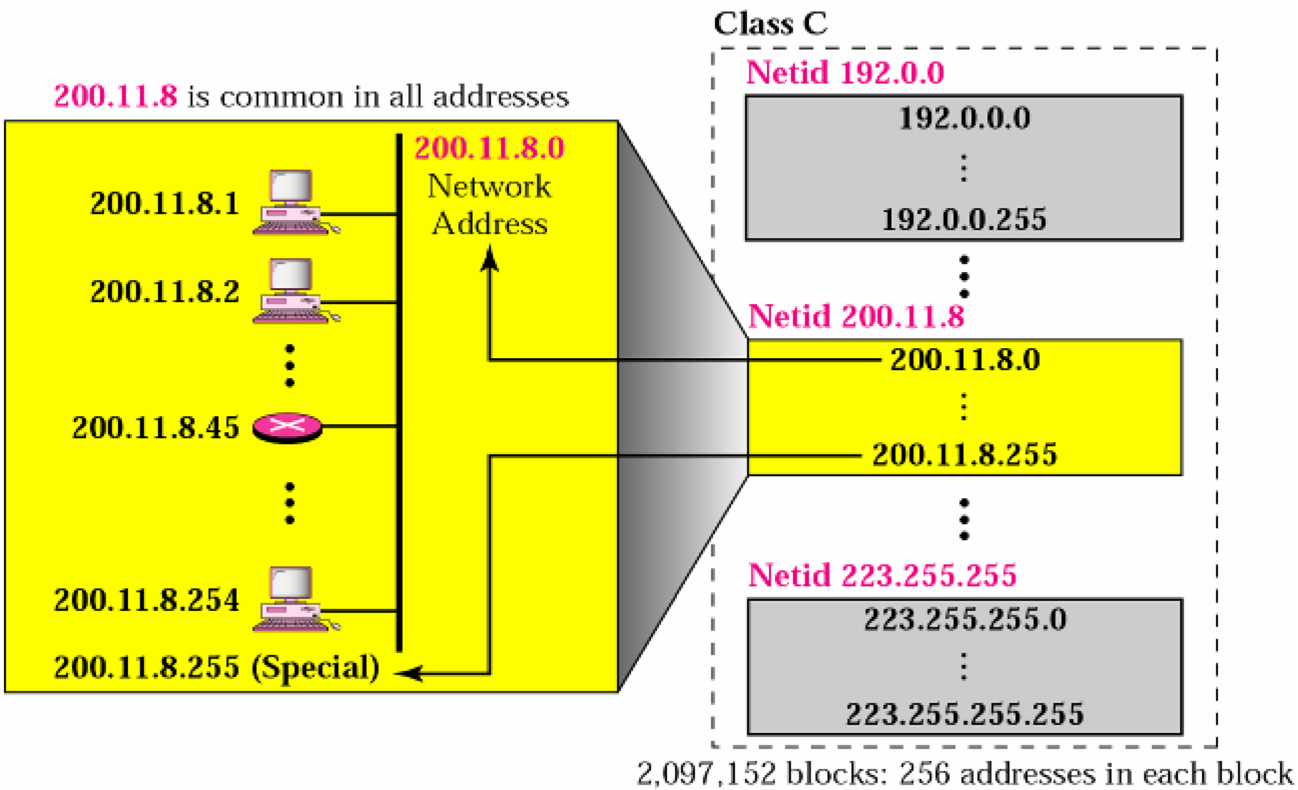
Class B



- Limited number of relatively large address ranges
- 16,384 networks with 65,354 hosts each

* Figure is courtesy of B. Forouzan

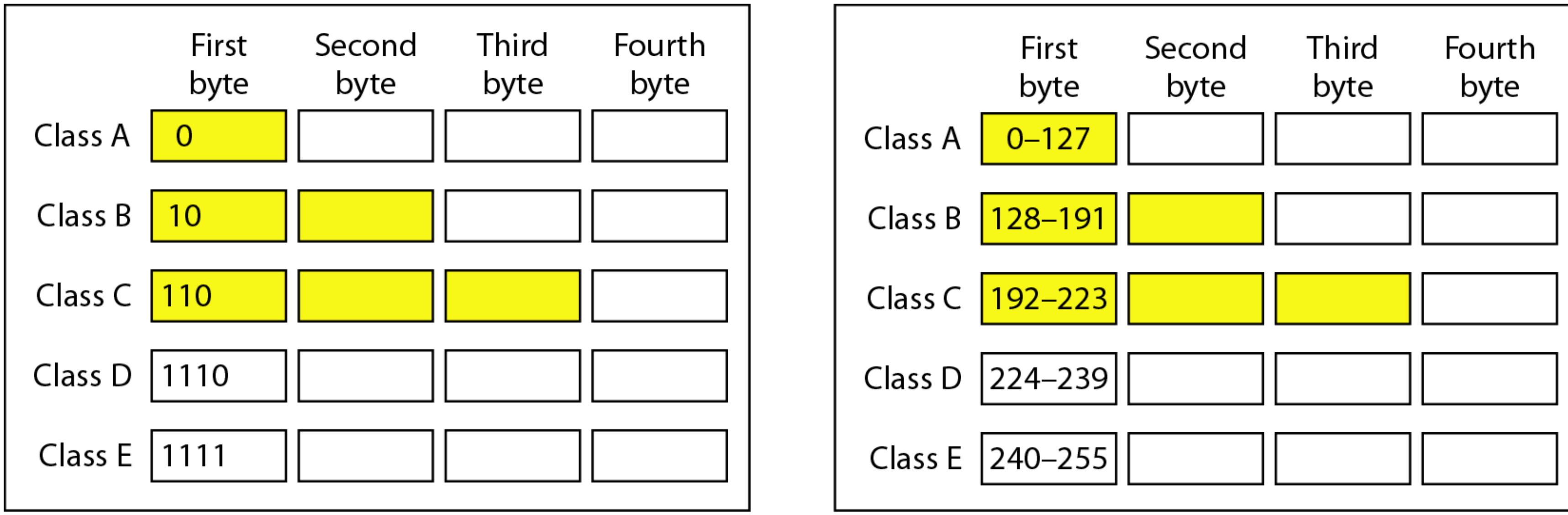
Class C



- Large number of small address ranges
- 2,097,152 networks with 254 hosts each

* Figure is courtesy of B. Forouzan

Classes & Private Addresses



a. Binary notation

b. Dotted-decimal notation

Private Address Ranges:

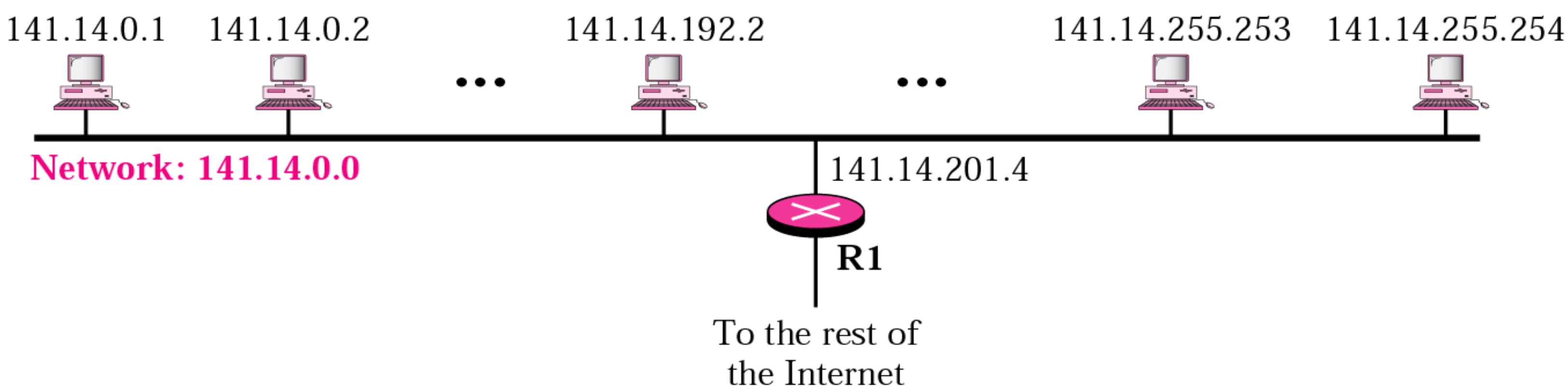
Range			*Total*
10.0.0.0	to	10.255.255.255	2^{24}
172.16.0.0	to	172.31.255.255	2^{20}
192.168.0.0	to	192.168.255.255	2^{16}

* Figure is courtesy of B. Forouzan

Special Addresses

- Loopback device: 127.x.x.x
  - e.g. 127.0.0.1 = localhost
- This network: 0.0.0.x (all zero's)
  - e.g. 0.0.0.54 = host 54 on this network
- Broadcast: x.x.255.255 (all one's)
  - e.g. 134.226.36.255 = all nodes in this network

2-Level Hierarchy with Classful Addresses



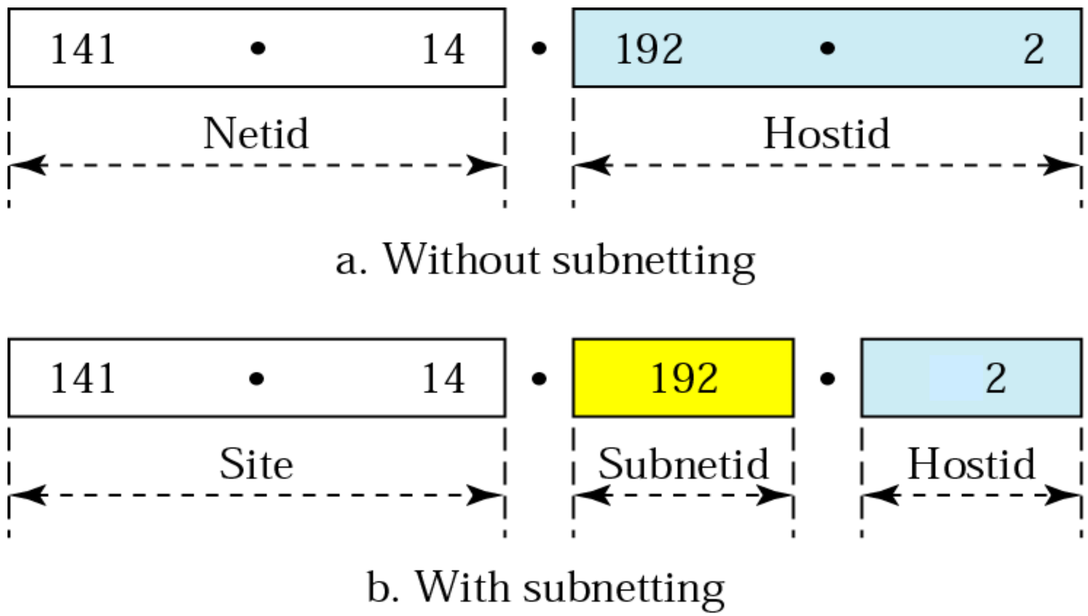
- 1st level: NetworkID within the Internet
- 2nd level: HostID within the network

* Figure is courtesy of B. Forouzan

College Network

- Flat Network with 1000s of Nodes

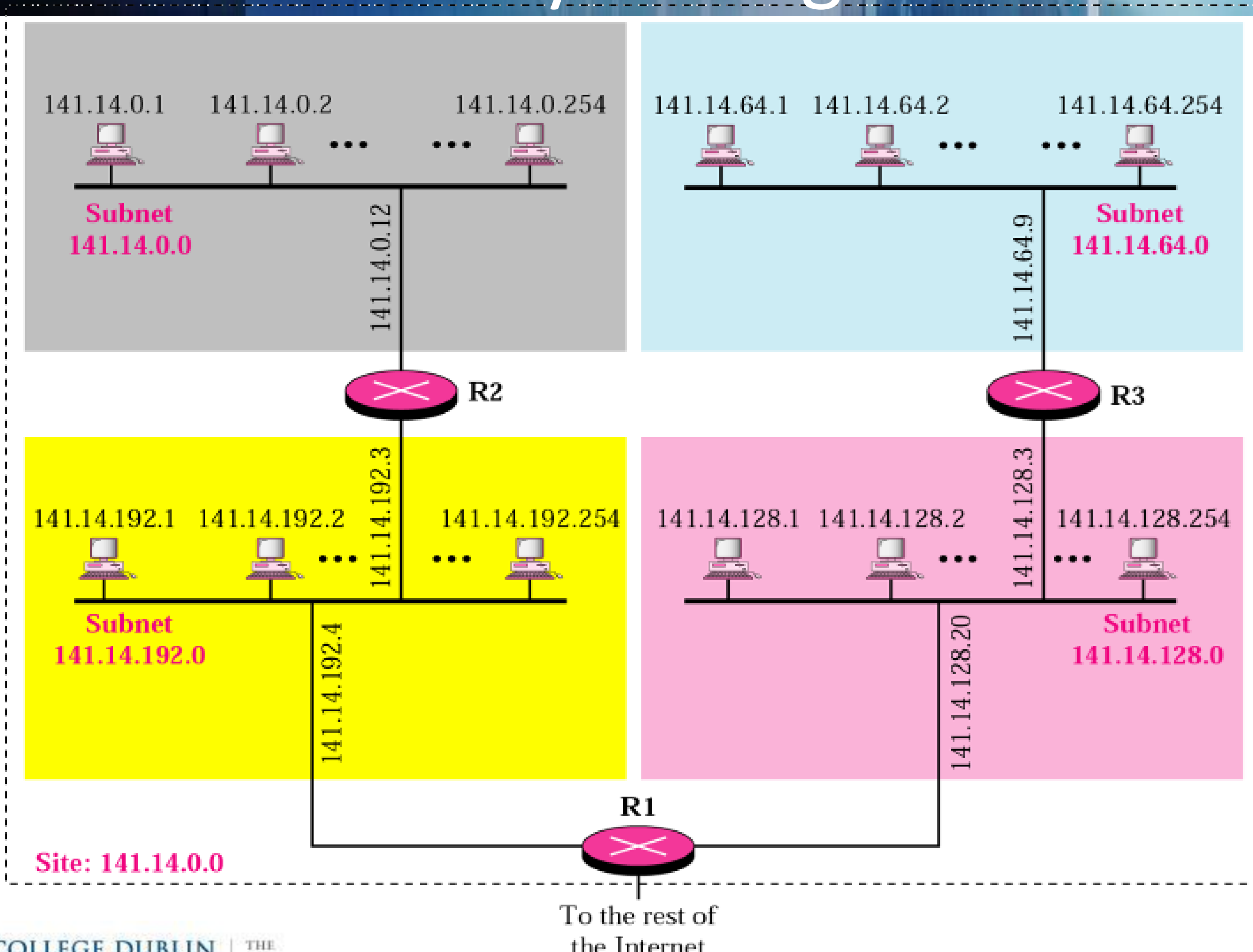
Subnetting



- Add another level to address hierarchy: *subnet*
- Splitting a class B network into a number of class C subnets

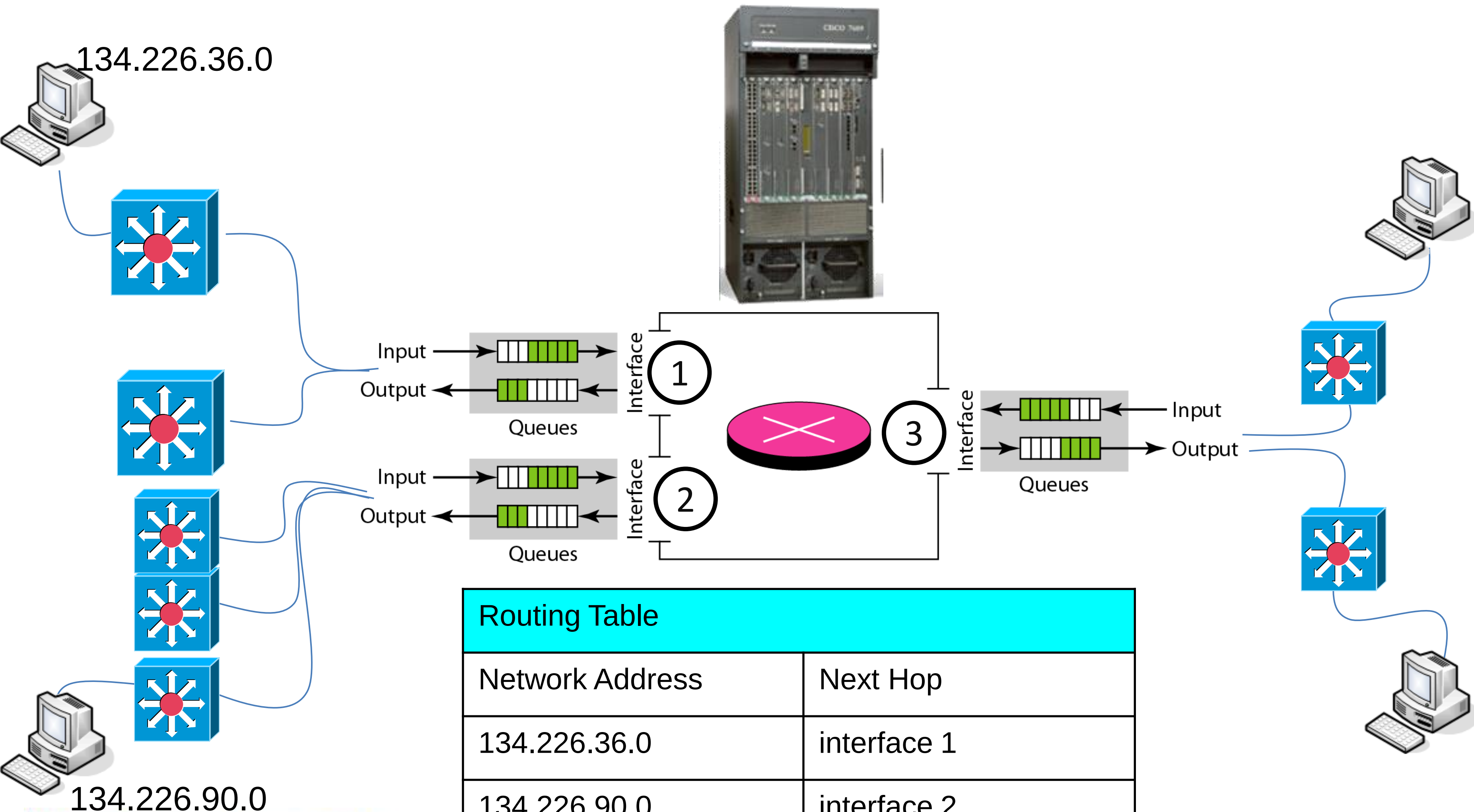
* Figure is courtesy of B. Forouzan

3-Level Hierarchy through Subnetting



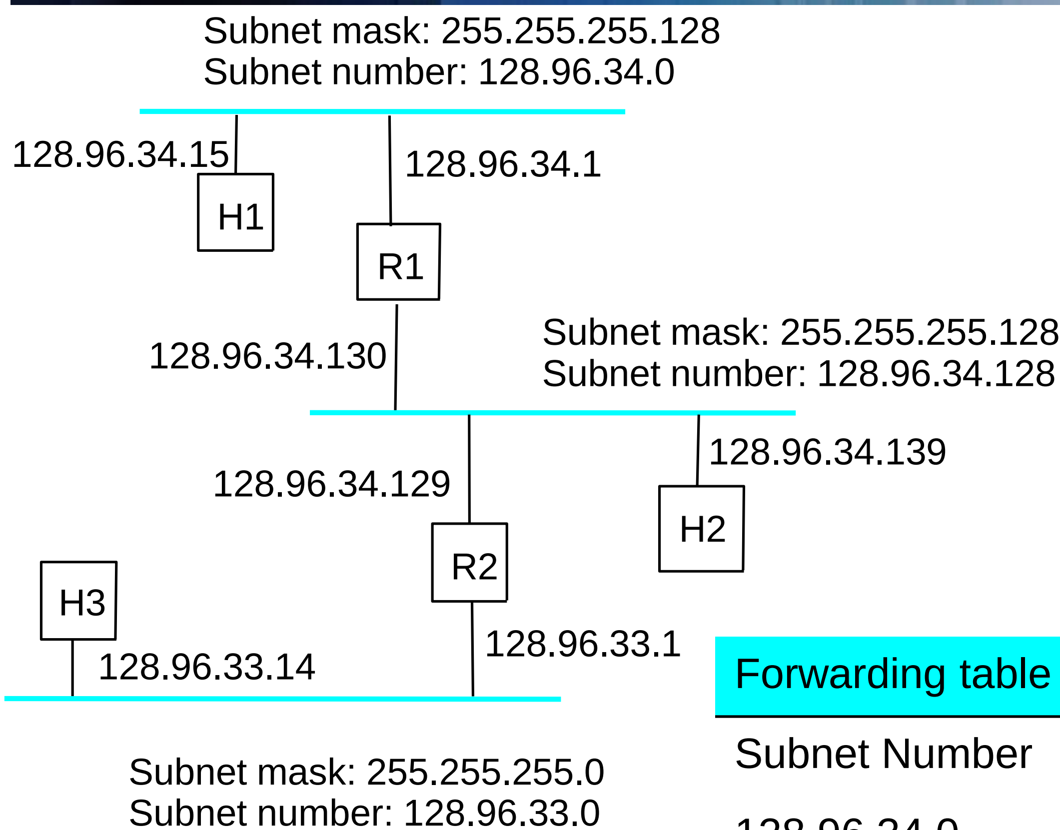
* Figure is courtesy of B. Forouzan

Task of Routers



Routing Table	
Network Address	Next Hop
134.226.36.0	interface 1
134.226.90.0	interface 2

Subnet Example



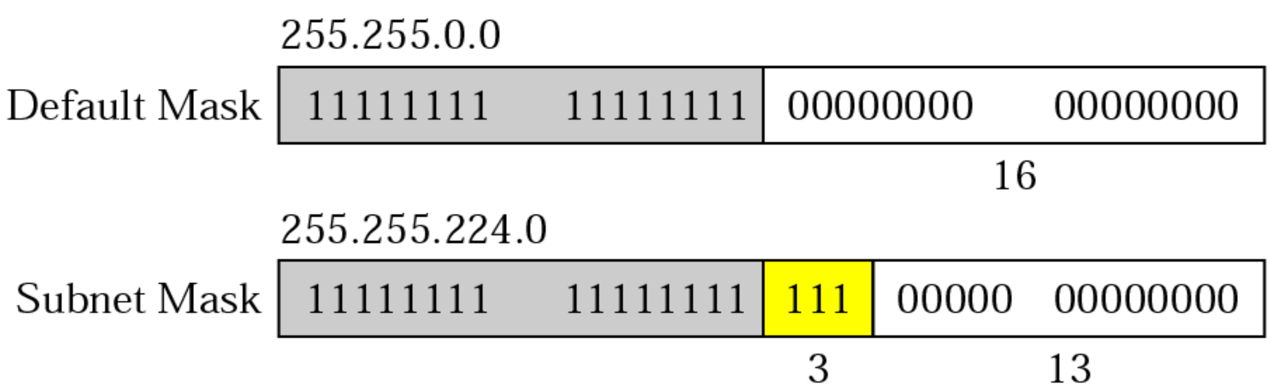
Forwarding table at router R1

Subnet Number	Subnet Mask	Next Hop
128.96.34.0	255.255.255.128	interface 0
128.96.34.128	255.255.255.128	interface 1
128.96.33.0	255.255.255.0	R2

Default Masks

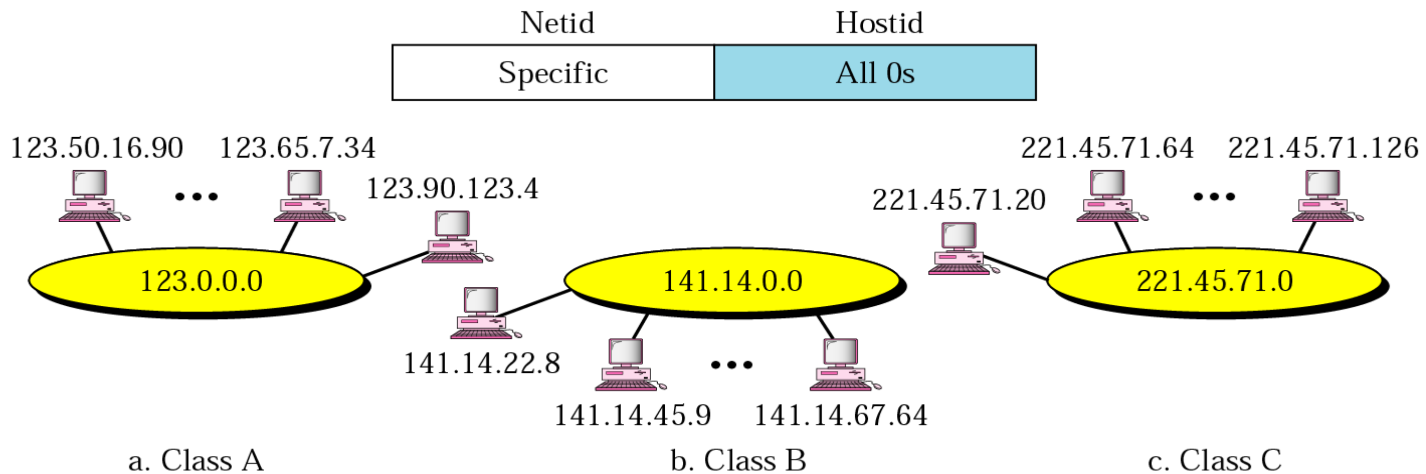
Class	In Binary	Dotted-Decimal	Using Slash
A	11111111 00000000 00000000 00000000	255.0.0.0	/8
B	11111111 11111111 00000000 00000000	255.255.0.0	/16
C	11111111 11111111 11111111 00000000	255.255.255.0	/24

- Subnet Masks



* Figure is courtesy of B. Forouzan

Classful Addresses & NetworkID

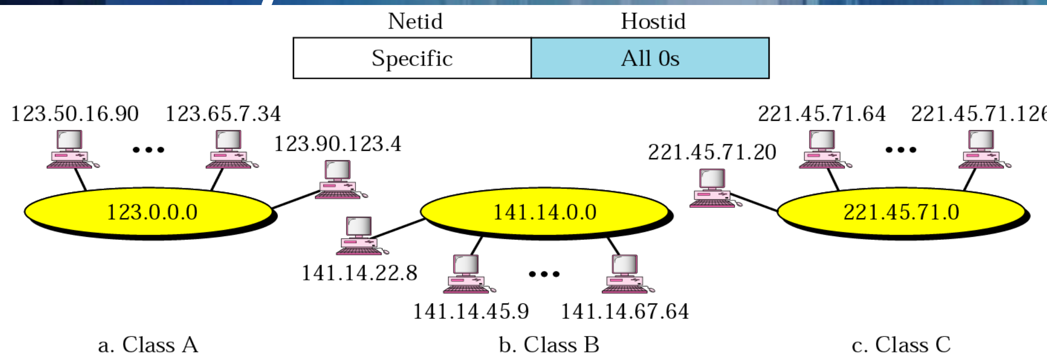


- Classful Addresses:

Class	Networks	Addresses
A	126	16,777,214
B	16,382	65,534
C	2,097,152	254

* Figure is courtesy of B. Forouzan

Inefficiency of Classful Addresses



- Classful Addresses:

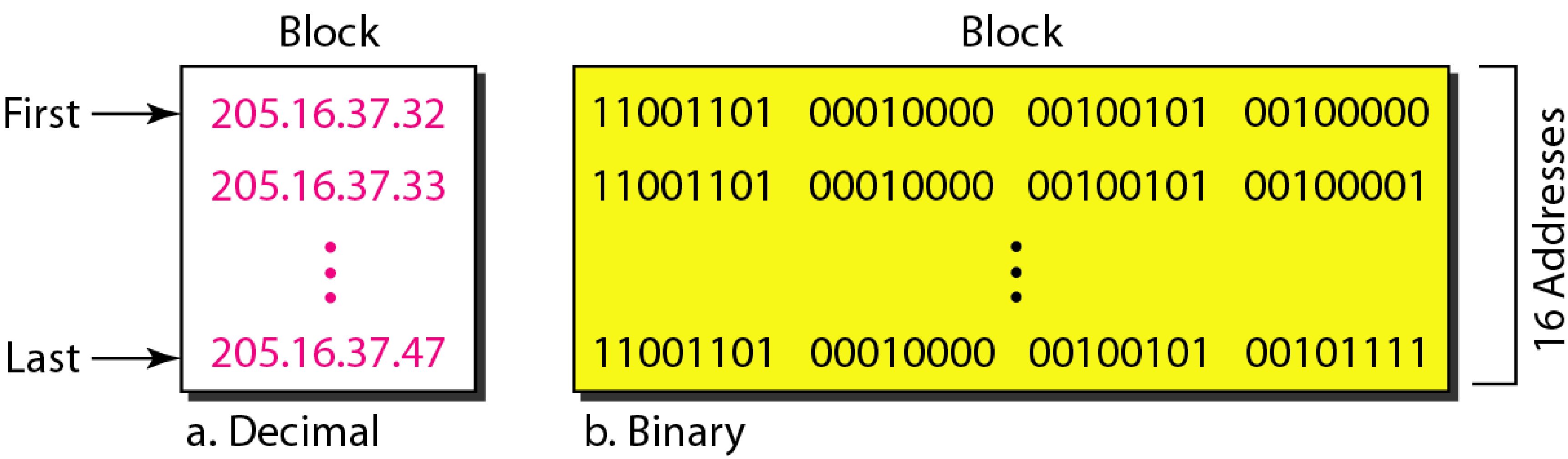
Class	Networks	Addresses
A	126	16,777,214
B	16,382	65,534
C	2,097,152	254

- Inefficient use of Hierarchical Address Space
  - Class C with 2 hosts (2/254 = 0.78% efficient)
  - Class B with 256 hosts (256/65534 = 0.39% efficient)

* Figure is courtesy of B. Forouzan

Classless Inter-Domain Routing(CIDR)

- Allow address space to be divided into blocks of addresses
  - only limited to the power of 2
- Notation as decimal number of the significant bits e.g. 134.226.36.0 /29
- 205.16.37.32/28
  - 32 bits – 28 bits are static - 4 bits are varied



* Figure is courtesy of B. Forouzan

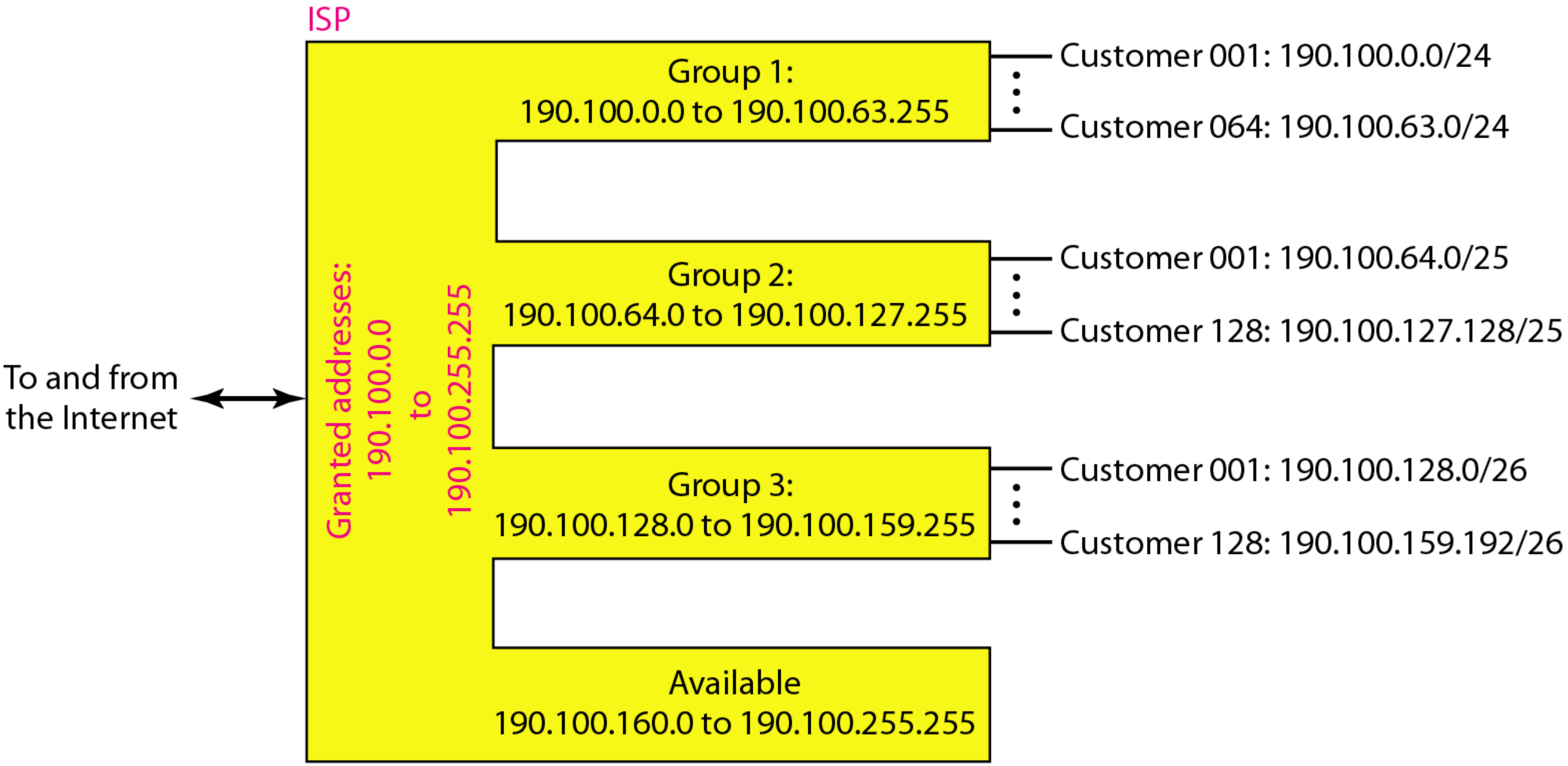
Classless Inter-Domain Routing(CIDR)

	Dotted Decimal	32-bit binary equivalent
Lowest	128.211.168.0	10000000 11010011 10101000 00000000
Highest	128.211.175.255	10000000 11010011 10101111 11111111

= 128.211.168.0/21

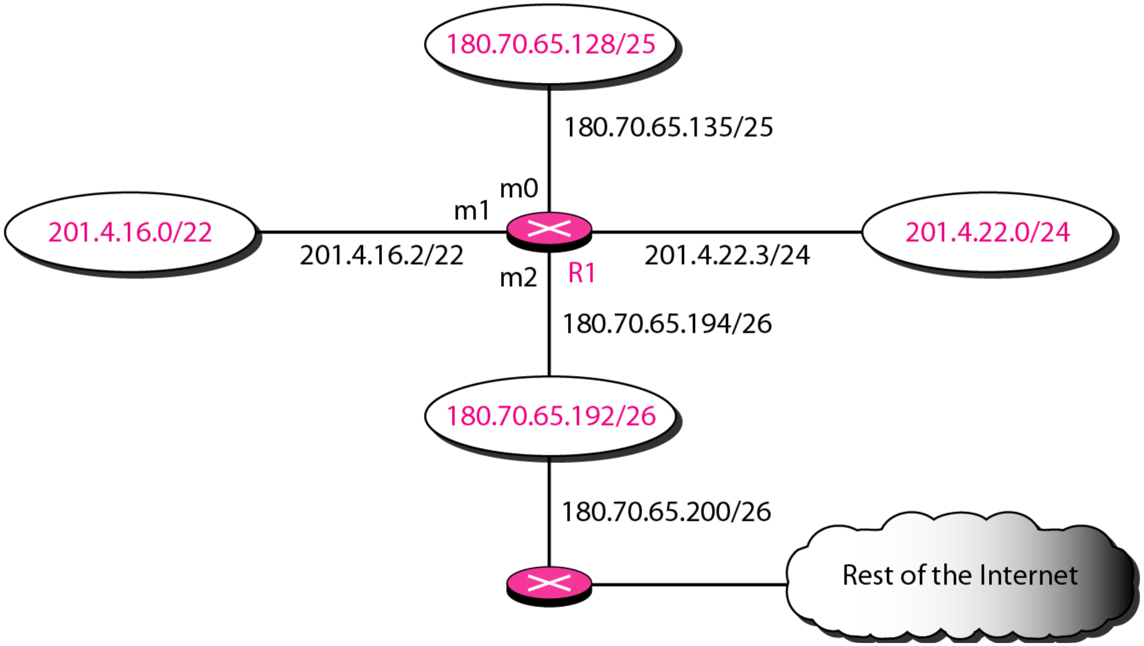
- Aggregation: For example, class C networks can be combined to larger networks
- /21 = 8 class C = 8 * 256 addresses = 2048 addresses

ISPs & Classless Addresses



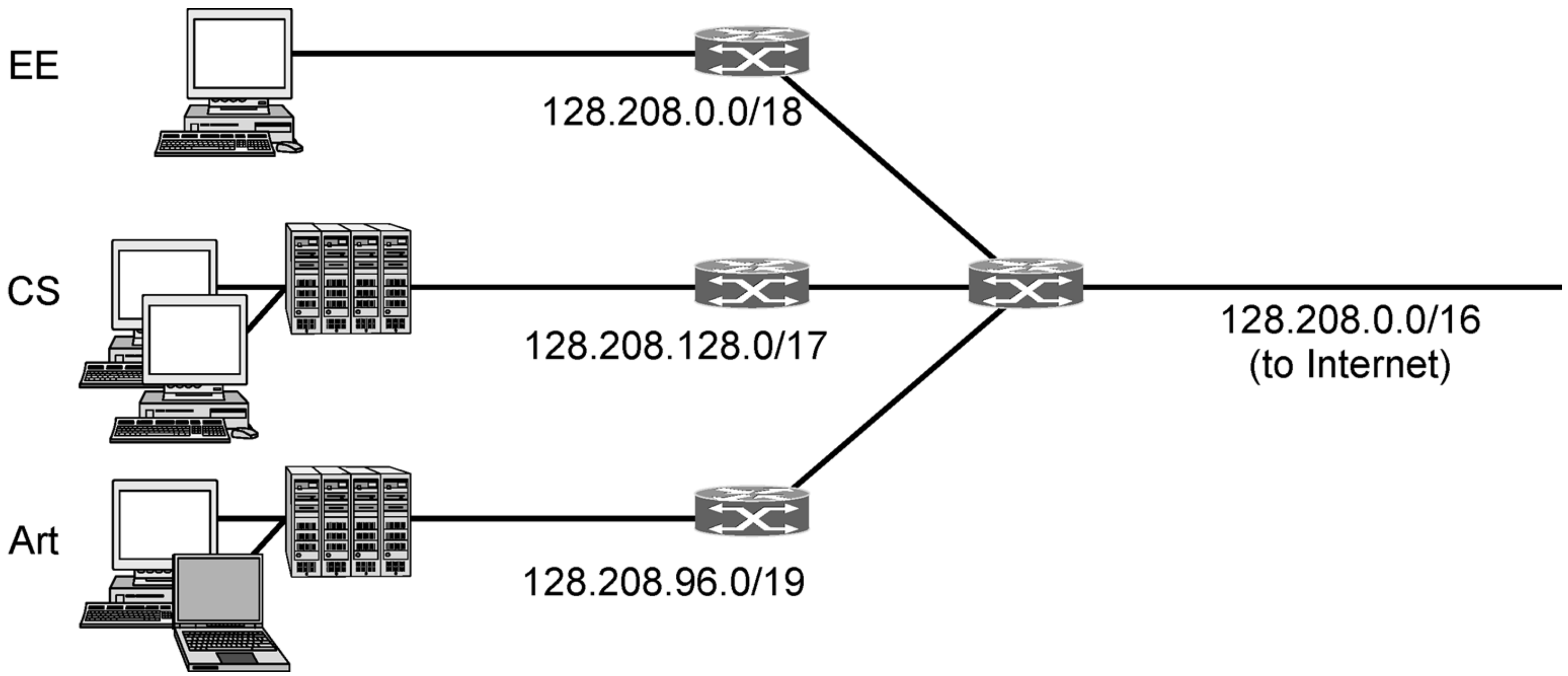
* Figure is courtesy of B. Forouzan

CIDR & Router



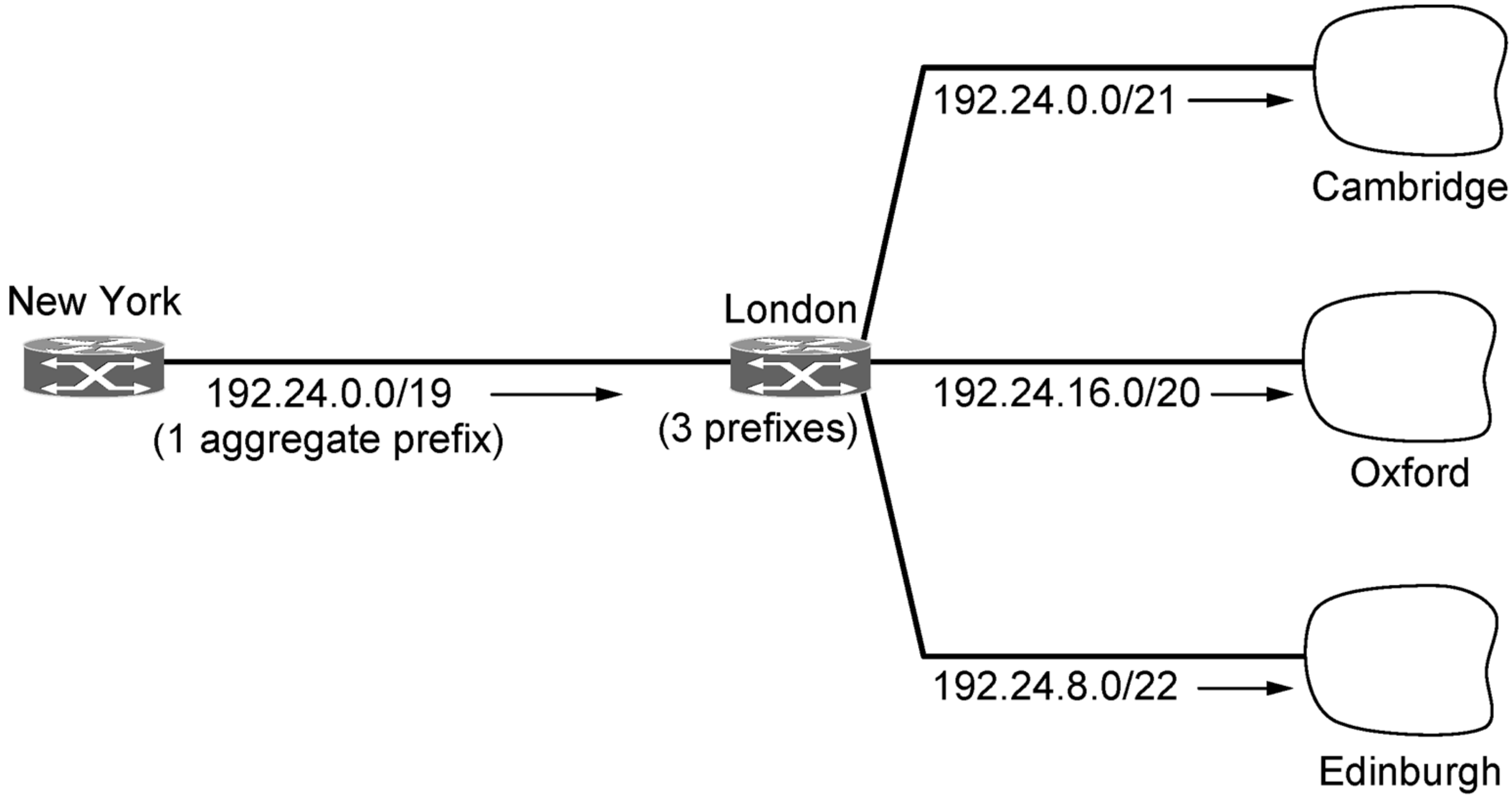
Mask	*Network Address*	*Next Hop*	*Interface*
/26	180.70.65.192	—	m2
/25	180.70.65.128	—	m0
/24	201.4.22.0	—	m3
/22	201.4.16.0	....	m1
Any	Any	180.70.65.200	m2

IP Prefix & Subnets



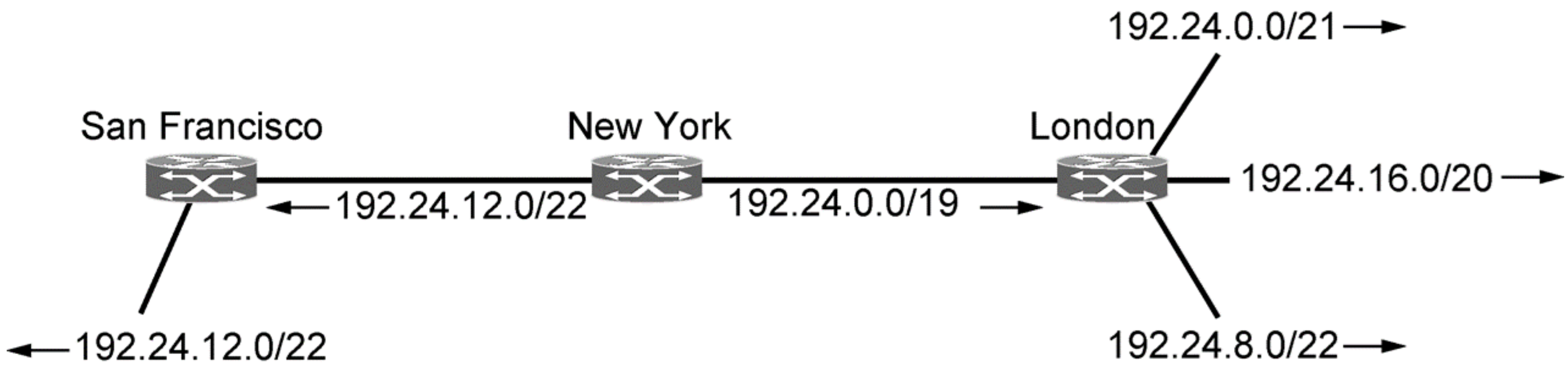
* Figure is courtesy of A. Tanenbaum

Aggregate Prefix



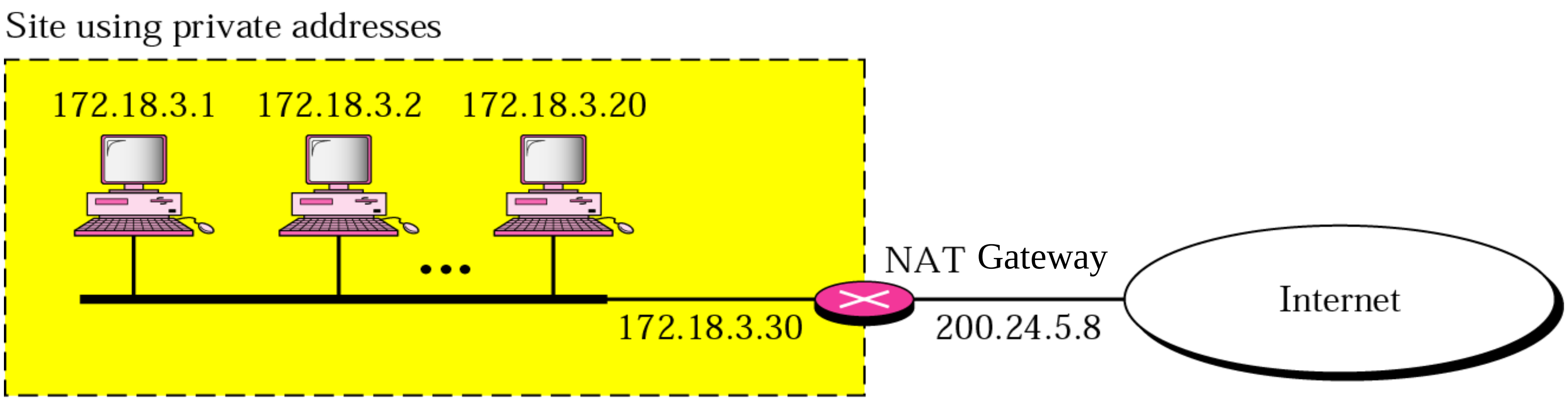
* Figure is courtesy of A. Tanenbaum

Longest matching Prefix



* Figure is courtesy of A. Tanenbaum

Network Address Translation (NAT)

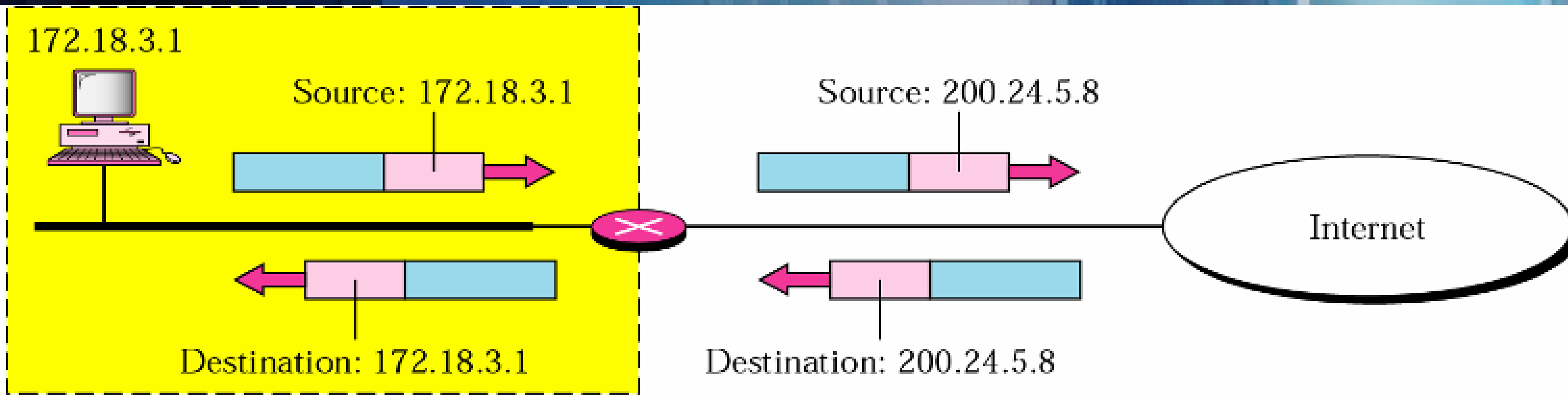


- NAT gateway translates traffic from the local network to the IP address of the gateway

- Involves processing of outgoing & incoming packet e.g. translation between addresses, recalculation of checksums, etc

* Figure is courtesy of B. Forouzan

Address Translation

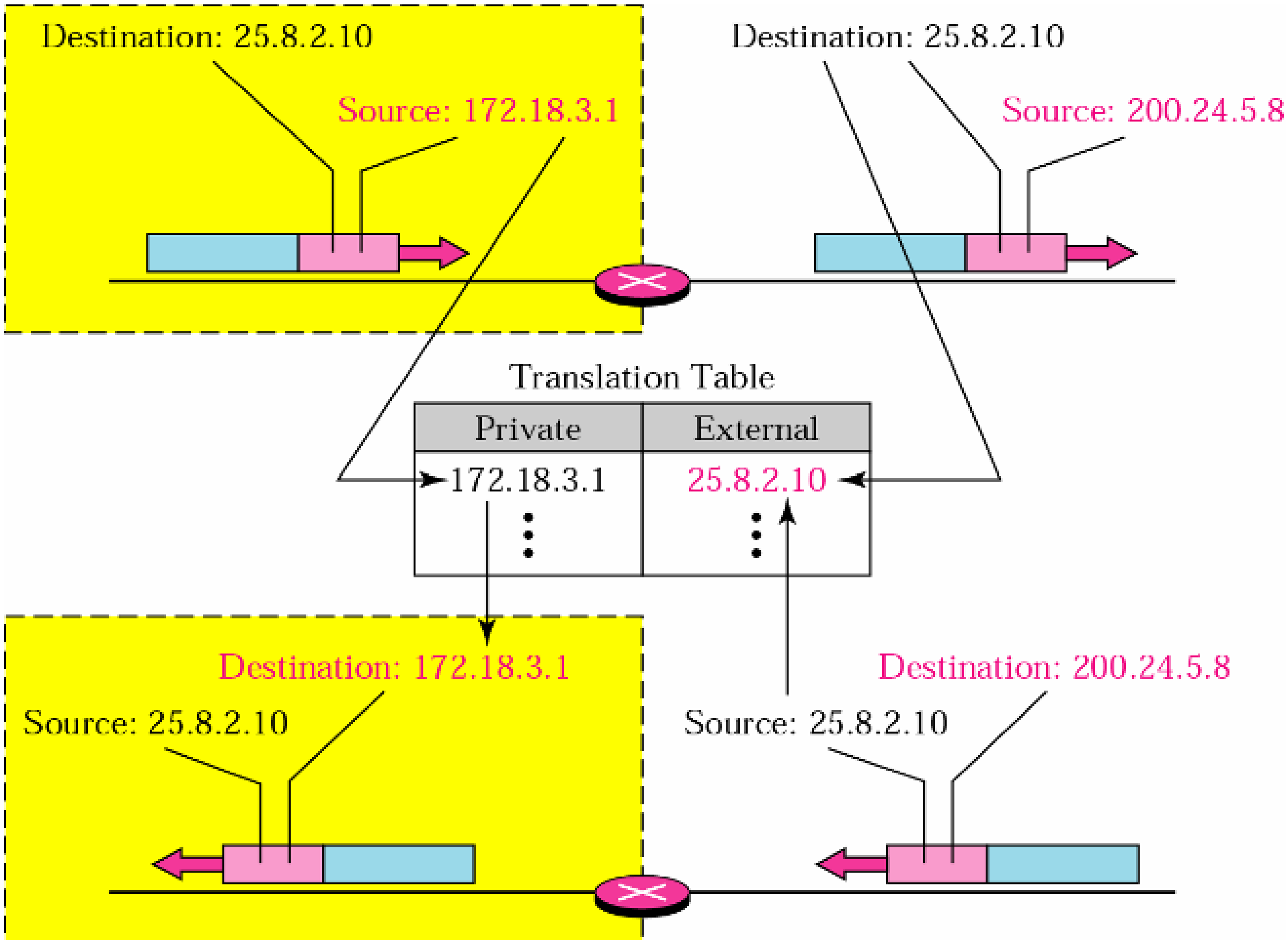


Private Address	Private Port	External Address	External Port	Transport Protocol
172.18.3.1	1400	25.8.3.2	80	TCP
172.18.3.2	1401	25.8.3.2	80	TCP
...	...	...	...	...

- Gateway maintains table to match incoming and outgoing packets; including IDs for applications

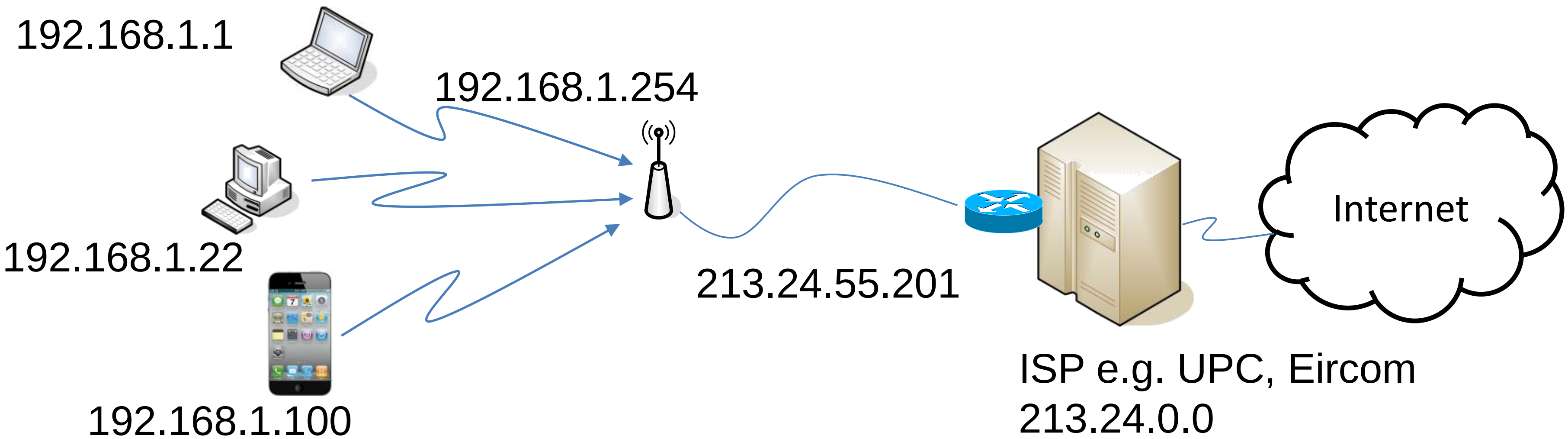
* Figure is courtesy of B. Forouzan

Example for NAT



* Figure is courtesy of B. Forouzan

NAT Example



Src 192.168.1.1
Dst 134.226.36.14

→

Src 213.24.55.201
Dst 134.226.36.14

→

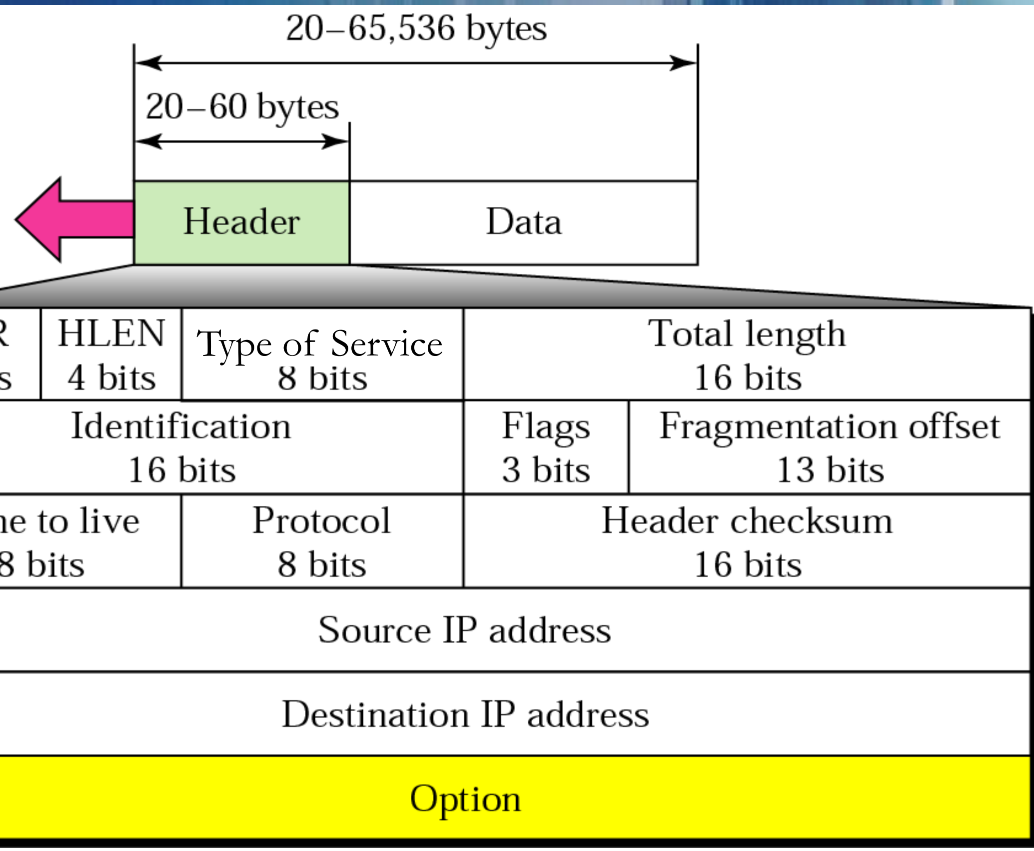
Source	Destination
192.169.1.1	134.226.36.14

Summary: Addresses

- 32-bit number / Dotted decimal notation
- IP addresses are unique and universal
  - Exception: Private Addresses

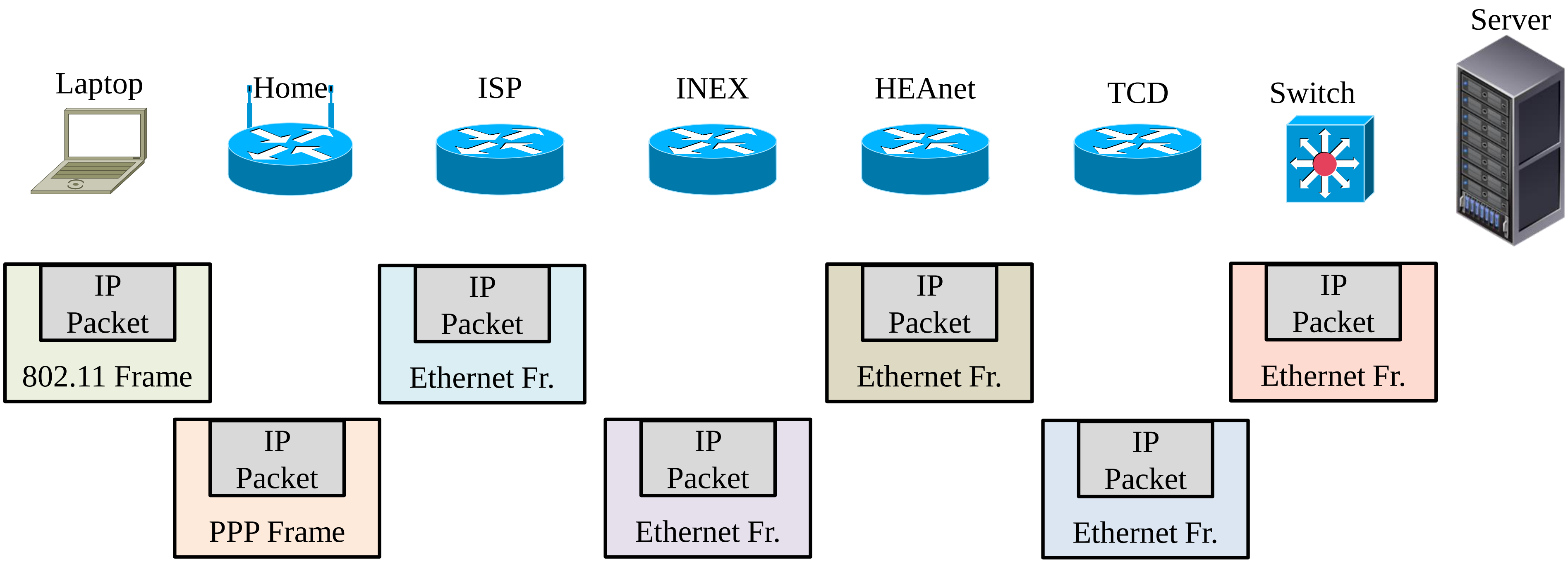
- Classful addresses
  - Classes A, B, and C for networks, D for multicast
  - Routing on Network IDs
- Subnetting + Netmasks
  - Dealing with scale in local networks
- Classless Inter-Domain Routing (CIDR)
  - / notation – significant bits of address
- Network address translation (NAT)

IP Datagram

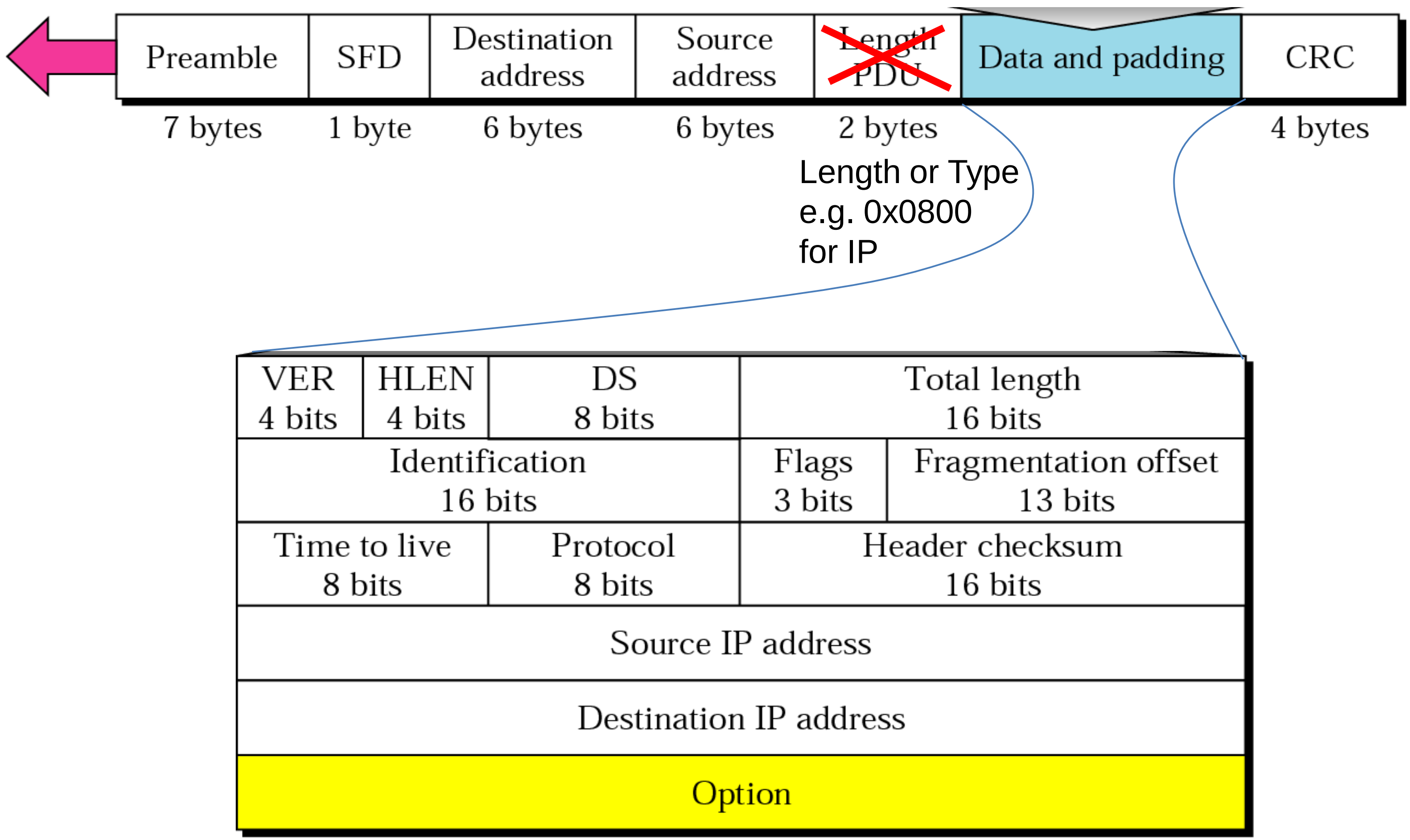


- The total length field defines the total length of the datagram including the header.

Encapsulation

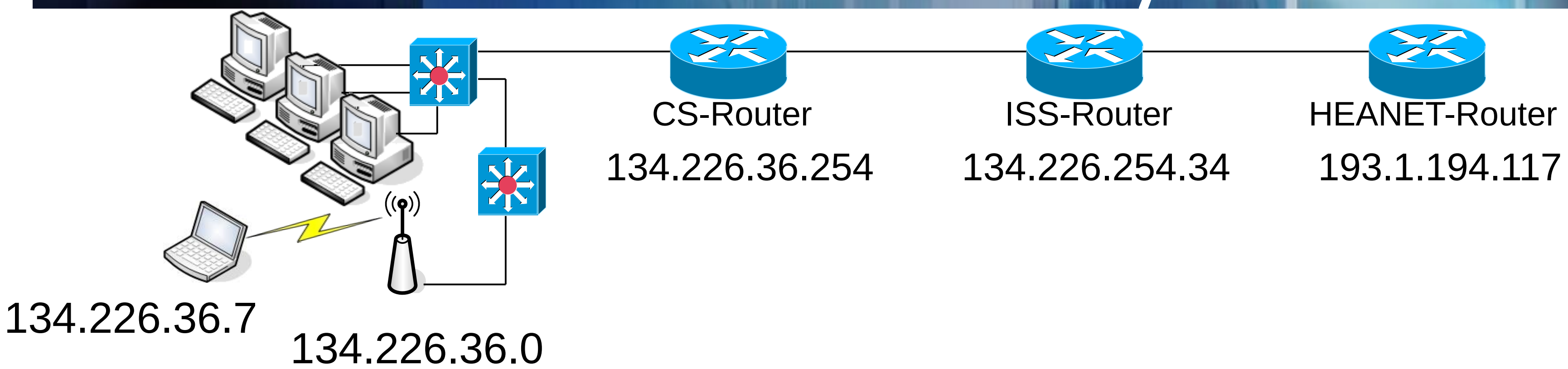


Ethernet & IP



* Figure is courtesy of B. Forouzan

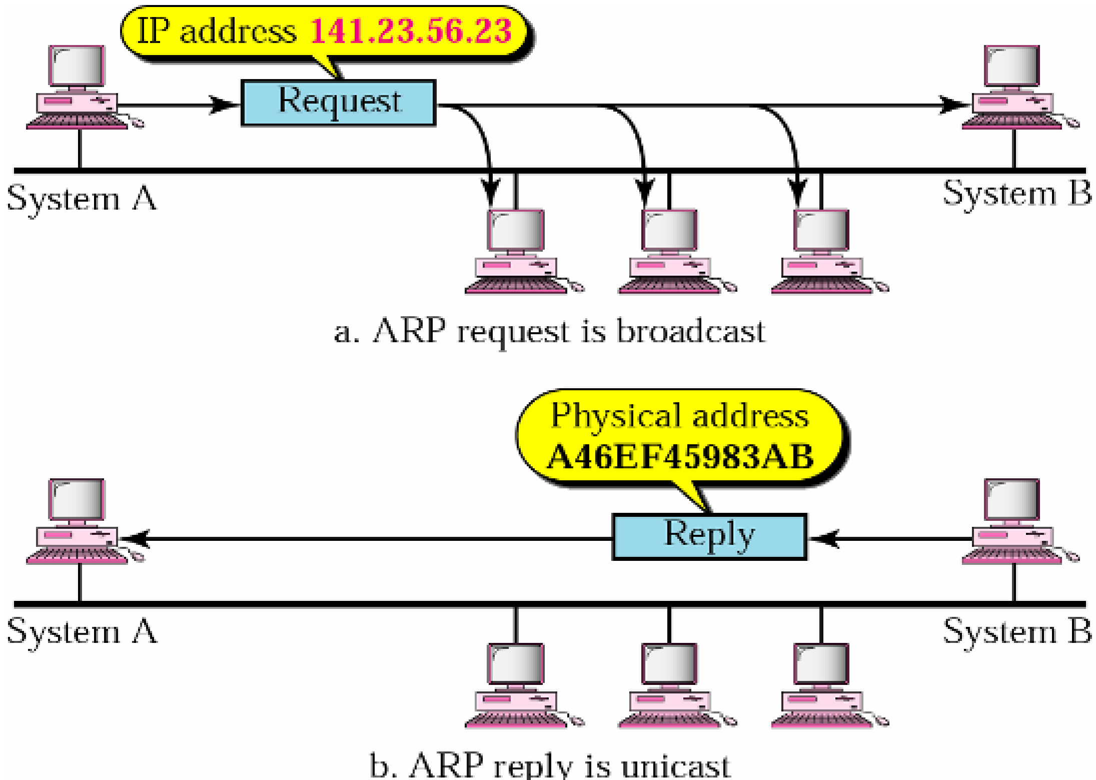
Default Gateway



Subnet	Gateway	Netmask	Interface
134.226.36.0	0.0.0.0	255.255.0.0	eth1
0.0.0.0	134.226.36.254	0.0.0.0	eth1

- All nodes within the subnet can communicate directly with each other
- All communication with nodes in other networks passes through the default gateway e.g. router 134.226.36.254

Address Resolution Protocol (ARP)



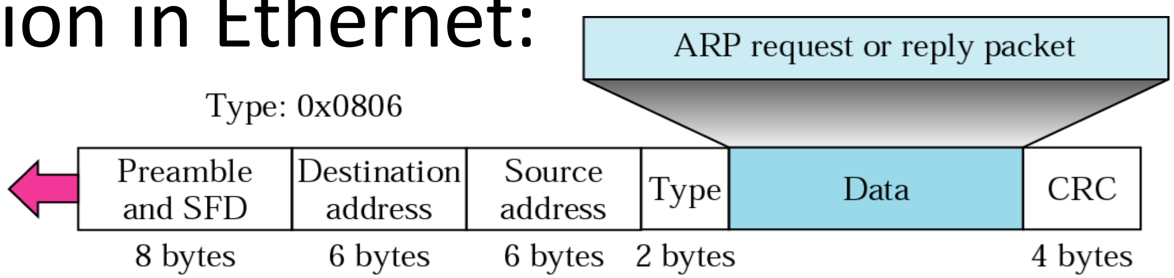
- Association between hardware address and IP address

* Figure is courtesy of B. Forouzan

ARP Packet

Hardware Type		Protocol Type
Hardware length	Protocol length	Operation Request 1, Reply 2
Sender hardware address (For example, 6 bytes for Ethernet)		
Sender protocol address (For example, 4 bytes for IP)		
Target hardware address (For example, 6 bytes for Ethernet) (It is not filled in a request)		
Target protocol address (For example, 4 bytes for IP)		

- Encapsulation in Ethernet:



* Figure is courtesy of B. Forouzan

"Who has"-Packet

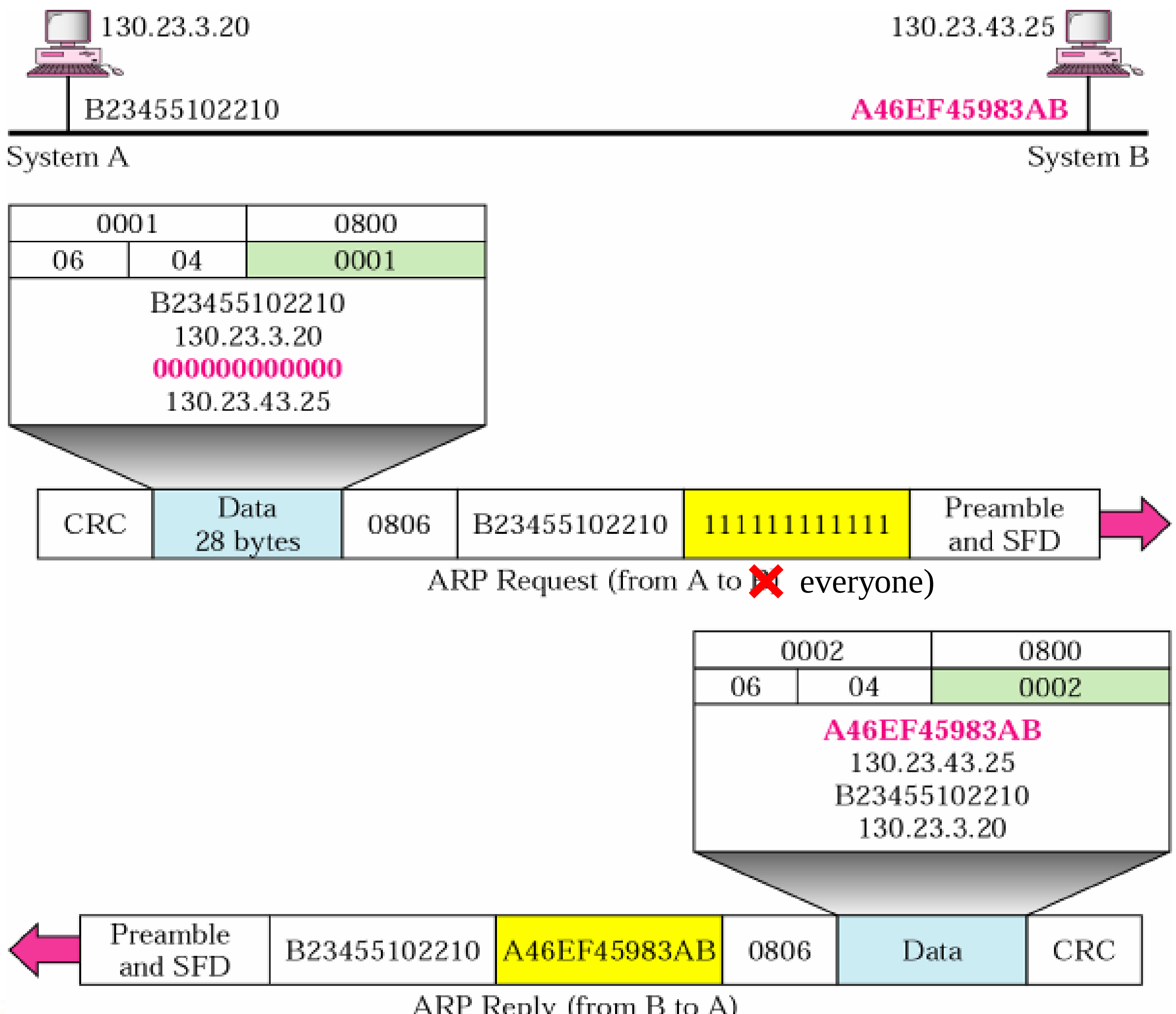
```
ARP      Who has 192.168.1.2?  Tell 192.168.1.5

⊟ Frame 34 (42 bytes on wire, 42 bytes captured)
    Arrival Time: Nov 27, 2005 02:30:26.608147000
    [Time delta from previous packet: 59.766200000 seconds]
    [Time since reference or first frame: 176.316976000 seconds]
    Frame Number: 34
    Packet Length: 42 bytes
    Capture Length: 42 bytes
    [Protocols in frame: eth:arp]
⊟ Ethernet II, Src: 00:0f:b5:96:19:e5 (00:0f:b5:96:19:e5), Dst: ff:ff:ff:ff:ff:ff
    Destination: ff:ff:ff:ff:ff:ff (ff:ff:ff:ff:ff:ff)
    Source: 00:0f:b5:96:19:e5 (00:0f:b5:96:19:e5)
    Type: ARP (0x0806)
⊟ Address Resolution Protocol (request)
    Hardware type: Ethernet (0x0001)
    Protocol type: IP (0x0800)
    Hardware size: 6
    Protocol size: 4
    Opcode: request (0x0001)
    Sender MAC address: 00:0f:b5:96:19:e5 (00:0f:b5:96:19:e5)
    Sender IP address: 192.168.1.5 (192.168.1.5)
    Target MAC address: 00:00:00:00:00:00 (00:00:00:00:00:00)
    Target IP address: 192.168.1.2 (192.168.1.2)

0000  ff ff ff ff ff ff 00 0f  b5 96 19 e5 08 06 00 01   ........ ........
0010  08 00 06 04 00 01 00 0f  b5 96 19 e5 c0 a8 01 05   ........ ........
0020  00 00 00 00 00 00 c0 a8  01 02                     ........ ..
```

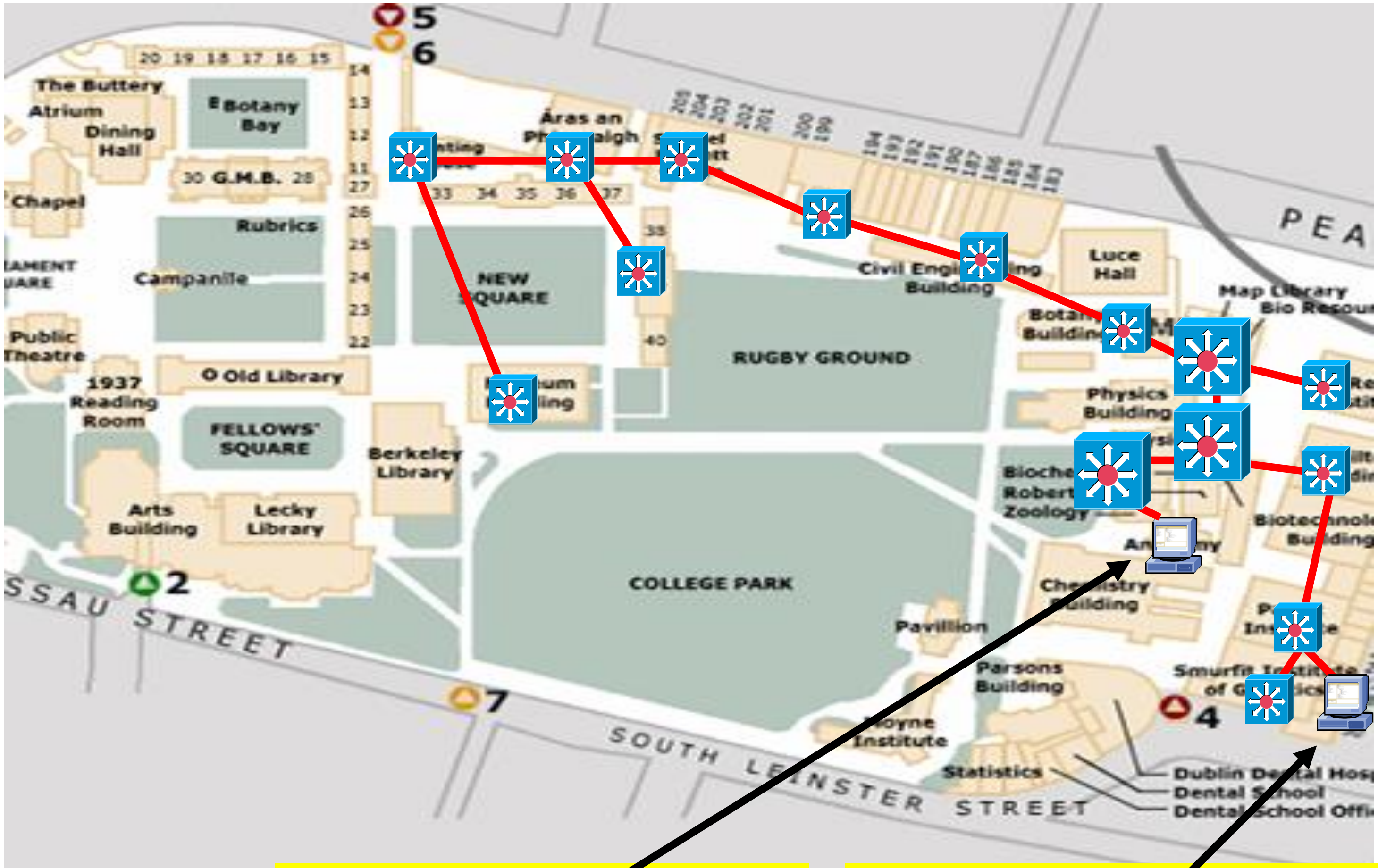
- ARP Request: Who has 192.168.1.2? Tell 192.168.1.5

ARP Example



* Figure is courtesy of B. Forouzan

Trinity Network with Switches

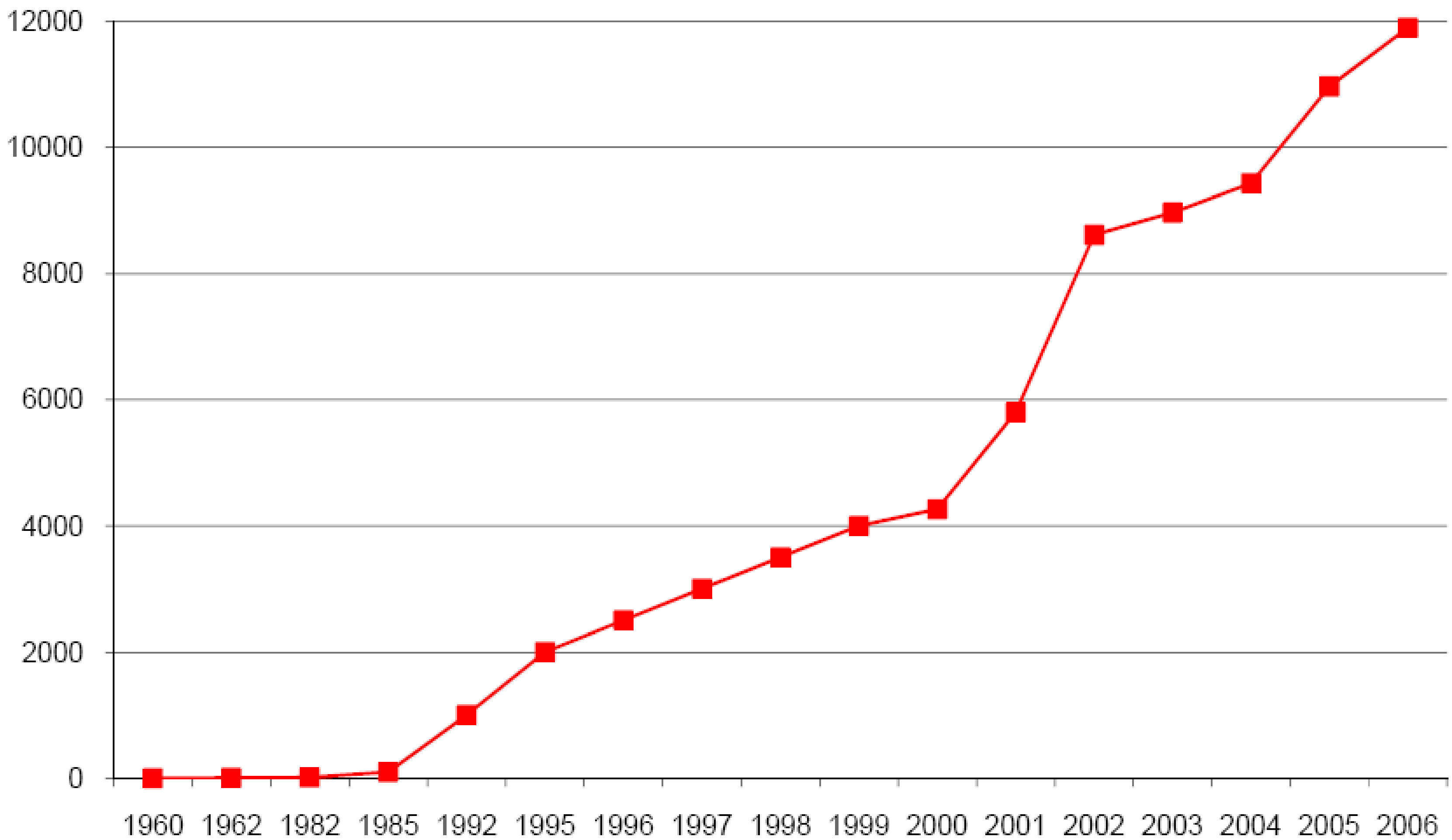


Switch

Address: 134.226.38.55
Subnet: 134.226.0.0

Address: 134.226.32.55
Subnet: 134.226.0.0

Number of Computers in College

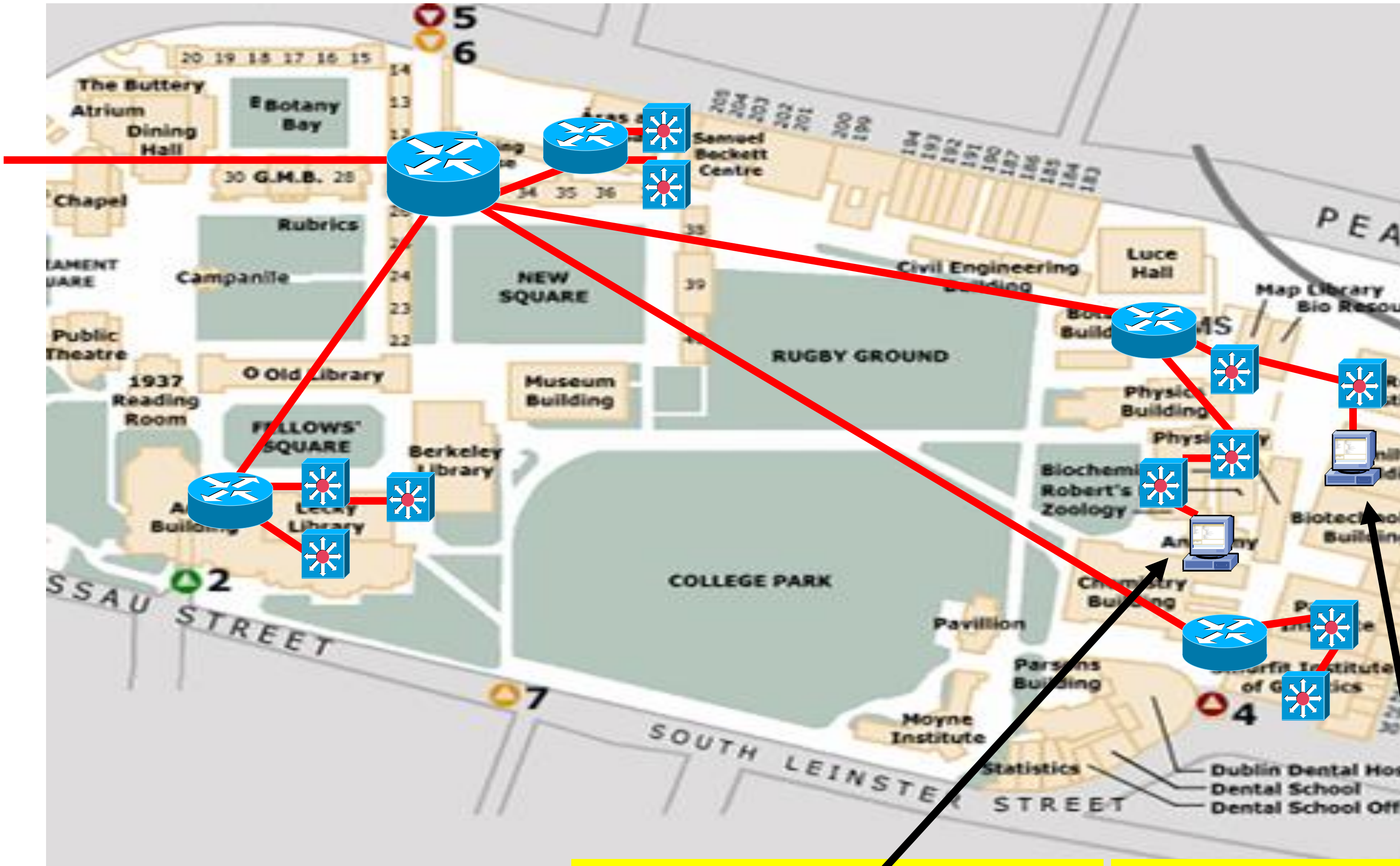


IS Services Annual Report 2006/2007

Broadcast-Storms

- Imagine 1000s of machines sending ARP requests

Trinity Network with Subnets

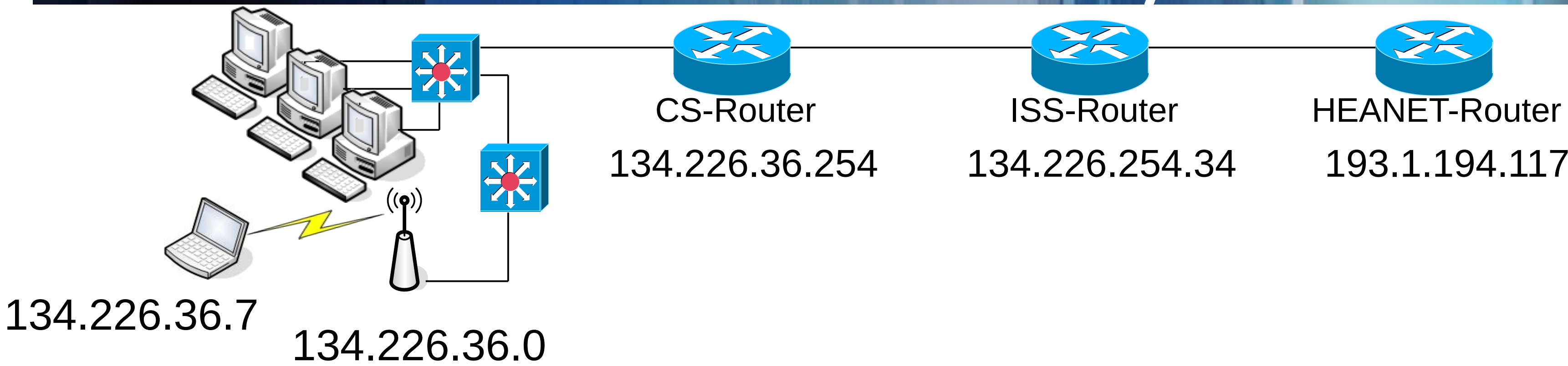


Switch Router

Address: 134.226.38.55
Subnet: 134.226.38.0

Address: 134.226.32.55
Subnet: 134.226.32.0

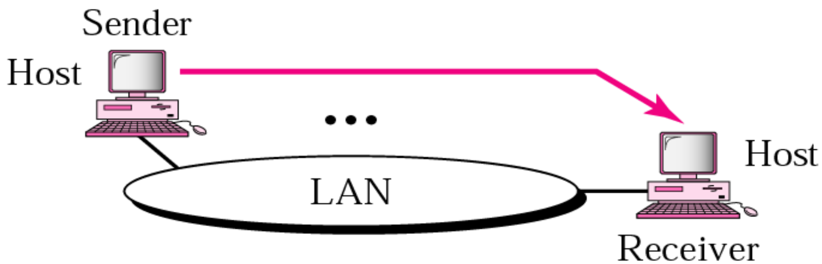
Default Gateway



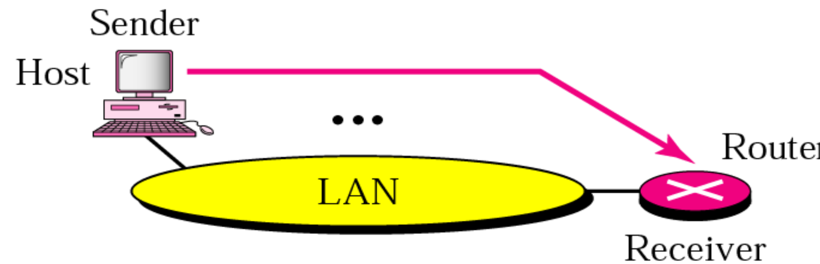
Subnet	Gateway	Netmask	Interface
134.226.36.0	0.0.0.0	255.255.0.0	eth1
0.0.0.0	134.226.36.254	0.0.0.0	eth1

- All nodes within the subnet can communicate directly with each other
- All communication with nodes in other networks passes through the default gateway e.g. router 134.226.36.254

4 Cases for ARP

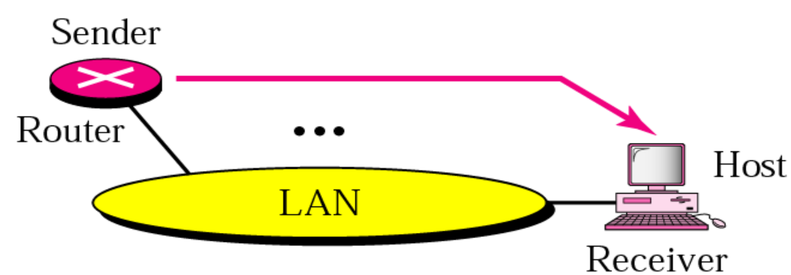


Case 1. A host has a packet to send to another host on the same network.



Case 2. A host wants to send a packet to another host on another network.
It must first be delivered to the appropriate router.

Case 3. A router receives a packet to be sent to a host on another network.
It must first be delivered to the appropriate router.



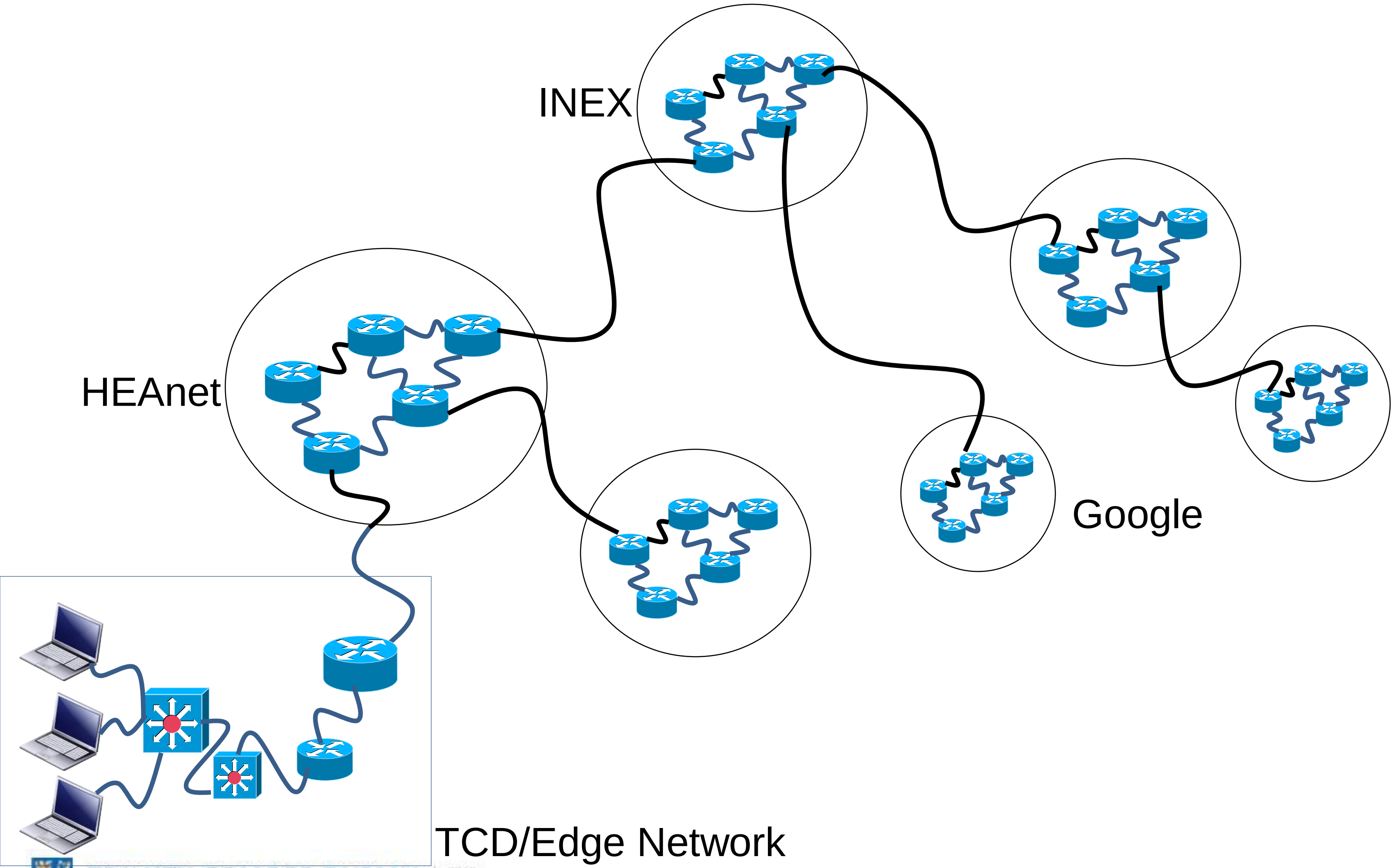
Case 4. A router receives a packet to be sent to a host on the same network.

* Figure is courtesy of B. Forouzan

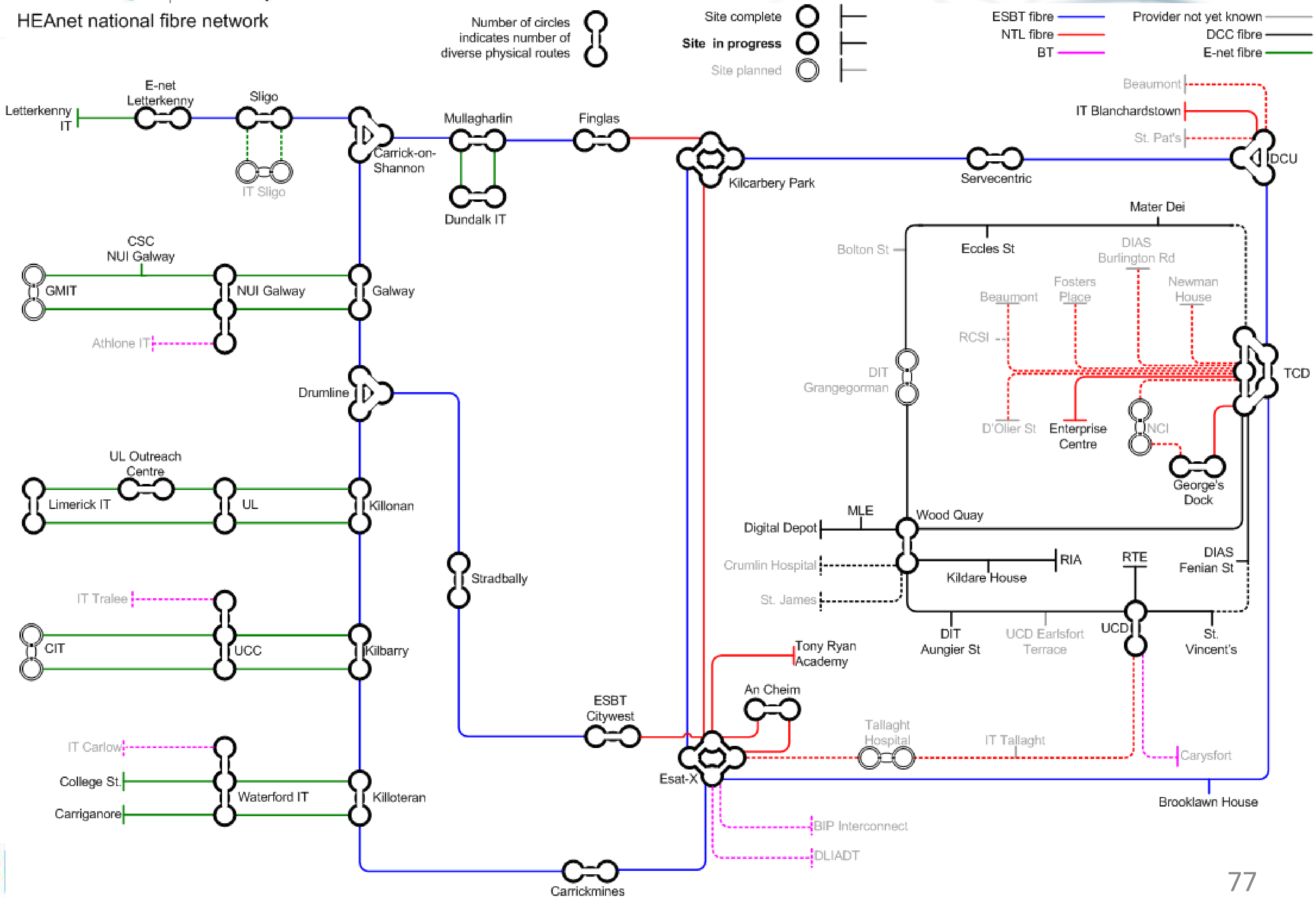
Summary: ARP

- “Who-has?” packet
- Associating IP addresses with hardware addresses
- Based on broadcast

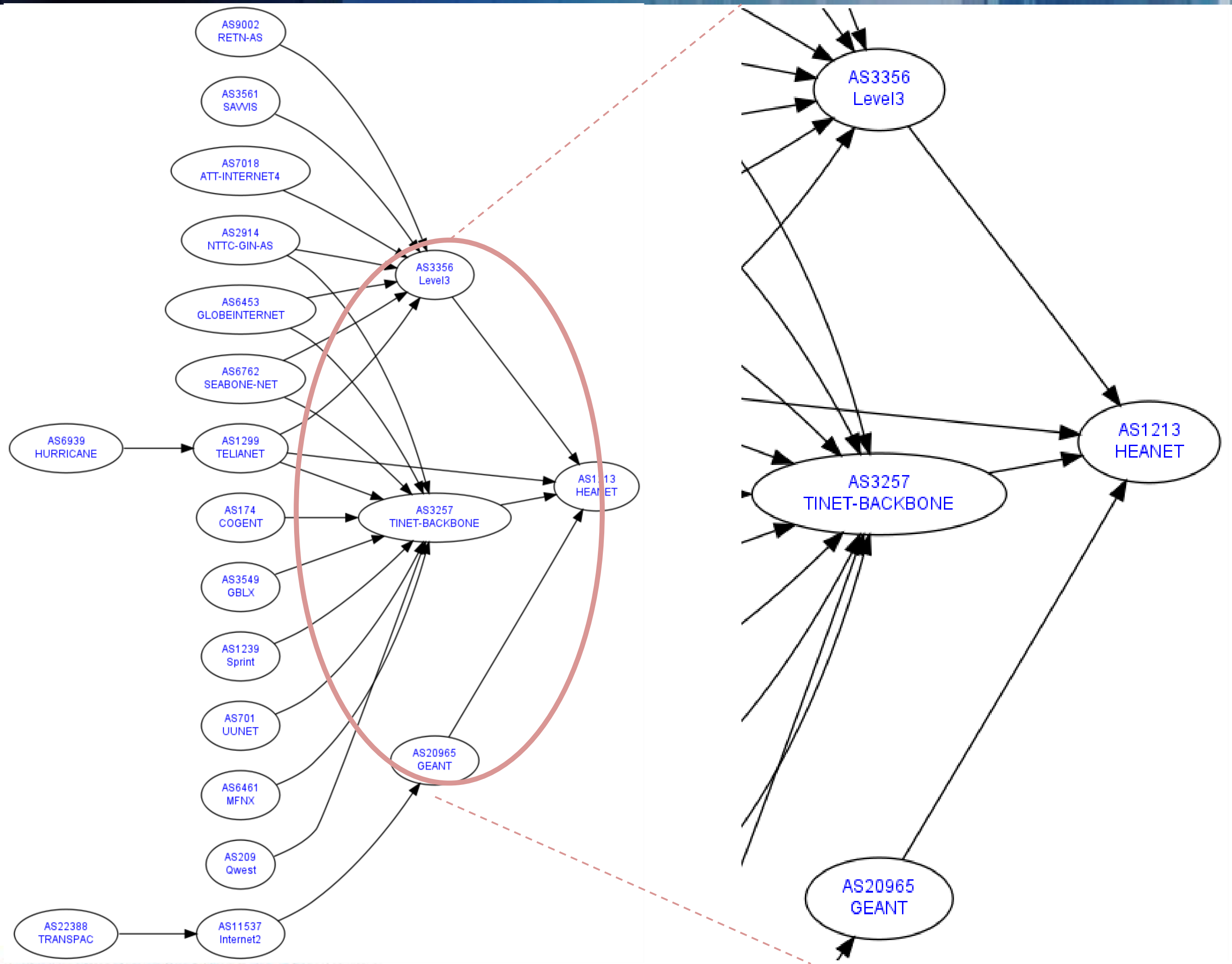
Internet = Network of Networks



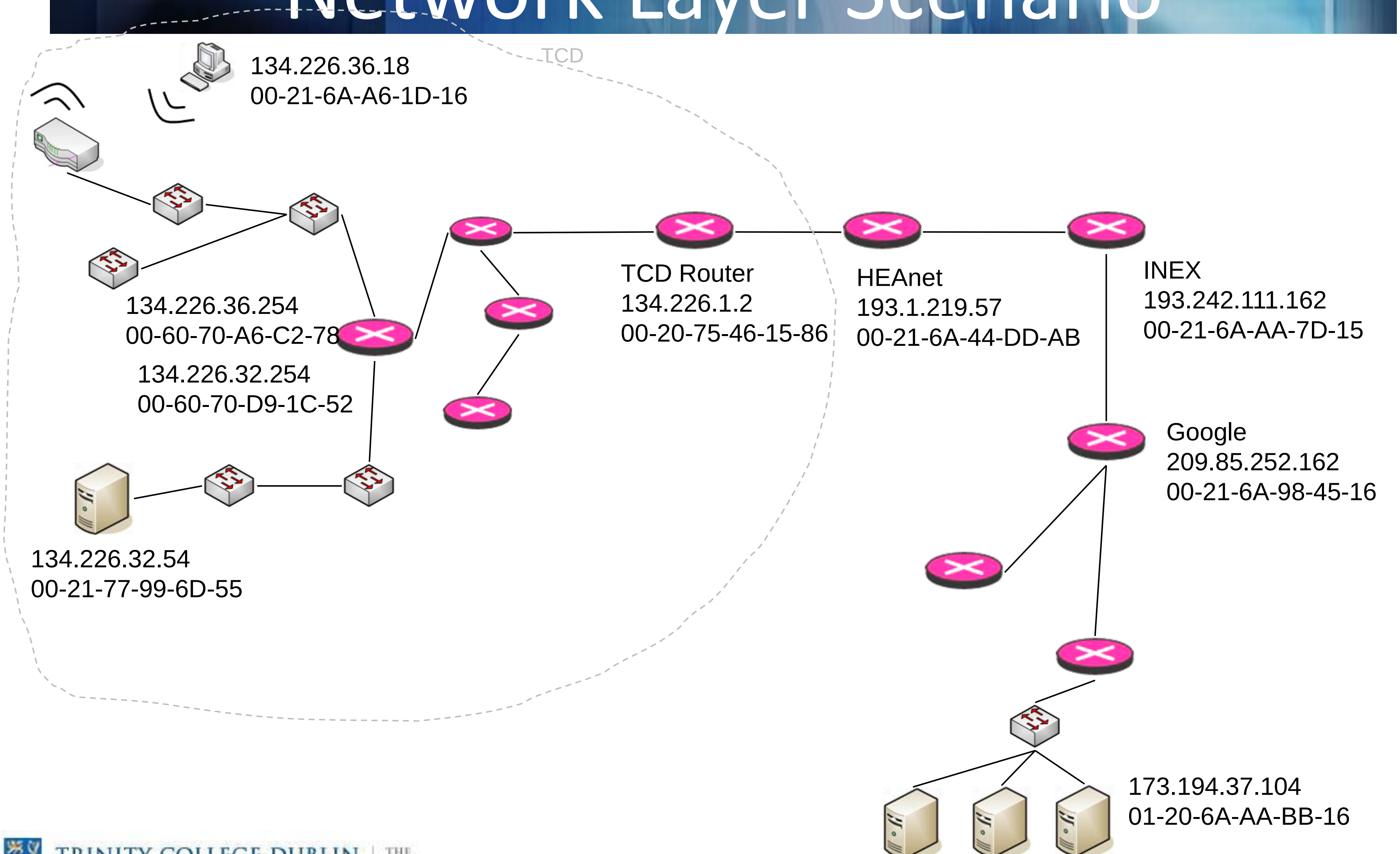
HEAnet national fibre network



AS1213 - HEANET

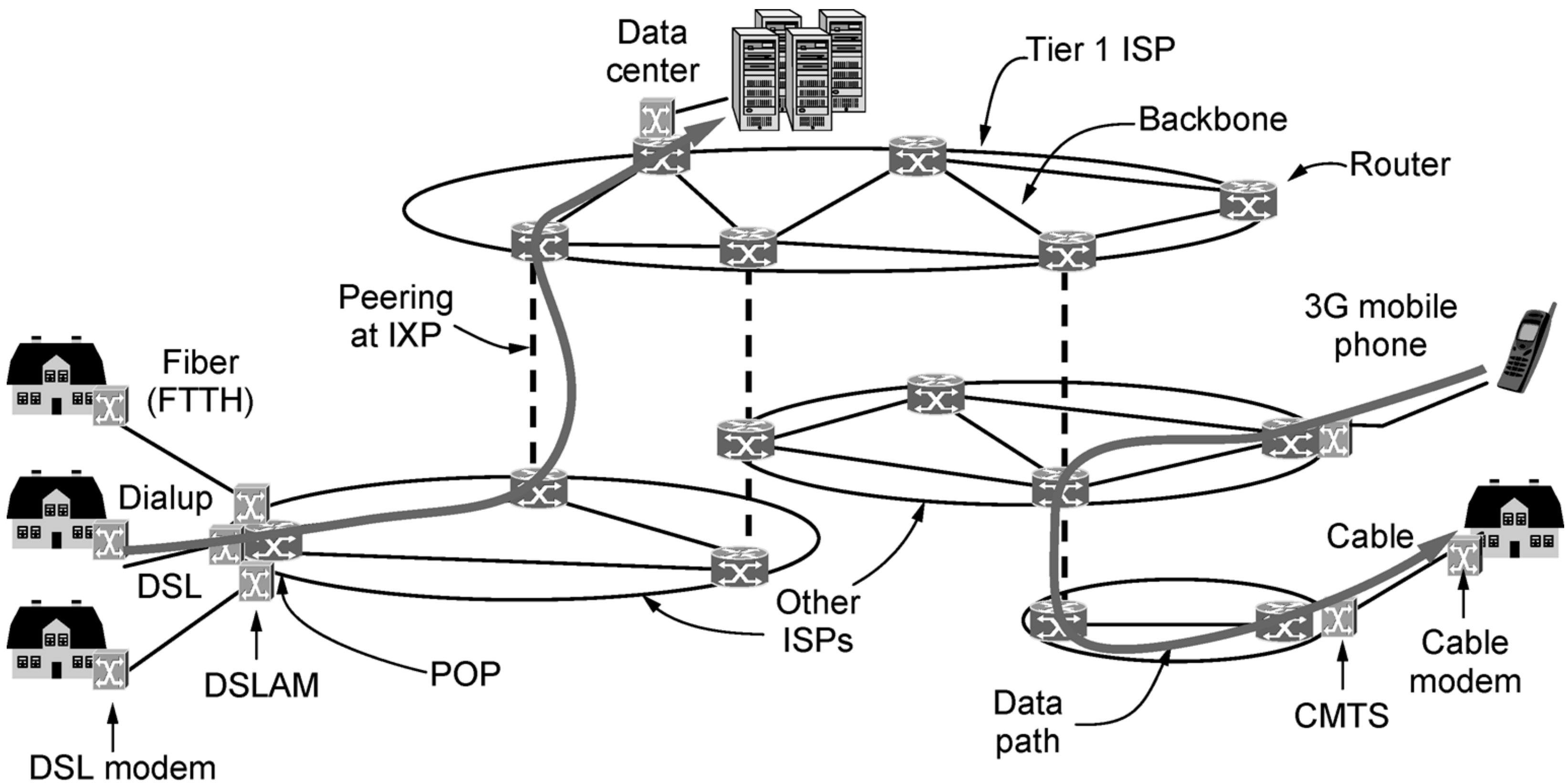


Network Layer Scenario



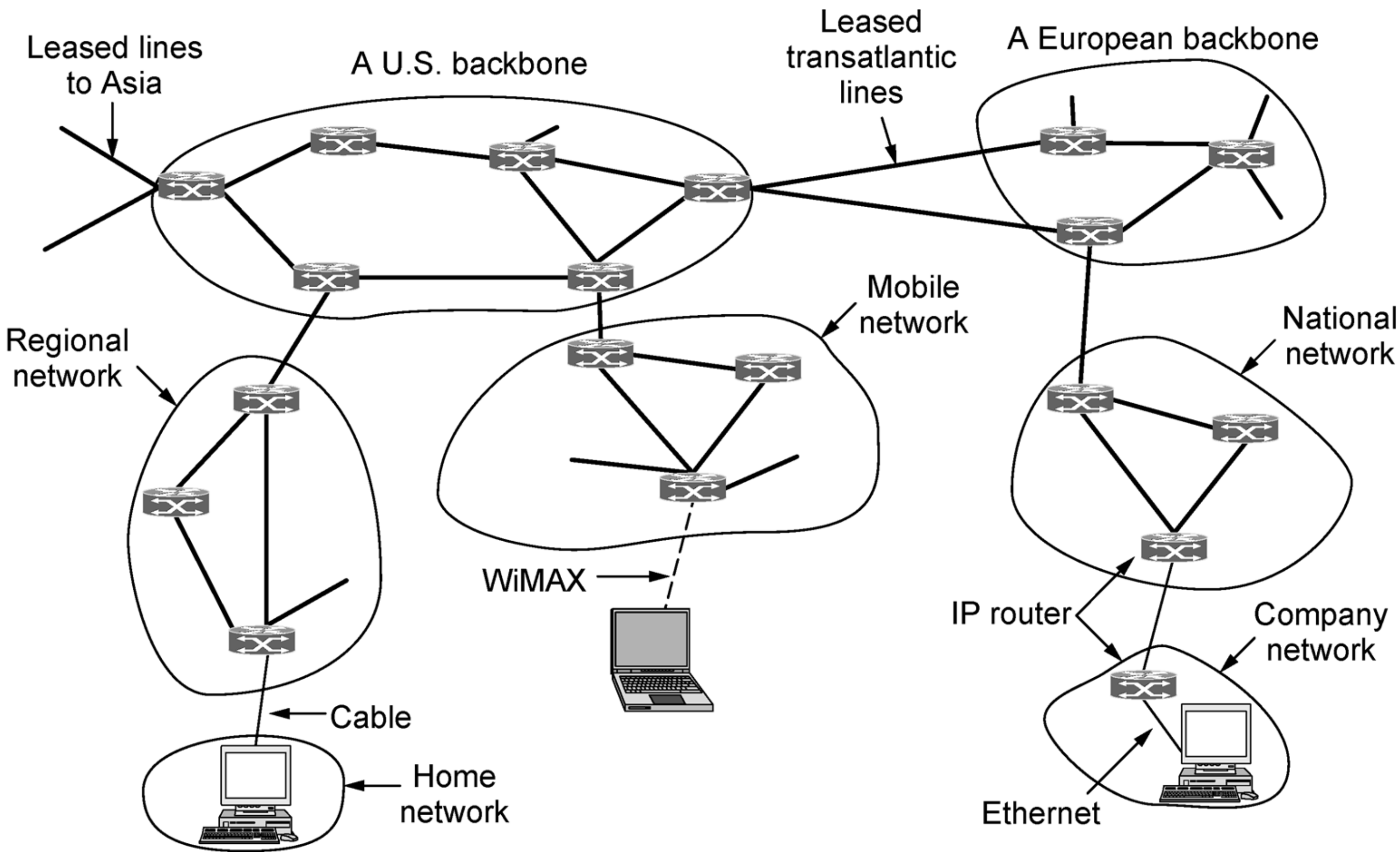

That's all folks
Telecomms II

Overview of the Internet Architecture



* Figure is courtesy of A. Tanenbaum

Collection of Networks



* Figure is courtesy of A. Tanenbaum