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Trinity College Dublin
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The University of Dublin

CSU33031 Computer Networks

Network Layer / IPv4

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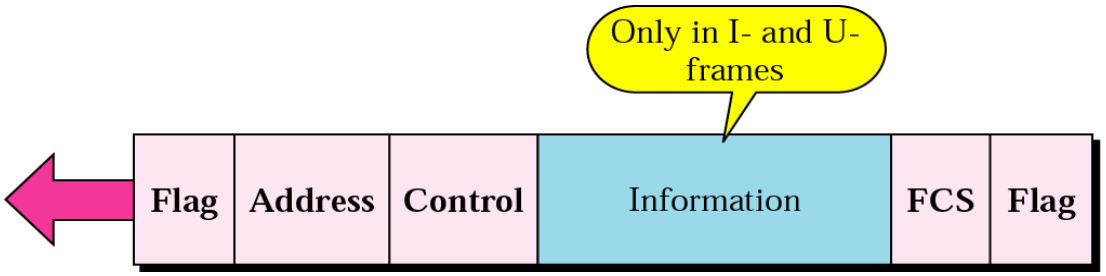
Plan for today

- HDLC/Ethernet as summary for Link Layer

- Network Layer – IPv4 Addressing (Internet Protocol v4)
  - The initial idea/motivation
  - Changes to make it workable (CIDR/NAT)

HDLC as a Summary/Review

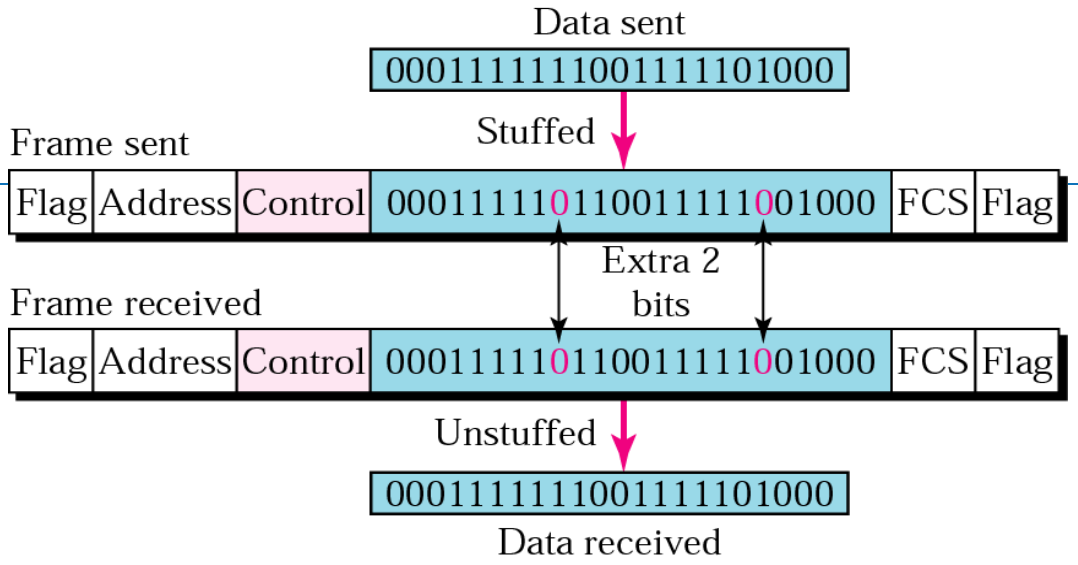
Example for Framing, Error Control, Flow Control



- Flag= 01111110
  - specifies beginning and end of frame
- Address
  - specifies secondary station
  - as either sender or receiver
- Control
  - specifies type of frame and seq.&ack. number
- Frame Check Sequence (FCS)
  - either 16- or 32-bit CRC

* Figure is courtesy of B. Forouzan

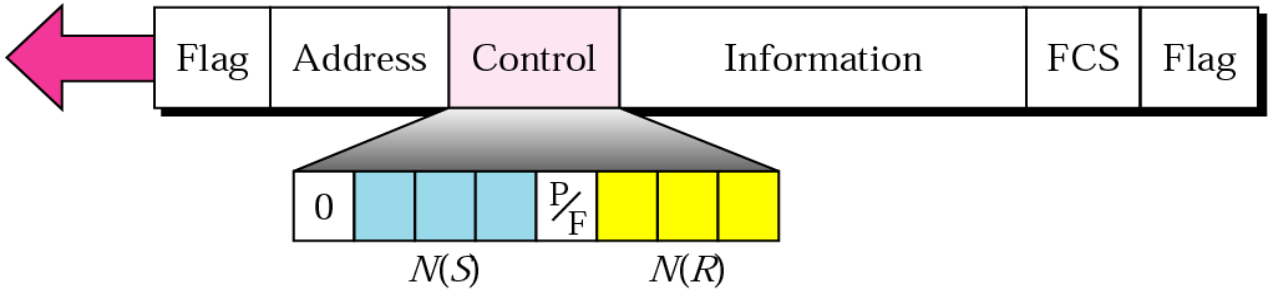
Bit-Stuffing



- Bit stuffing used to avoid confusion with data containing same combination as flag 01111110
  - 0 inserted after every sequence of five 1s
  - If receiver detects five 1s
    - it checks next bit
    - If 0, it is deleted
    - If 1 and seventh bit is 0, accept as flag
    - If sixth and seventh bits 1, sender is indicating abort

* Figure is courtesy of B. Forouzan

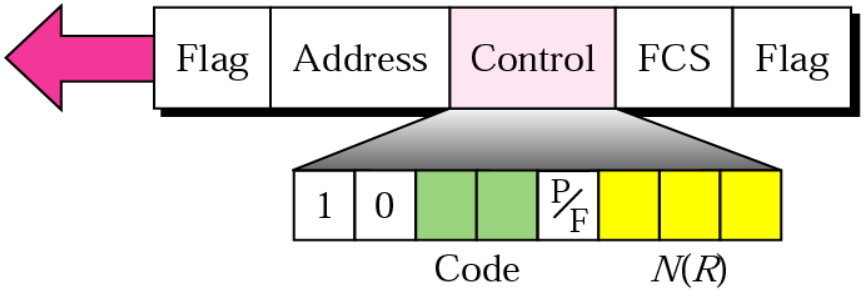
I-Frame



- N(S)
  - Sequence Number of Sender
- N(R)
  - Sequence Number of Receiver
- P/F
  - Poll/Final bit
  - Set by Primary station as request for information
  - Set by Secondary station to signal response or to signal final frame of a transmission

* Figure is courtesy of B. Forouzan

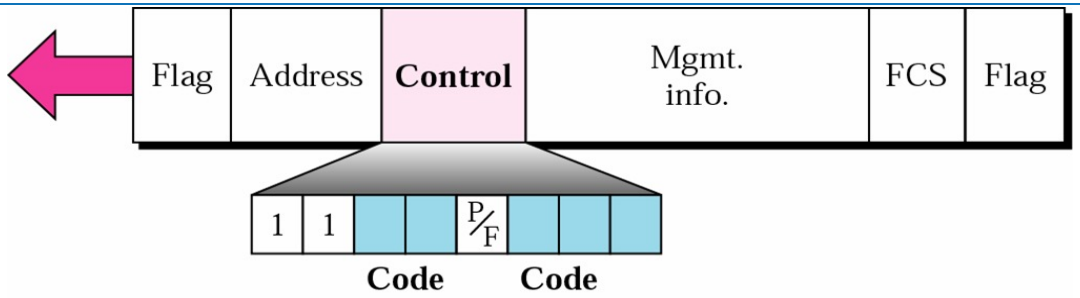
S-Frame Control Field



- Code 00 = Receive Ready (RR)
  - Acknowledge frames & waiting for more
- Code 10 = Receive Not Ready (RNR)
  - Acknowledge frames & busy right now
- Code 01 = Reject (REJ)
  - Go-Back-N NAK
- Code 11 = Selective Reject (SREJ)
  - Selective Repeat NAK

* Figure is courtesy of B. Forouzan

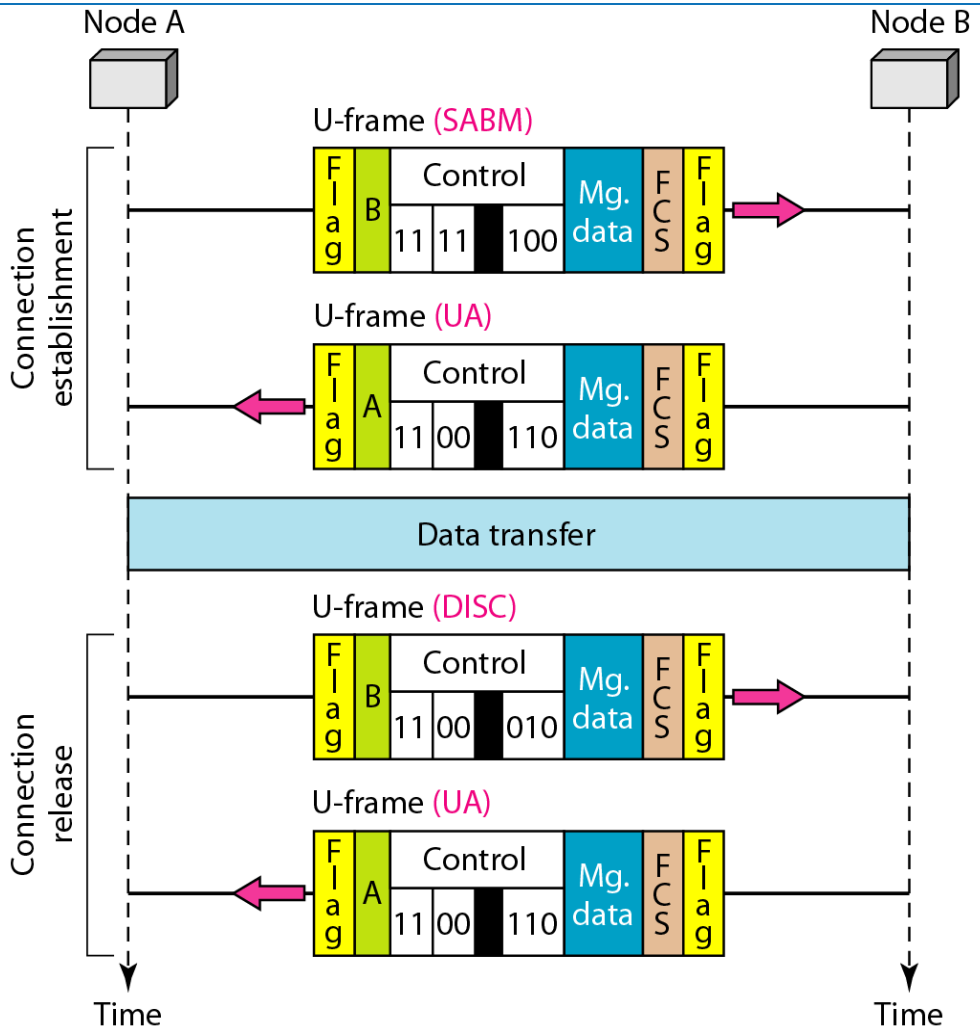
U-Frame Control Field



Code	Command/Response	Meaning
00 001	SNRM	Set normal response mode
11 100	SABM	Set asynchronous balanced mode
00 100	UP	Unnumbered poll
00 000	UI	Unnumbered information
00 110	UA	Unnumbered acknowledgment
00 010	DISC	Disconnect
10 000	SIM	Set initialization mode
11 001	RSET	Reset
11 101	XID	Exchange ID
10 001	FRMR	Frame reject

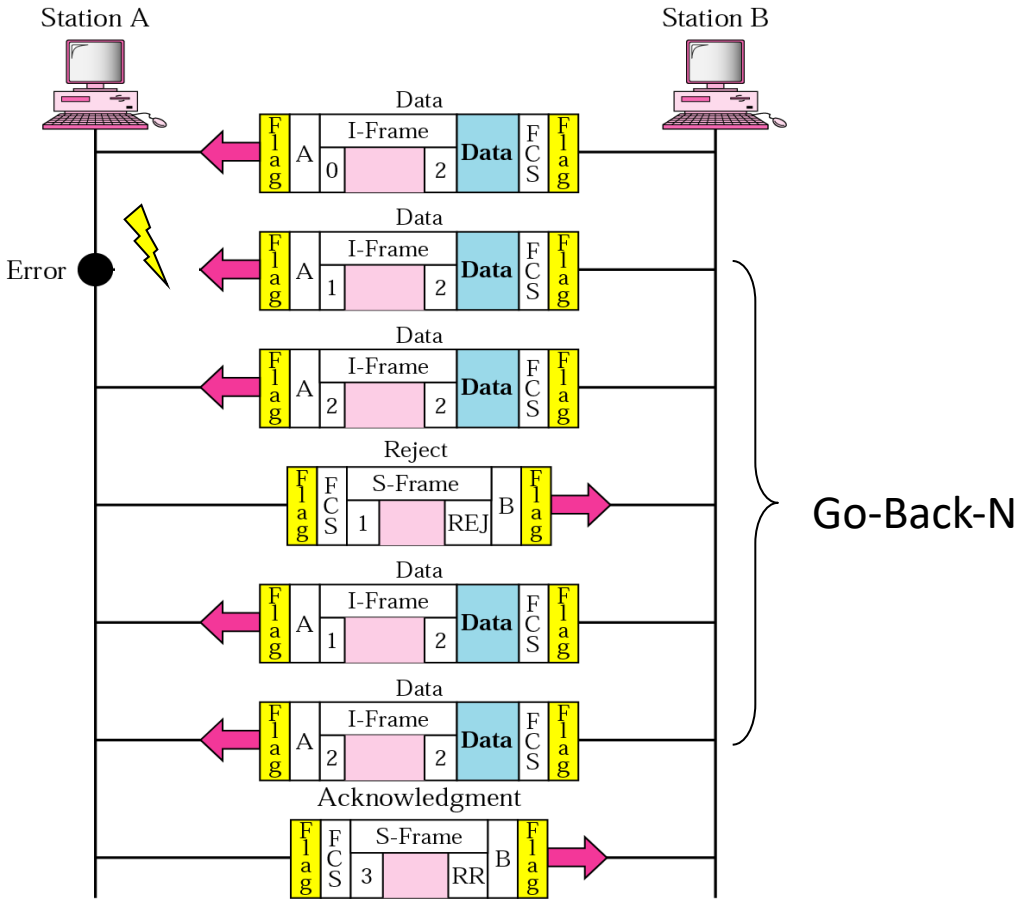
* Figure is courtesy of B. Forouzan

Connection & Disconnection



* Figure is courtesy of B. Forouzan

Piggybacking with Error



* Figure is courtesy of B. Forouzan

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CSU33031 Computer Networks

Ethernet

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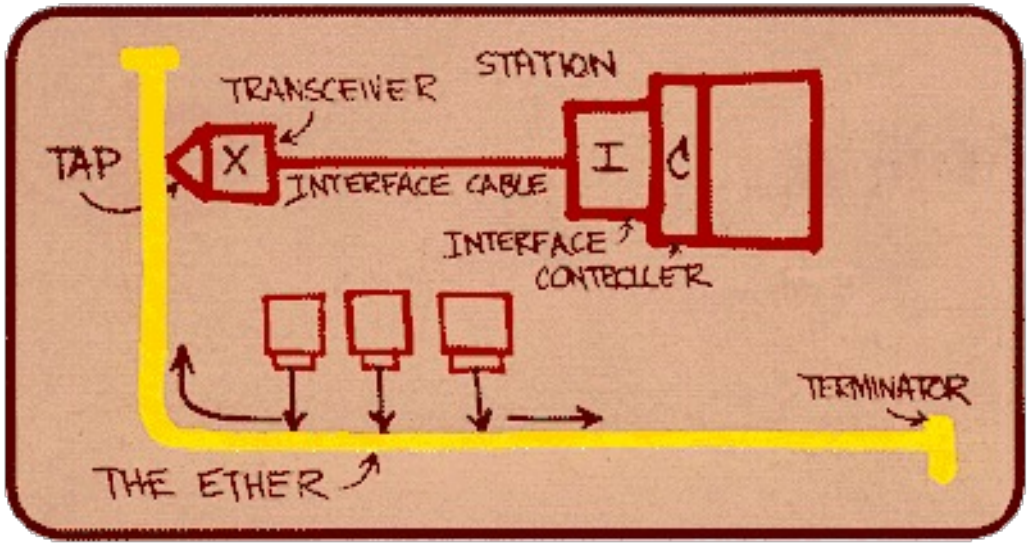
Ethernet

- Developed by Robert Metcalfe 1972/3
- Standards in 1978, 1995, 1998

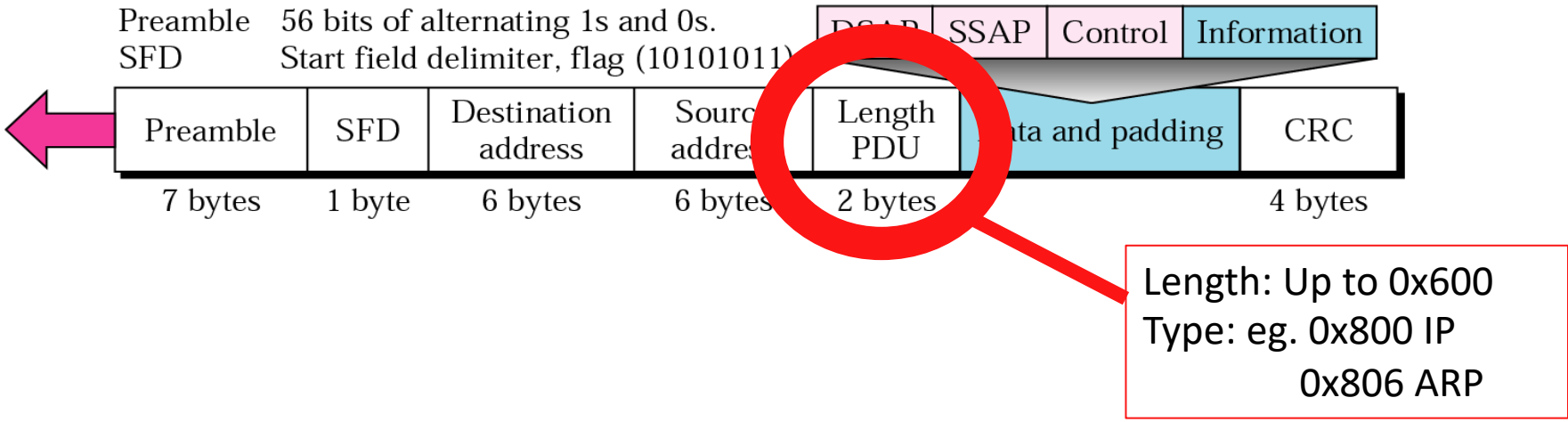
- Types of Ethernet
  - Original Ethernet
  - Switched Ethernet
  - Fast Ethernet
  - Gigabit Ethernet

- Manchester Encoding
- Medium Access Control
  - CSMA/CD



Metcalfe's Ethernet sketch

802.3 MAC Format



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

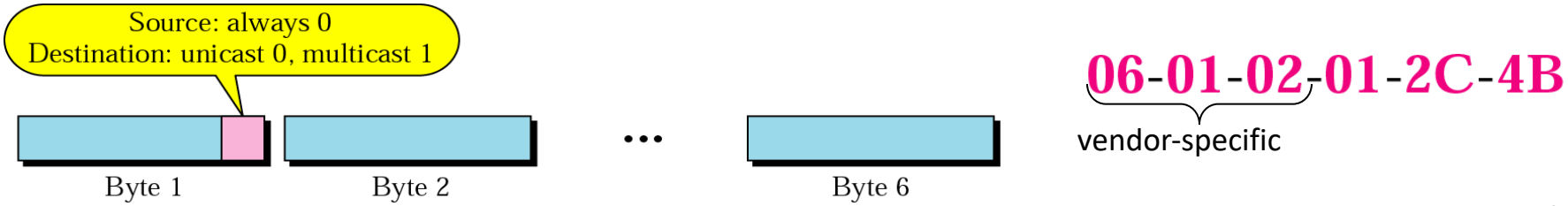
- Maximum frame length: 1536 bytes

  ⇨ Maximum Transmission Unit (MTU): 1500 bytes max payload

* Figure is courtesy of B. Forouzan

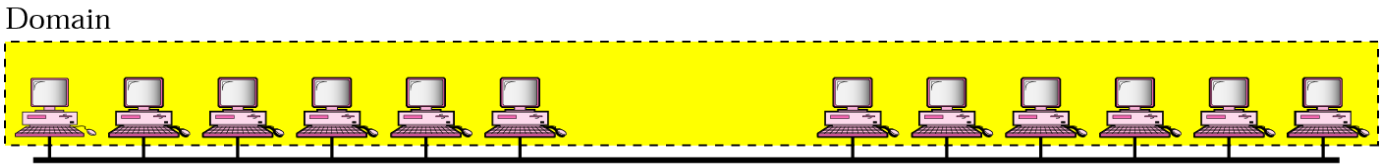
Ethernet Addresses

- Types of Addresses:
  - Unicast – delivered to one station
    - 00-10-4B 3Com 3C905-TX PCI
    - 00-A0-C9 Intel (PRO100B and PRO100+)
  - Multicast – delivered to a set of stations
    - 01-80-C2-00-00-00 Spanning tree (for bridges)
    - 03-00-00-00-00-01 NETBIOS
  - Broadcast – delivered to all stations
    - FF-FF-FF-FF-FF-FF

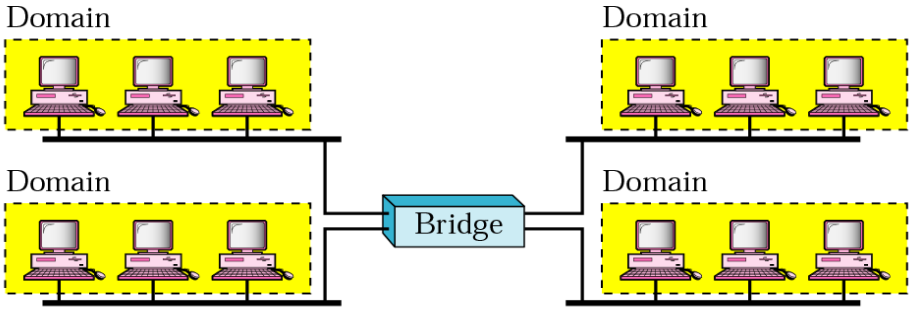


* Figure is courtesy of B. Forouzan

Collision Domains



a. Without bridging



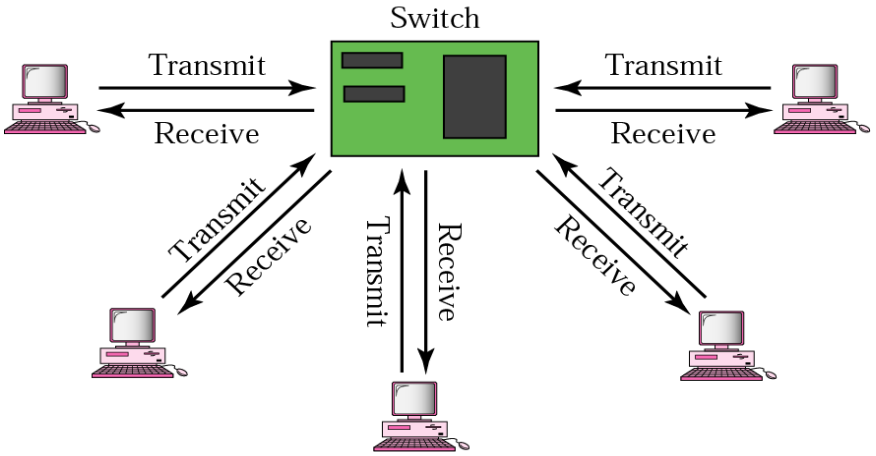
b. With bridging

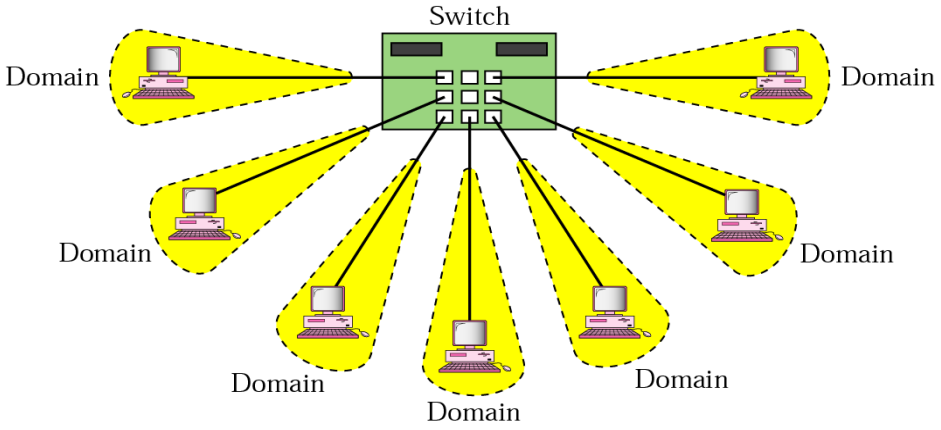
- Extension of Networks:
  - Repeaters, Hubs - Physical Layer
  - Bridges, Switches - Data Link Layer
  - Routers - Network Layer
- Collision domains:
  - Collision affects all machines in one segment

Medium Access Control:
How to decide who can transmit
After Reading Week

* 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

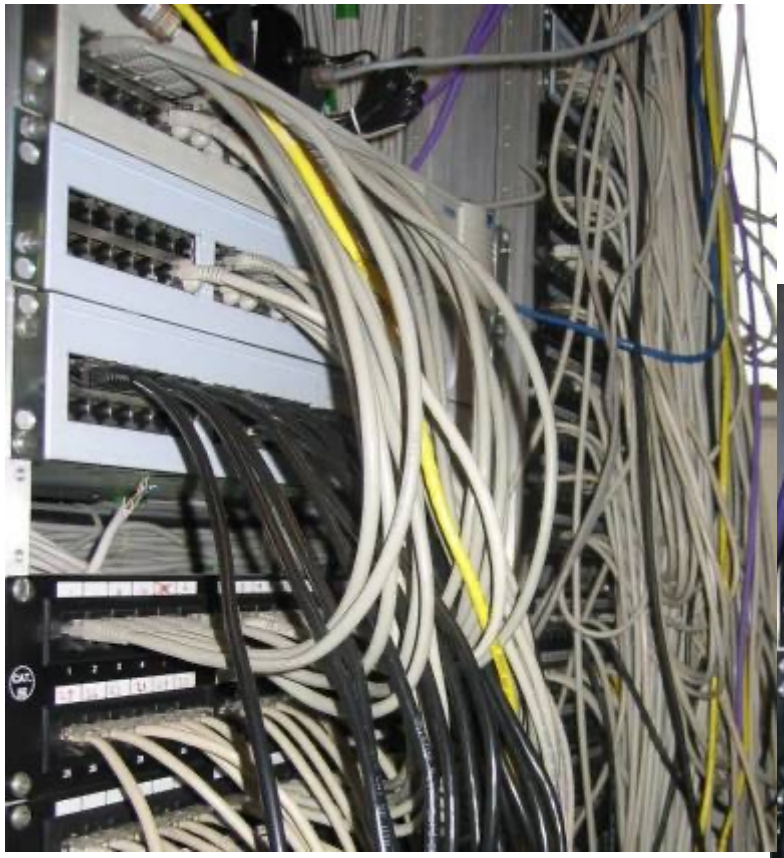
* Figure is courtesy of B. Forouzan

Switches

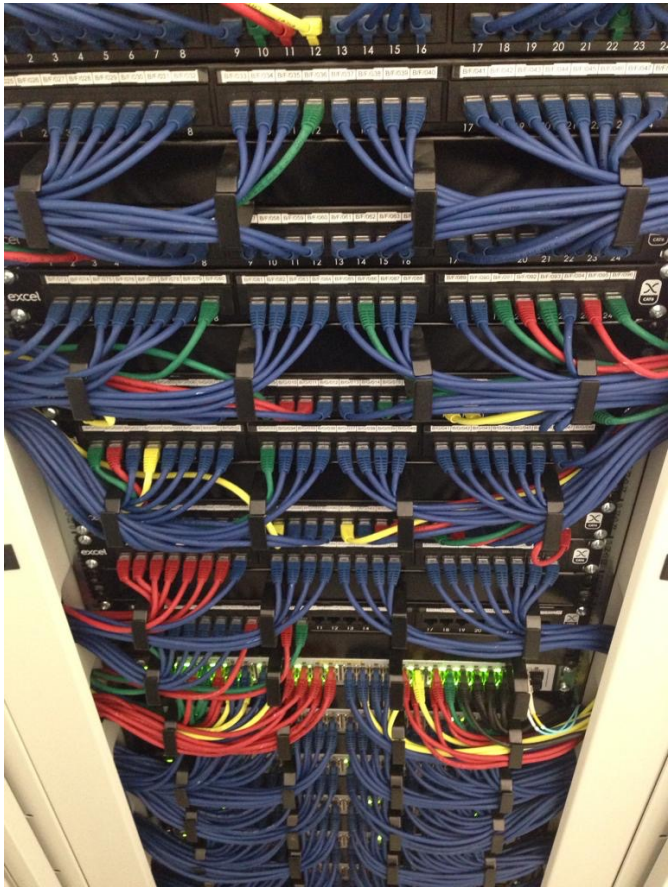
* Cisco Catalyst WS-C4948E-E

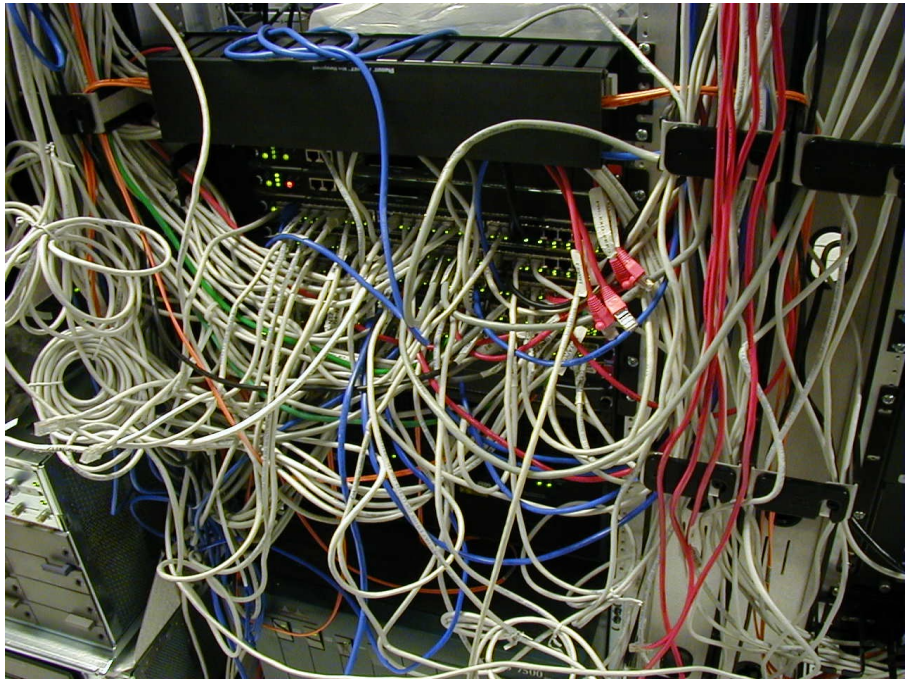
* Arista 7800R3

Switches in Comms Rooms

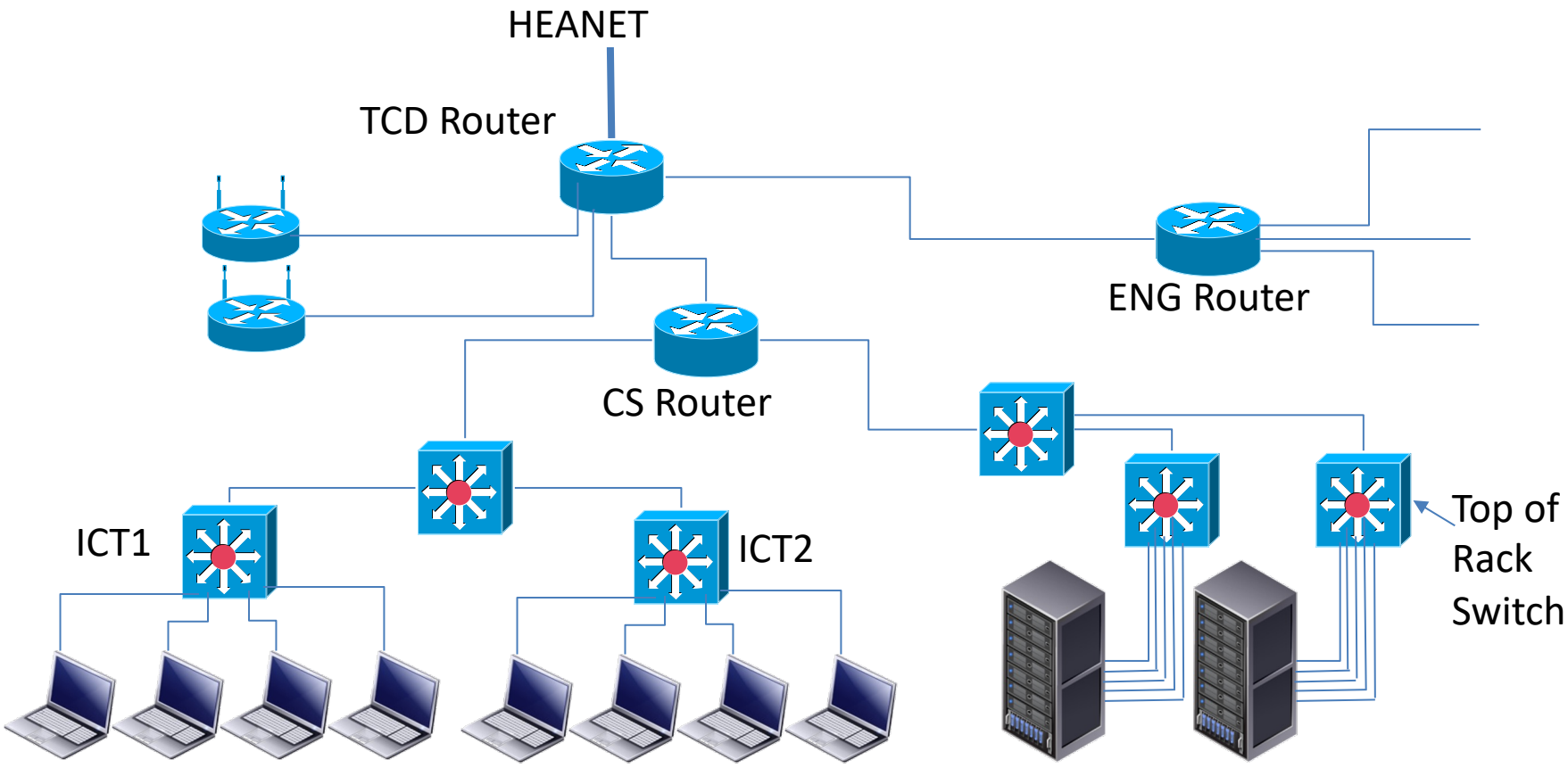


Wiring Example ☺



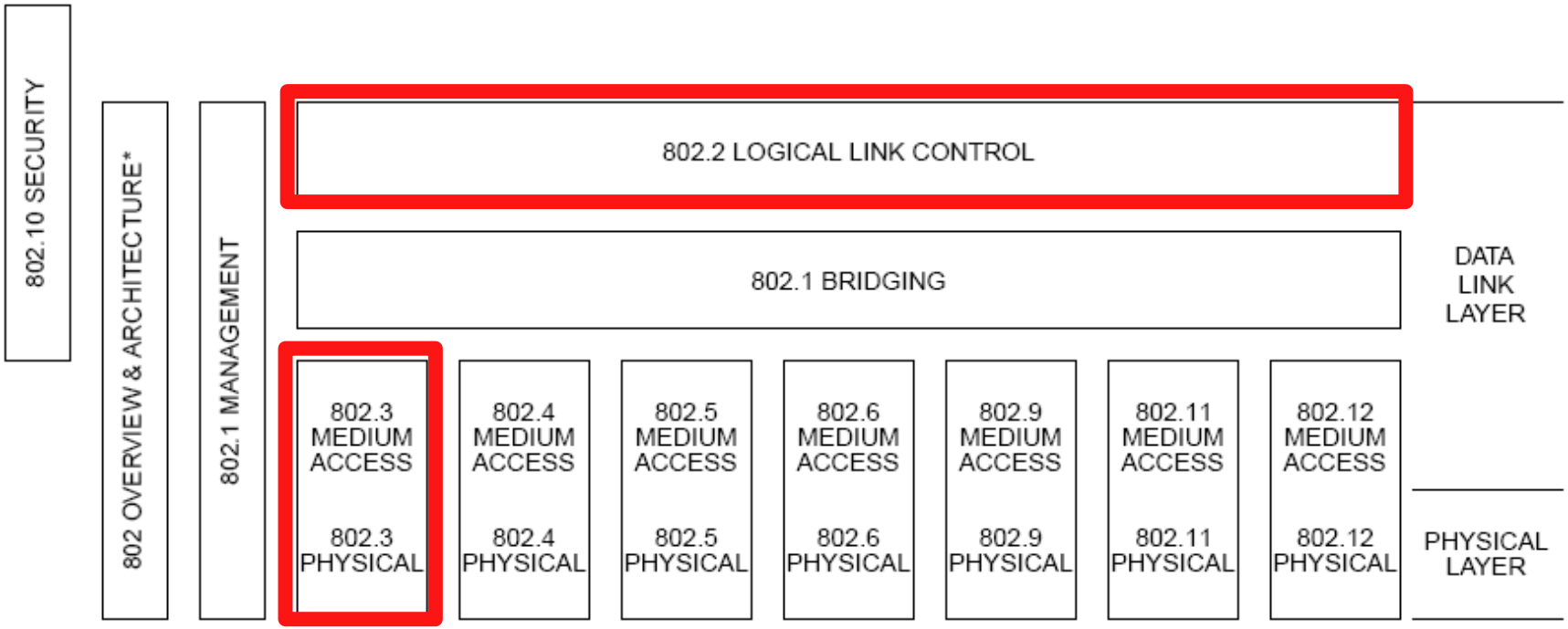


College Example



Potential topology of College; may or may not reflect the reality of our setup

IEEE 802



- 802.3: Ethernet
- 802.11: Wifi
- 802.16: WiMAX
- 802.20: Mobile Broadband Wireless Access (MBWA)
- 802.15.1: Bluetooth
- 802.15.4: ZigBee

* Figure is courtesy of ANSI/IEEE Std 802.11

802.2 LLC Control Fields

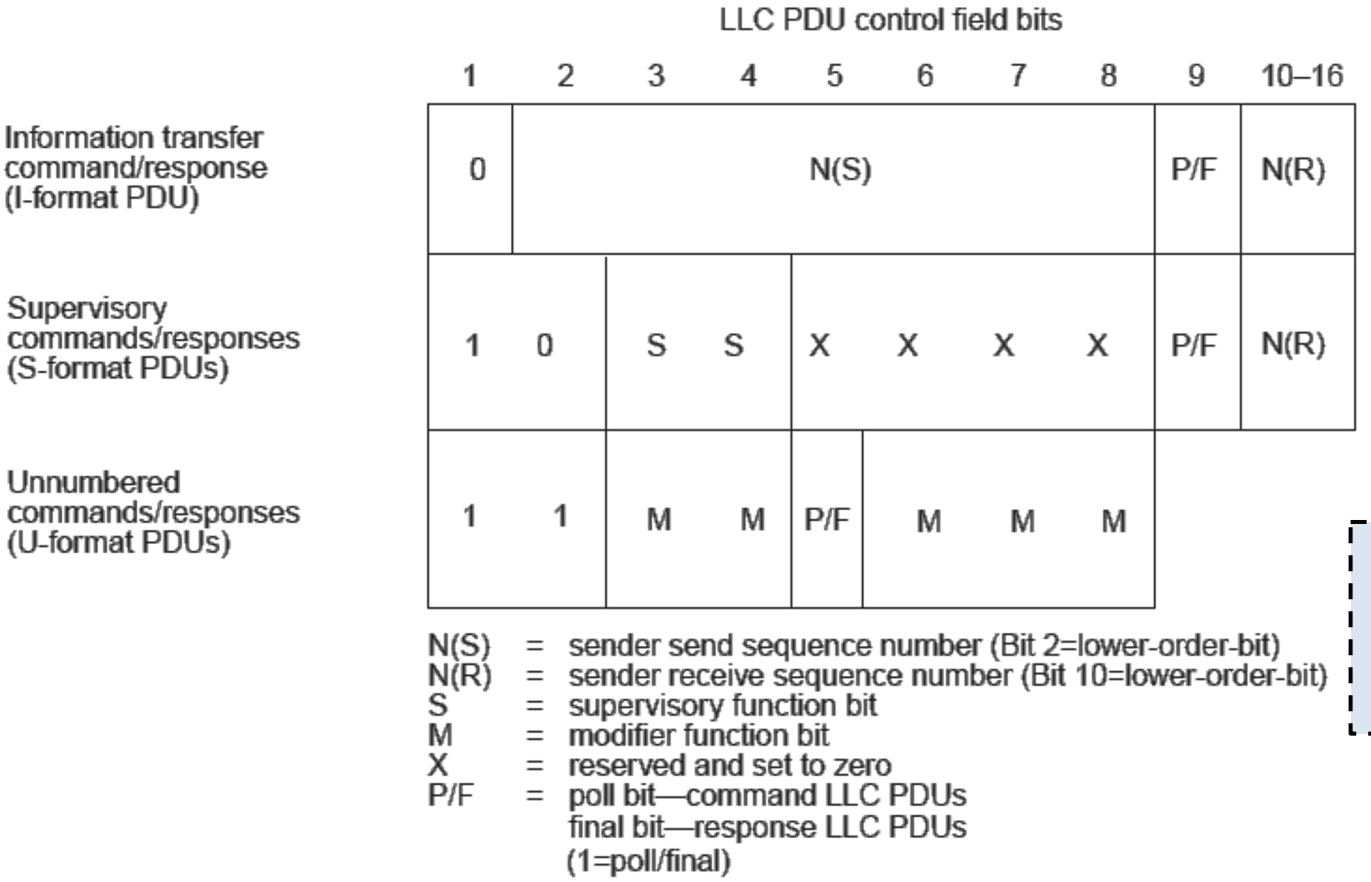


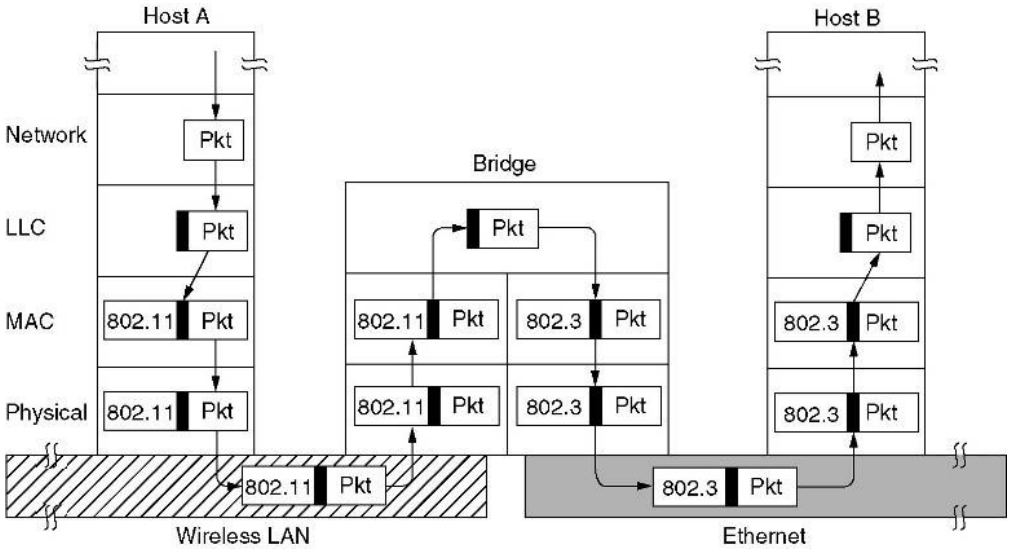
Figure 9—LLC PDU control field formats

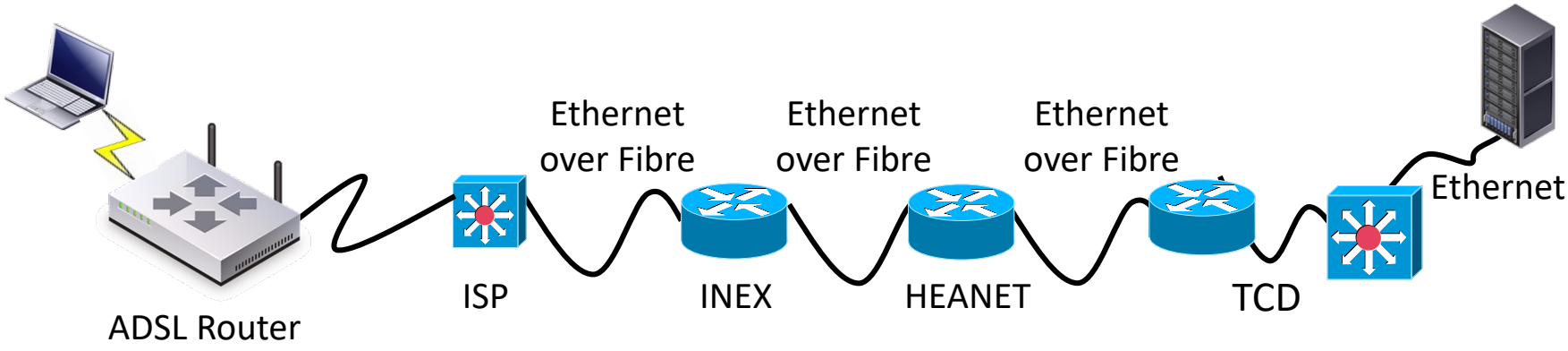
m = 7
$2^m = 128$
max w-size
for sel. repeat= 64 frames

ANSI/IEEE Std 802.2, 1998 Edition 12

Bridges from 802.x to 802.y

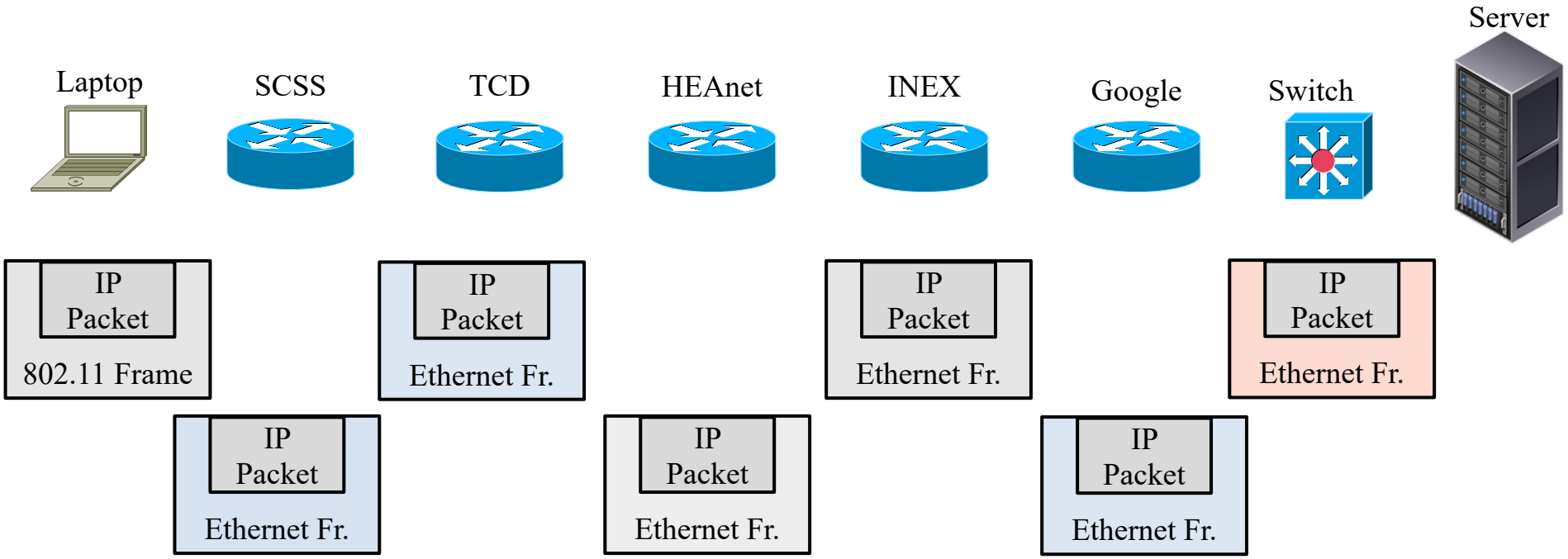
Operation of a LAN bridge from 802.11 to 802.3.



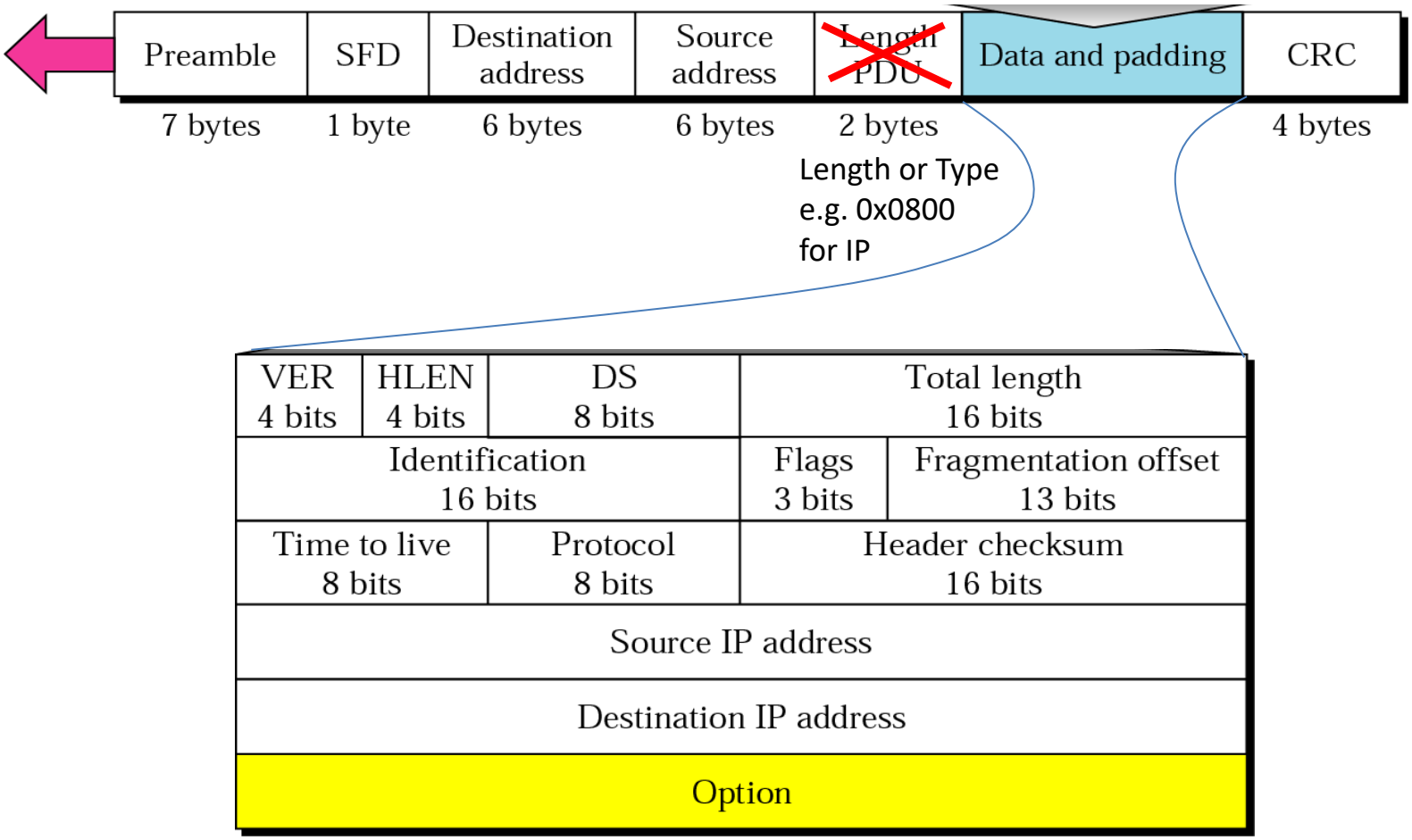


* Figure is courtesy of A. Tanenbaum

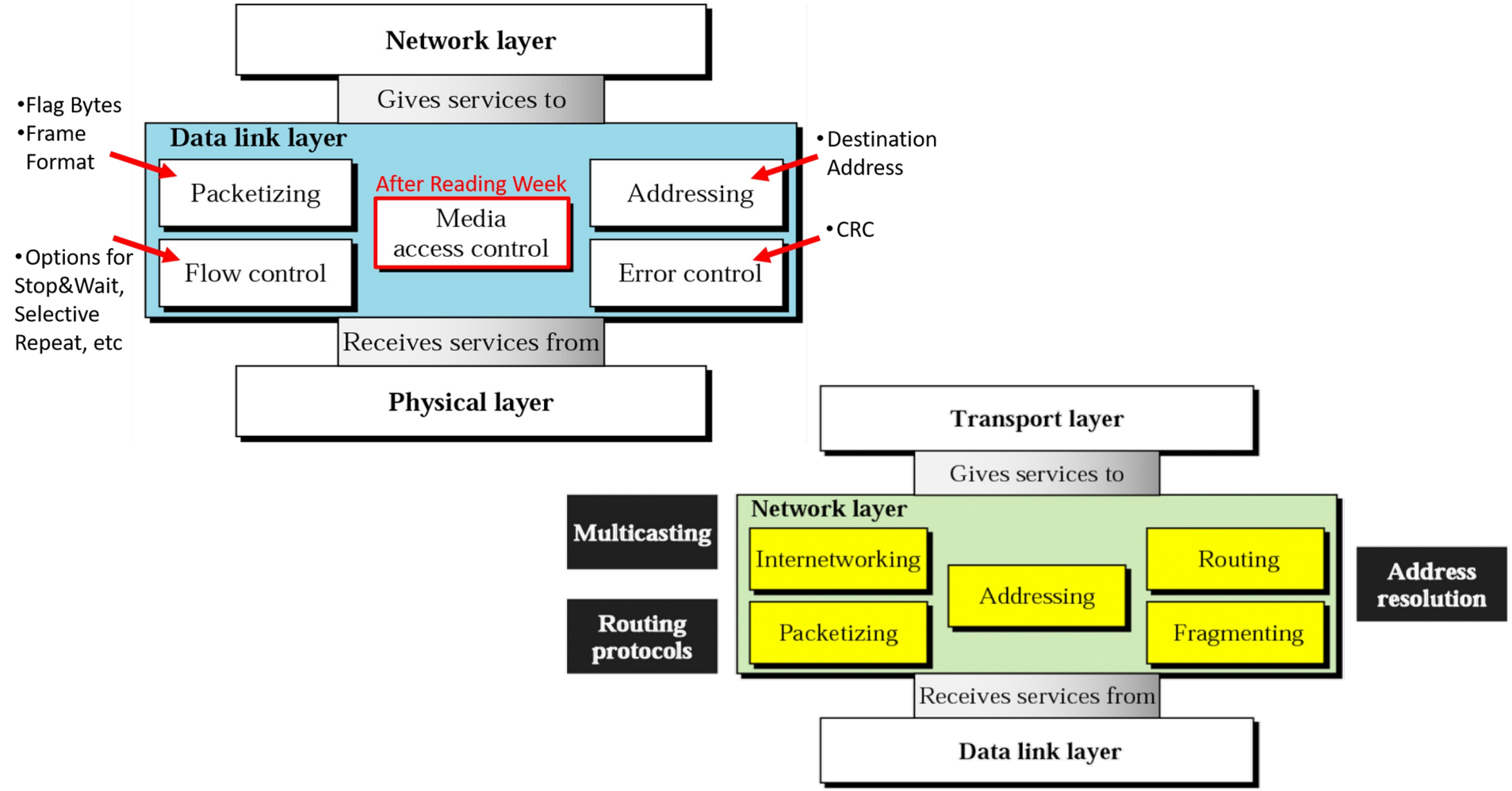
Encapsulation



Ethernet & IP

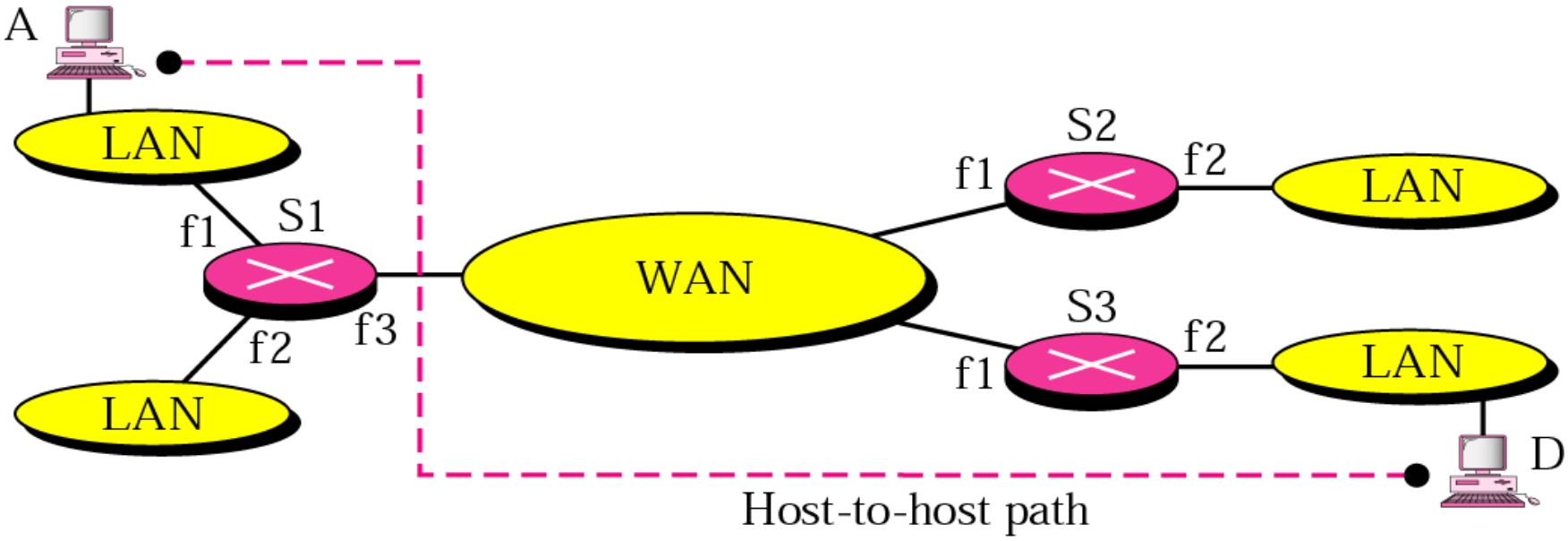

Preamble
SFD
Destination address
Source address
Length PDU
Data and padding
CRC
7 bytes
1 byte
6 bytes
6 bytes
2 bytes
4 bytes
Length or Type
e.g. 0x0800
for IP
VER 4 bits
HLEN 4 bits
DS 8 bits
Total length 16 bits
Identification 16 bits
Flags 3 bits
Fragmentation offset 13 bits
Time to live 8 bits
Protocol 8 bits
Header checksum 16 bits
Source IP address
Destination IP address
Option

Link Layer



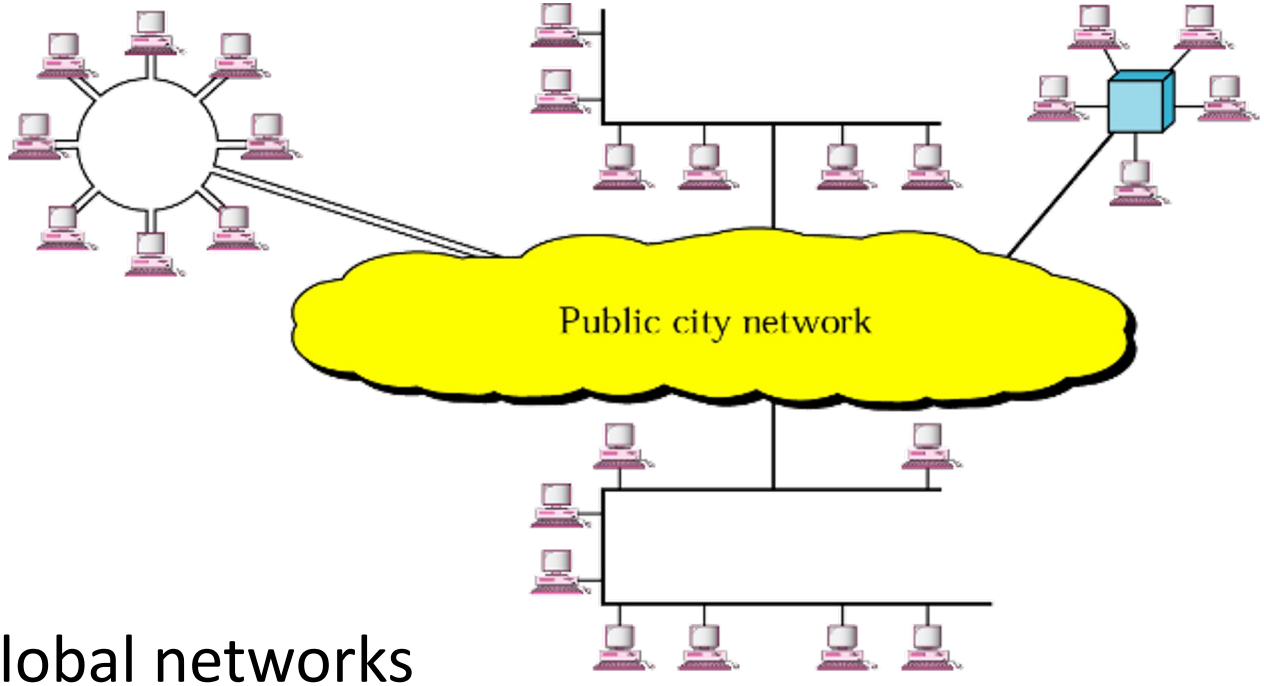
* Figure is courtesy of B. Forouzan

Network Layer



* Figure is courtesy of B. Forouzan

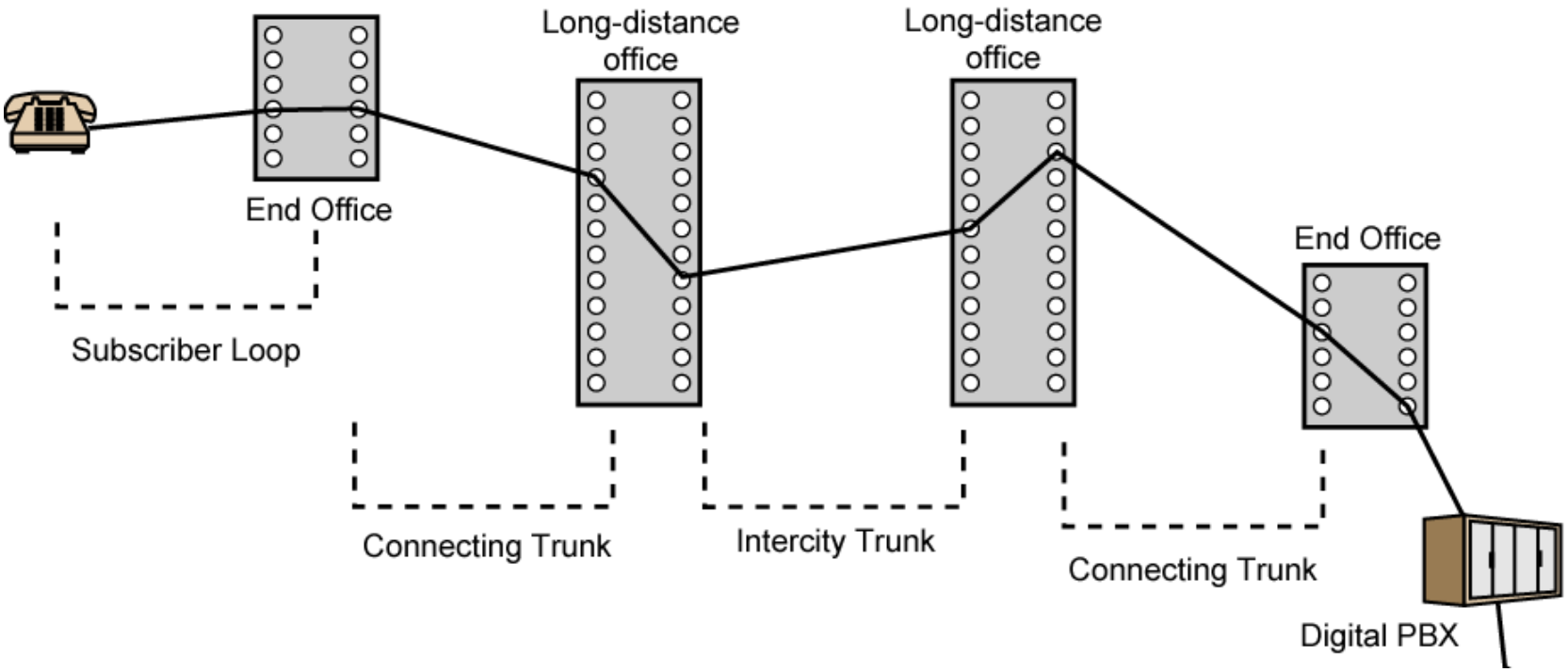
Problems faced by Network Layers



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

* Figure is courtesy of B. Forouzan

Circuit Switched Network



- Dedicated connection between two endpoints

* Figure is courtesy of A. Tanenbaum

Paul Baran

- 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)

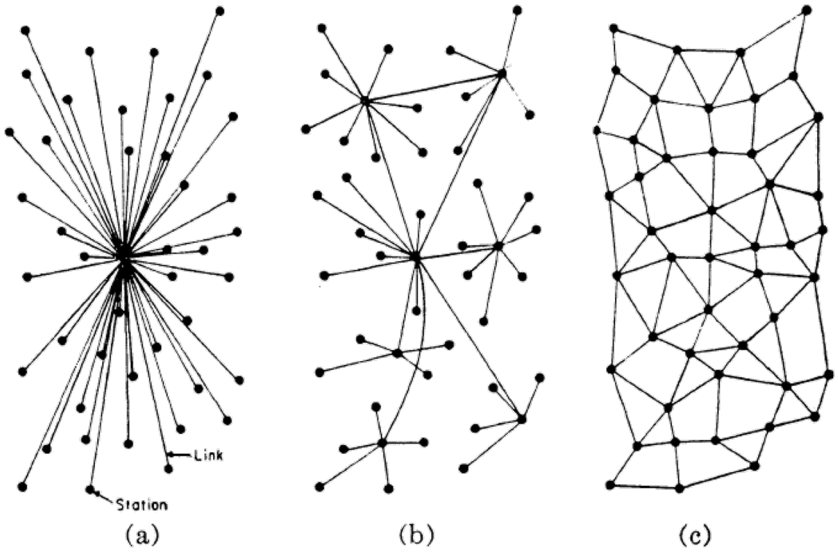
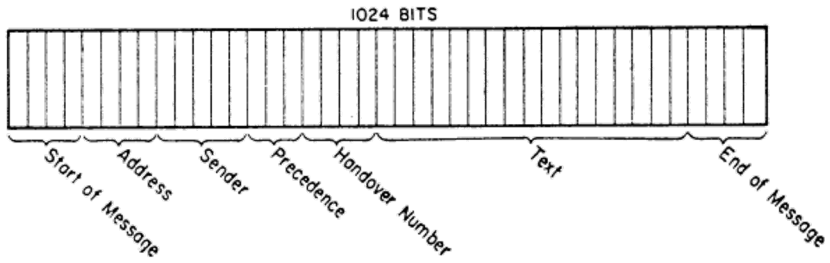


Fig. 1—(a) Centralized. (b) Decentralized. (c) Distributed networks.



AT&T's comment in the 1960s:

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

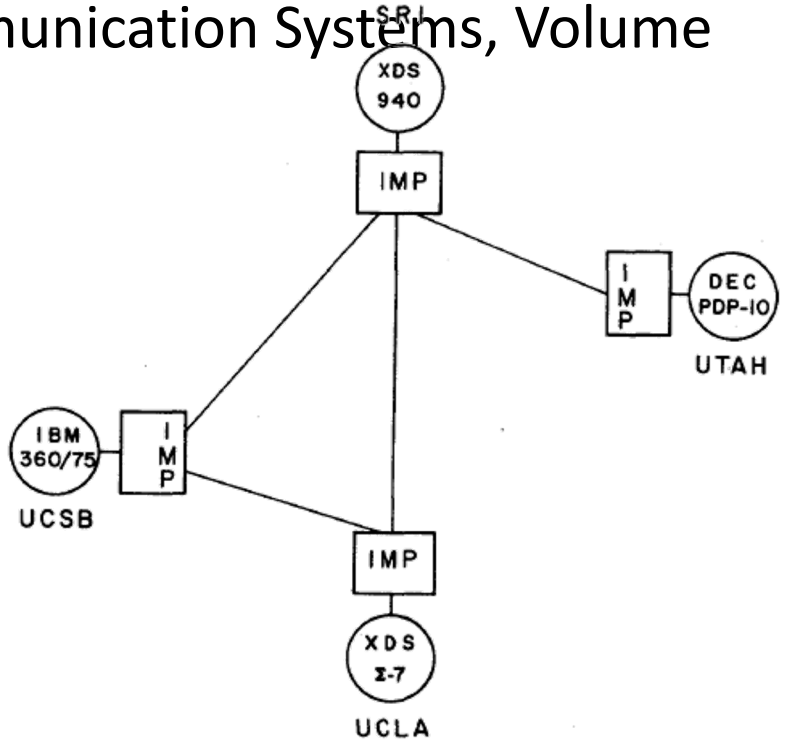
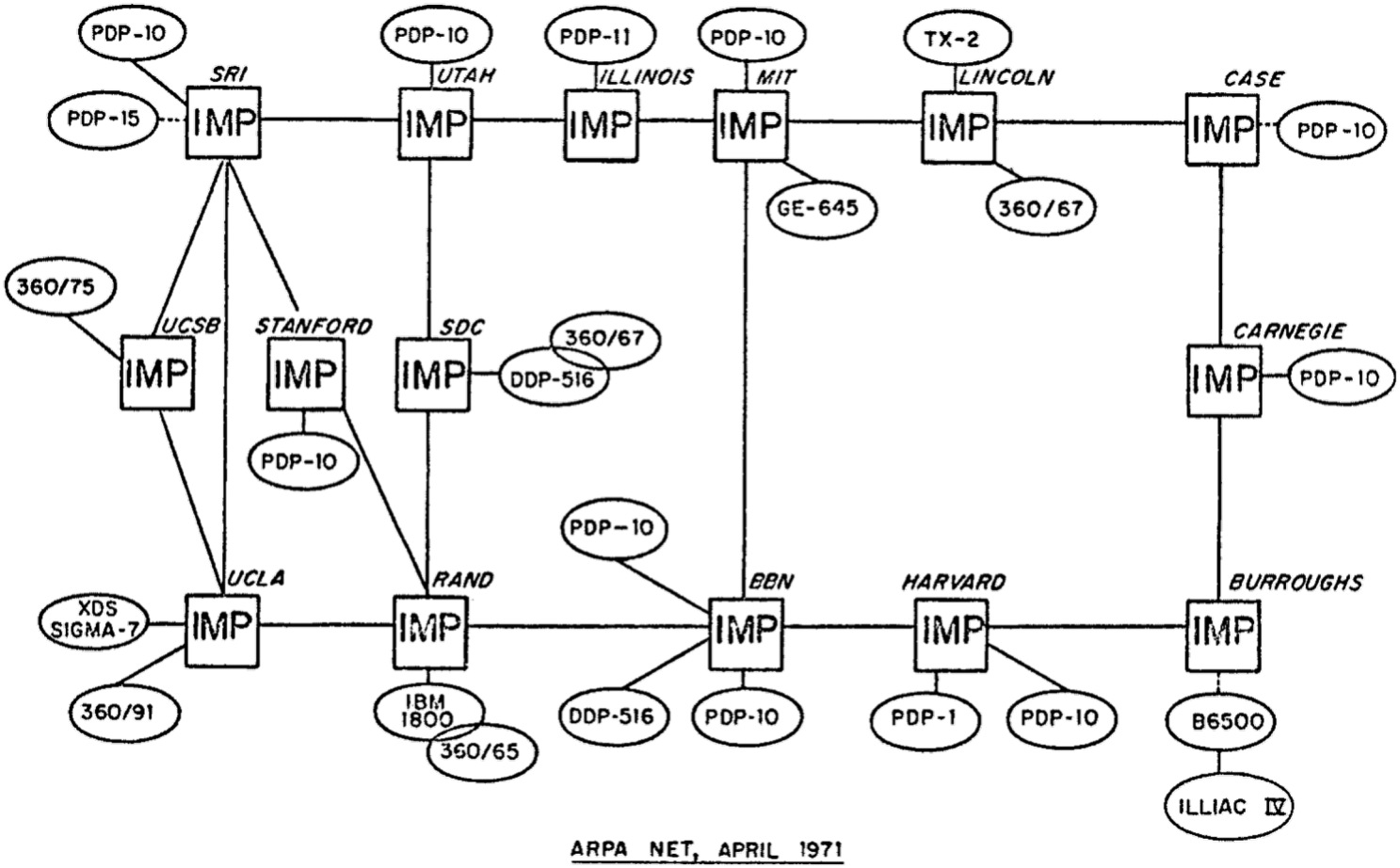


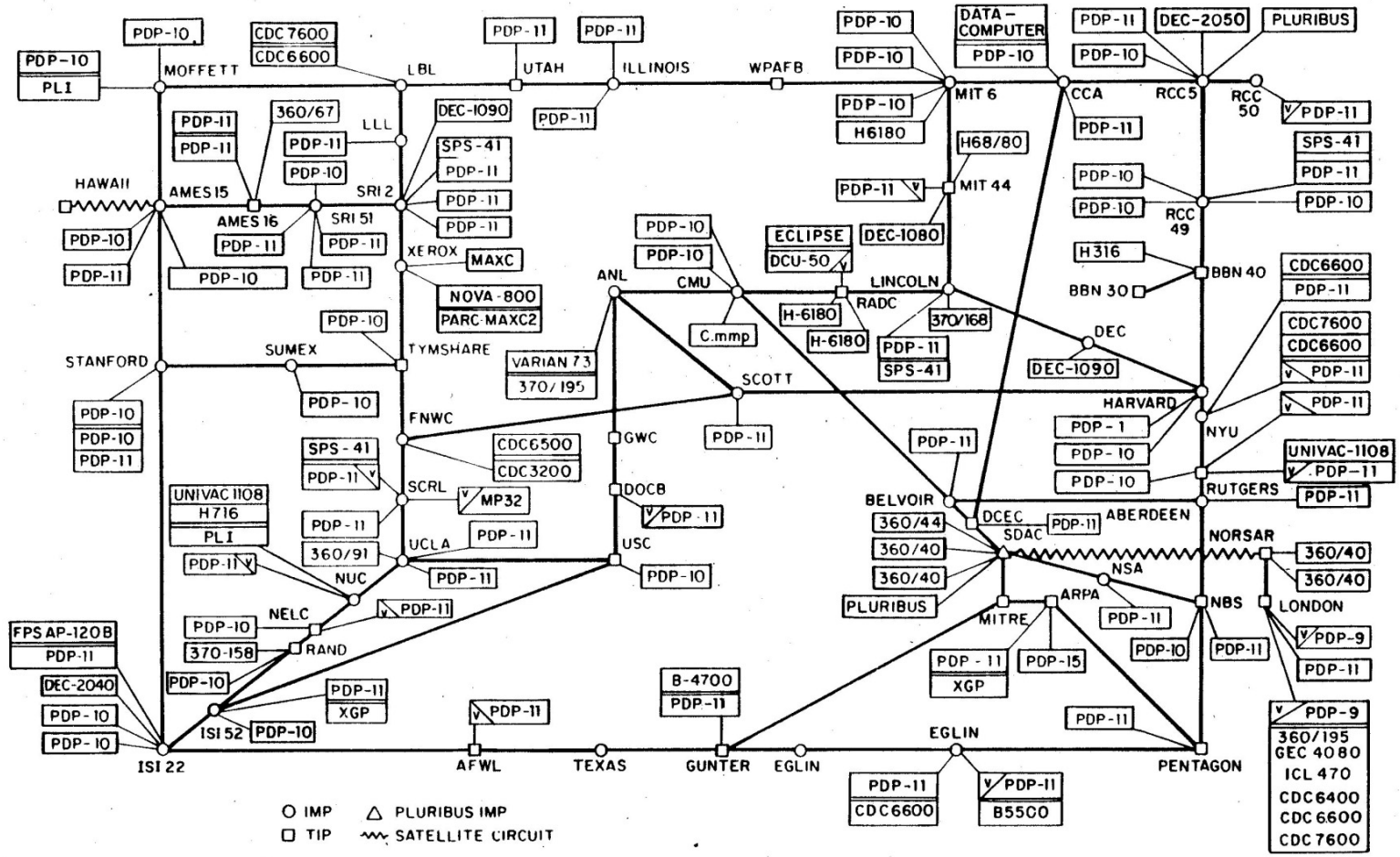
Figure 1—Initial network configuration

* 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

ARPANET 1971



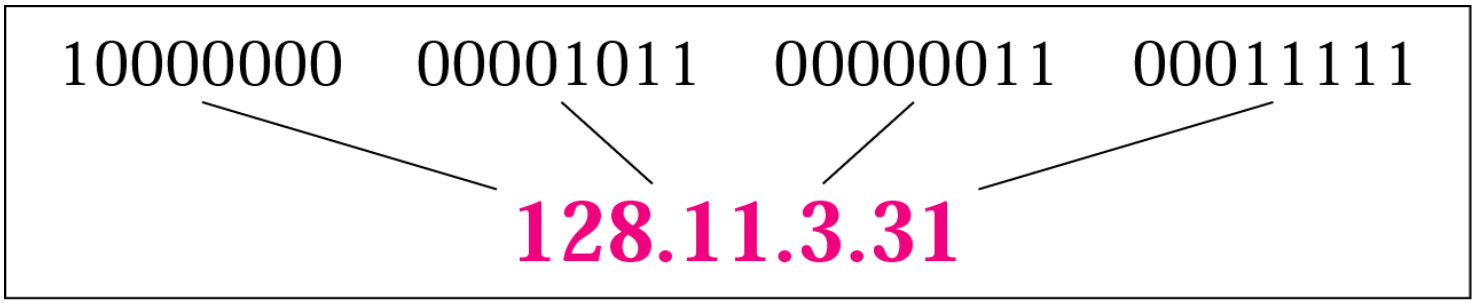
ARPANET 1977



(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)

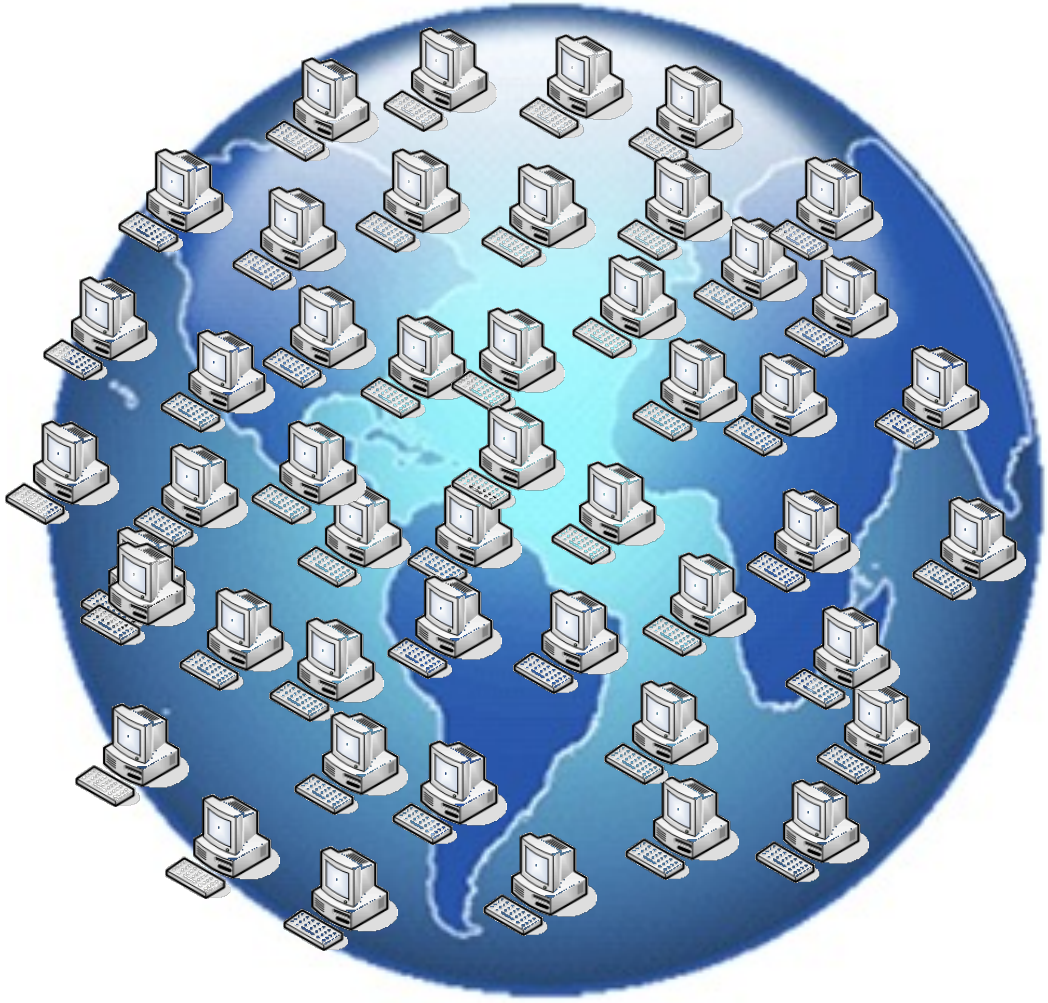
NAMES SHOWN ARE IMP NAMES, NOT (NECESSARILY) HOST NAMES

IP Addresses

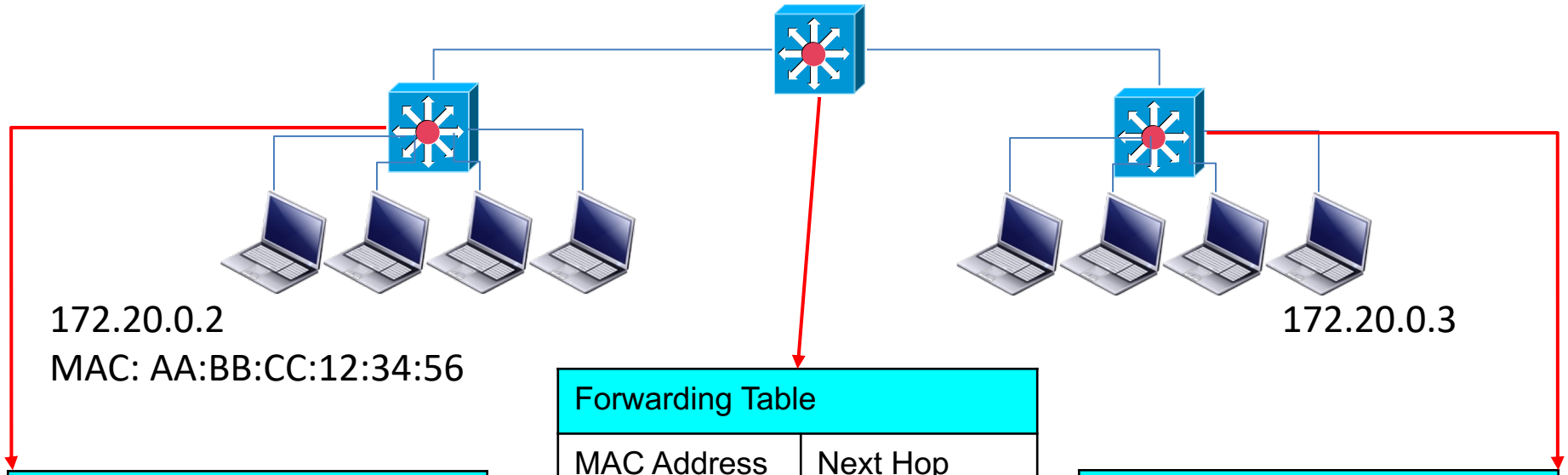


- 32-bit number
  - 4.294.967.296 addresses
- IP addresses are unique and universal
  - with some exceptions
- Dotted decimal notation:
  - Bytes of binary notation represented as decimal separated by dot

4.294.967.296 Possible Nodes???



Packet from .0.2 to .0.3



172.20.0.2
MAC: AA:BB:CC:12:34:56

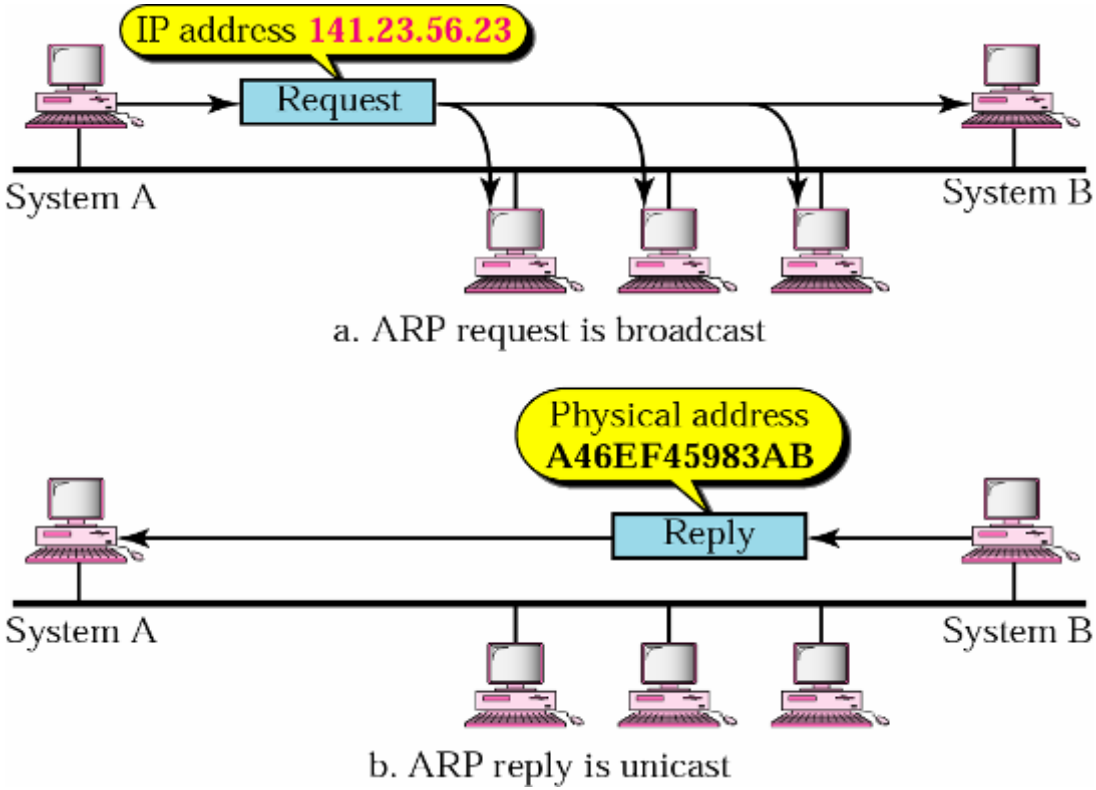
172.20.0.3

Forwarding Table	
MAC Address	Next Hop
AA:BB…34:56	Port 1
AA:BB…45:44	Port 2

Forwarding Table	
MAC Address	Next Hop
AA:BB…34:56	Port 7

Forwarding Table	
MAC Address	Next Hop
AA:BB:…:34:33	Port 13
CC:FF:…:55:66	Port 5

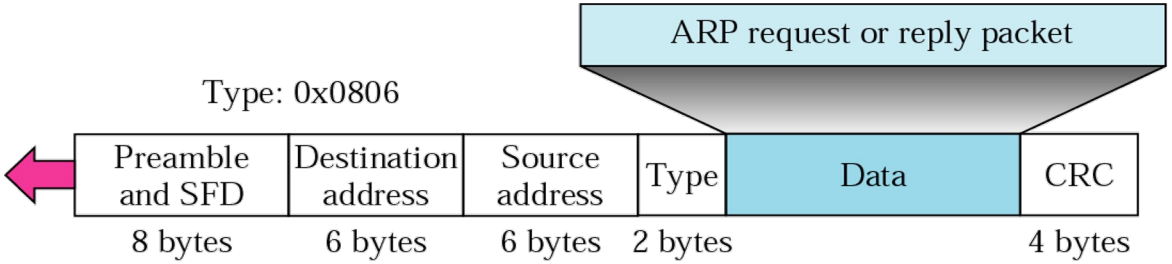
Address Resolution Protocol (ARP)



- Association between hardware address and IP address

* Figure is courtesy of B. Forouzan

ARP Encapsulation in Ethernet

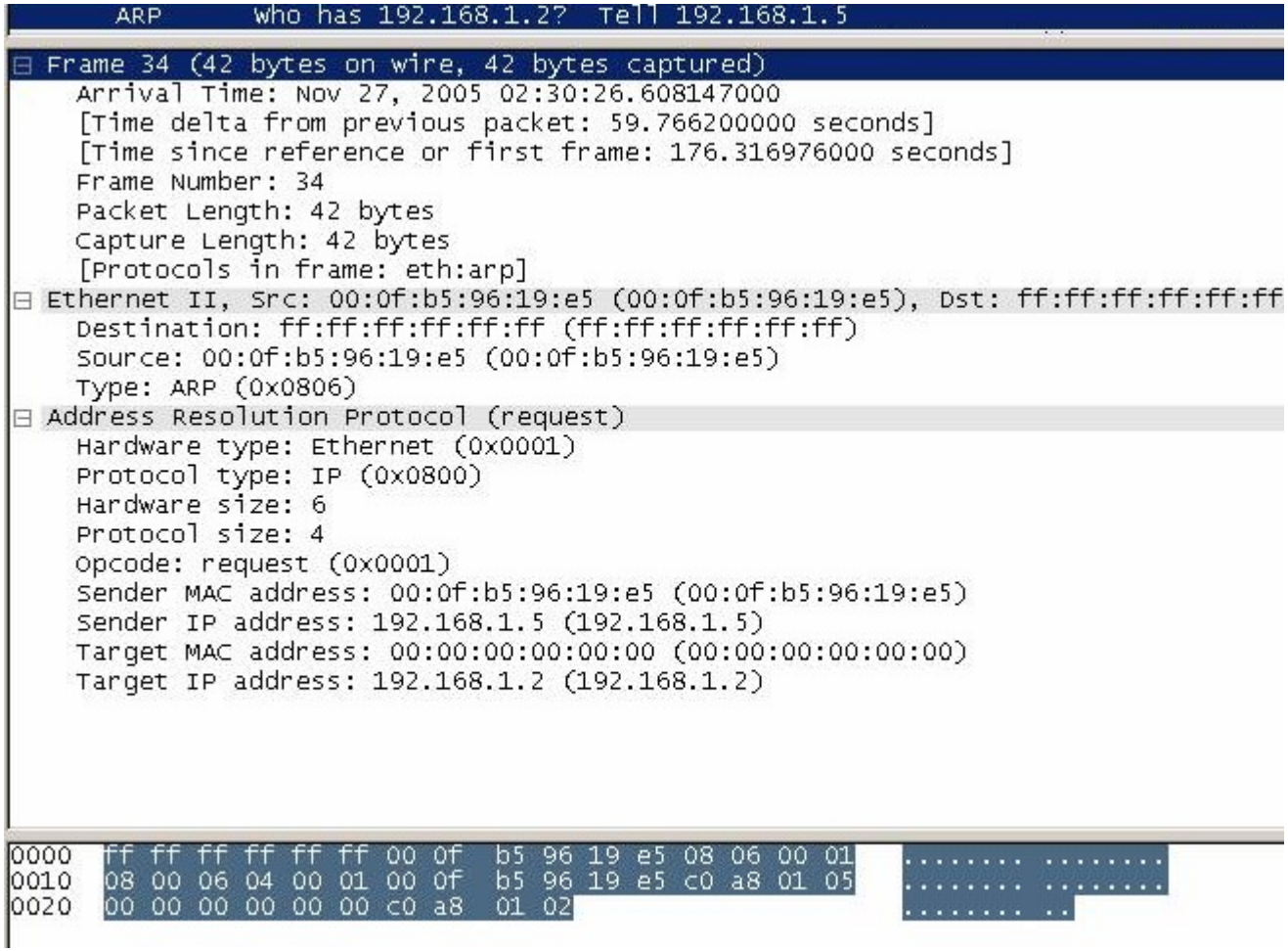


Hardware Type		Protocol Type
Hardware length	Protocol length	Operation Request 1, Reply 2
Sender hardware address (For example, 6 bytes for Ethernet)		
Sender protocol address (For example, 4 bytes for IP)		
Target hardware address (For example, 6 bytes for Ethernet) (It is not filled in a request)	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

* Figure is courtesy of B. Forouzan

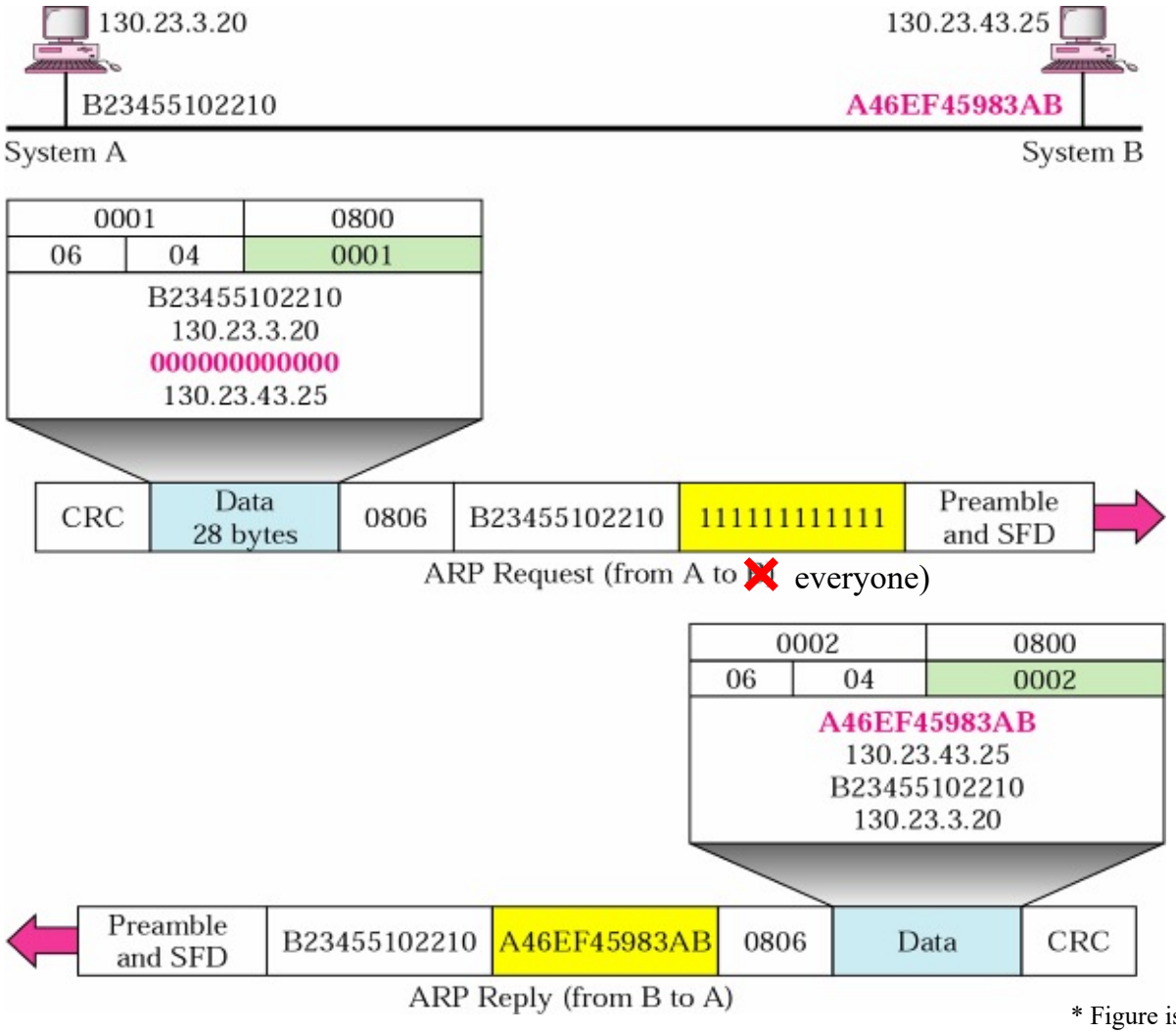
Example from Wireshark

"Who has …?" Packet



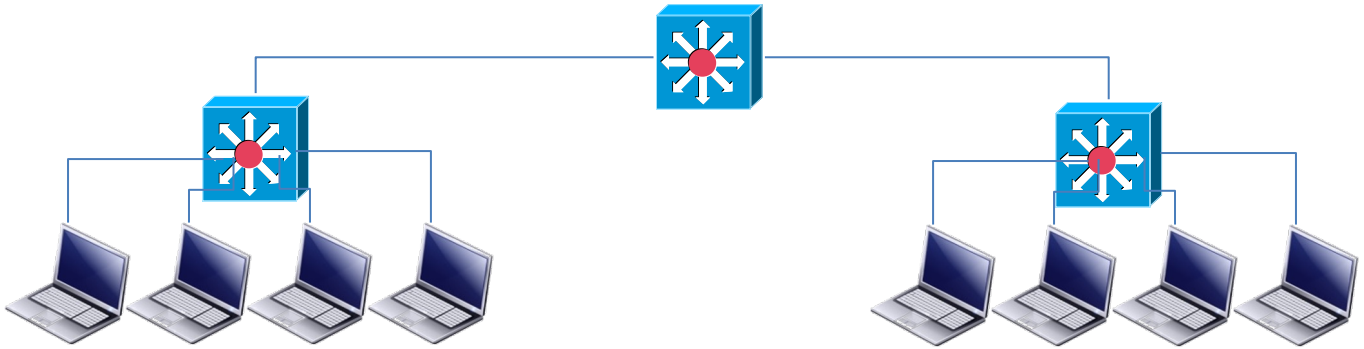
- ARP Request: Who has 192.168.1.2? Tell 192.168.1.5

ARP Request & Reply



* Figure is courtesy of B. Forouzan

Packet from .0.2 to .0.3



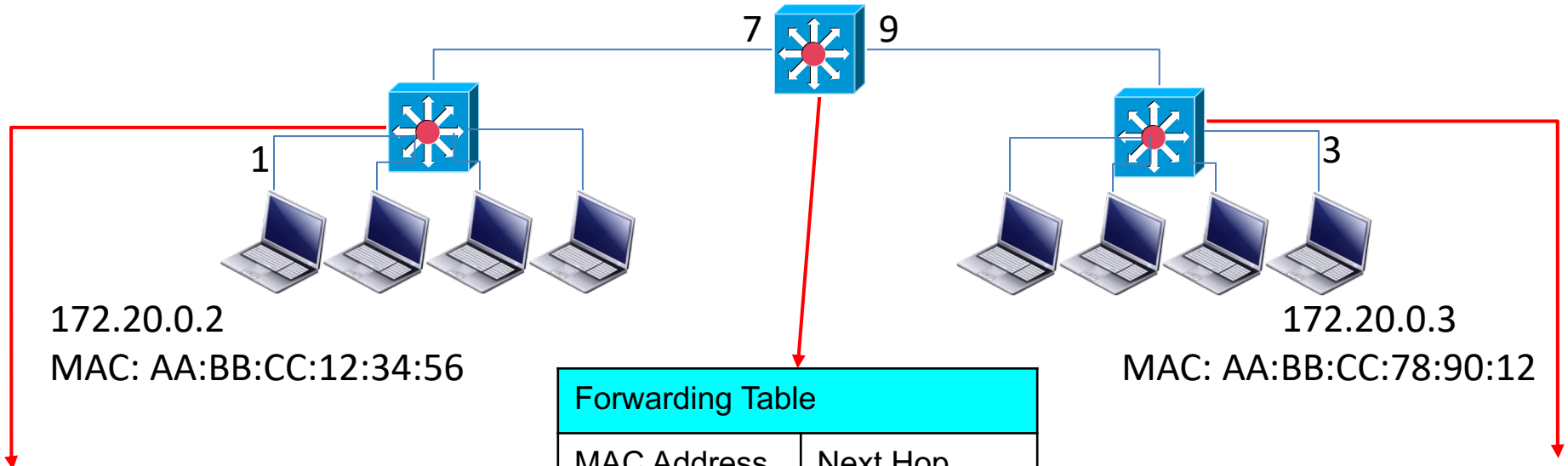
IP: 172.20.0.2
MAC: AA:BB:CC:12:34:56

134.226.0.3
MAC: AA:BB:CC:78:90:12

- ARP broadcast to everyone: 172.20.0.3?

- ARP reply from 172.20.0.3: AA:BB:CC:78:90:12

Packet from .0.2 to .0.3

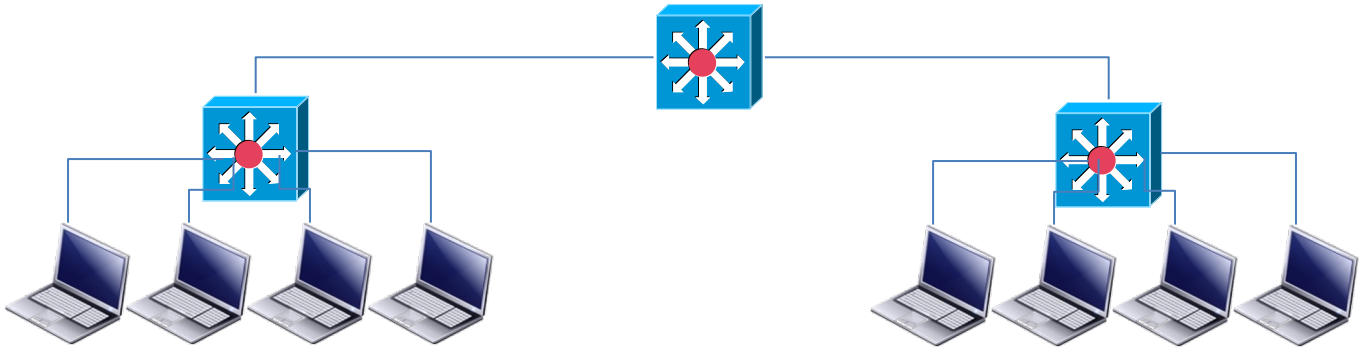


Forwarding Table	
MAC Address	Next Hop
AA:BB…34:56	Port 1
AA:BB…45:44	Port 2

Forwarding Table	
MAC Address	Next Hop
AA:BB…34:56	Port 7
AA:BB:..:90:12	Port 9

Forwarding Table	
MAC Address	Next Hop
AA:BB:…:34:33	Port 13
AA:BB:..:90:12	Port 3

Packet from .0.2 to .0.3



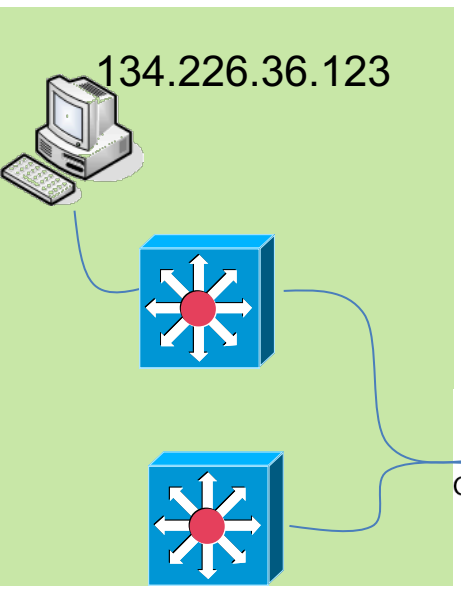
IP: 172.20.0.2
MAC: AA:BB:CC:12:34:56

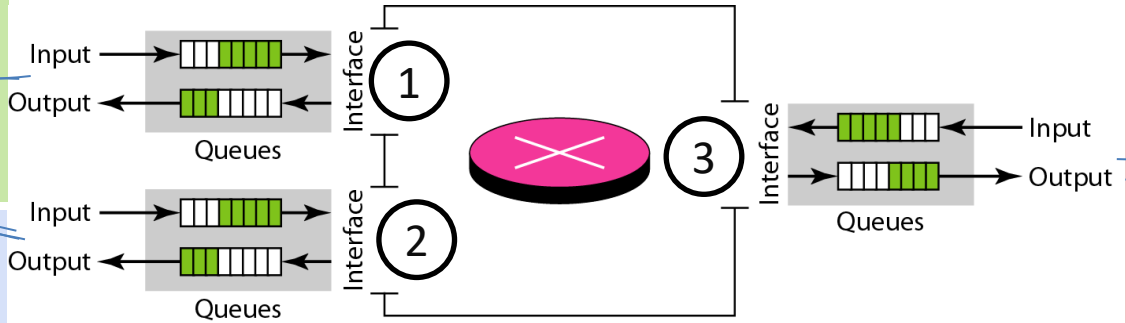
172.20.0.3
MAC: AA:BB:CC:78:90:12

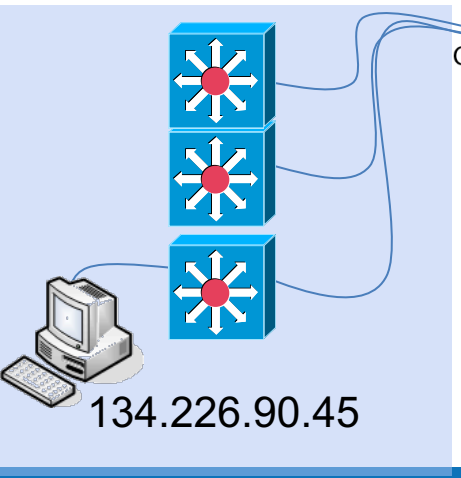
Ethernet Frame
From: AA:BB:CC:12:34:56
To: AA:BB:CC:78:90:12

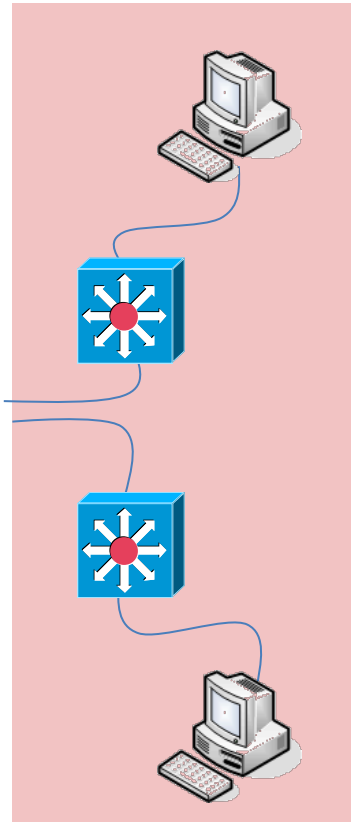
IP Packet
From: 172.20.0.2
To: 172.20.0.3

Routers (or Network Elements)





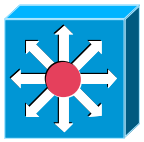




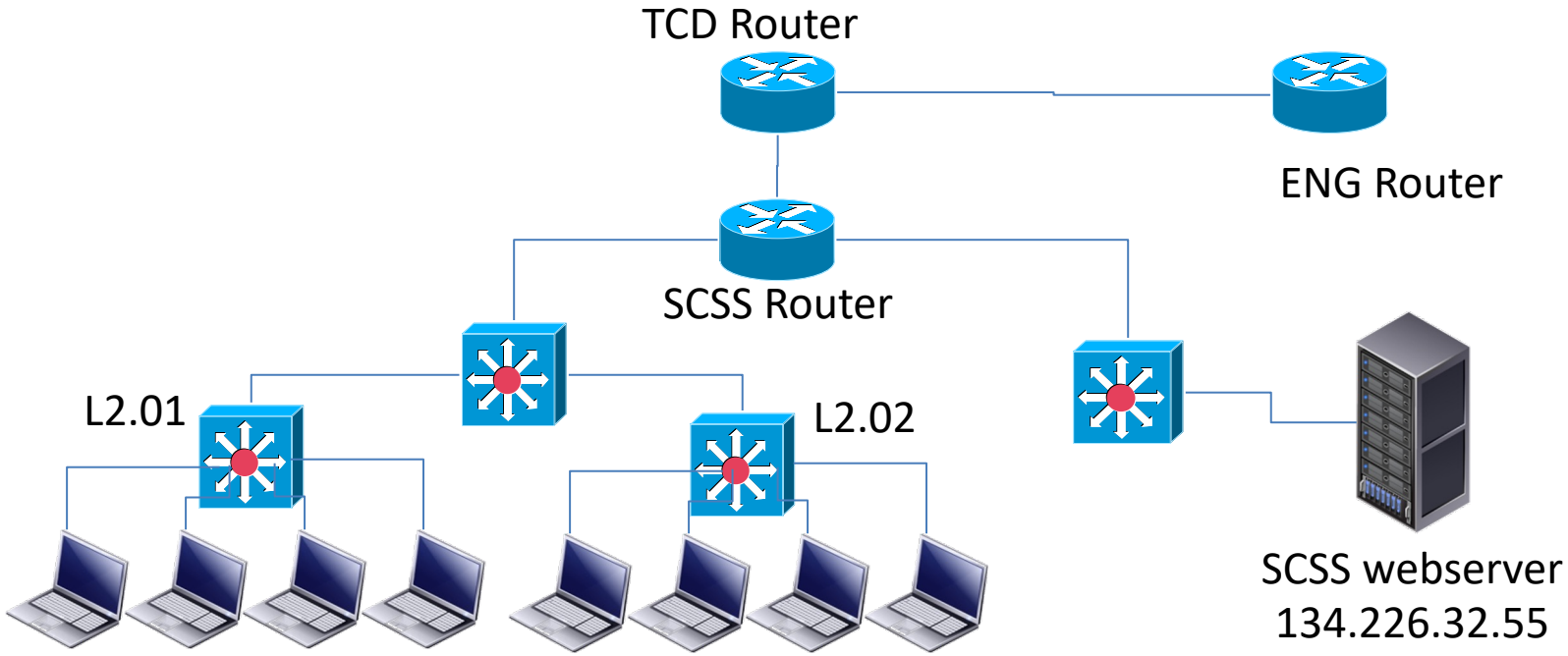
Forwarding Table or Routing Table	
Network Address	Next Hop
134.226.36.123	interface 1
134.226.90.45	interface 2

Network Elements

Router



Switch



Routers

- One Main Interest
  Forwarding Packets
- Important Aspects
  Queue Length
  Routing Table

Destination	Gateway	Interface
IP_1	$nextHop_3$	IF_1
IP_2	$nextHop_5$	IF_7
…	…	…

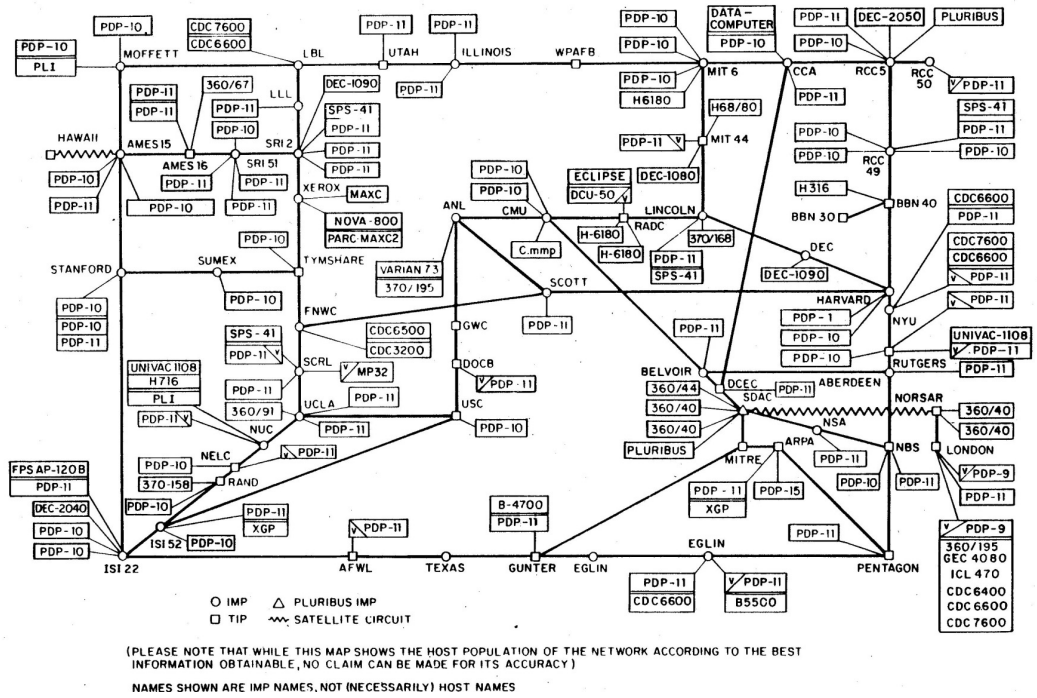
* Figure is courtesy of Cisco

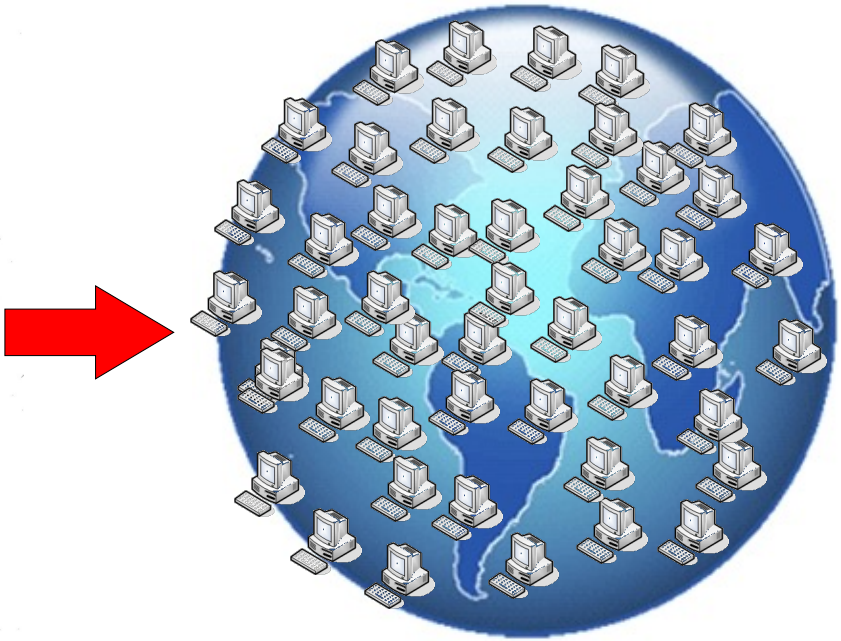
Everything's a Router

("route –n" or "netstat –r")

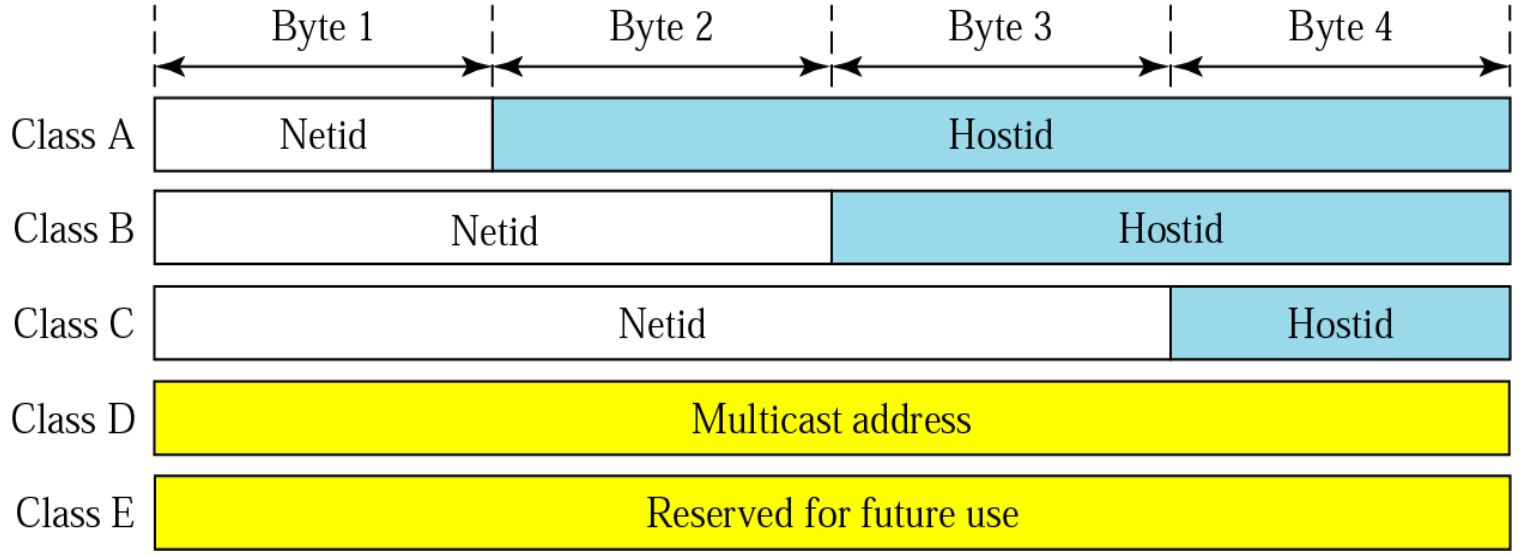
```
Active Routes:
Network Destination        Netmask          Gateway       Interface  Metric
          0.0.0.0          0.0.0.0    192.168.192.1   192.168.192.37     25
        127.0.0.0        255.0.0.0         On-link        127.0.0.1    306
        127.0.0.1  255.255.255.255         On-link        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
```

Few 100 to 4 Billion??





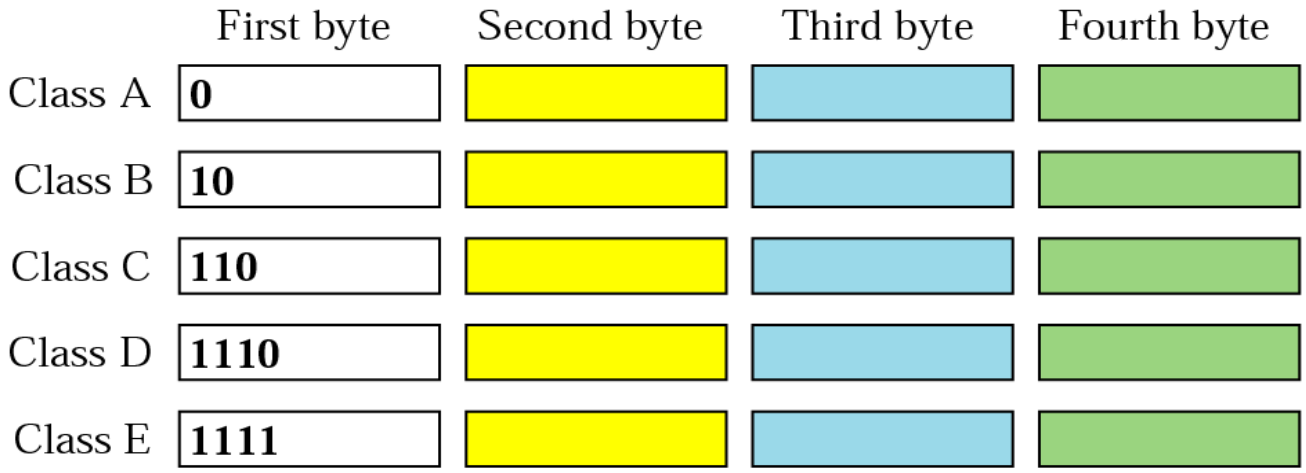
Network ID and Host ID



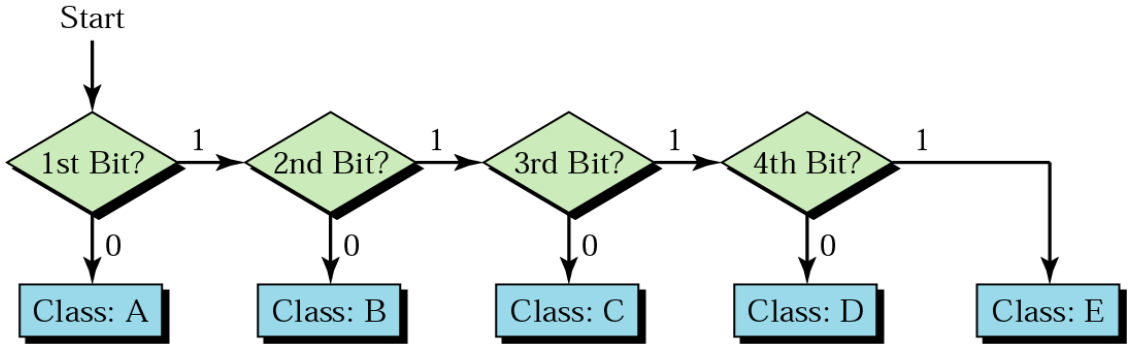
- Network ID: Used to find a particular network
- Host ID: Identifies indentify individual nodes

* Figure is courtesy of B. Forouzan

Classes in Binary Notation

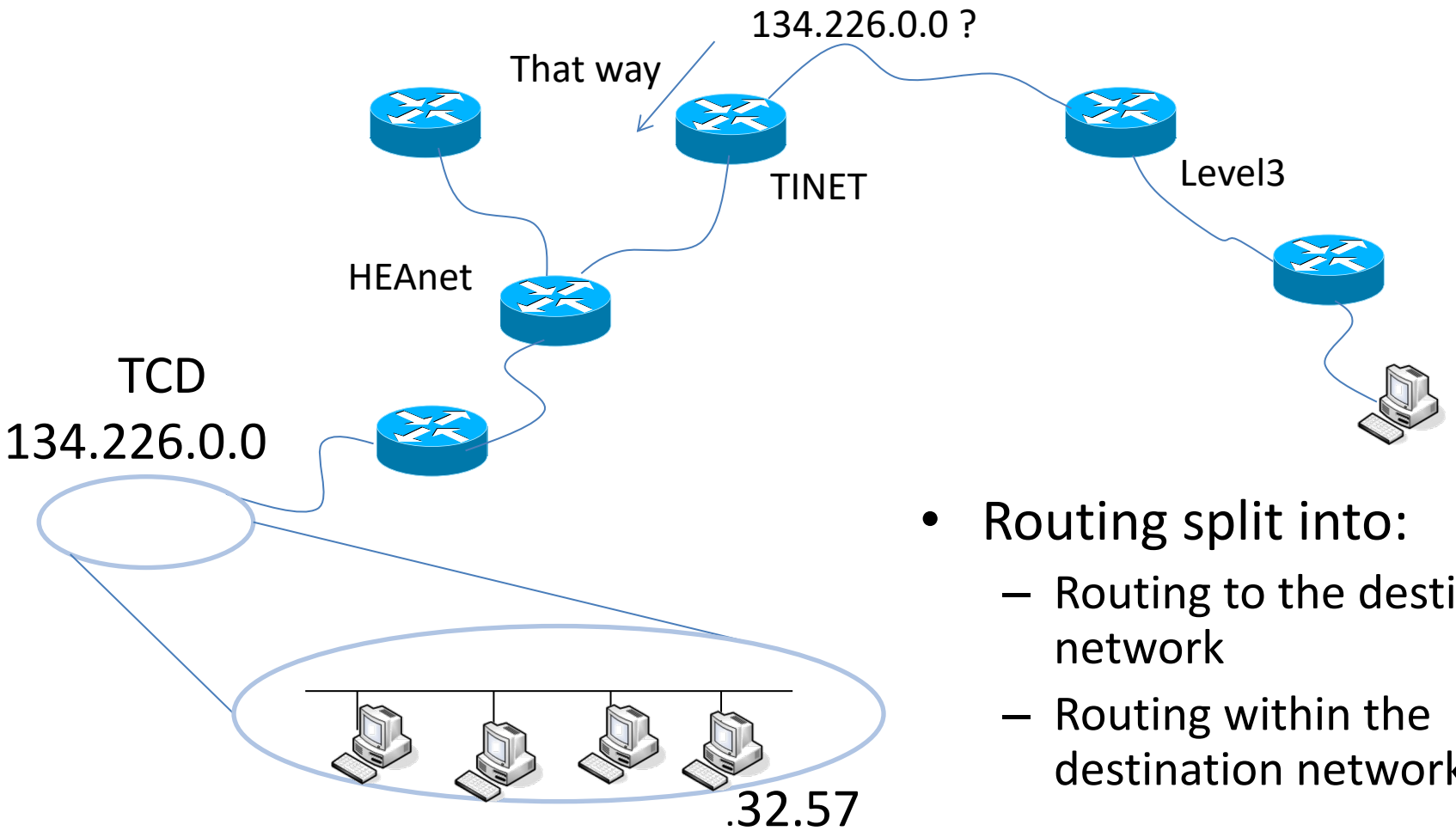


- Decision Process:



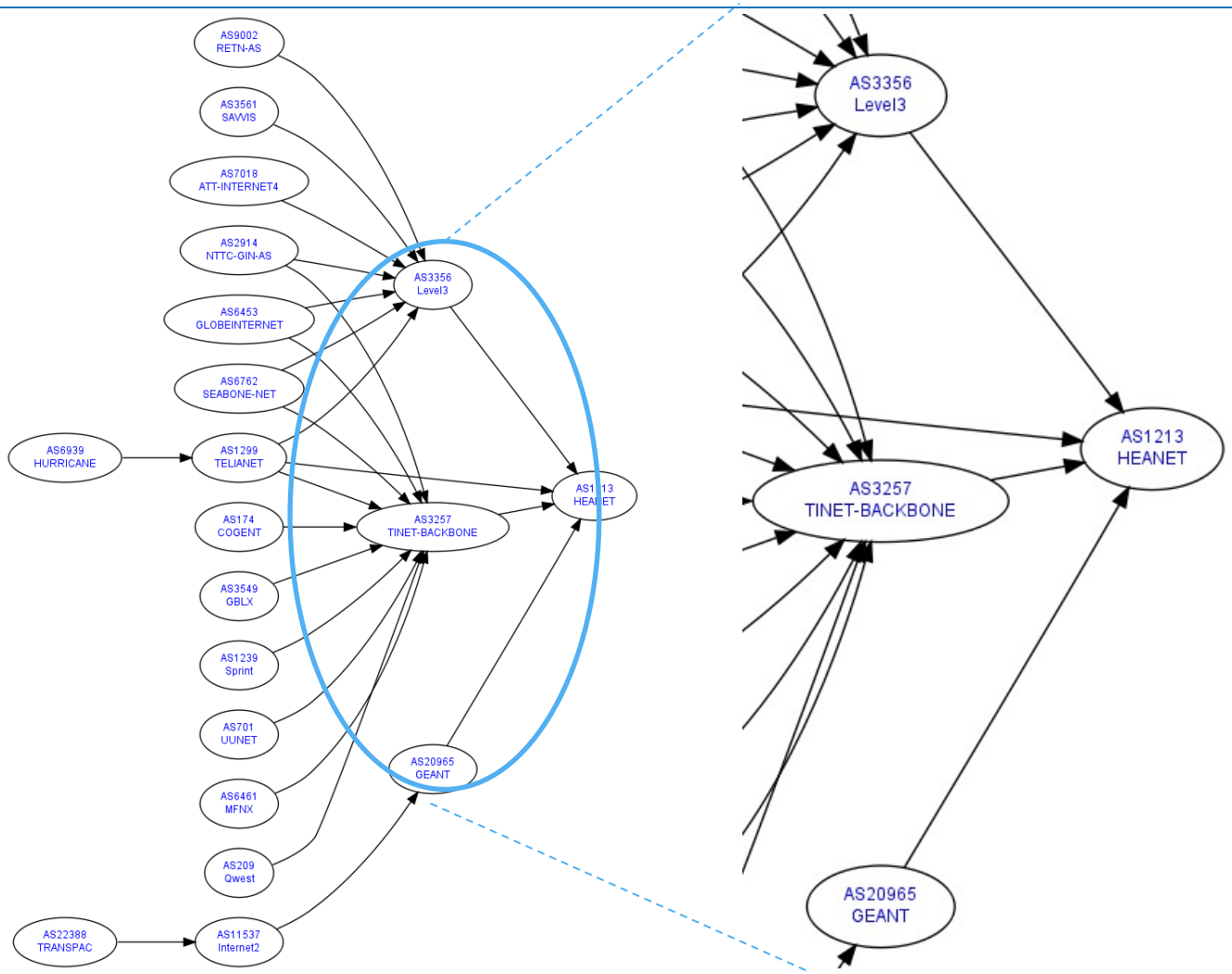
* Figure is courtesy of B. Forouzan

Network IDs and Host IDs

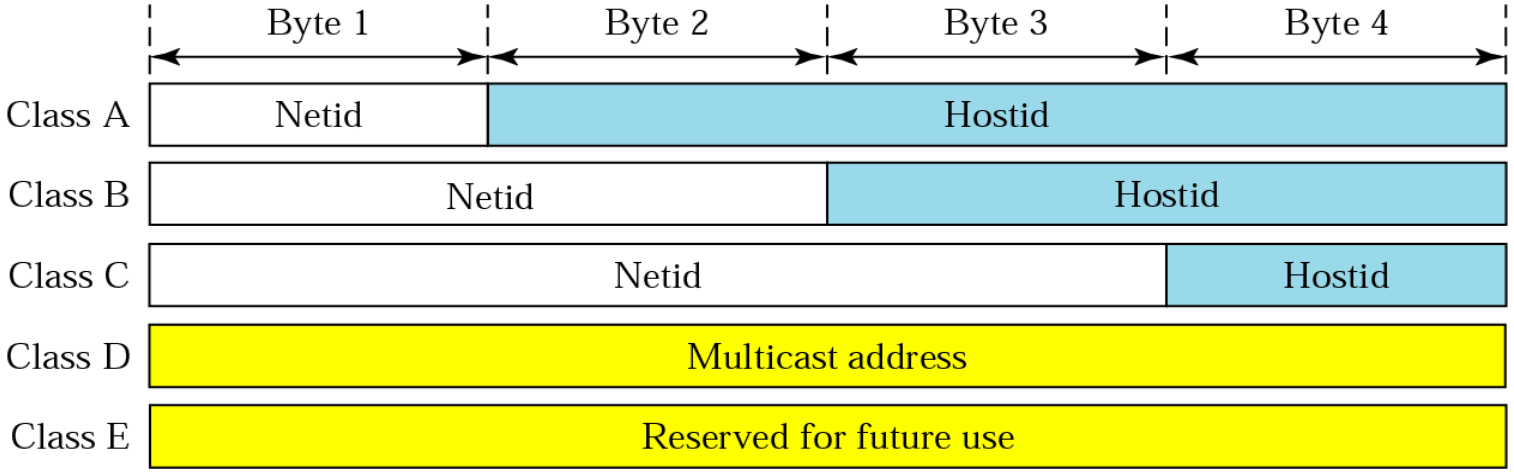


- Routing split into:
  - Routing to the destination network
  - Routing within the destination network

AS1213 - HEANET



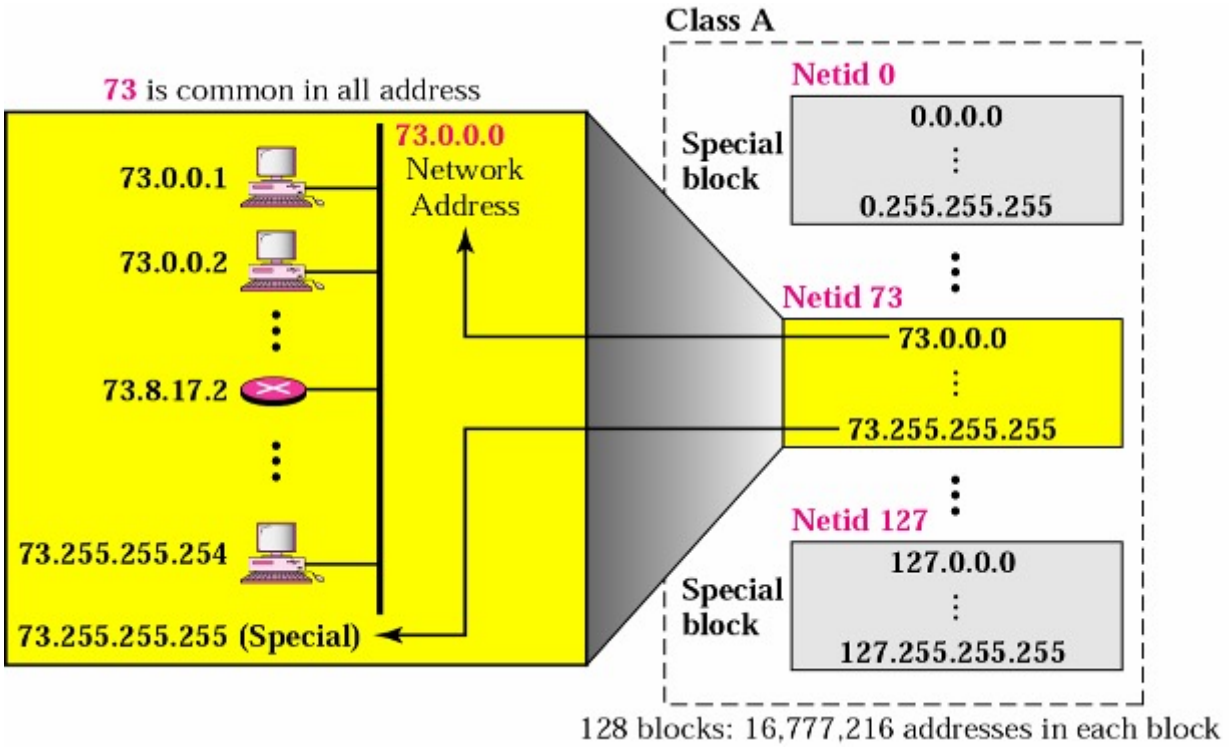
Classful Addresses



- 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

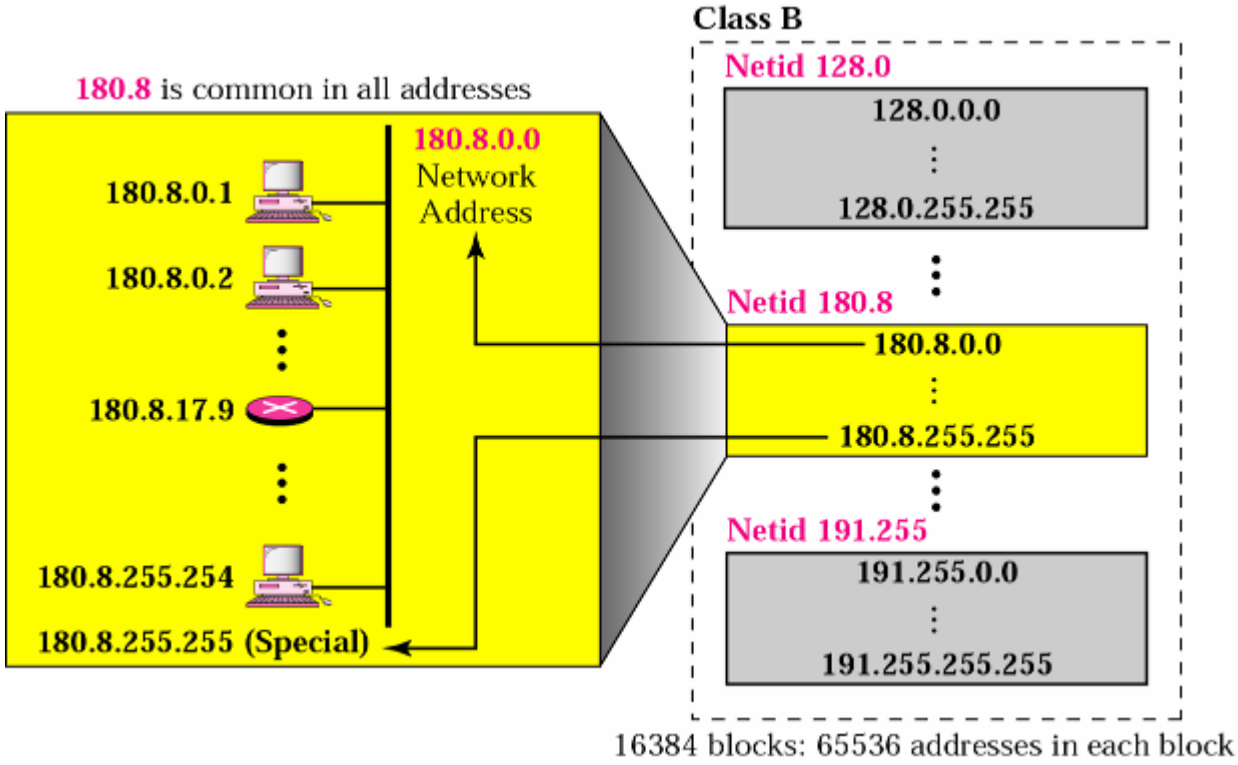
Class A



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

* Figure is courtesy of B. Forouzan

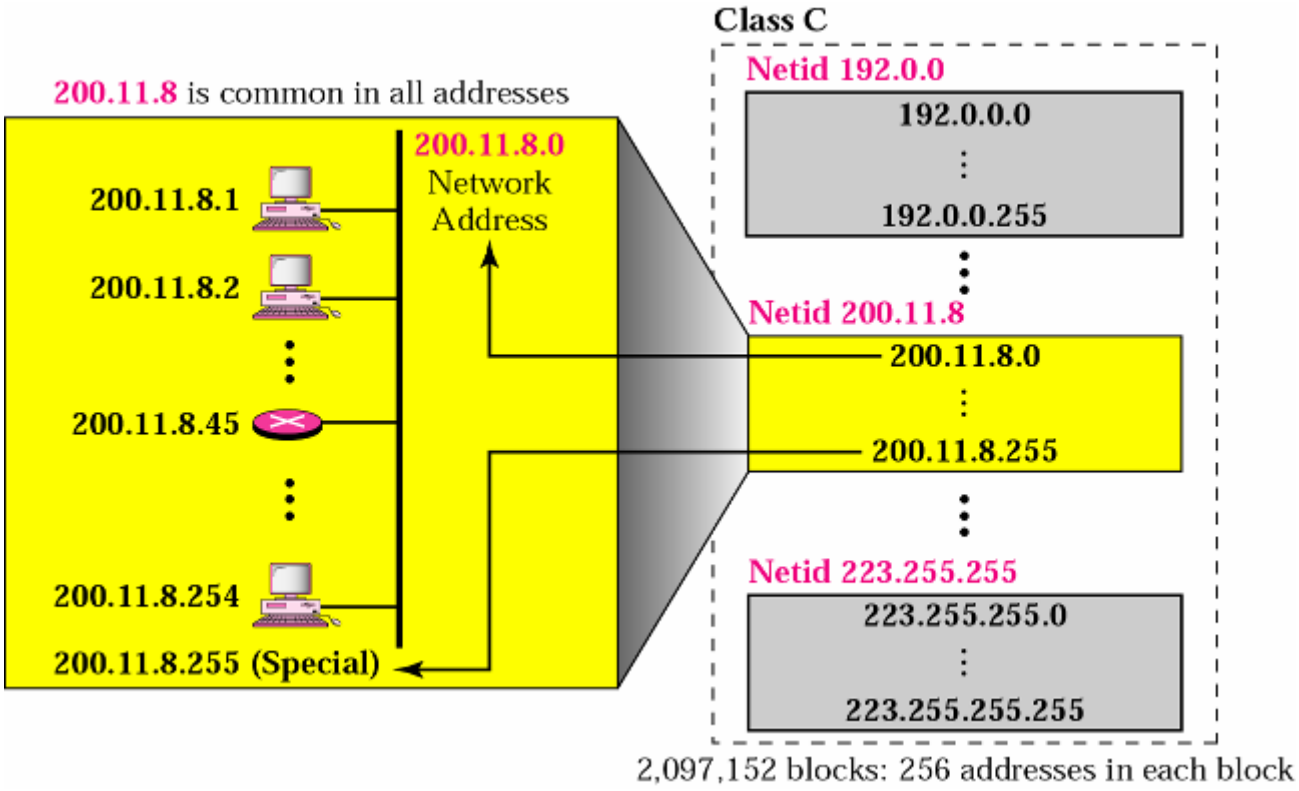
Class B



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

* Figure is courtesy of B. Forouzan

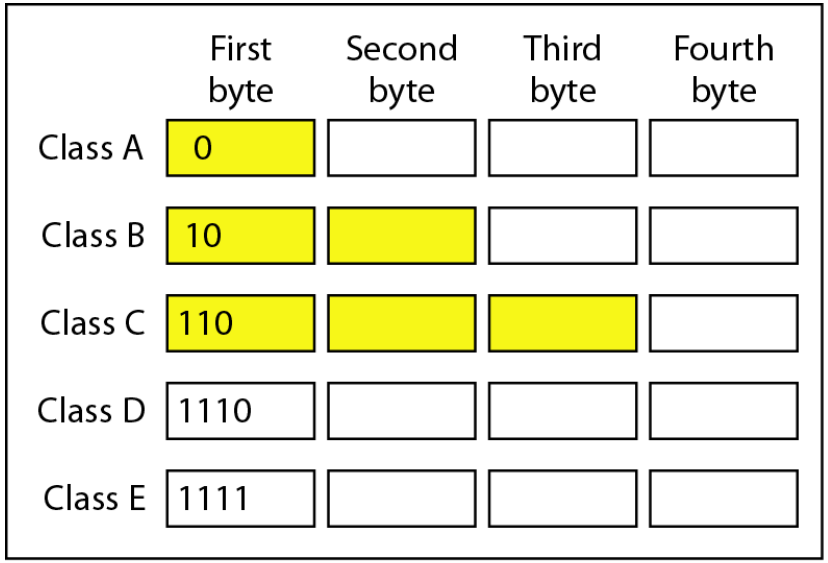
Class C



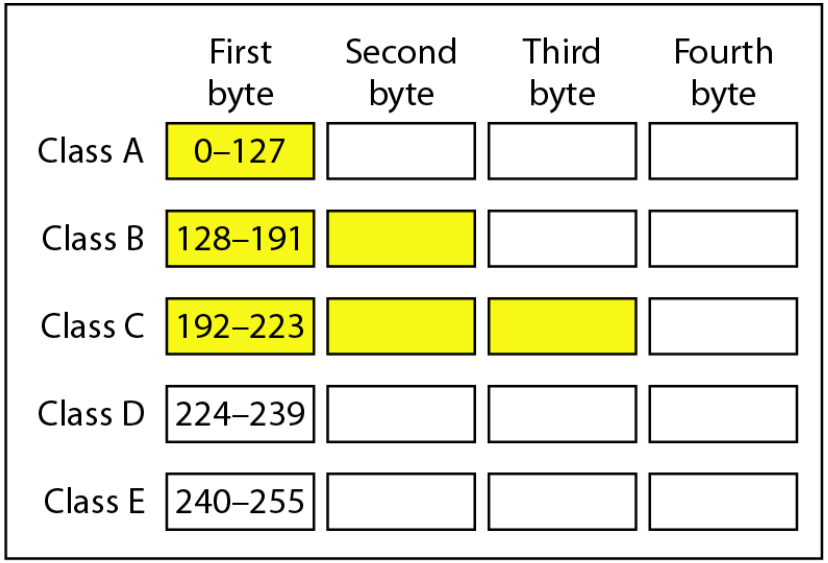
- Large number of small address ranges
- 2,097,152 networks with 254 hosts each

* Figure is courtesy of B. Forouzan

Classes & Private Addresses



a. Binary notation



b. Dotted-decimal notation

Private Address Ranges:

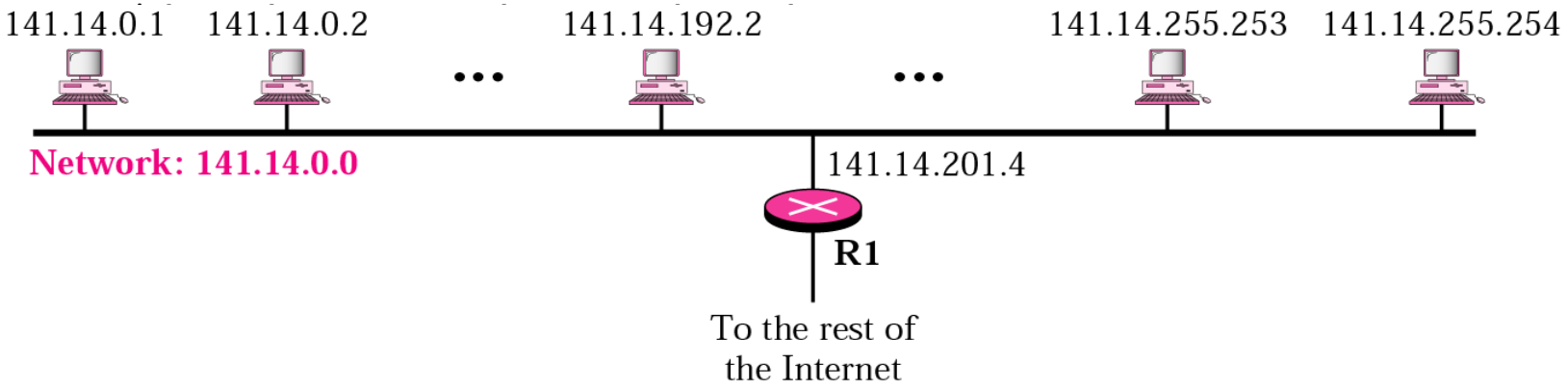
Range			*Total*
10.0.0.0	to	10.255.255.255	2^{24}
172.16.0.0	to	172.31.255.255	2^{20}
192.168.0.0	to	192.168.255.255	2^{16}

* Figure is courtesy of B. Forouzanv

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



* Figure is courtesy of B. Forouzan

College Network

(CLASS B network = 134.226.x.x = 64k of addresses)

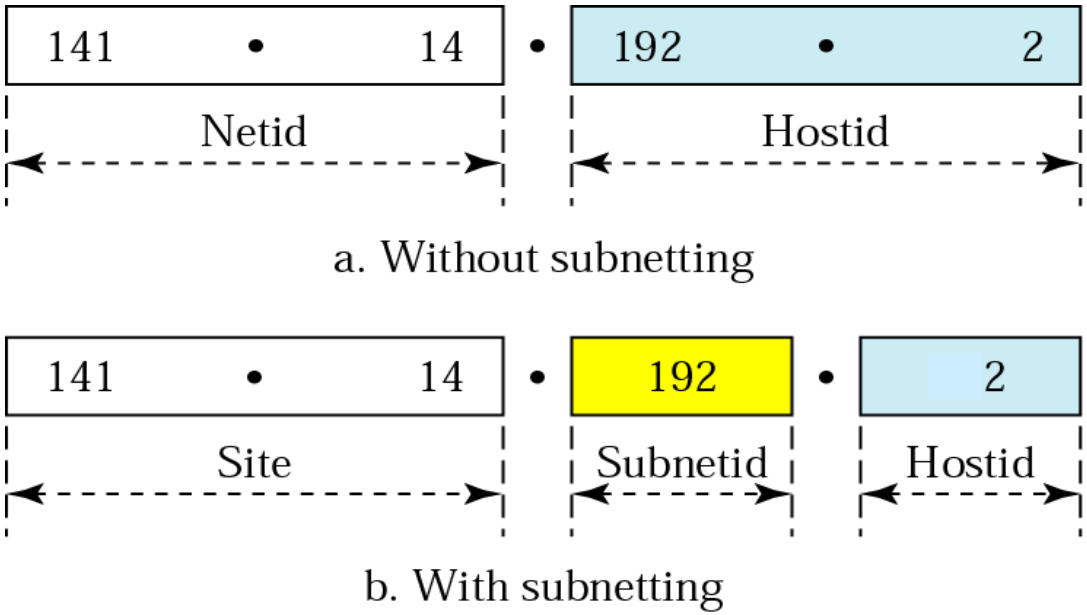
- Late 90s: Flat Network with 1000s of Nodes

Broadcast Storms

(134.226.x.x = 64k of addresses)

- ARP Request from 1000s of Nodes

Subnetting

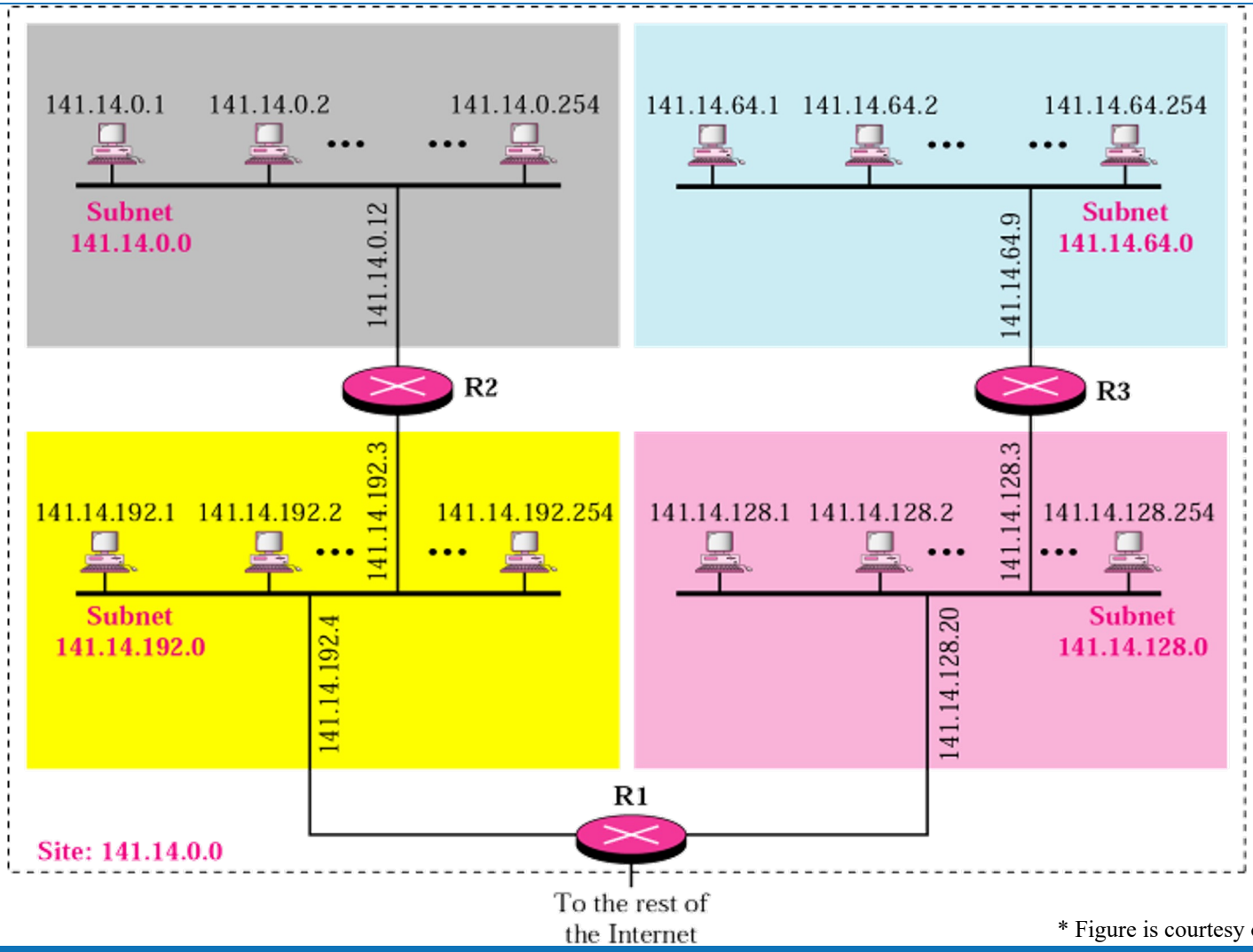


- Add another level to address hierarchy: *subnet*
- Splitting a class B network into a number of class C subnets

* Figure is courtesy of B. Forouzan

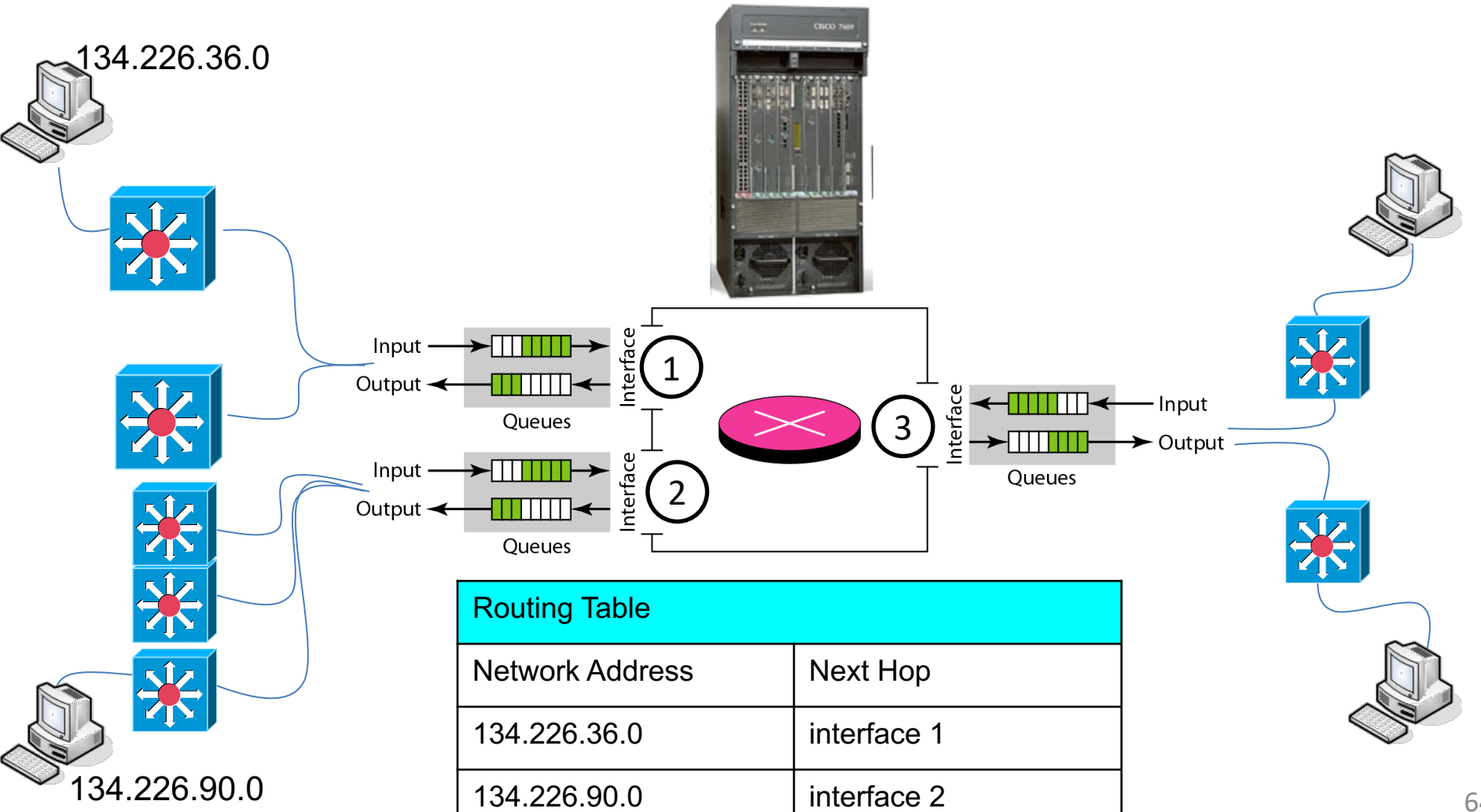
3-Level Hierarchy through Subnetting

(Internet -> Network -> Subnet)



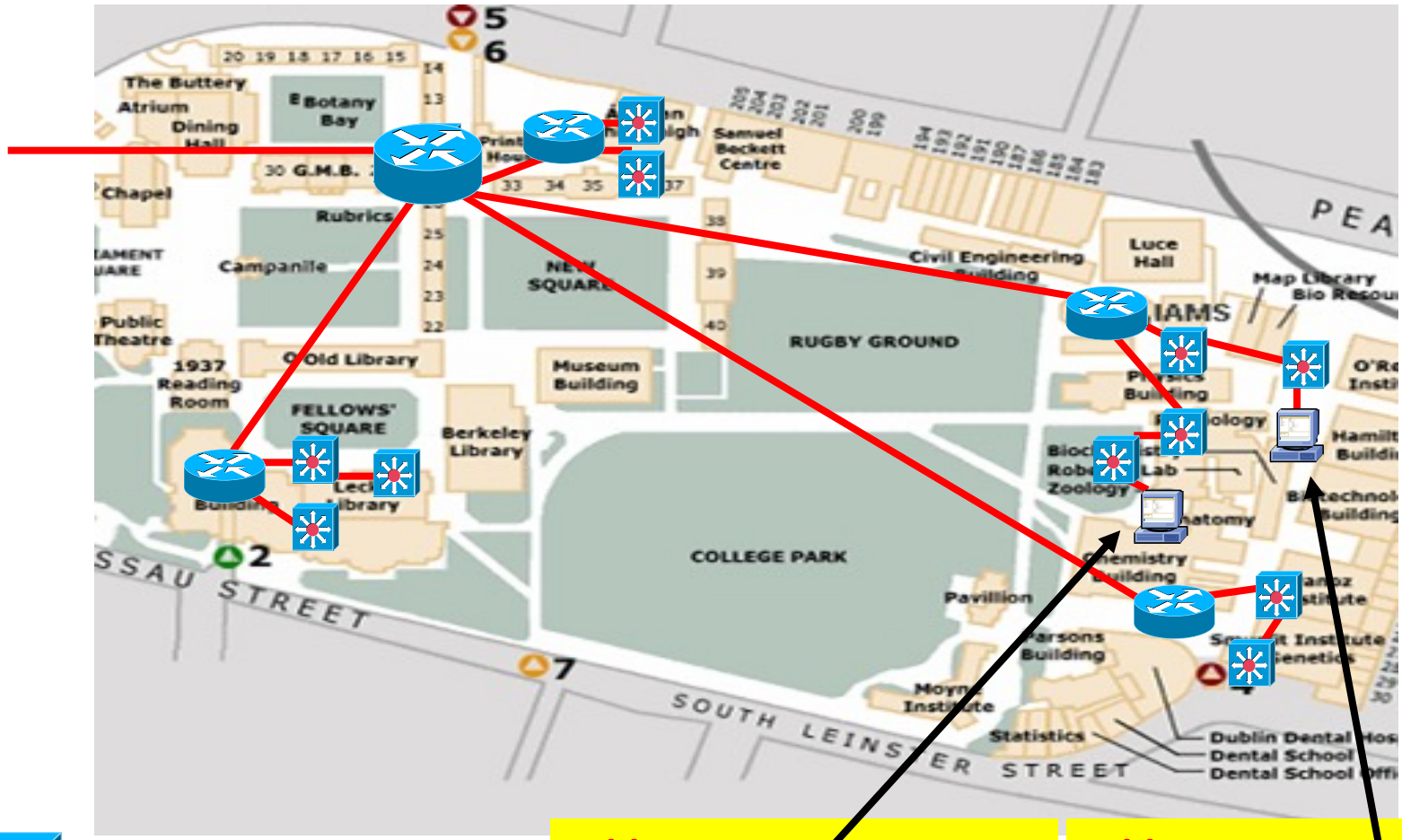
* Figure is courtesy of B. Forouzan

Task of Routers



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

Trinity Network with Subnets



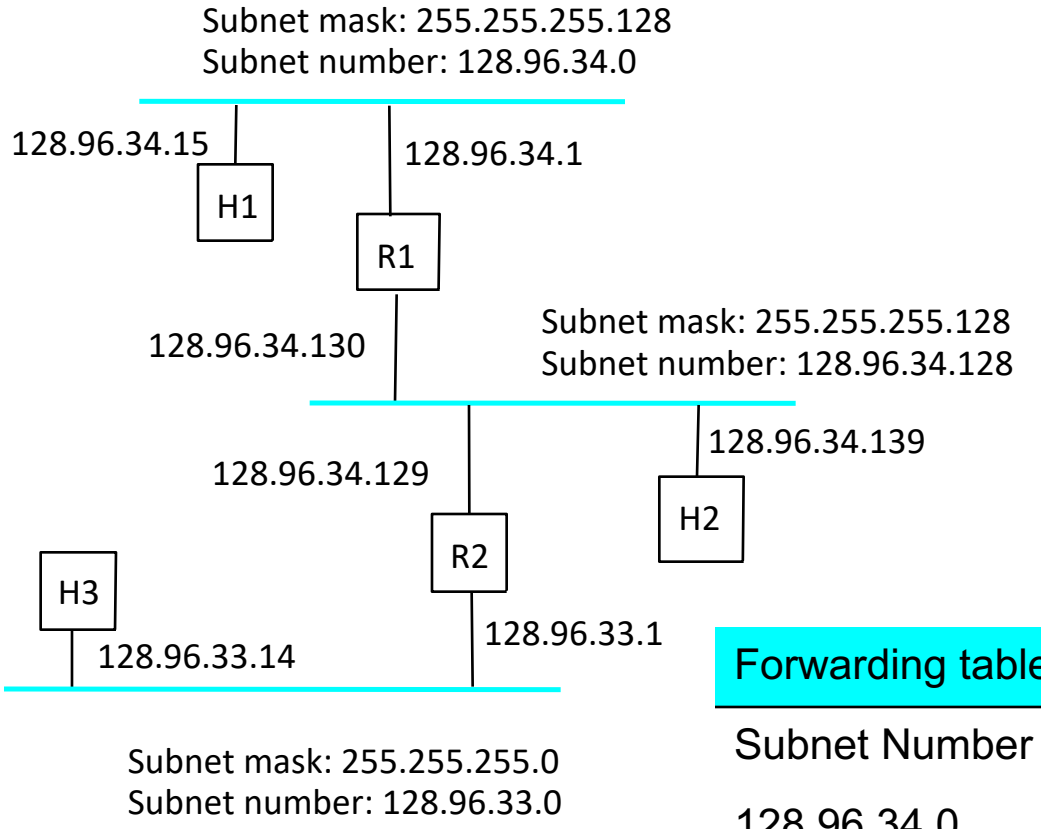
Switch

Router

Address: 134.226.38.55
Subnet: 134.226.38.0

Address: 134.226.32.55
Subnet: 134.226.32.0

Subnet Example

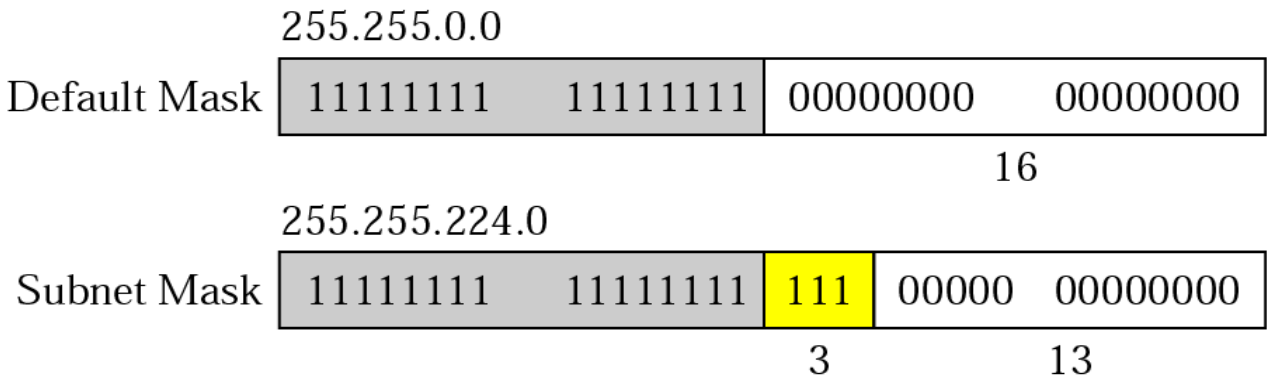


Forwarding table at router R1

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

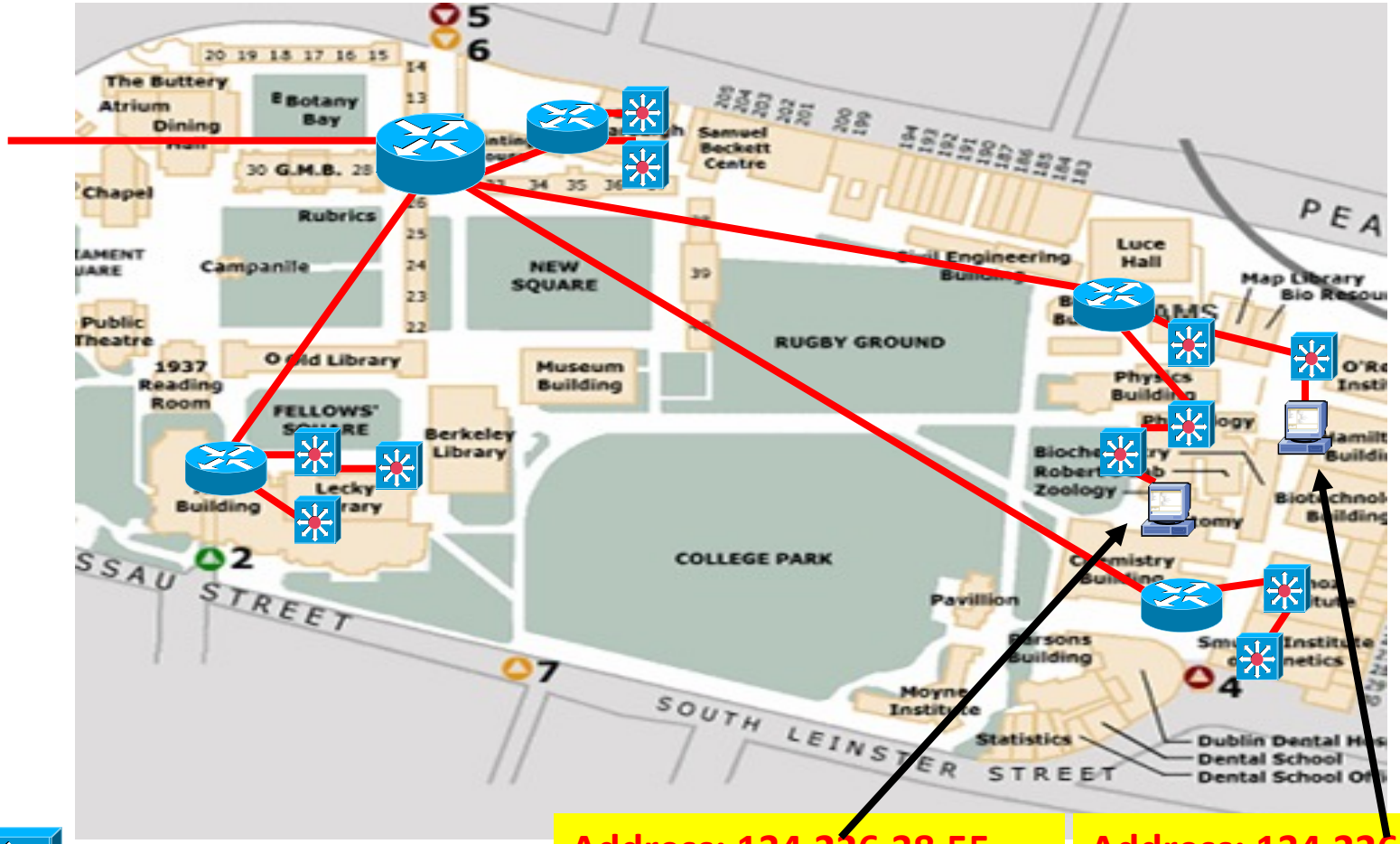
Default Masks

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



* Figure is courtesy of B. Forouzan

Trinity Network with Subnets



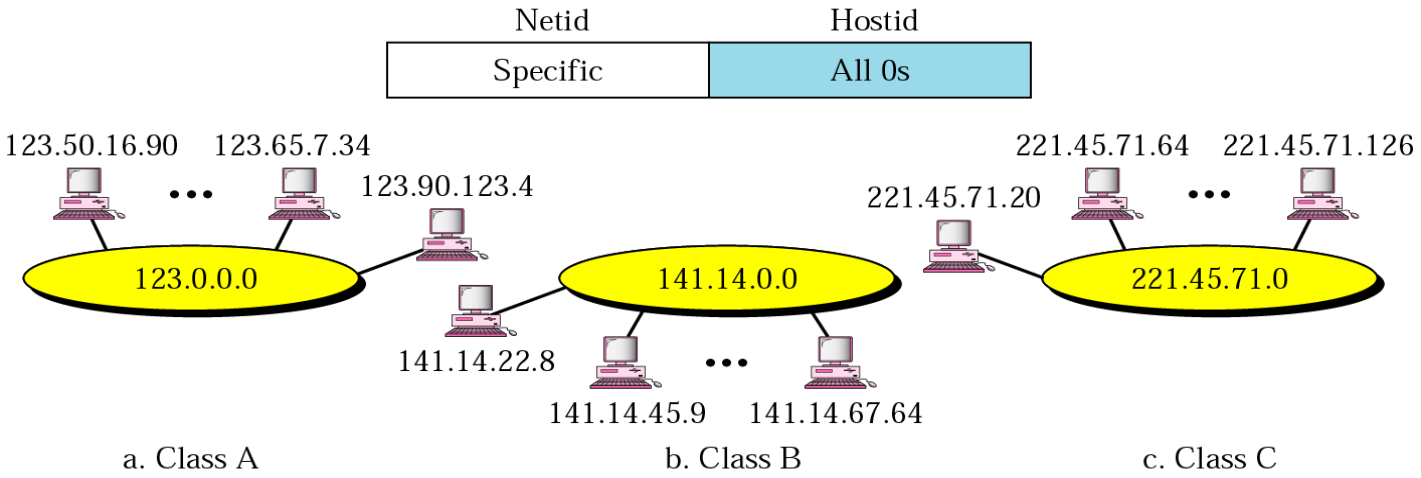
Switch

Router

Address: 134.226.38.55
Subnet: 134.226.38.0

Address: 134.226.32.55
Subnet: 134.226.32.0

Classful Addresses & NetworkID



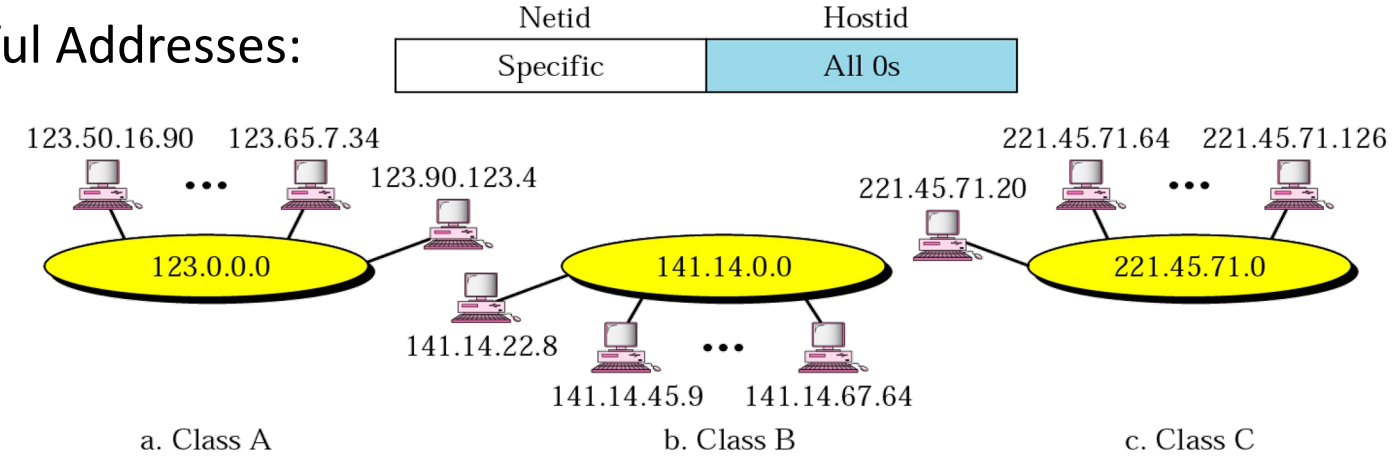
- Classful Addresses:

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:



- 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)

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

* Figure is courtesy of B. Forouzan

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The University of Dublin