Lecture 5

Network Layer – Data Transfer

ELEC 3506/9506
Communication Networks

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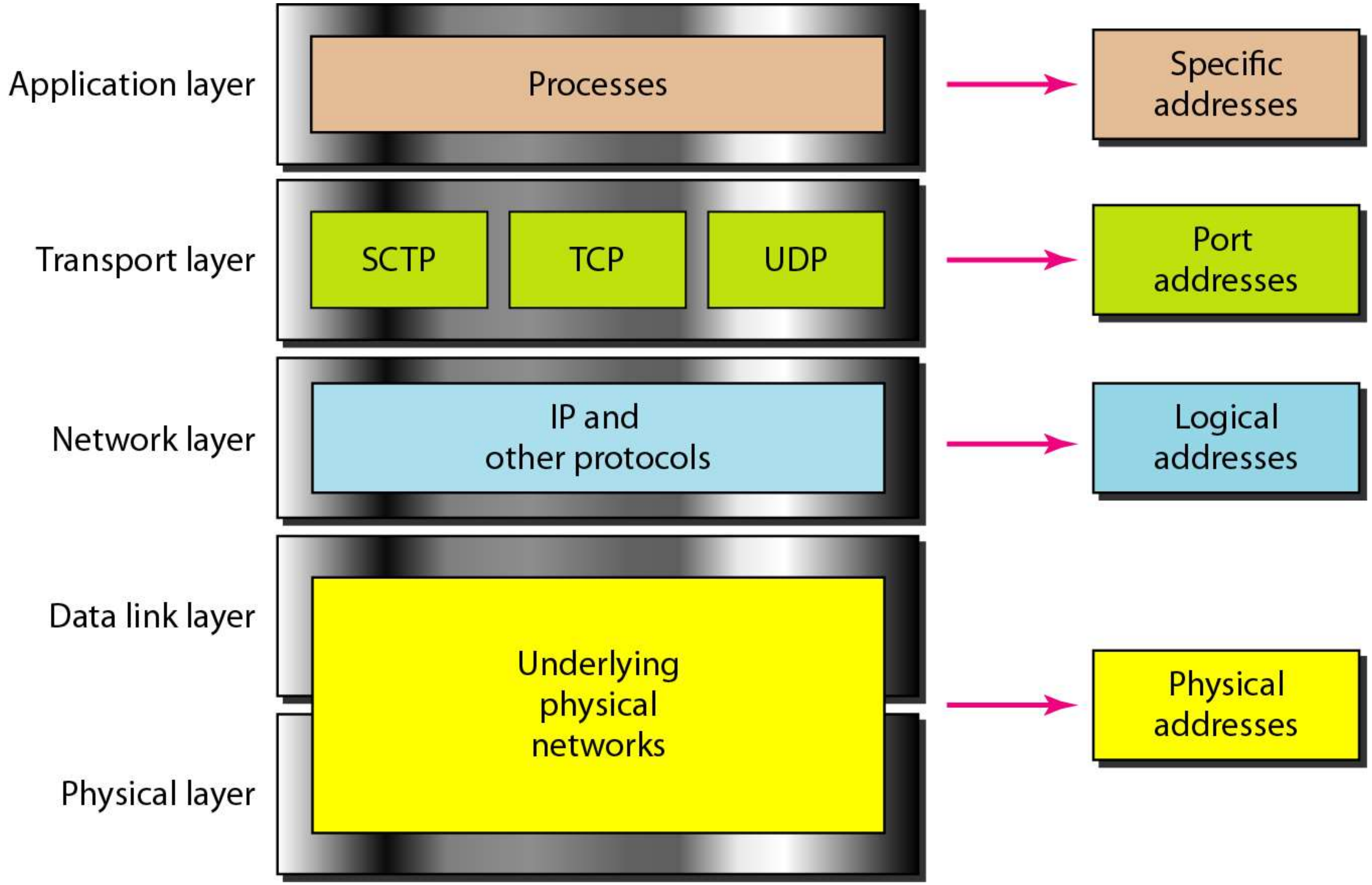
TCP/IP Protocol & Addressing



Topics for the Day

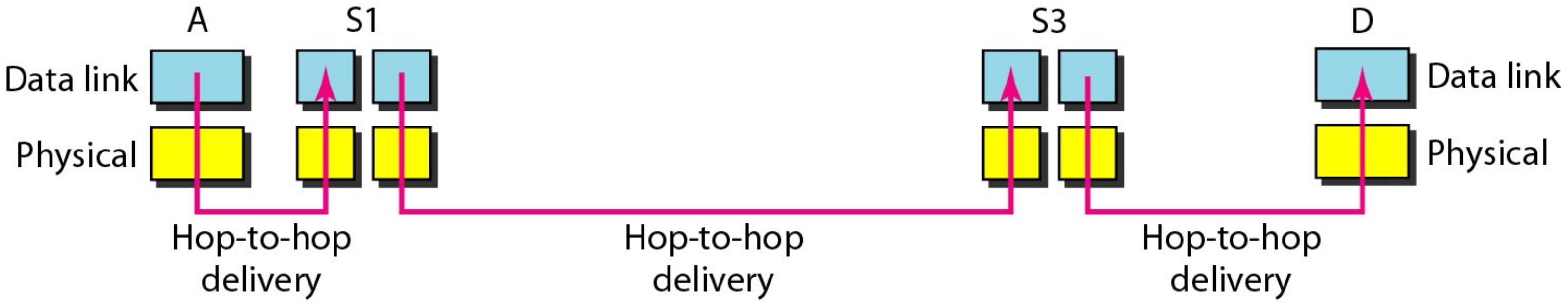
- Internetworking
- IP service model
- IPv4 datagram format
- IPv4 addressing – Classful Addressing
- Subnetting and Classless Addressing
- Private Addressing
- NAT and Address Translation
- Routing a datagram from Source to Destination
- ICMP
- IPv6

Internetworking

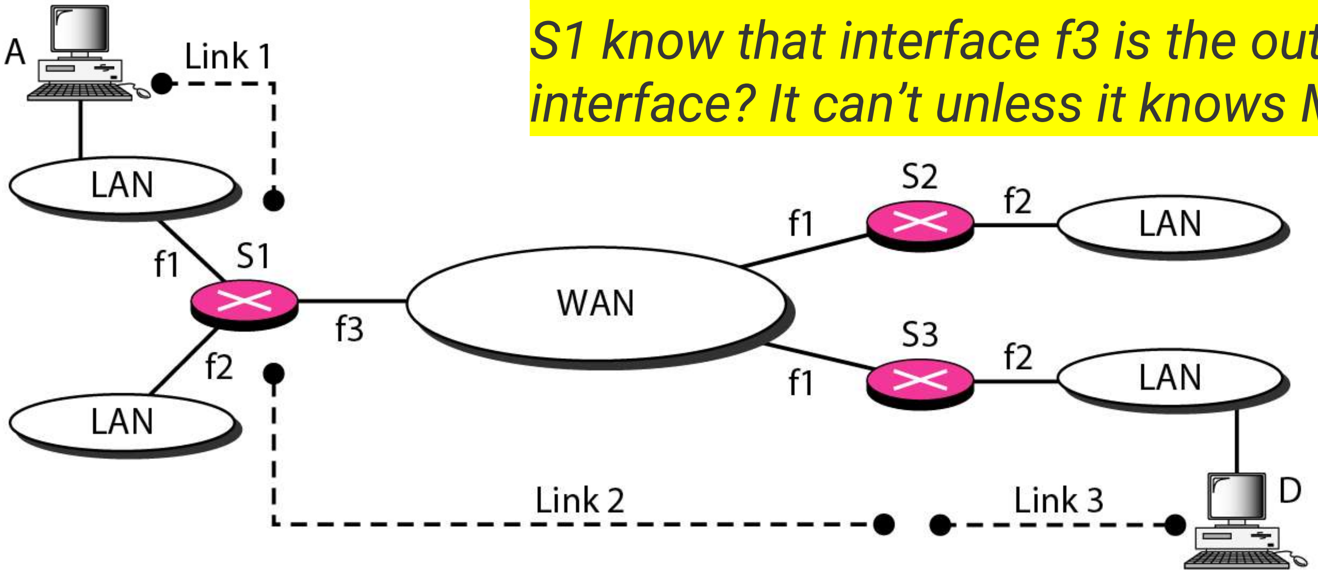
- The term "internetwork" refers to an arbitrary collection of networks interconnected to provide some sort of host-to-host packet delivery service
- Network Layer designed to solve the problem of
  - host-to-host delivery
  - Routing packets over networks
- Internetwork example
  - An internetwork is often referred to as a "network of networks" because it is made up of lots of smaller networks

Link Layer vs. Network Layer Delivery

- Hop-to-hop delivery

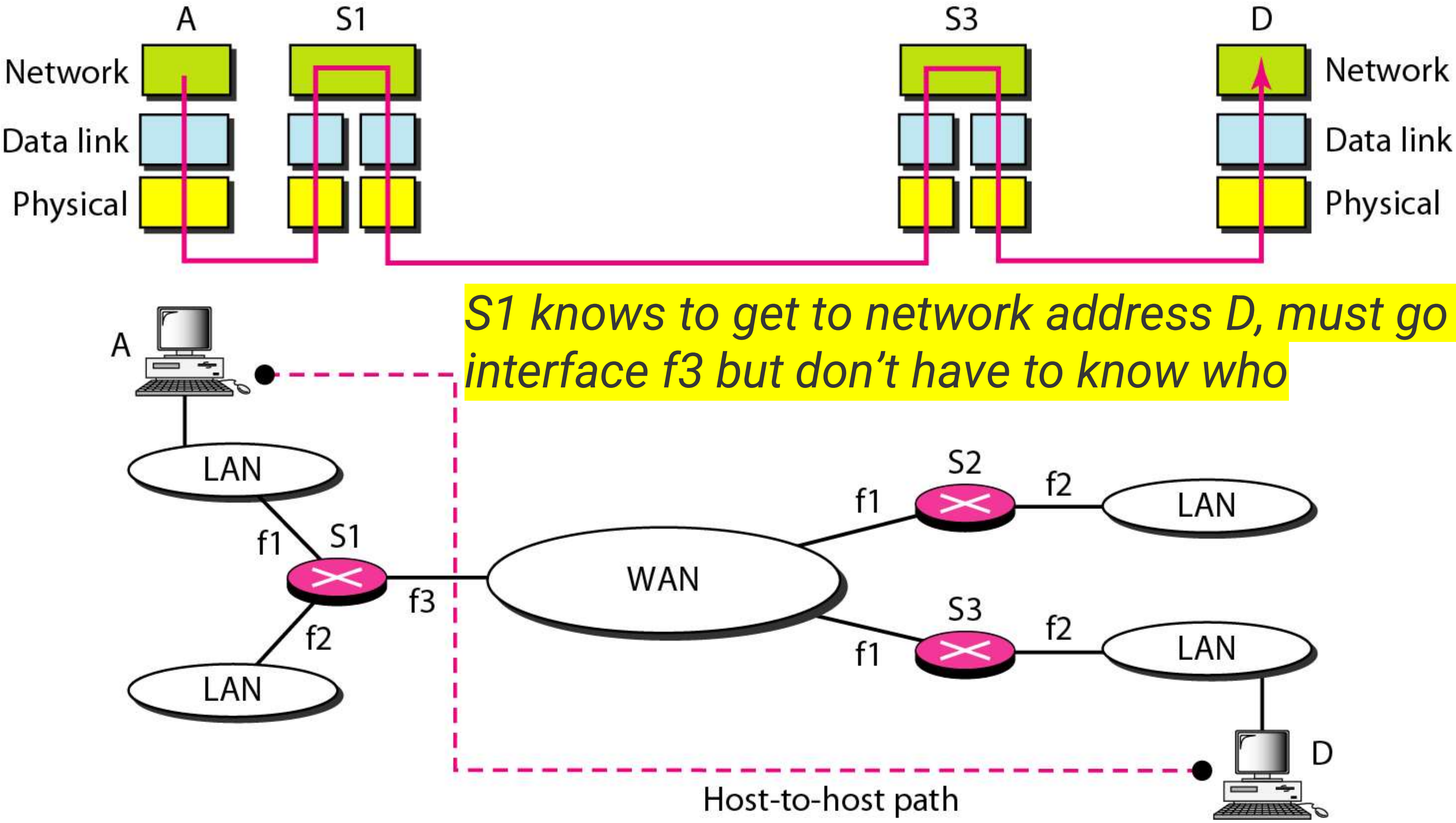


When the data arrives at interface f1 of S1, how does S1 know that interface f3 is the outgoing interface? It can't unless it knows MAC address of D.



Link Layer vs. Network Layer Delivery

- End-to-end delivery



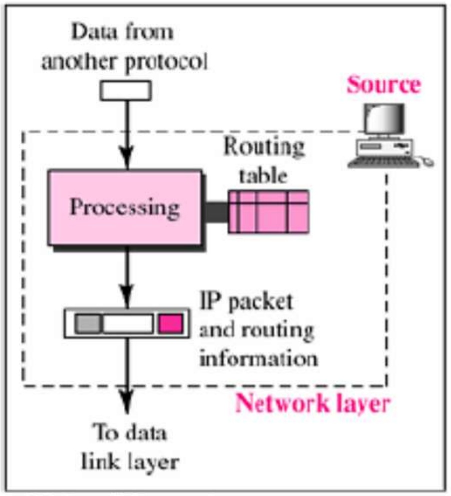
S1 knows to get to network address D, must go via interface f3 but don't have to know who

The network layer at source, destination and routers are responsible for host-to-host delivery and for routing the packets through the routers or switches.

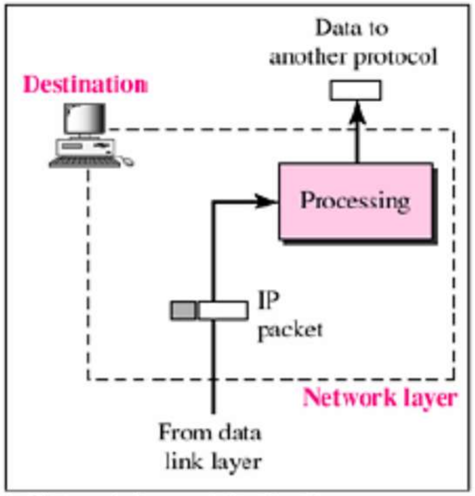
Function of Network Layer

At the source:

- Create a packet for the transport layer packet
- Embed logical addresses of the source and destinations
- check table for routing/outgoing info (interface or next MAC address)



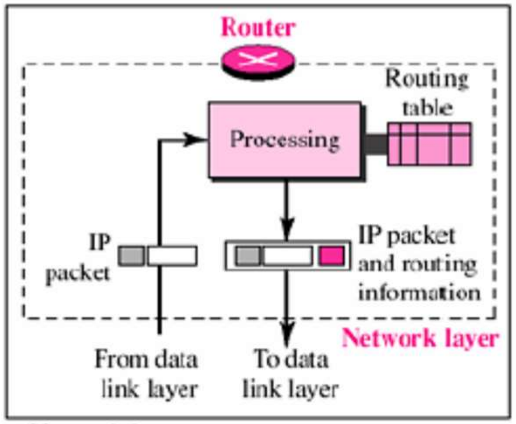
a. Network layer at source



b. Network layer at destination

At the router:

- Check routing table and finds the interface for sending
- Append this info to the packet



c. Network layer at a router

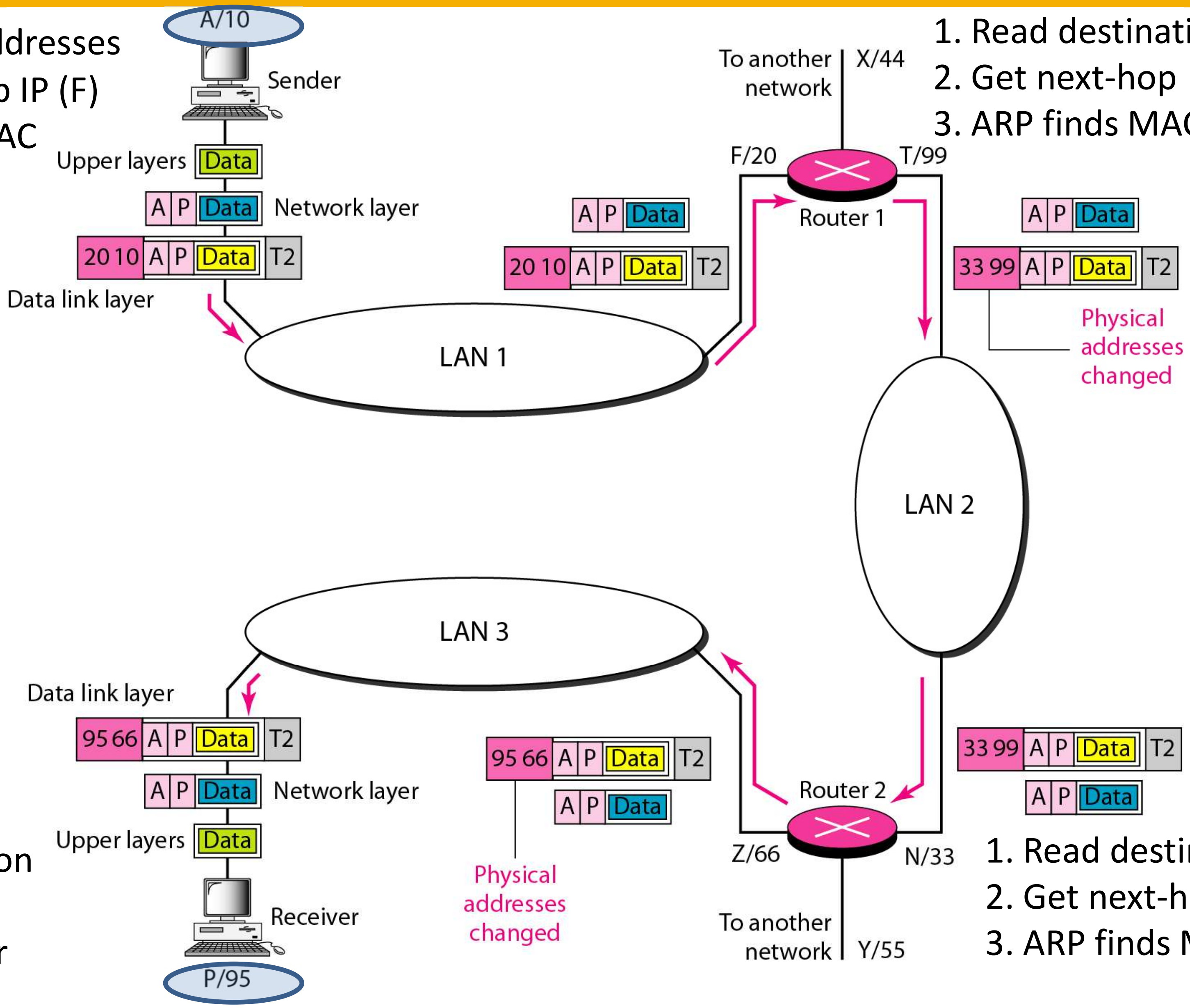
At the destination:

- Destination address verification
- Wait until all packets fragment is arrived if needed
- Passed to the transport layer

Logical/IP Address and Physical/MAC address

1. Embed IP addresses
2. Get next-hop IP (F)
3. ARP finds MAC address (20)

1. Read destination IP (P)
2. Get next-hop IP (N via T)
3. ARP finds MAC address (33)



1. Validate destination (P)
2. Decapsulation
3. Send to Transport layer

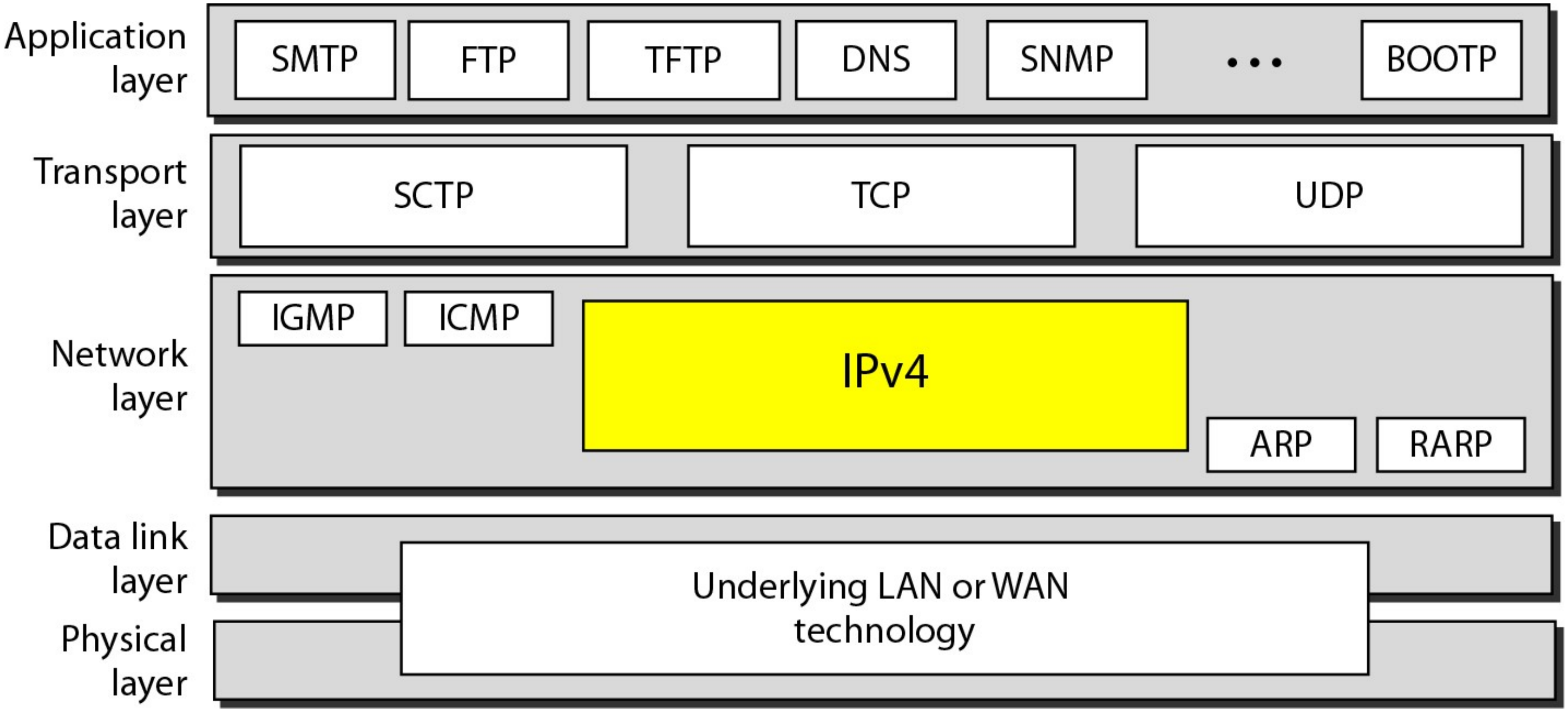
1. Read destination IP (P)
2. Get next-hop IP (P via Z)
3. ARP finds MAC address (95)

IP Service Model

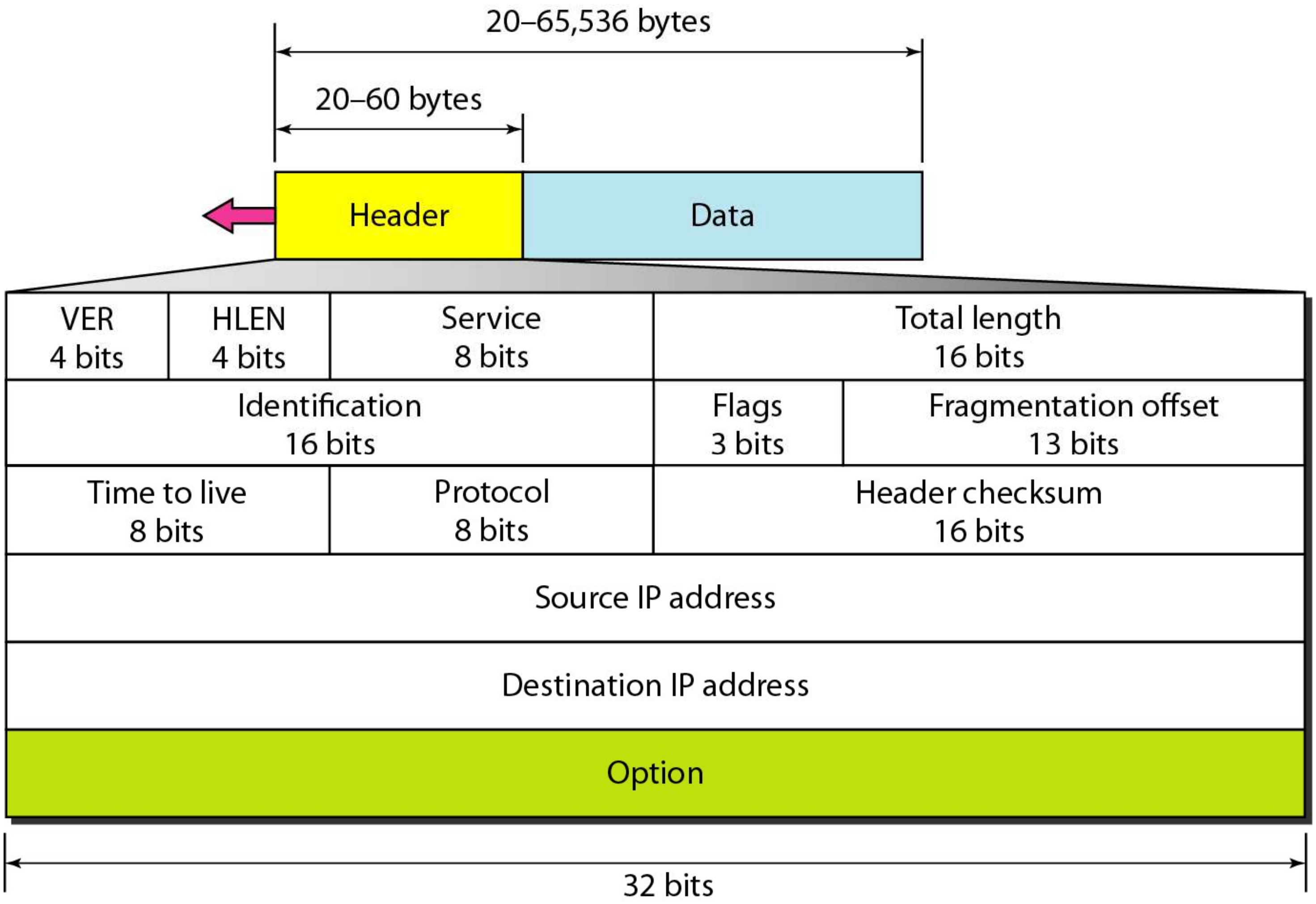
- A unique addressing scheme providing a way to identify all hosts in the internetwork
- A datagram approach for data delivery
  - Connectionless service
  - Unreliable - If something goes wrong and the packet gets lost, corrupted, miss-delivered, or in any way fails to reach its intended destination, the network layer does nothing
  - The network layer does best effort delivery, no guarantee
    - No Flow Control
    - No Error Control
  - It does not make any attempt to recover from the failure

Internet Protocol version 4 (IPv4)

- The Internet Protocol version 4 (IPv4) is the delivery mechanism used by the TCP/IP protocols.



IPv4 Datagram Format



20–65,536 bytes

20–60 bytes

Header

Data

VER 4 bits

HLEN 4 bits

Service 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

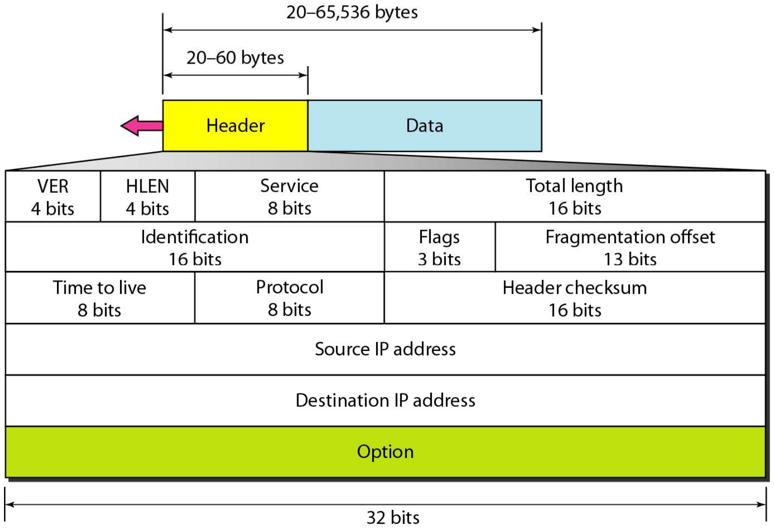
Destination IP address

Option

32 bits

IPv4 Datagram Format

- IP header has a 20-byte fixed part, followed by an optional part
- IP header fields
  - Version: IP version
  - Header Length (HLEN): find when the header stop, and data starts (per 4 bytes)
  - Type of service: allows packets to be treated differently based on application needs
  - Total Length: total datagram length (including header) in bytes
  - Identification: used in fragmentation. A datagram may be divided into several segments during transmission. When this happens, each fragment is identified as belonging to the same datagram by having the same number in this field
  - Flags
    - Identify whether the datagram can be fragmented
    - Most left bits is reserved
    - 2nd bit: data can (1) or cant be (0) fragmented
    - 3rd bit: 1 if not the last fragment and more to come
    - 3rd bit: 0 if last and only fragment



20–65,536 bytes

20–60 bytes

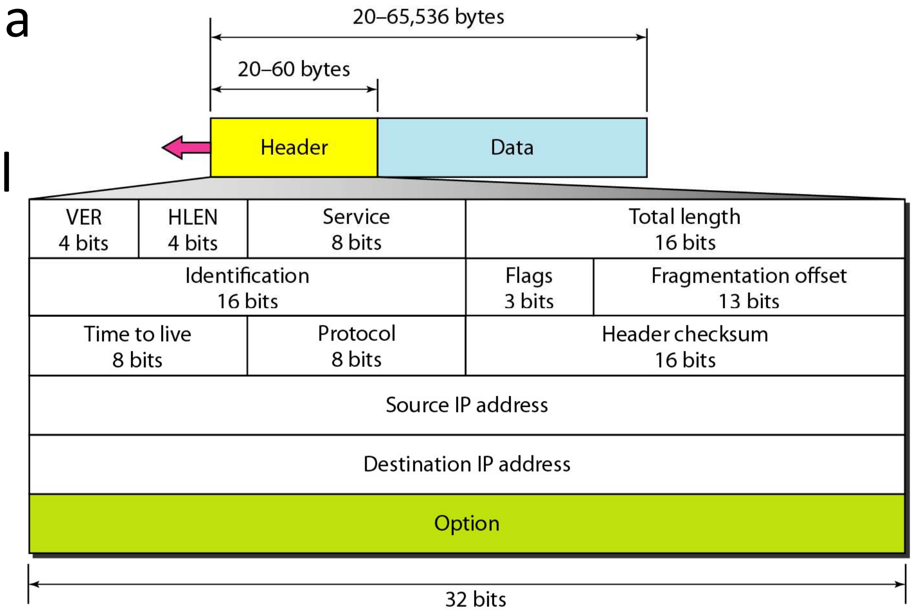
Header	Data

VER 4 bits	HLEN 4 bits	Service 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			

32 bits

IPv4 Datagram Format

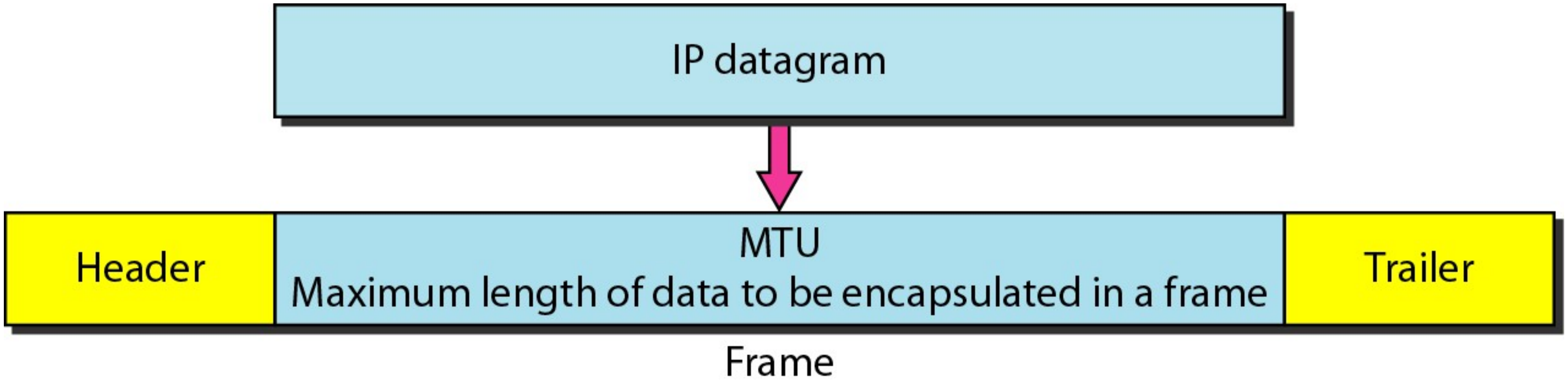
- Fragmentation Offset: used in fragmentation. Identify the position of the fragment in the datagram
- Time-to-live: defines the number of hops a datagram can travel before it is discarded
- Protocol: defines the upper-layer protocol encapsulated (TCP, UDP)
- Header checksum: header error check
- Source/destination address: 32-bit IP address of source and destination
- Options: carry optional field for routing, timing, management, etc.



VER 4 bits	HLEN 4 bits	Service 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				

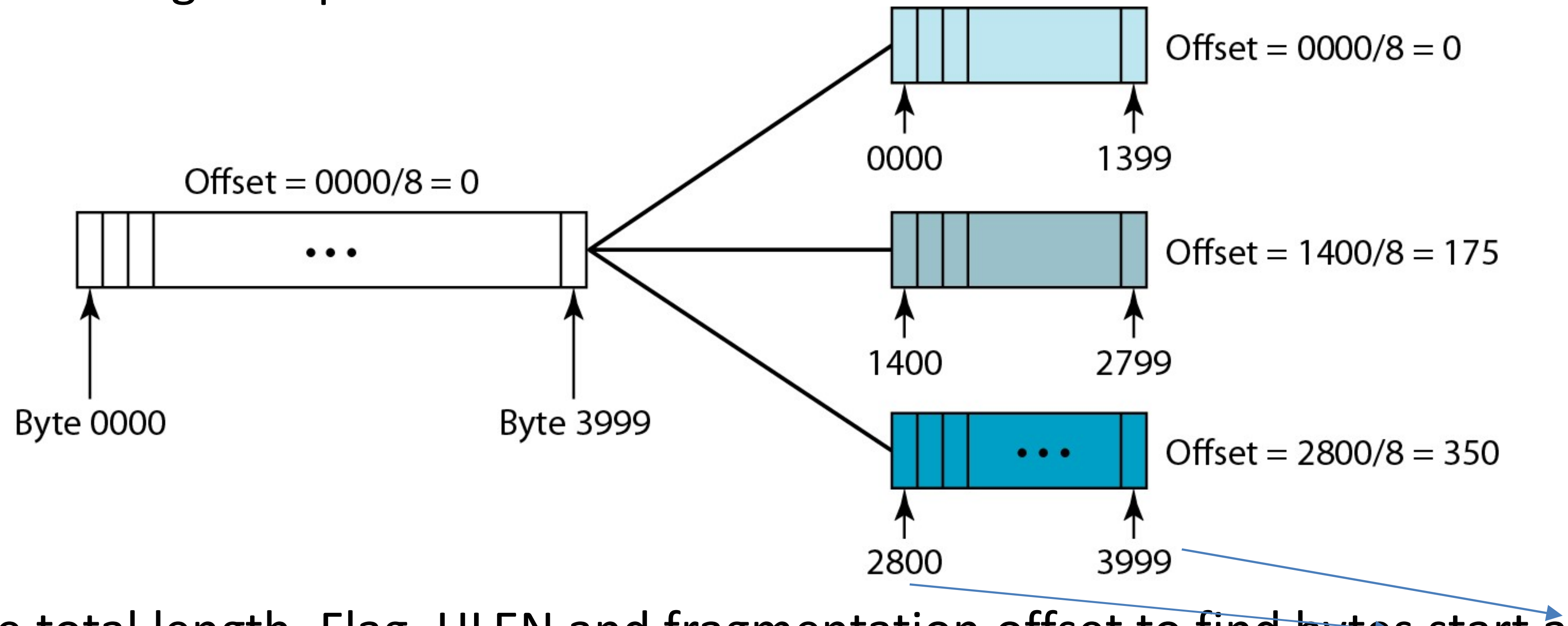
Maximum Transfer Unit (MTU)

- The maximum transfer unit (MTU) defines the largest Layer 3 packet that can be forwarded out an interface
- The MTU allowed is based on the data link layer protocol
  - The maximum size of the data portion of the data link frame is the MTU
  - The default MTU is 1500 bytes for Ethernet



Fragmentation

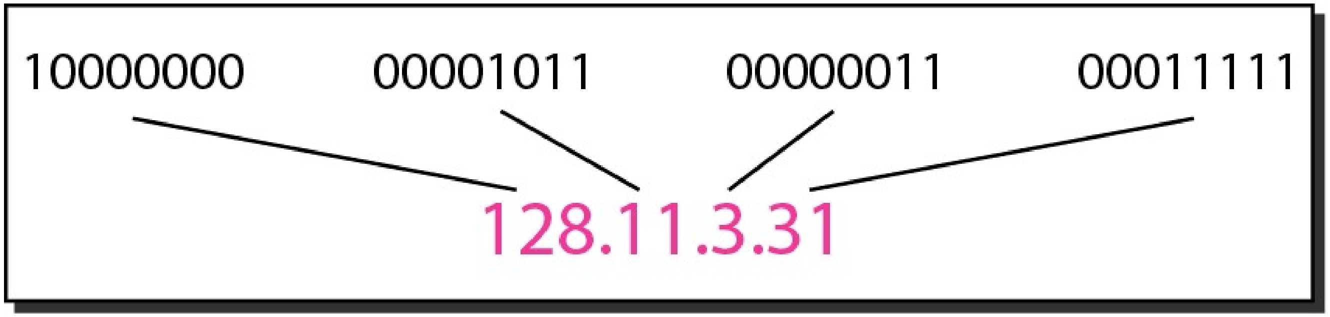
- Fragmentation is required if an interface's MTU is smaller than a packet that must be forwarded
  - Fragmentation breaks the packet into smaller packets
  - The fragmentation offset shows the relative position of the fragments with respect to the whole datagram (in units of 8 bytes)
  - 13 bits long to capture offset values



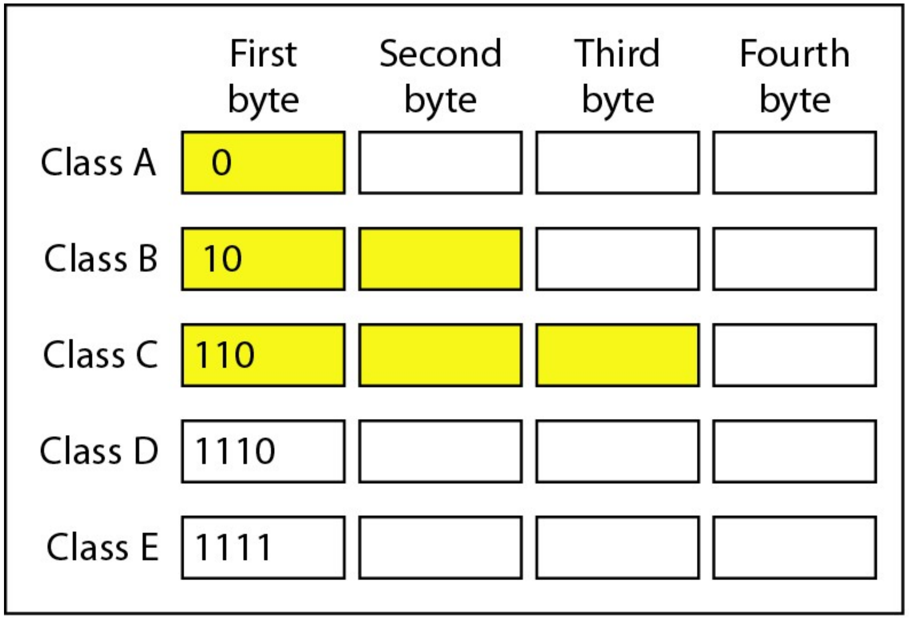
  - Use total length, Flag, HLEN and fragmentation offset to find bytes start and end

IP Addressing

- Each node using the TCP/IP protocol suite has a unique and universal 32-bit logical IP address
- The total address space of IPv4 is 2^{32} or 4295 Million (Usable 3706 M) .
- IP address has two parts: the network number and the host number
- Each network listed on the IP internetwork is seen as a single network that must be reached before an individual host within that network can be reached
- The IP address format is known as *dotted-decimal* notation

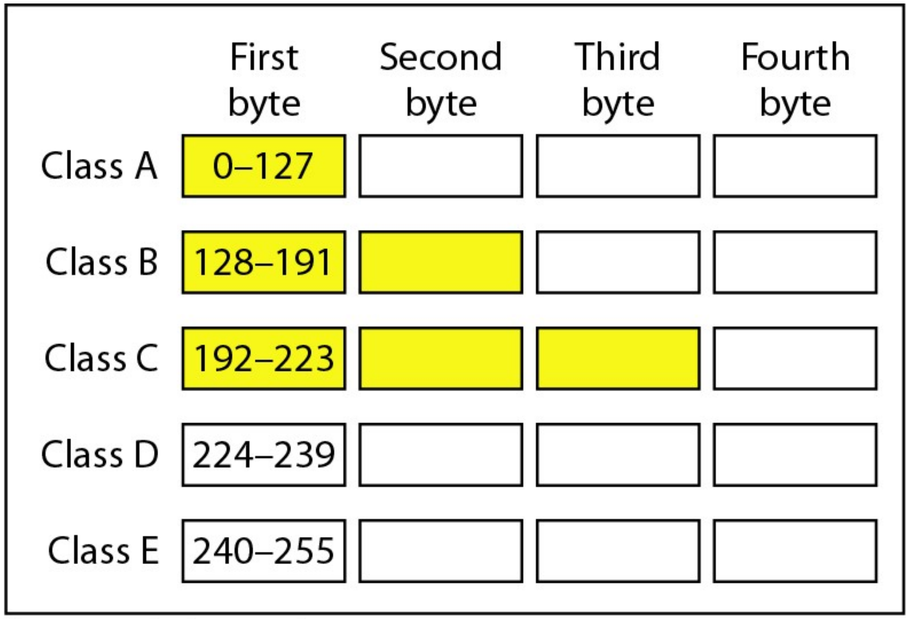


Classful Addressing



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

a. Binary notation



	First byte	Second byte	Third byte	Fourth byte
Class A	0–127			
Class B	128–191	🟨		
Class C	192–223	🟨	🟨	
Class D	224–239			
Class E	240–255			

b. Dotted-decimal notation

🟨 network number

Classes and Blocks (Networks)

- Number of blocks (networks) and block size in classful IPv4 addressing

Class	Number of Blocks (Networks)	Block (Network) Size
A	128	16 777 216
B	16 384	65 536
C	2 097 152	256
D	1	268 435 456
E	1	268 435 456

Reserved Addresses

Address Block	Present Use
0.0.0.0 to 0.255.255.255	"This" Network
10.0.0.0 to 10.255.255.255	Private Use Networks
14.0.0.0 to 14.255.255.255	Public Data Networks
24.0.0.0 to 24.255.255.255	Cable TV Networks
39.0.0.0 to 39.255.255.255	Reserved but subject to allocation
127.0.0.0 to 127.255.255.255	Loopback
128.0.0.0 to 128.0.255.255	Reserved but subject to allocation
169.254.0.0 to 169.254.255.255	Link Local
172.16.0.0 to 172.31.255.255	Private use networks

Reserved Addresses

Address Block	Present Use
191.255.0.0 to 191.255.255.255	Reserved but subject to allocation
192.0.0.0 to 192.0.0.255	Reserved but subject to allocation
192.0.2.0 to 192.0.2.255	Test Net
192.88.99.0 to 192.88.99.255	Relay anycast
192.168.0.0 to 192.168.255.255	Private Use Networks
198.18.0.0 to 198.18.0.127	Network interconnect device benchmark testing
223.255.255.0 to 223.255.255.255	Reserved but subject to allocation
224.0.0.0 to 239.255.255.255	Multicast
240.0.0.0 to 255.255.255.255	Reserved for future use

Examples

Find the class of each address:

a. 227.12.14.87

The first byte is 227 (between 224 and 239); the class is D.

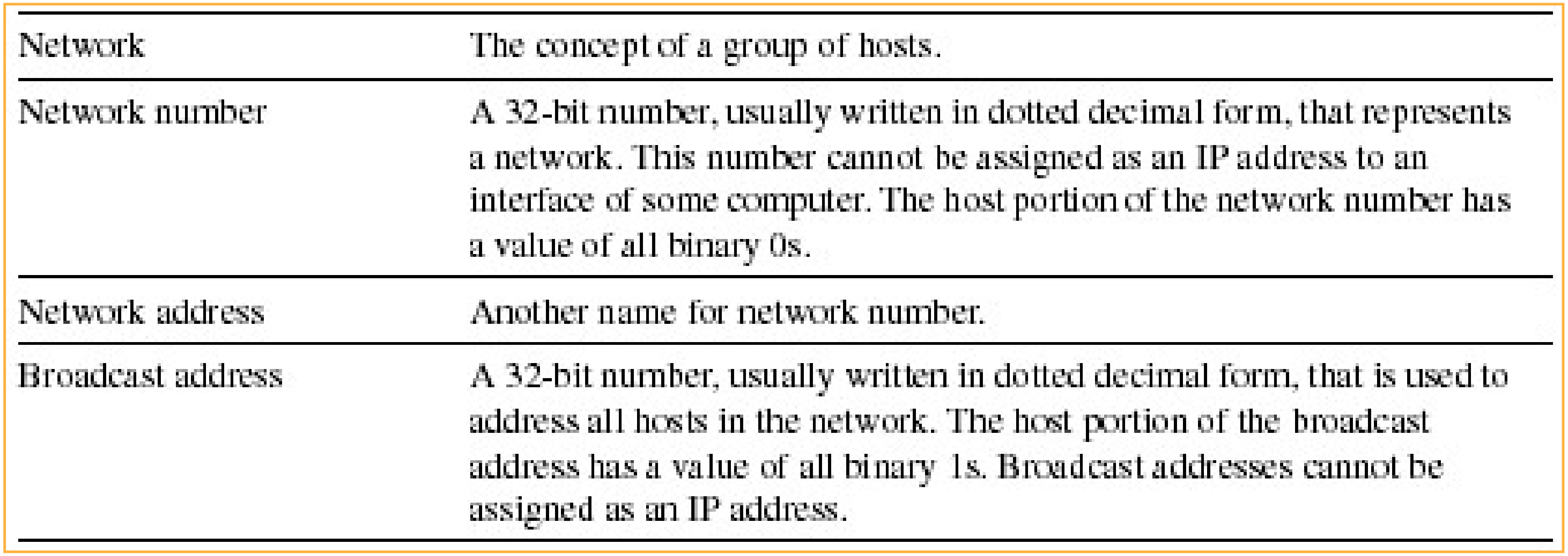
b. 252.5.15.111

The first byte is 252 (between 240 and 255); the class is E.

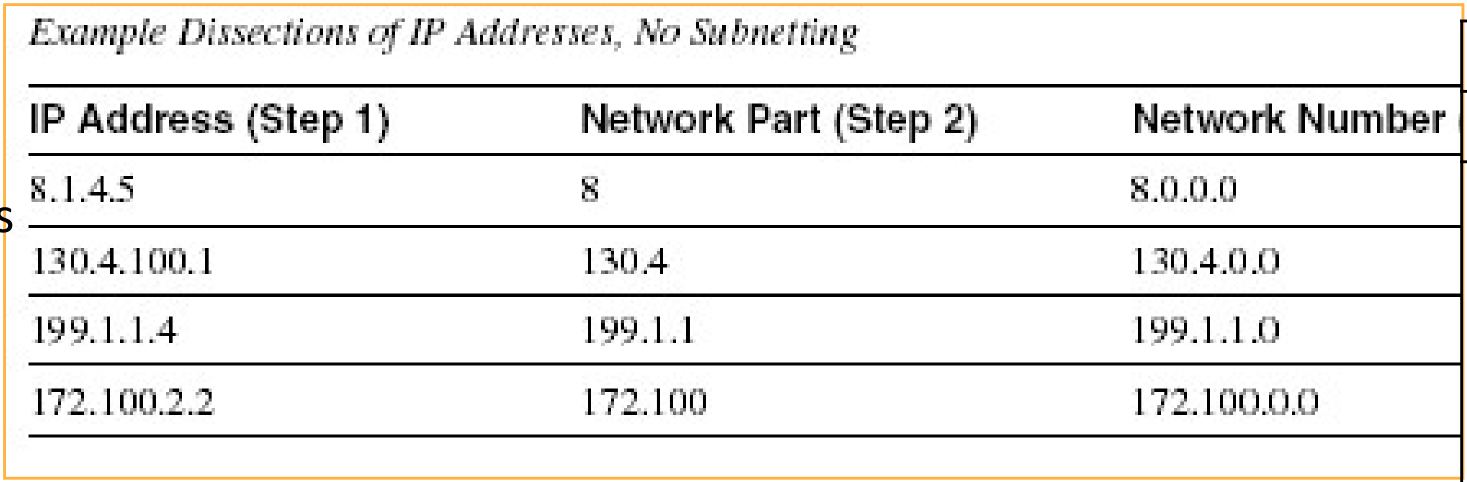
c. 134.11.78.56

The first byte is 134 (between 128 and 191); the class is B.

Network and Broadcast Addresses



Network	The concept of a group of hosts.
Network number	A 32-bit number, usually written in dotted decimal form, that represents a network. This number cannot be assigned as an IP address to an interface of some computer. The host portion of the network number has a value of all binary 0s.
Network address	Another name for network number.
Broadcast address	A 32-bit number, usually written in dotted decimal form, that is used to address all hosts in the network. The host portion of the broadcast address has a value of all binary 1s. Broadcast addresses cannot be assigned as an IP address.

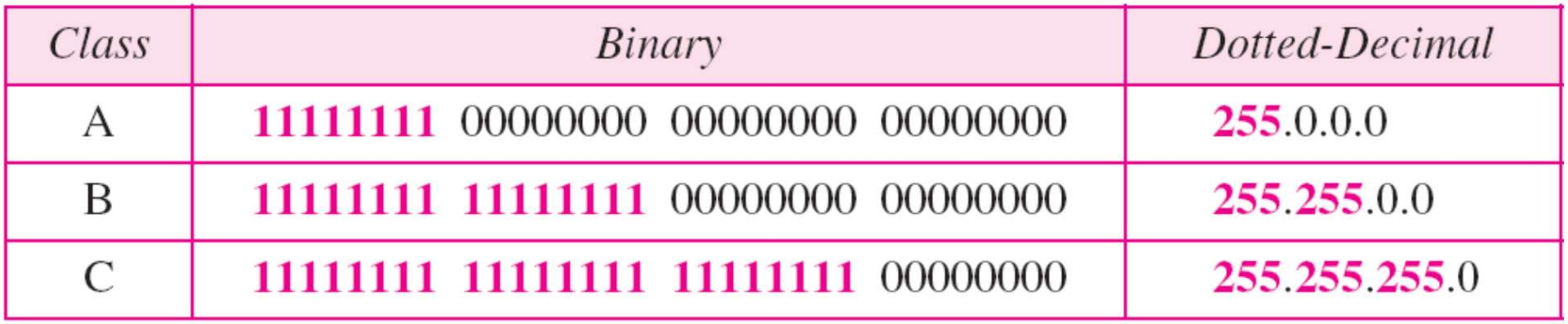


Example Dissections of IP Addresses, No Subnetting

	IP Address (Step 1)	Network Part (Step 2)	Network Number	Broadcast Address
A class	8.1.4.5	8	8.0.0.0	8.255.255.255
B class	130.4.100.1	130.4	130.4.0.0	130.4.255.255
C class	199.1.1.4	199.1.1	199.1.1.0	
Private	172.100.2.2	172.100	172.100.0.0	

Default Masks for Classful Addressing

- A mask can help identify the netid and hostid.
- Performing a bitwise logical AND operation between the IP address and the subnet mask results in the netid.



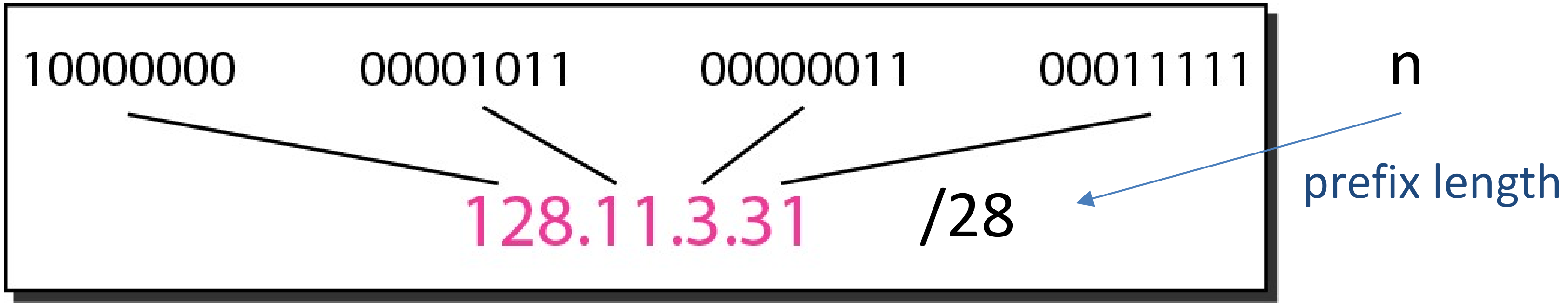
Class	*Binary*	*Dotted-Decimal*
A	11111111 00000000 00000000 00000000	255.0.0.0
B	11111111 11111111 00000000 00000000	255.255.0.0
C	11111111 11111111 11111111 00000000	255.255.255.0

IP Subnetting and Classless Addressing

- Subnetting is simply the process of treating subdivisions of a single Class A, B, or C network as if it were a network itself
- Problem with IP address classes
  - Inflexible, results in waste of IP address
    - Example 1: A network with four hosts will be assigned a Class C network number, the rest address space is wasted
    - Example 2: A network with 257 hosts will be assigned a Class B network number, the rest address space is wasted
- Without subnetting, the smallest group is a single, entire Class A, B, or C network number; the IP address space will soon be exhausted

Classless Addressing

- Commonly used now to deal with address shortage
- No class definition
- Prefix length “n” to classify IP address belong to a specific domain



10000000 00001011 00000011 00011111

128.11.3.31 /28

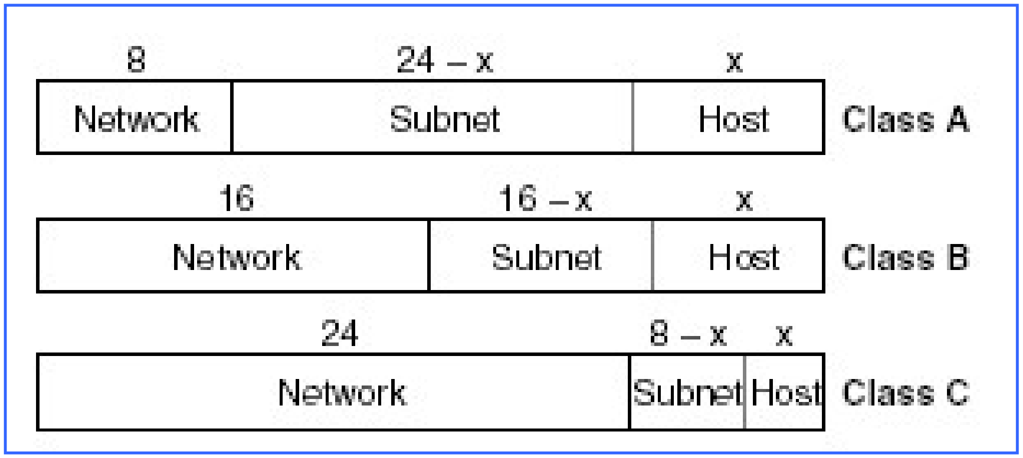
n

prefix length

- n=28 indicates first 28 bits for network address and thus 4 bits will denote start and end IP address for that domain
- IP addresses from 128.11.3.16 to 128.11.3.31 belong this prefix length/class

IP Subnetting

- IP addresses are designed with two levels of hierarchy
- With subneting, three potions of the address now exists: network, subnet and host



8	24 – x	x	
Network	Subnet	Host	Class A
16	16 – x	x	
Network	Subnet	Host	Class B
24	8 – x	x	
Network	Subnet	Host	Class C

– The number of hosts per subnet: 2^x -2

- Subnet Mask: defined with a value of n preceded by a slash notation (/n)

Example

- A block of addresses is granted to a small organization. We know that one of the addresses is 205.16.37.36/29. What is the first, the last, and the total number of addresses of this block? 29 bits for network address
- IP Address : 11001101.00100000.00100101.00100100 (205.16.37.36)

Mask : 11111111.11111111.11111111.11111000 (255.255.255.248)

Subnet Address : 11001101.00100000.00100101.00100000 (205.16.37.32)

SubNet. Add	11001101 =205	00001000 =16	00100101=37	00100000 = 32
1st Address	11001101 =205	00001000 =16	00100101=37	00100001 = 33
2nd Address	11001101 =205	00001000 =16	00100101=37	00100010 = 34
3rd Address	11001101 =205	00001000 =16	00100101=37	00100011 = 35
4th Address	11001101 =205	00001000 =16	00100101=37	00100100 = 36
5th Address	11001101 =205	00001000 =16	00100101=37	00100101 = 37
6th Address	11001101 =205	00001000 =16	00100101=37	00100110 = 38
Broadcast Add	11001101 =205	00001000 =16	00100101=37	00100111 = 39

Example

- A block of addresses is granted to a small organization. We know that one of the addresses is 205.16.37.36/30. What is the first, the last, and the total number of useable addresses of this block?

- A block of addresses is granted to a small organization. We know that one of the addresses is 192.168.10.64/28.
- What is the first, the last, and the number of useable addresses of this block?

Example

- A block of addresses is granted to a small organization. We know that one of the addresses is 205.16.37.36/30. What is the first, the last, and the total number of useable addresses of this block?

205.16.37.36/30 implies mask of 255.255.255.252 with two last bits that can be used

Start from 36=00100100; network address 205.16.37.36; 1st address 205.16.37.37; 2nd (last) address 205.16.37.38; 205.16.37.39 is broadcast address; in total this block has 2^2-2=2 useable addresses

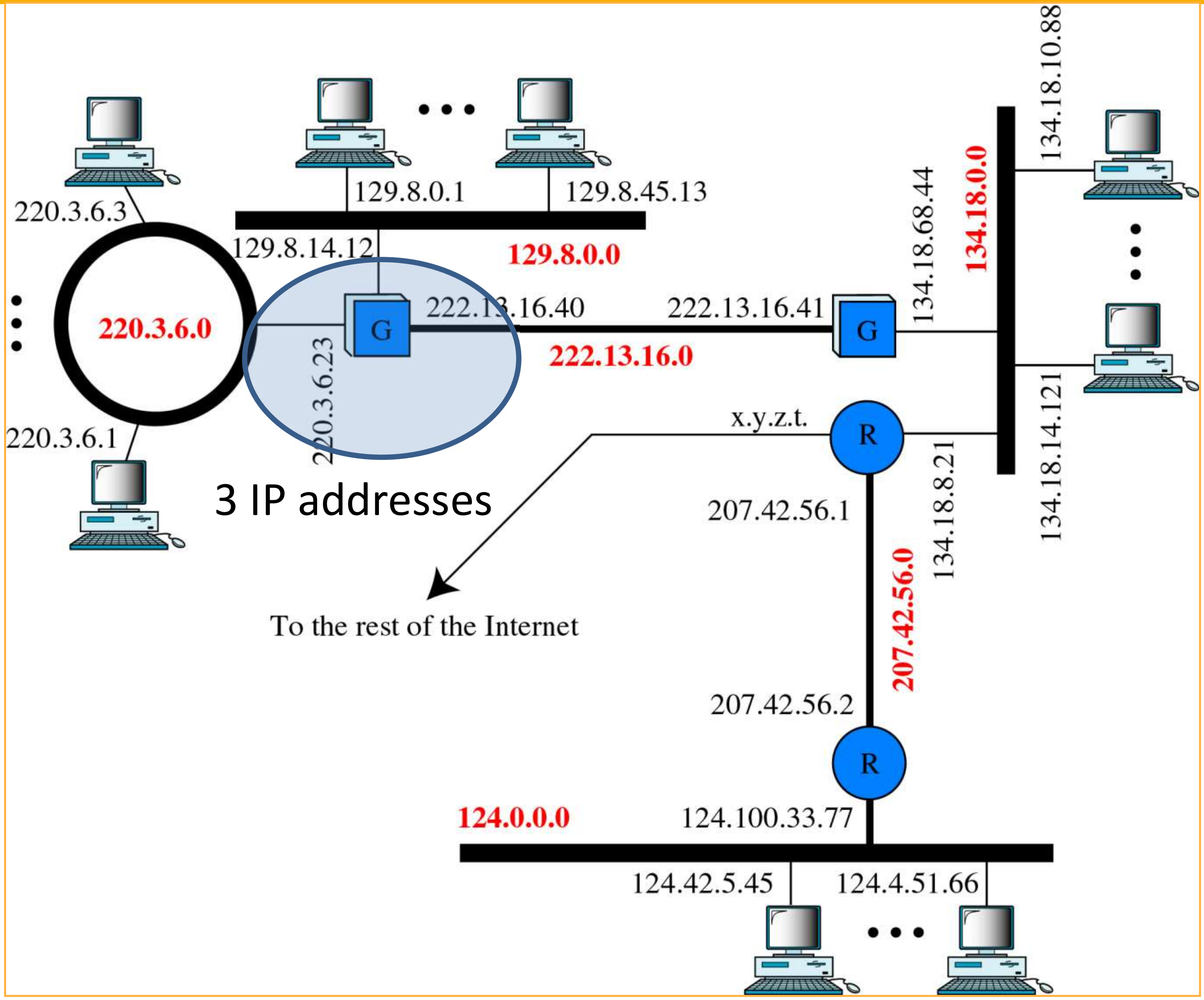
- A block of addresses is granted to a small organization. We know that one of the addresses is 192.168.10.64/28.
- What is the first, the last, and the number of useable addresses of this block?

192.168.10.64/255.255.255.240; last 6 bits that can be allocated, 64=01000000; network address 192.168.10.64; 1st address 192.168.10.65; 14th (last) address 192.168.10.78;
192.168.10.79 is broadcast address; in total this block has 2^4-2=14 useable addresses

Nodes with More Than One Address

- An Internet address defines the node’s connection to its network
- It specifies both the network to which a host belongs (netid) and the host itself (hostid)
- Therefore, any device connected to more than one network must have more than one internet address
  - *For example which device?? Router!!!*
- In fact, the device has a different address for each network connected to it

Example



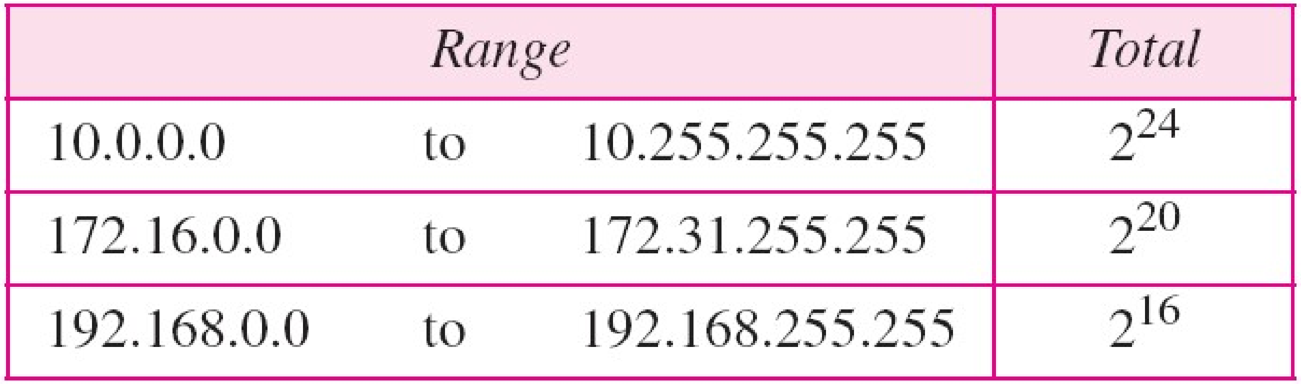
3 IP addresses

Private Addressing and NAT

- Some organization may only want IP addresses to identify hosts within networks of the organization
- These hosts do not need to communicate with the Internet outside the organization
- When designing the IP addressing convention for such a network, any network number can be used
- This kind of network is called private internet
- RFC 1918 defines a set of networks that will never be assigned to any organization as a registered network number
  - Any organization can use these network numbers
  - No organization is allowed to advertise these networks as route into the Internet

Addresses for Private Networks

- Advantages of private addressing
  - The organization saves by applying for a registered IP address segment
  - Saves IP address space
- Disadvantages
  - All hosts in the organization must stay away from the outside Internet
- Network address translation (NAT) is proposed to address the problem
  - NAT allows a host that do not have a valid registered IP address to communicate with other hosts through the Internet



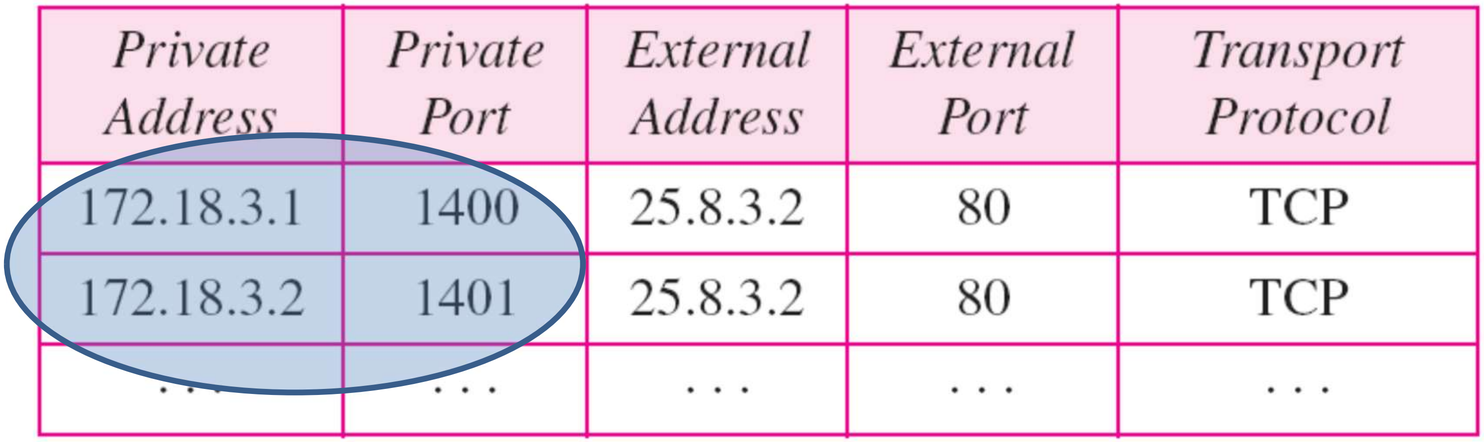
Range			*Total*
10.0.0.0	to	10.255.255.255	2^{24}
172.16.0.0	to	172.31.255.255	2^{20}
192.168.0.0	to	192.168.255.255	2^{16}

NAT

- NAT can significantly save IP address space while satisfying the requirement of hosts to be connected to the Internet
- It is widely used by small organizations and/or ISP
- NAT achieves its goal by obtaining several valid registered IP addresses
- These valid registered IP addresses are only assigned to those hosts requiring to communicate through the Internet
- They are assigned on demand

NAT Address Translation

- Using a Pool of IP Addresses:
  - Since the NAT router has only one global address, only one private network host can access the same external host.
  - Using a pool of IP addresses at the router solves this problem
- Using both IP Address and Port Numbers:
  - To allow many-to-many relationship between private network hosts and external server programs, more information is included in the translation tables

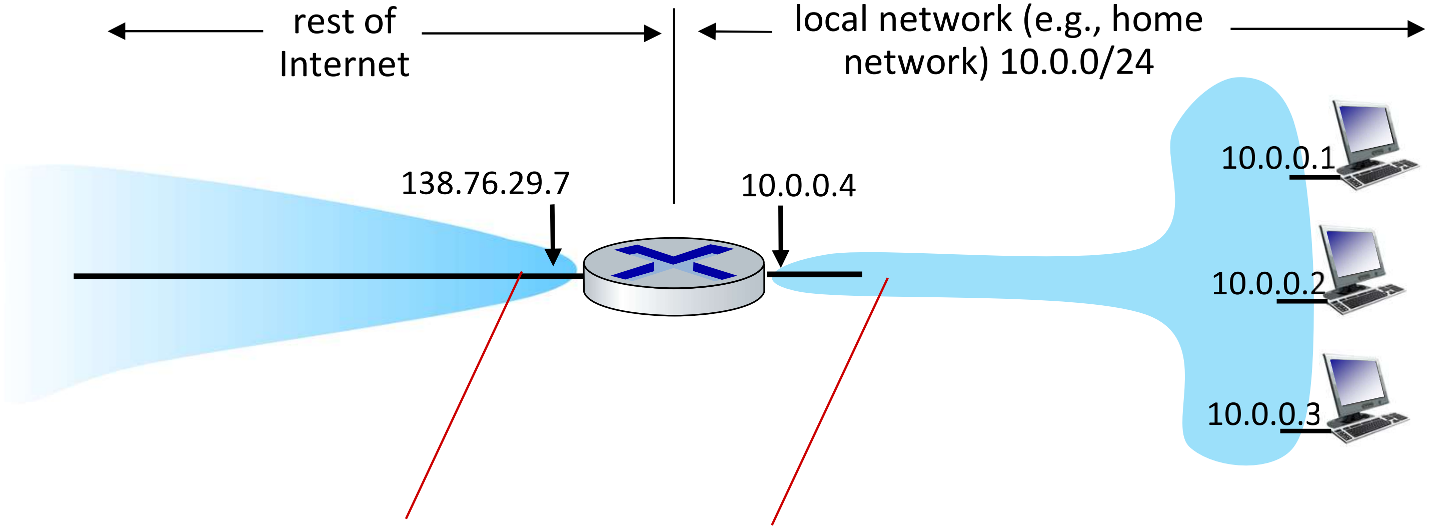


Private Address	*Private Port*	*External Address*	*External Port*	*Transport Protocol*
172.18.3.1	1400	25.8.3.2	80	TCP
172.18.3.2	1401	25.8.3.2	80	TCP
. . .	. . .	. . .	. . .	. . .

socket

NAT: network address translation

NAT: all devices in local network share just one IPv4 address as far as outside world is concerned



all datagrams *leaving* local network have *same* source NAT IP address: 138.76.29.7, but *different* source port numbers

datagrams with source or destination in this network have 10.0.0/24 address for source, destination (as usual)

NAT: network address translation

- all devices in local network have 32-bit addresses in a “private” IP address space (10/8, 172.16/12, 192.168/16 prefixes) that can only be used in local network
- advantages:
  - just one IP address needed from provider ISP for *all* devices
  - can change addresses of host in local network without notifying outside world
  - can change ISP without changing addresses of devices in local network
  - security: devices inside local net not directly addressable, visible by outside world

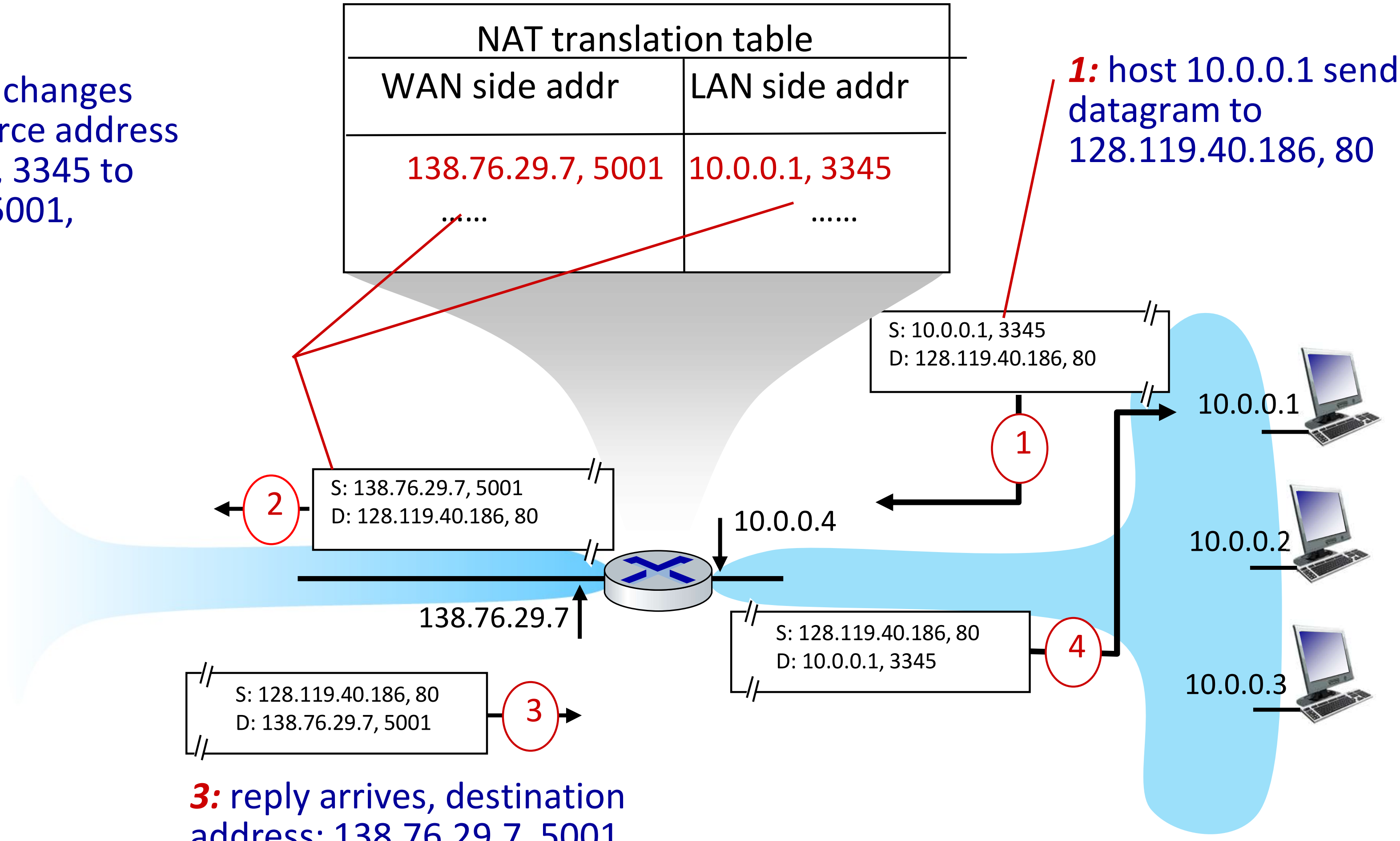
NAT: network address translation

implementation: NAT router must (transparently):

- outgoing datagrams: replace (source IP address, port #) of every outgoing datagram to (NAT IP address, new port #)
  - remote clients/servers will respond using (NAT IP address, new port #) as destination address
- remember (in NAT translation table) every (source IP address, port #) to (NAT IP address, new port #) translation pair
- incoming datagrams: replace (NAT IP address, new port #) in destination fields of every incoming datagram with corresponding (source IP address, port #) stored in NAT table

NAT: network address translation

2: NAT router changes datagram source address from 10.0.0.1, 3345 to 138.76.29.7, 5001, updates table



NAT translation table

WAN side addr	LAN side addr
138.76.29.7, 5001	10.0.0.1, 3345
……	……

1: host 10.0.0.1 sends datagram to 128.119.40.186, 80

3: reply arrives, destination address: 138.76.29.7, 5001

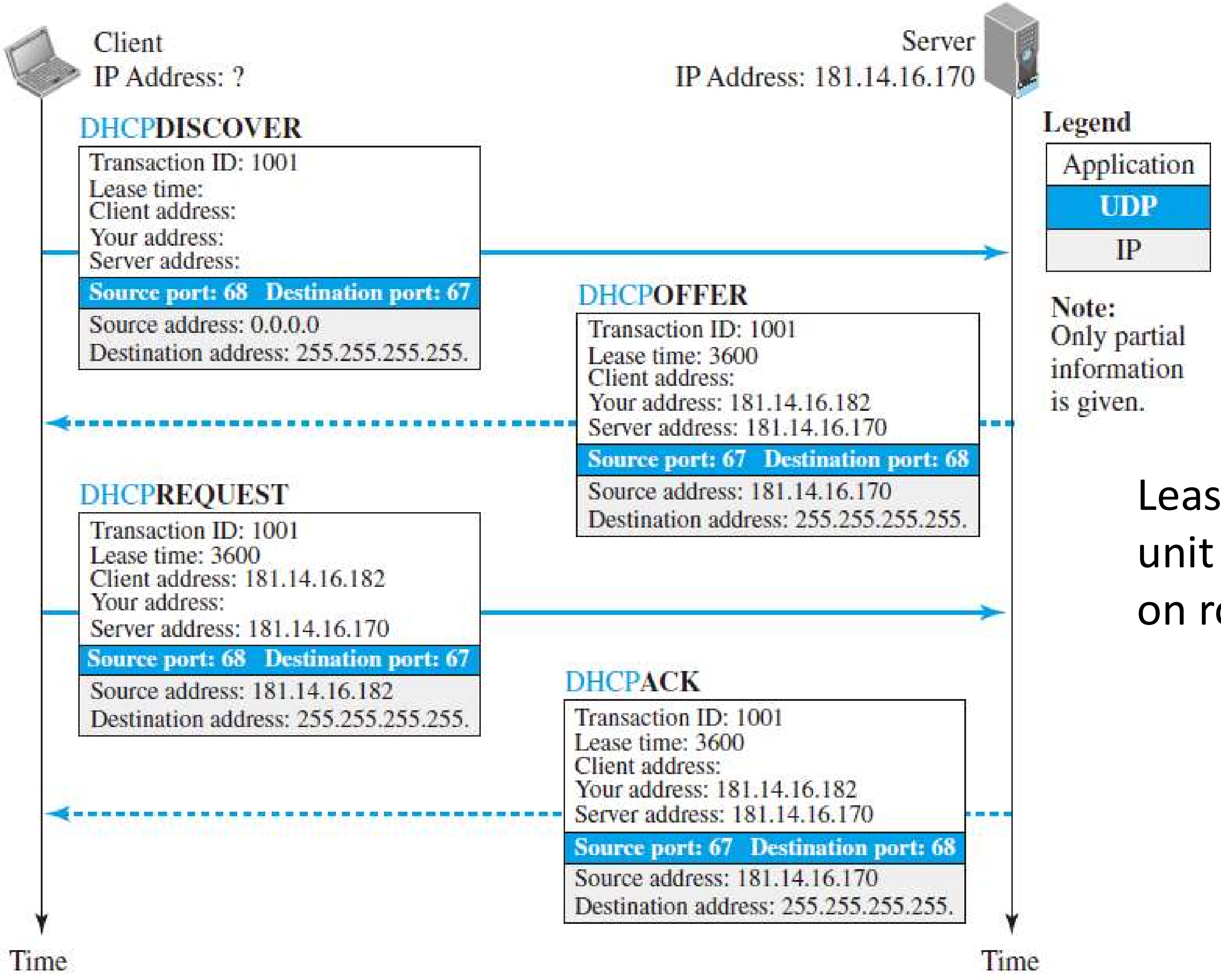
NAT: How to get an IP Address

Hosts (host portion):

- hard-coded by system admin in a file
- DHCP: Dynamic Host Configuration Protocol: dynamically get address: “plug-and-play”
  - Assign permanent or temporary IP addresses
  - host broadcasts “DHCP discover” msg
  - DHCP server responds with “DHCP offer” msg
  - host requests IP address: “DHCP request” msg
  - DHCP server sends address: “DHCP ack” msg

NAT: How to get an IP Address

broadcast



DHCPDISCOVER

Transaction ID: 1001
Lease time:
Client address:
Your address:
Server address:
Source port: 68 Destination port: 67
Source address: 0.0.0.0
Destination address: 255.255.255.255.

DHCPOFFER

Transaction ID: 1001
Lease time: 3600
Client address:
Your address: 181.14.16.182
Server address: 181.14.16.170
Source port: 67 Destination port: 68
Source address: 181.14.16.170
Destination address: 255.255.255.255.

DHCPREQUEST

Transaction ID: 1001
Lease time: 3600
Client address: 181.14.16.182
Your address:
Server address: 181.14.16.170
Source port: 68 Destination port: 67
Source address: 181.14.16.182
Destination address: 255.255.255.255.

DHCPACK

Transaction ID: 1001
Lease time: 3600
Client address:
Your address: 181.14.16.182
Server address: 181.14.16.170
Source port: 67 Destination port: 68
Source address: 181.14.16.170
Destination address: 255.255.255.255.

Note:
Only partial
information
is given.

Lease time
unit depends
on router

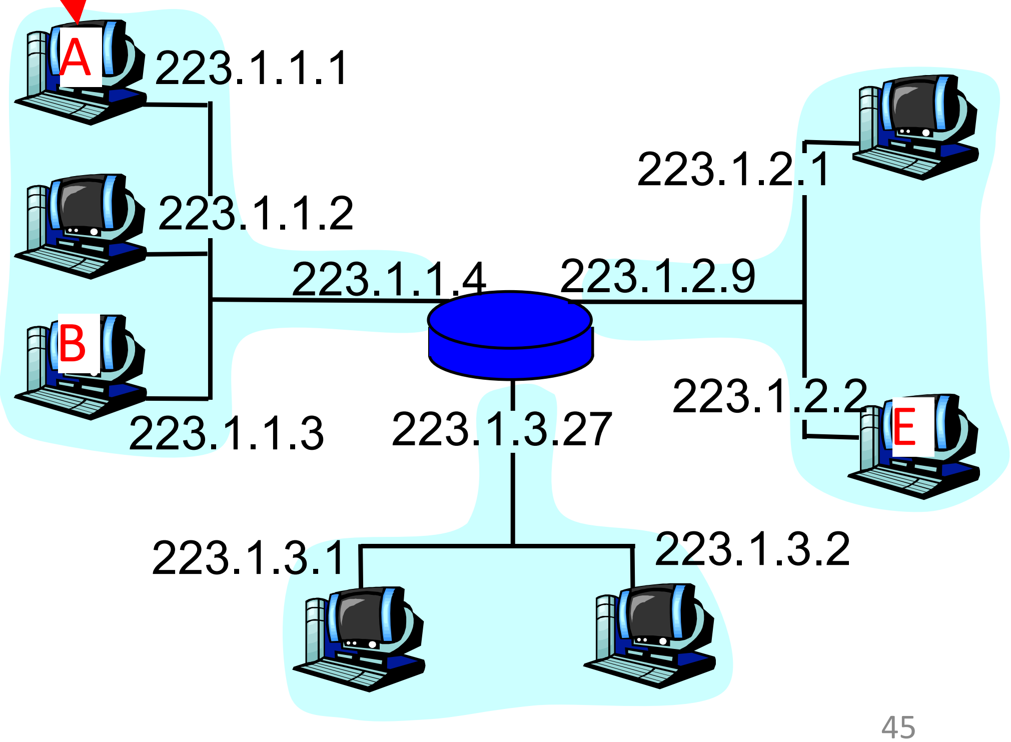
Routing a IP datagram from source to destination (same subnet)

misc fields	223.1.1.1	223.1.1.3	data

Dest. Net.	next router	Nhops
223.1.1.0		1
223.1.2.0	223.1.1.4	2
223.1.3.0	223.1.1.4	2

Starting at A, given IP datagram addressed to B:

- look up net. IP address of B
- find B is on same subnet as A
- link layer will send datagram directly to B inside link-layer frame
  - B and A are directly connected



assume the subnet mask is 255.255.255.0

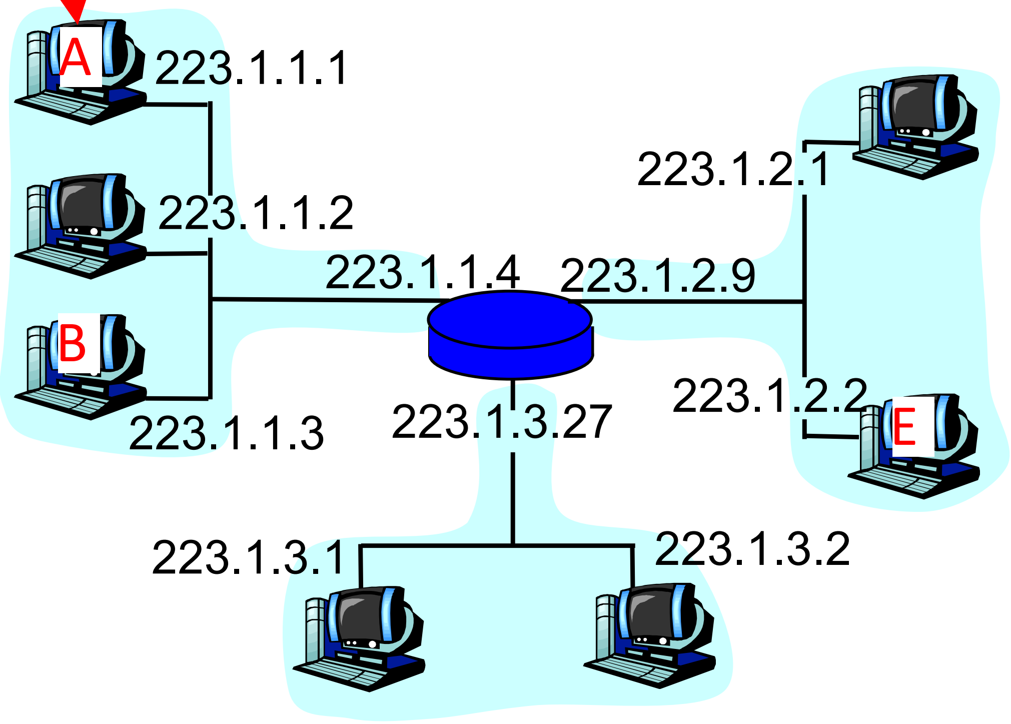
Routing a IP datagram from source to destination (different subnet)

misc fields	223.1.1.1	223.1.2.2	data

Dest. Net.	next router	Nhops
223.1.1.0		1
223.1.2.0	223.1.1.4	2
223.1.3.0	223.1.1.4	2

Starting at A, dest. E:

- ❒ look up network IP address of E
- ❒ E on *different* subnet network
  - ❍ A, E not directly attached
- ❒ routing table: next hop router to E is 223.1.1.4
- ❒ link layer sends datagram to router 223.1.1.4 inside link-layer frame
- ❒ datagram arrives at IP 223.1.1.4 router interface
- ❒ continued…..



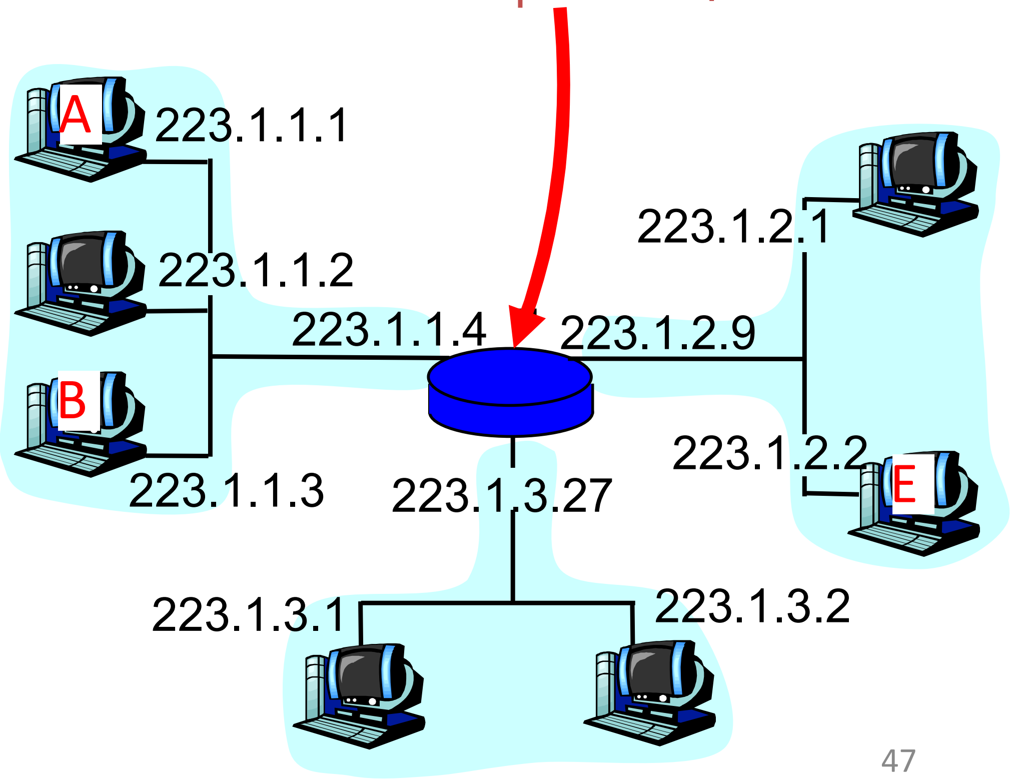
Routing a IP datagram from source to destination (different subnet)

misc fields	223.1.1.1	223.1.2.2	data

Arriving at 223.1.4, destined for 223.1.2.2

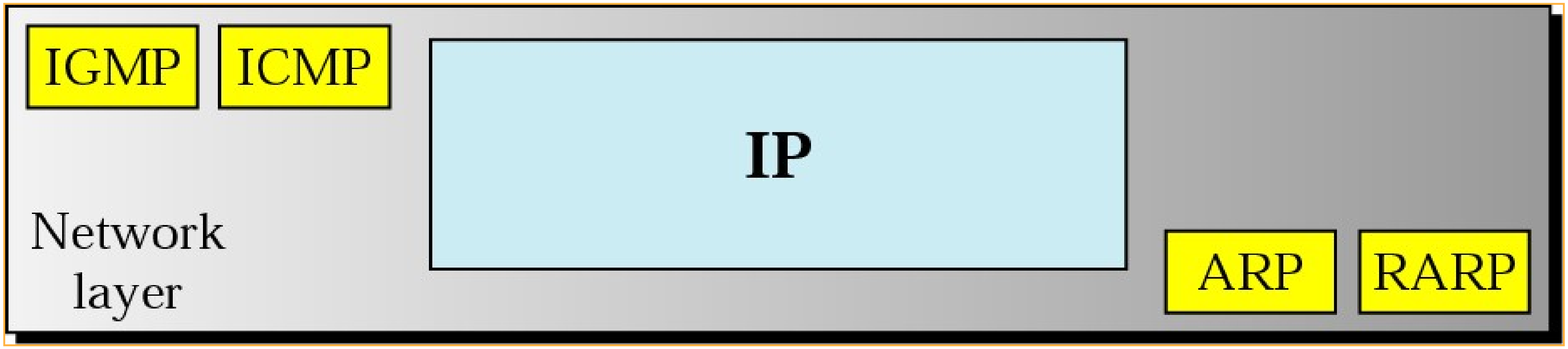
- look up network IP address of E
- E on *same* network as router's interface 223.1.2.9
  - router, E directly attached
- link layer sends datagram to 223.1.2.2 inside link-layer frame via interface 223.1.2.9
- datagram arrives at 223.1.2.2 by E's MAC address !!! (hooray!)

Dest. network	next router	Nhops	interface
223.1.1.0	-	1	223.1.1.4
223.1.2.0	-	1	223.1.2.9
223.1.3.0	-	1	223.1.3.27



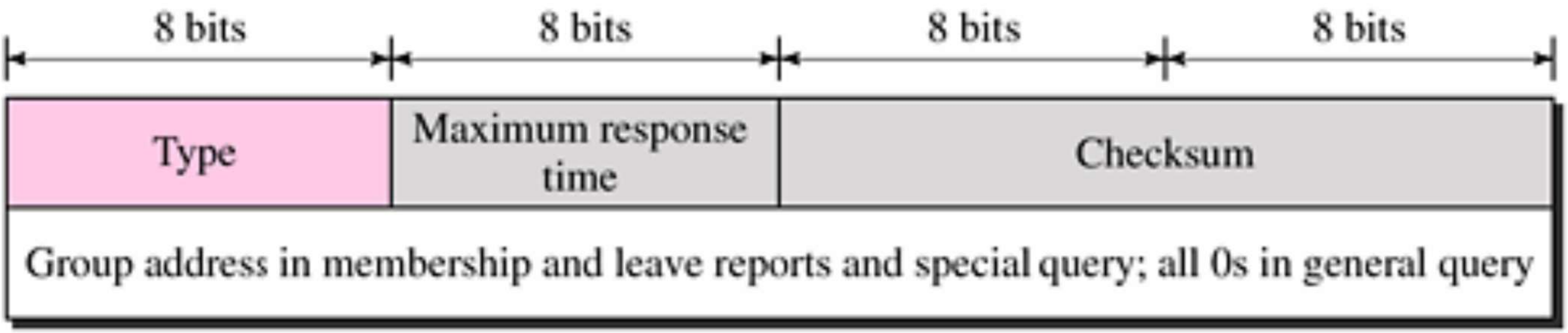
Internet Control Protocols

- In addition to IP, the Internet has several control protocols (if the transmission goes wrong or to find addresses) used in the network layer as follows:
  - ICMP
  - IGMP
  - ARP
  - RARP



Internet Group Management Protocol (IGMP)

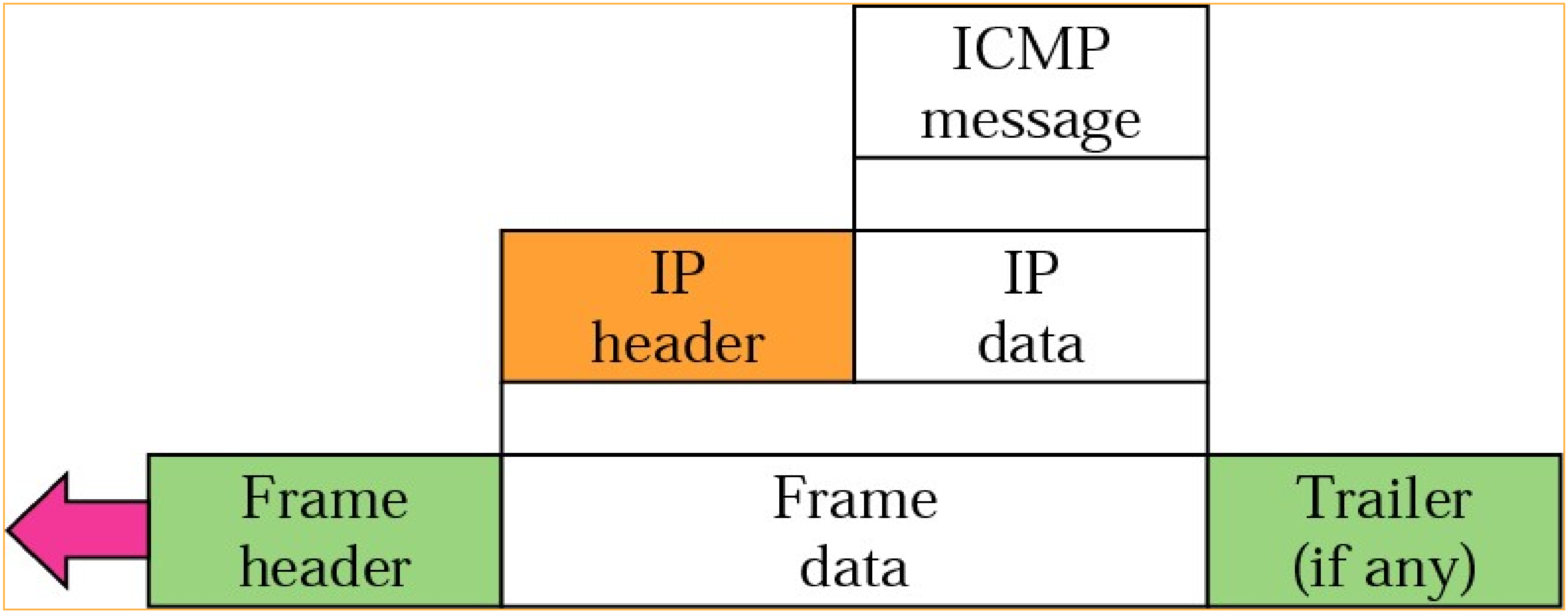
- It is used to manage multicasting (one-to-many communication)
- Query: check membership continuation and interest on multicast group
- Membership report: request to join multicast group
- Leave Report: request to leave multicast group
- Max response time: max time to answer a query
- Checksum: Error detection
- Group Address: group id (multicast address of the group)



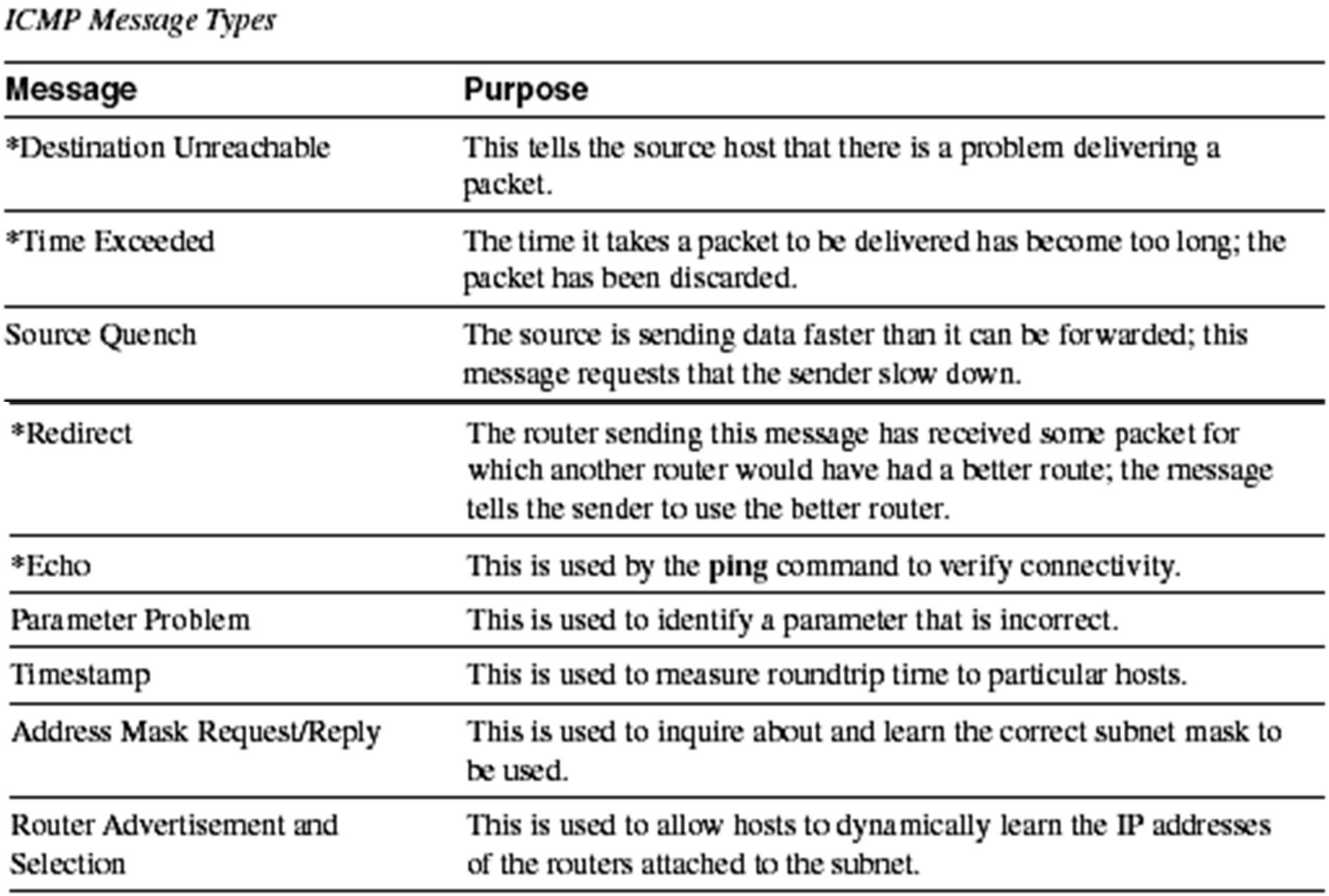
8 bits	8 bits	8 bits	8 bits
Type	Maximum response time	Checksum	
Group address in membership and leave reports and special query; all 0s in general query			

Internet Control Message Protocol (ICMP)

- IPv4 has no error reporting or correcting mechanism
- ICMP is implemented by all TCP/IP hosts
- When something unexpected occurs, the event is reported



ICMP Message Types



ICMP Message Types

Message	Purpose
*Destination Unreachable	This tells the source host that there is a problem delivering a packet.
*Time Exceeded	The time it takes a packet to be delivered has become too long; the packet has been discarded.
Source Quench	The source is sending data faster than it can be forwarded; this message requests that the sender slow down.
*Redirect	The router sending this message has received some packet for which another router would have had a better route; the message tells the sender to use the better router.
*Echo	This is used by the **ping** command to verify connectivity.
Parameter Problem	This is used to identify a parameter that is incorrect.
Timestamp	This is used to measure roundtrip time to particular hosts.
Address Mask Request/Reply	This is used to inquire about and learn the correct subnet mask to be used.
Router Advertisement and Selection	This is used to allow hosts to dynamically learn the IP addresses of the routers attached to the subnet.

Applications of ICMP

- “ trace” command (variants: tracert, traceroute, etc.)
  - Is used to discover the route from source to destination
  - It uses “Time exceeded” message. By purposefully sending IP packets with TTL set to 1, an “ICMP Time Exceeded” message is returned by the first router in the route
  - It learns the IP address of the first router by receiving the “ICMP Time Exceeded” message from that router
  - It then sends IP packets with TTL set to 2 and learns the IP address of the second router. ……………………………
  - Eventually, a set of packets is delivered to the destination and the addresses of all routers along the route is learned
- Exercises:
  - Try the command “tracert www.yahoo.com” in your home computer (internet enabled) to find the name of the routers along the route from your computer to www.yahoo.com

  Note: In case tracert does not work in your computer, try other form “trace” or “traceroute”

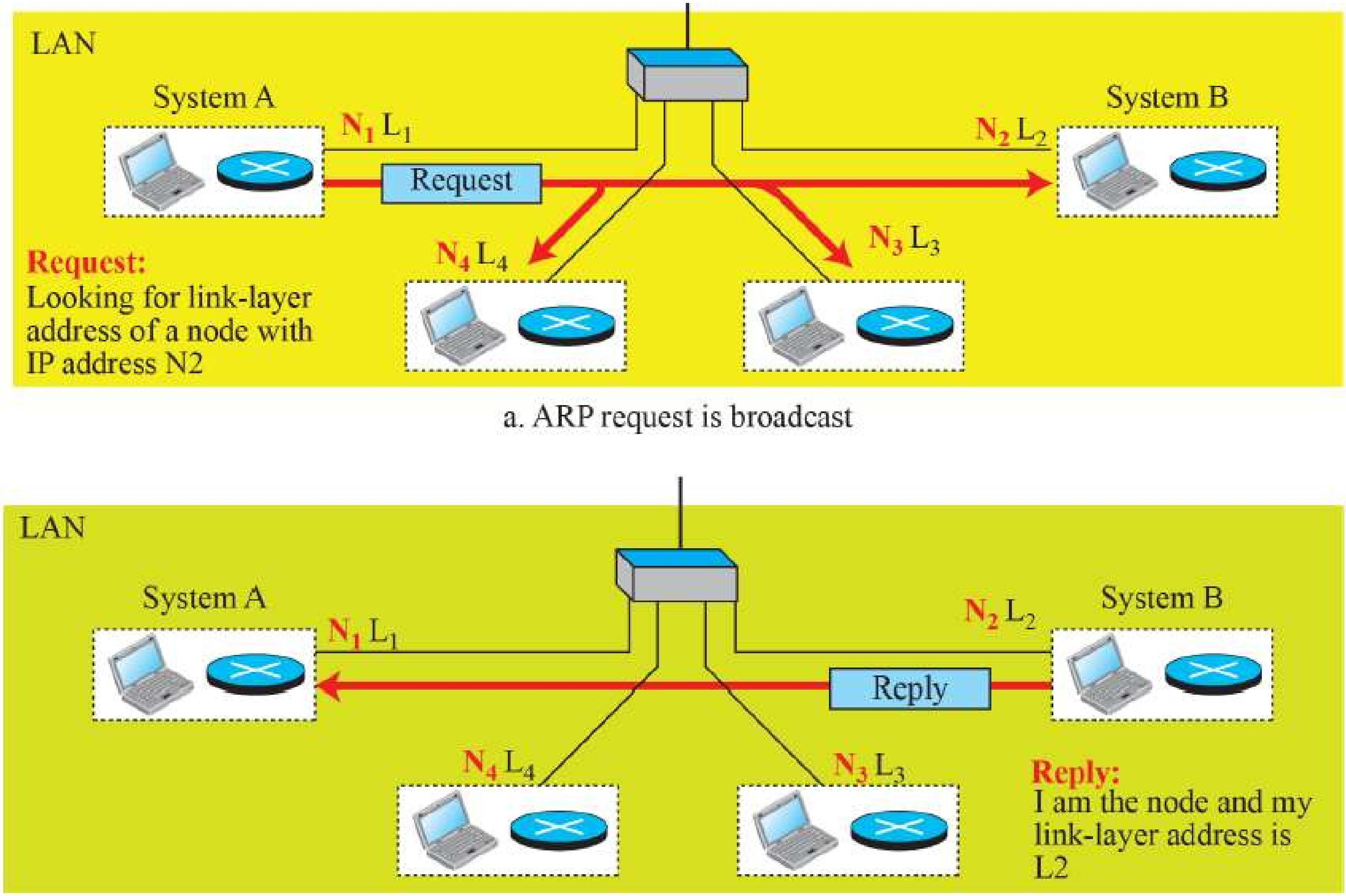
Applications of ICMP

- “ping” command
  - Is widely used to test connectivity between your host and a destination host
  - An “echo request” is sent with the ping command
    - The Echo Request means that the host to which it is addressed should reply to the packet
  - The destination host will reply with an “Echo Reply”
  - If the destination host cannot be reached, the packet will time out and a “destination unreachable” message is returned
- Exercise:
  - Try the command “ping www.yahoo.com” at your home computer and record the following data
    - The average time taken for your packet to reach www.yahoo.com and return (average round trip time)
    - The maximum/minimum round trip time

Address Resolution Protocol (ARP)

- ARP is used to find the physical address of a node when it’s IP address is known.
- A host/router needs to find a physical address of another host on the same network, it forms an ARP query packet that includes the IP address and broadcasts it over the network.
- Every host on the network receives and processes it, but only the recipient recognizes it and send back the it’s physical address.

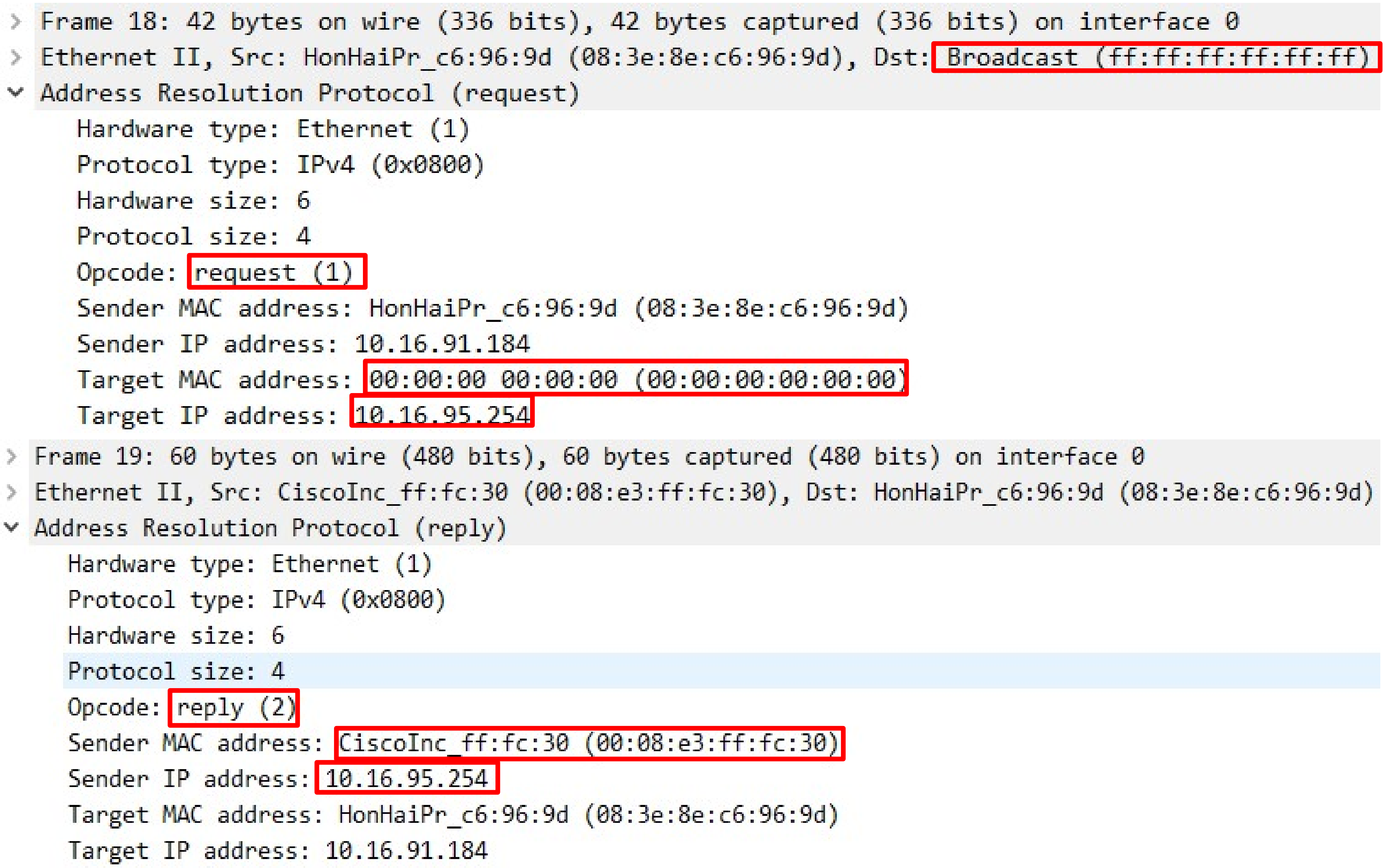
Address Resolution Protocol (ARP)



a. ARP request is broadcast

b. ARP reply is unicast

ARP Example (you will do more in labs)



```
> Frame 18: 42 bytes on wire (336 bits), 42 bytes captured (336 bits) on interface 0
> Ethernet II, Src: HonHaiPr_c6:96:9d (08:3e:8e:c6:96:9d), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
v Address Resolution Protocol (request)
    Hardware type: Ethernet (1)
    Protocol type: IPv4 (0x0800)
    Hardware size: 6
    Protocol size: 4
    Opcode: request (1)
    Sender MAC address: HonHaiPr_c6:96:9d (08:3e:8e:c6:96:9d)
    Sender IP address: 10.16.91.184
    Target MAC address: 00:00:00_00:00:00 (00:00:00:00:00:00)
    Target IP address: 10.16.95.254
> Frame 19: 60 bytes on wire (480 bits), 60 bytes captured (480 bits) on interface 0
> Ethernet II, Src: CiscoInc_ff:fc:30 (00:08:e3:ff:fc:30), Dst: HonHaiPr_c6:96:9d (08:3e:8e:c6:96:9d)
v Address Resolution Protocol (reply)
    Hardware type: Ethernet (1)
    Protocol type: IPv4 (0x0800)
    Hardware size: 6
    Protocol size: 4
    Opcode: reply (2)
    Sender MAC address: CiscoInc_ff:fc:30 (00:08:e3:ff:fc:30)
    Sender IP address: 10.16.95.254
    Target MAC address: HonHaiPr_c6:96:9d (08:3e:8e:c6:96:9d)
    Target IP address: 10.16.91.184
```

IP addresses: how to get one?

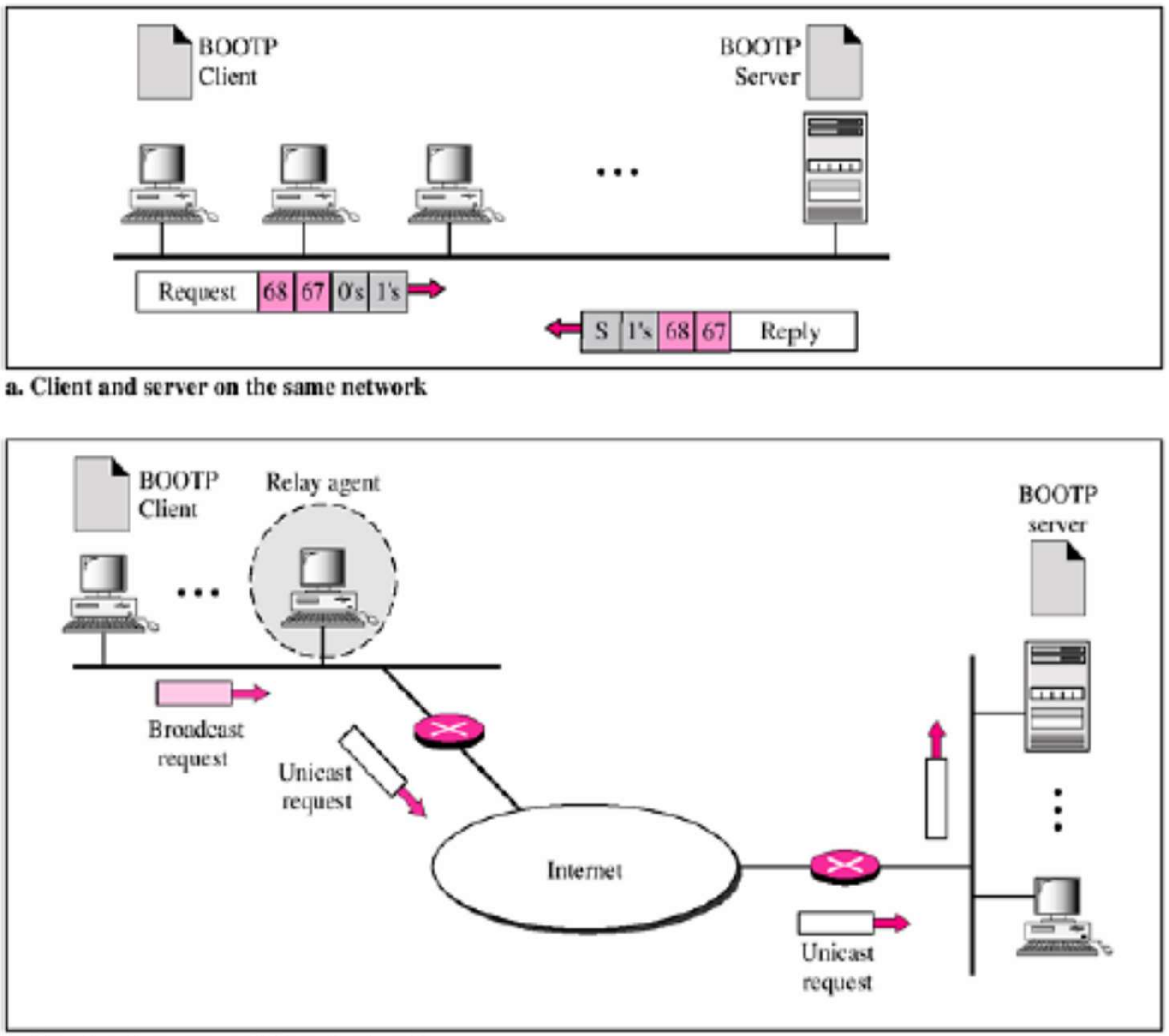
How does *the host get an* IP address?

- hard-coded by sysadmin in config file (e.g., /etc/rc.config in UNIX)
- The station can send (broadcast) its physical address and ask for a short time lease, becoming a link layer problem
  - Bootstrap
  - DHCP: Dynamic Host Configuration Protocol: dynamically get address from the server

Bootstrap Protocol

A client/server protocol designed to provide physical address to logical address mapping (an application layer protocol)

Server has fixed MAC and IP table mapping



a. Client and server on the same network

b. Client and server on different networks

DHCP: Dynamic Host Configuration Protocol

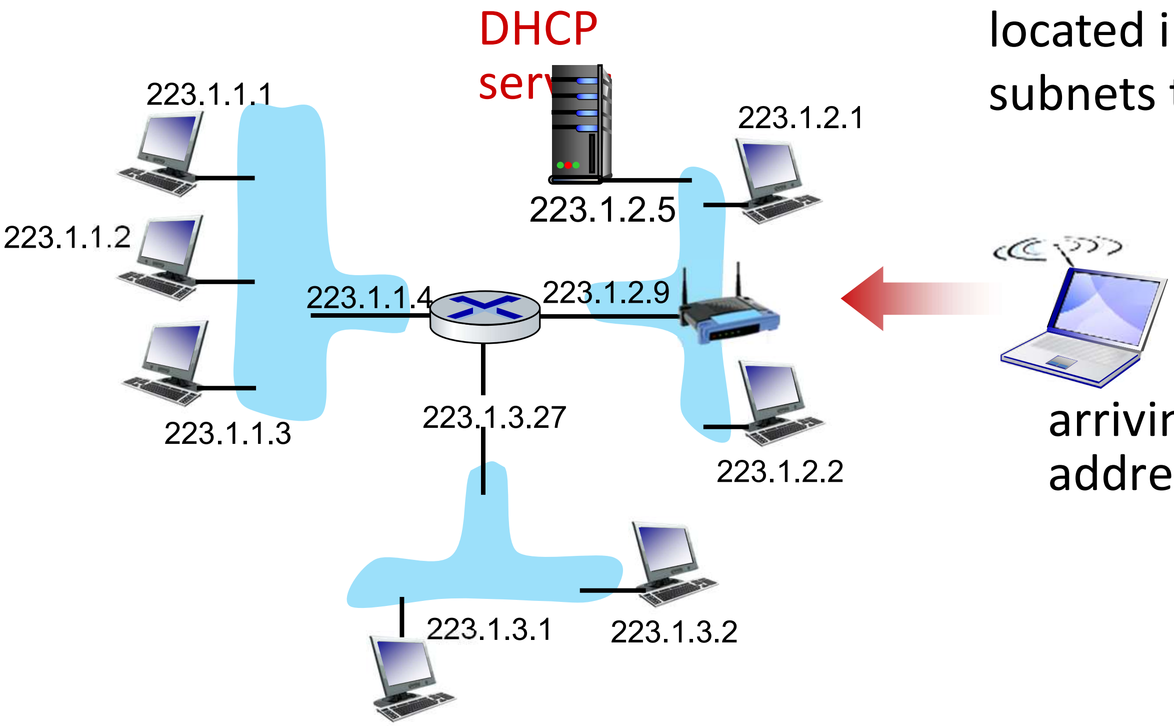
goal: host ***dynamically*** obtains IP address from IP **pool** at the network server when it “joins” network

- can renew its lease on address in use
- allows reuse of addresses (only hold address while connected/on)
- support for mobile users who join/leave network

DHCP overview:

- host broadcasts DHCP discover msg [optional]
- DHCP server responds with DHCP offer msg [optional]
- host requests IP address: DHCP request msg
- DHCP server sends address: DHCP ack msg

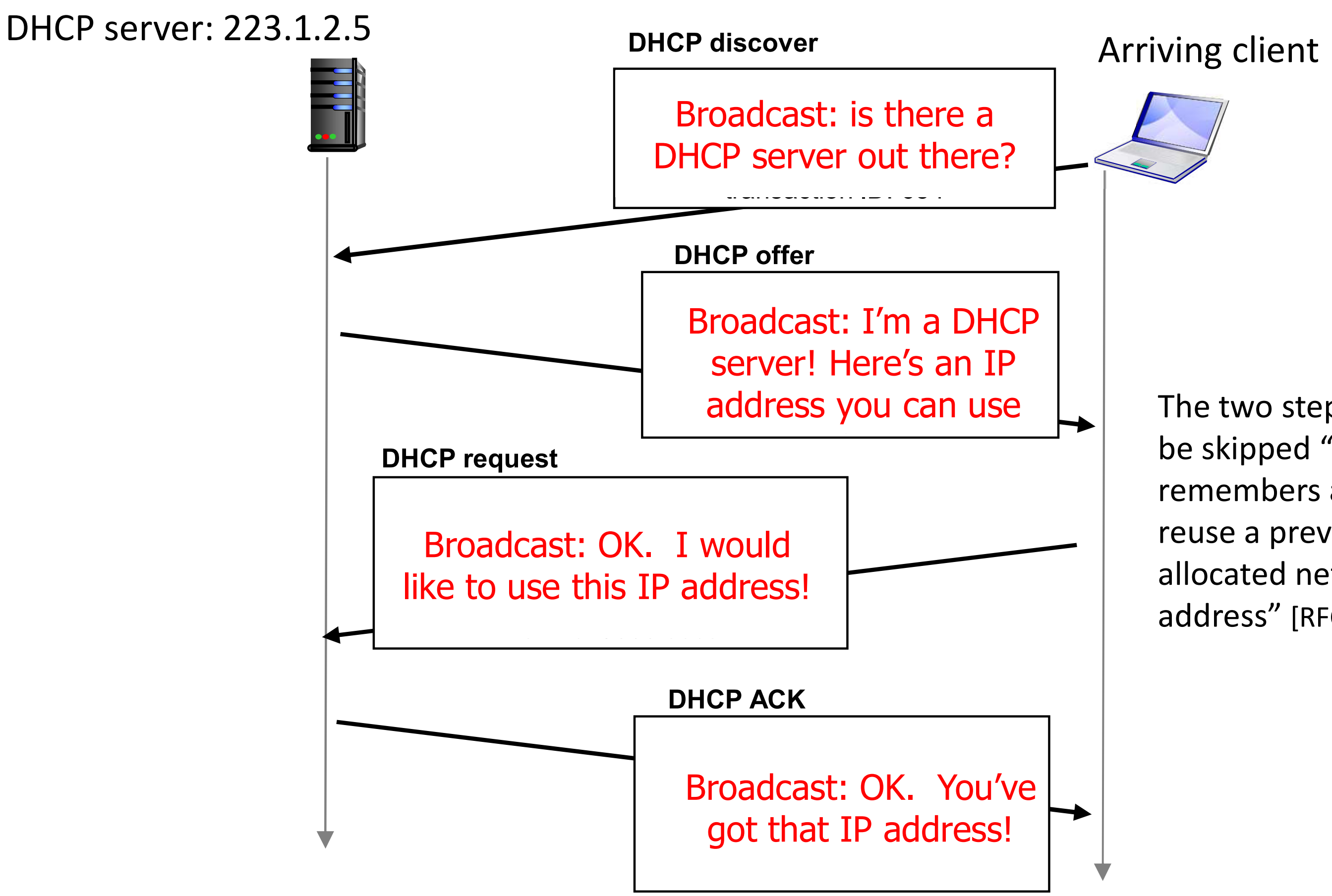
DHCP client-server scenario



Typically, DHCP server will be co-located in router, serving all subnets to which router is attached

arriving DHCP client needs address in this network

DHCP client-server scenario


DHCP server: 223.1.2.5
Arriving client
DHCP discover
Broadcast: is there a DHCP server out there?
DHCP offer
Broadcast: I'm a DHCP server! Here's an IP address you can use
DHCP request
Broadcast: OK. I would like to use this IP address!
DHCP ACK
Broadcast: OK. You've got that IP address!

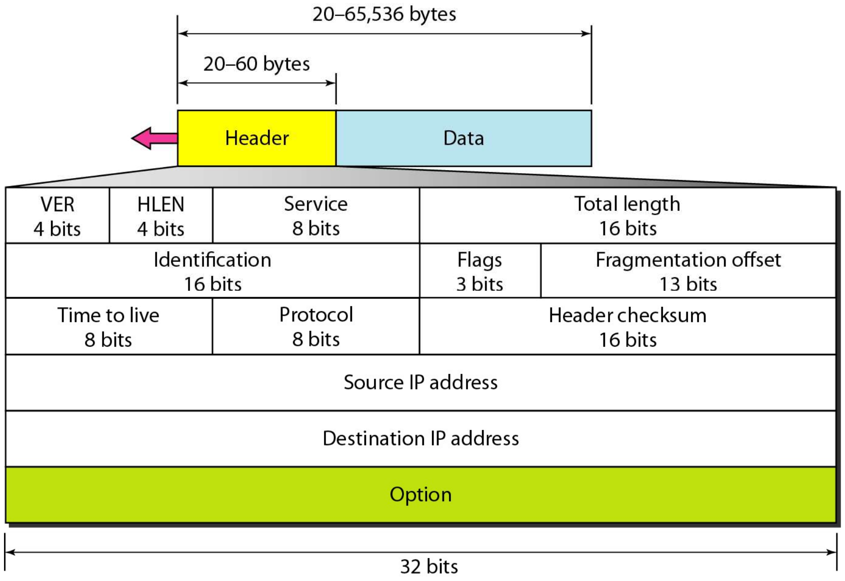
The two steps above can be skipped "if a client remembers and wishes to reuse a previously allocated network address" [RFC 2131]

IPv6

- IPv6 is created to address the fear that address space of IPv4 may run out soon
- Increasing the size of the address field dictates a change in IP header format – a new version of Internet Protocol
- In addition to the need to accommodate scalable routing and addressing, other desirable features are:
  - Support for real-time audio/video service (min delay and resource reservation)
  - Security support (encryption and authentication)
  - Auto configuration
  - Enhanced routing functionality

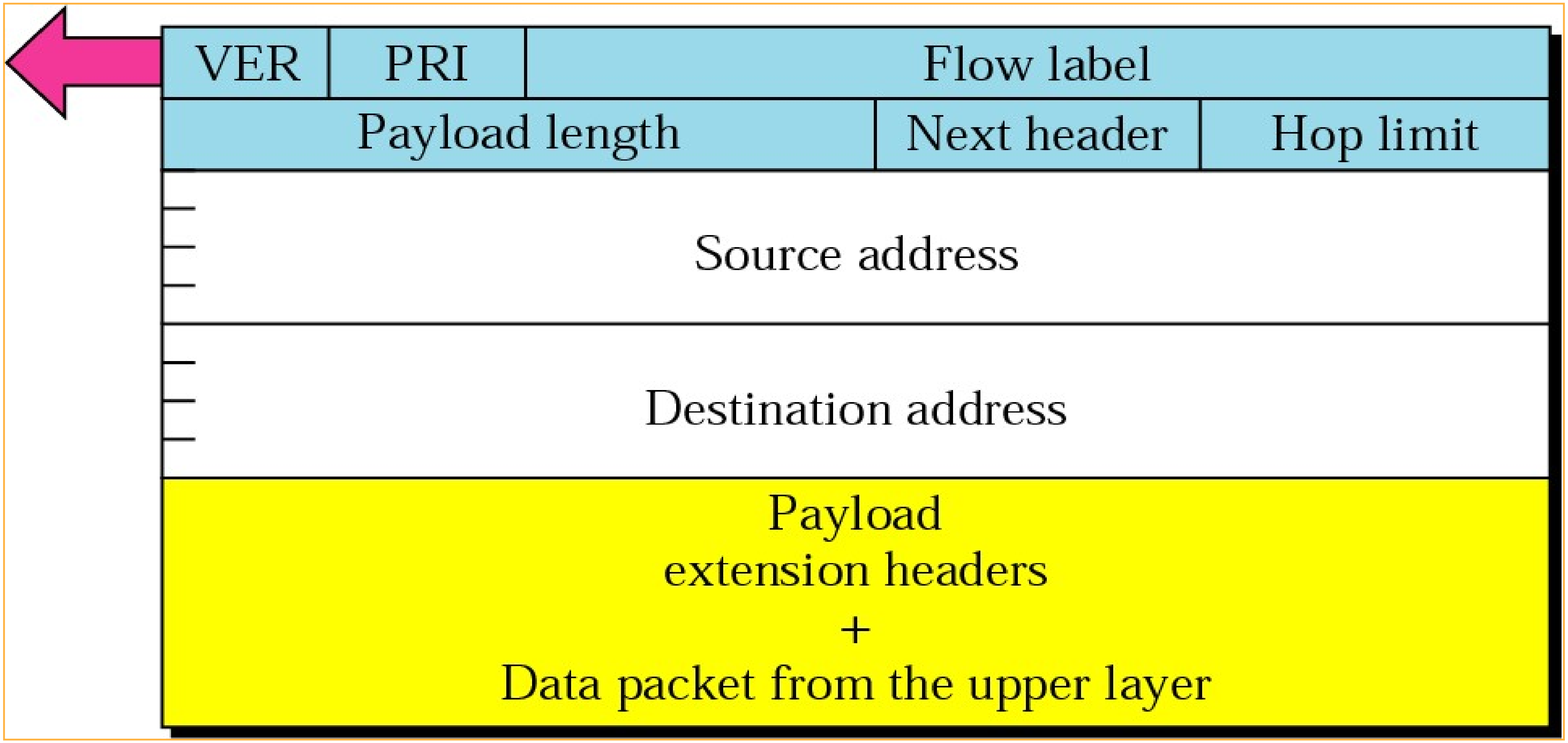
Advantages of IPv6

- Larger address space – An IPv6 address is 128 bits long
- Better header format – options separated from base header speeds up routing
- Support for resource allocation – flow labels used for special handling of packets
- Support for more security – encryption and authentication option
- Allowance for extension
- New options



IPv4 Datagram Format

IPv6 Header Format



VER | PRI | Flow label

Payload length | Next header | Hop limit

Source address

Destination address

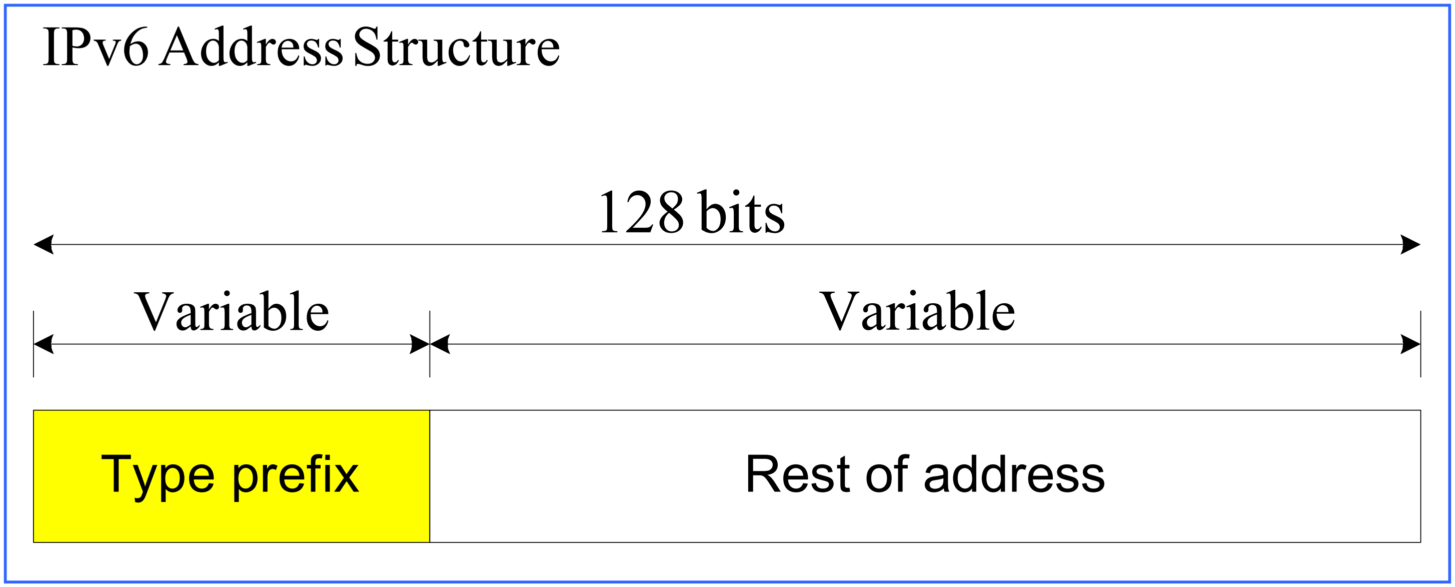
Payload
extension headers
+
Data packet from the upper layer

IPv6 Header Format

- Mandatory Base Header (40 bytes) has 8 fields
  - Version: indicate the version number of the IP protocol
  - Priority: priority of each packets with respect to other packets
  - Flow label: can be used to provide special handling for a particular flow of data (e.g., travelling the same path, using same resources, etc.)
  - PayloadLen: indicates the length of the packet, excluding the IPv6 header
  - NextHeader: replaces optional field and protocol field of IPv4
    - Indicate whether there are more headers (options) follow
    - Indicate higher layer protocols running over IP
  - HopLimit: the same as TTL in IPv4

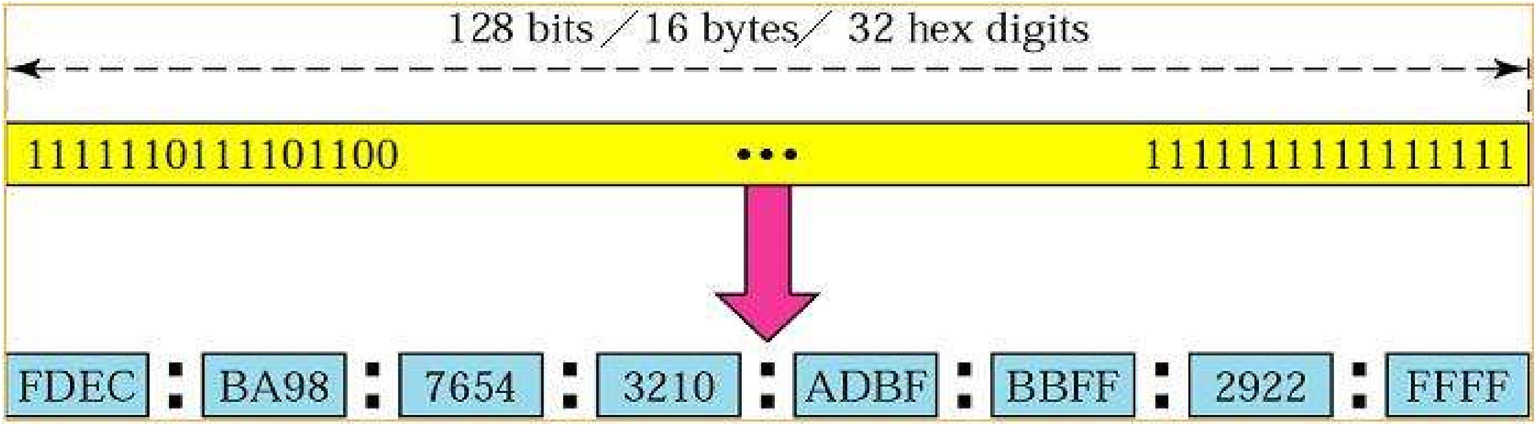
IPv6 Address Types

- The address space is divided into two parts with the first part called the *type prefix*
- Address Types
  - Unicast, Multicast, Anycast, Reserved, Local



Representation of IPv6 address

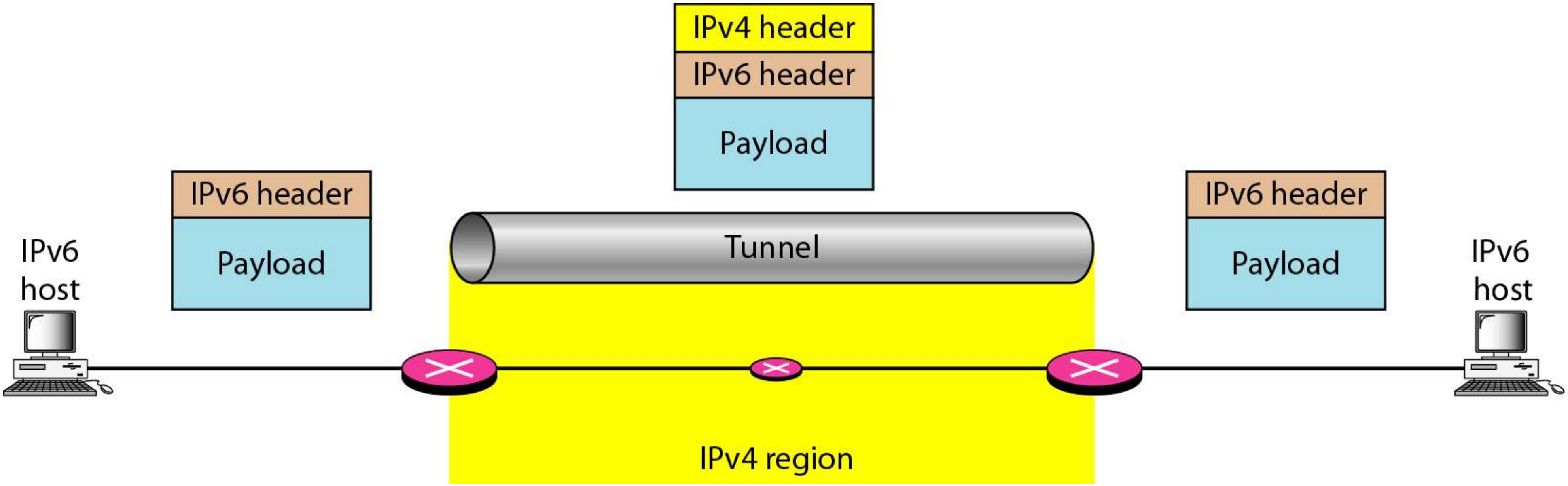
- IPv6 specifies hexadecimal colon notation consisting of 32 hex digits



Transition from IPv4 to IPv6

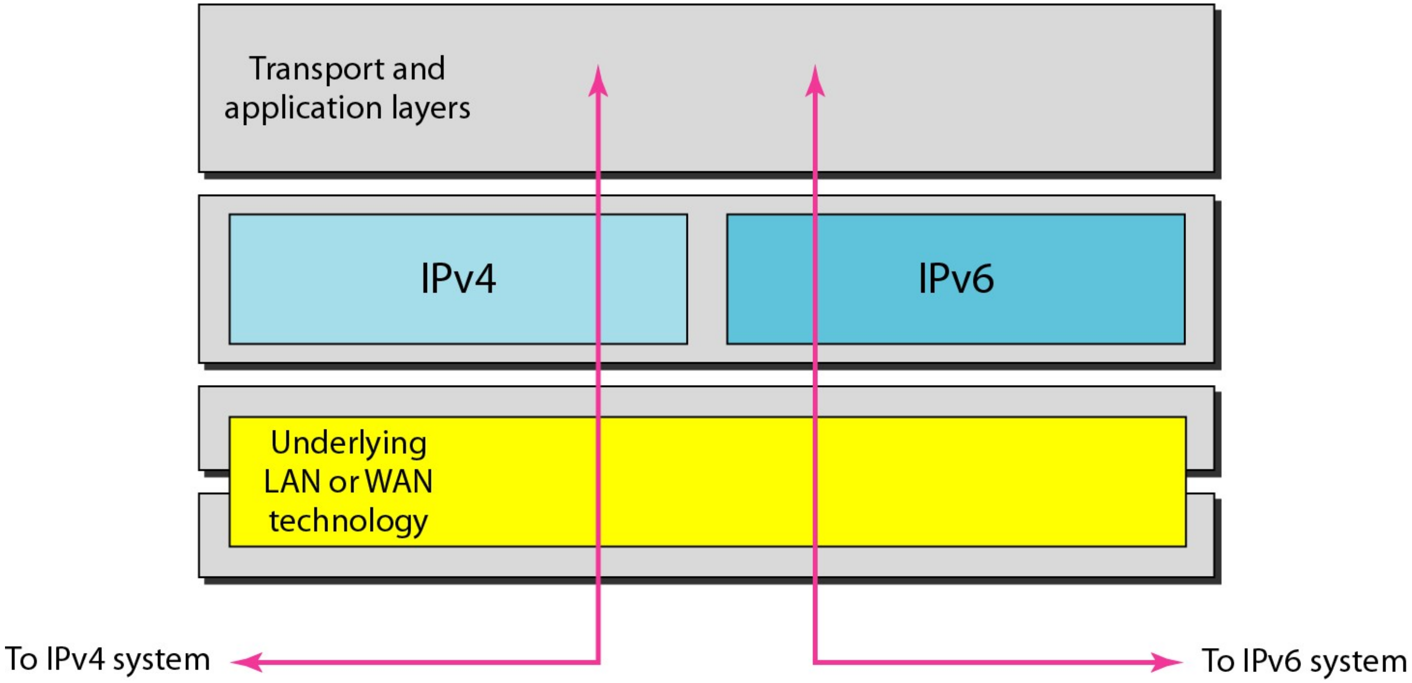
- Not all routers can be upgraded simultaneously
  - no “flag days”
  - How will the network operate with mixed IPv4 and IPv6 routers?
- Two proposed approaches:
  - *Dual Stack*: some routers with dual stack (v6, v4) can “translate” between formats
  - *Tunneling:* IPv6 carried as payload in IPv4 datagram among IPv4 routers

Tunneling


IPv4 header
IPv6 header
Payload
IPv6 header
Payload
Tunnel
IPv6 header
Payload
IPv6
host
IPv6
host
IPv4 region

Dual Stack

- IPv6 nodes have a complete IPv4 implementation
  - Use IPv6 when interact with IPv6 nodes
  - Use IPv4 when interact with IPv4 nodes
  - IPv6/IPv4 nodes must have both IPv6 and IPv4 capabilities


Transport and application layers
IPv4
IPv6
Underlying LAN or WAN technology
To IPv4 system
To IPv6 system

Recommended Reading

- Behrouz A. Forouzan, Data Communications and Networking with TCP/IP Protocol Suite, 6th ed., 2022, Chapters 7

- J. F. Kurose and K. W. Ross, Computer Networking: A Top-Down Approach, 8th ed., 2022, Chapter 4