# COMP 3331/9331: Computer Networks and Applications

Week 7

Network Layer: Data Plane

**Reading Guide: Chapter 4: Sections 4.1, 4.3**

# Network Layer, data plane: outline

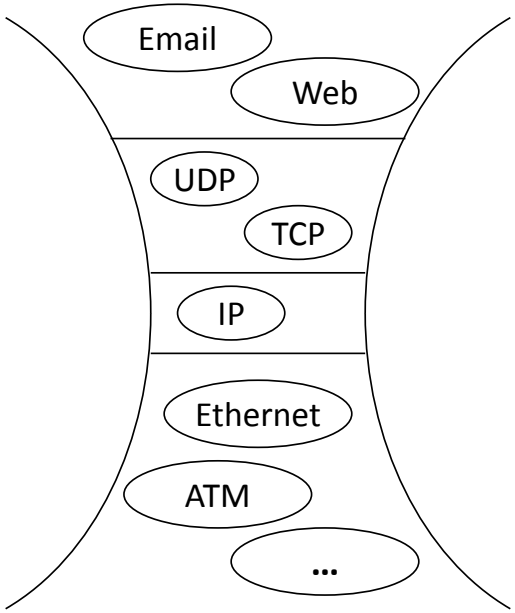
4.1 Overview of Network layer
- data plane
- control plane

4.2 What's inside a router
-- **Not Covered**

4.3 IP: Internet Protocol
- datagram format
- fragmentation
- IPv4 addressing
- network address translation
- IPv6

4.4 Generalized forwarding and Software Defined Networking (SDN)
- **Not Covered**

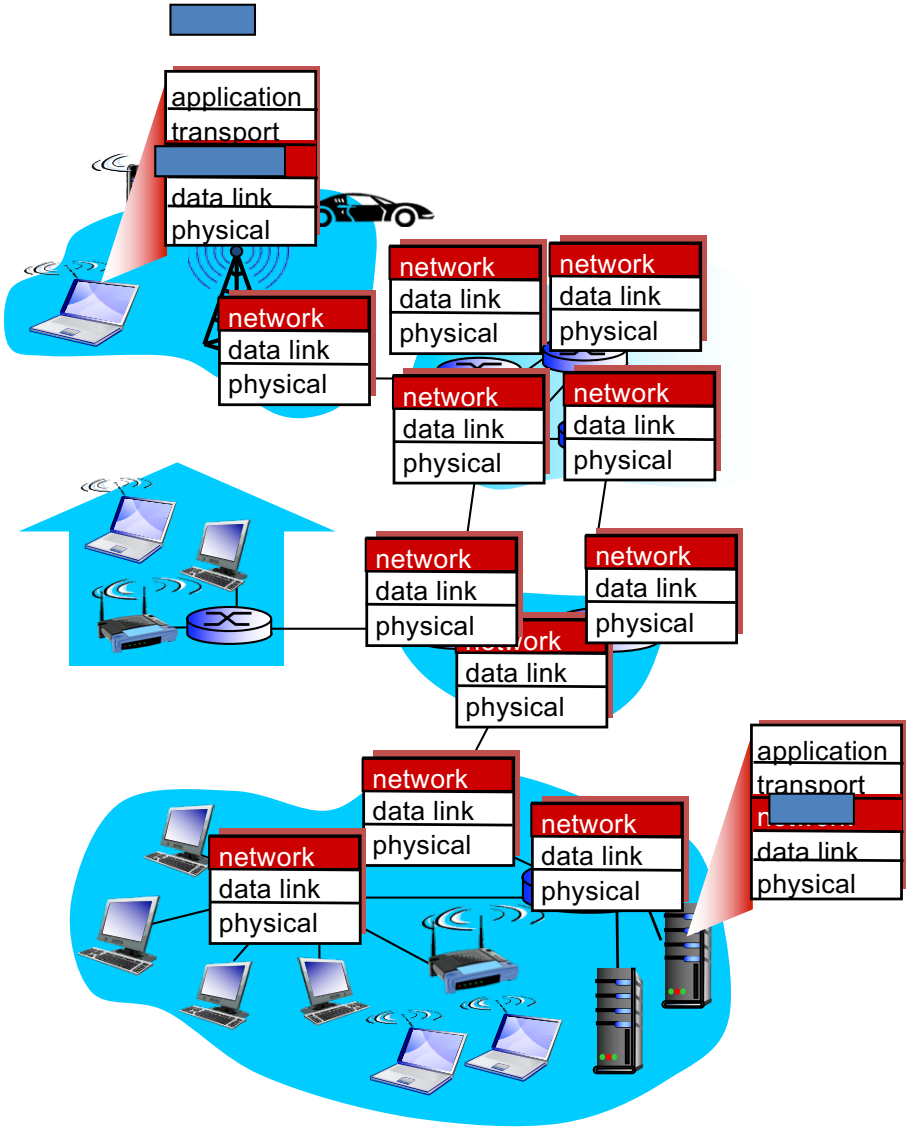
# Internetworking




- Cerf & Kahn in 1974,
  - "A Protocol for Packet Network Intercommunication"
  - Foundation for the modern Internet
- **Routers** forward **packets** from source to destination
  - May cross many separate networks along the way
- All packets use a common **Internet Protocol**
  - Any underlying data link protocol
  - Any higher layer transport protocol

# Network Layer

- transport segment from sending to receiving host
- on sending side encapsulates 包含 segments into datagrams 数据电报
- on receiving side, delivers segments to transport layer
- network layer protocols in *every* host, router
- router examines header fields in all IP datagrams passing through it



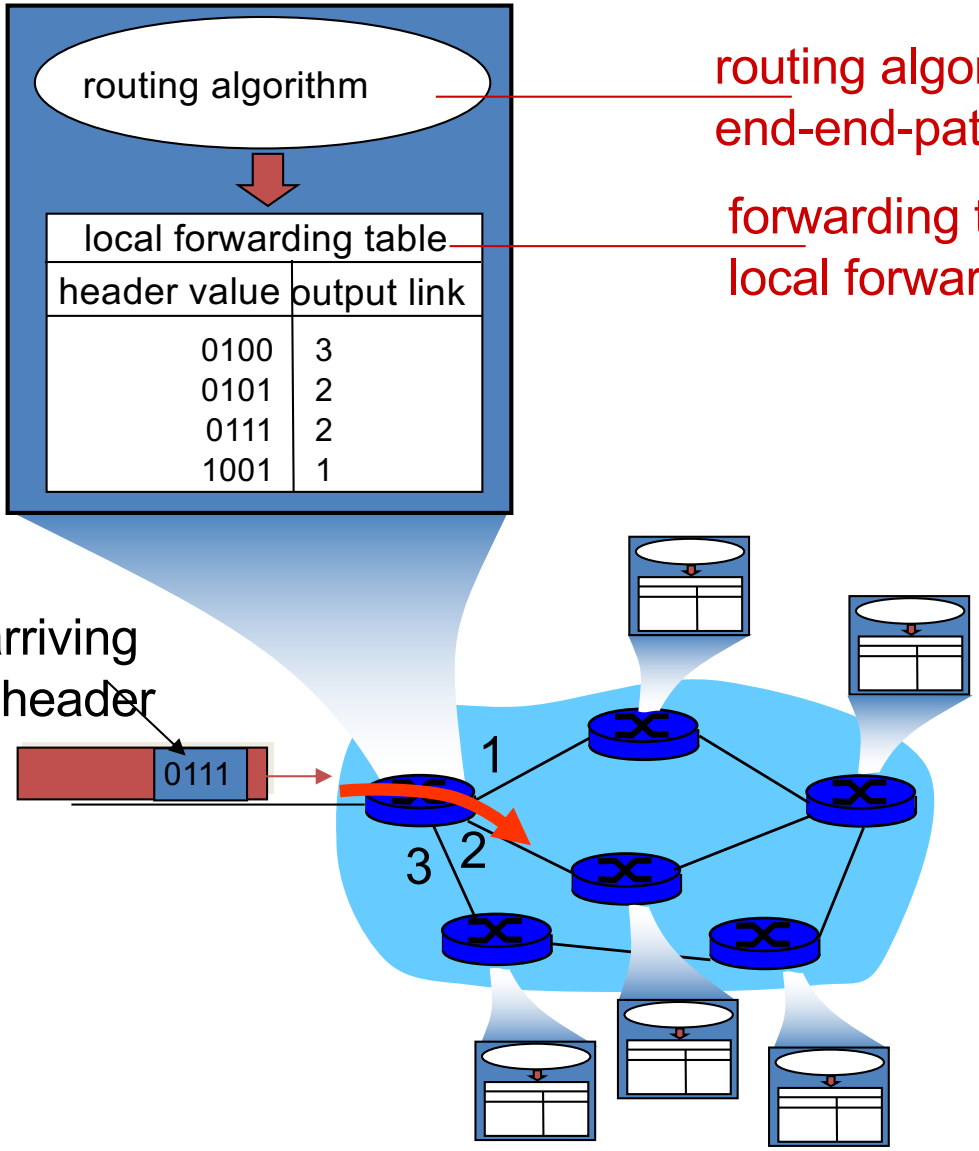
# Two key nework-layer functions

- *forwarding:* move packets from router's input to appropriate router output
- *routing:* determine route taken by packets from source to dest.
  - *routing algorithms*

*analogy:*

- *routing:* process of planning trip from source to dest
- *forwarding:* process of getting through single interchange

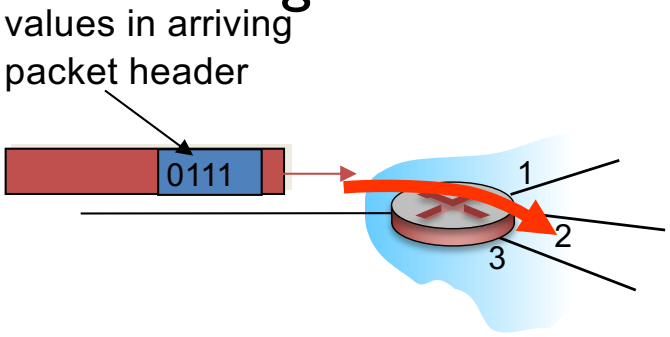
# Interplay between routing and forwarding



# Network Layer: data vs control plane

## *Data plane*

- local, per-router function
- determines how datagram arriving on router input port is forwarded to router output port
- forwarding function

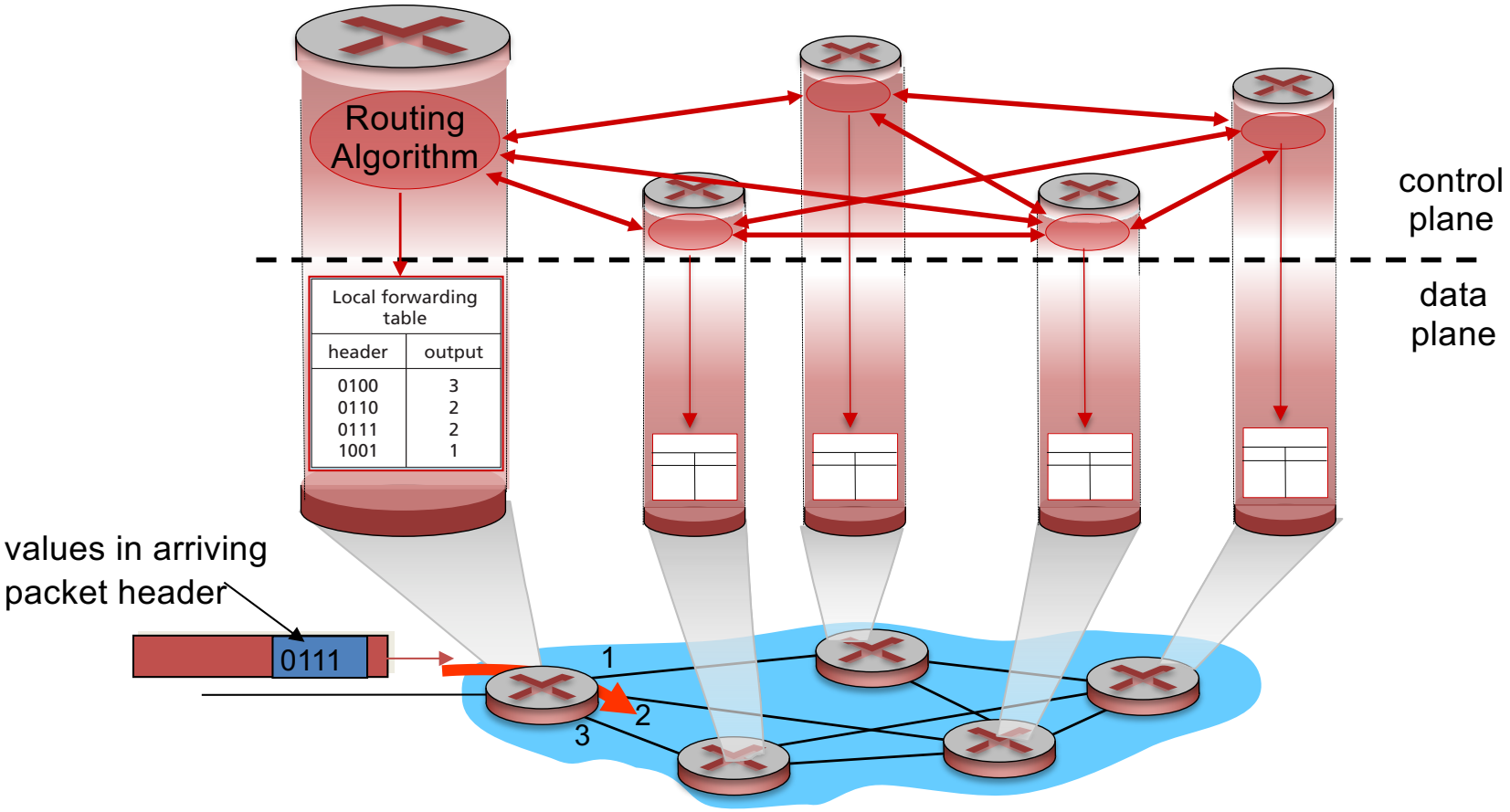



## *Control plane*

- network-wide logic
- determines how datagram is routed among routers along end-end path from source host to destination host
- two control-plane approaches:
  - *traditional routing algorithms:* implemented in routers
  - *software-defined networking (SDN)*: centralised (remote) servers

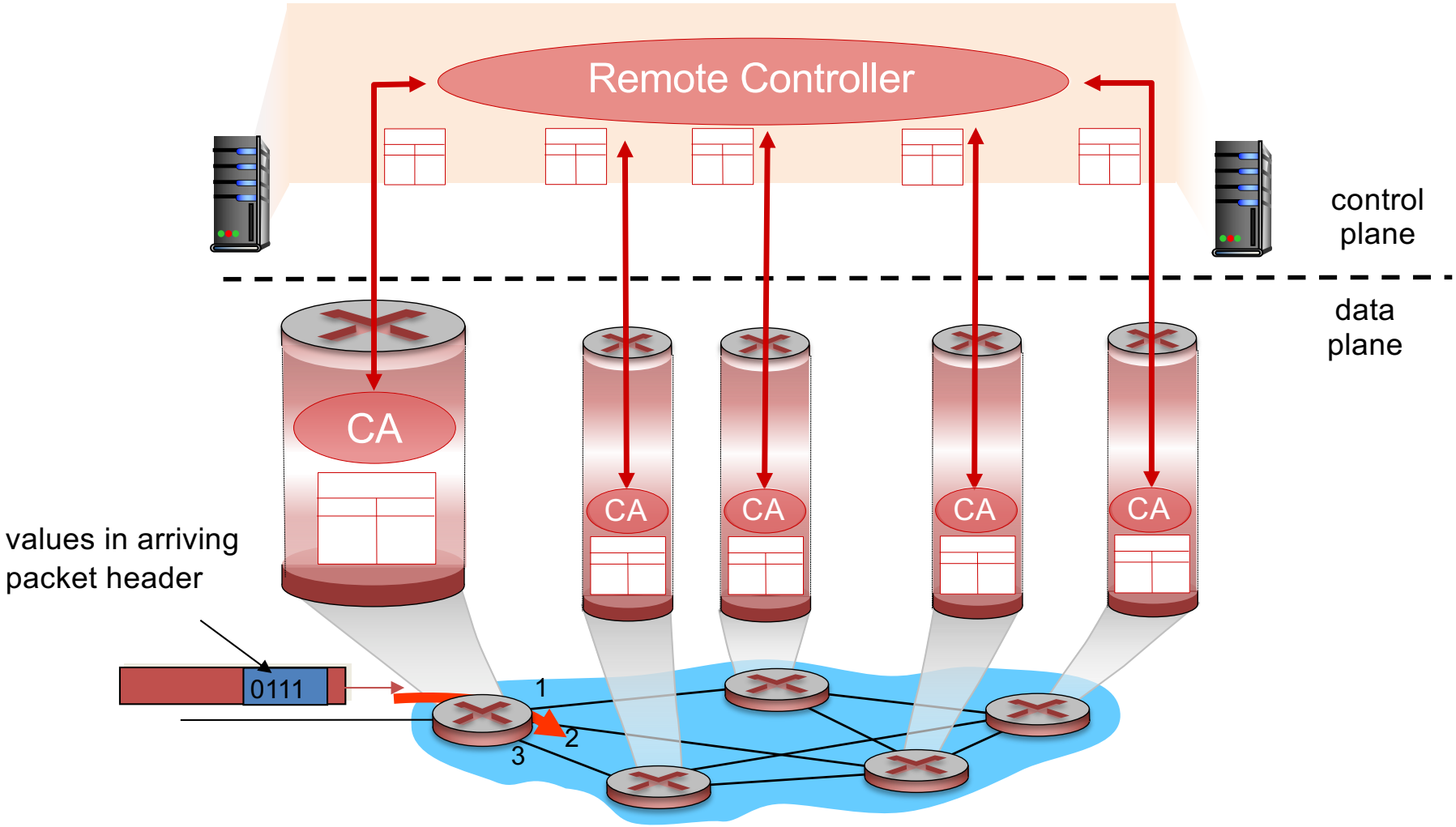
# Per-router control plane

Individual routing algorithm components *in each and every router* interact in the control plane



# Logically centralized control plane (SDN)

A distinct (typically remote) controller interacts with local control agents (CAs)



# Network Layer: service model

*Q:* What *service model* is used for transporting datagrams from sender to receiver?

A. No guarantee whatsoever is provided by IP layer in TCP/IP protocol stack. It's "best effort service".

# Network Layer, data plane: outline

4.1 Overview of Network layer
- data plane
- control plane

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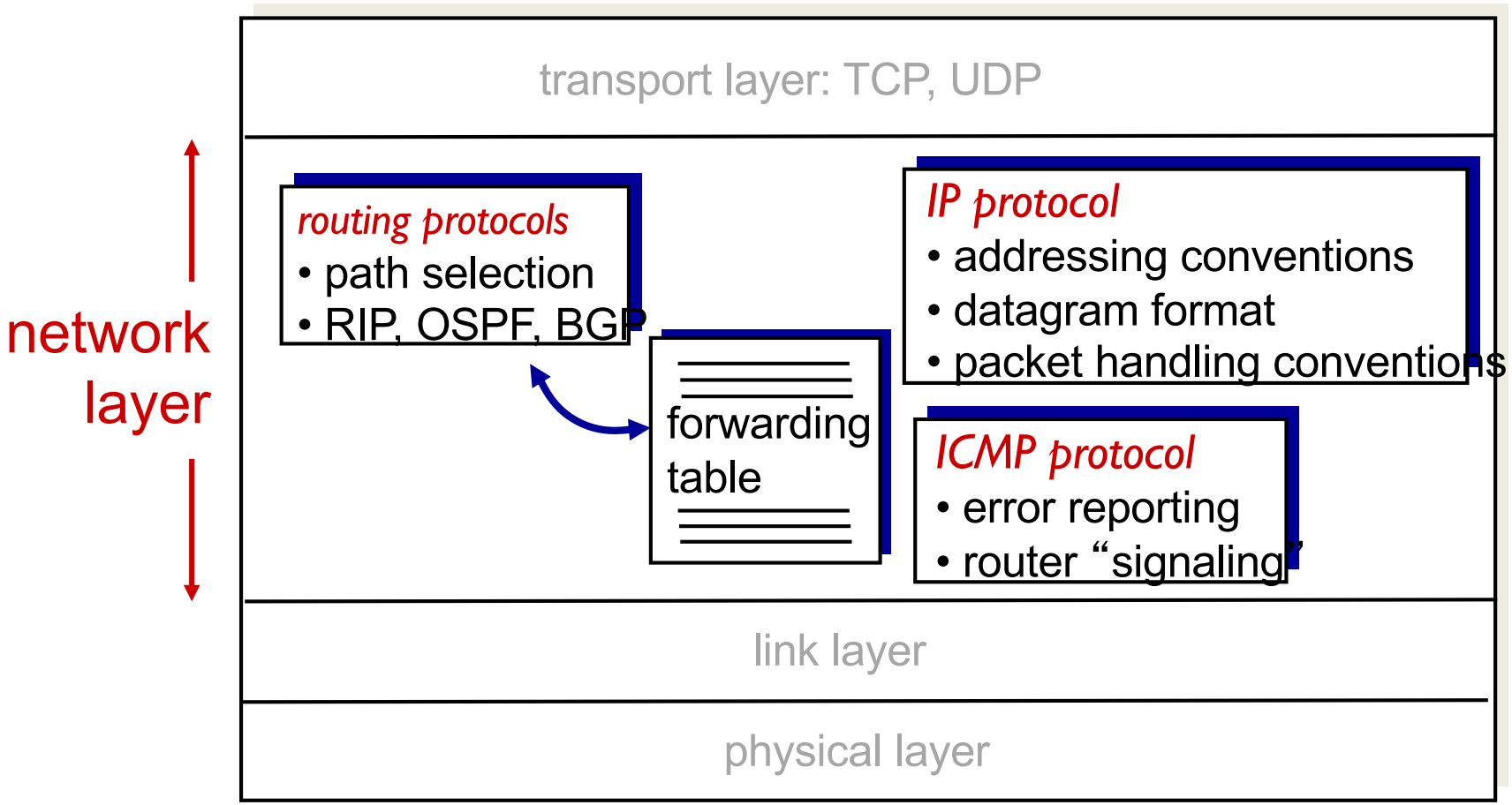
-- **Not Covered**

4.3 IP: Internet Protocol
- datagram format
- fragmentation
- IPv4 addressing
- network address translation
- IPv6

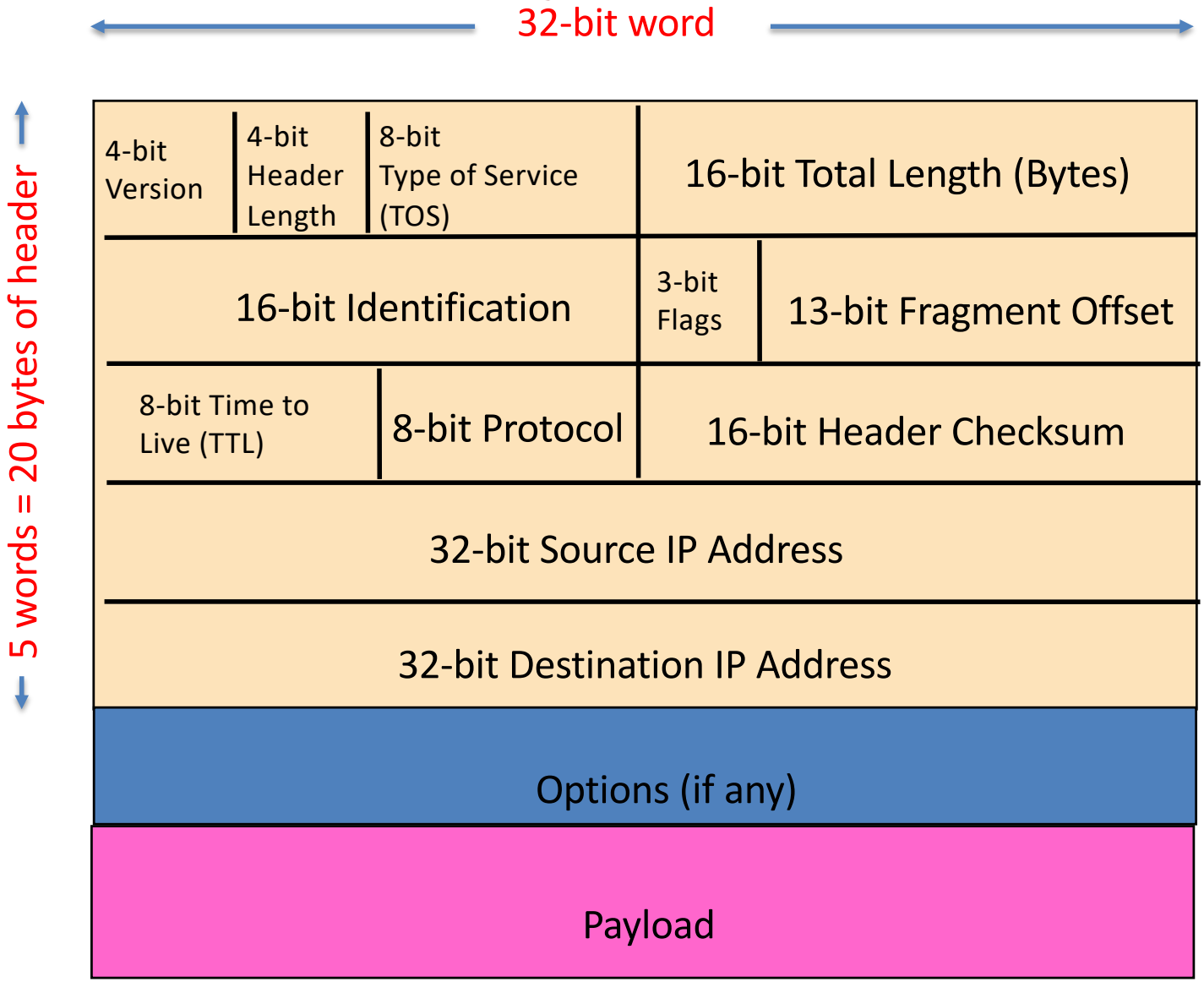
4.4 Generalized forwarding and Software Defined Networking (SDN)
- **Not Covered**

# The Internet network layer

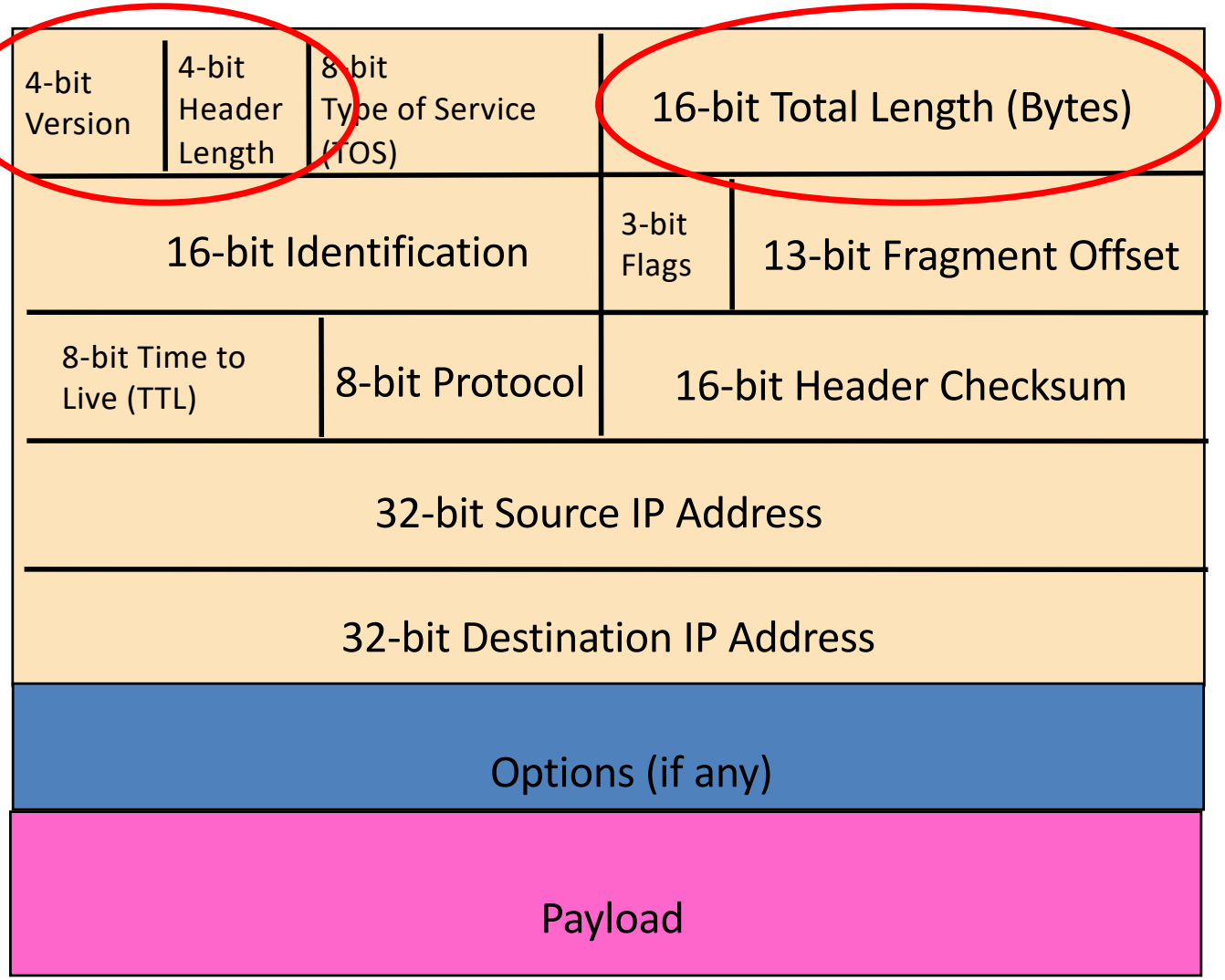
host, router network layer functions:



# IP Packet Structure



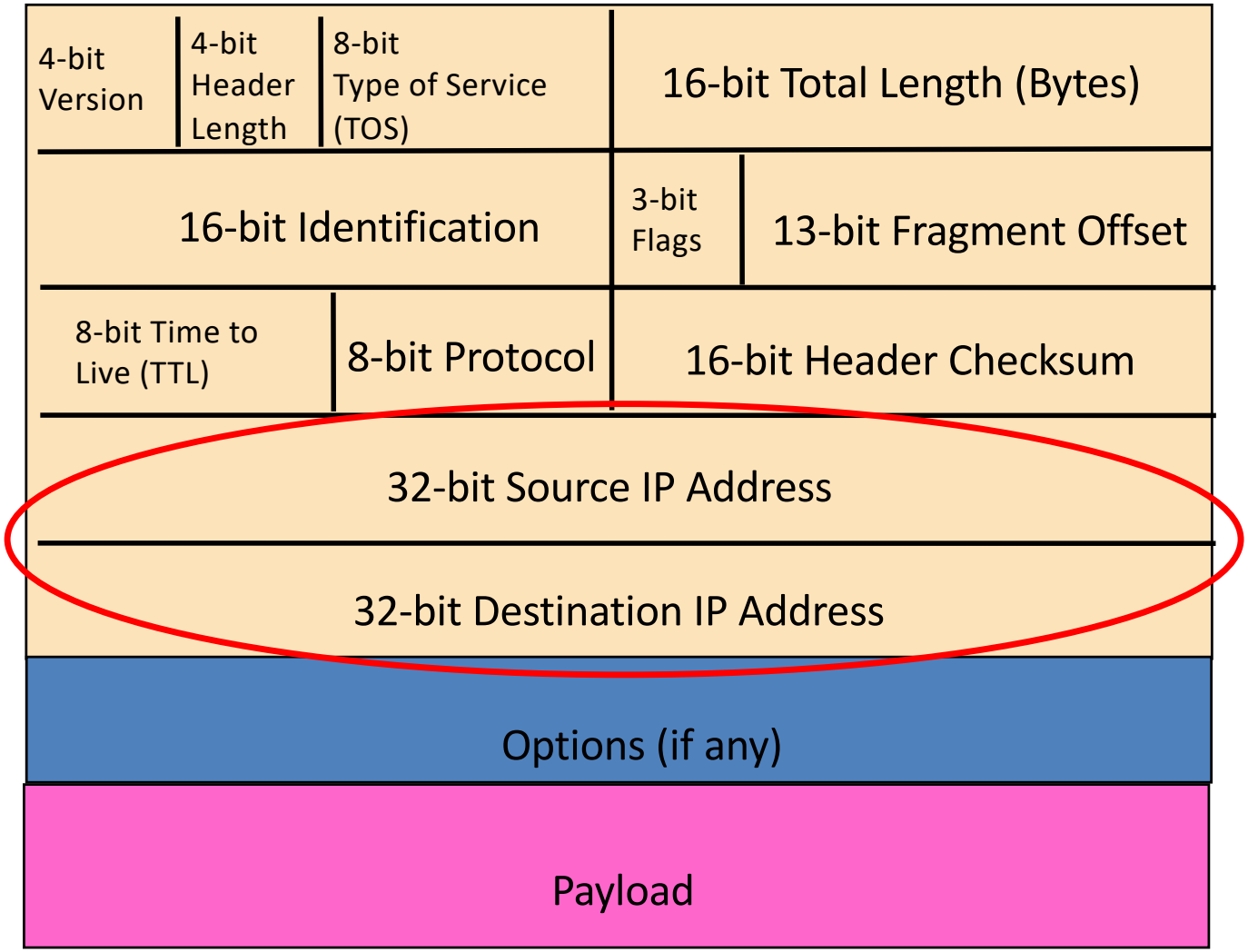
# Fields for Reading Packet Correctly



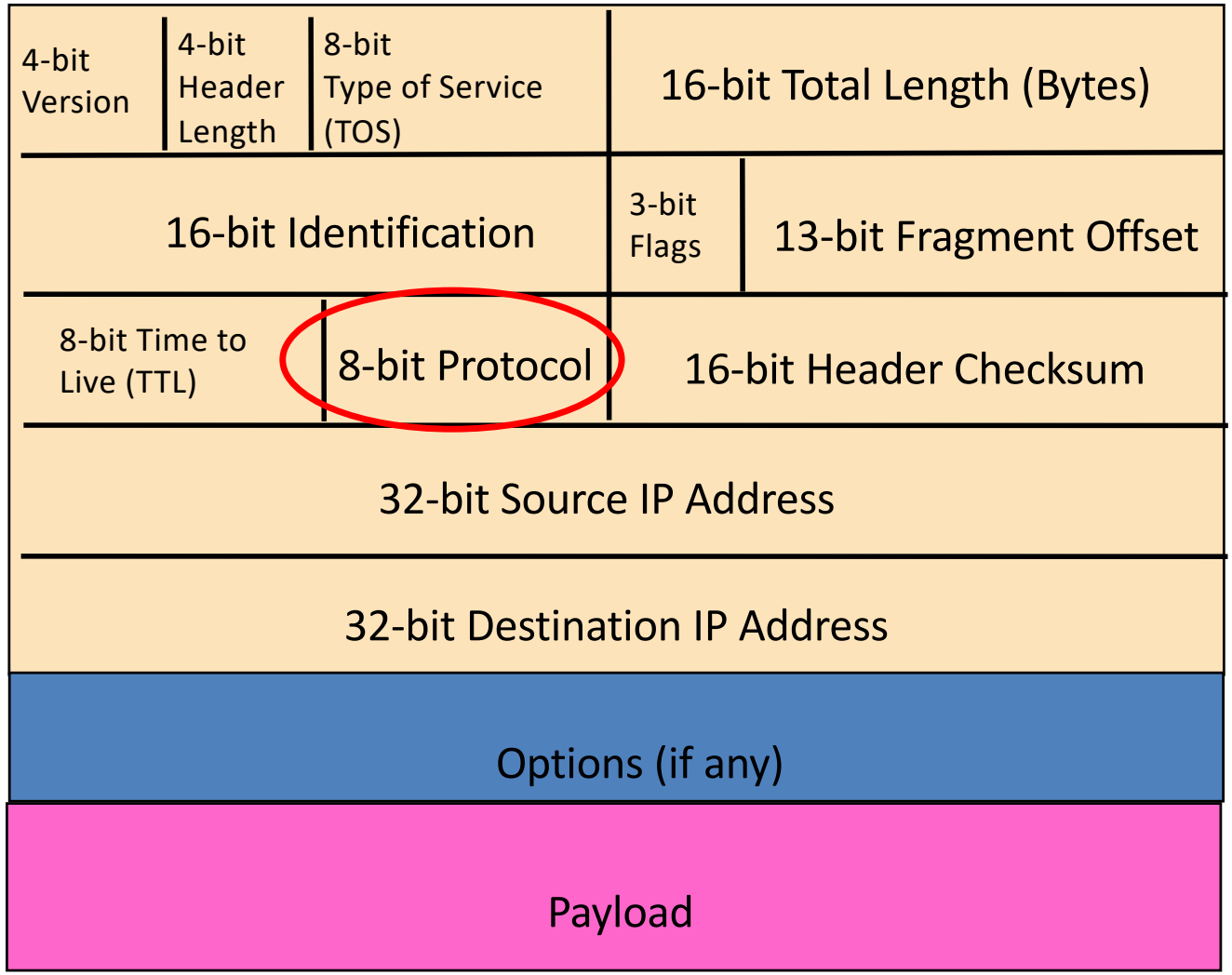
# Reading Packet Correctly

- Version number (4 bits)
  - Indicates the version of the IP protocol
  - Necessary to know what other fields to expect
  - Typically “4” (for IPv4)
- Header length (4 bits)
  - Number of 32-bit words in the header
  - Typically “5” (for a 20-byte IPv4 header): # of 32-bit words
  - Can be more when IP options are used
- Total length (16 bits)
  - Number of bytes in the packet
  - Maximum size is 65,535 bytes ($2^{16}$ -1)
  - … though underlying links may impose smaller limits

# Fields for Reaching Destination and Back



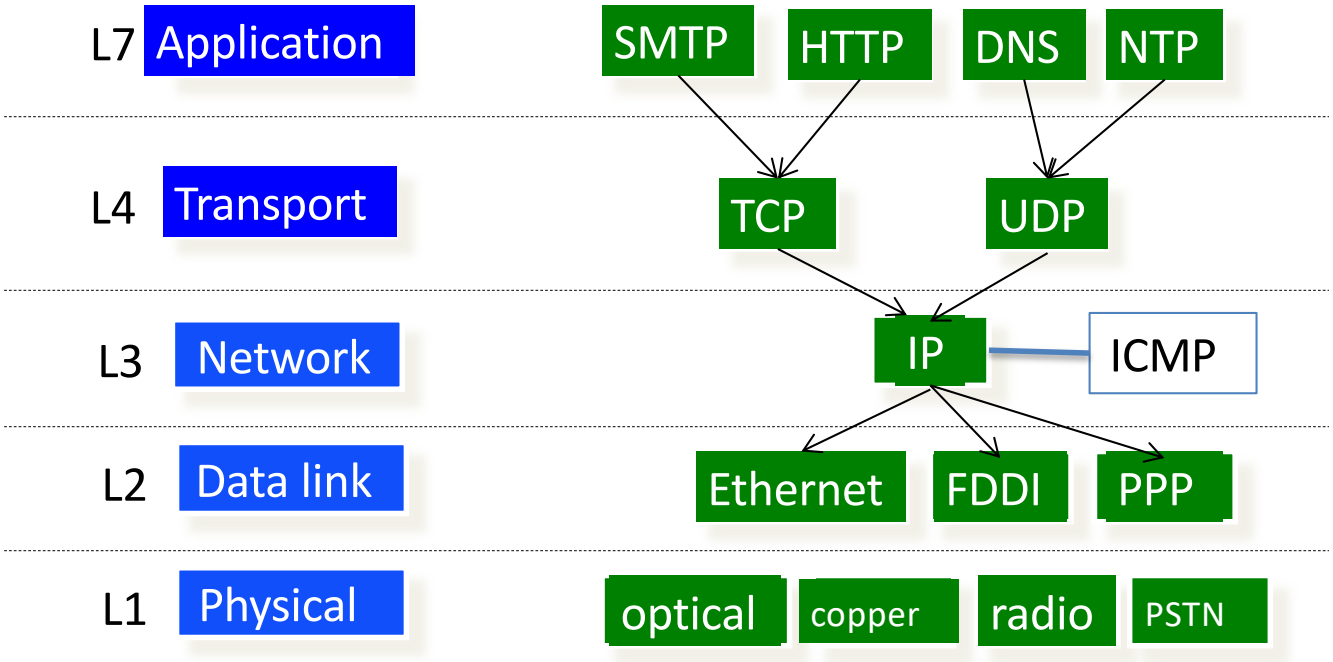
# Telling End-Host How to Handle Packet



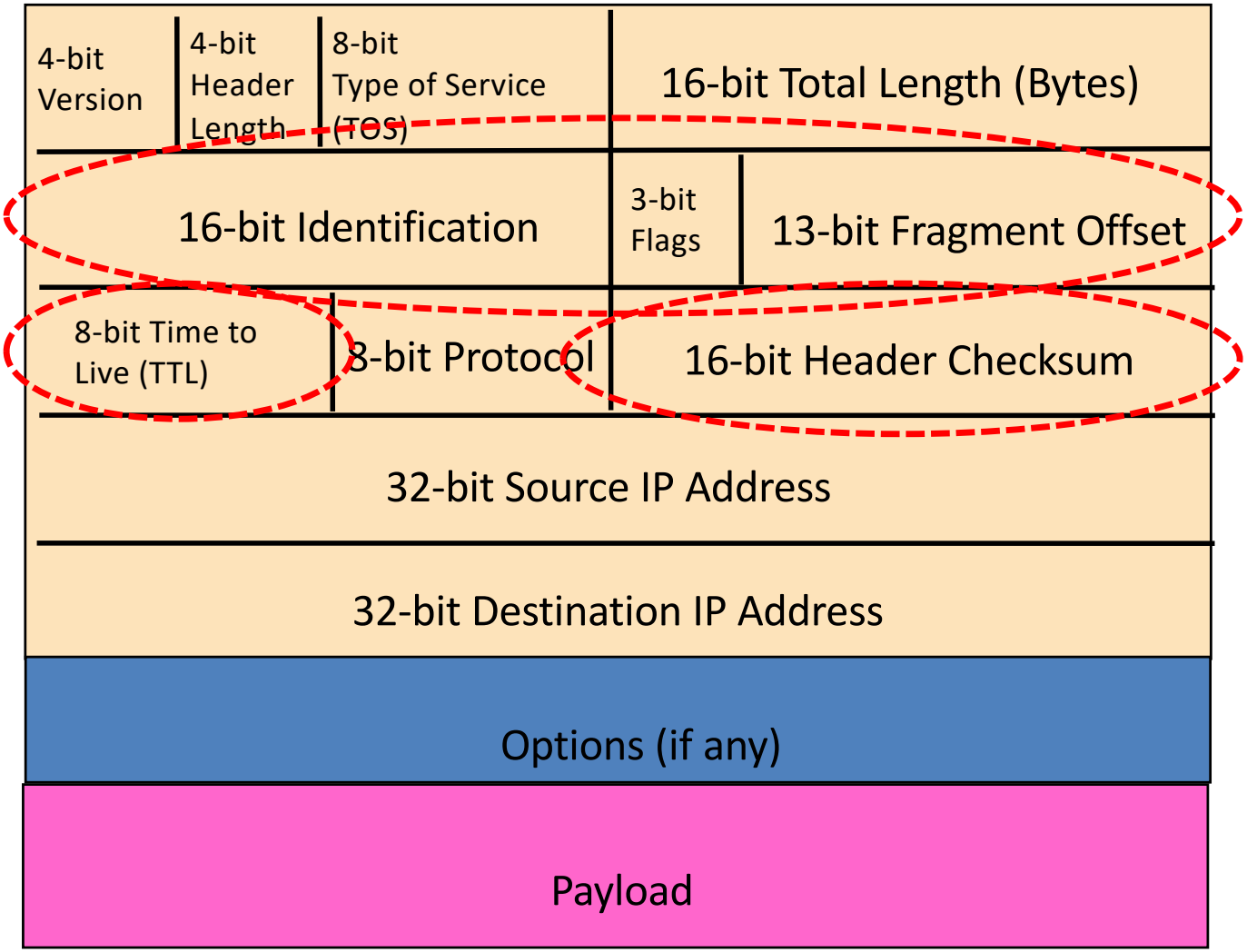
# Telling End-Host How to Handle Packet

6 TCP
17 UDP
1 ICMP

- Protocol (8 bits)
  - Identifies the higher-level Transport protocol
  - Important for demultiplexing at receiving host



# Checksum, TTL and Fragmentation Fields



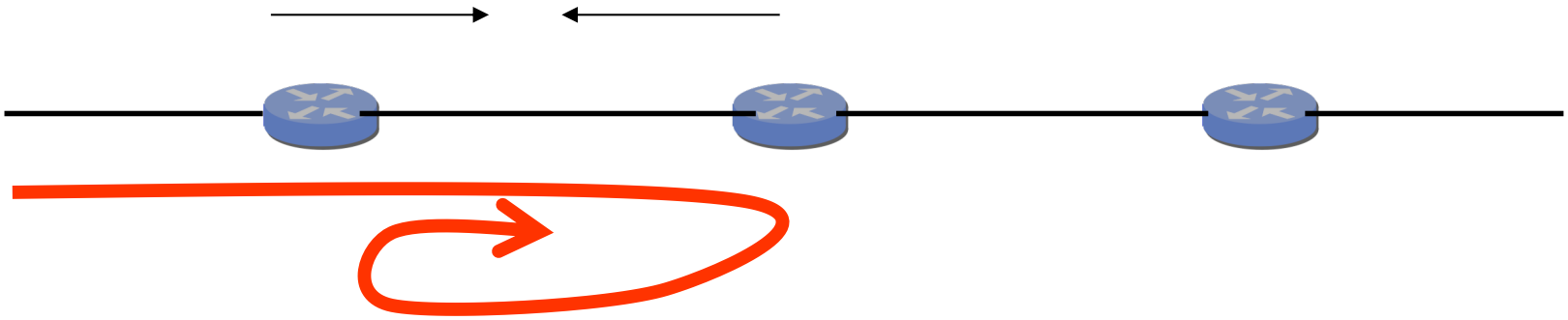
# Potential Problems

- Loop: **TTL**
- Header Corrupted: **Checksum**
- Packet too large: **Fragmentation**

Note: Checksum checks the integrity of the *header* only

# Preventing Loops (TTL)

- Forwarding loops cause packets to cycle for a long time
  - As these accumulate, eventually consume **all** capacity



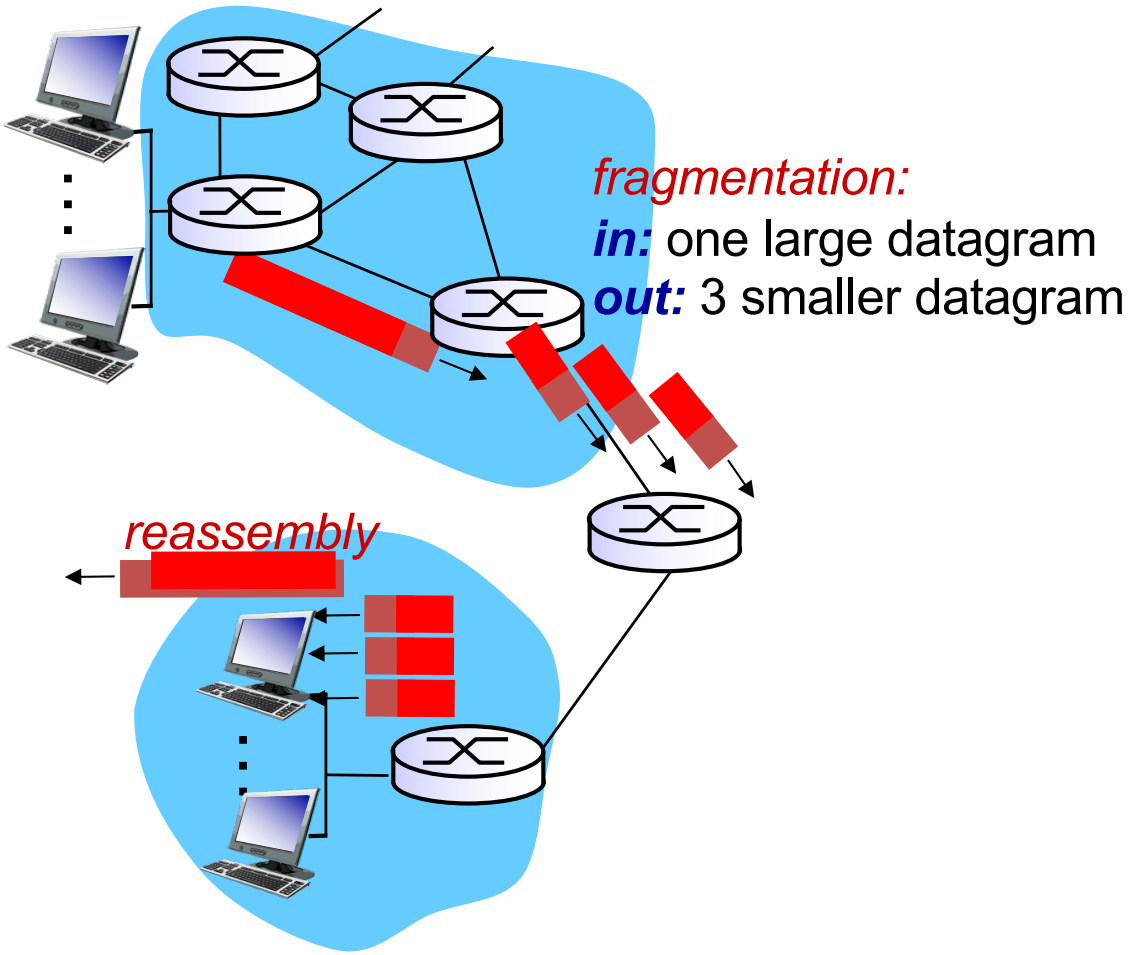
- Time-to-Live (TTL) Field (8 bits)
  - Initially set to usually 255 (all 1's)
  - Decremented at each hop, packet discarded if reaches 0
  - …and "time exceeded" ICMP message is sent to the source

# Header Corruption (Checksum)

- Checksum (16 bits)
  - Particular form of checksum over packet header
- If not correct, router discards packets
  - So it doesn't act on bogus information
- Checksum recalculated at every router
  - **Why only header?** **(A. payload already protected by checksum in TCP/UDP)**

# IP fragmentation, reassembly

- network links have MTU (max.transfer size) - largest possible link-level frame
  - different link types, different MTUs
- large IP datagram divided ("fragmented") within net
  - one datagram becomes several datagrams
  - "reassembled" only at final destination
  - IP header bits used to identify and order related fragments



# IP fragmentation, reassembly

MF=0 and Offset=0 -> this datagram is not a fragment  MF = more fragments


*example:*

- 4000-byte datagram
- MTU = 1500 bytes

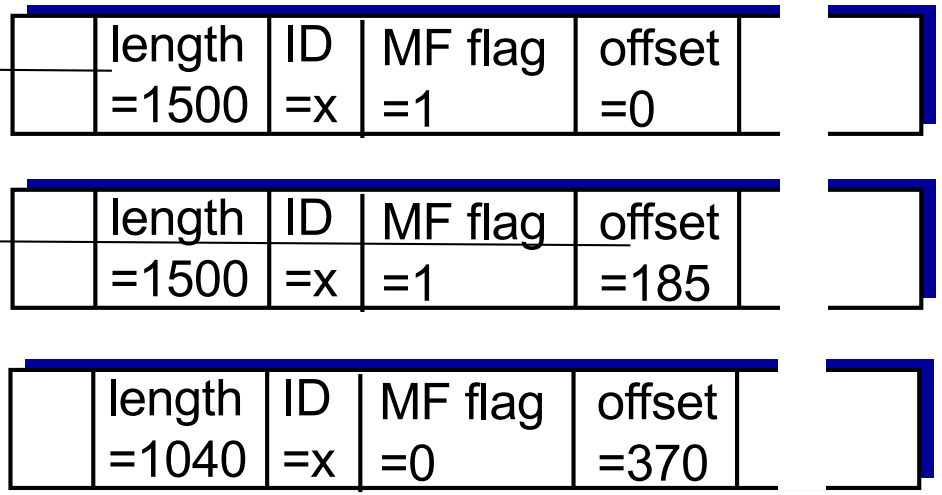
*one large datagram becomes several smaller datagrams*

Data = 4000 – 20 (IP header) =3980
F1=1480
F2=1480
F3=1020

1480 bytes in data field

offset = 1480/8 = 185

offset = 185x2 = 370

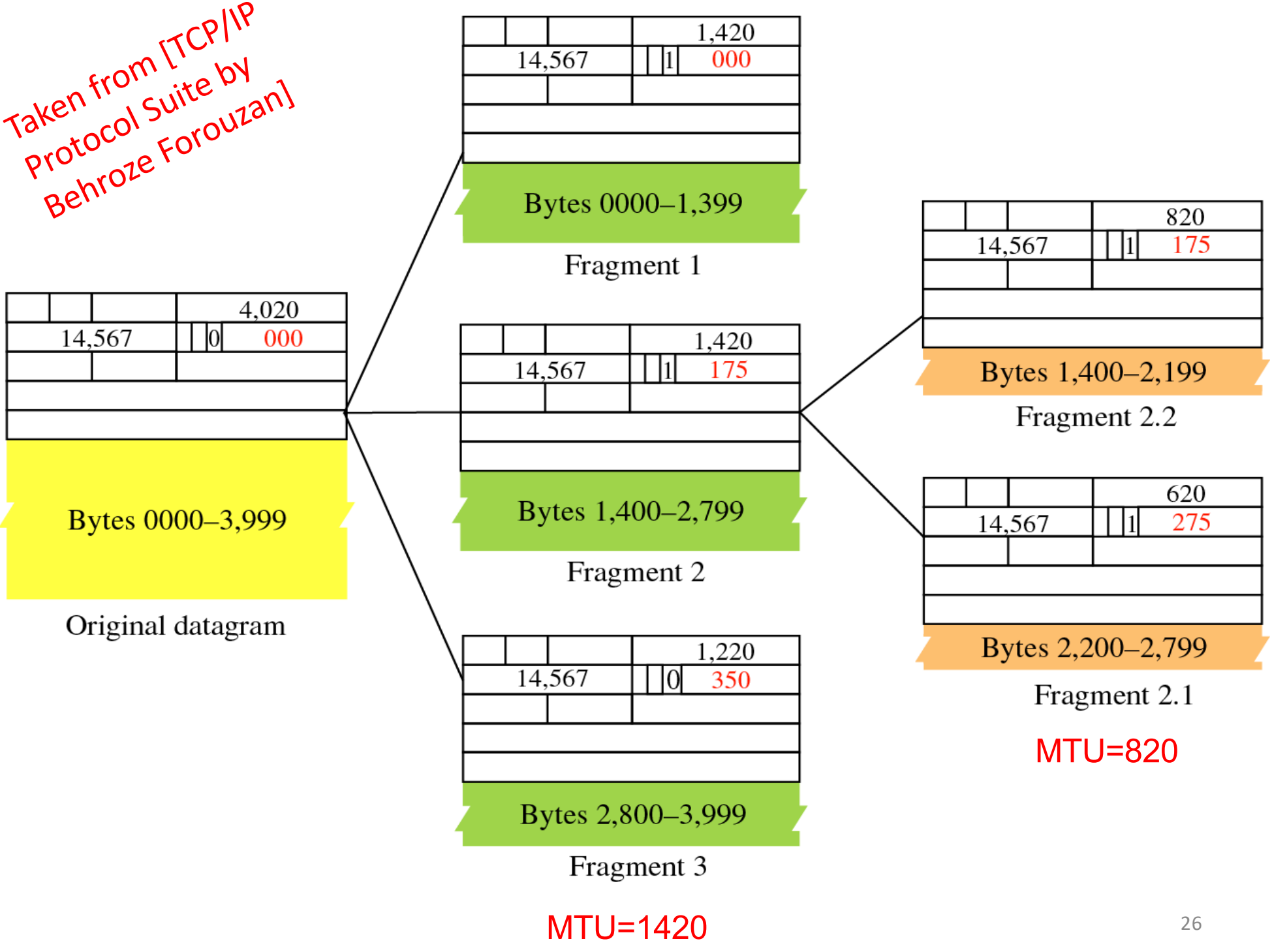



There are online IP fragmentation calculators

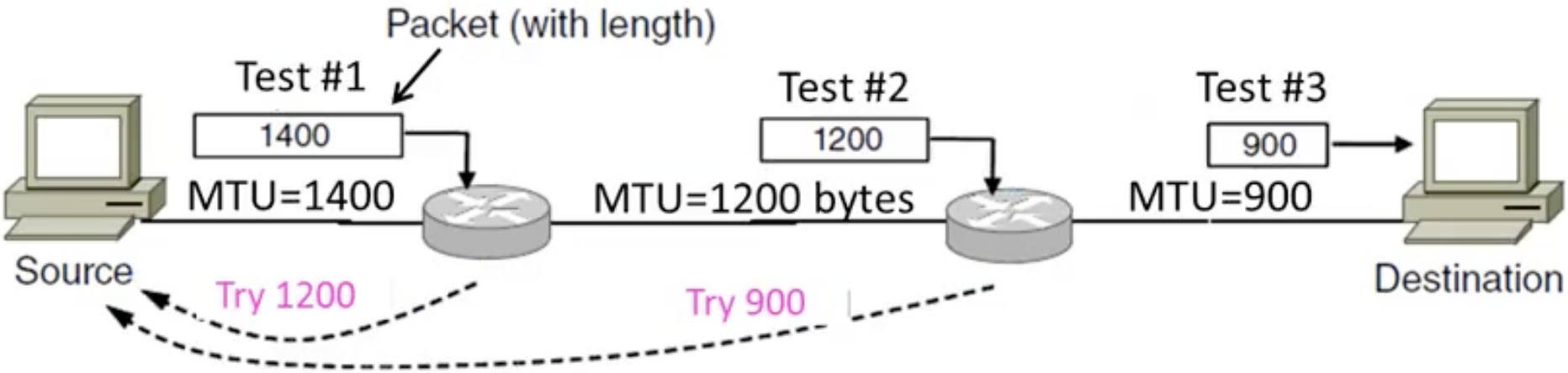
# IPv4 fragmentation procedure

- Fragmentation
  - Router breaks up datagram in size that output link can support
  - Copies IP header to pieces
  - Adjust length on pieces
  - Set offset to indicate position
  - Set MF (More fragments) flag on pieces except the last
  - Re-compute checksum
- Re-assembly
  - Receiving host uses identification field with MF and offsets to complete the datagram.
- Fragmentation of fragments also supported

Taken from [TCP/IP Protocol Suite by Behroze Forouzan]

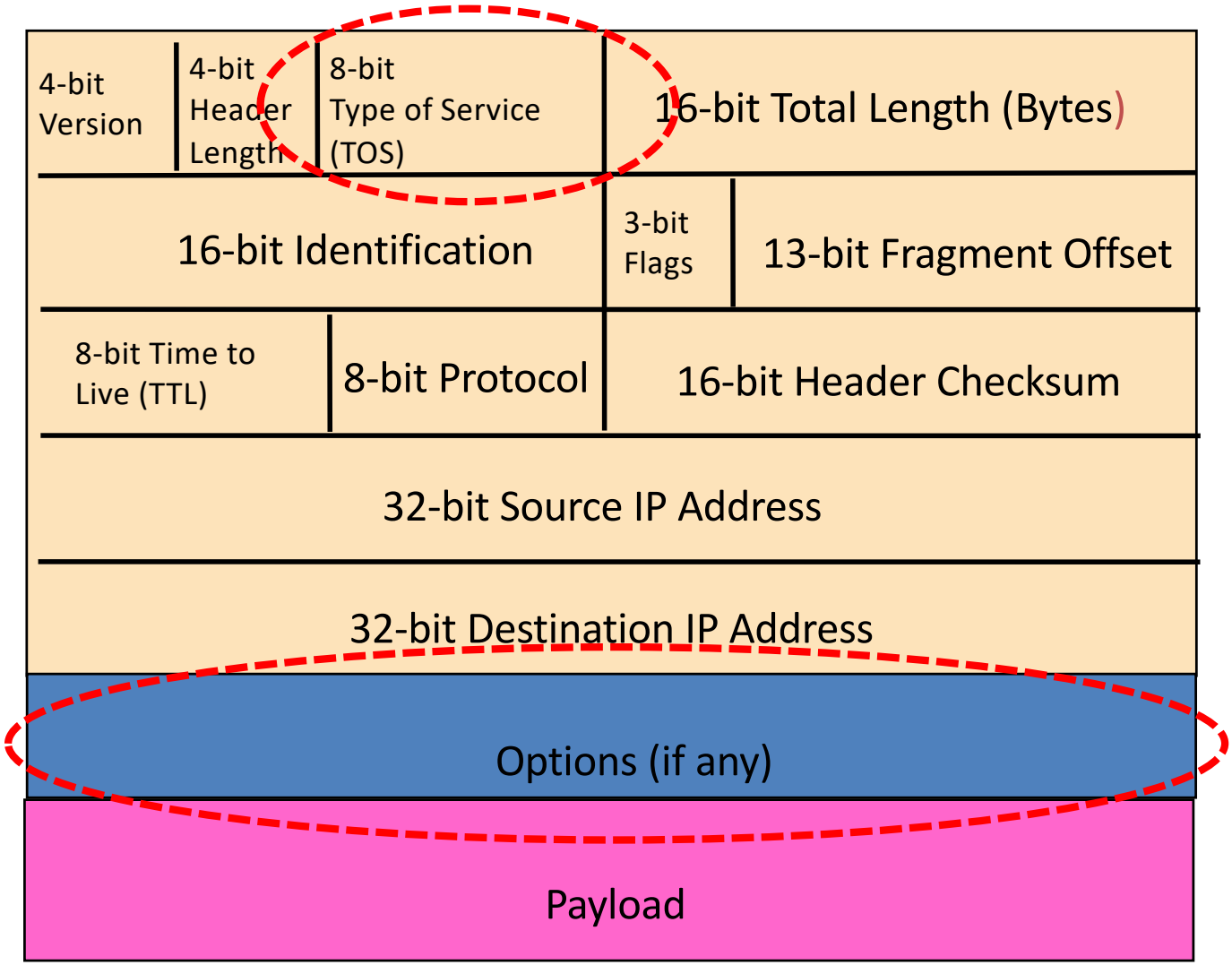


# Path MTU Discovery procedure




- Host
  - Sends a big packet to test whether all routers in path to the destination can support or not
  - Set DF (Do not fragment) flag
- Routers
  - Drops the packet if it is too large (as DF is set)
  - Provides feedback to Host with ICMP message telling the maximum supported size

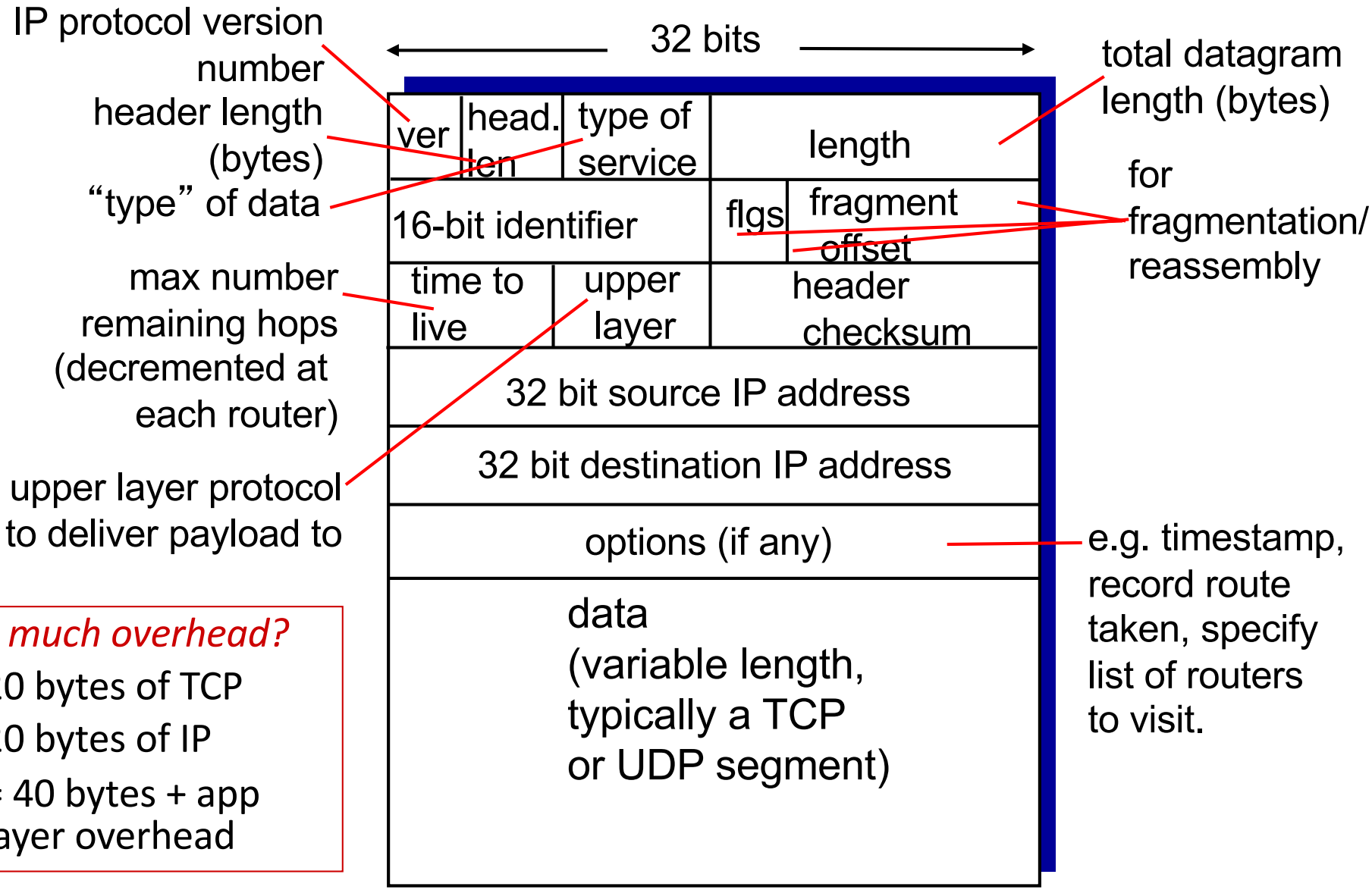
# Fields for Special Handling



# Special Handling

- "Type of Service", or "Differentiated Services Code Point (DSCP)" (8 bits)
  - Allow packets to be treated differently based on needs
  - E.g., low delay for audio, high bandwidth for bulk transfer
  - Has been redefined several times
- Options (not often used)

# RECAP: IP datagram format




*how much overhead?*

- 20 bytes of TCP
- 20 bytes of IP
- = 40 bytes + app layer overhead

# Network Layer, data plane: outline

4.1 Overview of Network layer

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- control plane

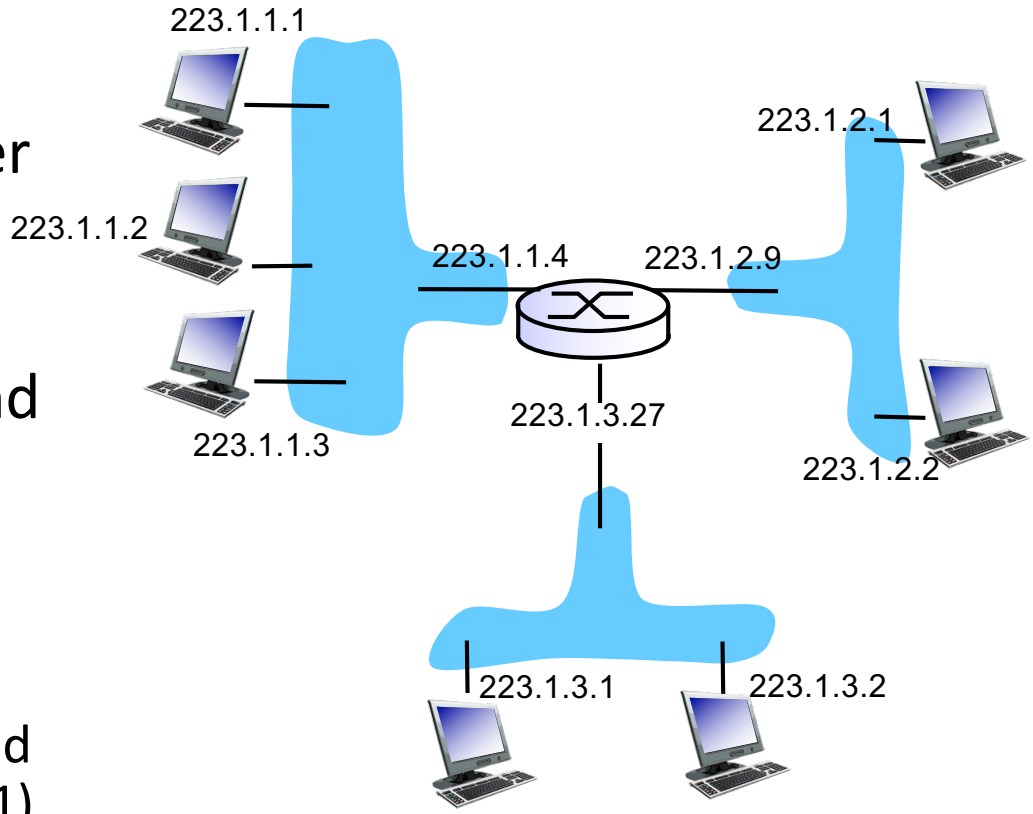
4.2 What's inside a router

4.3 IP: Internet Protocol

- datagram format
- fragmentation
- IPv4 addressing
- network address translation
- IPv6

# IP addressing: introduction

- *IP address:* 32-bit identifier for host, router *interface*
- *interface:* connection between host/router and physical link
  - router's typically have multiple interfaces
  - host typically has one or two interfaces (e.g., wired Ethernet, wireless 802.11)
- *IP addresses associated with each interface*



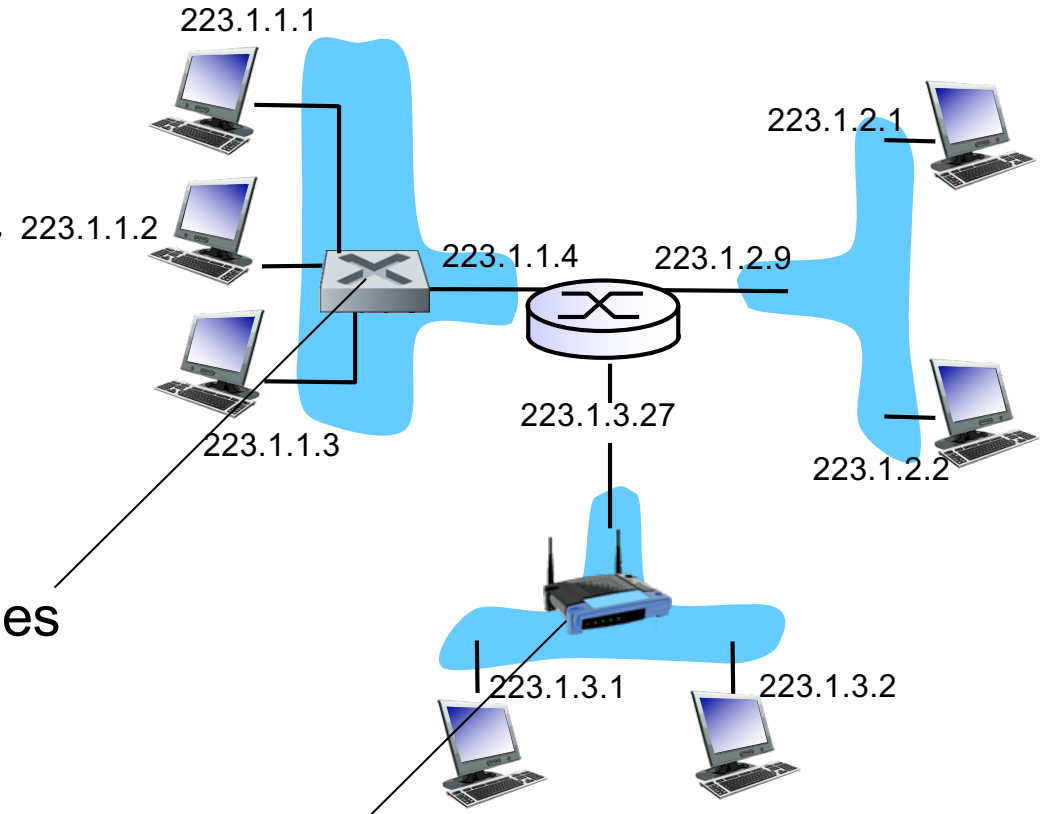

223.1.1.1 = 11011111 00000001 00000001 00000001

223 1 1 1

# IP addressing: introduction

*Q: how are interfaces actually connected?*

*A: we'll learn about that in the link layer*

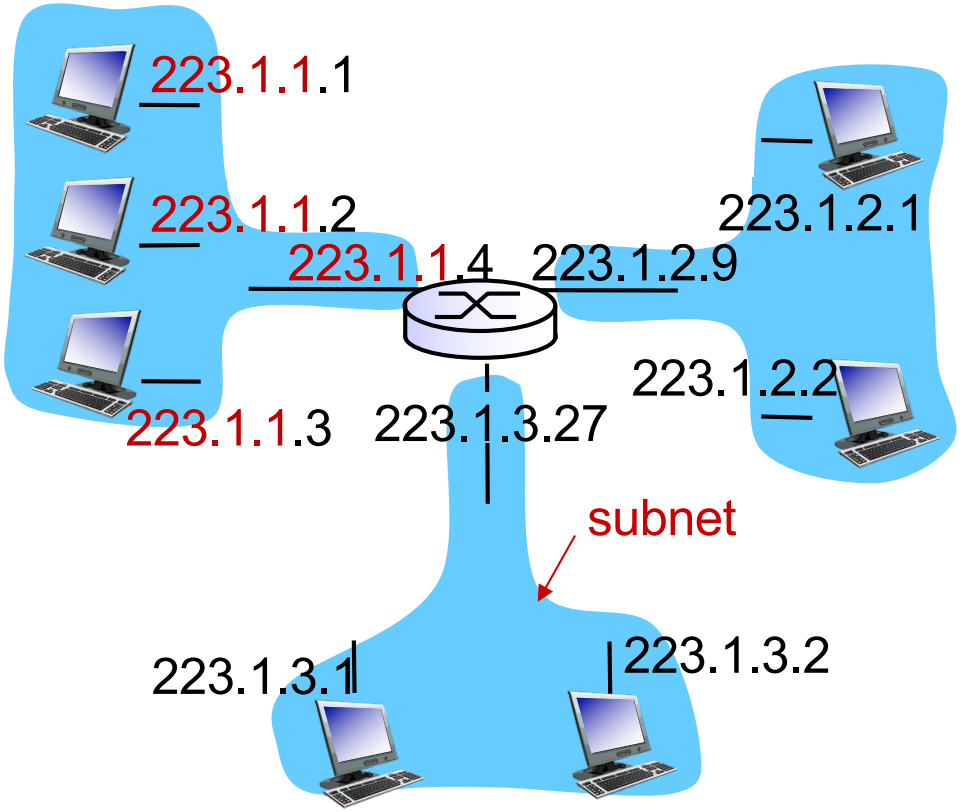



*A:* wired Ethernet interfaces connected by Ethernet switches

*A:* wireless WiFi interfaces connected by WiFi access point or wireless router

# Networks

- IP address:
  - –network part - high order bits
  - –host part - low order bits
- *what's a network ?*
  - –device interfaces with same network part of IP address
  - –can physically reach each other *without intervening router*

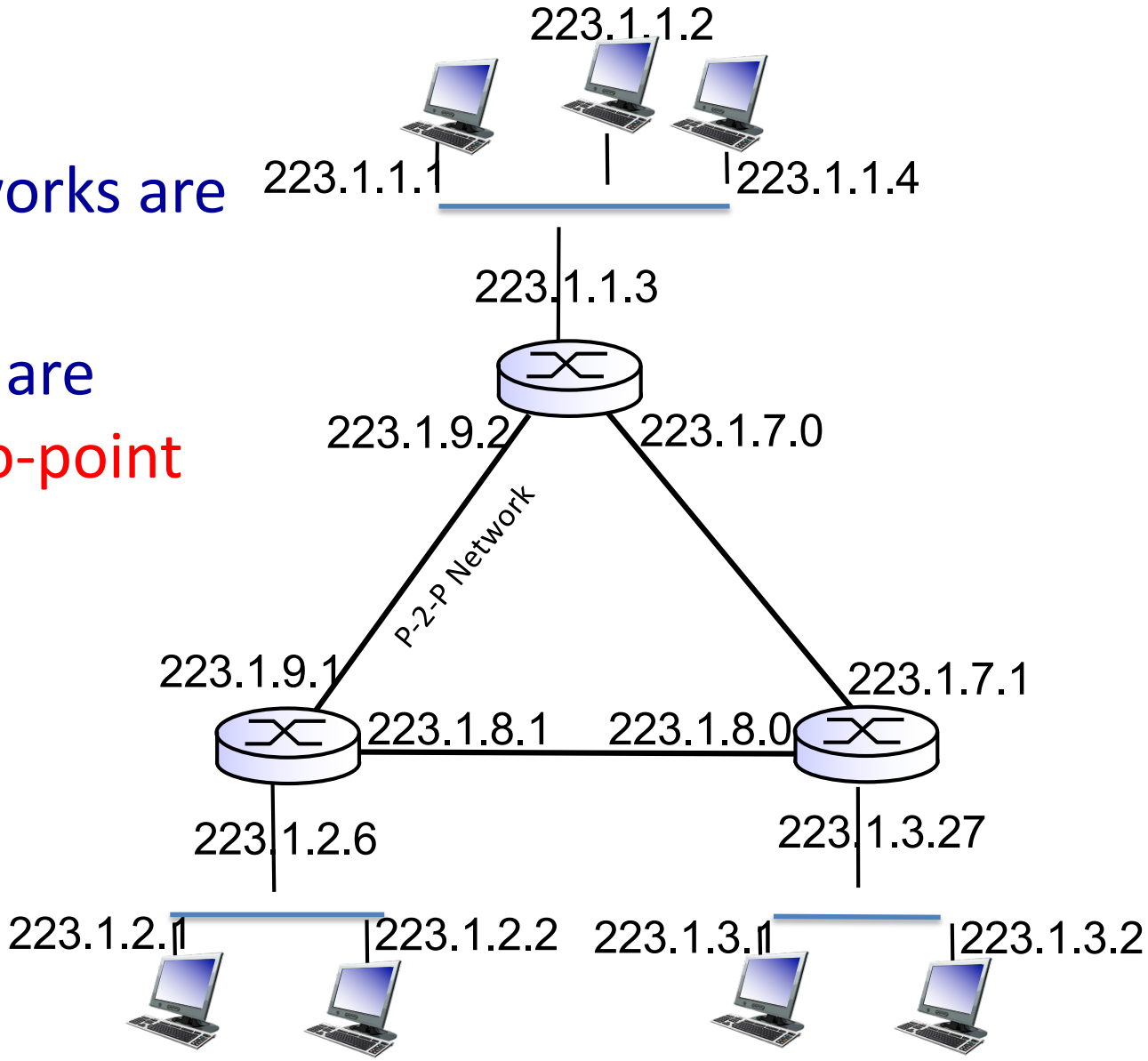



inter-network consisting of 3 nets

# Networks

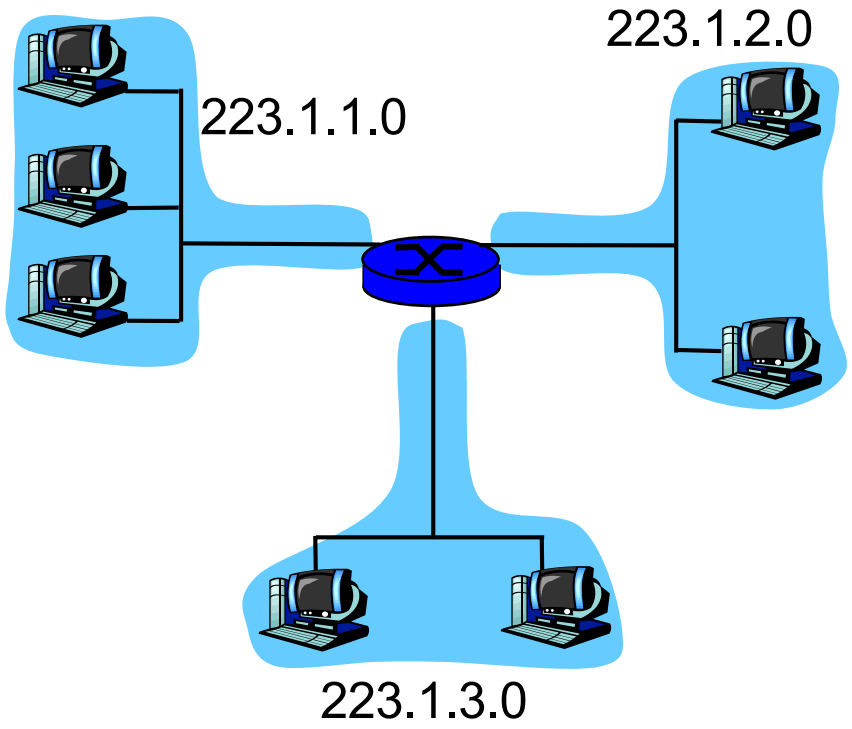
how many networks are there?

Note that there are some point-to-point networks



# Masking

- Mask
  - Used in conjunction with the network address to indicate how many higher order bits are used for the network part of the address
    - Bit-wise AND
  - 223.1.1.0 with mask 255.255.255.0 11111111 = 255
- Broadcast Address
  - host part is all 111's
  - E.g. 223.1.1.255
- Network Address
  - Host part is all 0000's
  - E.g. 223.1.1.0
- Both of these are not assigned to any host




| **Host B** | Dot-decimal address | Binary |
|---|---|---|
| IP address | 223.1.1.2 | 11111101.00000001.00000001.00000010 |
| Mask | 255.255.255.0 | 11111111.11111111.11111111.00000000 |
| Network Part | 223.1.1.0 | 11111101.00000001.00000001.00000000 |
| Host Part | 0.0.0.2 | 00000000.00000000.00000000.00000010 |

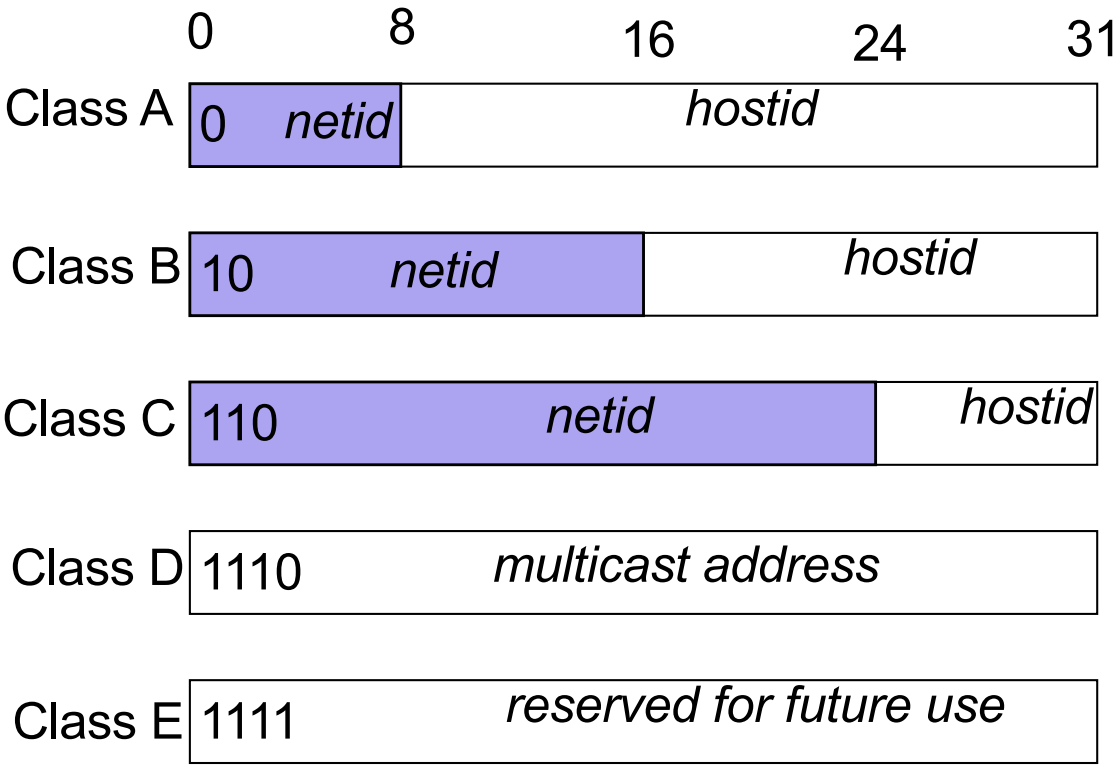
# Original Internet Addresses

- First eight bits: network address (/8)
- Last 24 bits: host address, ~16.7 million

*Assumed 256 networks were more than enough!*

# Next design: Class-ful Addresses

Used till the introduction of CIDR 1993




$2^7$ nets, $2^{24}$hosts/net — 1.0.0.0 to 127.255.255.255

$2^{14}$ nets, $2^{16}$ hosts/net — 128.0.0.0 to 191.255.255.255

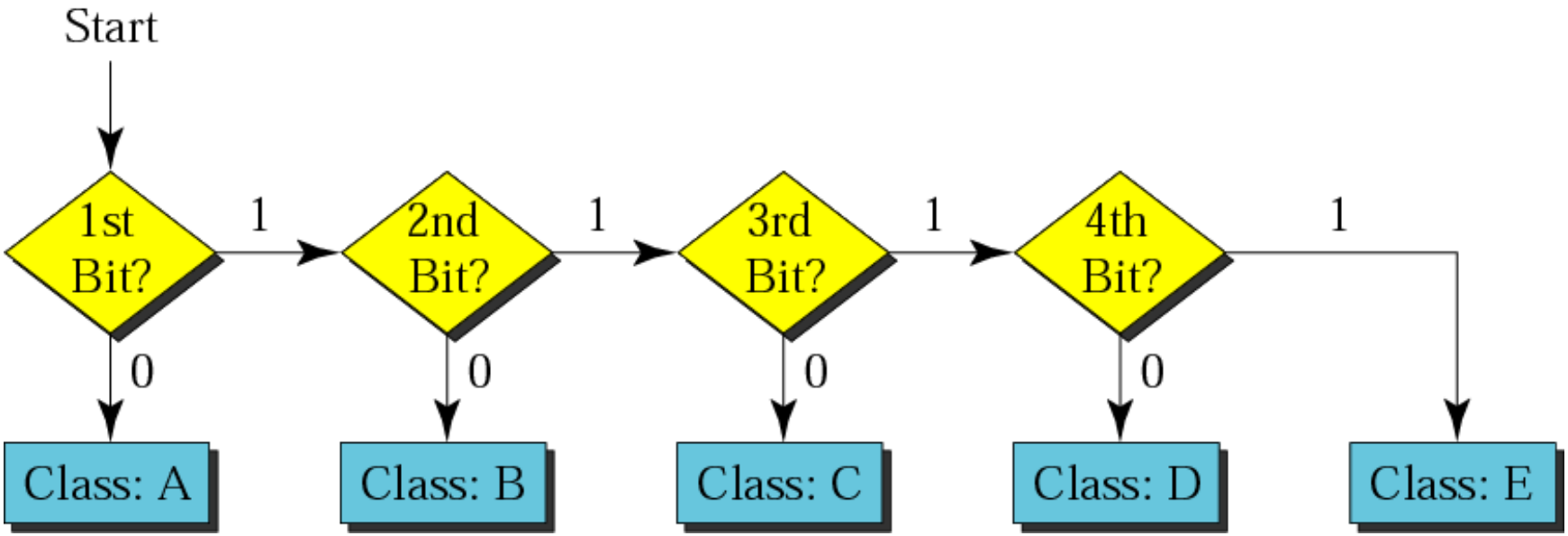
$2^{21}$ nets, $2^8$ hosts/net — 192.0.0.0 to 223.255.255.255

224.0.0.0 to 239.255.255.255

240.0.0.0 to 255.255.255.255

Problem: Networks only come in three sizes!

# Finding the address class



# What are the issues?

- An organization requires 6 nets each of size 30. Does it have to buy 6 class C address blocks?

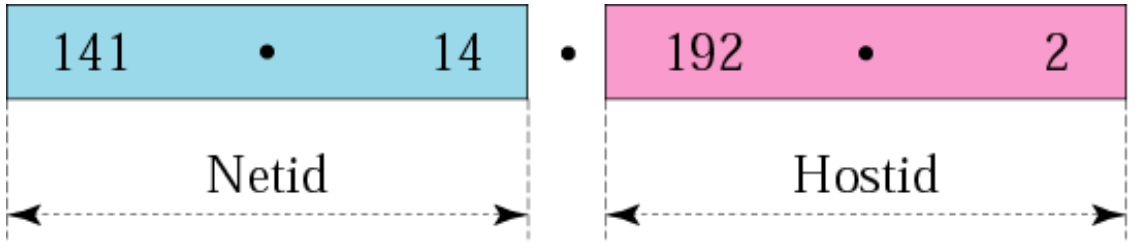
- An organization requires 512 addresses? How many IP addresses should it buy?

# Subnetting

- Subnetting is the process of dividing the class A, B or C network into more manageable chunks that are suited to your network's size and structure.
- Subnetting allows 3 levels of hierarchy 等级制度
  - netid, subnetid, hostid
- Original netid remains the same and designates the site 命名
- Subnetting remains transparent outside the site 透明的，显而易见的

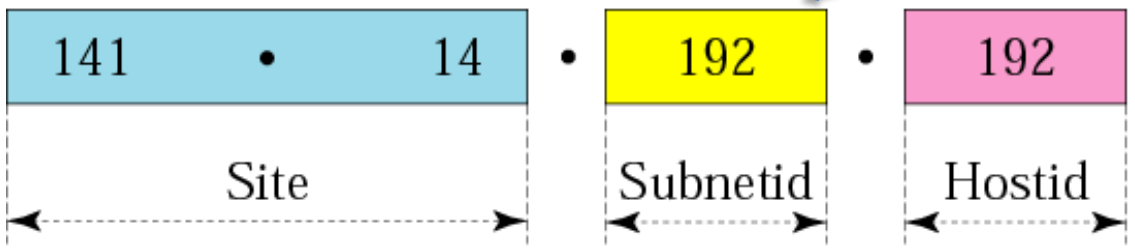
# Subnetting

- The process of subnetting simply extends the point where the 1's of Mask stop and 0's start
- You are sacrificing some host ID bits to gain Network ID bits




a. Without subnetting

8 bits taken from host ID to gain subnetting




b. With subnetting

# Quiz?

A company is granted the site address 201.70.64.0 (class C). The company needs six subnets. Design the subnets.

The company needs six subnets. 6 is not a power of 2. The next number that is a power of 2 is 8 ($2^3$). We need 3 more 1s in the subnet mask. The total number of 1s in the subnet mask is 27 (24 + 3). The mask is

11111111 11111111 11111111 11100000

or 255.255.255.224

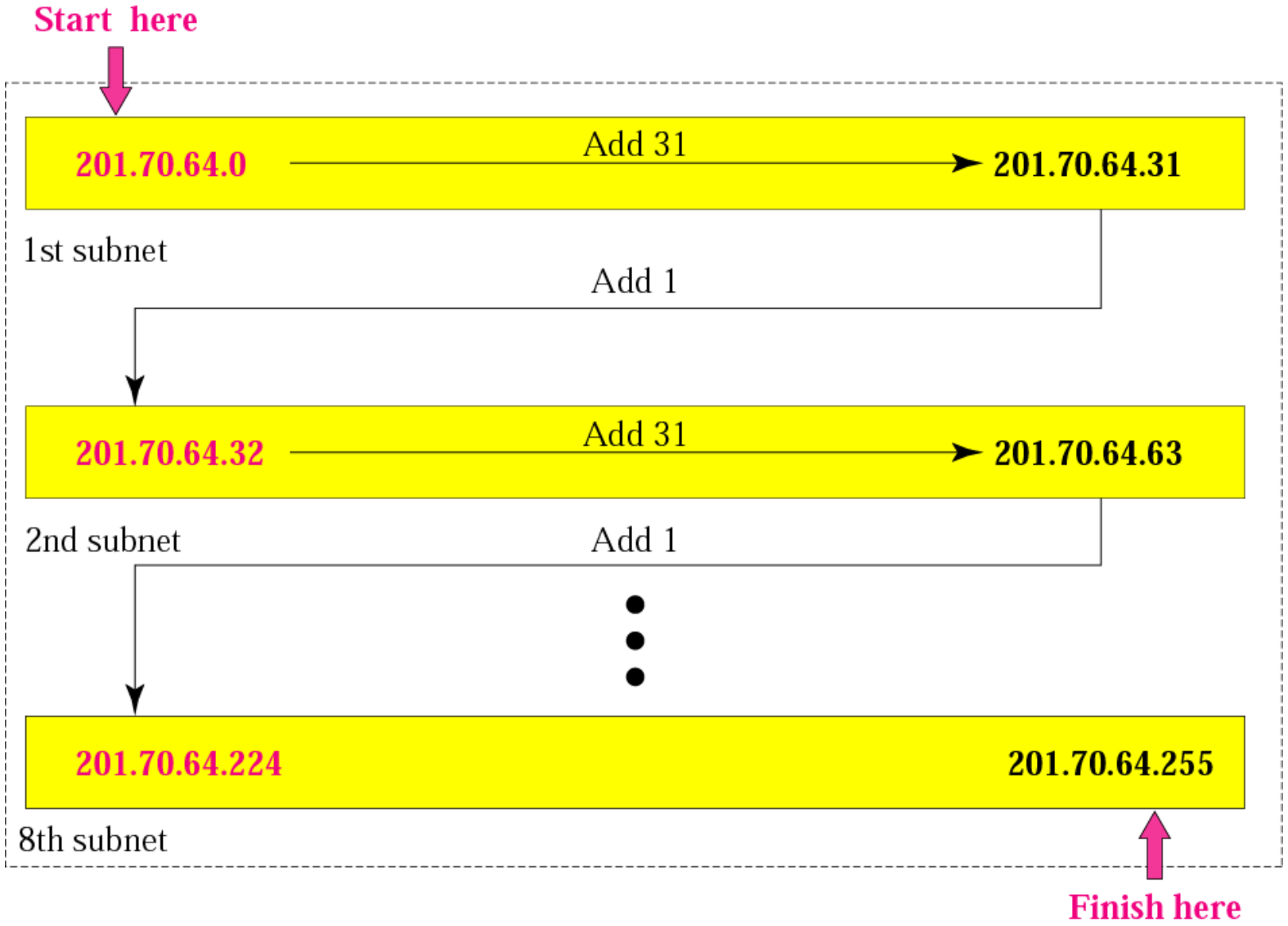
3 bits taken from host ID to gain subnetting

Number of addresses in each subnet = $2^5$

= 32

# The number of addresses in each subnet is $2^5$ or 32.

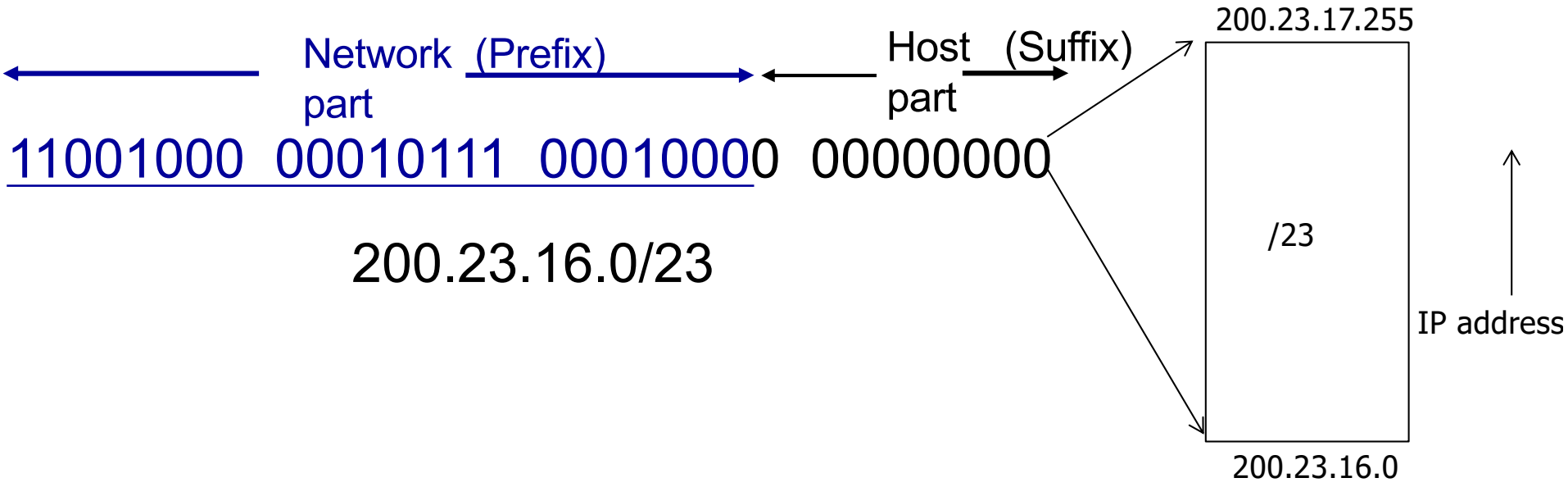
Three bits of 1st subnet = 000, 2nd subnet = 001, ….last subnet = 111



# Today's addressing: CIDR

CIDR: Classless InterDomain Routing

- network portion of address of arbitrary length
- address format: a.b.c.d/x, where x is # bits in network portion of address



# How to get IP addresses?

- How does organisations get their block of IP addresses? Block Allocation
- How does an individual device within an organization gets its IP address? DHCP
- How ISPs are involved in allocating IP addresses to their customers?

# Obtaining a Block of Addresses

*Q:* how does an organisation get its (sub)network part of IP address?

*A:* gets allocated portion of its provider ISP's address space (each customer organization becomes a *subnet* of the ISP)

| | | | |
|---|---|---|---|
| ISP's block | 11001000 00010111 00010000 | 00000000 | 200.23.16.0/20 |
| Organization 0 | 11001000 00010111 00010000 | 00000000 | 200.23.16.0/23 |
| Organization 1 | 11001000 00010111 00010010 | 00000000 | 200.23.18.0/23 |
| Organization 2 | 11001000 00010111 00010100 | 00000000 | 200.23.20.0/23 |
| ... | ….. | …. | …. |
| Organization 7 | 11001000 00010111 00011110 | 00000000 | 200.23.30.0/23 |

# Quiz: IP address distribution

An ISP is granted a block of addresses starting with 190.100.0.0/16. The ISP needs to distribute these addresses to three groups of customers as follows:

1. The first group has 64 customers; each needs 256 addresses (including all 0's and all 1's).

2. The second group has 128 customers; each needs 128 addresses (including all 0's and all 1's).

3. The third group has 128 customers; each needs 64 addresses (including all 0's and all 1's).

Design the sub-blocks and give the slash notation for each sub-block. Find out how many addresses are still available after these allocations.

# Group 1

For this group, each customer needs 256 addresses. This means the suffix length is 8 ($2^8 = 256$). The prefix length is then $32 - 8 = 24$.

01: 190.100.0.0/24 ➔ 190.100.0.255/24

02: 190.100.1.0/24 ➔ 190.100.1.255/24

……..

64: 190.100.63.0/24 ➔ 190.100.63.255/24

Total = 64 × 256 = 16,384

# Group 2

For this group, each customer needs 128 addresses. This means the suffix length is 7 ($2^7 = 128$). The prefix length is then $32 - 7 = 25$. The addresses are:

001: 190.100.64.0/25 ➔190.100.64.127/25

002: 190.100.64.128/25 ➔190.100.64.255/25

003: 190.100.65.0/25 ➔190.100.65.127/25

004: 190.100.65.128/25 ➔190.100.65.255/25

……

127: 190.100.127.0/25 ➔190.100.127.127/25

128: 190.100.127.128/25 ➔190.100.127.255/25

Total = 128 × 128 = 16,384

# Group 3

For this group, each customer needs 64 addresses. This means the suffix length is 6 ($2^6 = 64$). The prefix length is then $32 - 6 = 26$.

001:190.100.128.0/26 ➔190.100.128.63/26

002:190.100.128.64/26 ➔190.100.128.127/26

003:190.100.128.128/26 ➔190.100.128.191/26

004:190.100.128.192/26 ➔190.100.128.255/26

……

125:190.100.159.0/26 ➔190.100.159.63/26

126:190.100.159.64/26 ➔190.100.159.127/26

127:190.100.159.128/26 ➔190.100.159.191/26

128:190.100.159.192/26 ➔190.100.159.255/26

Total = $128 \times 64 = 8{,}192$

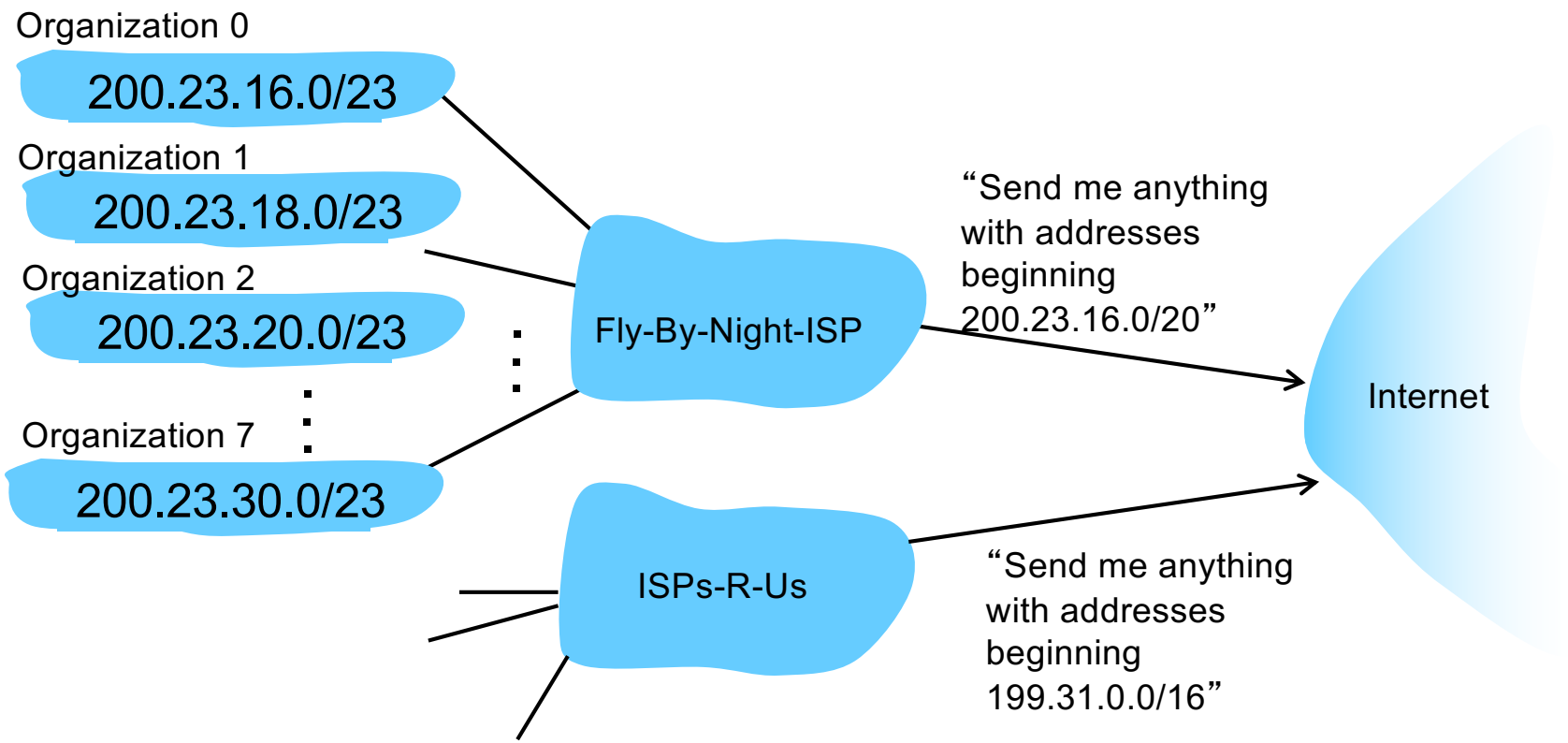
Number of granted addresses: 65,536

Number of allocated addresses: 40,960

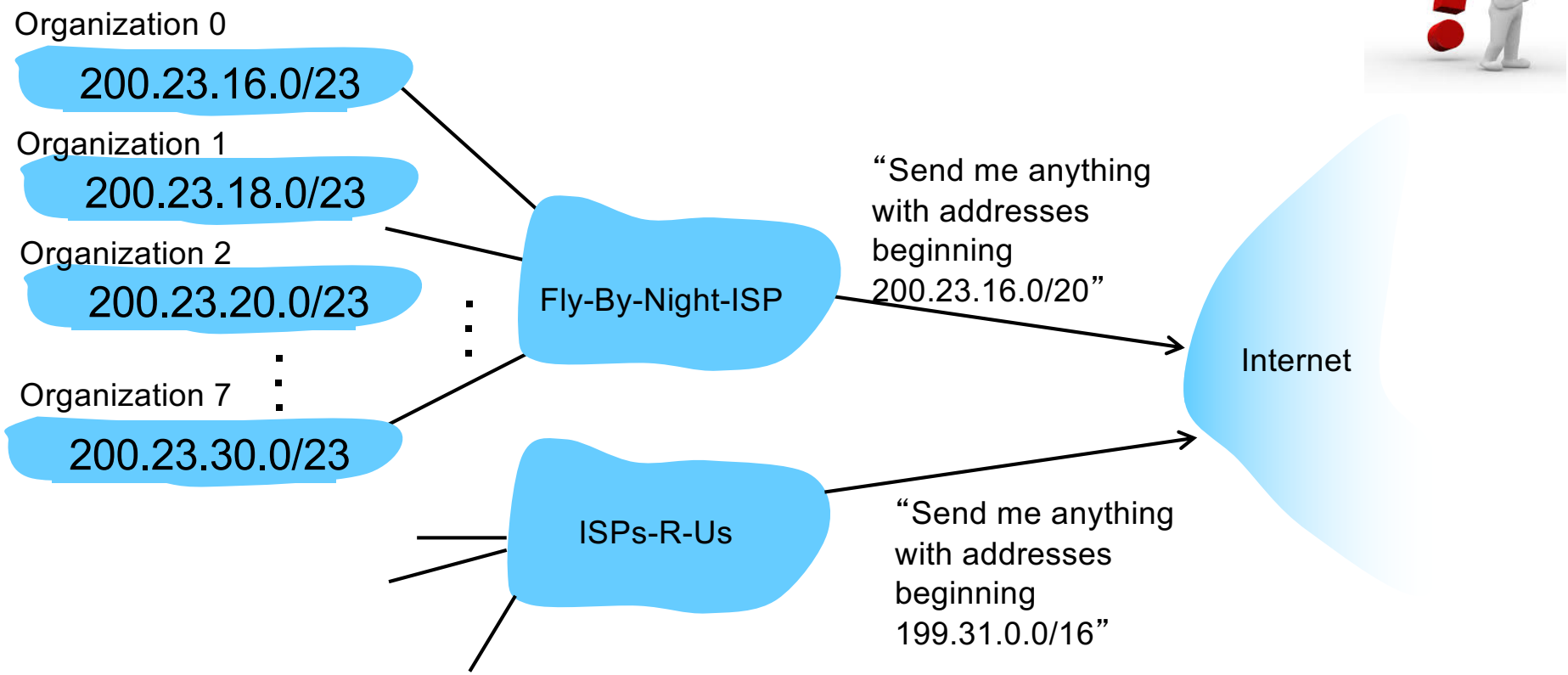
Number of available addresses: 24,576

# Hierarchical addressing: route aggregation

hierarchical addressing allows efficient advertisement of routing information:



# Problem: What should we do if organization 1 decides to switch to ISPs-R-Us




Possible options:

A: Move 200.23.18.0/23 to ISPs-R-Us (and break up Fly-By-Night's/20 block).

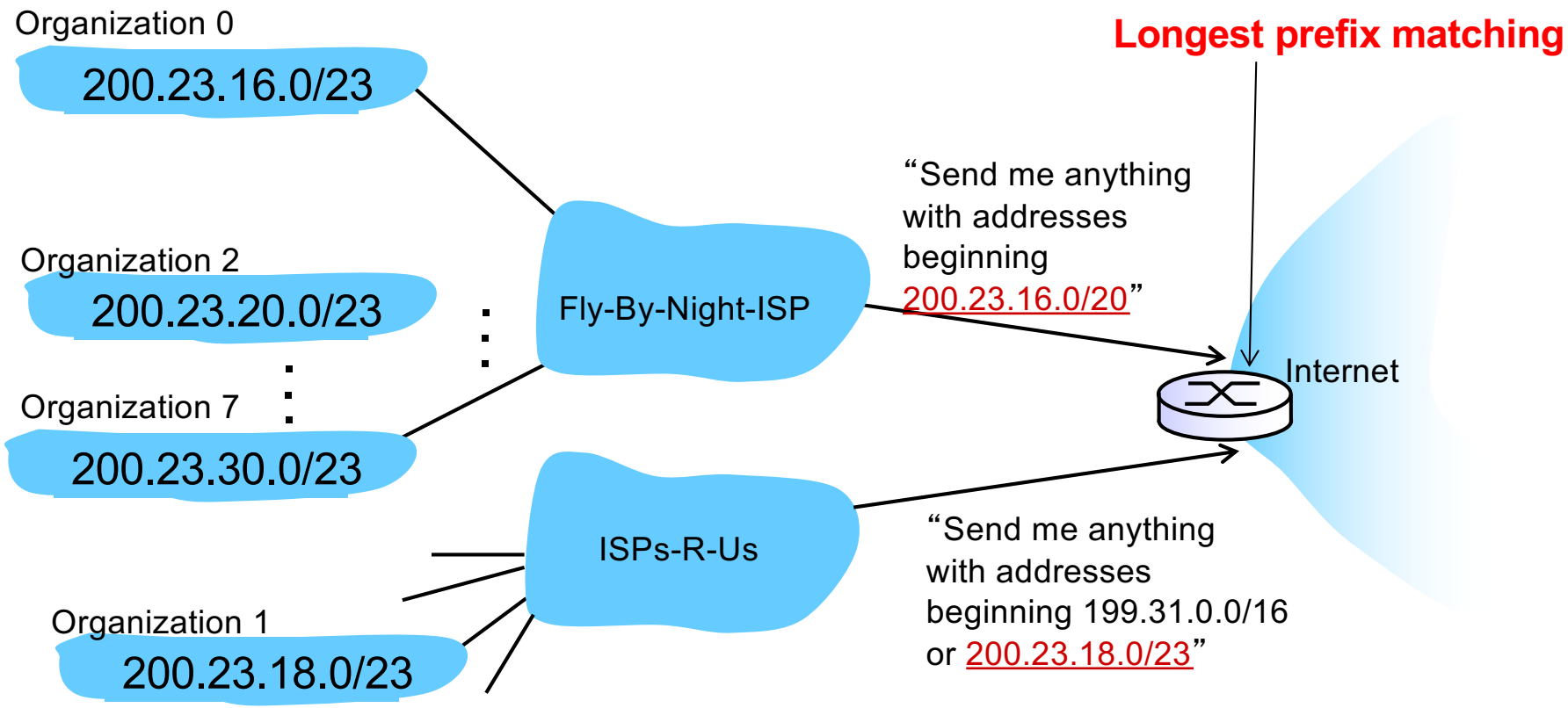
B: Give new addresses to Organization 1 (and force them to change all their addresses)

C: Some other solution

层次编址

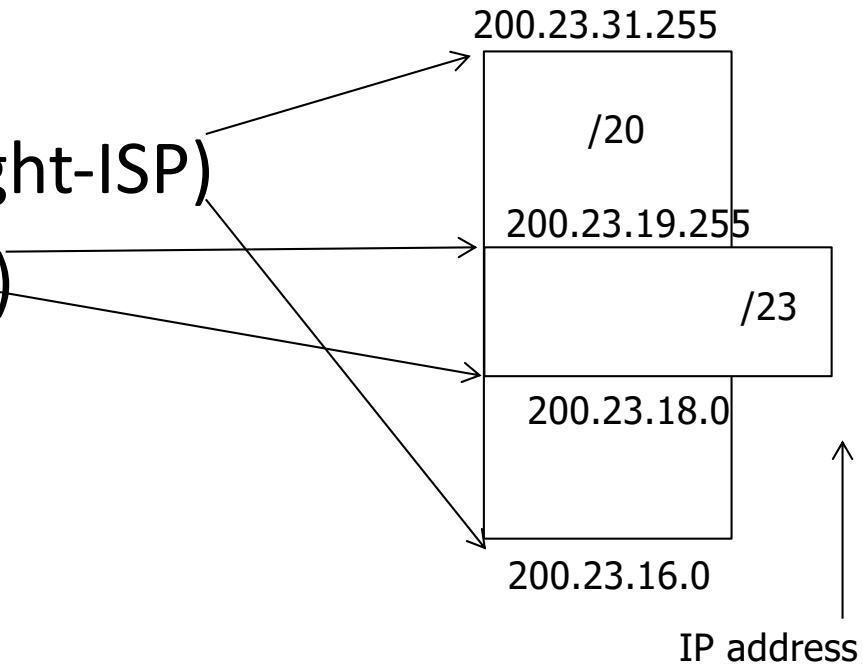
# Hierarchical addressing: more specific routes

ISPs-R-Us has a more specific route to Organization 1



# Example: continued

- But how will this work?
- Routers in the Internet will have two entries in their tables
  - 200.23.16.0/20 (Fly-by-Night-ISP)
  - 200.23.18.0/23 (ISPs-R-Us)
- Longest prefix match



# Longest prefix matching

*longest prefix matching*

when looking for forwarding table entry for given destination address, use *longest* address prefix that matches destination address.

| Destination Address Range | Link interface |
|---|---|
| 11001000 00010111 00010*** ********* | 0 |
| 11001000 00010111 00011000 ********* | 1 |
| 11001000 00010111 00011*** ********* | 2 |
| otherwise | 3 |

examples:

DA: 11001000 00010111 00010110 10100001 which interface? 0

DA: 11001000 00010111 00011000 10101010 which interface? 1

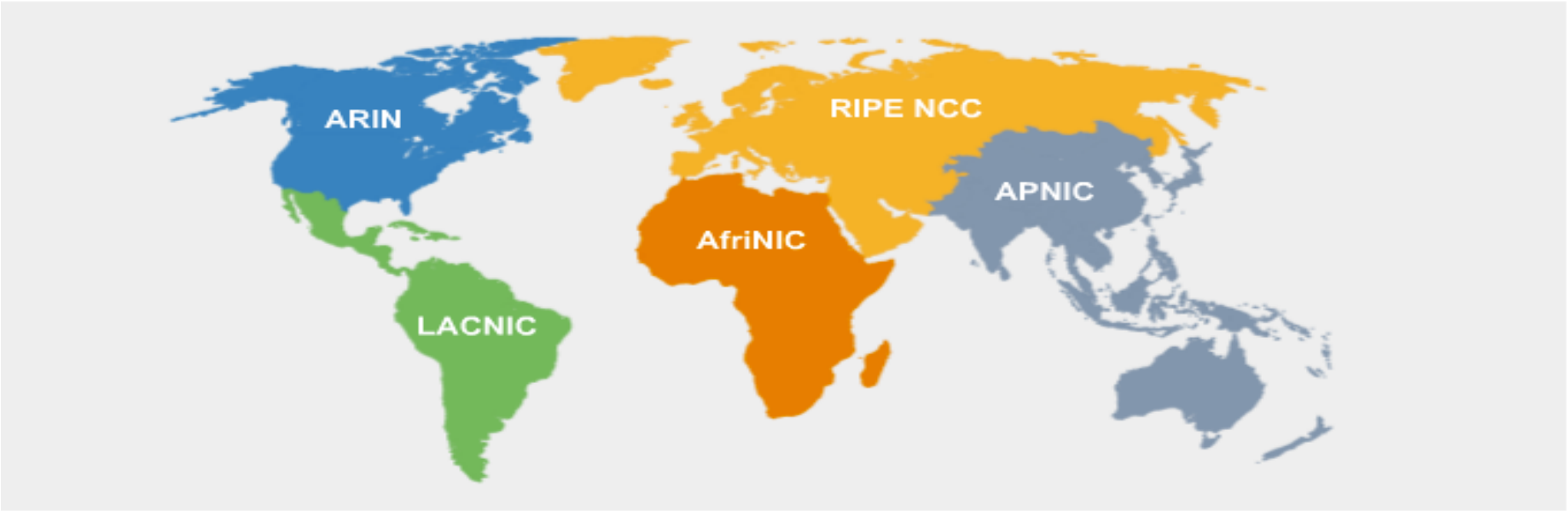
# IP Addressing: the last word...

*Q:* How does an ISP get block of addresses?

*A:* ICANN: Internet Corporation for Assigned Names and Numbers http://www.icann.org/

IANA works through Regional Internet Registries (RIRs):

- RIPE NCC — IRéseaux IP Européens Network Coordination Centre
- ARIN — American Registry for Internet Numbers
- APNIC — Asia-Pacific Network Information Center
- LACNIC — Latin America and Caribbean Network Information Centre
- AfriNIC — African Network Information Centre



# Example of Progressive Address Allocation

- ICANN gives APNIC several /8s
- APNIC gives Telstra  one /8, **129/8**
  - Network Prefix**: 10000001**
- Telstra gives UNSW a /16, **129.94/16**
  - Network Prefix**: 1000000101011110**
- UNSW gives CSE a /24, **129.94.242/24**
  - Network Prefix**: 100000010101111011110010**
- CSE gives me a specific address **129.94.242.51**
  - Address: **10000001010111101111001000110011**

# Address allocation for hosts

Q: How does a *host* get IP address?

- hard-coded by system admin in a file
  - Windows: control-panel->network->configuration->tcp/ip->properties
  - UNIX: /etc/rc.config
- DHCP: Dynamic Host Configuration Protocol: dynamically get address from a server
  - "plug-and-play"

# DHCP

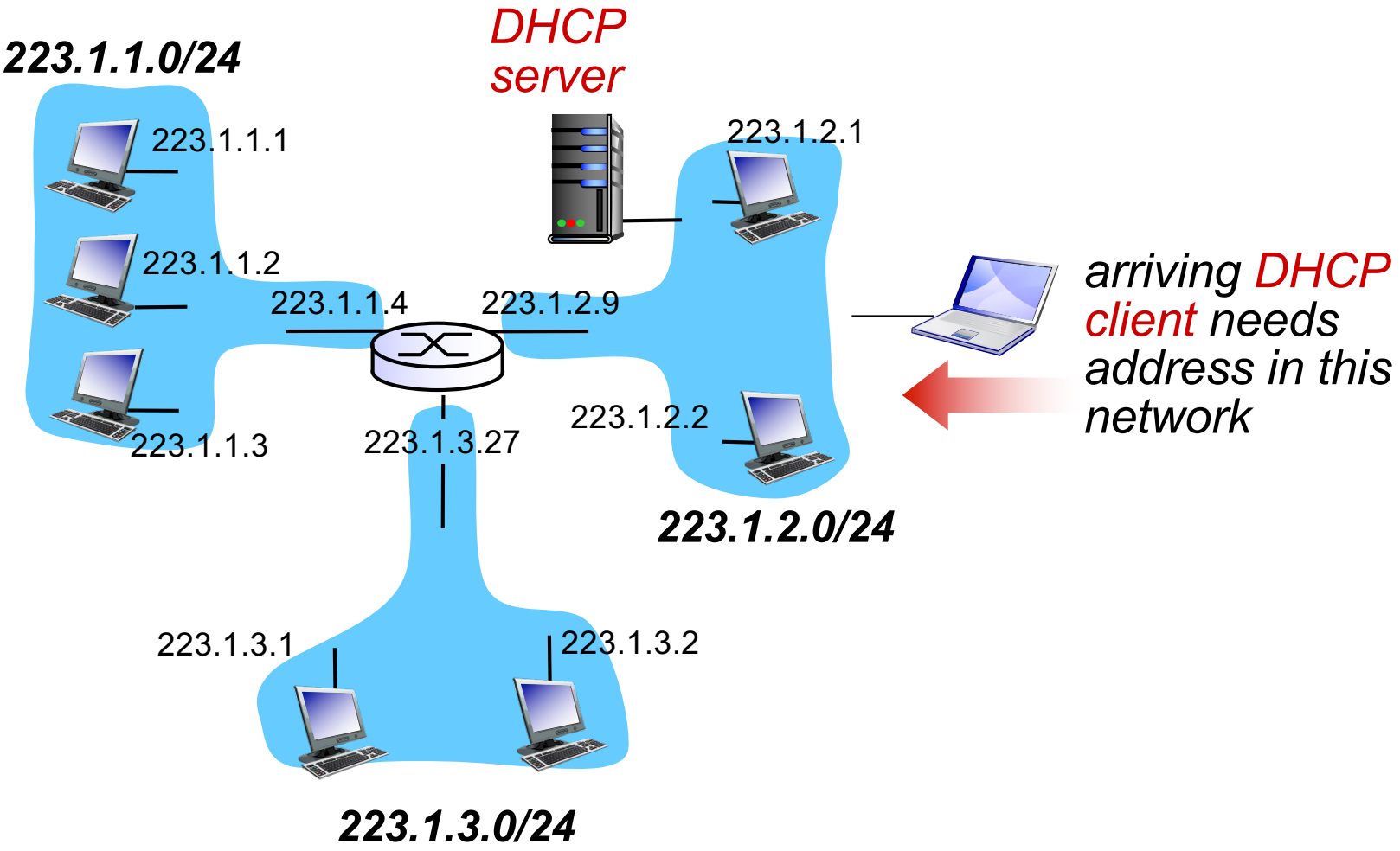
*goal:* allow host to *dynamically* obtain its IP address from network server when it joins network

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

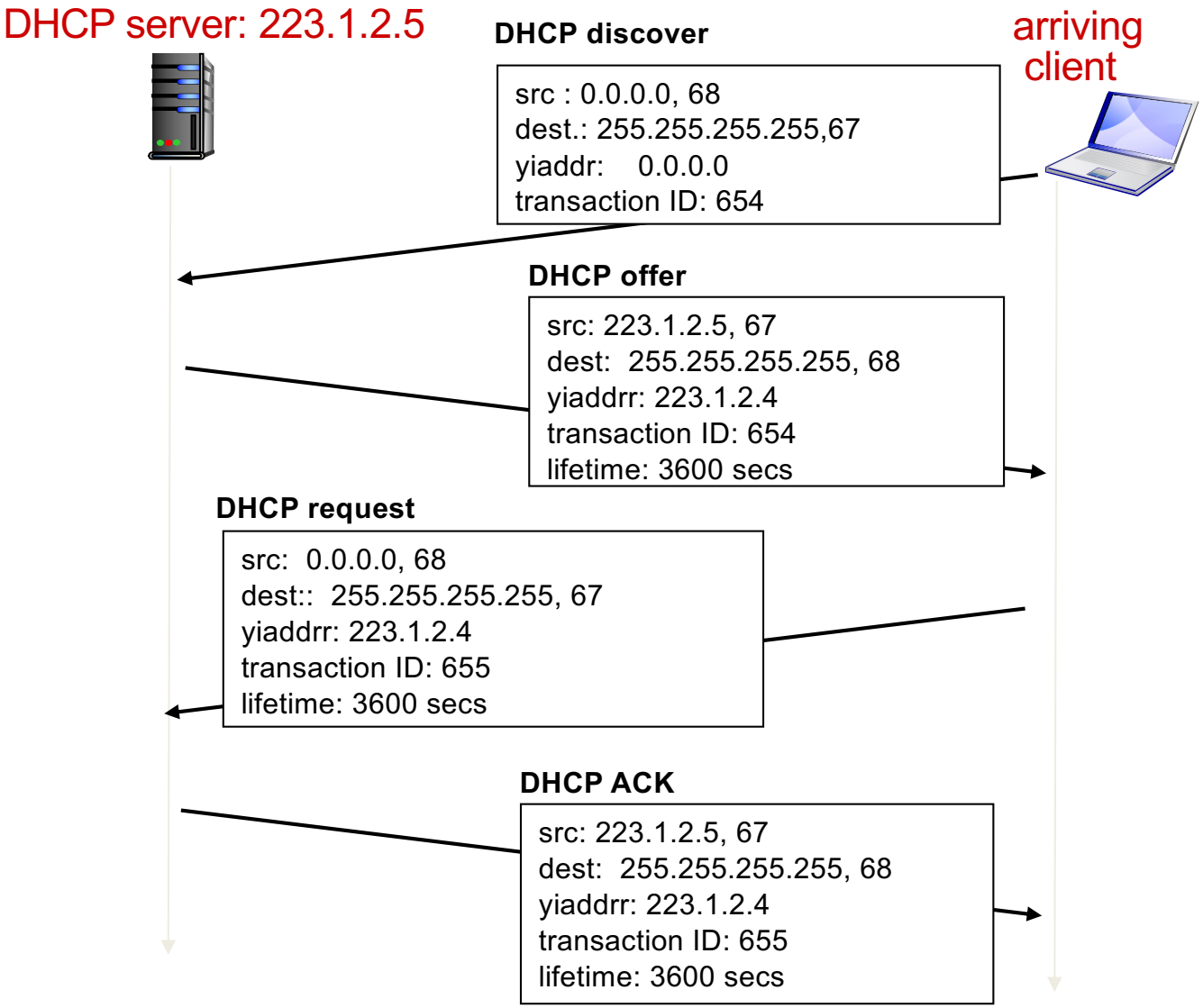
*DHCP overview:*

- 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

# DHCP client-server scenario



# DHCP client-server scenario

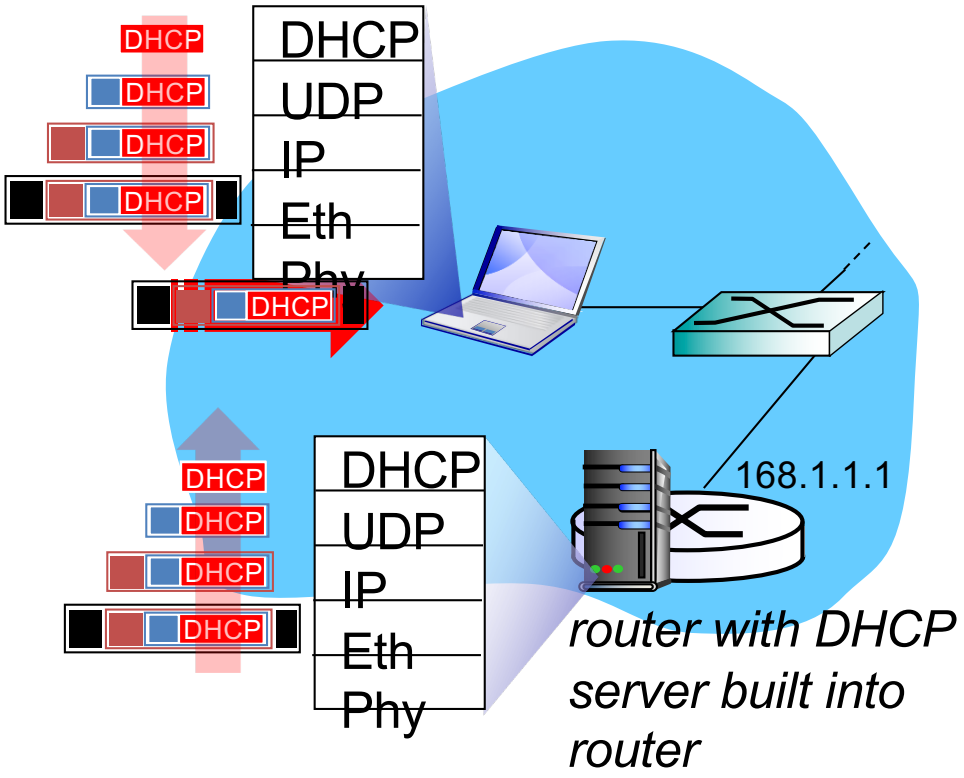


# DHCP: more than IP addresses

DHCP can return more than just allocated IP address on subnet:

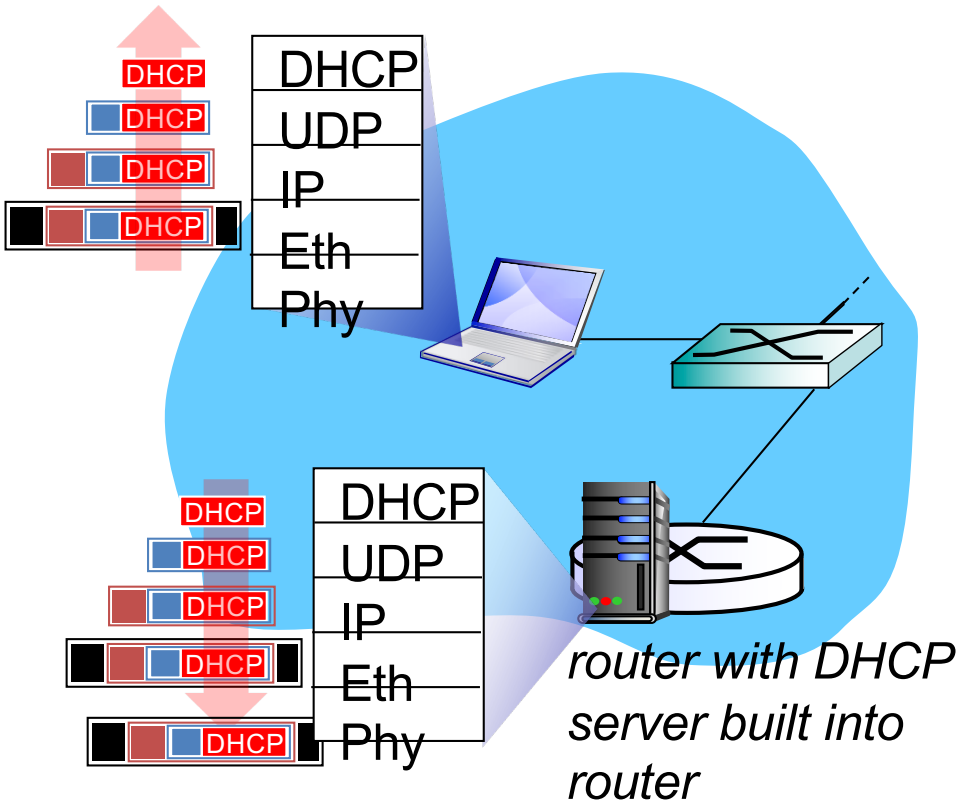
- address of first-hop router for client
- name and IP address of DNS sever
- network mask (indicating network versus host portion of address)

# DHCP: example




- connecting laptop needs its IP address, addr of first-hop router, addr of DNS server: use DHCP
- DHCP request encapsulated in UDP, encapsulated in IP, encapsulated in 802.1 Ethernet
- Ethernet frame broadcast (dest: FFFFFFFFFFFF) on LAN, received at router running DHCP server
- Ethernet demuxed to IP demuxed, UDP demuxed to DHCP

# DHCP: example




- DHCP server formulates DHCP ACK containing client's IP address, IP address of first-hop router for client, name & IP address of DNS server
- Encapsulation of DHCP server, frame forwarded to client, demuxing up to DHCP at client
- Client now knows its IP address, name and IP address of DSN server, IP address of its first-hop router

# DHCP: Wireshark output (home LAN)

## request

Message type: **Boot Request (1)**
Hardware type: Ethernet
Hardware address length: 6
Hops: 0
**Transaction ID: 0x6b3a11b7**
Seconds elapsed: 0
Bootp flags: 0x0000 (Unicast)
Client IP address: 0.0.0.0 (0.0.0.0)
Your (client) IP address: 0.0.0.0 (0.0.0.0)
Next server IP address: 0.0.0.0 (0.0.0.0)
Relay agent IP address: 0.0.0.0 (0.0.0.0)
**Client MAC address: Wistron_23:68:8a (00:16:d3:23:68:8a)**
Server host name not given
Boot file name not given
Magic cookie: (OK)
Option: (t=53,l=1) **DHCP Message Type = DHCP Request**
Option: (61) Client identifier
    Length: 7; Value: 010016D323688A;
    Hardware type: Ethernet
    Client MAC address: Wistron_23:68:8a (00:16:d3:23:68:8a)
Option: (t=50,l=4) Requested IP Address = 192.168.1.101
Option: (t=12,l=5) Host Name = "nomad"
**Option: (55) Parameter Request List**
    Length: 11; Value: 010F03062C2E2F1F21F92B
    **1 = Subnet Mask; 15 = Domain Name**
    **3 = Router; 6 = Domain Name Server**
    44 = NetBIOS over TCP/IP Name Server
    ……

## reply

Message type: **Boot Reply (2)**
Hardware type: Ethernet
Hardware address length: 6
Hops: 0
**Transaction ID: 0x6b3a11b7**
Seconds elapsed: 0
Bootp flags: 0x0000 (Unicast)
**Client IP address: 192.168.1.101 (192.168.1.101)**
Your (client) IP address: 0.0.0.0 (0.0.0.0)
**Next server IP address: 192.168.1.1 (192.168.1.1)**
Relay agent IP address: 0.0.0.0 (0.0.0.0)
Client MAC address: Wistron_23:68:8a (00:16:d3:23:68:8a)
Server host name not given
Boot file name not given
Magic cookie: (OK)
**Option: (t=53,l=1) DHCP Message Type = DHCP ACK**
**Option: (t=54,l=4) Server Identifier = 192.168.1.1**
**Option: (t=1,l=4) Subnet Mask = 255.255.255.0**
**Option: (t=3,l=4) Router = 192.168.1.1**
**Option: (6) Domain Name Server**
    **Length: 12; Value: 445747E2445749F244574092;**
    **IP Address: 68.87.71.226;**
    **IP Address: 68.87.73.242;**
    **IP Address: 68.87.64.146**
**Option: (t=15,l=20) Domain Name = "hsd1.ma.comcast.net."**

# DHCP: further details

- DHCP uses UDP and port numbers 67 (server side) and 68 (client side)
- Usually the MAC address is used to identify clients
  - DHCP server can be configured with a "registered list" of acceptable MAC addresses
- DHCP offer message includes ip address, length of lease, subnet mask, DNS servers, default gateway
- DHCP security holes
  - DoS attack by exhausting pool of IP addresses
  - Masquerading as a DHCP server
  - Authentication for DHCP - RFC 3118

# Network Layer, data plane: outline

4.1 Overview of Network layer

- data plane
- control plane

4.2 What's inside a router

4.3 IP: Internet Protocol

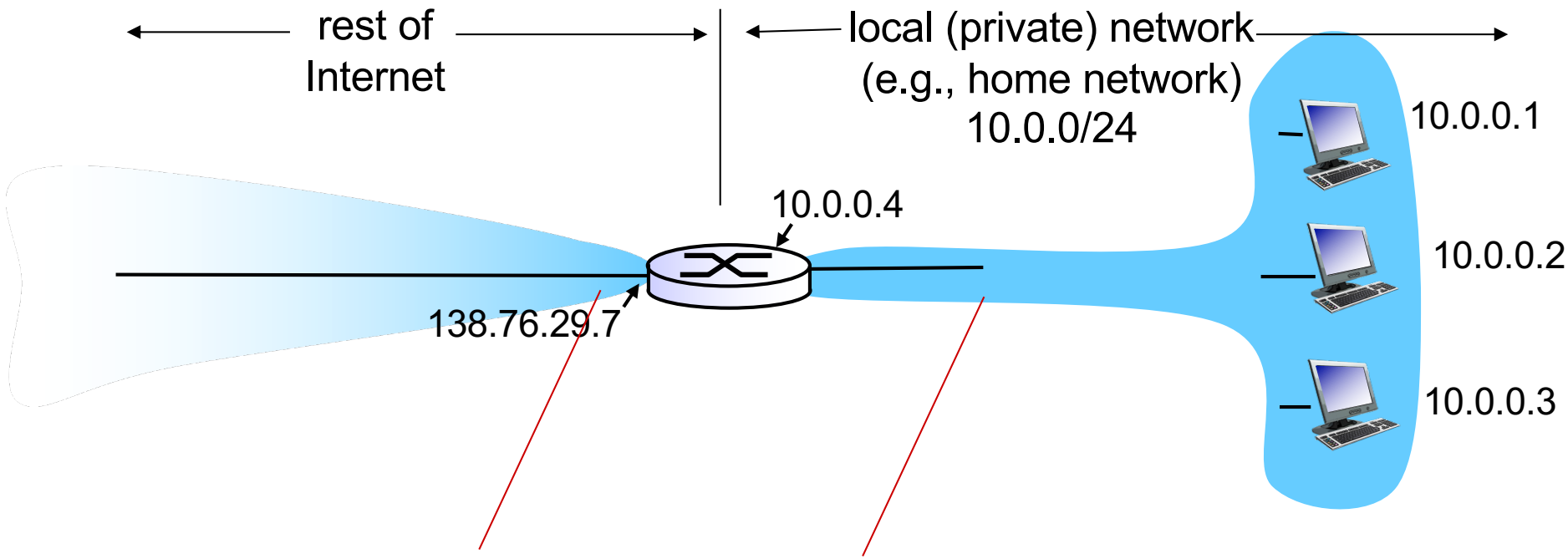
- datagram format
- fragmentation
- IPv4 addressing
- network address translation
- IPv6

# Private Addresses

- Defined in RFC 1918:
  - 10.0.0.0/8 (16,777,216 hosts)
  -172.16.0.0/12 (1,048,576 hosts)
  -192.168.0.0/16 (65536 hosts)

- These addresses cannot be routed (Internet routers would drop them)
  - Anyone can use them
  -Typically used for NAT (network address translation)

# NAT: network address translation




*all* datagrams *leaving* local network have *same* single source NAT IP address: 138.76.29.7,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

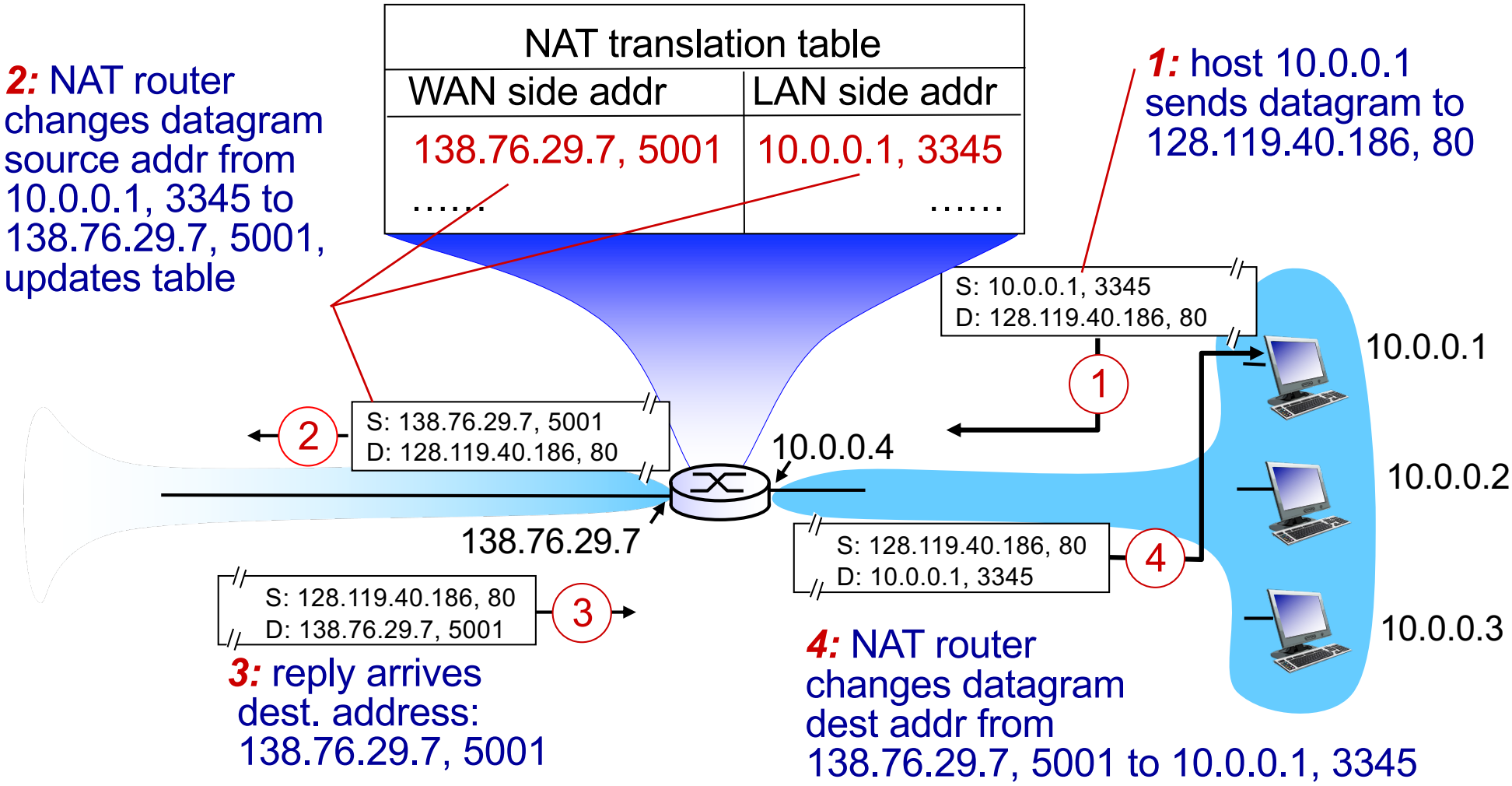
*implementation*: NAT router must:

- *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 addr

- *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 dest fields of every incoming datagram with corresponding (source IP address, port #) stored in NAT table

# NAT: network address translation



# NAT Advantages

Local network uses just one IP address as far as outside world is concerned:

- range of addresses not needed from ISP: just one IP address for all devices
- can change addresses of devices in local network without notifying outside world
- can change ISP without changing addresses of devices in local network

# NAT Disadvantages

- NAT violates the architectural model of IP
  - Every IP address uniquely identifies a single node on Internet
  - routers should only process up to layer 3
- Changing port numbers may cause problem with some applications (can you give an example?)

# Discussion: NAT

- Devices inside the local network are not explicitly addressable or visible by outside world.

  A: This is an advantage

  B: This is a disadvantage

# NAT: network address translation

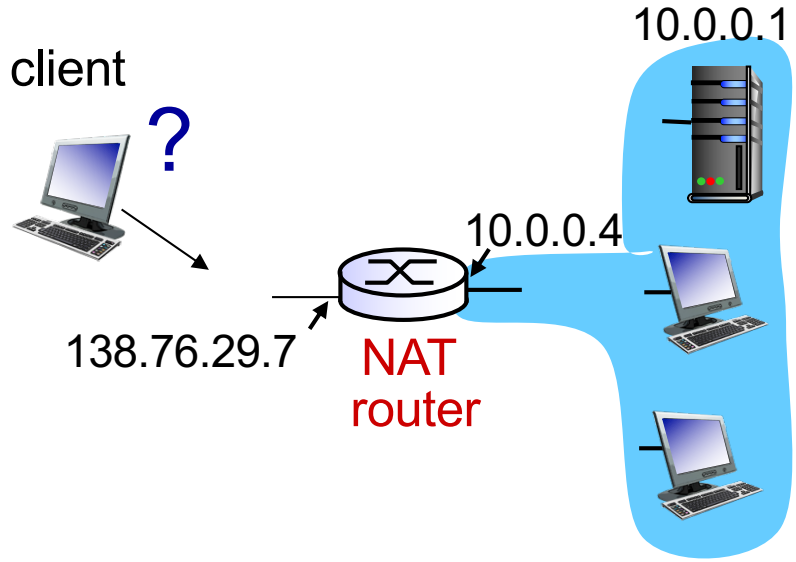
- 16-bit port-number field:
  - ~65,000 simultaneous connections with a single WAN-side address!
- NAT is controversial:
  - routers should only process up to layer 3
  - violates end-to-end argument
    - NAT possibility must be taken into account by app designers, e.g., P2P applications
  - address shortage should instead be solved by IPv6

# NAT: Practical Issues

- NAT modifies port # and IP address
  - *Requires recalculation of TCP and IP checksum*
- Some applications embed IP address or port numbers in their message payloads
  - DNS, FTP (PORT command), SIP, H.323
  - For legacy protocols, NAT must look into these packets and translate the embedded IP addresses/port numbers
  - Duh, What if these fields are encrypted ?? (SSL/TLS, IPSEC, etc.)
  - **Q: In some cases why may NAT need to change TCP sequence number??**
- E.g: If applications change port numbers periodically, the NAT must be aware of this
- NAT Traversal Problems
  - How to setup a server behind a NAT router?
  - How to talk to a Skype user behind a NAT router?

# NAT traversal problem

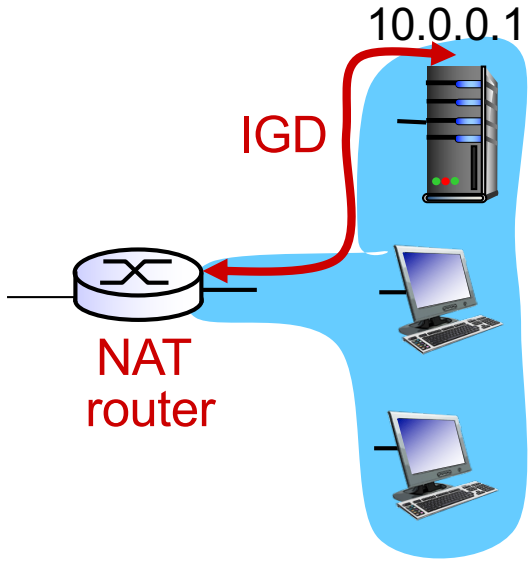
- client wants to connect to server with address 10.0.0.1
  - server address 10.0.0.1 local to LAN (client can't use it as destination addr)
  - only one externally visible NATed address: 138.76.29.7
- *solution1:* Inbound-NAT. Statically configure NAT to forward incoming connection requests at given port to server
  - e.g., (138.76.29.7, port 2500) always forwarded to 10.0.0.1 port 2500



# NAT traversal problem

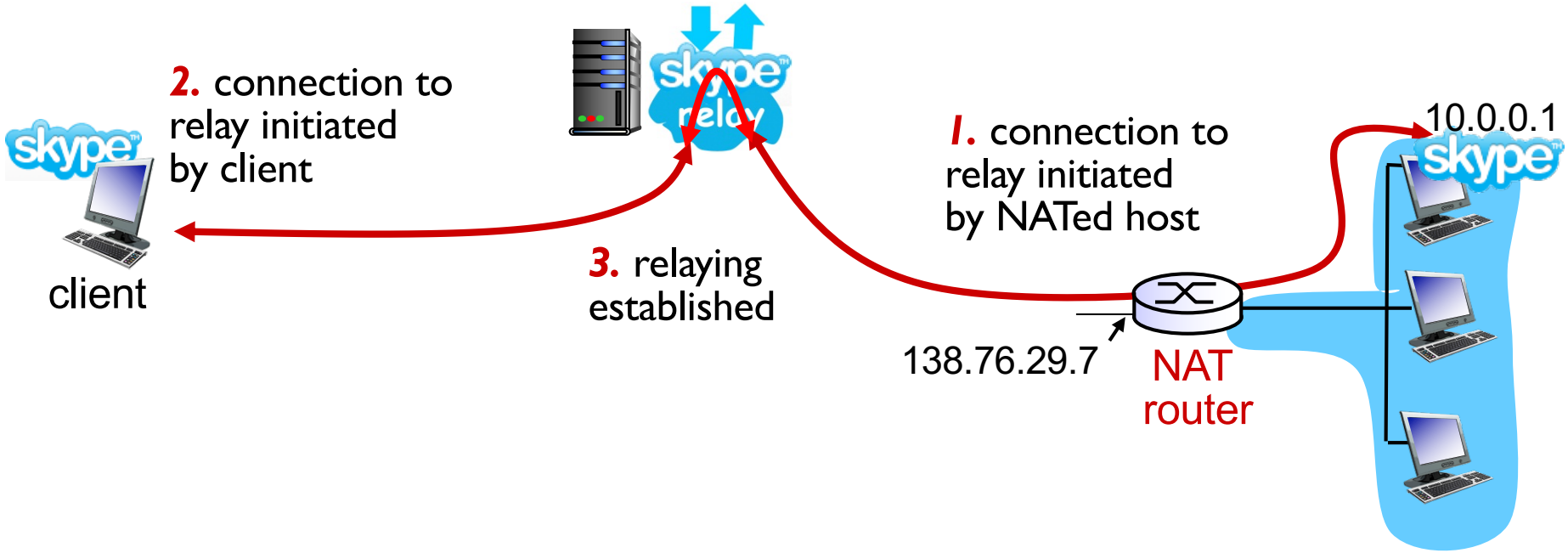
- *solution 2:* Universal Plug and Play (UPnP) Internet Gateway Device (IGD) Protocol. Allows NATed host to:
  - learn public IP address (138.76.29.7)
  - add/remove port mappings (with lease times)

  i.e., automate static NAT port map configuration



# NAT traversal problem

- *solution 3:* relaying (used in Skype)
  - NATed client establishes connection to relay
  - external client connects to relay
  - relay bridges packets between two connections

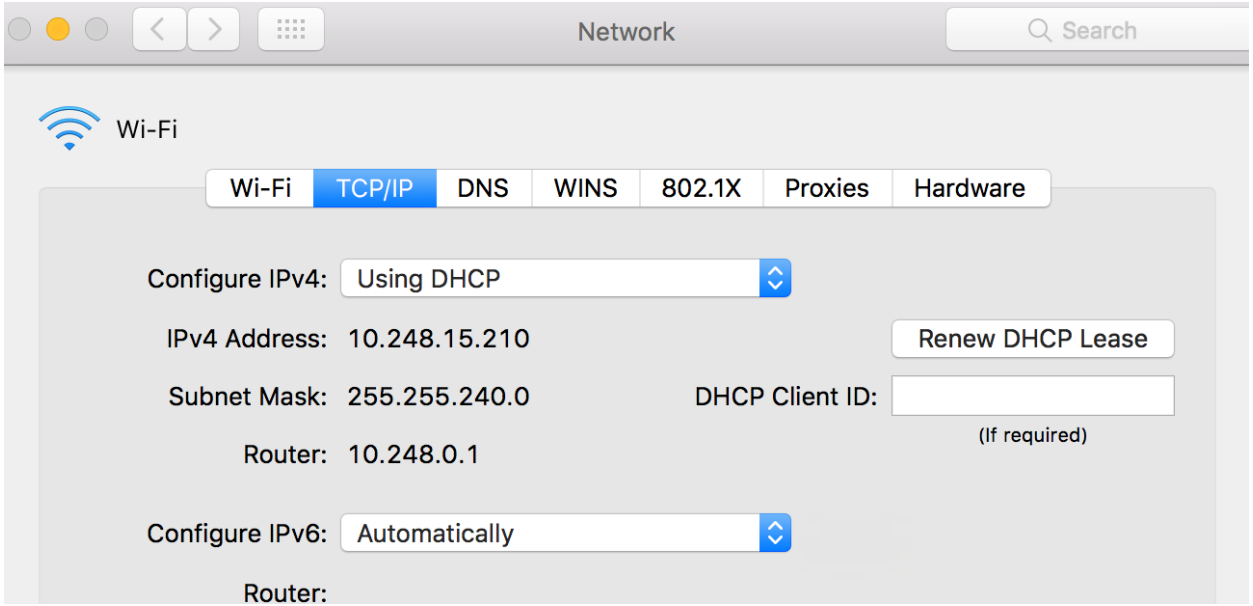


# Practical Demand for NAT

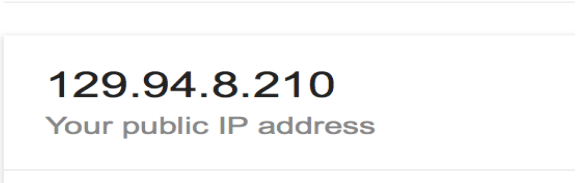
- Despite the problems, NAT has been widely deployed
- Most protocols can be successfully passed through a NAT, including VPN
- Modern hardware can easily perform NAT functions at > 100 Mbps
- IPv6 is still not widely deployed commercially, so the need for NAT is real
- After years of refusing to work on NAT, the IETF has been developing “NAT control protocols” for hosts
- Lot of practical variations
  - Full-cone NAT, Restricted Cone NAT, Port Restricted Cone NAT, Symmetric NAT, …..

# Discussion

- The picture below shows you the IP address of my machine connected to the uniwide wireless network.




- However when I ask Google (“whats my ip”) it says my IP address is as noted below. Can you explain t



# Network Layer, data plane: outline

4.1 Overview of Network layer

- data plane
- control plane

4.2 What's inside a router

4.3 IP: Internet Protocol

- datagram format
- fragmentation
- IPv4 addressing
- network address translation
- IPv6

# IPv6: motivation

- *initial motivation:* 32-bit address space soon to be completely allocated.
- additional motivation:
  - header format helps speed processing/forwarding
  - header changes to facilitate QoS

*IPv6 datagram format:*

- fixed-length 40 byte header
- no fragmentation allowed

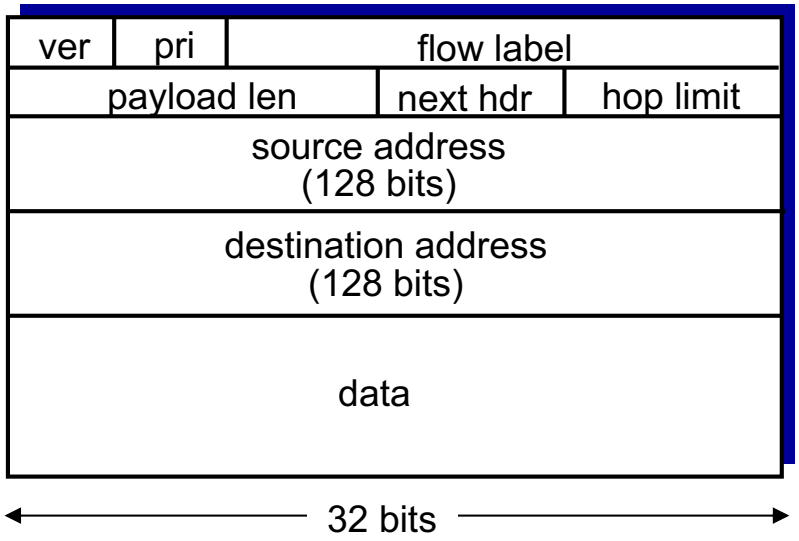
https://www.google.com/intl/en/ipv6/statistics.html

# IPv6 datagram format

*priority:* identify priority among datagrams in flow (traffic class)

*flow Label:* identify datagrams in same "flow."
(concept of"flow" not well defined).

*next header:* identify upper layer protocol for data

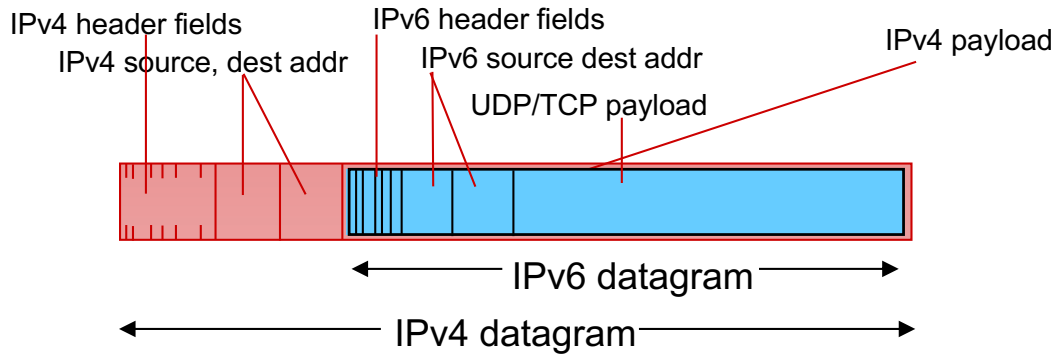


# Other changes from IPv4

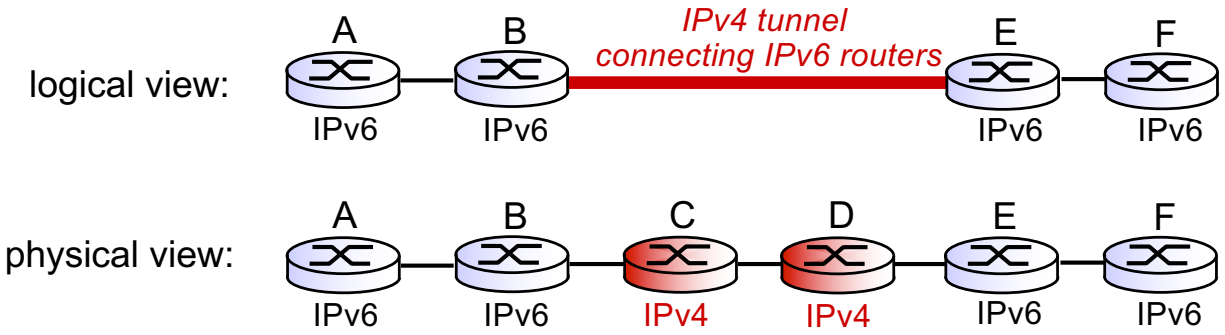
- *checksum*: removed entirely to reduce processing time at each hop
- *options:* allowed, but outside of header, indicated by "Next Header" field
- *ICMPv6:* new version of ICMP
  - additional message types, e.g. "Packet Too Big"
  - multicast group management functions

# Transition from IPv4 to IPv6

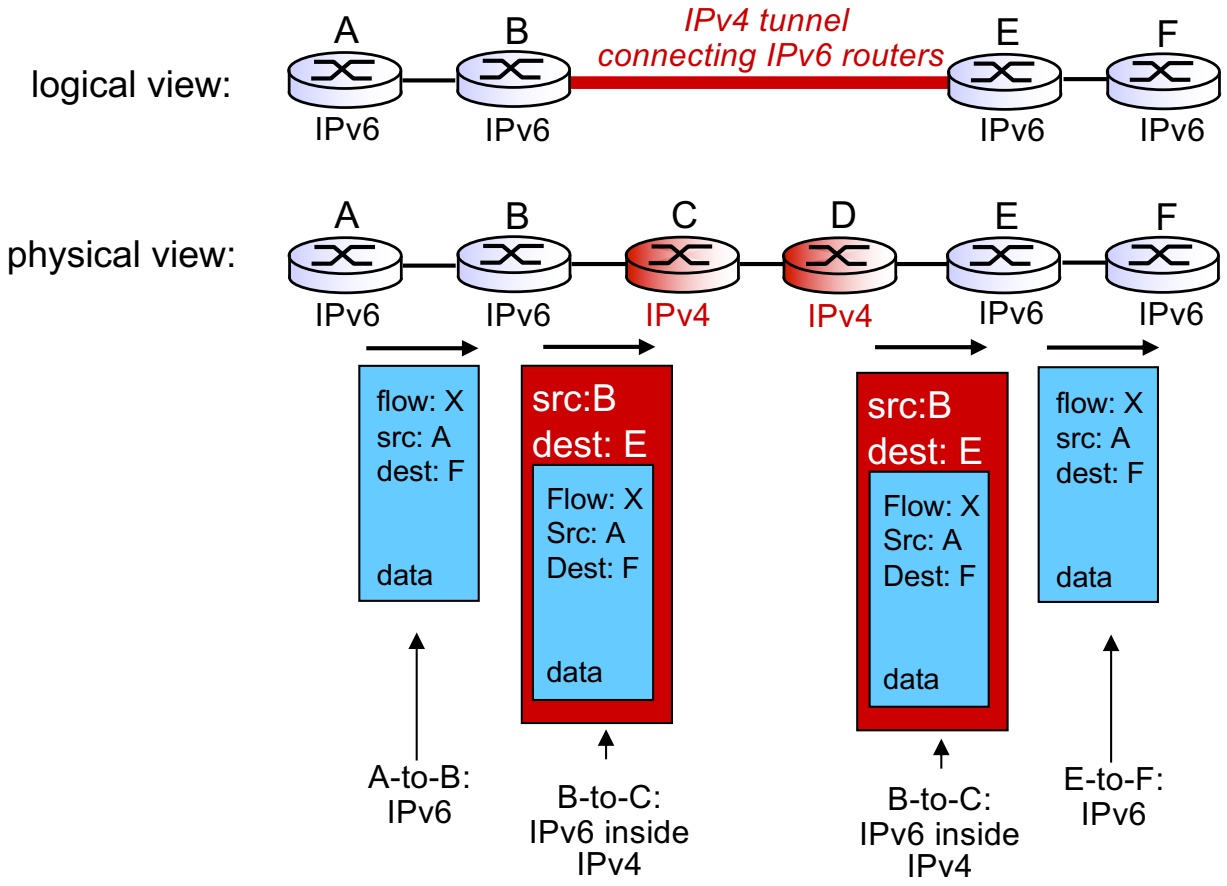
- not all routers can be upgraded simultaneously
  - no "flag days"
  - how will network operate with mixed IPv4 and IPv6 routers?
- *tunneling:* IPv6 datagram carried as *payload* in IPv4 datagram among IPv4 routers



# Tunneling (IPv6 over IPv4)

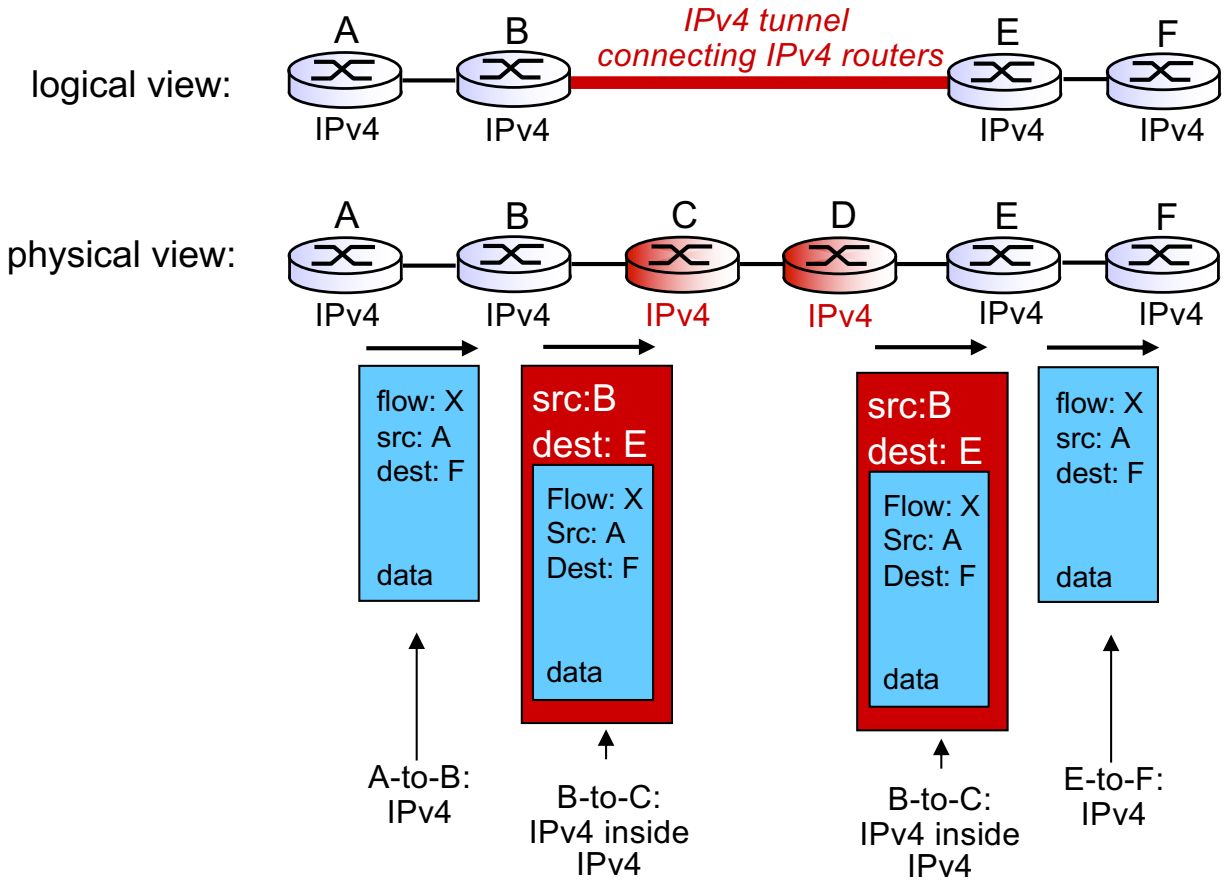


# Tunneling (IPv6 over IPv4)



# Tunneling (IPv4 over IPv4)

**Used in VPNs**



# Summary

- We have learned the data plane of network layer
- Next week, we will learn the control plane of network layer