CMSC 332
Computer Networks
IP

Professor Szajda

Last Time

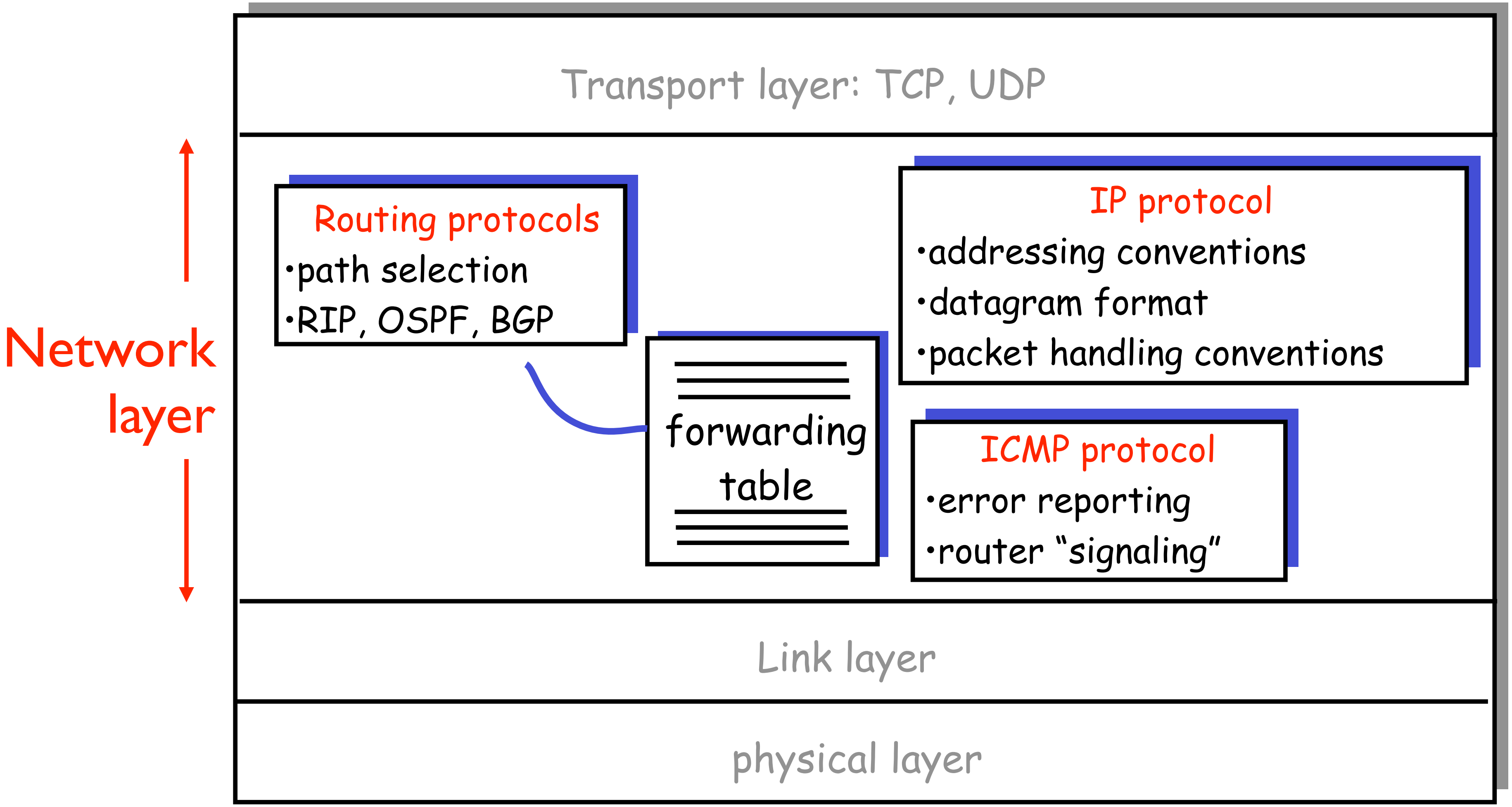
- What is forwarding? Routing?
- What's the difference between TCP and VC networks?
- What is longest prefix matching? How does it work?
- What is additive increase/multiplicative decrease?

Chapter 4: Network Layer

- 4. 1 Introduction
- 4.2 Virtual circuit and datagram networks
- 4.3 What's inside a router
- 4.4 IP: Internet Protocol
  - Datagram format
  - IPv4 addressing
  - ICMP
  - IPv6
- 4.5 Routing algorithms
  - Link state
  - Distance Vector
  - Hierarchical routing
- 4.6 Routing in the Internet
  - RIP
  - OSPF
  - BGP
- 4.7 Broadcast and multicast routing

The Internet Network layer

Host, router network layer functions:



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IP datagram format

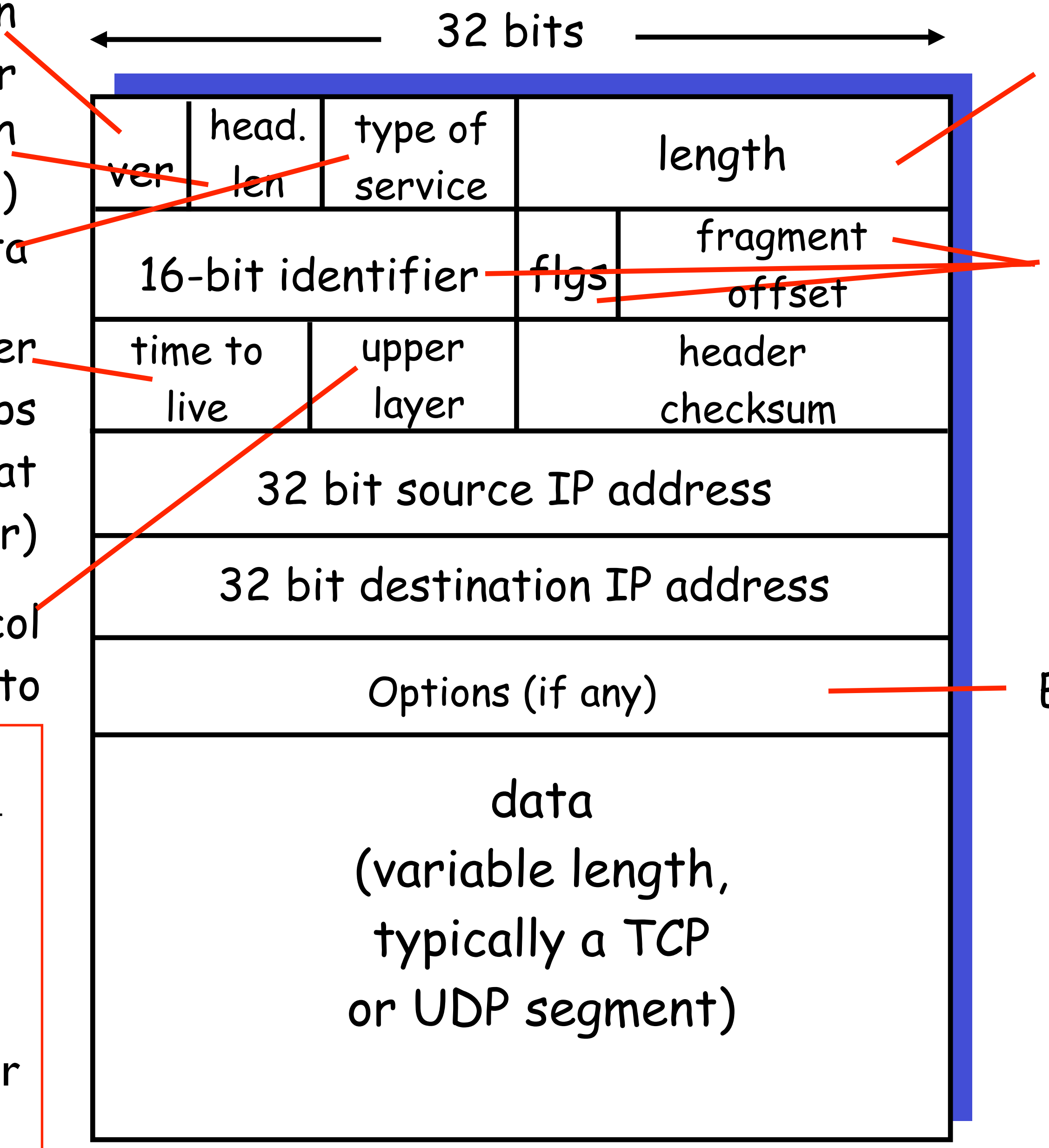
IP protocol version number

header length (words)

“type” of data

max number remaining hops (decremented at each router)

upper layer protocol to deliver payload to



32 bits

ver | head. len | type of service | length

16-bit identifier | flgs | fragment offset

time to live | upper layer | header checksum

32 bit source IP address

32 bit destination IP address

Options (if any)

data (variable length, typically a TCP or UDP segment)

total datagram length (bytes)

for fragmentation/ reassembly

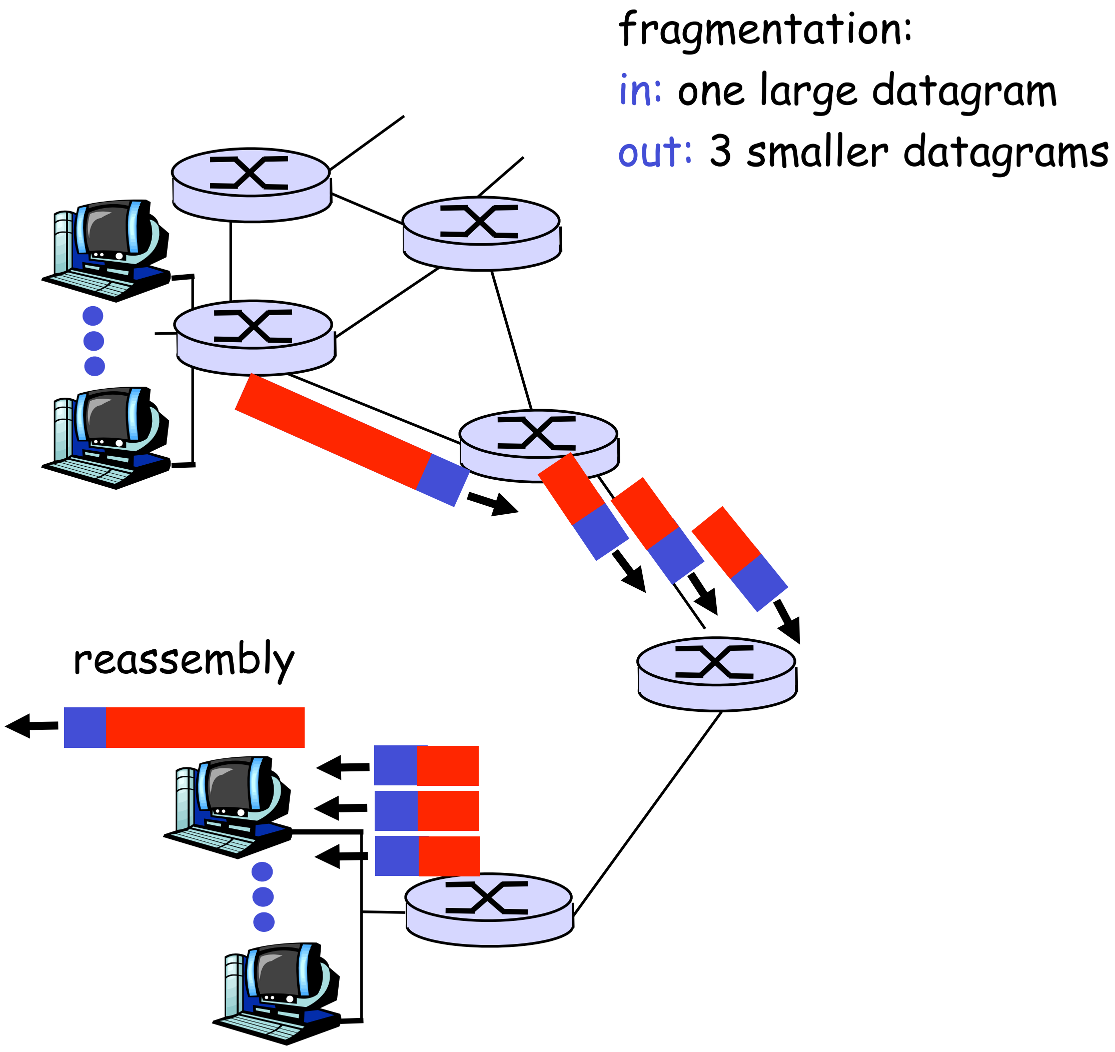
E.g. timestamp, record route taken, specify list of routers to visit.

<u>how much overhead with TCP?</u>

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

IP Fragmentation & Reassembly

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



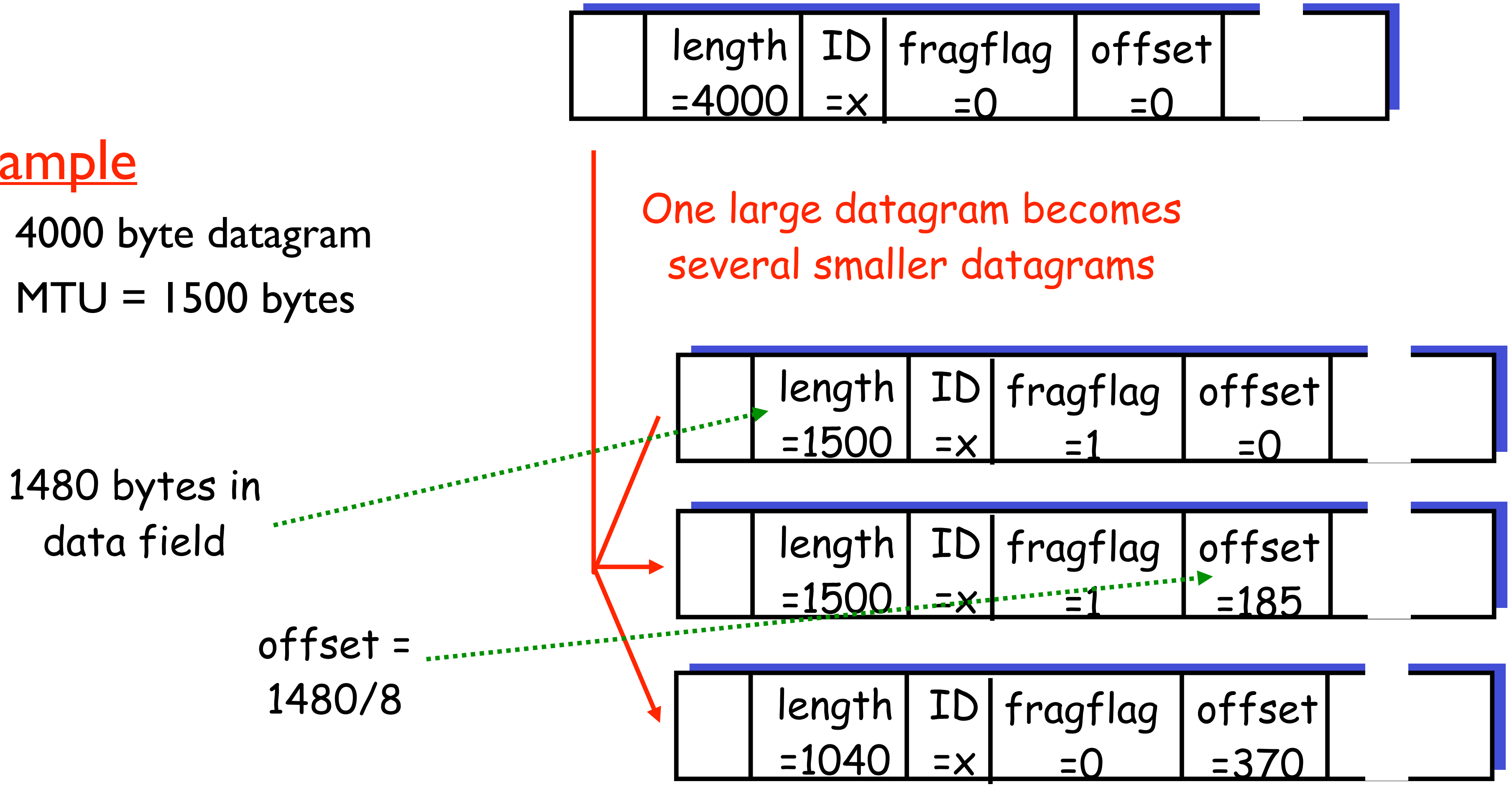
fragmentation:
in: one large datagram
out: 3 smaller datagrams

reassembly

IP Fragmentation and Reassembly

Example

- 4000 byte datagram
- MTU = 1500 bytes



	length	ID	fragflag	offset	
	=4000	=x	=0	=0	

One large datagram becomes several smaller datagrams

	length	ID	fragflag	offset	
	=1500	=x	=1	=0	

	length	ID	fragflag	offset	
	=1500	=x	=1	=185	

	length	ID	fragflag	offset	
	=1040	=x	=0	=370	

1480 bytes in data field

offset = 1480/8

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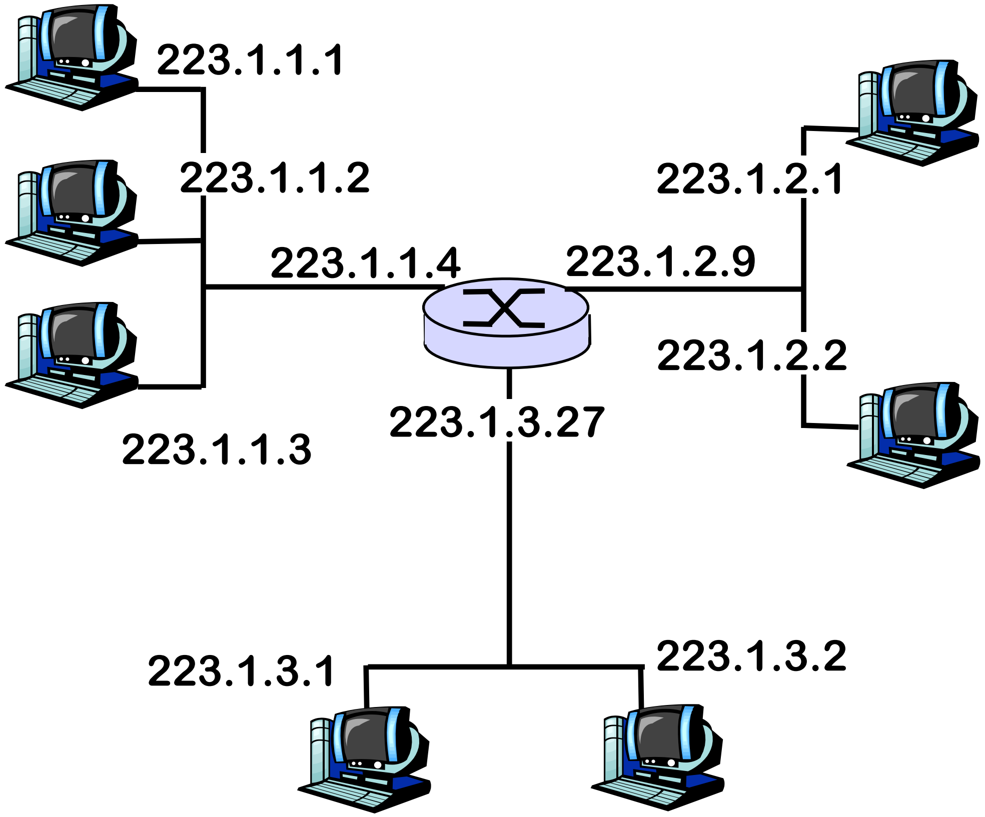
IP Addressing: introduction

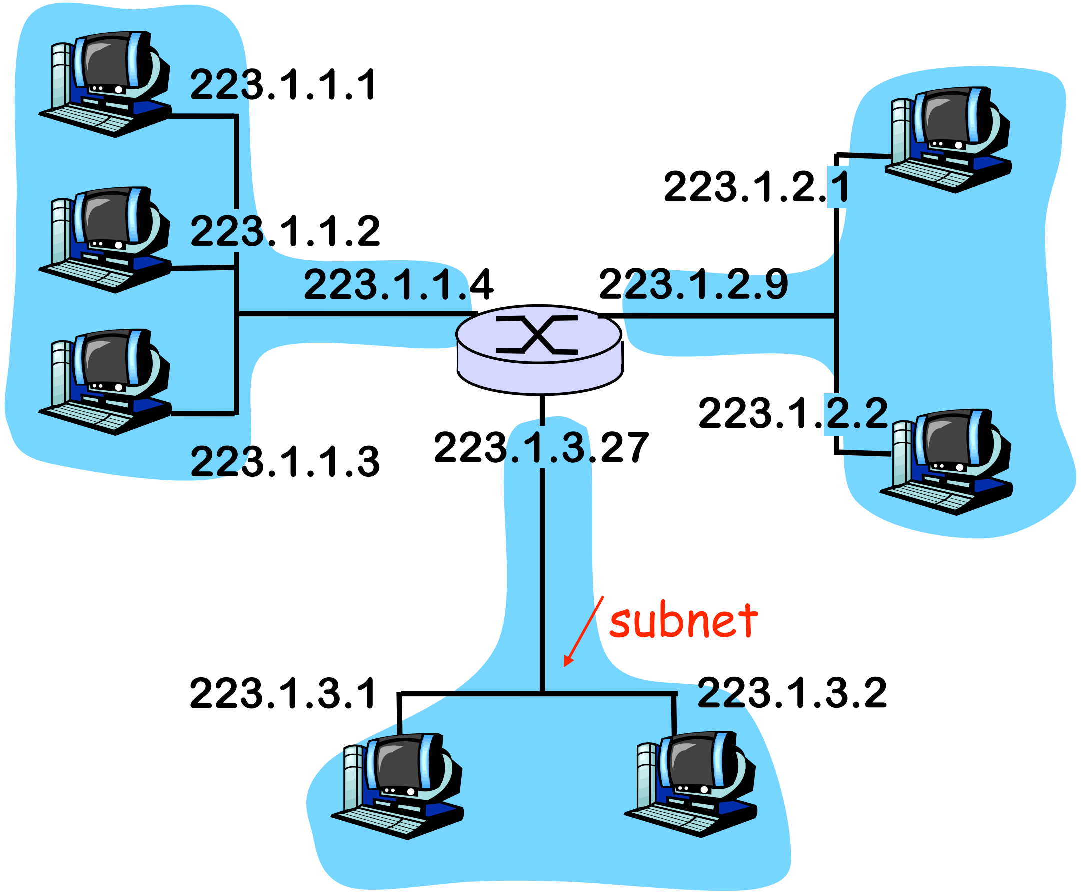
- IP address: 32-bit identifier for host, router interface
- interface: connection between host/router and physical link
  - router's typically have multiple interfaces
  - host typically has one interface
  - IP addresses associated with each interface



$$223.1.1.1 = \underbrace{11011111}_{223}\ \underbrace{00000001}_{1}\ \underbrace{00000001}_{1}\ \underbrace{00000001}_{1}$$

Subnets

- IP address:
  - subnet part (high order bits)
  - host part (low order bits)
- What's a subnet ?
  - device interfaces with same subnet part of IP address
  - can physically reach each other without intervening router

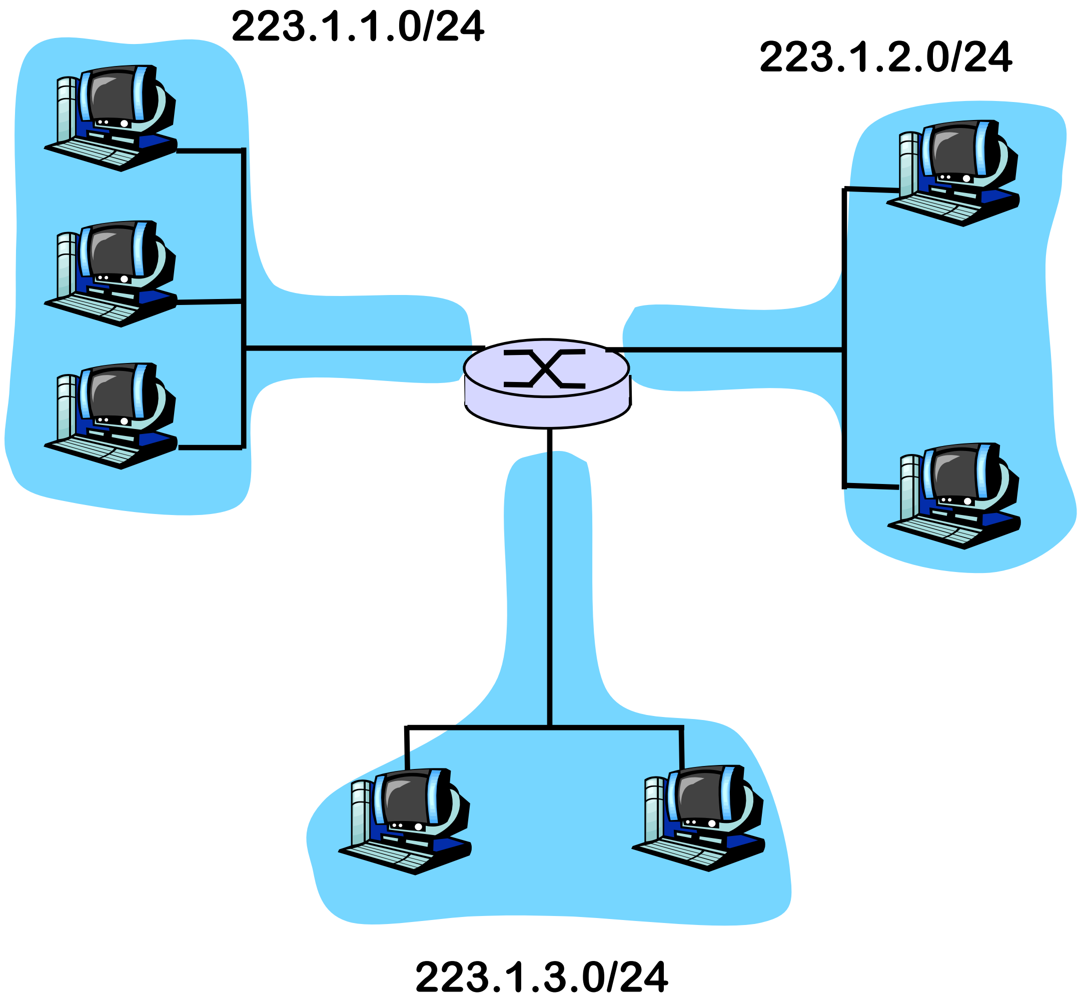


network consisting of 3 subnets

Subnets

Recipe

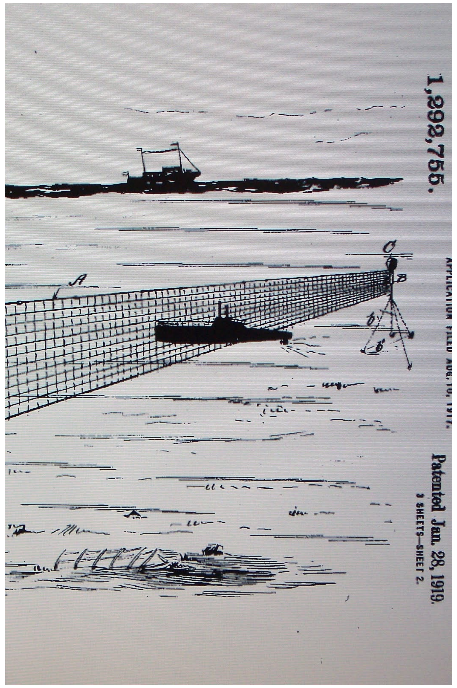
- To determine the subnets, detach each interface from its host or router, creating islands of isolated networks. Each isolated network is called a subnet.

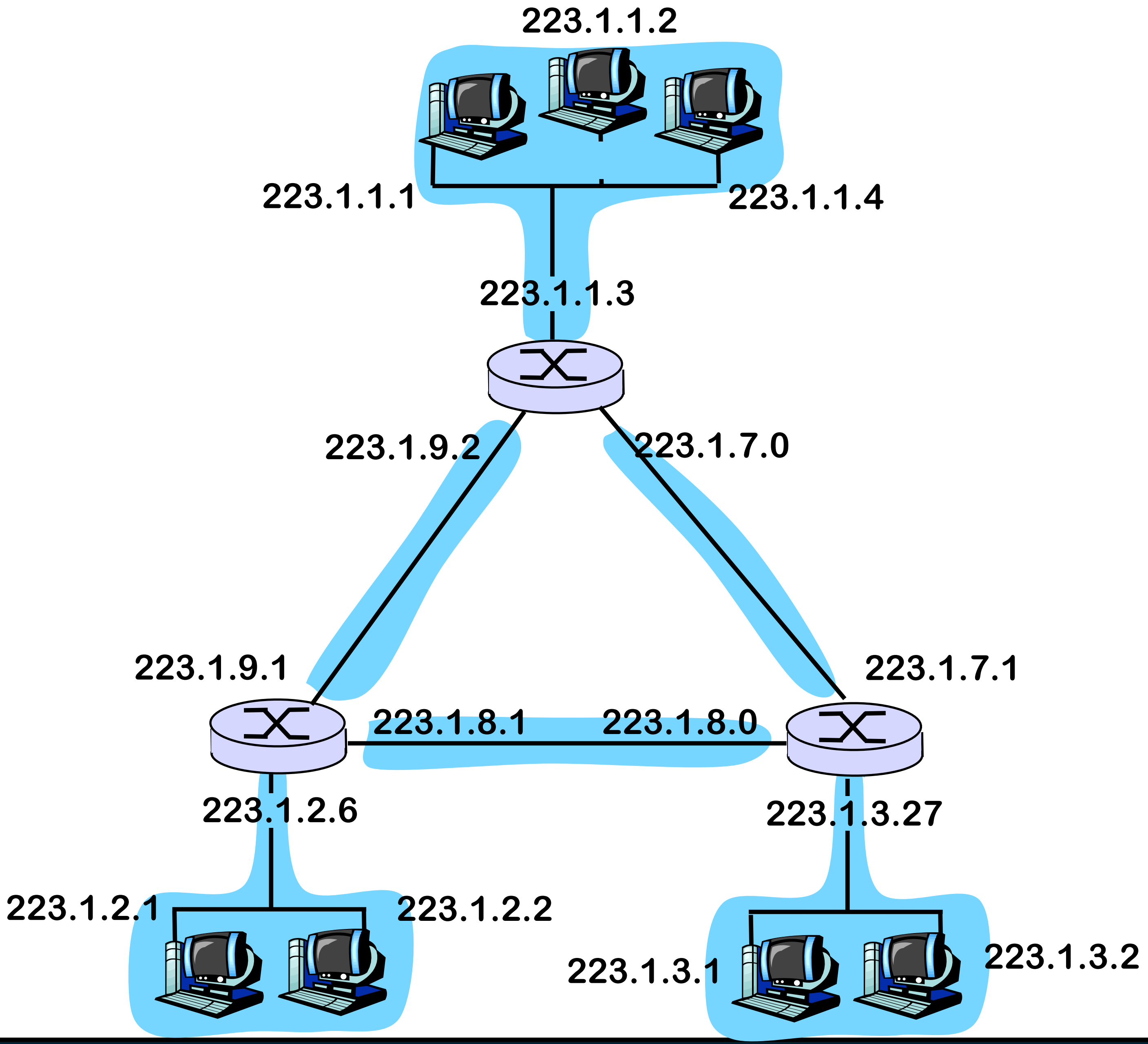


Subnet mask: /24

Subnets

How many?

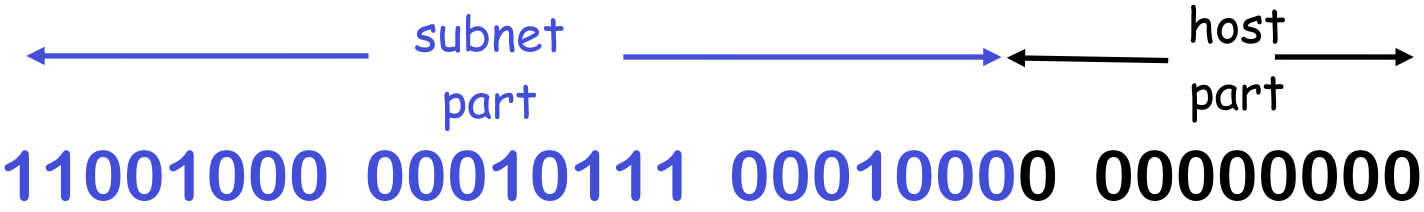




IP addressing: CIDR

CIDR: Classless InterDomain Routing

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

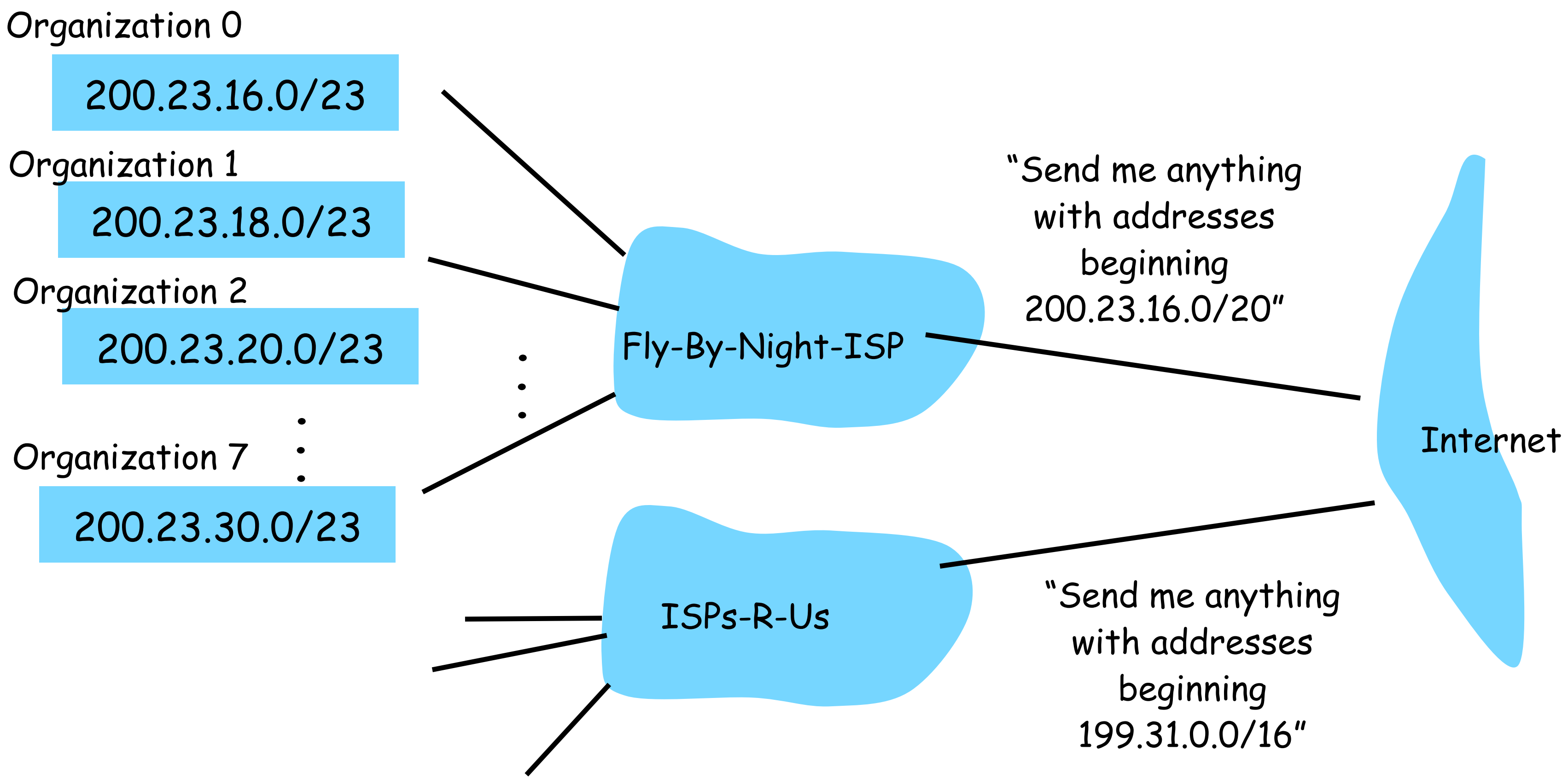


11001000 00010111 00010000 00000000

200.23.16.0/23

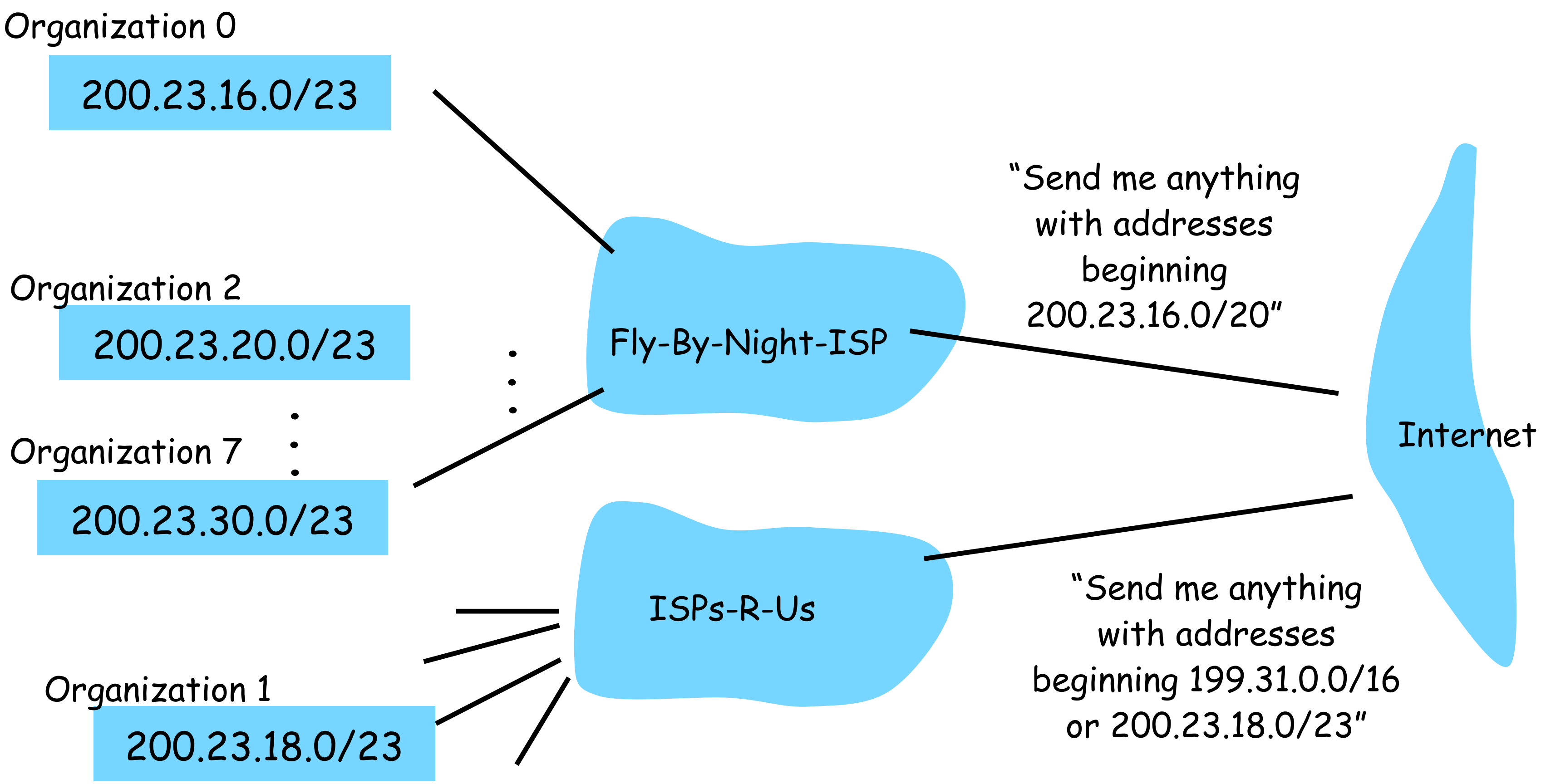
Hierarchical addressing: route aggregation

Hierarchical addressing allows efficient advertisement of routing information:



Hierarchical addressing: more specific routes

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



IP addresses: how to get one?

Q: How does a network get the subnet part of IP addr?

A: gets allocated portion of its provider ISP's address space

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

IP addressing: the last word...

Q: How does an ISP get block of addresses?

A: ICANN: Internet Corporation for Assigned Names and Numbers

- allocates addresses
- manages DNS
- assigns domain names, resolves disputes

ICANN

The Internet Corporation for Assigned Names and Numbers

IP addresses: how to get one?

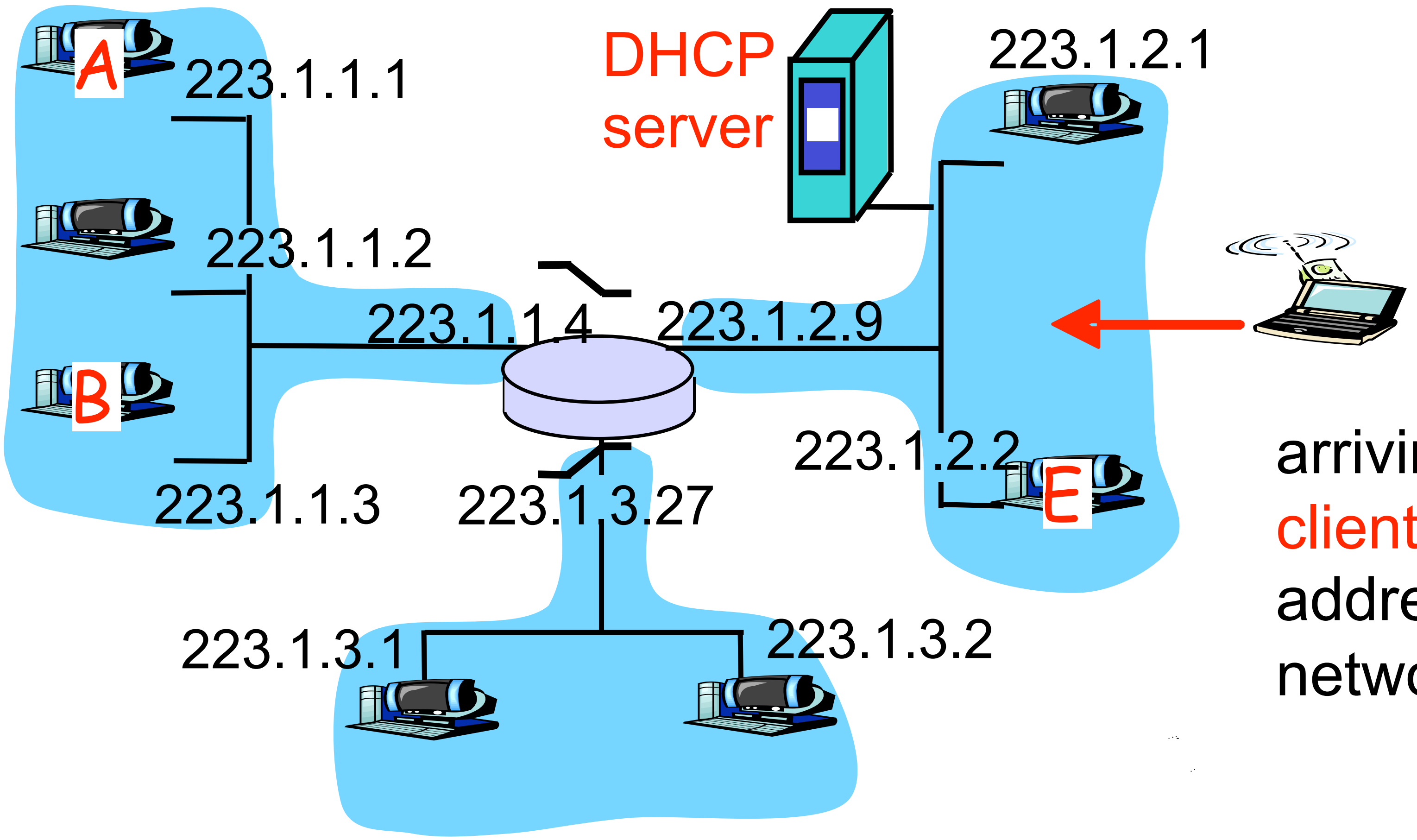
Q: How does a host get an IP address?

- 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: Dynamic Host Configuration Protocol

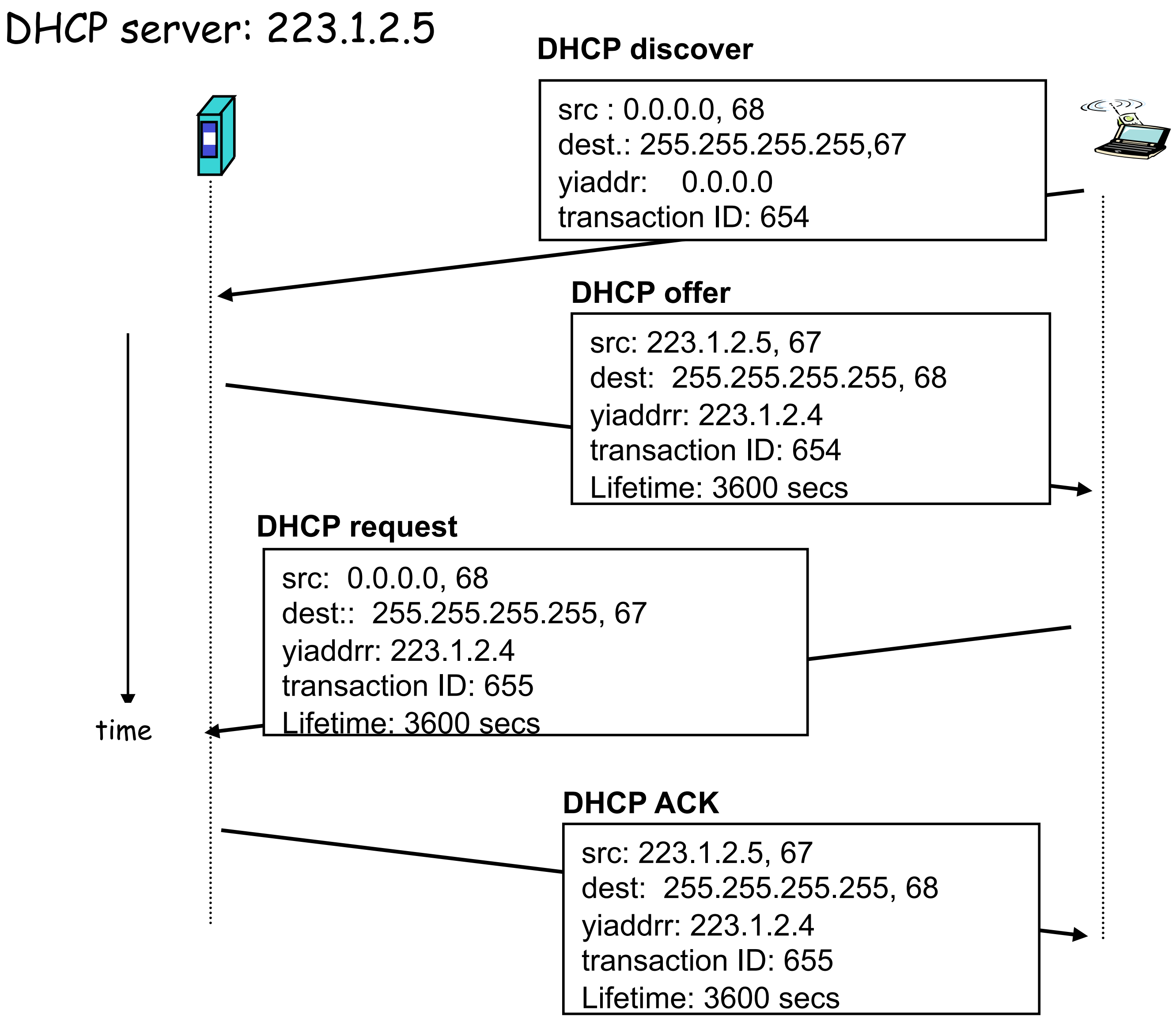
- Goal: allow host to dynamically obtain its IP address from network server when it joins network
  - Can renew its lease on address in use
  - Allows reuse of addresses (only hold address while connected and "on")
  - Support for mobile users who want to join network (more shortly)
- DHCP overview:
  - 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



arriving DHCP client needs address in this network

DHCP client-server scenario



DHCP discover

src : 0.0.0.0, 68
dest.: 255.255.255.255,67
yiaddr: 0.0.0.0
transaction ID: 654

DHCP offer

src: 223.1.2.5, 67
dest: 255.255.255.255, 68
yiaddrr: 223.1.2.4
transaction ID: 654
Lifetime: 3600 secs

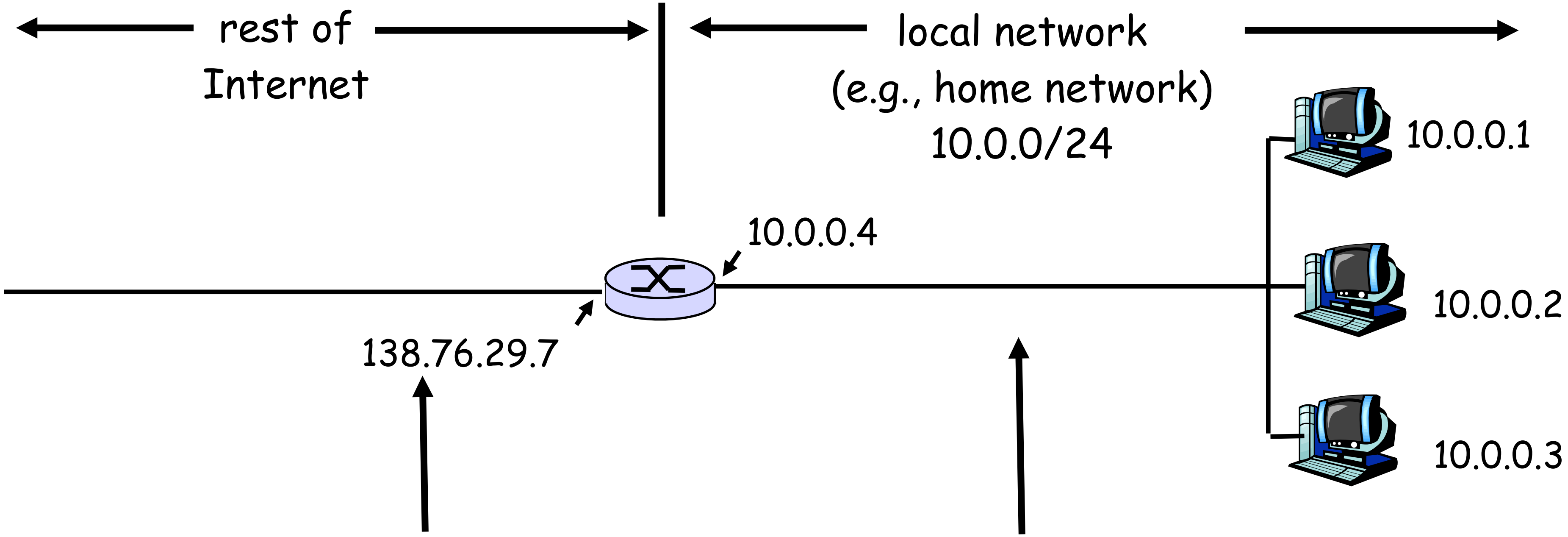
DHCP request

src: 0.0.0.0, 68
dest:: 255.255.255.255, 67
yiaddrr: 223.1.2.4
transaction ID: 655
Lifetime: 3600 secs

DHCP ACK

src: 223.1.2.5, 67
dest: 255.255.255.255, 68
yiaddrr: 223.1.2.4
transaction ID: 655
Lifetime: 3600 secs

NAT: Network Address Translation



<span style="color:red">All</span> datagrams <span style="color:red">leaving</span> local network have <span style="color:red">same</span> 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

- Motivation: 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
  - devices inside local net not explicitly addressable, visible by outside world (a security plus).

NAT: Network Address Translation

Implementation: NAT router must:

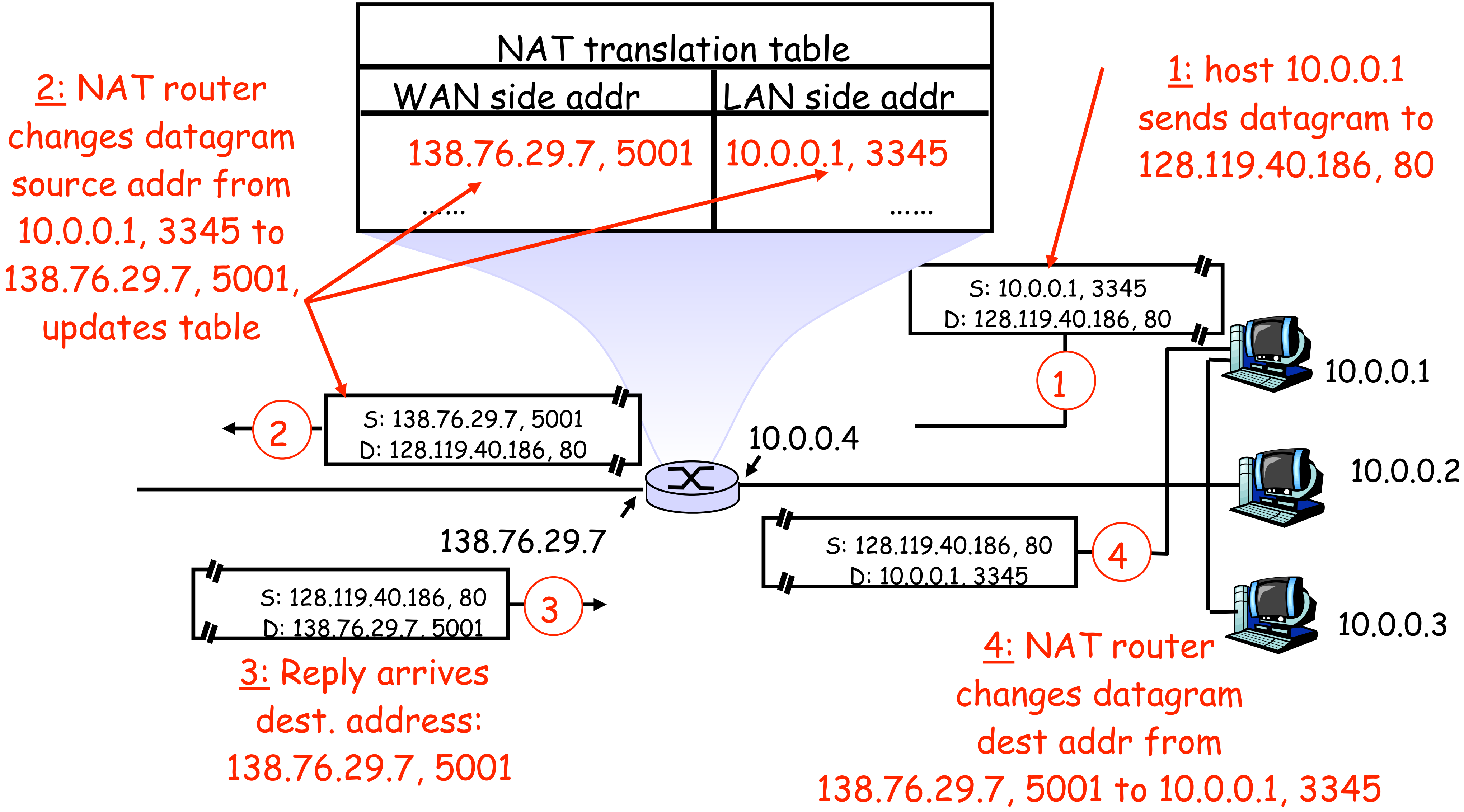
- outgoing datagrams: replace (source IP address, port #) of every outgoing datagram to (NAT IP address, new port #)

  . . . 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 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

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

3: Reply arrives dest. address: 138.76.29.7, 5001

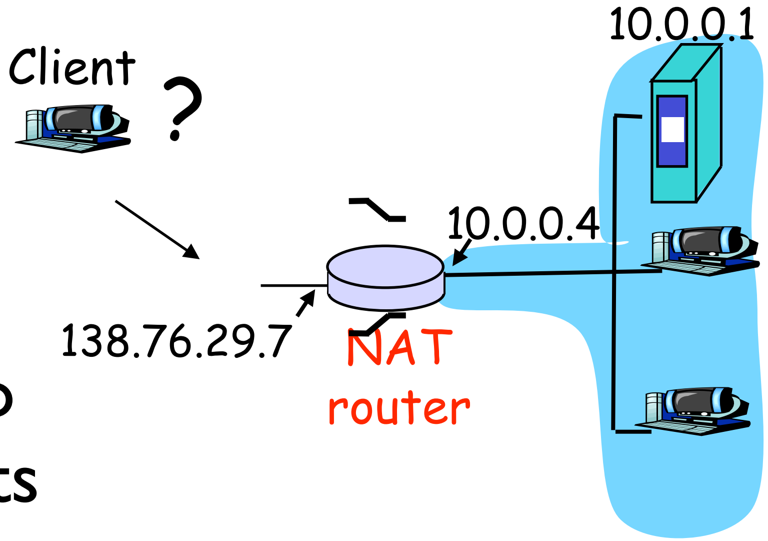
4: NAT router changes datagram dest addr from 138.76.29.7, 5001 to 10.0.0.1, 3345

NAT: Network Address Translation

- 16-bit port-number field:
  - 60,000+ simultaneous connections with a single LAN-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, eg, P2P applications
  - address shortage should instead be solved by IPv6
    - Anything idea why this might be a problem?

NAT traversal problem

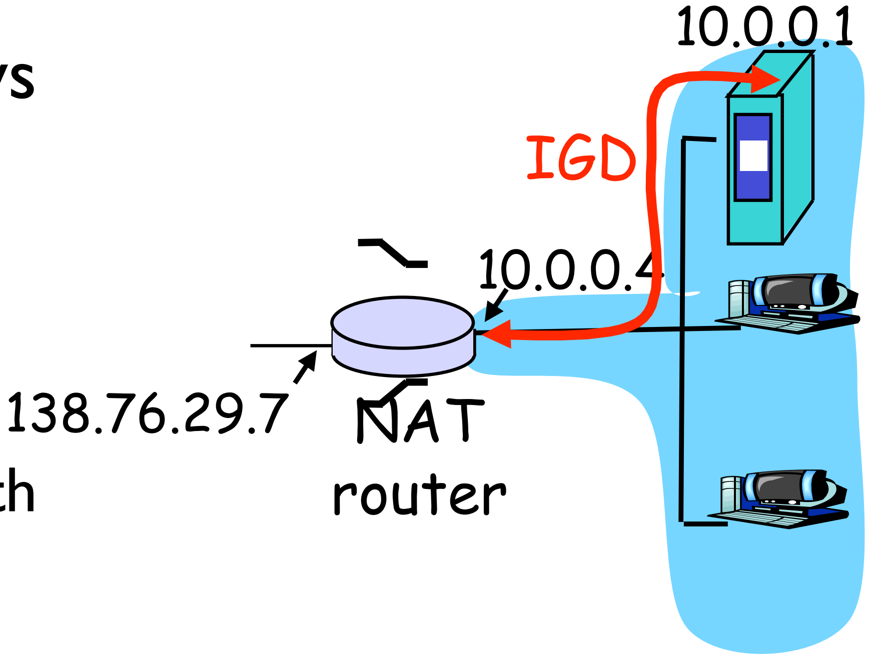
- client wants to connect to server with address 10.0.0.1
  - server address 10.0.0.1 local to LAN (client can't use it as destination addr)
  - only one externally visible NATted address: 138.76.29.7



- solution 1: statically configure NAT to forward incoming connection requests at given port to server
  - e.g., (123.76.29.7, port 2500) always forwarded to 10.0.0.1 port 25000

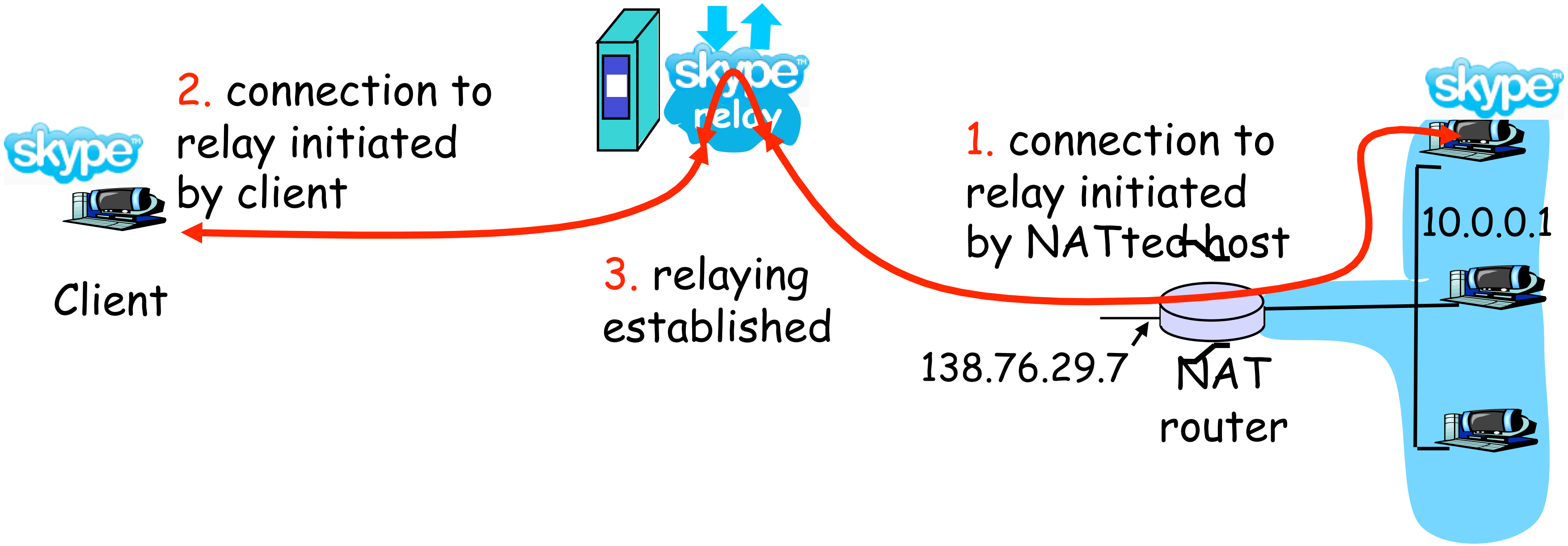
NAT traversal problem

- solution 2: Universal Plug and Play (UPnP) Internet Gateway Device (IGD) Protocol. Allows NATted 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 to connections


skype relay
2. connection to relay initiated by client
skype
Client
3. relaying established
1. connection to relay initiated by NATted host
skype
10.0.0.1
138.76.29.7
NAT router

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ICMP: Internet Control Message Protocol

- used by hosts & routers to communicate network-level information
    - error reporting: unreachable host, network, port, protocol
    - echo request/reply (used by ping)
- network-layer "above" IP:
    - ICMP msgs carried in IP datagrams
- ICMP message: type, code plus first 8 bytes of IP datagram causing error

Type	Code	description
0	0	echo reply (ping)
3	0	dest. network unreachable
3	1	dest host unreachable
3	2	dest protocol unreachable
3	3	dest port unreachable
3	6	dest network unknown
3	7	dest host unknown
4	0	source quench (congestion control - not used)
8	0	echo request (ping)
9	0	route advertisement
10	0	router discovery
11	0	TTL expired
12	0	bad IP header

Traceroute and ICMP

- Source sends series of UDP segments to dest
  - First has TTL =1
  - Second has TTL=2, etc.
  - Unlikely port number
- When nth datagram arrives to nth router:
  - Router discards datagram
  - And sends to source an ICMP message (type 11, code 0)
  - Message includes name of router& IP address

- When ICMP message arrives, source calculates RTT
- Traceroute does this 3 times

Stopping criterion

- UDP segment eventually arrives at destination host
- Destination returns ICMP "port unreachable" packet (type 3, code 3)
- When source gets this ICMP, stops.

Smurf Attack

- ICMP Messages can be used in a classic "amplification" attack.
- An ICMP "ping" is sent to the broadcast address in a subnet (255.255.255.255) or network (192.168.1.255).
- All hosts receiving this message would automatically respond, thereby clogging the network.
  - Only took one message to initiate.

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IPv6

- Initial motivation: 32-bit address space completely allocated as of Feb. 2011.
- Additional motivation:
  - header format helps speed processing/forwarding
  - header changes to facilitate QoS

IPv6 datagram format:

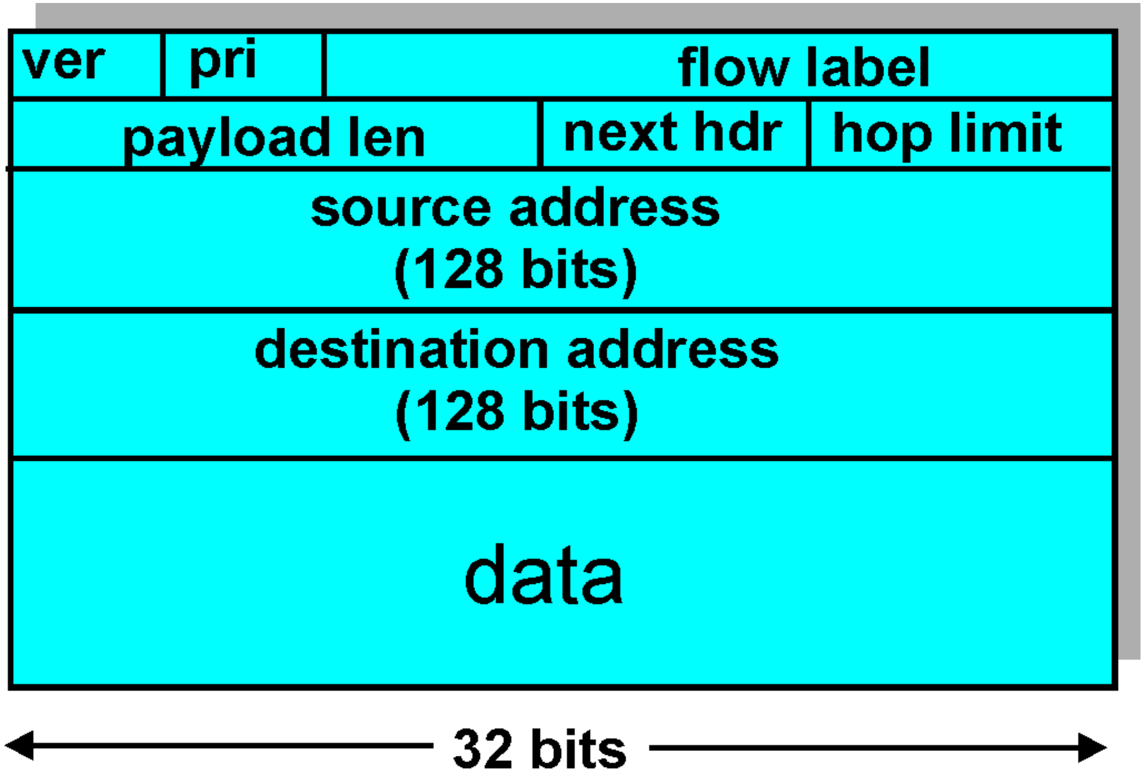
- fixed-length 40 byte header
- no fragmentation allowed

IPv6 Header (Cont)

Priority: identify priority among datagrams in flow

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

Next header: identify upper layer protocol for data



ver
pri
flow label
payload len
next hdr
hop limit
source address
(128 bits)
destination address
(128 bits)
data
32 bits

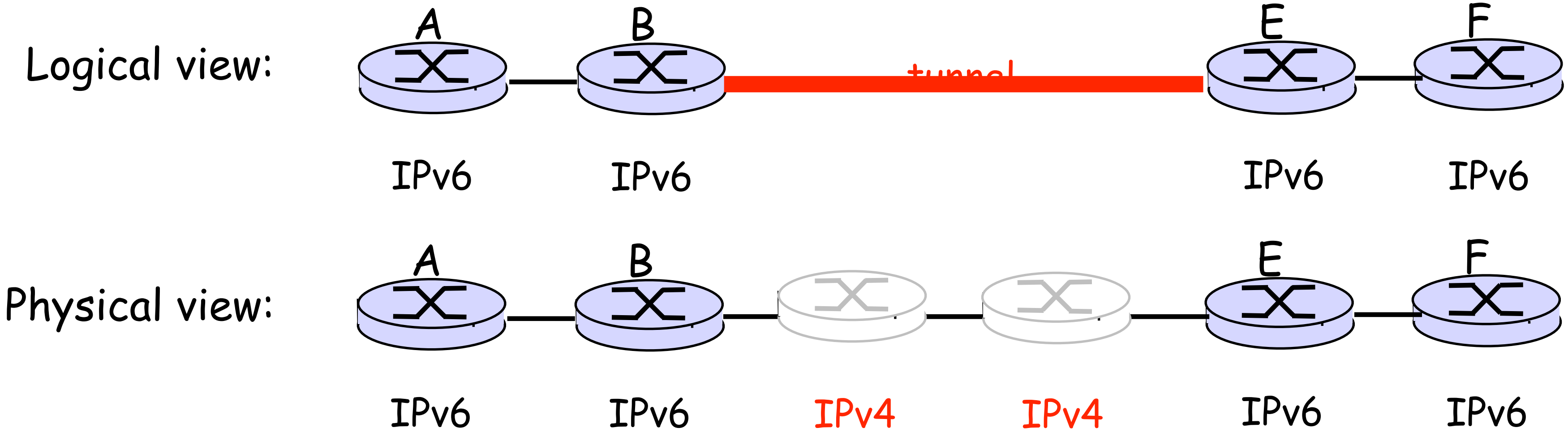
Other Changes from IPv4

- 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

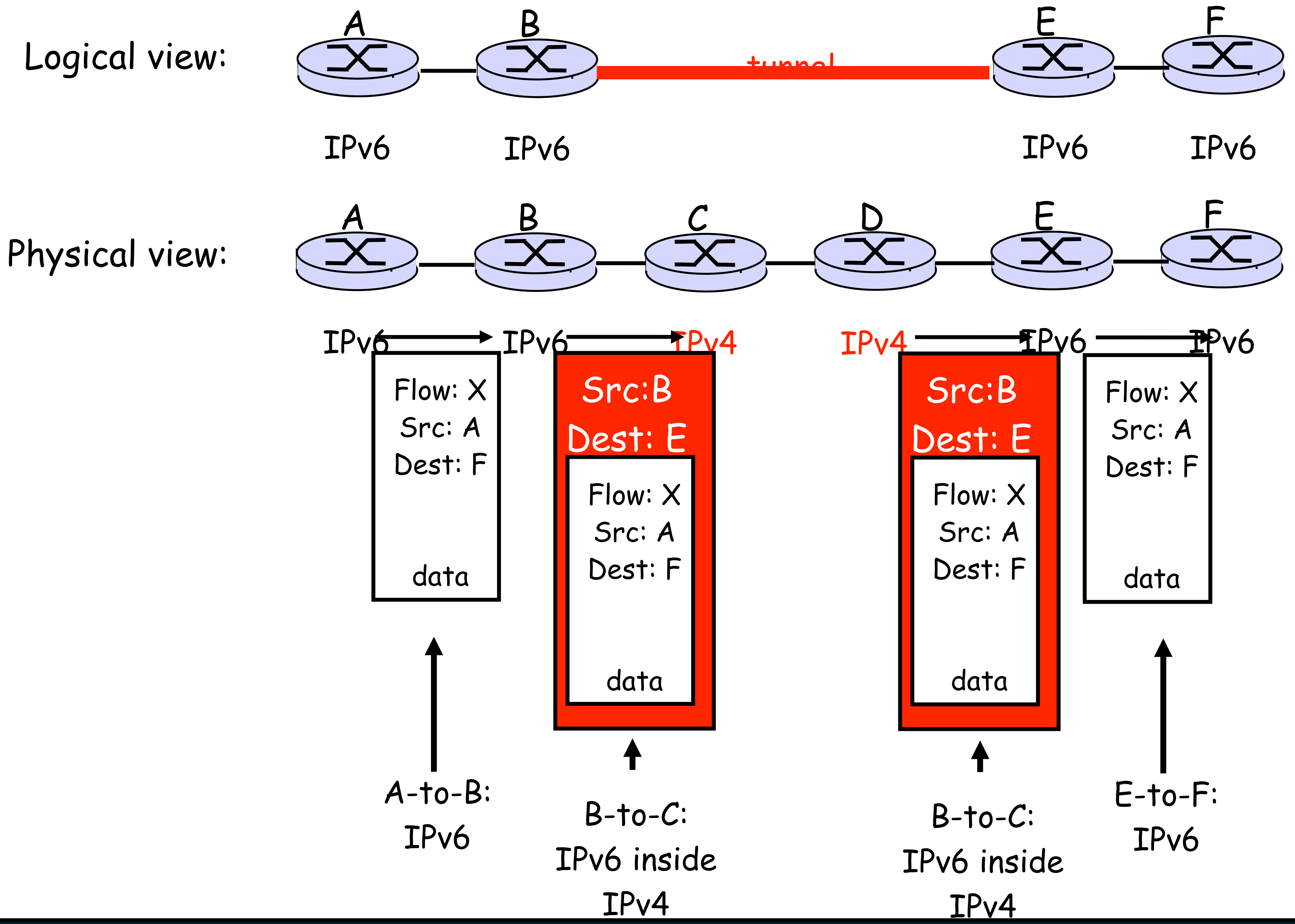
Transition From IPv4 To IPv6

- Not all routers can be upgraded simultaneous
  - no "flag days"
  - How will the network operate with mixed IPv4 and IPv6 routers?
- Tunneling: IPv6 carried as payload in IPv4 datagram among IPv4 routers

Tunneling


Logical view:
A
B
tunnel
E
F
IPv6
IPv6
IPv6
IPv6
Physical view:
A
B
E
F
IPv6
IPv6
IPv4
IPv4
IPv6
IPv6

Tunneling



Logical view:

A B E F

tunnel

IPv6 IPv6 IPv6 IPv6

Physical view:

A B C D E F

IPv6 IPv6 IPv4 IPv4 IPv6 IPv6

Flow: X
Src: A
Dest: F

data

Src:B
Dest: E

Flow: X
Src: A
Dest: F

data

Src:B
Dest: E

Flow: X
Src: A
Dest: F

data

Flow: X
Src: A
Dest: F

data

A-to-B:
IPv6

B-to-C:
IPv6 inside
IPv4

B-to-C:
IPv6 inside
IPv4

E-to-F:
IPv6

Next Time

- Read Section 4.5
  - Routing algorithms - this is important stuff